DOT/FAA/AR-07/35

Air Traffic Organization
Operations Planning
Office of Aviation Research
And Development
Washington, DC 20591

Summary and Comparison Report on Teardown Evaluation of Cessna 402A and Cessna 402C Airplanes

June 2007

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-07/35		

4. Title and Subtitle	5. Report Date
SUMMARY AND COMPARISON REPORT ON TEARDOWN EVALUATION OF CESSNA 402A AND CESSNA 402C AIRPLANES	June 2007
	6. Performing Organization Code
7. Author(s) Melinda Laubach, Michael Montgomery, Dale Cope National Institute for Aviation Research, Wichita State University	8. Performing Organization Report No.
9. Performing Organization Name and Address National Institute for Aviation Research Wichita State University 1845 Fairmount Wichita, Kansas 67260	10. Work Unit No. (TRAIS) 11. Contract or Grant No. 01-C-AW-WISU
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Air Traffic Organization Operations Planning Office of Aviation Research and Development Washington, DC 20591	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code ACE-110

15. Supplementary Notes

The Federal Aviation Administration Airport and Aircraft Safety R&D Division Technical Monitor was Michael Shiao.

16. Abstract

To determine if potential continuing airworthiness problems exist for the small airplane fleet as a function of the aging process, the Federal Aviation Administration (FAA) established a research program to conduct a destructive evaluation of two aged airplanes (both Cessna 402 models) used in the commuter service. The intent of the program is to provide insight into the condition of a typical aged airplane and to see if a correlation exists between its maintenance history and current condition from a safety of flight perspective. This report provides a summary and comparison of the findings from the teardown examination of a 1969 Cessna 402A and a 1979 Cessna 402C model airplane in support of the research program. The results provide information for use in future investigations into the aged small airplane fleet and may determine if additional research is required to address specific problems observed (if any). The destructive evaluations of the commuter-class airplanes were separated into three main tasks: (1) inspection of the airframe and airplane systems, (2) teardown examination of the airframe and airplane systems, and (3) assessment of the airplane wiring. During the inspection phase, three subtasks were performed: a survey of the airplane maintenance records, visual inspection of the airframe and airplane systems, and supplemental airframe inspections. The teardown examination involved disassembly of the airframe and major airplane sections, inspection of airplane systems' components, inspections of primary airplane structure using alternative nondestructive inspection techniques prior to teardown, and microscopic examination of critical structural areas. As part of the destructive evaluation, inspections and testing were also performed on the airplane wiring to assess the condition and degradation of electrical wiring in small airplanes and to evaluate maintenance procedures. Specific observations were made regarding findings discovered during the teardown evaluation on the particular airplane selected. Comparisons were also made on the overall condition of the two airplanes.

17. Key Words	18. Distribution Statement
Aging airplanes, Teardown evaluation, Structural integrity, Airworthiness, Cracks, Corrosion, Airplane systems, Wiring	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	76	

Form DOT F1700.7 (8-72) Reproduction of completed page authorized

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LIST OF ACRONYMS

AD	Airworthiness Directive
BL	Body line
CFR	Code of Federal Regulations
DWV	Dielectric withstand voltage
FAA	Federal Aviation Administration
LH	Left hand
MOI	Magnetic-Optic Imaging
NDI	Nondestructive Inspection
NIAR	National Institute for Aviation Research
RH	Right hand
SB	Service Bulletins
SDR	Service Difficulty Report
SID	Supplemental Inspection Document
WL	Water line
WS	Wing station

EXECUTIVE SUMMARY

To determine if potential continuing airworthiness problems exist for the small airplane fleet as a function of the aging process, the Federal Aviation Administration (FAA) established a research program to conduct a destructive evaluation of aged airplanes. The intent of the program was to provide insight into the condition of a typical aged airplane and to see if a correlation exists between its maintenance history and current condition from a safety of flight perspective. The first two airplanes evaluated were Cessna 402 models used in commuter service. This document provides a summary and comparison of the findings from the teardown evaluations of a 1969 Cessna 402A airplane and a 1979 Cessna 402C airplane in support of the research program. The results provide information for use in future investigations into the aged small airplane fleet and to determine if additional research is required to address specific problems observed (if any). Specific observations are made regarding findings discovered during the teardown evaluation on the particular model selected, and comparisons are made regarding the overall condition of the two airplanes.

The destructive evaluations of the commuter-class airplanes were separated into three main tasks: (1) inspection of the airframe and airplane systems, (2) teardown examination of the airframe and airplane systems, and (3) assessment of the airplane wiring. During the inspection phase, three subtasks were performed: a survey of the airplane maintenance records, visual inspections of the airframe and airplane systems, and supplemental airframe inspections. The teardown examination involved disassembly of the airframe and major airplane sections, inspection of airplane systems' components, assessment of primary airplane structure using alternative nondestructive inspection (NDI) techniques, and microscopic examination of critical structural areas. As part of the destructive evaluation, inspections and testing were also performed on the airplane wiring to assess the condition and degradation of electrical wiring in small airplanes and to evaluate maintenance practices for airplane wiring.

A 1969 Cessna 402A, tail number N812BW, with 19,698.9 total airframe hours and a 1979 Cessna 402C, tail number N780EA, with 25,546.6 total airframe hours were evaluated through a comprehensive nondestructive and destructive teardown evaluation. The Cessna 402A, purchased from Sunshine Airlines, was primarily used later in life for tours of the Grand Canyon. The Cessna 402C, obtained from Cape Air, was operated in commuter service on the eastern North American coast, flying in and around Cape Cod, the Florida Keys, and the Virgin Islands.

During the inspection phase, the survey of airplane maintenance records revealed that the volume or the maintenance records data varied significantly between the two airplanes. Detailed log books, inspection logs, FAA form 337s, and an Airworthiness Directives compliance list were included with the Cessna 402C, while only the less-detailed log books and FAA form 337s were available for the Cessna 402A maintenance records review. No direct correlation was observed between the predominant issues in the FAA service difficulty reports and the teardown evaluation findings for either airplane. During the airframe and systems visual inspections on the Cessna 402A, only four findings were deemed noteworthy by airframe mechanics. Two 2.5-inch cracks were observed on the leading edge of the horizontal stabilizer, a loose nut was found on a wing flap, and broken gear teeth were observed on the left fuel selector valve. Three visual inspection findings were deemed noteworthy on the Cessna 402C. These findings included a leak in the hydraulic flow pressure switch, an improper repair on the right exhaust pipe, and an area of corrosion on the skin under the antenna. During the supplemental inspections, 25 NDI indications were found on the Cessna 402A, while only 13 were noted on the Cessna 402C. In general, many of the findings on the Cessna 402A could be repaired with minimal maintenance effort, while the discrepancies found on the Cessna 402C would require more extensive maintenance. From the visual and supplemental inspections, it was observed that the overall condition of the Cessna 402A appeared better than the 402C.

During the detailed disassembly of the Cessna 402C, 24 additional cracks were observed on the engine beam structure, and 43 cracks were found on the carry-through structure. No additional defects were noted during the detailed disassembly on the Cessna 402A. Leak testing of pressurized lines revealed nine lines with leaks on the Cessna 402A and five lines with leaks on the Cessna 402C, with an additional Cessna 402C line found deeply pitted during visual inspections of the pressurized lines. Each leak was caused by material damage, loss of fitting joint integrity, or corrosion. The assessment of primary airplane structure using alternative NDI techniques was performed on the front spars of the horizontal stabilizer and left wing on the Cessna 402A, and on all wing spars, horizontal and vertical stabilizer spars and both fuselage channels on the Cessna 402C airplane. All indications were further investigated during the microscopic examination for validity and damage extent. Even though some alternative NDI indications were verified microscopically, not all alternative NDI indications were verified during the microscopic examination.

During the microscopic examination of the Cessna 402A, cracks were observed on the wing auxiliary spars, nose gear steering bellcrank, rudder bellcrank, a stub wing attach fitting, and the wing tip tank baffles. Corrosion was observed on the left fuselage channel, right stub wing skin, four wing attach fittings, and the wing front spar cap. On the Cessna 402C, cracks were observed on the carry-through webs, a bracket supporting an elevator attachment fitting, engine beams and surrounding structure, and a right stub wing angle common to the outboard stub wing rib and carry-through structure. Corrosion was observed on the Cessna 402C right fuselage channel, horizontal stabilizer spars, seven stub wing attach fittings, eight wing attach fittings, the wing spars, and the vertical stabilizer skin under the antenna.

The wiring assessment on the Cessna 402A found 103 wiring condition defects, and 245 installation defects, and 14 termination defects. The general visual inspections of the Cessna 402C wiring revealed 179 wiring condition defects and 8 termination defects. During the Cessna 402A circuit breaker testing, 21 circuit breakers were tested with one found open or completely nonfunctional. During the first round of testing, five of the circuit breakers did not trip in the specified time. When the test was repeated, only three did not meet specification. The third time the test was performed all circuit breakers, excluding the nonfunctional breaker, met specification. Each time the circuit breaker testing was performed the circuit breakers were cycled thermally. The trip times of the functioning circuit breakers that first failed changed drastically as the breakers were cycled. On the Cessna 402C, 46 circuit breakers were tested. Four of the circuit breakers tested had open circuits, and two of the circuit breakers did not meet specification. Even with cycling, these two breakers still did not meet specification. The circuit breakers on the 402C were also mechanically cycled during the operational checks.

1. INTRODUCTION.

Economic and market conditions of present day aviation companies are requiring the use of airplanes far beyond their original design life objectives. The aging airplane concern exists for all types of airplanes including commercial, military, and general aviation. The concern is being amplified as more companies use aged airplanes and rely on standard inspection practices for a guarantee of airworthiness assurance. Standard practices to ensure continuing airworthiness include scheduled inspection and maintenance tasks contained in service manuals, Instructions for Continued Airworthiness (ICAs), Airworthiness Directives (ADs), and Service Bulletins (SBs). These practices are not just limited to structural integrity but also extend to wiring and systems integrity. These initiatives have provided timely preventative maintenance recommendations that permit the continued safe operation of aging airplanes until retirement from service for economic reasons.

1.1 BACKGROUND.

Although the general public is primarily concerned with the airworthiness of large transport airplanes, which is where most research funding resources and efforts have been focused, a growing concern also exists in the small airplane fleet. Investigations performed on large transport and military airplanes have focused on the structural integrity as well as wiring and systems related aging concerns. The results of these investigations can benefit a similar research program that investigates the same issues on small airplanes.

The reliability and maintenance of electrical wiring and electrical components in aging airplanes have also become a major concern for the aviation industry. The Federal Aviation Administration (FAA) and the Aging Transport Systems Rulemaking Advisory Committee have been working to assess the condition of electrical wiring and the effectiveness of wiring maintenance procedures. However, their efforts have been primarily focused on larger commercial transport airplanes. The large number of small airplanes in service has created a need for examining the condition of their wiring and electrical components and reviewing their maintenance procedures.

Most small airplanes are generally classified as general aviation airplanes. When one mentions general aviation, the traditional image usually involves a four-passenger airplane like a Cessna 172; however, general aviation covers a wide range of airplanes. In the context of this program, a general aviation airplane is defined as Title 14 Code of Federal Regulations (CFR) Part 23 (or predecessor Civil Air Regulation 3) airplane, which includes normal, utility, acrobatic, and commuter category airplanes. This classification includes airplanes operating in the commuter, cargo, or taxi service capacity under 14 CFR Part 135. The general aviation fleet includes approximately 210,000 fixed-wing airplanes classified as about 71% single-engine piston, 10% multiengine piston, 10% experimental, and 9% turboprop, jet, glider, or lighter-than-air. Usage of the general aviation fleet is categorized as follows: 60% for personal use, 21% for business use, 6% for instruction, 4% for aerial application and observation, 3% for commuter service, 2% for public use, and 4% for other usage.

Due to the large number of general aviation airplanes and their wide usage, the aging aspects of these airplanes must be addressed. In September 2002, the FAA Small Airplane Directorate and the Office of Aviation Research and Development Airport and Aircraft Safety R&D Division established a research program to address the aging concerns regarding the small airplanes. The main purpose for this program is to provide insight into the condition of typical aged small airplanes and determine if a correlation exists between the maintenance history and the airplane's apparent condition. The research program is primarily conducted by the Aging Aircraft Research Laboratory at the National Institute for Aviation Research (NIAR), Wichita State University. This research program's major objective focuses on the integrity and aging aspects of small airplanes.

1.2 RESEARCH OBJECTIVES.

Much of the current concern related to aging effects on airplanes involves calendar age as opposed to flight hours. For instance, regarding deterioration of wiring, aging effects on airplane systems (control systems, seals, cables, etc.), and corrosion are calendar related, and these effects may possibly be a continued safety of flight concern. For example, approximately 25,000 airplanes presently exist that are older than 50 years and still have the original electrical systems. Currently, no inspection criteria exist for evaluating the condition of aged wiring. In addition, major attachment fittings, such as wing attachment fittings, are typically never removed and inspected. These are issues that this research program primarily focused on to address and provide insight to the aging small airplane fleet.

The research program has a short-term objective to be achieved over two years during Phase I, and a long-term objective to be achieved over three additional years during Phase II. The short-term objective is to determine if potential continuing airworthiness problems exist for the small airplane fleet as a function of the aging process. The long-term objective is to establish guidance to ensure current maintenance programs of small airplanes are providing acceptable levels of continued airworthiness. Achievement of the short-term objective should determine if generic degradation indicators exist in the small airplane fleet. These indicators will likely include structural (cracking or corrosion), electrical systems or wiring; airplane systems (such as fuel, hydraulic, pneumatic, mechanical, and flight control); and maintenance, service, and inspection quality. Determination of generic degradation indicators will assist in providing initial generic inspection guidance such as:

- Do maintenance inspection programs address all areas of concern appropriately?
- What was found in areas that normal maintenance would not see?
- Are additional inspection criteria required for aged airplanes?
- Should specialized, one-time inspections be required at a certain age?
- Should inspections and maintenance programs become more extensive as the airplane ages?

To achieve the research objectives in the initial phase of the program, a destructive evaluation was conducted on two aged airplanes (both Cessna 402 models) that were used in commuter service. This summary report can be used in future investigations into the aged small airplane fleet, to determine if additional research is required to address specific problems observed (if any). Specific observations were made regarding the particular airplane selected. Generic recommendations that are applicable to the small airplane fleet were provided. Comparisons were also made to the overall condition of the two airplanes.

To achieve the long-term objectives of the research program, Phase II conducted extensive teardown evaluations on a Piper Navajo Chieftain and a Beechcraft 1900D. The results from these teardown evaluations will allow conclusions to be drawn regarding aging airplane issues facing small airplane fleet-wide. Recommendations will also be provided for guidance on maintenance programs to provide acceptable levels of continued airworthiness on aging small airplanes.

1.3 TECHNICAL APPROACH.

The destructive evaluation of the Cessna 402A and Cessna 402C were separated into three main tasks: (1) inspection of the airframe and systems, (2) teardown examination of the airframe and airplane systems, and (3) assessment of the airplane wiring. Each section below describes the airplane selected for teardown evaluation and the subtasks conducted within each of the main tasks. The process involved in accomplishing these teardown examinations are detailed in final reports for each airplane [1 and 2] and summarized in this report.

1.3.1 Airplane Selection.

The Cessna 402 model was selected because it represents a large portion of the small airplane commuter fleet. It shares many design commonalities with other small twin-engine airplanes, such as the Piper Navajo. The design concepts of both systems (mechanical, electrical, and flight controls) and structures (layout and materials) are similar model-to-model and manufacturer-to-manufacturer. Therefore, findings from the destructive evaluation of the Cessna 402s would be applicable to all small airplane models regardless of manufacturer.

Shown in figure 1, the first airplane selected for destructive evaluation was a 1969 Cessna 402A model (tail number N812BW), which was used in the typical commuter class role. The twin-engine airplane had almost 20,000 total airframe hours with a current registration, and it was most recently used for commuter service by Sunshine Airlines. This airplane was used to fly tours of the Grand Canyon, which is classified as severe usage by Cessna Aircraft Company, during the latter portion of its service life. Log books, the AD compliance list, and FAA 337 forms were included with the purchase of this airplane.

The second airplane selected for teardown evaluation was a 1979 Cessna 402C model (tail number N780EA), which was used in the typical commuter class role. The twin-engine airplane, shown in figure 2, had over 25,500 total airframe hours with a current registration. It was most recently used for commuter service by Cape Air/Nantucket Airlines of Hyannis, MA, flying in and around Cape Cod and the Caribbean Islands, which is an environment conducive to corrosion. Maintenance records, log books, the AD compliance list, and FAA 337 forms were included with the acquisition of this airplane.

Figure 1. The 1969 Cessna 402A, Tail No. N812BW

Figure 2. The 1979 Cessna 402C, Tail No. N780EA

1.3.2 Inspection Phase.

During the inspection phase, three subtasks were performed on both airplanes: a survey of the airplane maintenance records, routine visual inspections of the airframe and airplane systems as prescribed by the service manual, and supplemental inspections per the Supplemental Inspection Document (SID) developed by Cessna Aircraft Company. The maintenance records survey provided information on the airplane maintenance history for correlation of maintenance practices to airplane condition, while the inspections determined the condition of the airplane based on normal maintenance activity.

1.3.3 Teardown Examination Phase.

The research program focused on the destructive evaluation of commuter-class airplanes, yet a nondestructive evaluation was also conducted according to recommended practices prior to the destructive evaluation. The teardown examination involved disassembly of the airframe and major airplane sections, inspection of the airplane systems' components, assessment of primary airplane structure using alternative nondestructive inspection (NDI) techniques, microscopic examination of critical and suspect areas, and fractographic analysis of selected cracks and areas of corrosion. All airplane systems' components and wiring were removed during disassembly allowing full access to all critical structural areas on the airplane. Inspection of the airplane systems' components assisted in determining if any signs of aging affects were apparent on the airplane systems. The alternative NDI techniques were performed to assess the condition of primary structural components prior to disassembly in an effort to detect additional cracks and areas of corrosion. The microscopic examination of suspect and critical structural areas provided verification and detailed quantification of the extent of damage found during the supplemental inspections, alternative NDI assessment, and disassembly of the entire airframe. Fractographic analysis was used to determine the failure mode of selected cracks as well as to provide a more detailed characterization of cracks and areas of corrosion.

1.3.4 Airplane Wiring Assessment.

As part of the airplane's destructive evaluation, electrical wiring inspections and tests were performed to assess the condition and degradation of electrical wiring in small airplanes and to evaluate maintenance procedures. The wiring inspections and tests were mainly divided into two categories: nondestructive and destructive. The nondestructive inspections and tests were comprised of general visual inspections, in situ wiring tests, and laboratory tests. The destructive tests were comprised of dielectric withstand voltage tests and mandrel bend/wrap back tests.

2. SUMMARY OF CESSNA 402A TEARDOWN EVALUATION.

The first airplane selected for destructive evaluation was a 1969 Cessna 402A model (tail number N812BW), which was used in the typical commuter class role. The twin-engine airplane had amassed a total of 19,698.9 airframe hours with a current registration, and it was most recently used for commuter service by Sunshine Airlines. Its primary usage later in its service life was tourism flights from Las Vegas to the Grand Canyon. The purchase of the airplane also included log books, the AD compliance list, and FAA 337 forms. Detailed results of the teardown evaluation on this airplane are reported in the FAA report titled "Teardown Evaluation of 1969 Cessna 402A Model Airplane" [1], and this report section summarizes those results.

2.1 INSPECTION PHASE.

The inspection phase of the Cessna 402A teardown established the current condition of the airplane by a survey of the airplane maintenance records, visual inspections per the "Cessna 402A Maintenance Manual" [3], and supplemental inspections per the "Cessna 402A Supplemental Inspection Document" (SID) [4]. These inspections allowed the NIAR team to determine which flaws could be found through normal maintenance inspections. The visual inspections were prescribed for specific airframe locations, system components, and wiring locations. The supplemental inspections were composed of NDI techniques targeted at specific airframe locations. These locations were determined based upon engineering analysis predictions, structural test results, and maintenance experience. Upon completion of the inspections, the NIAR team made an effort to correlate airplane condition with airplane usage and maintenance history through the survey of the airplane maintenance records and a review of Cessna 402A Service Difficulty Reports (SDRs).

2.1.1 Maintenance Record Review.

The Cessna 402A was registered under four different tail numbers (N4686Q, N3BL, N300UV, and N812BW) and was operated by ten different charter services (Green Bay Aviation in Green Bay, WI, Aero Electronics in Memphis, TN, Airline Services, Air Midwest in Wichita, KS, Cruse Aviation in Houston, TX, Bee Line Airlines in Houston, TX, Universal Airways in Gulfport, MS, Clary Aircraft Services in Houston, TX, Air Vegas in Las Vegas, NV, and Sunshine Airlines). Primarily used later in life for touring the Grand Canyon from Las Vegas, the airplane accumulated 19698.9 total airframe hours. A seven-year gap existed in the maintenance logs from May 1991 to May 1998. Airframe hours were also not recorded between May 1984 and May 1998. MEB71-2, Wing Rib Inspection was the only SB performed on the airplane that was relevant to this research program, while AD 79-10-15, Wing Spar Inspection was the only relevant AD performed on the airplane. The major repair of interest documented in the maintenance records involved installing doublers on the right wing lower front spar cap from Wing Station (WS) 75.24 to 65.99.

A comprehensive review of the SDR database from January 1974 to November 2002 was performed for the Cessna 402A. Of the 593 records, nearly 33% were related to landing gear with an additional 43% related to engines. Only 14% were related to the airframe, which is the area of primary interest for this teardown evaluation. It is important to note that since SDRs are not mandatory they are not always generated for each issue that arises. Therefore, common problems may exist with a specific airplane model that are not appropriately represented by the SDR database.

2.1.2 Visual Inspections of the Airframe and Airplane Systems' Components.

The visual airframe inspections were performed with the intent of finding every detectible flaw on the airplane, which led to a large number of documented flaws. The results of these inspections were reviewed by licensed airframe mechanics to determine which findings were noteworthy. Noteworthy findings are defined as defects that require further maintenance action, and most of the findings from the visual inspections were deemed minor. With aged airplanes, flaws such as minor cracks, scratches, dents, and slight corrosion were expected and posed no immediate threat to the safety of the airplane. In addition to areas of missing paint, slight to moderate corrosion was noted on a majority of the screws on the airplane. Also, it was noted that some of the disposable parts, such as hoses and seals, were due to be replaced.

A few defects noted by the inspectors were determined to be more serious in nature. Two 2.5-inch cracks on the leading edge of each horizontal stabilizer were discovered during inspections. One of these cracks is shown in figure 3. The cracks were further investigated and found to be body filler that cracked where the deicing boots were removed. One loose nut was found during inspection of the flaps. The loose nut could possibly be attributed to the initial disassembly of the airplane prior to transportation. Broken gear teeth, shown in figure 4, were observed on the left fuel selector valve.

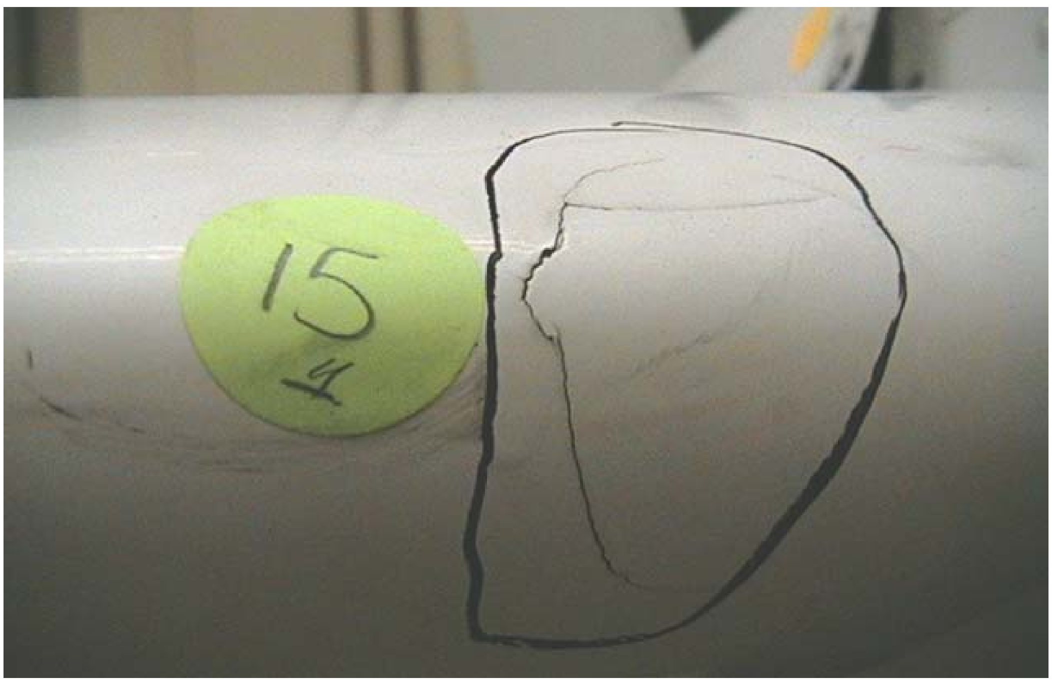

Figure 3. Leading-Edge Crack on the Cessna 402A Horizontal Stabilizer

Figure 4. Broken Teeth on the Cessna 402A Left Fuel Selector Valve

2.1.3 Supplemental Inspections.

The inspections prescribed in the SID for the Cessna 402A under investigation were performed at the Aging Aircraft Laboratory by qualified personnel. Two certified airframe mechanics from Cessna Aircraft Company and Cape Air performed the visual supplemental inspections, while all other supplemental NDIs were performed by a Cessna-provided Level III NDI examiner, a NIAR Level II inspector, and three Kansas Air National Guard NDI technicians. The SID inspections consisted of visual testing, eddy-current testing, fluorescent liquid penetrant testing and magnetic particle testing methods. The structure targeted for these inspections was located on the landing gear, wings, stabilizers and fuselage.

During the SID visual inspections, the following indications were identified:

- Two rivets needed replacement on an aileron hinge
- A patched rib in the rudder structure due for replacement
- Elongated holes on a lower rudder fitting
- A cracked doubler located at the rudder top hinge fairing
- A bonded angle in the rudder structure not attached at one end
- Corrosion on the inside and outside of the rudder torque tube
- Corrosion on the inside and outside of the elevator torque tube
- Several locations of cherry max and hi-loks needed to be replaced by solid rivets
- A patched crack on the horizontal stabilizer leading edge
- A crack in the left side inboard rib of the horizontal stabilizer

During the SID fluorescent liquid penetrant inspections, three cracks in the nose gear steering bellcrank were detected:

During the SID magnetic particle inspections, two cracked welds, one on each main landing gear torque tube, were detected:

During the SID bolthole eddy-current inspections, the following indications were detected:

- Damage to two upper cap left side holes on the vertical stabilizer rear attach at water line (WL) 108.38
- One crack indication on the lower cap of the left wing rear spar at WS 97
- Crack indications to all holes on the lower cap of the rear carry-through spar at body line (BL) 37.60
- One crack indication on the front fastener row of the lower cap of the right wing front spar at WS 55
- One 1-inch crack between two fasteners on the lower cap of the right wing front spar at WS 57.5
- One crack indication on the lower cap of the aft left wing auxiliary spar at WS 92
- Two crack indications on the aft row of the lower cap of the aft left wing auxiliary spar at WS 90
- Two crack indications on the aft row of the lower cap of the aft right wing auxiliary spar at WS 92
- Crack indications at all holes on the lower cap of the front carry-through spar at BL 37.60
- One crack indication of the aft row of the lower cap of the left wing forward auxiliary spar at WS 89
- Severe damage to most lug holes on the right- and left-side wing front spar lugs at WS 46.89
- Crack indications at all holes of the right- and left-side wing tip tank attachments

Conductivity tests also showed that both engine firewalls should be replaced.

Figure 5 shows a cracked rib in the horizontal stabilizer found during the supplemental visual inspections, while figure 6 shows a skin crack found during the bolthole eddy-current inspection of the lower front spar. The crack in figure 6 measures approximately 1-inch and is common to both fastener holes shown.

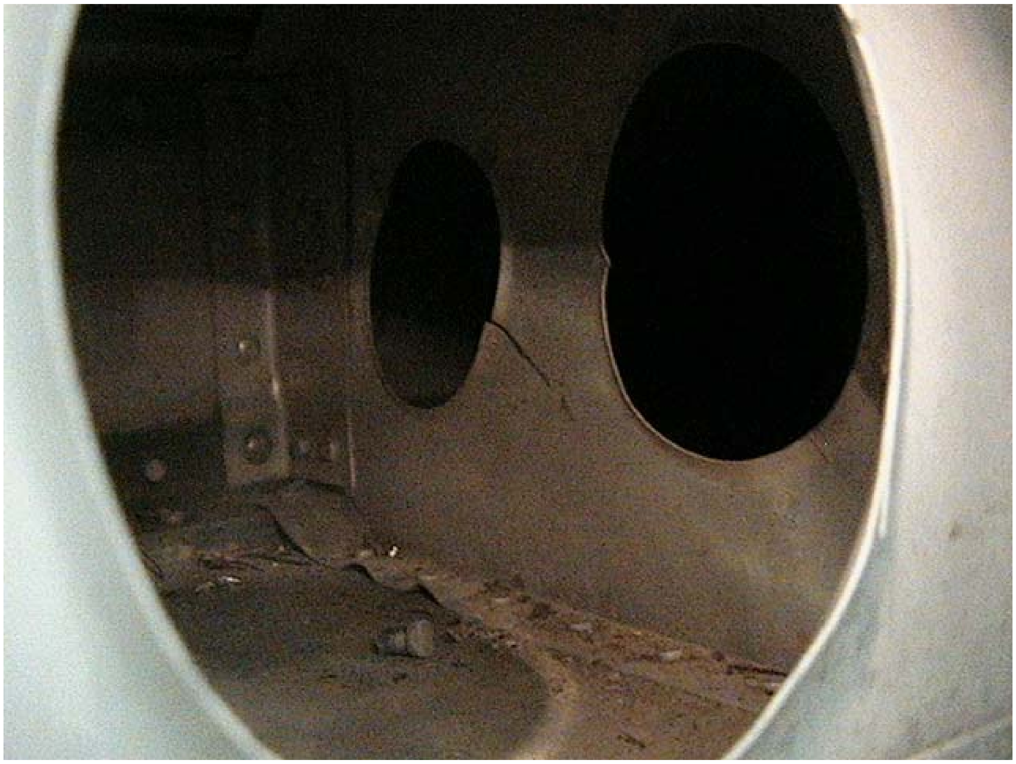

Figure 5. Cracked Rib in the Cessna 402A Horizontal Stabilizer

Figure 6. Crack on the Cessna 402A Right Wing Lower Skin

2.2 TEARDOWN EXAMINATION PHASE.

The teardown examination involved disassembly of the airframe and major airplane sections, inspection of airplane systems' components, inspection of primary airplane structure using alternative NDI techniques, and microscopic examination of critical structural areas. All airplane systems' components and wiring were removed during disassembly to provide full access to all critical structural areas on the airplane. Inspection of the systems' components assisted in determining if any aging effects were related to the airplane systems. The inspections of primary airplane structure using alternative NDI techniques were performed to assess the primary structural components prior to disassembly. The intent of the NDI using alternative techniques was to find additional cracks and areas of corrosion prior to teardown. The microscopic examination of critical structural areas provided verification and detailed quantification of the extent of damage found during the supplemental inspections, alternative NDI, and/or disassembly of the entire airframe.

2.2.1 Disassembly.

The airplane was disassembled using methods to minimize damage to surrounding structure. Once removed from the airplane, all parts were tagged to aid in identification after disassembly. All primary structural members were removed from the airplane, paint stripped using dry media blasting, and etched using a sodium hydroxide etching compound to enhance damage detection.

2.2.2 Inspections of Airplane Systems' Components.

The systems' component visual inspections were accomplished to identify areas where mechanical wear or chemical attack had caused material damage, loss of joint integrity, or corrosion on Cessna 402A mechanical components. The only finding during system component visual inspections consisted of broken teeth on a fuel selector valve gear.

Leak tests were performed on 74 pressurized lines from the Cessna 402A. Nine lines were found to have leaks. The leaks were caused by material damage, loss of fitting joint integrity, or corrosion. None of these leaks appeared to be caused by any two or three of these defects in combination.

2.2.3 Assessment of Primary Airplane Structure Using Alternative NDI Techniques.

An assessment of primary structure on the Cessna 402A was performed using the alternative NDI techniques of magnetic-optic imaging (MOI), a sliding eddy-current probe, and a spot eddy-current probe. Surface and subsurface cracks and corrosion were the conditions of interest. The purpose of these inspections was to find additional defects in the airframe using alternative NDI techniques prior to disassembly. These techniques are not called out in either the Cessna 402A or Cessna 402C SIDs; therefore, no procedures had been established or validated for using these techniques on the Cessna 402s. Using existing structure and locally manufactured calibration standards, inspectors attempted to identify target areas for further microscopic examination. No effort was made to evaluate the capabilities of the alternative NDI techniques, and conclusions about the capabilities of MOI, sliding probe, or spot probe should not be made from the results presented in this report. All indications were investigated during the microscopic examination for validity and extent of the defect.

During the structural assessment using alternative NDI techniques, the following indications were identified:

- Four indications on the horizontal stabilizer front spar upper cap
- Four indications on the horizontal stabilizer front spar lower cap
- Eleven crack indications on the left wing front spar lower cap
- Five indications on the left wing front spar upper cap

<u>2.2.4 Microscopic Examination</u>.

Microscopic examinations were conducted on suspect areas from all inspections, on defects found during disassembly, and on critical structural details in order to locate and characterize cracks and areas of corrosion. Cracks of greater than 0.01 inch were recorded and assigned a crack description code along with recording the clock position, hole diameter, part thickness, and geometry. The extent of corrosion was measured by area and documented photographically. The severity of the corrosion was characterized by the percentage of thickness loss based on the deepest area of corrosion as follows:

- Light (0%-2%)
- Light-to-moderate (2%-5%)
- Moderate (5%-7%)
- Moderate-to-severe (7%-10%)
- Severe (>10%)

All indications from the supplemental inspections were examined microscopically. None of the crack indications on the lower cap of the front carry-through spar, on the lower cap of the rear carry-through spar, or on the welds of main landing gear torque tube were verified microscopically. The following areas had at least one or more defects identified in the microscopic examination.

- Stub wing attach fittings
- Right stub wing skin
- Wing attach fittings
- Front spars of the left and right wings
- Tip tank fittings on the left and right wings
- Forward and aft auxiliary spars on the left and right wings
- Rudder bellcrank
- Nose gear steering bellcrank
- Left-hand fuselage channel

Indications from the structural assessment using alternative NDI techniques were also microscopically examined to determine whether the indications could be verified. Only a limited number of the alternative NDI indications on the Cessna 402A horizontal stabilizer and left wing front spars were verified microscopically. The results of the microscopic examination of alternative NDI indications are as follows:

- Two of the eight spot probe indications on the horizontal stabilizer were verified as light corrosion.

- Six of the sixteen advanced NDI indication locations on the left wing were verified to have corrosion.

- One skin crack found using MOI was verified microscopically.

A discussion of the results from the microscopic examination on the 402A airplane follows in the remainder of this subsection.

One of the eight stub wing attach fittings was found to have a 0.24-inch crack, as shown in figure 7. This crack was oriented parallel to the load path and found to be caused by stress corrosion. This fitting was the only stub wing attach fitting that had any defects. Two of the right stub wing upper skins had areas of corrosion. These corrosion areas were classified as severe and only occurred on the right wing. Four of the eight front wing attach fittings were found to have corrosion. Three of these fittings were located on the left wing. The left wing front spar lower front root fitting had the most significant corrosion, which was classified as moderate-to-severe and is shown in figure 8. The front spars on both wings had several areas of corrosion, located on the lower cap of the front spars. The left wing exhibited the most corrosion, with an area of moderate corrosion.

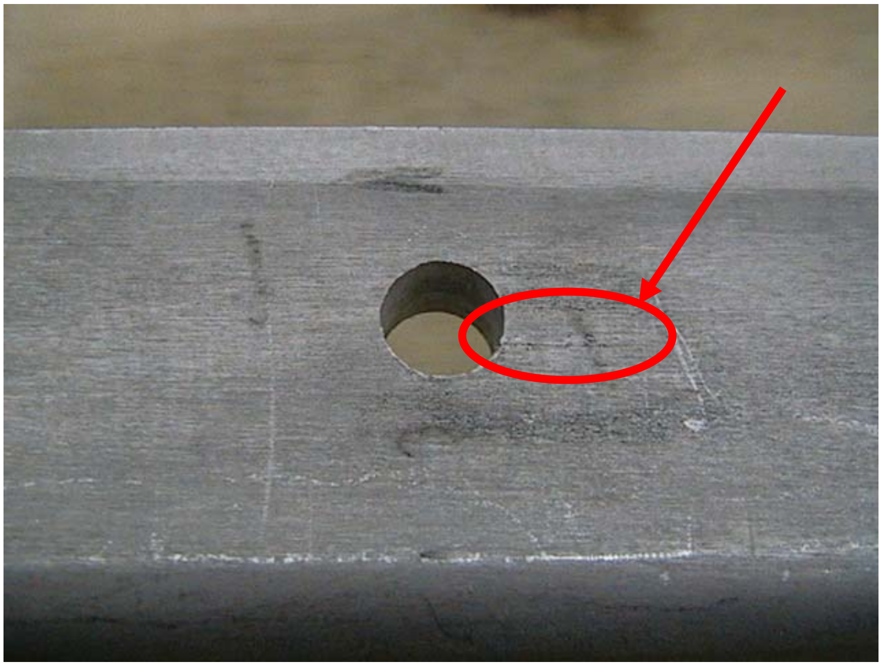

Figure 7. Stress Corrosion Crack on the Cessna 402A Stub Wing Attach Fitting

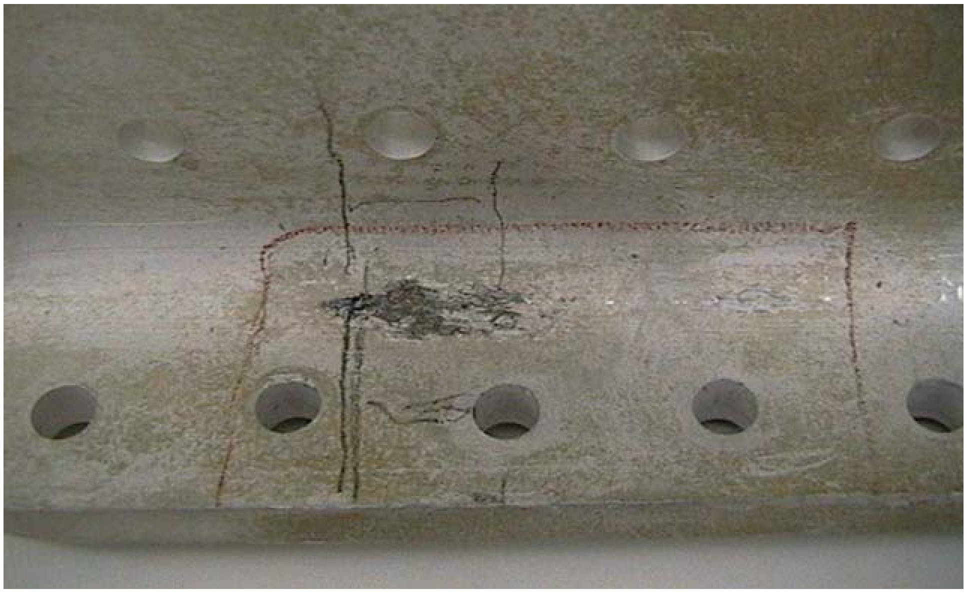

Figure 8. Moderate-Severe Corrosion on the Cessna 402A Left Wing Lower Front Fitting

Both tip tank fittings had areas of cracking. The left wing tip tank baffle, shown in figure 9, had two cracks measuring 0.252 and 0.295 inch, which were both caused by fatigue. The right wing tip tank fitting had several cracks, which were apparently induced during manufacturing due to the heat treatment process.

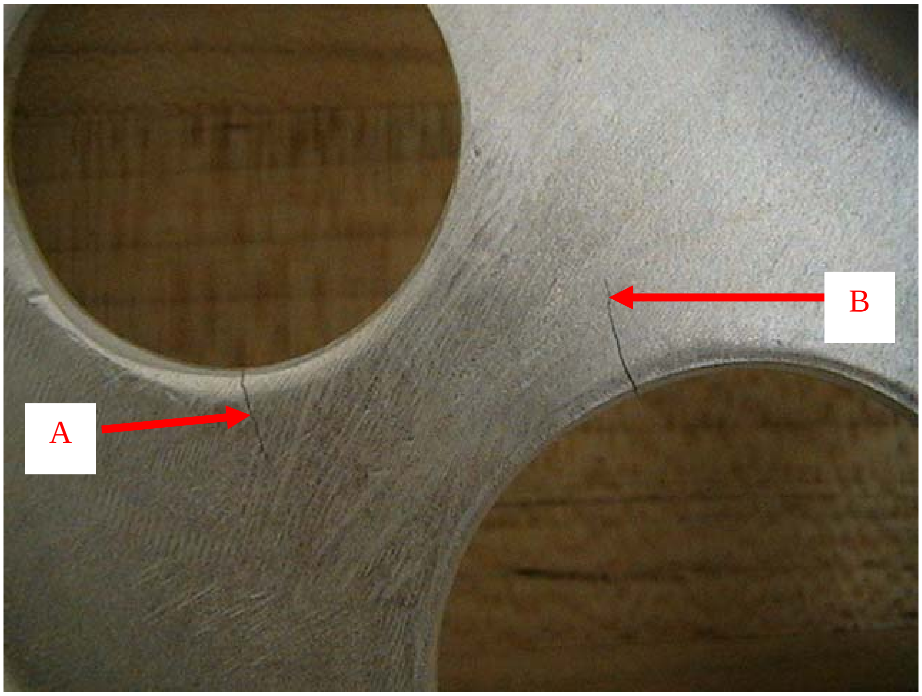

Figure 9. Two Cracks in the Cessna 402A Left Wing Tip Tank Baffle

All four auxiliary spars had multiple cracks. Eight total cracks were found on the left wing auxiliary spars, ranging from 0.046 to 0.598 inch. Twelve total cracks were found on the right wing auxiliary spars, ranging from 0.041 to 0.74 inch. All auxiliary spar cracks show signs of typical fatigue cracks. Figures 10 and 11 show examples of the 20 total cracks found on the wing auxiliary spars.

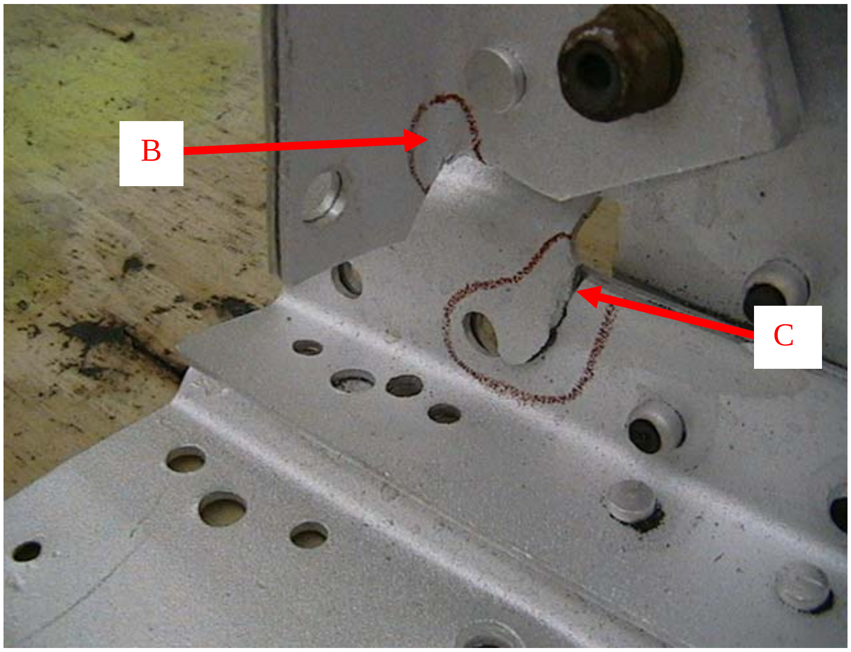

Figure 10. Two Cracks Found on the Cessna 402A Left Wing Forward Auxiliary Spar

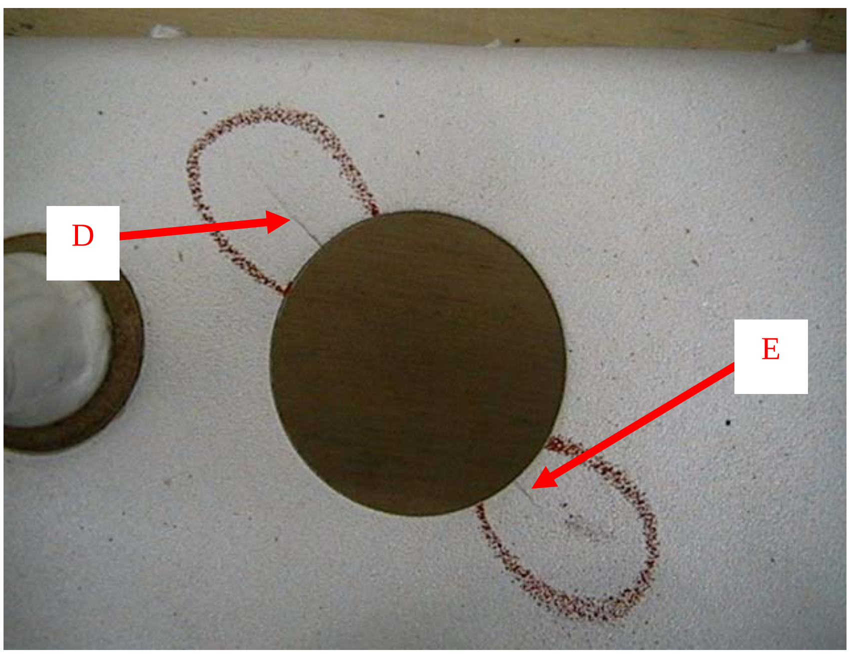

Figure 11. Cracks Around Lightening Hole on the Cessna 402A Left Wing Forward Auxiliary Spar

Two cracks ranging from 0.03 to 0.045 inch, were detected on the rudder bellcrank. Both cracks exhibited fatigue-like characteristics. Eight total cracks were found on the nose gear steering bellcrank, ranging from 0.039 to 0.093 inch. These cracks were located at the corners of the bellcrank and were caused by fatigue. Cessna is aware of this issue and had redesigned the bellcrank prior to this research program. The left-hand fuselage channel exhibited several small areas of corrosion, classified as light-to-moderate.

2.3 WIRING ASSESSMENT.

As part of the airplane destructive evaluation, electrical wiring inspections and tests were performed to assess the condition and degradation of electrical wiring in small airplanes and to evaluate maintenance procedures. The wiring inspections and tests were divided into two categories: nondestructive and destructive. The nondestructive inspections and tests were comprised of general visual inspections, in situ wiring tests, and laboratory tests. The destructive tests were comprised of wet dielectric withstand voltage tests, mandrel bend/wrap back tests, and dynamic cut-through tests.

2.3.1 General Visual Inspections.

The general visual inspections were performed on undisturbed wires. The purpose of these inspections was to determine the general condition of the wires in the right and left engine compartment, right and left console, forward bulkhead, baggage compartment, upper bulkhead, tail, right and left wings, landing gear, cockpit floor, and the instrument panel. The inspectors were looking for wiring defects such as rubbing and chafing of the outer insulation, exposed inner conductor, damaged shield, repaired wires, contamination, cracked wires, corroded terminals, improper termination, and heat damage. Figure 12 shows an exposed inner conductor found in the engine compartment, while figure 13 shows repaired wires observed in the side console. Heat-damaged terminals in the nose compartment are shown in figure 14, while cracked wires near the landing gear are shown in figure 15. Figure 16 shows wire bundles riding on control cables, which leads to chafing of the wire. A partially stripped wire, shown in figure 17, was found in the instrument panel. A cause of rubbing and chafing of wires is often missing grommets. An example of a missing grommet is shown in figure 18.

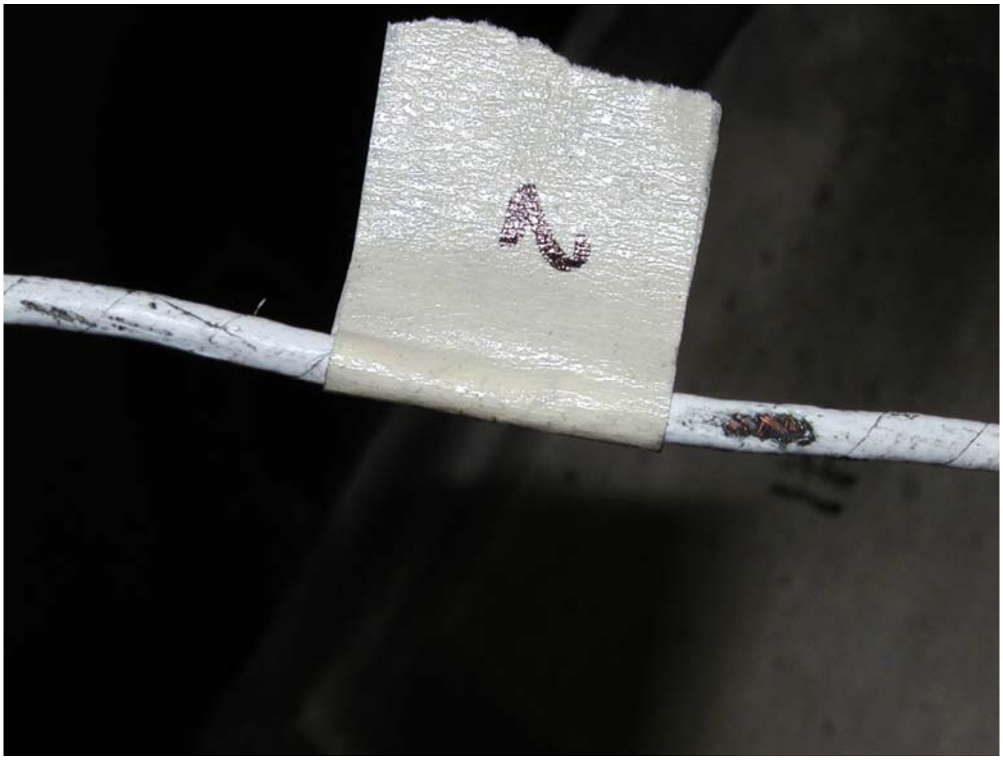

Figure 12. Exposed Inner Conductor in the Cessna 402A Engine Compartment

Figure 13. Repaired Wires in the Cessna 402A Side Console

Figure 14. Heat-Damaged Terminals in the Cessna 402A Nose Compartment

Figure 15. Cracked Wires in the Cessna 402A Landing Gear

Figure 16. Wire Bundles Riding on the Cessna 402A Control Cables

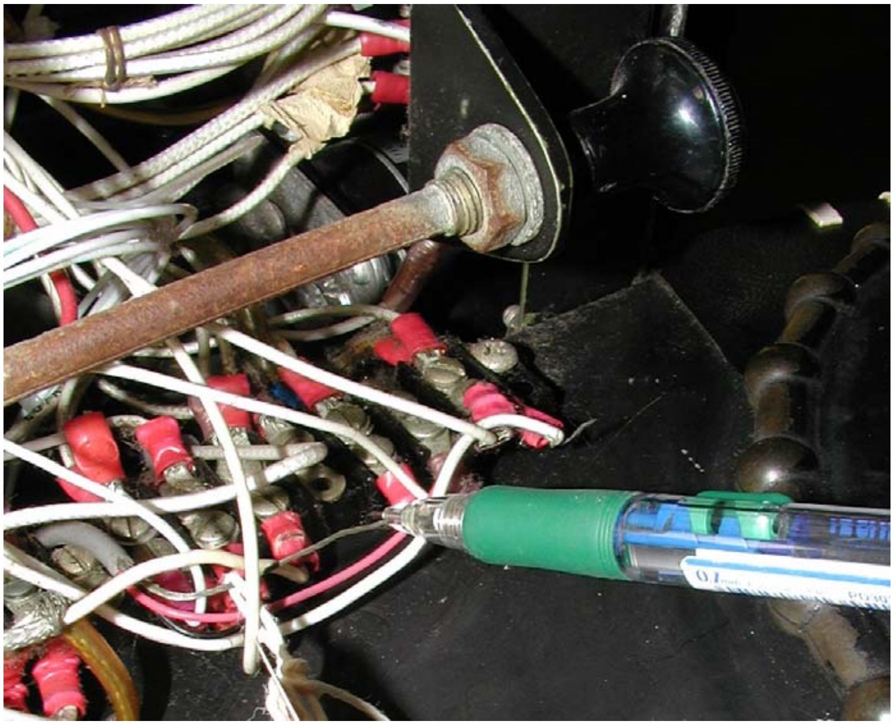

Figure 17. Partially Stripped Wire in the Cessna 402A Instrument Panel

Figure 18. Missing Grommet Near Cessna 402A Upper Forward Bulkhead

Of the 103 wiring condition defects found on the Cessna 402A, 30% were cut outer insulation, 24% were rubbing or chafing of outer insulation, 14% had exposed inner conductors, and 11% had exposed shields. Two hundred forty-five installation defects were reported on the Cessna 402A. Nearly 33% of these defects were repaired wires, 20% were inadequate clearance to structure, and 11% were unused wires that were improperly stowed. Only 14 termination defects were reported on the Cessna 402A.

2.3.2 Nondestructive Inspection and Tests.

A loop resistance test, a Del™ test, and an excited dielectric test were performed on the airplane prior to conducting laboratory tests. The loop resistance measurement shows how well the airplane structure is electrically grounded, to demonstrate the capability of the airplane to discharge static that is generated during flight. The lower the value measured, the better the dissipation of the static charges accumulated. The other two tests did not yield any reportable results.

The laboratory tests were performed after the teardown of the airplane. During the teardown phase, all the wires were removed from the airplane and were subjected to various tests and inspections. The lab tests consisted of the following:

- Intrusive Visual Inspection
- Wiring Insulation Microscopic Inspection
- Insulation Resistance Test

- Circuit Breaker Test
- Relay Inspection

All flaws found in the general visual inspection were very conspicuous, and the intrusive visual inspection and the microscopic inspection were used to confirm these results. Intrusive visual inspection data provided more information on the wiring condition of the specific location inspected. The insulation resistance test was used to determine the insulation resistance of a finished wire specimen. Insulation resistance is of interest in high-impedance circuits and as a measure of quality control.

Since circuit breakers are designed to limit the current flow through the wires in different sections of the airplane, they were tested for various current ratings, e.g., 135%, 200%, and 300%. There were a total of 21 circuit breakers tested. One breaker did not function and would not conduct any current, five circuit breakers did not meet trip time specifications after the first test, three did not meet trip time specifications after the second test, and all functioning circuit breakers met specifications by the third test. The trip times of the functioning circuit breakers that first failed changed drastically as the breakers were cycled. The trip times of the circuit breakers that were functioning barely changed, if at all.

2.3.3 Destructive Tests.

Three destructive laboratory tests were performed on the wires. These tests were:

- Wet Dielectric Withstand Voltage Test (DWV)
- Mandrel Bend/Wrap Back Test
- Dynamic Cut-Through Test

The DWV test provides a method to determine insulation integrity following any type of performance test. This test was performed soon after the insulation resistance measurement test. The test was used to determine whether exposure to environmental test conditions had reduced the breakdown strength of the wires below some prescribed level. The mandrel bend/wrap back test was used to determine whether a wire specimen would crack when wrapped around itself or around a mandrel. This test was used to determine the degree of sintering of wire insulations. The dynamic cut-through test is used to determine the amount of force required to cut through the outer insulation of a wire.

The destructive laboratory tests also demonstrated few issues with wires with respect to aging airplane. Since no wires were 26 feet or more in length as required by the standard, they could not be reliably tested for DWV. Only 12.5% of the wires failed the mandrel bend/wrap back test, which indicated that the wires generally had good quality insulation. The dynamic cut-through test gave a wide variability in the force required to cut each specimen, therefore, no solid conclusion could be drawn about the wire’s ability to resist cutting of the outer insulation.

3. SUMMARY OF CESSNA 402C TEARDOWN EVALUATION.

The second airplane selected for destructive evaluation was a 1979 Cessna 402C model (tail number N780EA), which was also used in the typical commuter class role. The twin-engine airplane had over 25,500 total airframe hours with a current registration, and it was most recently used for commuter service by Cape Air/Nantucket Airlines of Hyannis, MA, flying in and around Cape Cod and the Caribbean. Maintenance records, log books, the AD compliance list, and FAA 337 forms were included with the purchase of this airplane. Detailed results of the teardown evaluation on this airplane are reported in the FAA report titled "Teardown Evaluation of 1979 Cessna 402C Model Airplane" [2], and this report section summarizes those results.

3.1 INSPECTION PHASE.

The inspection phase of the Cessna 402C teardown established the current condition of the airplane by survey of airplane maintenance records, visual inspections per the "Cessna 402C Maintenance Manual" [5], and supplemental inspections per the "Cessna 402C Supplemental Inspection Document" (SID) [6]. These inspections allowed the NIAR team to determine which flaws could be found through normal maintenance inspection. The visual inspections were prescribed for specific airframe locations, system components, and wiring locations. The supplemental inspections were composed of NDI techniques targeted at specific airframe locations. These locations were determined based upon engineering analysis predictions, structural test results, and maintenance experience. Upon completion of the inspections, the NIAR team made an effort to correlate airplane condition with airplane usage and maintenance history through the survey of the airplane maintenance records and a review of Cessna 402C service difficulty reports (SDRs).

3.1.1 Maintenance Record Review.

The Cessna 402C airplane was registered under four different tail numbers and was operated by five charter services (Provincetown Boston Airlines, Gulfstream Airlines, Air Nevada Airlines, Eagle Canyon Airlines, and Hyannis Air Service). Primarily used for commuter service along the eastern North American coast, flying in and around Cape Cod, the Florida Keys, and the Caribbean, the airplane accumulated a total of 25,546.6 hours. The SBs performed on the airplane that were of concern included MEB85-3 (Supplemental Engine Mount Inspections), MEB99-3 (Inspection of Lower Spar), and MEB99-7-10-13 (Installation and Inspection of Stainless Steel Engine Beams). The AD of most concern included AD 81-11-05 (Engine Mount Beams), AD 97-26-16 (Engine Mount Beams), AD 99-11-13 (Wing Spars), and AD 2000-23-01 (Wing Spars). The major repairs and alterations that were of main concern included a rudder damage repair performed in September 1986, repair to left wing leading edge performed in May 1991, repair to nose area performed in May 1991, and repair of left forward upper stub wing spar web performed in October 1994.

The review of Cessna 402C SDRs involved reviewing 2094 reports from January 1974 to November 2002. Almost a third of these documents were related to the landing gear with an additional quarter related to the engines. Only 18% were related to the airframe, which is the area of primary interest for the teardown evaluation. Service difficulty reports are not always generated for each issue that arises. Therefore, common problems may exist that are not appropriately represented by the SDR database.

3.1.2 Visual Inspections of the Airframe and Airplane Systems' Components.

The visual airframe inspections were performed with the intent of finding every detectible flaw on the airplane, which led to a large number of documented flaws. The results of these inspections were reviewed by licensed airframe mechanics to determine which findings were noteworthy. Noteworthy findings are defined as defects that require further maintenance action. Most of the findings from the visual inspections were deemed minor. With aged airplanes, flaws such as minor cracks, scratches, dents and slight corrosion were expected and pose no immediate threat to the safety of the airplane. In addition to areas of missing paint, slight-to-moderate corrosion was noted on a majority of the screws on the airplane. Also, it was noted that some of the disposable parts, such as hoses and seals, were due to be replaced.

Three defects noted by the inspectors were determined to be more serious in nature. A static leak was observed in a hydraulic flow pressure switch. The right exhaust pipe was improperly repaired with a welded plate patch. When maintenance technicians from Cape Air removed the antenna (part number VT10-56-5) from the vertical stabilizer, they found that the skin had a significant area of corrosion. The antenna is not removed as part of any inspection; therefore, the area of corrosion, which is shown in figure 19, would not have been found during any prescribed visual or supplemental inspections.

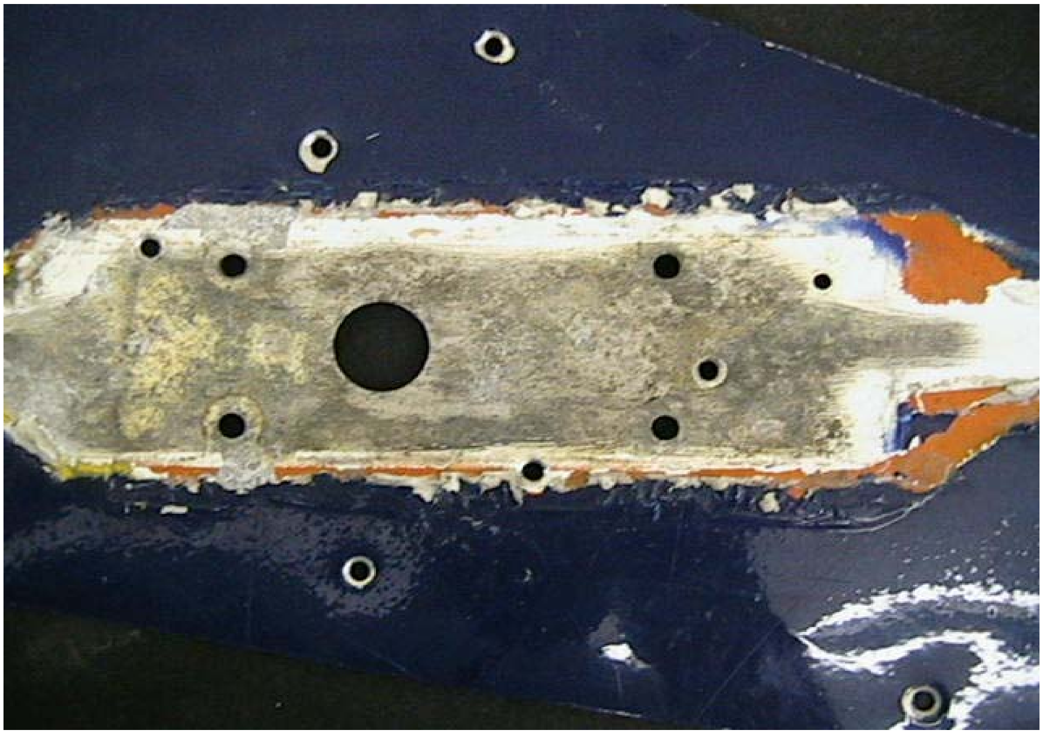

Figure 19. Corrosion on the Cessna 402C Vertical Stabilizer Skin Common to the Antenna

3.1.3 Supplemental Inspections.

After completing the visual inspections, supplemental NDIs were performed on the Cessna 402C as prescribed by the SID. These inspections consisted of visual testing, eddy current testing, liquid penetrant testing, magnetic particle testing, and ultrasonic testing inspection methods. The 19 visual testing inspections were performed by certified Cessna and Cape Air airframe mechanics. Twenty-eight additional supplemental inspections using the other four testing methods were performed independently by three different NDI inspectors: a Cessna provided Level III NDI examiner, an Aging Airplane Level II NDI inspector, and an Aging Airplane Level I NDI operator.

The following damage was identified in the visual testing inspections:

- Paint scratches and corrosion in the rudder structure
- Skin crack in an engine beam flange
- Corrosion and damaged holes due to removal in several upper wing to carry-through attachment fittings
- Corroded fittings and missing paint on the main/nose gear retraction system

The bolthole eddy current inspections resulted in the finding of nine well-defined indications on the following structure:

- Horizontal stabilizer upper spar cap skin cracks
- Horizontal stabilizer forward spar web hole out of round
- A wing attach fitting crack
- Bolthole cracks in an angle on the outboard right stub wing
- Left wing lower aft auxiliary spar cap skin cracks

Surface eddy-current inspections resulted in the finding of seven well-defined crack indications on the right wing outboard engine beam and left wing front spar lower cap. Fluorescent liquid penetrant inspections resulted in the finding of a crack on a support bracket for the elevator hinge. No findings were discovered during the magnetic particle inspections on landing gear components. Tap testing was used to check bond integrity of upper wing skin due to the unavailability of the highly specialized *Bond Master* ultrasonic testing machine. Tap testing resulted in the finding of one disbonded area in the left wing upper trailing edge at WS 211.

An example of the corrosion observed on the stub wing spar attachment fittings is shown in figure 20. Damage induced on the stub wing attachment fittings is illustrated in figure 21. According to maintenance technicians from Cape Air, this damage is typical when removing these fittings due to limited access. This damage is also consistent with damaged induced on the Cessna 402A wing attachment fittings. Figure 22 shows a 0.25-inch crack found on a bracket supporting the left inboard elevator fitting. Although the support bracket was not prescribed as a supplemental inspection location, inspectors observed the crack while inspecting the elevator attachment fitting. Figure 23 shows a 2-inch crack found on an angle common to the right stub wing outboard rib and the carry-through structure during the bolthole eddy-current SID inspections.

Figure 20. Corrosion Observed on the Cessna 402C Stub Wing Spar Attachment Fittings

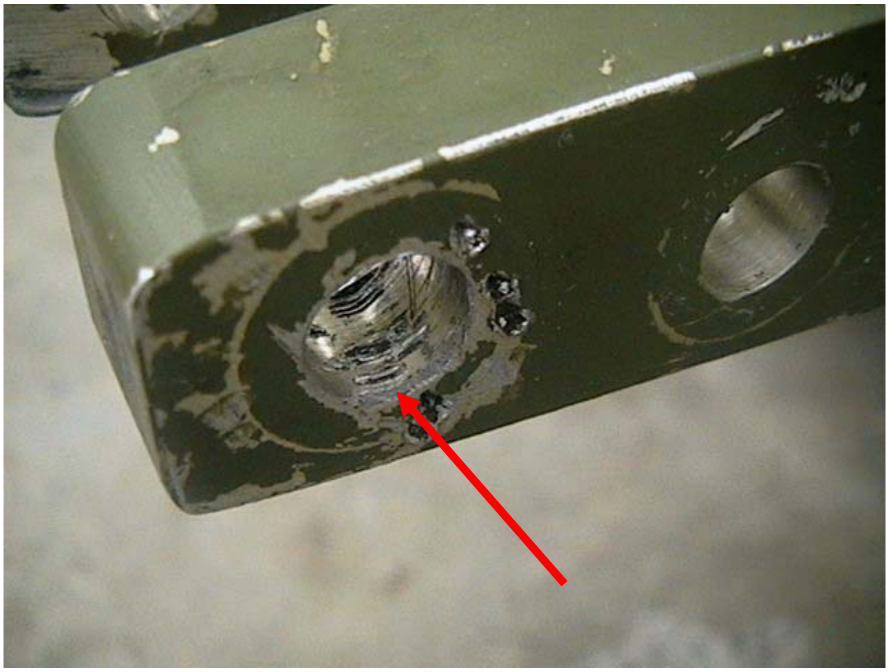

Figure 21. Example of Damage Induced During Removal of the Cessna 402C Stub Wing Attachment Fittings

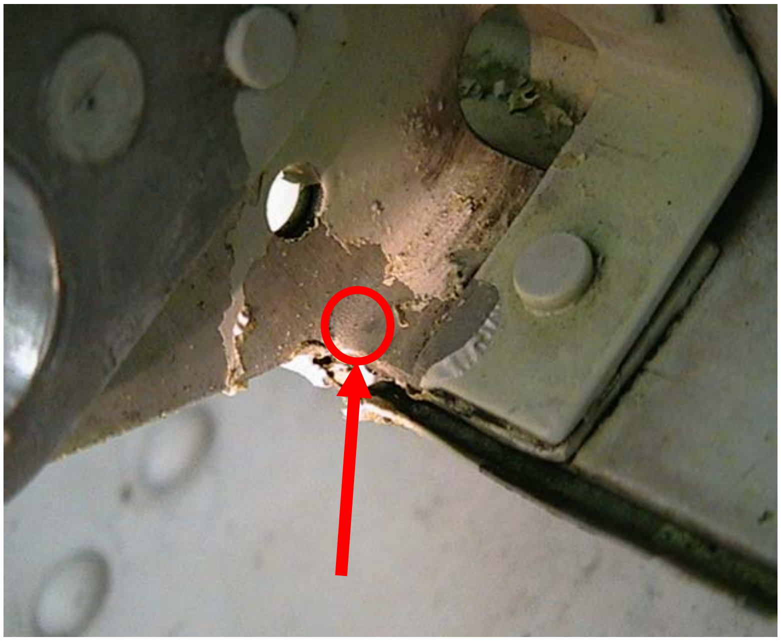

Figure 22. Crack in the Bracket Supporting Cessna 402C Left Inboard Elevator Attach Fitting

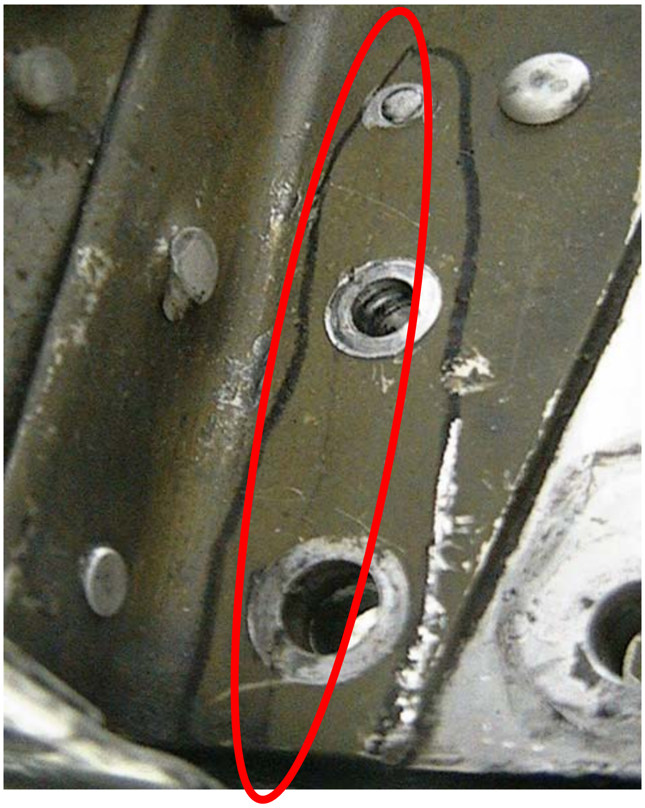

Figure 23. Crack in the Cessna 402C Angle Common to the Right Stub Wing Rib and Carry-Through Structure

3.2 TEARDOWN EXAMINATION PHASE.

Following the completion of the inspection phase, the teardown examination phase was performed to find defects not found by typical maintenance or supplemental inspections. Every defect found in the inspection phase and the teardown examination phase was completely characterized during the microscopic examination portion of this project. The airplane was first disassembled into the major airplane sections including the wings, forward fuselage, aft fuselage, cabin, landing gear, horizontal stabilizer, and vertical stabilizer. The systems' components were inspected both on the airplane and, when necessary, after removal. Alternative NDI techniques were used to examine the wing spars, fuselage channels, and the horizontal and vertical stabilizer spars to assess the primary airplane structure prior to disassembly. Following the alternative NDI investigation, the major airplane sections were disassembled to remove the critical structural details and suspect locations identified during inspections. These details were then examined microscopically to find and characterize all the defects. Certain cracks and areas of corrosion were sectioned and mounted for fractographic analysis to further determine the extent of the flaw and the mode of failure for cracks, such as fatigue or stress corrosion cracking.

3.2.1 Disassembly.

To facilitate the alternative NDI and detailed disassembly, the airplane was disassembled per the Cessna 402C Maintenance Manual into its major airframe sections: wings, horizontal stabilizer, vertical stabilizer, landing gear, forward fuselage, aft fuselage, and cabin. Prior to any disassembly of the airplane into sections, the engines were removed and were not investigated as part of this program. Systems' components were also removed for inspection. All disassembly was done as carefully as possible to minimize damage to the wiring, systems components, and the underlying structure of the airplane.

During the detailed disassembly, cracks were found on the engine structure. Table 1 lists structural details found cracked in the engine structure as well as the crack orientation relative to the wing front spar. As illustrated in figure 24, cracks were located on the inboard and outboard engine beams where they attach to the lower front wing spar. Specifically, cracks were located on the inboard engine beam of the right wing, on an angle assembly on the right outboard engine beam and on the channels of the left and right outboard engine beams along with the channel of the right inboard engine beam.

Table 1. Crack Locations and Orientations on the Cessna 402C Engine Beams

IPB Figure Item Number	Part Number	Nomenclature	Crack Orientation with Front Spar
01-9,-9A	5654109-3/-7	Beam-Nacelle INB RH	Parallel
01-22	5650118-2	Angle Assembly-OTB RH	Parallel
01-33	5654111-1	Channel-OTB LH	Perpendicular
01-34	5654111-2	Channel-OTB RH	Perpendicular
01-36	5654110-2	Channel-INB RH	Parallel

IPB = Illustrated parts breakdown   OTB = Outboard   LH = Left hand
INB = Inboard   RH - Right hand

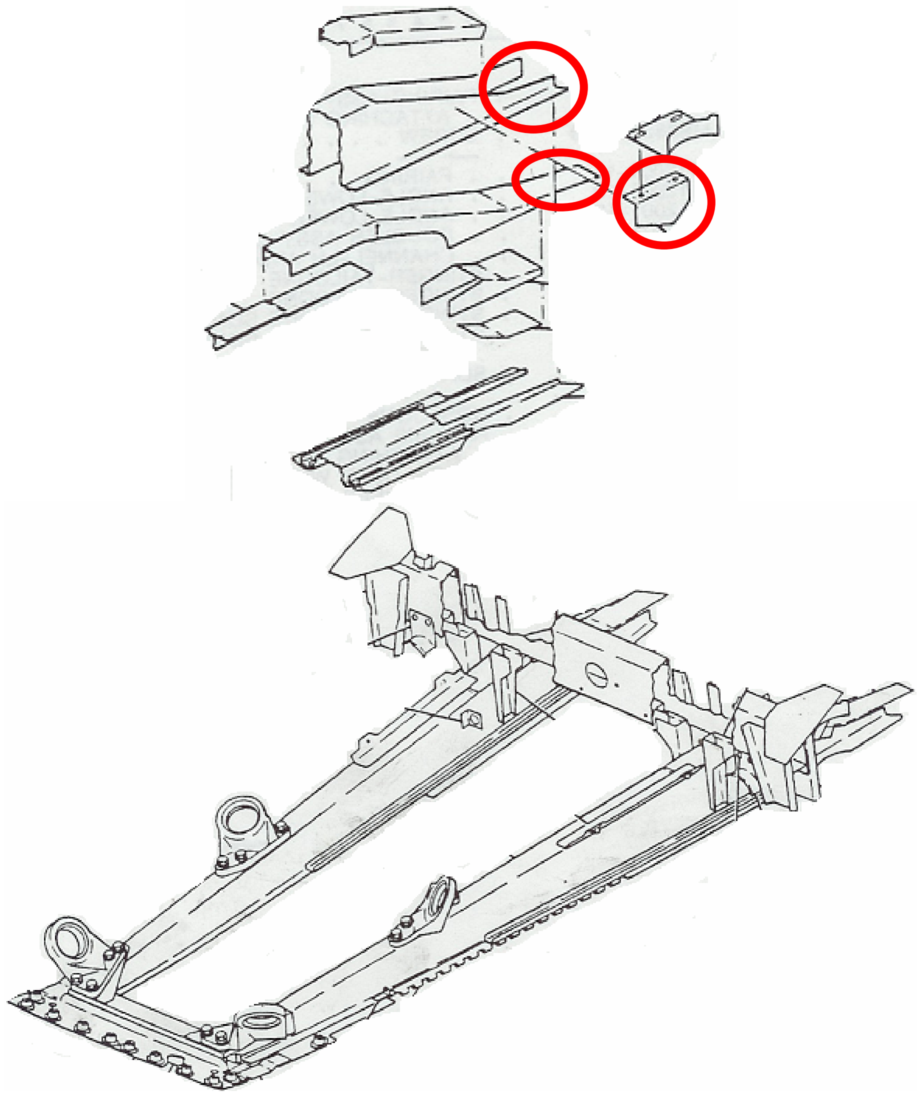

Figure 24. Illustrated Parts Breakout of the Cessna 402C Engine Beam Structure

Figure 25 shows the right wing engine structure. The listed figure numbers refer to detailed pictures of the cracks found in the right wing engine beam structure. Figure 26 shows a crack found on the channel of the inboard engine beam. This crack runs completely across the channel almost parallel to the front spar on the upper surface of the channel, and it continues across the outboard flange of the inboard engine beam. Figure 27 shows a 2.062-inch-long crack found on the channel of the outboard engine beam that runs along the inboard upper side perpendicular to the front spar. A similar 1.437-inch-long crack was also found on the left outboard engine beam. Figure 28 shows a crack on the angle bracket on the outboard right nacelle beam. This crack runs mostly perpendicular to the front spar. Additional damage was found between the right inboard engine beam and its attachment location on the right lower front spar. The skin was worn completely through, and the spar cap itself exhibited evidence of wear, as seen in figure 29.

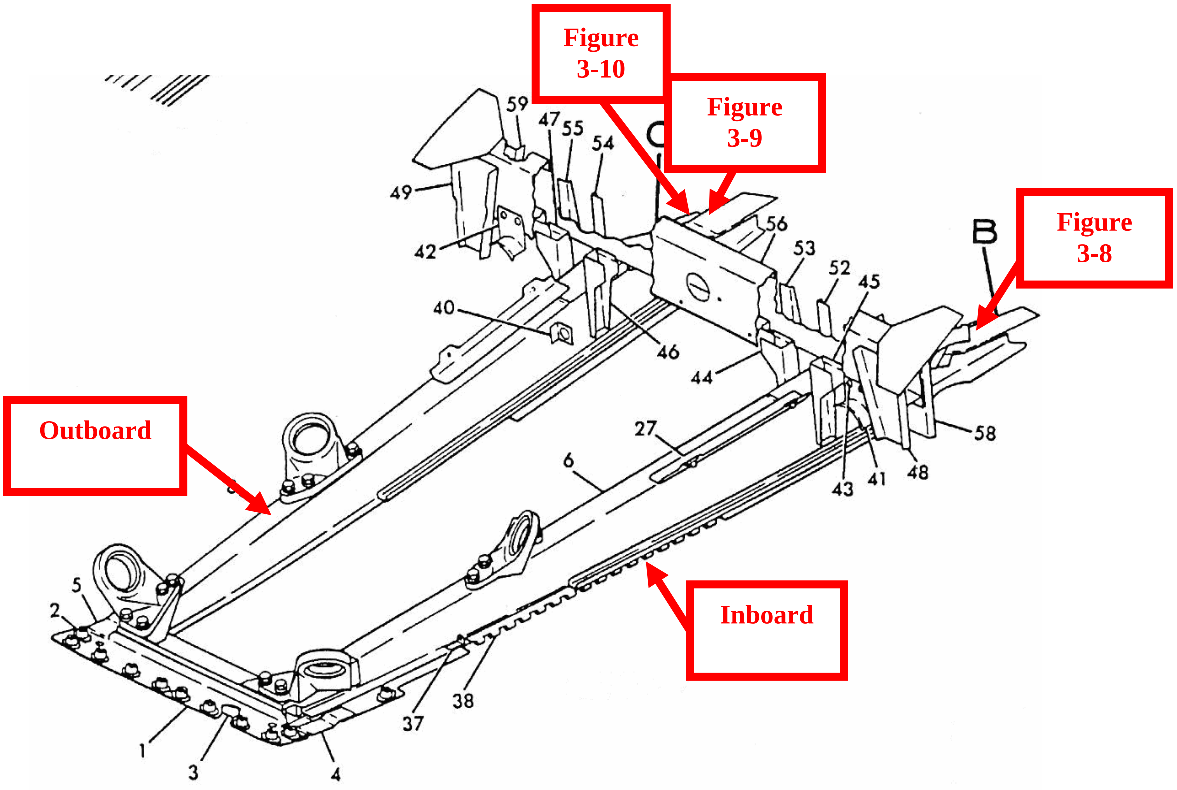

Figure 25. Location of Cracks on the Cessna 402C Right Wing Engine Beams

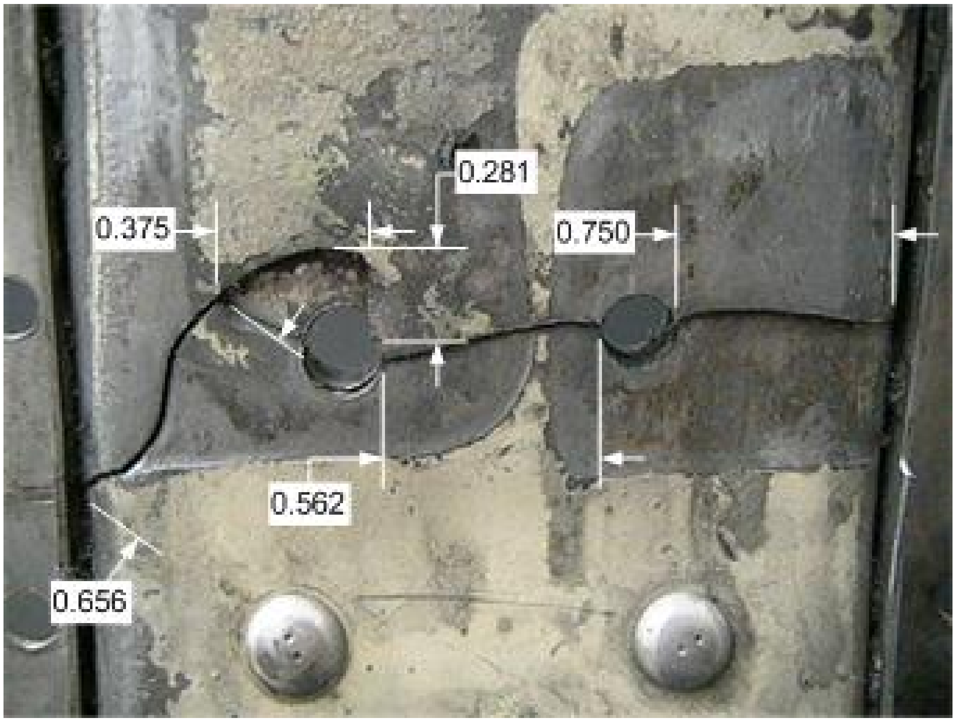

Figure 26. Cracked Cessna 402C Right Wing Inboard Engine Beam

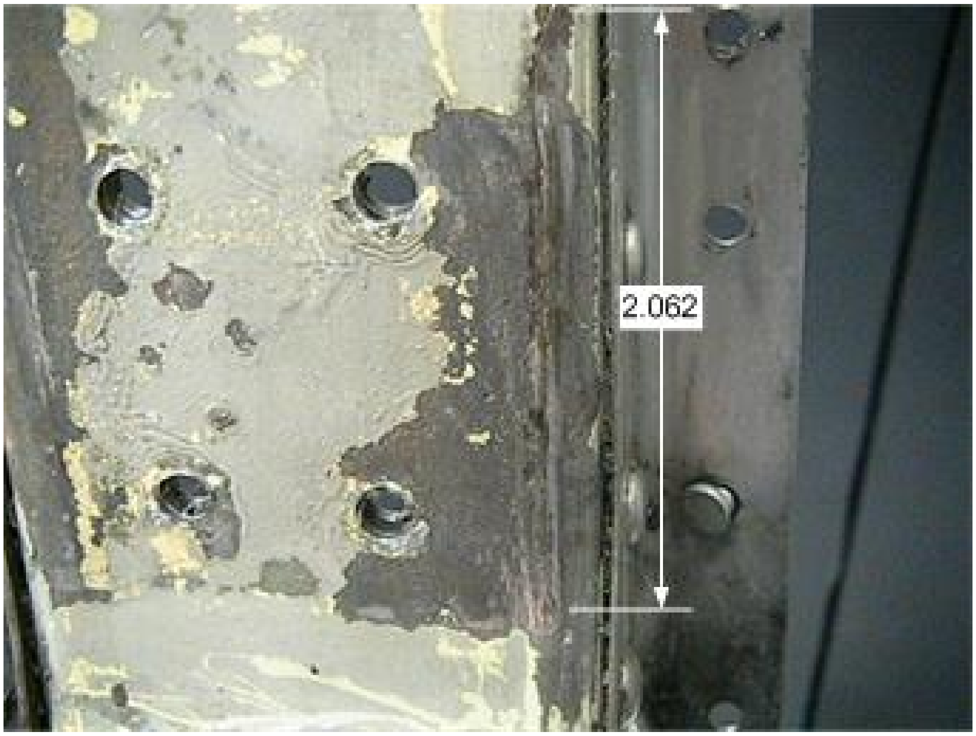

Figure 27. Cracked Cessna 402C Inboard Upper Surface of the Right Wing Outboard Engine Beam

Figure 28. Cracked Cessna 402C Angle Bracket of the Right Wing Outboard Engine Beam

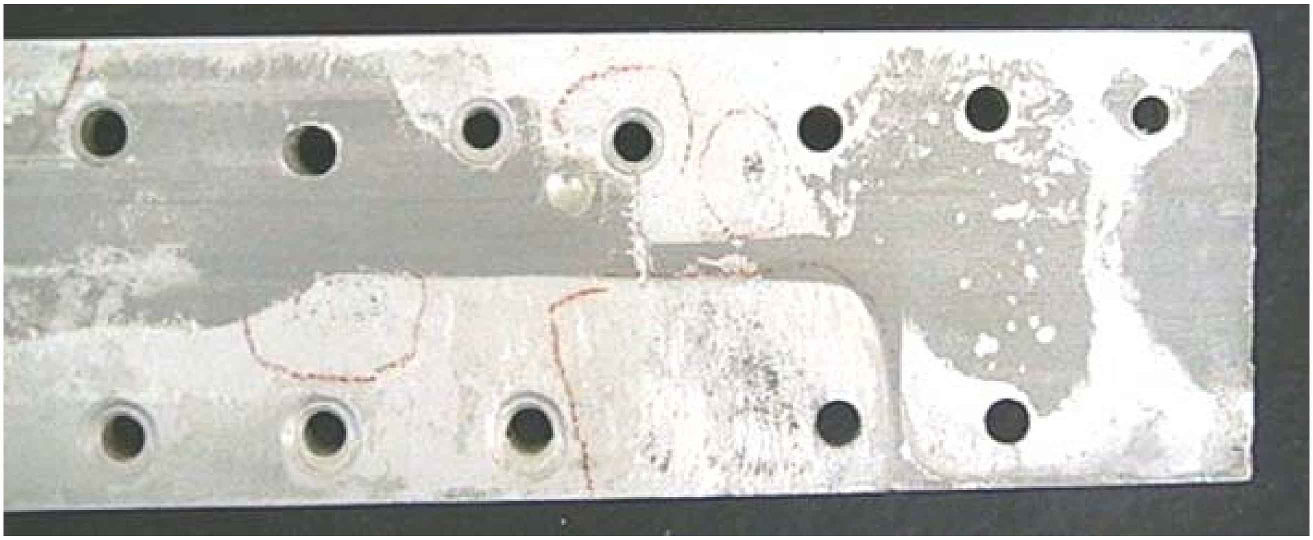

Figure 29. Wear on the Cessna 402C Right Wing Front Spar Lower Cap

Cracks were also discovered on the fuselage carry-through structure during removal. Table 2 documents the location and number of cracks found in the carry-through structure. Forty-three total cracks were discovered, ranging in length from 0.13 to 2.98 inches. Figure 30 shows the carry-through structure. Figure 31 shows a crack found in the aft carry-through forward web, part number 5211173-4. This particular crack was found on the left-hand side at BL 1. The forward carry-through forward web, part number 5211172-5, was found to have 17 cracks. Four of these cracks are shown in figure 32. Figure 33 shows four of the cracks found in the forward carry-through aft web. The mode of failure for these cracks was determined to be fatigue during the microscopic examination.

Table 2. Damage in Cessna 402C Carry-Through Structure

Part Numbers	Nomenclature	Damage Found
5211173-(4-8)	Aft carry-through forward web	9 cracks
5211173-(2-3)	Aft carry-through aft web	6 cracks
5211172-(5-8)	Forward carry-through forward web	17 cracks
5211172-(2-4)	Forward carry-through aft web	9 cracks
5111367-21	Left stub wing outboard web	2 cracks

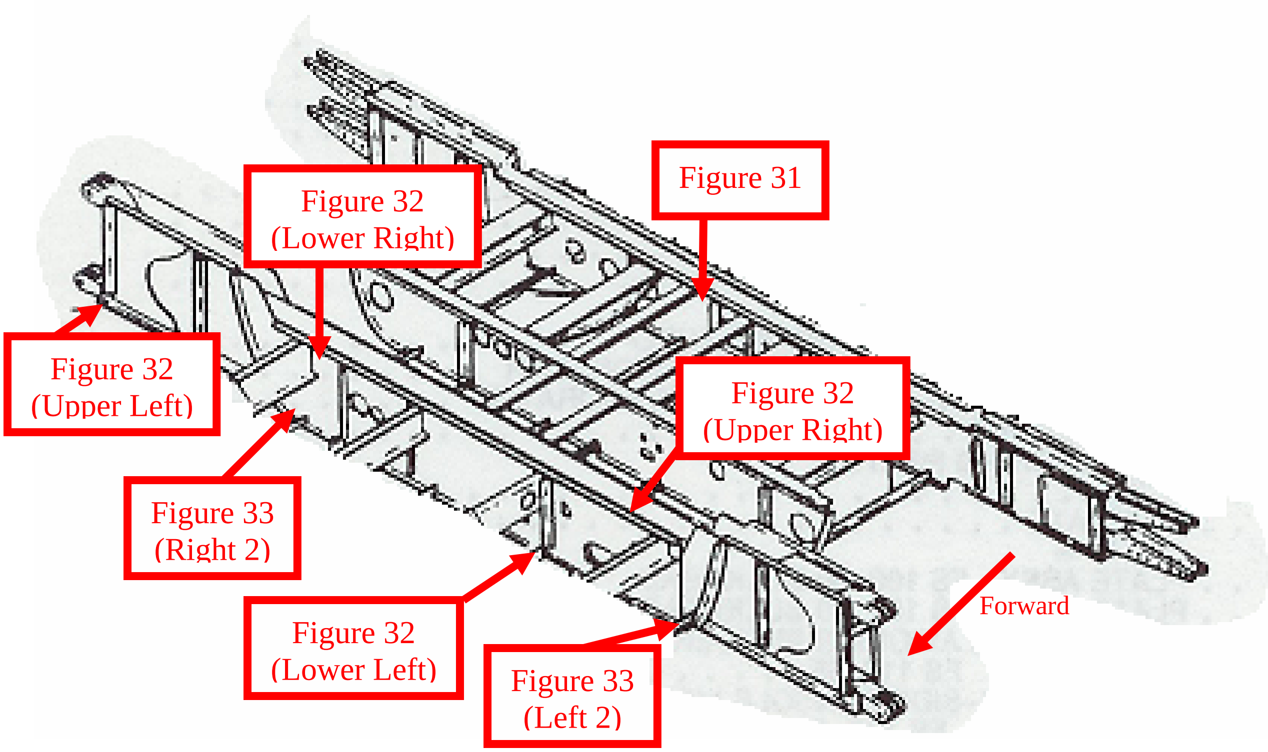

Figure 30. Wing Carry-Through Structure

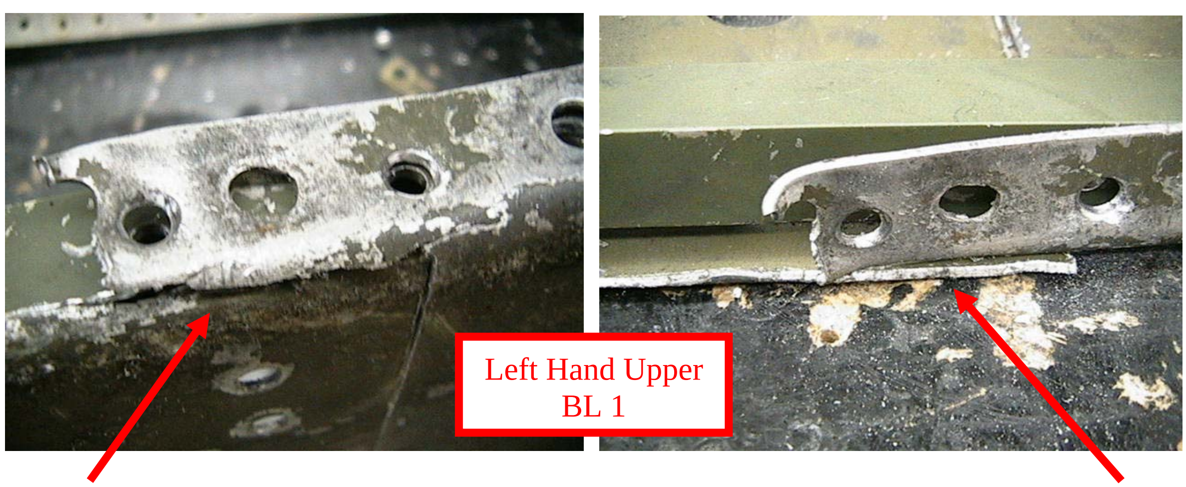

Figure 31. Crack in the Aft Carry-Through Forward Web

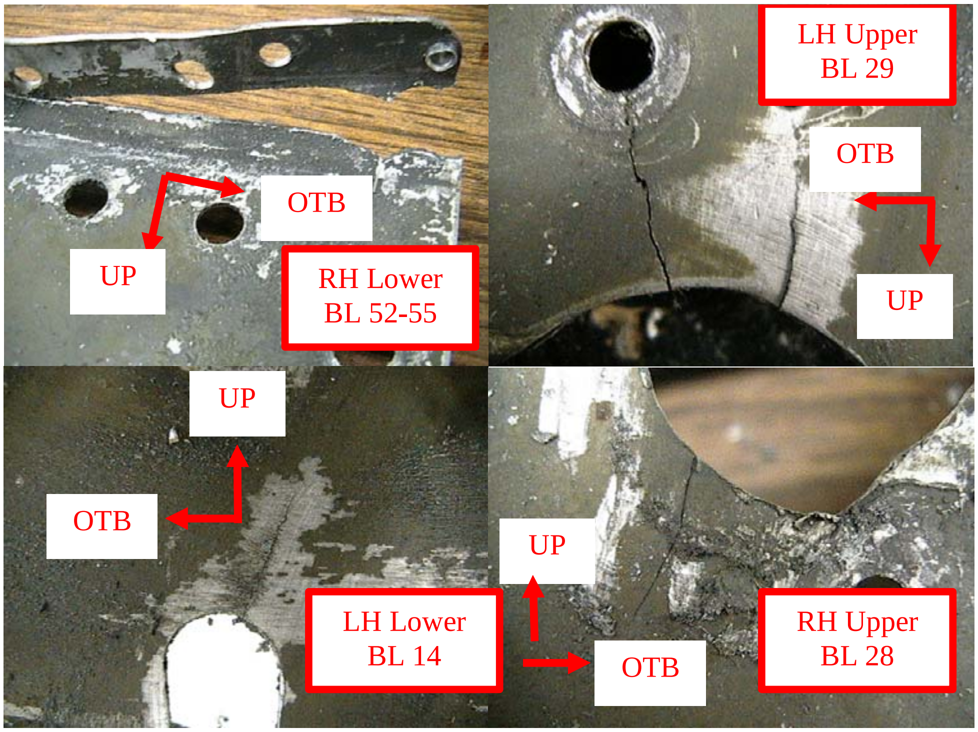

Figure 32. Cracks in the Forward Carry-Through Forward Web

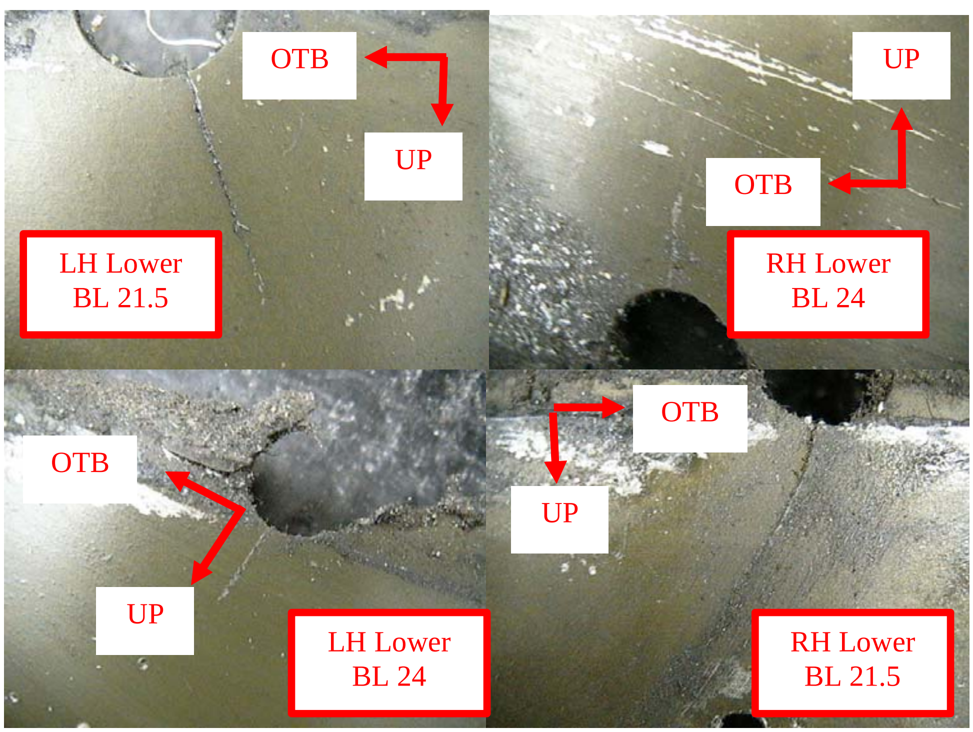

Figure 33. Cracks in the Forward Carry-Through Aft Web

Following the detailed disassembly, all critical structural parts and parts from suspect areas were paint stripped using plastic media blasting and etched with a sodium hydroxide base in order to enhance damage detection during the microscopic examination.

3.2.2 Inspections of Airplane Systems' Components.

Systems' components inspections were accomplished to identify areas where mechanical wear or corrosion had affected either the operation of actuators, linkages, and cables, or the ability of hydraulic systems to sustain pressurization. No additional findings were discovered on systems' components during the teardown examination over the exhaust pipe repair and leaking hydraulic flow pressure switch found during the visual systems' components inspections. A leak test was performed on all oxygen, fuel, and vent lines by pressuring the lines and using soapy water to identify leaks. Five cabin vent lines were found to have leaks during the test, and an additional vent line was found to be deeply pitted upon visual inspection.

3.2.3 Assessment of Primary Airplane Structure Using Alternative NDI Techniques.

As with the Cessna 402A, a structural assessment was performed on the Cessna 402C using three alternative NDI techniques: an MOI unit, a sliding eddy-current probe, and a spot eddy-current probe. Surface and subsurface cracks and corrosion were the conditions of interest. It is important to note that these inspections were performed without standards that exactly replicated the airplane structure. Baseline signals were established for each structural stackup. Significant deviations from these baseline signals were noted as cracks or corrosion. No attempt was made to quantify the extent of the indication. The NIAR team inspected the wing spars, fuselage channels, and horizontal and vertical stabilizer spars in order to assess the condition of the structure prior to disassembly. All indications were investigated during the microscopic examination for validity and extent of the defect.

During the structural assessment using alternative NDI techniques, the following indications were identified:

- Eight crack indications and 34 corrosion indications on the left wing
- Thirteen crack indications and 22 corrosion indications on the right wing
- Two crack indications and nine corrosion indications on the left-side fuselage channel
- One crack indication and ten corrosion indications on the right-side fuselage channel
- Nine crack indications and 13 corrosion indications on the horizontal stabilizer
- Two crack indications and 14 corrosion indications on the vertical stabilizer

3.2.4 Microscopic Examination.

As with the Cessna 402A, microscopic examinations were conducted on suspect areas from all inspections, on defects found during disassembly, and on critical structural details to locate and characterize cracks and areas of corrosion. Cracks greater than 0.01 inch were recorded and assigned a crack description code along with recording the clock position, hole diameter, part thickness and geometry. The extent of corrosion was measured by area and documented photographically. The severity of the corrosion was characterized by the percentage of thickness loss based on the deepest area of corrosion as follows:

- Light (0%-2%)
- Light-to-moderate (2%-5%)
- Moderate (5%-7%)
- Moderate-to-severe (7%-10%)
- Severe (>10%)

All indications from the Cessna 402C supplemental inspections were examined and verified microscopically. The following areas had at least one or more defects:

- Stub wing attach fittings
- Wing attach fittings
- Front and rear spars of the left and right wings
- Engine beam assemblies
- Carry-through beams and webs
- Front and rear spars of the horizontal and vertical stabilizers
- Fuselage channels

Indications from the structural assessment using alternative NDI techniques were also microscopically examined to determine whether the indications could be verified. As before, only a limited number of the alternative NDI indications on the left and right wing, left- and right-side fuselage channels, and horizontal and vertical stabilizer could be verified microscopically. The results of the microscopic examination of alternative NDI indications are as follows:

- On the left wing, microscopic examination found areas of corrosion with 10%-20% thickness loss on the upper surface, which were not identified using the alternative NDI techniques. The alternative NDI indications of corrosion on the lower surface were verified microscopically to be severe corrosion with thickness loss of 10%-20% and greater than 20%.

- On the right wing, microscopic examination found areas of corrosion with less than 10% thickness loss on the front spar upper surface that were identified using the alternative NDI techniques. However, none of the alternative NDI indications on the rear spar upper surface were verified microscopically. On the front and rear spar lower surfaces, microscopic examination found areas of corrosion with less than 10% thickness loss that were identified using the alternative NDI techniques.

- On the right-side fuselage channel, microscopic examination verified the alternative NDI indications.

- On the left-side fuselage channels, none of the alternative NDI indications were verified microscopically.

- On the horizontal stabilizer, none of the alternative NDI indications on the upper surface were found microscopically, and only two of alternative NDI indications on the lower surface were found microscopically.

- On the vertical stabilizer, one alternative NDI indication on the left-side front spar and several alternative NDI indications on right side front spar were found microscopically, but the alternative NDI indications on the right-side rear spar were not verified microscopically.

A discussion of the results from the microscopic examination on the Cessna 402C follows in the remainder of this subsection.

Seven of the eight stub wing attach fittings were found to have corrosion. In general, the corrosion on the aft fittings was relatively light, but the forward fittings had much more corrosion on them, primarily at the attach points. Figure 34 shows an area of corrosion on the left stub wing forward lower attach fitting, while an area of corrosion located on the right stub wing forward attach fitting is shown in figure 35.

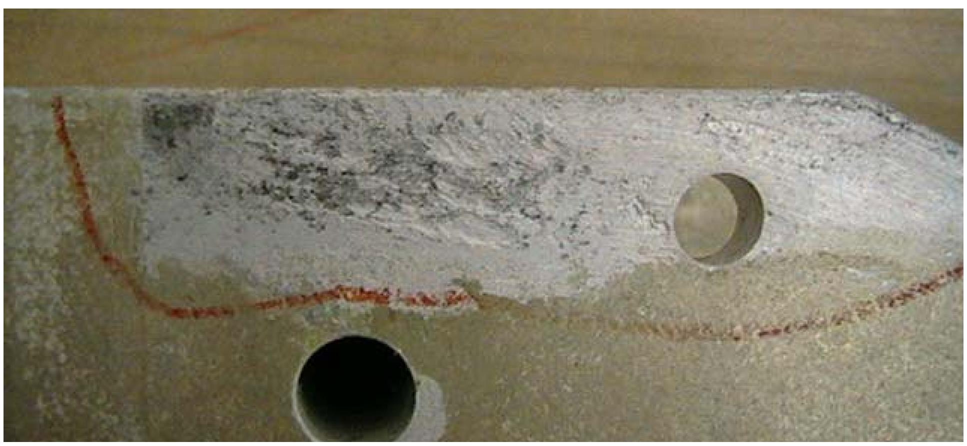

Figure 34. Area of Corrosion on the Cessna 402C Left Stub Wing Forward Lower Attach Fitting

Figure 35. Area of Corrosion on the Cessna 402C Right Stub Wing Forward Upper Attach Fitting

All wing attach fittings had corrosion in several areas. The most significant corrosion was located around the attach points, but slight corrosion was found on different areas of the fittings. Several fastener holes had areas of metal separation due to mechanical damage incurred during the removal of the fasteners. Figure 36 shows an area of corrosion on the right wing forward upper attach fitting near the attachment point, while figure 37 shows an area of corrosion near the attachment point on the left wing lower attachment fitting.

Figure 36. Area of Corrosion on the Cessna 402C Right Wing Forward Upper Attach Fitting

Figure 37. Area of Corrosion on the Cessna 402C Left Wing Lower Attach Fitting

Corrosion was found on the wings in multiple areas, with both front and rear spars having the most areas of corrosion. On the whole, the left wing rear spar tended to be the most corroded, with areas up to 25% thickness loss. Figure 38 shows one of the more severe areas of corrosion observed on the left wing rear spar lower cap. Another area of corrosion, pictured in figure 39, was observed on the left wing rear spar upper cap. The remainder of the spars had scattered areas of 0%-10% corrosion, with the outboard sections of the rear spars having the most corrosion in general. Several areas of the wing spars looked as if they had not been anodized, which could be a cause for the severe corrosion. Slight corrosion was observed on the auxiliary spars, but it was loosely scattered. In total, 50 wing parts were found to have some type of defect.

Figure 38. Area of Corrosion on the Cessna 402C Left Wing Rear Spar Lower Cap

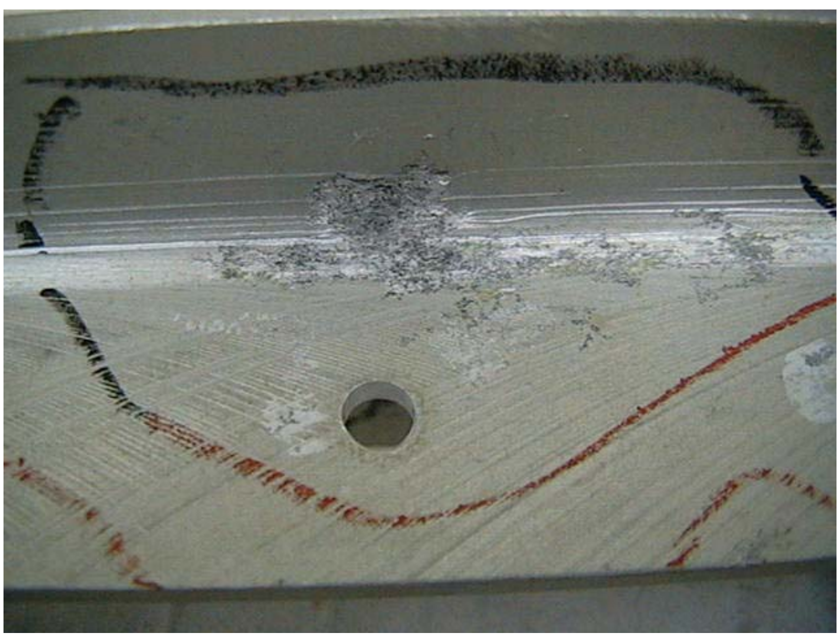

Figure 39. Area of Corrosion on the Cessna 402C Left Wing Rear Spar Upper Cap

The engine beam assemblies had a total of 25 cracks and several areas of corrosion. This corrosion was slight, but some of the cracks were deemed potentially unsafe. All of the cracks were caused by fatigue. Figure 40 shows a longitudinal crack on the left wing outboard engine beam. A crack that traverses the right wing inboard engine beam is pictured in figure 41, while a longitudinal crack on the right wing outboard engine beam is shown in figure 42.

Figure 40. Crack on the Cessna 402C Left Wing Outboard Engine Beam

Figure 41. Crack Across Cessna 402C Right Wing Inboard Engine Beam

Figure 42. Crack in the Cessna 402C Right Wing Outboard Engine Beam

The carry-through beams had some areas of mostly light surface corrosion with just a few areas of slightly deeper corrosion. The carry-through webs had a total of 43 cracks, an example of which is shown in figure 43. Two additional cracks were also found on the left stub wing outboard rib where a cable pulley was attached, as shown in figure 44. The cracks found on the rib were caused by fatigue. On the right stub wing, an angle, shown in figure 45, that was found cracked during the SID inspection, was determined to be caused by fatigue.

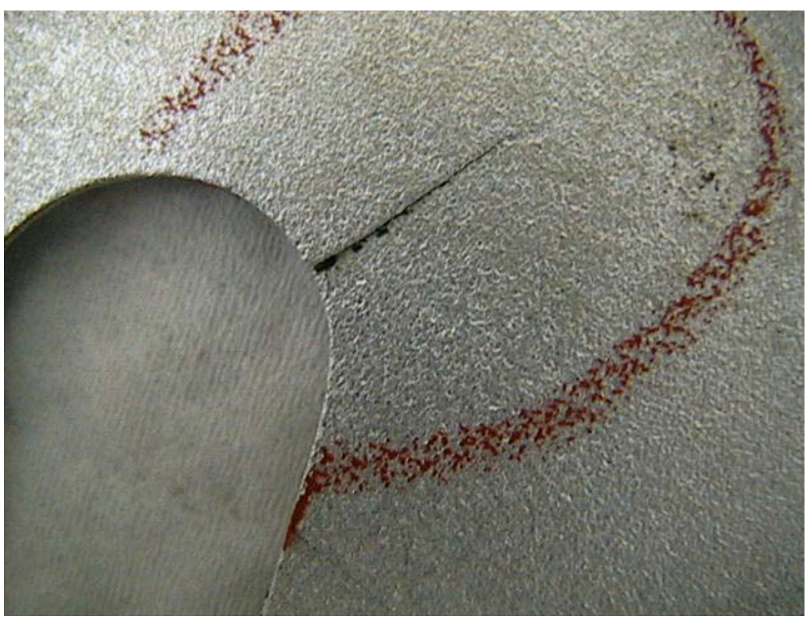

Figure 43. Crack in the Cessna 402C Carry-Through Aft Web

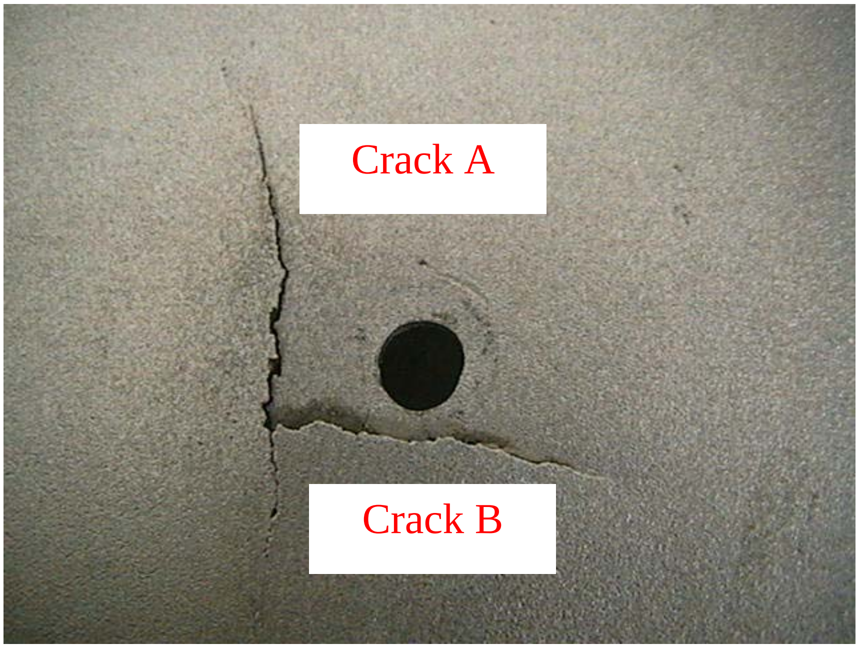

Figure 44. Cracks on the Cessna 402C Left Stub Wing Rib

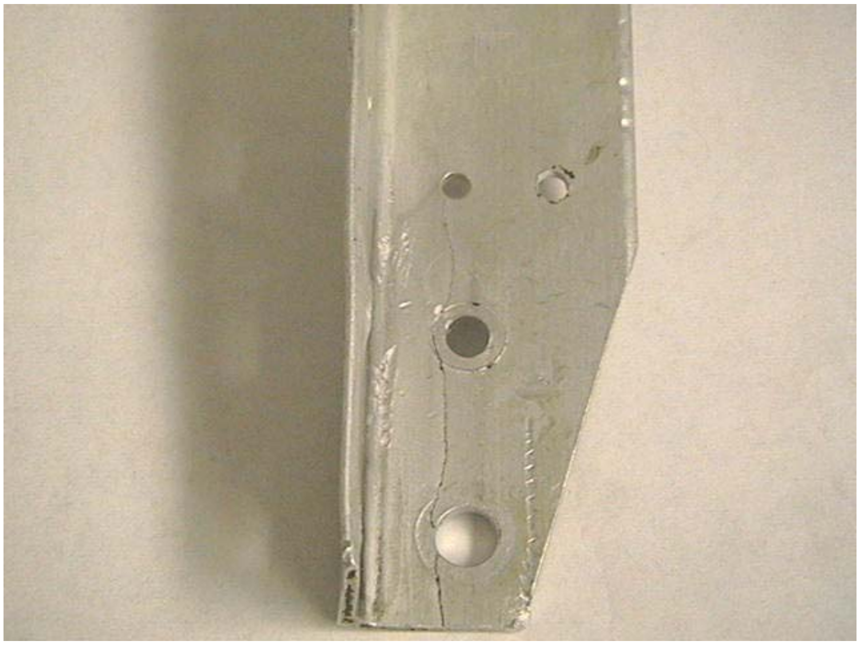

Figure 45. Crack in the Cessna 402C Right Stub Wing Angle Common to the Outboard Rib and Carry-Through Structure

The front and rear spars of the horizontal stabilizer were inspected, as well as the elevator attach fittings. One crack, shown in figure 46, found on a bracket supporting the elevator attach fitting, was caused by fatigue. Light corrosion was found scattered on the front and rear spars of the horizontal stabilizer. An example of the corrosion observed on the horizontal stabilizer is shown in figure 47.

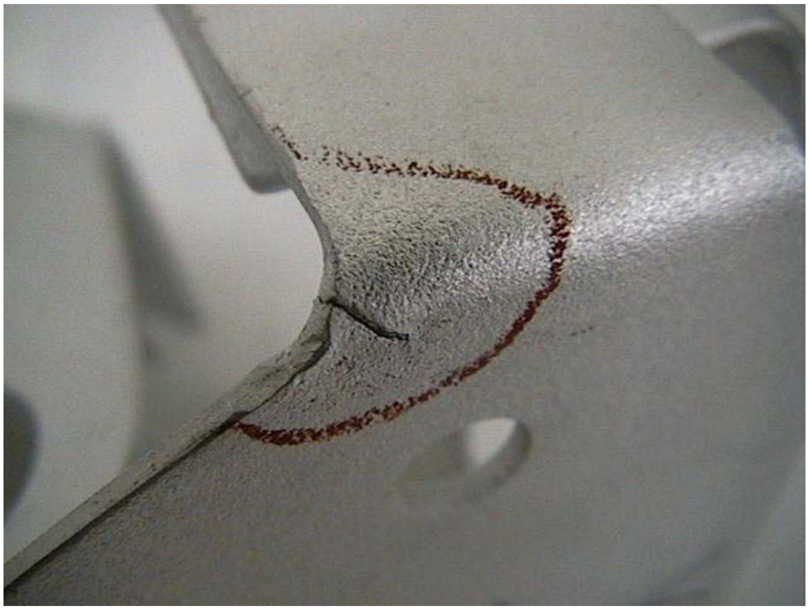

Figure 46. Crack on the Cessna 402C Left Inboard Elevator Attach Bracket

Figure 47. Corrosion on the Cessna 402C Horizontal Stabilizer Rear Spar Lower Cap

Both the front and rear spars on the vertical stabilizer were inspected, as well as the stabilizer mount. No cracks were found. Only slight corrosion was found scattered on the spars. The corrosion that was discovered on the vertical stabilizer left side skin under the antenna at WL 164 was determined to have 25% skin thickness loss. Both fuselage channels were inspected with only the right side having light surface corrosion in several areas.

3.3 WIRING ASSESSMENT.

As part of the airplane destructive evaluation, electrical wiring inspections and tests were performed to assess the condition and degradation of electrical wiring in small airplanes and to evaluate maintenance procedures. The wiring inspections and tests were divided into two categories: nondestructive and destructive. The nondestructive inspections and tests were comprised of general visual inspections, in situ wiring tests, and laboratory tests. The destructive tests were comprised of wet dielectric withstand voltage tests, and mandrel bend/wrap back tests.

3.3.1 General Visual Inspections.

The general visual inspections were performed on undisturbed wires. The purpose of these inspections was to determine the general condition of the wires in the right and left engine compartments, right and left consoles, forward bulkhead, baggage compartment, upper bulkhead, tail, right and left wings, landing gear, cockpit, floor and the instrument panel. The inspectors were looking for wiring defects such as rubbing/chafing of the outer insulation, exposed inner conductor, damaged shield, repaired wires, contamination, cracked wires, corroded terminals, improper termination, and heat damage.

Figure 48 shows worn and dirty wires found in the right engine compartment, while figure 49 shows an exposed inner conductor on a wire in the right engine compartment. A damaged shield due to cut outer insulation in the right engine is shown in figure 50. Figure 51 shows a damaged outer shield in the left engine, while figure 52 shows grease contamination at the splices in the left engine. A broken connection in the right console is shown in figure 53, while a heat-damaged inner conductor in the right console is shown in figure 54. Figure 55 shows a wire bundle that damaged an air inlet in the forward bulkhead region due to improper clearance. Dust contamination and an example of an improper bend radii found in the baggage compartment are shown in figures 56 and 57, respectively. Figure 58 shows unused wires improperly stowed in the upper bulkhead region. A heat-damaged wire found in the tail section is shown in figure 59, while a wire with cracked insulation found in the cockpit floor is shown in figure 60. An example of improper clamp size in the instrument panel region is shown in figure 61.

Figure 48. Worn and Dirty Wires in the Cessna 402C Right Engine Compartment

Figure 49. Exposed Inner Conductor in the Cessna 402C Right Engine Compartment

Figure 50. Damaged Shield Due to Cut Insulation in the Cessna 402C Right Engine Compartment

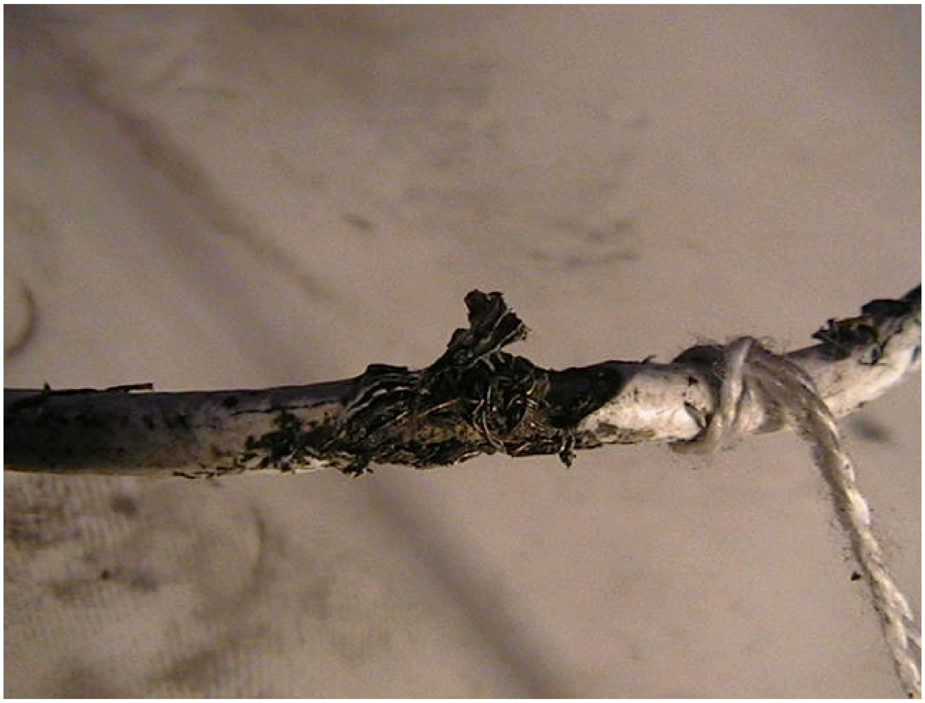

Figure 51. Damaged Outer Shield in the Cessna 402C Left Engine Compartment

Figure 52. Grease Contamination at the Splices in the Cessna 402C Left Engine Compartment

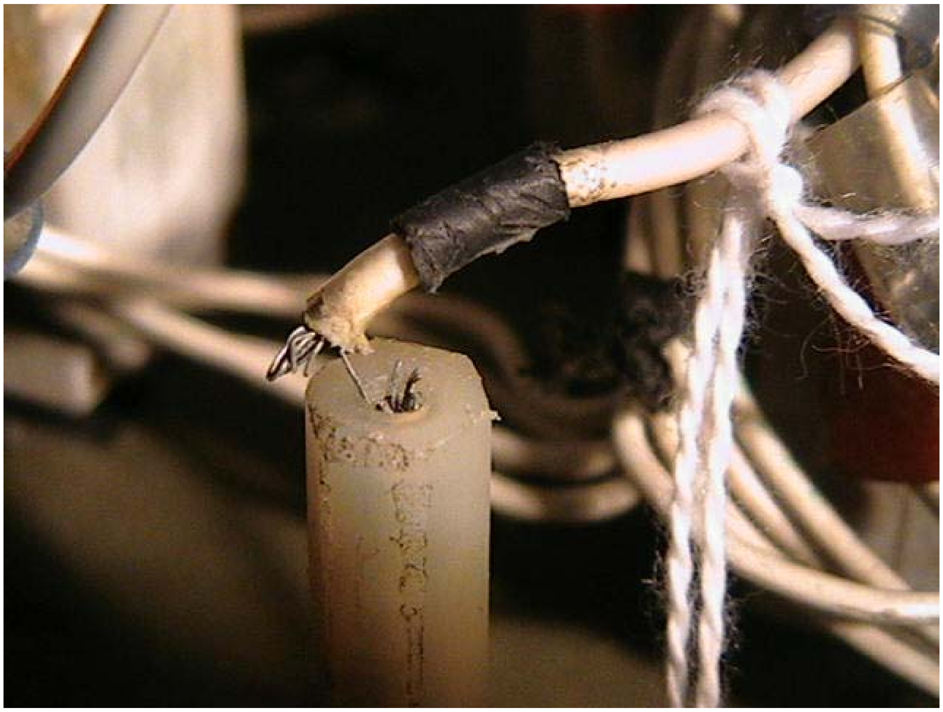

Figure 53. Broken Connection in the Right Console of the Cessna 402C

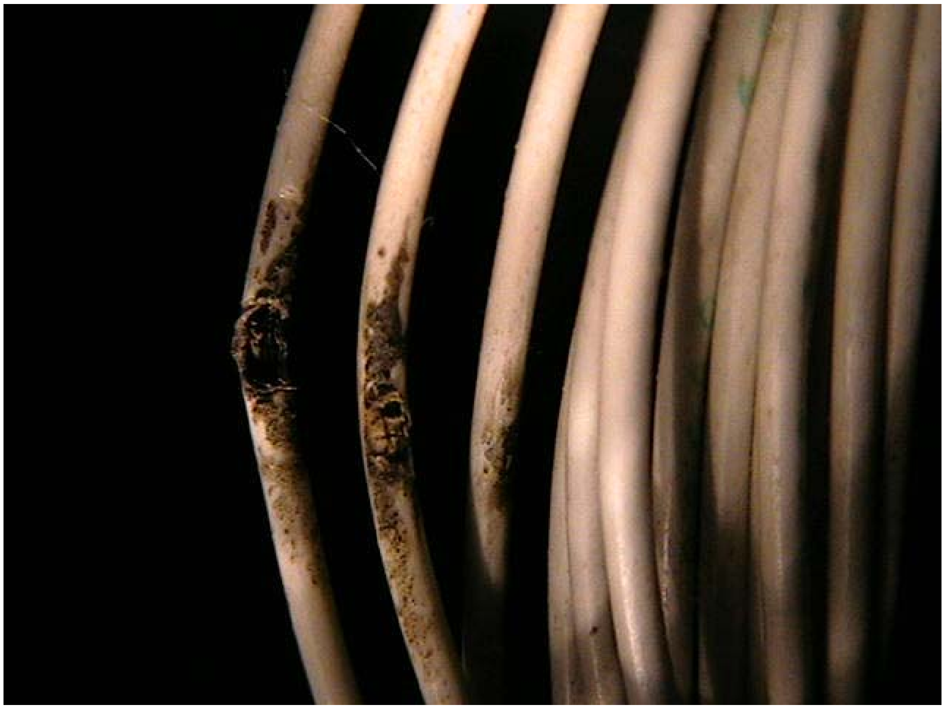

Figure 54. Heat-Damaged Inner Conductor in the Cessna 402C Right Console

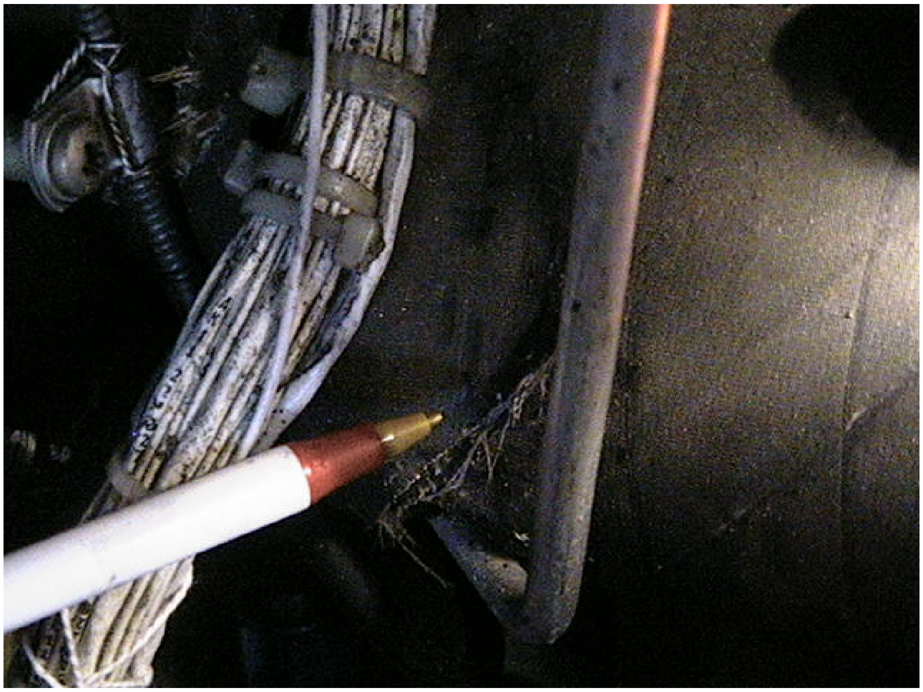

Figure 55. Damaged Air Inlet Pipe Due to Inadequate Clearance of the Wire Bundle in the Cessna 402C Forward Bulkhead Region

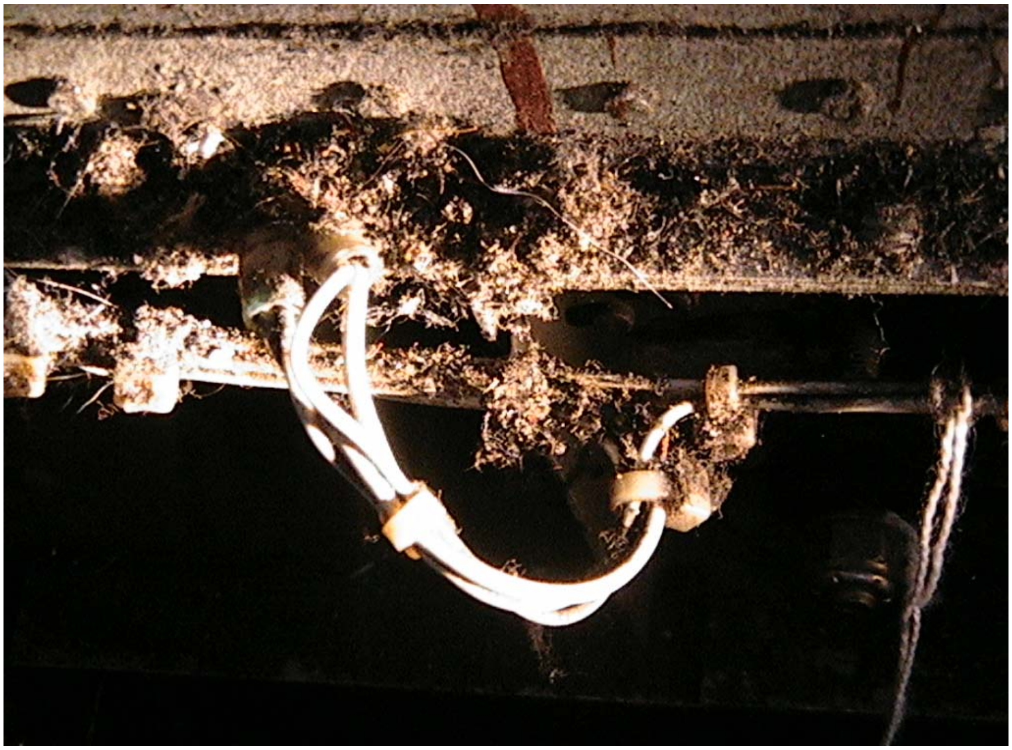

Figure 56. Dust Contamination of Wire Bundle in the Cessna 402C Baggage Compartment

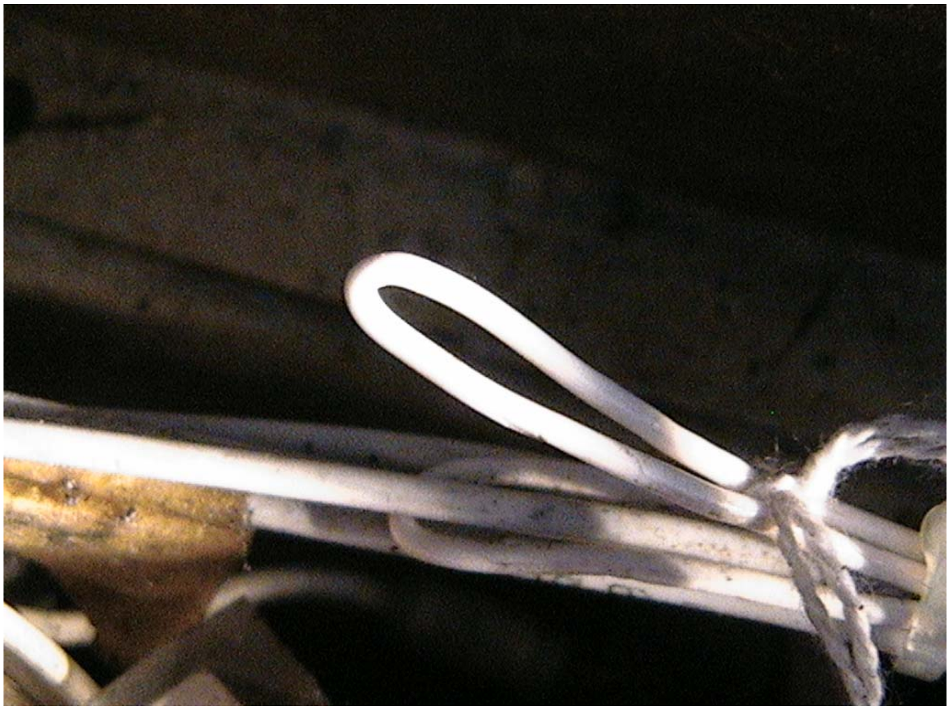

Figure 57. Improper Bend Radii Observed in the Cessna 402C Baggage Compartment

Figure 58. Unused Wires Improperly Stowed in the Cessna 402C Upper Bulkhead Region

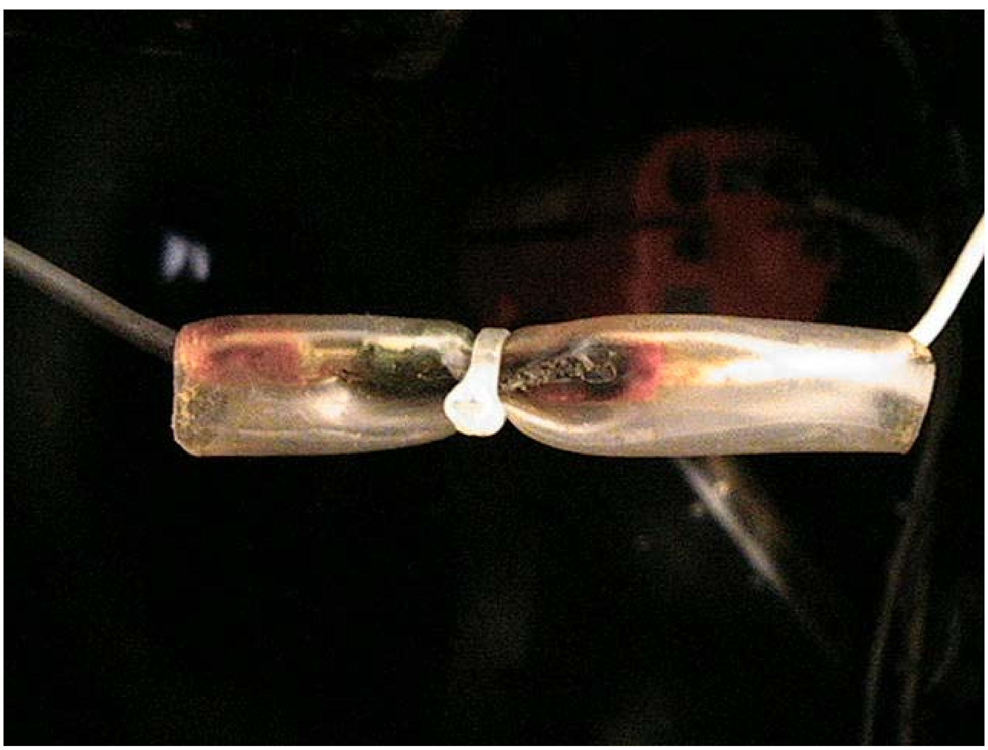

Figure 59. Heat-Damaged Wire in the Cessna 402C Tail Section

Figure 60. Cracked Insulation in the Cessna 402C Cockpit Floor

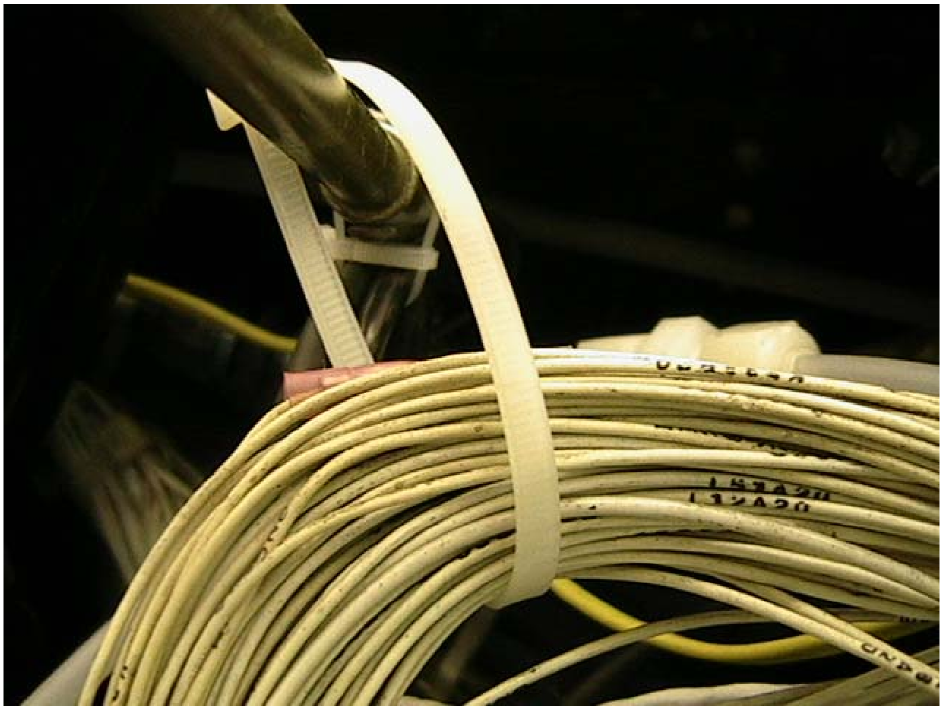

Figure 61. Improper Clamp Size in the Cessna 402C Instrument Panel

Of the 179 wiring condition defects found on the Cessna 402C airplane, 44% were rubbing and chafing, 18% had an exposed shield, and 13% of the wires had an exposed inner conductor. Of the 59 installation defects, 37% were improper termination of wires with no wire caps and 18% had improper clamp condition or size. Only eight termination defects were noted on this airplane. A total of 251 wiring defects were observed on the Cessna 402C with half of the defects located in the engines and 12% located in the instrument panel.

3.3.2 Nondestructive Inspection and Tests.

A bond resistance measurement test and a hard fault detection test were performed on the airplane prior to conducting laboratory tests. The bond resistance measurement shows how well the airplane structure is electrically grounded, to demonstrate the capability of the airplane to discharge static that is generated during flight. The lower the value measured, the better the dissipation of the static charges accumulated. The hard fault detection test determined whether a wire had any hard faults, such as open or short circuit. The test used a hand-held fault location analyzer, which uses the principle of time domain reflectometry and standing wave ratio for its operation.

The laboratory tests were performed after the teardown of the airplane. During the teardown phase, all wires were removed from the airplane and were subjected to various tests and inspections. The lab tests consisted of the following:

- Intrusive Visual Inspection
- Wiring Insulation Microscopic Inspection
- Insulation Resistance Test
- Circuit Breaker Test
- Relay Inspection

All flaws found in the general visual inspections were very conspicuous, and the intrusive visual inspection and the microscopic inspection confirmed these results. Intrusive visual inspection data provided more information of the wiring condition of the specific location inspected. The insulation resistance test was used to determine the insulation resistance of a finished wire specimen. Insulation resistance is of interest in high-impedance circuits and as a measure of quality control.

Since circuit breakers are designed to limit the current flow through the wires in different sections of the airplane, they were tested for various current ratings, e.g., 135%, 200%, and 300%. Of the 46 circuit breakers tested, 4 had open circuit fault, which does not provide a safety concern, while 2 did not meet trip time specifications. It should be noted that all circuit breakers were cycled during the operational checks of the airplane before this testing. Further mechanical cycling of the two breakers that did not trip in the specified time provided little effect on the trip times. Four relays were opened for inspection, and they all were found to have normal pitting.

3.3.3 Destructive Testing.

Two destructive laboratory tests were performed on the wires. These tests were:

- Wet Dielectric Withstand Voltage Test (DWV)
- Mandrel Bend/Wrap Back Test

The DWV test provides a method to determine insulation integrity following any type of performance test. This test was performed soon after the insulation resistance measurement test. The test was used to determine whether exposure to environmental test conditions had reduced the breakdown strength of the wires below some prescribed level. The mandrel bend/wrap back test was used to determine whether a wire specimen would crack when wrapped around itself or around a mandrel. This test was used to determine the degree of sintering of wire insulations.

The destructive laboratory tests also demonstrated few issues with wires with respect to aging airplane. Since only a few wires were 26 feet or more in length, only a few wires could be reliably tested for DWV, and all wires passed the test successfully. Only 16.67% of the wires failed the mandrel bend/wrap back test, which indicated that the wires generally had good quality insulation.

4. COMPARISON OF CESSNA 402A AND CESSNA 402C AIRPLANES.

A 1969 Cessna 402A (tail number N812BW) with 19,698.9 total airframe hours and a 1979 Cessna 402C (tail number N780EA) with 25,546.6 total airframe hours were evaluated through comprehensive nondestructive and destructive teardown evaluations [1 and 2]. The Cessna 402A, purchased from Sunshine Airlines, was primarily used later in life for tours of the Grand Canyon from Las Vegas. The Grand Canyon flight profile is classified as severe by Cessna Aircraft Company, since these flights are typically highly turbulent, low profile, and short duration. The Cessna 402C, obtained from Cape Air, was operated in commuter service on the eastern North American coast flying in and around Cape Cod, the Florida Keys, and the Caribbean Islands. Corrosion is of concern with airplane spending long durations in a saltwater environment.

4.1 INSPECTION PHASE COMPARISON.

The maintenance records review, visual inspections of the airframe and airplane systems' components, and the supplemental inspections were all performed in the same manner on both airplanes. While the personnel performing the inspections were different, their qualifications remained the same. Also, there was significantly more information available for the Cessna 402C maintenance records review than there was for the Cessna 402A. The purpose of the inspection phase is to find all defects that could be found during normal maintenance activity.

4.1.1 Comparison of Maintenance Records Review.

Since leaving the manufacturer's production line in 1969, the Cessna 402A airplane, evaluated through teardown evaluation, was operated under four different tail numbers by ten different charter services. The Cessna 402C was also operated under four different tail numbers but had only five different owners/operators over its service life. The Cessna 402A flew Grand Canyon tour flights later in its service life, which is a flight environment conducive to fatigue due to highly turbulent, low-level flights. In contrast, the Cessna 402C was operated primarily in the saltwater environment of the East Coast for short-duration flights (<60 minutes) to nearby coastal or tropical islands. The only major repair of interest to this research program performed on the Cessna 402A was the installation of doublers on the right wing lower front spar cap from WS 75.24 to WS 65.99. Major repairs to the Cessna 402C included repaired rudder damage (September 1986), a repair to the left wing leading edge (May 1991), repair to the nose area (May 1991) and a repair of the left forward stub wing spar web (October 1994).

The volume of maintenance record data also varied significantly between the two airplane. Detailed log books, inspection logs, FAA 337 forms, and an AD compliance list were included with the Cessna 402C, while only the less-detailed log books and FAA 337 forms were available for the Cessna 402A maintenance records review. Also, a 7-year gap in the Cessna 402A maintenance logs existed between 1991 and 1998.

Service Difficulty Reports (SDRs) were also reviewed for the Cessna 402A and 402C from January 1974 to November 2002. Of the 593 SDRs reviewed for the Cessna 402A, nearly one third were related to the landing gear, 43% to the engines, and only 14% to the airframe, which is the primary area of focus for this project. For the Cessna 402C, 2094 SDRs were reviewed with a third related to the landing gear, an additional quarter related to the engines and 18% related to the airframe. All findings of the teardown evaluations were compared to the SDR database and no correlation was observed between the predominate issues found in the SDR database and the findings of the teardown evaluation on these airplanes. It is important to note that since the SDR database is not mandatory, its contents may not accurately represent all issues occurring in the field.

<u>4.1.2 Comparison of Visual Inspections of the Airframe and Airplane Systems' Components</u>.

Visual inspections of the airplanes were performed under the supervision of licensed airframe mechanics and per the airplane's respective maintenance or service manuals. Four noteworthy findings were documented on the Cessna 402A. Noteworthy findings are defects that require further maintenance action, according to a licensed airframe mechanic. Two 2.5-inch cracks were observed on the leading edge of the horizontal stabilizer. It was later determined that these cracks occurred in body filler used to cover holes resulting from the removal of the deice system, not the aluminum leading edge. A loose nut was observed on one of the flaps; however, this could have been caused during the disassembly required to transport the airplane. A broken gear tooth on the left fuel selector valve was also observed. Three noteworthy defects were found during the visual inspections of the Cessna 402C. These included a static leak in the hydraulic flow pressure switch, an improper repair on the right exhaust pipe, and an area of corrosion under the antenna on the vertical stabilizer. The corrosion on the vertical stabilizer would not have been detected during the visual inspections, except that the antenna was removed to be returned to Cape Air.

Of the 1930 findings on the Cessna 402A, 44% of these were rusted fasteners, and 61% of the total findings occurred on the fuselage with 34% occurring on the forward fuselage. Only four of the 1930 findings were deemed noteworthy on the Cessna 402A, while only three were determined to require further maintenance action on the Cessna 402C. Of the 357 finding on the Cessna 402C, 63% were corrosion related with 44% occurring on the fuselage and an additional 20% occurring on the wings. Although the number of findings on the Cessna 402A was significantly higher than the number found on the Cessna 402C, possibly due to different inspection personnel, the overall condition of the Cessna 402A appeared better than the 402C.

4.1.3 Comparison of Supplemental Inspection Results.

Supplemental inspections were performed per the SID created by Cessna Aircraft Company. All visual inspections were performed by licensed airframe mechanics, while the other supplemental inspections were performed by qualified NDI personnel. The following defects were noted during the visual SID inspections:

- Two rivets needed replaced on an aileron hinge (Cessna 402A)
- A patched rib in the rudder structure due for replacement (Cessna 402A)
- Elongated holes on a lower rudder fitting (Cessna 402A)
- A cracked doubler located at the rudder top hinge fairing (Cessna 402A)
- A bonded angle in the rudder structure not attached at one end (Cessna 402A)
- Corrosion on the inside and outside of the rudder torque tube (Cessna 402A)
- Corrosion on the inside and outside of the elevator torque tube (Cessna 402A)
- Several locations of cherry max and hi-loks needing to be replaced by solid rivets (Cessna 402A)
- A patched crack on the horizontal stabilizer leading edge (Cessna 402A)
- A crack in the left side inboard rib of the horizontal stabilizer (Cessna 402A)
- Damaged holes due to removal in several upper wing to carry-through attach fittings (Cessna 402C)
- Paint scratches and corrosion in the rudder structure (Cessna 402C)
- Skin crack in an engine beam (Cessna 402C)
- Corrosion and damaged holes due to removal in several upper wing to carry-through attachment fittings (Cessna 402C)
- Corroded fittings and missing paint on the main/nose gear retraction system (Cessna 402C)

During the SID inspections using fluorescent liquid penetrant, magnetic particle, and eddy current techniques, the following indications were noted.

- Three cracks in the nose gear steering bellcrank (Cessna 402A)

- Two crack indications at welds, one on each main landing gear torque tube (Cessna 402A) Note: Neither of these cracks were verified during the microscopic examination.

- Damage to two upper cap left side holes on the vertical stabilizer rear attach at WL 108.38 (Cessna 402A)

- One crack indication on the lower cap of the left wing rear spar at WS 97 (Cessna 402A)

- Two crack indications on the lower cap of the right wing front spar; one indication on the front fastener row at WS 55 and a 1-inch crack between two fasteners at WS 57.5 (Cessna 402A)

- Six crack indications on the lower cap of the front and aft auxiliary spars in both the left and right wings (Cessna 402A)

- Crack indications at all holes on the lower cap of the front and rear carry-through spars (Cessna 402A) Note: None of these crack indications were verified during the microscopic examination.

- Severe damage to most lug holes on the right- and left-side wing front spar lugs at WS 46.89 (Cessna 402A)

- Crack indications at all holes of the right- and left-side wing tip tank attachments (Cessna 402A)

- Conductivity tests also showed that both engine firewalls should be replaced (Cessna 402A)

- Crack on support bracket for the elevator hinge (Cessna 402C)

- Horizontal stabilizer upper spar cap skin cracks (Cessna 402C)

- Horizontal stabilizer forward spar web hole out of round (Cessna 402C)

- A wing attach fitting crack (Cessna 402C)

- Bolthole cracks in an angle on the outboard right stub wing (Cessna 402C)

- Left wing lower aft auxiliary spar cap skin cracks (Cessna 402C)

- Seven crack indications on the right wing outboard engine beam and left wing front spar lower cap (Cessna 402C)

Tap tests also resulted in the finding of one disbonding area in the left wing upper trailing edge at WS 211 on the Cessna 402C.

While more indications from the supplemental inspections were documented on the Cessna 402A than the Cessna 402C, a number of the Cessna 402A indications were not verified in the microscopic examination. Also, many of the findings on the Cessna 402A could be repaired with minimal maintenance effort, while the discrepancies found on the Cessna 402C would likely require more extensive maintenance.

4.2 TEARDOWN EXAMINATION COMPARISON.

The disassembly, inspections of airplane systems' components, assessment of primary airplane structure utilizing alternative NDI techniques, microscopic examination and fractographic analysis were conducted in the same manner on both airplanes. While the personnel performing the teardown examination were different, their qualifications were the same. The purpose of this phase of the project is to find defects that were undetectable during the NDI phase of the project, which is representative of normal maintenance activity.

4.2.1 Comparison of Defects Found During Disassembly.

The airplanes were completely disassembled to provide full access to all critical structural details and suspect locations. Suspect locations are defined as areas with defects or indications from the inspection phase or the advanced NDI. The disassembly methods selected minimized the possibility of damage to underlying structure, systems' components, and wiring. Following the complete disassembly of the major airplane sections, critical structural details, and suspect locations were paint stripped using dry media blasting and etched using a sodium hydroxide base to enhance damage detection during the microscopic examination portion of the project. No additional findings were discovered during the disassembly of the Cessna 402A. However, during the disassembly of the Cessna 402C, 24 additional cracks were found on the engine beam structure and 43 cracks were found in the carry-through structure. None of these cracks could be found during the inspection phase, since the locations of the defects are inaccessible without extensive disassembly.

4.2.2 Comparison of Inspection Results of Airplane Systems' Components.

Following disassembly, the airplane mechanical systems' components were again visually inspected. No additional defects were found on either airplane after disassembly. Leak tests were performed on 74 pressurized lines from the Cessna 402A and all lines from the Cessna 402C. Nine lines were found to have leaks for the Cessna 402A. Each of these leaks was caused by either material damage, loss of fitting joint integrity, or corrosion. Five cabin vent lines were found to have leaks during the testing of the Cessna 402C lines, and an additional vent line was found to be deeply pitted upon visual inspection.

4.2.3 Comparison of Structural Assessment Using Alternative NDI Techniques.

Primary structure on both airplanes was assessed using commercially available eddy-current inspection techniques, which are capable of detecting surface and subsurface cracks and/or corrosion. These techniques included the MOI, sliding probe, and spot probe, and while they are not frequently used to inspect commuter-class airplanes, the techniques may be able to identify flaws or extensive defects in a structure without requiring disassembly of the structure. These techniques are not called out in either the Cessna 402A or Cessna 402C SIDs; therefore, no procedures had been established or validated for using these techniques on the Cessna 402s. Using existing structure and locally manufactured calibration standards, inspectors attempted to identify target areas for further microscopic examination. No effort was made to evaluate the capabilities of the alternative NDI techniques and conclusions about the capabilities of MOI, sliding probe, or spot probe should not be made from the results presented in this report. Structural assessments were performed on the Cessna 402A horizontal stabilizer front spar and left wing front spar. On the Cessna 402C, structural assessments were performed prior to disassembly on the front and rear spars of both wings, the horizontal stabilizer, and the vertical stabilizer, along with the channels on left and right side of the fuselage.

The microscopic examinations were used to attempt to validate indications obtained during the structural assessment. On the Cessna 402A, two of eight spot probe indications on the horizontal stabilizer front spar were verified during the microscopic examination as corrosion. Six of 16 NDI indications on the left wing were verified as corrosion and one skin crack, found by MOI, was confirmed during the microscopic examinations. On the Cessna 402C, extensive crack and corrosion indications were recorded on all of the primary structure that was inspected; however, only a limited correlation was observed between the locations of the indications identified in the structural assessment and the areas examined under the microscope. In general, the NDI techniques were able to identify some cracks and areas with extensive corrosion of greater than 10%; however, a number of areas that were identified with flaws in the inspections could not be verified during the microscopic examination.

4.2.4 Microscopic Examination and Fractographic Analysis Results Comparison.

Following the paint removal and etching of structural details and suspect areas, microscopic examination was performed with the aid of a 7-45 power optical microscope, pin gauge for corrosion depth assessment, optical micrometer, and a scanning electron microscope to detect and characterize all damage on these details. Corrosion was classified by the percentage of thickness loss with 0%-2% light corrosion, 2%-5% light-to-moderate, 5%-7% moderate, 7%-10% moderate-to-severe, and over 10% classified as severe. The results of the microscopic examination and fractographic analysis are shown in table 3.

Table 3. Comparison of Microscopic Examinations

Location	Cessna 402A	Cessna 402C
Auxiliary spars	8 fatigue cracks (0.046 to 0.598 in.) on left wing 12 fatigue cracks (0.041 to 0.740 in.) on right wing	Loosely scattered corrosion
Carry-through structure	No defects found	43 cracks primarily in carry-through webs
Elevator attach fitting	No defects found	Crack on supporting bracket
Engine beams	No defects found	25 fatigue cracks and light corrosion
Fuselage channels	Light to moderate corrosion on left fuselage channel	Light surface corrosion on right fuselage channel
Horizontal stabilizer spars	No defects found	Light scattered corrosion
Nose wheel steering bellcrank	8 fatigue cracks (0.039 to 0.093 in.)	No defects found
Rudder bellcrank	2 cracks (0.03 and 0.045 in.)	No defects found
Stub wing attach fittings	0.24-in. stress corrosion crack	7 of 8 fittings with corrosion aft fittings with light corrosion forward fittings with severe
Stub wing outboard rib	No defects found	Right stub wing angle with 2-in. fatigue crack
Stub wing skins	Both right upper skins with severe corrosion	No defects found
Wing attach fittings	4 of 8 corroded. Moderate-to-severe corrosion on left wing front spar lower front fitting.	All corroded with metal separation
Wing front spar cap	Moderate corrosion on left wing	Scattered 0%-10% corrosion on left wing, 25% corrosion on left wing rear spar, no anodizing observed
Tip tank baffle	2 fatigue cracks	No defects found
Vertical stabilizer	No defects found	Light scattered corrosion on front and rear spars, 25% corrosion on skin under antenna

4.3 WIRING ASSESSMENT COMPARISON.

The wiring assessment included a general visual inspection of all accessible wires prior to disassembly, nondestructive inspections and tests and destructive tests. The NDIs and tests included an intrusive visual inspection, wiring insulation microscopic inspection, insulation resistance test, circuit breaker test, and relay inspections. The destructive wiring tests included the wet dielectric withstand voltage test and the mandrel bend/wrap back test for both airplanes, plus the dynamic cut-through test on the Cessna 402A. Additional, highly specialized tests were performed on the airplanes; however, no information could be ascertained from the results since these procedures are still in the experimental development stage.

4.3.1 Comparison of General Visual Inspection Results.

During the general visual inspections, inspectors were looking for general wiring defects like rubbing and chafing, exposed shield, exposed inner conductor, and contamination. Inspectors also looked for installation defects such as inadequate clearance to structure and improper clamp condition or size. Termination defects were also investigated for both the Cessna 402A and Cessna 402C. Table 4 compares the general visual inspections results of the airplane wiring.

Table 4. Comparison of General Visual Inspection Results of Airplane Wiring

Defect	Cessna 402A	Cessna 402C
Number of Wiring Condition Defects	103	179
- Cut outer insulation	30%	N/A
- Rubbing/chafing of outer insulation	24%	44%
- Exposed inner conductor	14%	13%
- Exposed shields	11%	18%
Number of installation defects	245	59
- Repaired wires	33%	N/A
- Inadequate clearance to structure	20%	N/A
- Improperly stowed wires	11%	N/A
- Improper termination of wires	N/A	37%
- Improper clamp condition	N/A	18%
Number of termination defects	14	8

4.3.2 Nondestructive Inspections and Tests.

The NDIs and tests included an intrusive visual inspection, wiring insulation microscopic inspection, insulation resistance test, circuit breaker test and relay inspections. The intrusive visual inspection was conducted after the disassembly of the airplanes and followed the same inspection guidelines as the general visual inspection. The same types of defects were found in the intrusive visual inspections for both airplanes as was found during the general visual inspections. Wiring insulation microscopic inspection consisted of looking at defects under 50 to 300 power magnification. Minimal additional data was gathered by these inspections. The American Society of Testing and Materials specification for the insulation resistance test required 26-foot specimens. Since few wires, if any, are that length on the airplane, no usable data was obtained for either airplane from the insulation resistance test.

Circuit breakers were tested for both airplanes by applying an external current of 135%, 200%, and 300% of the rated current capacity and then measuring the time for the breaker to trip. On the Cessna 402A, 21 circuit breakers were tested. One breaker did not function and would not conduct any current, five circuit breakers did not meet trip time specifications after the first test, three did not meet trip time specifications after the second test, and all functioning circuit breakers met specifications by the third test. Each time the test was performed, the circuit breakers were cycled thermally. The trip times of the functioning circuit breakers that first failed changed drastically as the breakers were cycled. The trip times of the circuit breakers that were functioning barely changed, if at all. Of the 46 circuit breakers tested on the Cessna 402C, 4 had open circuit fault, which did not present a safety concern, while 2 did not meet trip time specifications. Further mechanical cycling of the two breakers that did not trip in the specified time provided little effect on the trip times. Relays were also opened on both airplanes and were found to have a normal amount of pitting.

4.3.3 Destructive Testing.

The destructive tests on both airplanes included the wet dielectric withstand voltage test and the mandrel bend/wrap back test. The dynamic cut-through test was performed only on the Cessna 402A. No reliable results could be obtained from the wet dielectric withstand voltage test because, like the insulation resistance test, the specification requires wires that are 26 feet in length. During the mandrel bend/wrap back test, 12.5% of the Cessna 402A wires failed compared to 16.67% of the Cessna 402C wires.

5. CONCLUSIONS AND RECOMMENDATIONS.

Upon completion of the teardown evaluations of the Cessna 402A and Cessna 402C airplanes, it was apparent that the condition of the airplane structure and systems are directly impacted by the usage and the operating environment of the airplane. Fatigue cracking occurred in isolated areas on the Cessna 402A airframe, such as the wing auxiliary spars and nose gear steering bellcrank. Moderate or severe corrosion was limited to only a few areas on the Cessna 402A airframe like the stub wing skins, wing front spar cap, and wing attachment fittings. In contrast, more widespread cracking and corrosion was observed on the Cessna 402C. Fatigue cracking was widespread on the Cessna 402C engine beams and surrounding structure and on the carry-through webs. A 2.0-inch crack was also observed on an angle common to the stub wing outboard rib. Corrosion was reported on the Cessna 402C wing auxiliary spars, fuselage channels, horizontal stabilizer spars, stub wing and wing attachment fittings, wing front spar cap, and vertical stabilizer. The Cessna 402A was ten years older than the Cessna 402C and flown in a severe flight environment (increased turbulence due to low-level flights in a desert climate) for most of its service life. However, the 402A was considered to be in better condition than the Cessna 402C. The Cessna 402C had a higher number of incidents of cracking and corrosion, likely due to its higher number of flight hours and cycles while being operated in a more corrosive environment.

During the maintenance records review, a drastic difference in the amount of records information was noted. The Cessna 402A had only scattered log book entries to represent its maintenance history, where the Cessna 402C had significantly more information obtained from detailed log book entries and detailed inspection logs. Maintenance history can also directly impact the current condition of the airplane, as seen by the Cessna 402A. In general, many of the defects found on the Cessna 402A would have required only minimal maintenance activity to correct. It was also noted that the deficiencies recorded in the Service Difficulty Report (SDR) database did not correlate with many of the major findings from the teardown evaluations of the Cessna 402A and Cessna 402C airplanes.

Listed below are the results of this research program point to some recommended actions that may improve the continued airworthiness of aging small airplanes. Recommendations 1 and 2 are specific to the airplane structure, and recommendations 3 and 4 apply to airplane wiring. Recommendations 5, 6, and 7 deal with general maintenance practices, and recommendations 8 and 9 pertain to the teardown evaluation research program.

1. Airplane antenna should be removed during inspections to look for corrosion. The most severe corrosion found during these evaluations was found under an antenna. Input from experienced mechanics and engineers suggest this issue likely extends to the entire general aviation fleet. There are several reasons that the airplane skin surface under the antenna is prone to corrosion. Dissimilar metals and improper electrical bonding between the airplane skin surface and the mounting base of the airplane antenna as well as a small amount of electrical current in the vicinity of the antenna base create a local environment conducive to corrosion. A poor seal around the perimeter of the base of the antenna base or mount allow moisture intrusion that further accelerates the corrosion process.

2. Inspections of the Cessna 402C wing carry-through and engine beam structures should be considered for additions to the Supplemental Inspection Document (SID). Given the large number of cracks found in the carry-through webs and engine beams of the Cessna 402C, inspection and possible repair of these areas could be beneficial to continued airworthiness.

3. Periodic cycling of circuit breakers should be performed. This research showed that the functionality of circuit breakers is an issue. When initially tested, 7 of 67 circuit breakers tested did not meet their design specification for overload protection. The functionality of all but two of the seven circuit breakers improved to meet the specifications when they are thermally or mechanically cycled. Periodic cycling will improve the reliability of circuit breakers and also spot defective breakers that need to be replaced.

4. Maintenance and inspection practices regarding wiring could be significantly improved. The results presented in this report show that a variety of wiring repairs and modifications are not done correctly. Through better training and with inspections targeted at specific wiring locations, wiring precursors, such as exposed conductors and heat-damaged wires could be found and repaired prior to a problem with the airplane's wiring system.

5. Owners and operators should adhere to the manufacturer's instructions for continued airworthiness. Routine visual inspections were not comprehensive or intrusive enough to identify all areas of concern found on the two airplanes. The supplemental inspections, service bulletins and airworthiness directives for the Cessna 402 model airplane do address a majority of the concern due to aging effects that were discovered in the teardown evaluations.

6. Maintenance inspection programs for small airplane should include supplemental inspections. As noted above, the research showed that routine visual inspections were not comprehensive or intrusive enough to identify all areas of concern. Supplemental inspections should be predicated on engineering damage tolerance analysis and service history. These supplemental inspections should be comprehensive and should begin later in the airplane's service life, but early enough to detect the onset of age related problems.

7. Owners and mechanics need to understand the importance of diligent (SDR) reporting. The SDR database for the models evaluated did not represent many of the major findings from the teardown evaluations. Because SDR reporting is voluntary, many significant concerns found in the field go unreported. Therefore, this service history is not captured and does not benefit the collective fleet.

8. The teardown evaluation research program should be expanded to other models of small airplanes. Expansion of the research program will help provide recommendations for general airplane inspection programs instead of model specific recommendations. Additional teardown evaluations should be conducted on airplanes without manufacturer developed supplemental inspection programs so that the supplemental inspection development process can be evaluated and improved.

9. Results from all teardown evaluation projects should be used to develop Federal Aviation Administration guidance and changes to regulations. This research highlighted several areas where maintenance and inspection practices could be improved with better guidance. This research also indicates that routine inspections for small airplanes may not be adequate to maintain them safely as they grow older. This research can help manufacturers and operators develop supplemental inspection programs that will enhance the maintenance and inspection programs for aging airplanes.

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