SAND98-0248C
SAND-98-0248C

RECEIVED
AUG 24 1998
OSTI

Experimental Flight Test Vibration Measurements and Nondestructive Inspection on a USCG HC-130H Aircraft

David G. Moore and Craig R. Jones
FAA Airworthiness Assurance NDI Validation Center (AANC)
Sandia National Laboratories, Albuquerque, NM 87185-0615

CONF-980830--

and

LCDR Joseph E. Mihelic and ADC James D. Barnes
U.S. Coast Guard (USCG) Aircraft Repair and Supply Center (ARSC)
Elizabeth City, NC 27909-5001

ABSTRACT

This paper presents results of experimental flight test vibration measurements and structural inspections performed by the Federal Aviation Administration's Airworthiness Assurance NDI Validation Center (AANC) at Sandia National Laboratories and the U.S. Coast Guard Aircraft Repair and Supply Center (ARSC). Structural and aerodynamic changes induced by mounting a Forward Looking Infrared (FLIR) system on a USCG HC-130H aircraft are described. The FLIR adversely affected the air flow characteristics and structural vibration on the external skin of the aircraft's right main wheel well fairing. Upon initial discovery of skin cracking and visual observation of skin vibration in flight by the FLIR, a baseline flight without the FLIR was conducted and compared to other measurements with the FLIR installed. Nondestructive inspection procedures were developed to detect cracks in the skin and supporting structural elements and document the initial structural condition of the aircraft. Inspection results and flight test vibration data revealed that the FLIR created higher than expected flight loading and was the possible source of the skin cracking. The Coast Guard performed significant structural repair and enhancement on this aircraft, and additional in-flight vibration measurements were collected on the strengthened area both with and without the FLIR installed. After three months of further operational FLIR usage, the new aircraft skin with the enhanced structural modification was reinspected and found to be free of flaws. Additional U.S. Coast Guard HC-130H aircraft are now being similarly modified to accommodate this FLIR system. Measurements of in-flight vibration levels with and without the FLIR installed, and both before and after the structural enhancement and repair were conducted on the skin and supporting structure in the aircraft's right main wheel fairing. Inspection results and techniques developed to verify the aircraft's structural integrity are also discussed.

This work was supported by a reimbursable agreement between Sandia National Laboratories and the USCG Aircraft Repair and Supply Center. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94-AL85000.

DISCLAIMER

DISCLAIMER

Portions of this document may be illegible electronic image products. Images are produced from the best available original document.

INTRODUCTION

The USCG deploys the HC-130H 'Hercules' fixed-wing aircraft for long range surveillance and cargo transport to satisfy the needs of the maritime community. The USCG monitors radio coverage on distress frequency bands for recreational boats and commercial craft. When emergencies occur, the HC-130H is deployed to aid and assist in the search and rescue mission. Other aircraft are specifically outfitted to perform other unique functions such as drug interdiction and environmental compliance monitoring. The Aircraft Repair and Supply Center (ARSC) is the engineering center for all of the USCG fixed wing aircraft. One role of ARSC is to examine existing or impending problems for the HC-130H fleet, then seek solutions based upon scientific advancements in science and technology. ARSC has created an aggressive program of research and development in the area of nondestructive inspection to support appropriate advancements to the HC-130H maintenance program. To improve its mission effectiveness and efficiency, ARSC concentrates its engineering efforts where there is potential for high payoff to increase quality and productivity. Due to shrinking federal budgets, ARSC desired to maximize its engineering support activities. To this end, ARSC completed a Work-for-Others (WFO) agreement with Sandia National Laboratories – AANC. The mutually agreed upon Scope of Work specified that AANC would conduct inspections and engineering studies in conjunction with ASRC support activities that could help ARSC better use their assets to extend the service life of their HC-130H fleet.

PROBLEM HISTORY

A permanent universal FLIR system installation was proposed to be added to several U.S. Coast Guard HC-130H aircraft. A permanent universal FLIR mount was designed by Lockheed Martin and attaching hardware was installed on three HC-130H aircraft (See Figure 1). After 2.7 hours of flight operations with a FLIR system installed on aircraft S/N 1719, cracks were discovered in the skin and supporting stiffeners in the right main wheel well fairing near the new FLIR installation (See Figure 2). It was believed was that these cracks had developed in the main wheel well skin structure as a result of this new permanent FLIR installation. Air flow conditions, skin surface vibration and possible flutter were observed by the FLIR during initial flights with the FLIR prototype and after the Lockheed Martin permanent mount was installed. The overall structural integrity condition of this area of aircraft S/N 1719 was raised by ARSC, and an inspection to verify the structural integrity of this area of this aircraft was deemed prudent. In addition, an on-aircraft test was desired to measure and document the vibration environments in this area, and to determine if the new FLIR installation was the source of the recently discovered cracks in the wheel well skin and substructure of this HC-130H aircraft.

NONDESTRUCTIVE INSPECTION DEVELOPMENT

The HC-130H aircraft configuration originally had an outer skin thickness of 1.016 mm (0.040") and attached to 1.016 mm thick channel (forward to aft) or frame (inboard to outboard). The fasteners were button head configuration with an outside diameter of

8.128 mm (0.320"). Figures 3 and 4 display the inspection configuration. The inspection area on the HC-130H aircraft contains several square meters of aircraft skin and over one thousand fastener sites. Since the inspection technique must penetrate through the outer skin and fit over the raised fastener heads, it requires reducing the operating frequency and increasing coil probe inside diameter. Both conditions result in a larger detectable crack.

The probe selected to inspect the HC-130H structure is a low frequency, flat surface encircling 'ring' reflectance-type probe. It has an inside diameter of 7.62 mm (0.30"), an outside diameter of 19.56 mm (0.77") and operates at 2 kHz. The equipment selected for this inspection was an impedance plane instrument with test set-up storage capability. A reference standard was designed and manufactured using 2024 aluminum (See Figure 5). The ring probe and instrument is standardized over a raised fastener site containing no flaws. Probe lift-off is rotated to yield a nearly horizontal response on the screen. The probe is placed over each fastener site on the reference standard and the response is obtained. Figure 6 displays the signal response from the reference standard at positions A, B, C, and D. After calibration, the 'ring' probe is placed over each raised fastener and the inspector monitors the screen for crack indications.

INSPECTION RESULTS OF PROTOTYPE AND PERMANENT FLIR

Detailed eddy current measurements were performed on the right wheel well skin structure of HC-130H (S/N 1719) at the CGAS-Clearwater, Florida by Sandia on 26-28 Aug 97 (See Figure 2). No significant problems were encountered in accomplishing these inspections. Only relatively few small cracks were found and documented during the initial inspections (See Table 1).

Approximately 15 man-hours were required to perform these inspections using an impedance plane eddy current instrument that the Coast Guard has available. The aircraft was inspected with the FLIR hardware removed, and only minor additional disassembly was performed to allow better access to the upper portion of the FLIR mounting hardware.

FLIGHT TEST VIBRATION MEASUREMENTS

The structural area of interest was instrumented with 10 Wilcoxon Research Model 722 accelerometers. Four accelerometers were mounted directly on longerons and stiffeners, and several others were mounted to the internal surface of the right main landing gear pod skin using strain gauge cement. A tabulation of these accelerometers and their approximate locations is contained in Table 2. A photograph of some typical installations is shown in Figure 7. A flight of 2.0 hours duration was flown on 27 Aug 97 and vibration data recorded for a range of flight conditions. See Table 3 for a review of the flight profile and test conditions. A U.S. Coast Guard Rotor Analysis Diagnostic System - Advanced Technology (RADS-AT) data collection and analysis system was used to collect all accelerometer data during the flight testing.

Upon the end of the first flight, the accelerometer data were reviewed and determined to be valid and of good quality. All accelerometer installations except two hidden in difficult to access areas (on inner skin at FS 516 and 576 - BL 60) were inspected and found to be completely intact. These two accelerometers were still operational but did not remain rigidly bonded to the skin in this area after the engine ground runup of the test flight.

The FLIR was then installed on the aircraft. Two additional accelerometers were added at this time and a third was moved to the FLIR mount support plate to measure three-axis acceleration response of this structure (See Figure 8). A flight of 2.7 hours duration was flown on 28 Aug 97 and vibration data recorded for a range of flight conditions. The flight profile and test conditions for this flight were kept as close as possible to those on the previous flight. Approximately a third of the way through the second flight, data channels began to drop out or fail for no immediately explained reason. It was assumed that the flight vibration environments were becoming increasingly harsh at the higher indicated airspeeds and dynamic pressures, and the increased vibration levels being encountered were breaking the high strength cement bond causing the accelerometers to become detached.

Upon the end of the second flight, the data were reviewed and determined to be valid and of good quality. All accelerometer installations were inspected. Only four of the twelve accelerometers were found to have remained attached to the structure which it was intended to monitor. Three of these remaining four were those on the FLIR mounting plate and the other one was attached to the longeron at approximate FS 474 - BL 63. Upon the completion of this flight profile, it was concluded that significant structural modification was necessary to permit long term operation of this aircraft with the FLIR installed.

The aircraft was ferried to ARSC in Elizabeth City, NC where it underwent significant structural repair and modification. This repair and modification effort included replacing the entire lower skin panel of the right main wheel well fairing with a skin of a heavier gauge, 1.60 mm (0.063"), and adding additional stiffeners and longerons to further stiffen and strengthen this region of structure. These repairs and modifications were completed on 31 Oct 97. The aircraft was then instrumented with fourteen accelerometers in this area to as closely as possible repeat the locations that were instrumented in the earlier flight tests of 27-28 Aug 97. In a few cases, the exact locations were not repeated since new structure had been added at or very near the original locations. Two test flights were conducted on 1 Nov 97 to measure vibration environments in this structure to compare with the earlier environments measured on the original structure both with and without the FLIR installed. These test flight profiles were designed to duplicate the test conditions at which data were collected during the earlier series of flight tests. The following is an overview of the vibration results obtained after the structural repair and modification. These data were compared directly with those taken during the earlier flight tests to display the effects that the heavier gauge skin and additional internal stiffening members had on reducing the vibration environments in this area of the HC-130H aircraft.

FLIGHT TEST DATA REVIEW AND ANALYSIS

All data taken were plotted out in spectrum form, acceleration in g's vs. frequency from 0 to 1000 Hz in 2.5 Hz intervals. Selected conditions shown here are plotted as Maximum G's observed versus Flight Test Event Number for test cases where 'exact' flight test conditions were available for *both* baseline and FLIR attached configurations. A typical data graph (See Figure 9) allows for easy comparison between vibration environments at the same location for the baseline (without FLIR) and FLIR attached configurations and can be directly compared to the same locations (or nearly so) and conditions measured after the structural modifications and repairs.

Figures 10 and 11 (Maximum G's versus. Flight Event Number) show the loading experienced by right wheel well fairing structure throughout all phases of the test flight at one typical location. Generally, loading increased with increased airspeed and torque settings. Significant increased loading was observed with the FLIR installed. The stiffener shown here experienced an increase in loading by up to a factor of ten with the FLIR installed.

After the structural repairs, the vibration environments encountered by the skin structure and the MLG inner door with the FLIR attached are still high in some areas. FLIR video was also available during the second flight and confirmed that there was a significant reduction in visible skin panel vibration from that observed on a previous FLIR systems testing flight in August. Comparison plots directly showed that the vibration environments with the FLIR attached were almost always higher (sometimes significantly) than those measured during the first (baseline) flight and that the structural repairs and modifications were very effective in reducing vibration environments in this part of the HC-130H structure.

CONCLUSIONS

Accelerometer data from those attached to the FLIR mounting plate provide an overview of the vibration environments encountered at this location through a flight test profile of ground idle, ground engine runup, low speed level flight, climb and higher speed level flight conditions. The most severe vibration environments at this location appear to be during ground engine runup and at the higher indicated airspeed conditions, especially those with high torque settings. It should be noted that no significant loading of the FLIR mounting plate was encountered throughout any phase of flight during all of these flight tests.

This simple test demonstrated that the change in loading observed on the right wheel well fairing with the FLIR mount and FLIR installed has been substantially reduced by repairs and modifications done by ARSC. Further aerodynamic analysis is being performed to identify the cause of these high loading conditions so that appropriate additional modifications can be made to prevent further damage from occurring in the future to aircraft with the FLIR installed.

Subsequent NDI of this portion of new structure was performed after three months of flight operations with the FLIR installed and no cracks or other flaws were detected.

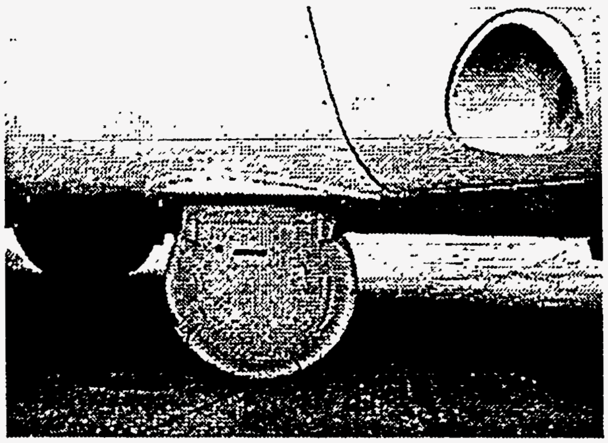

Figure 1: Permanent universal mount is Located internally and the FLIR Is mounted externally on HC-130H S/N 1719.

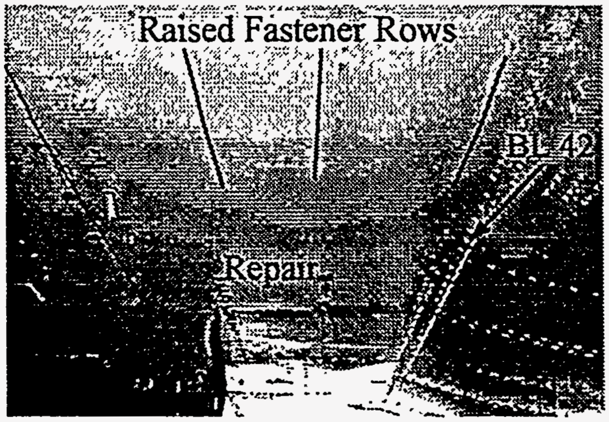

Figure 2: Inspection area (looking aft) of the FLIR. Repair location is where Initial damage was detected.

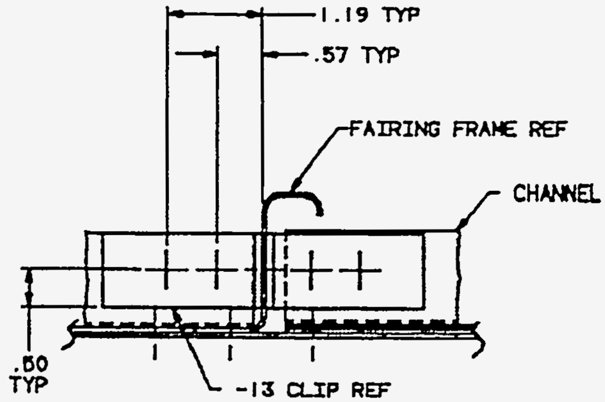

Figure 3: Sectional view of the wheel well Fairing. Button head fasteners are Not shown.

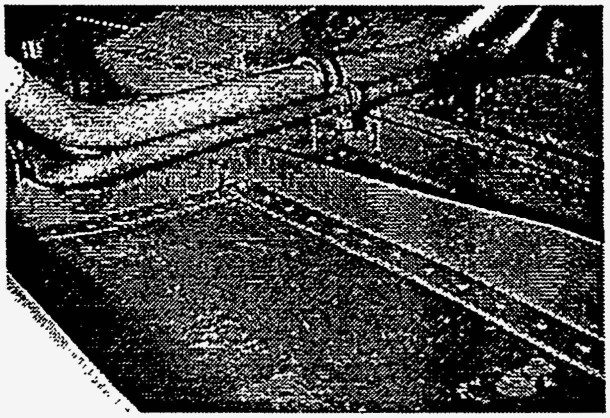

Figure 4: Inside view (looking aft) from the FLIR showing wheel well fairing skin and supporting structure.

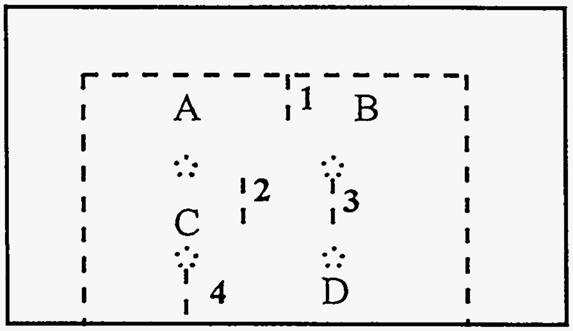

Figure 5: Reference standard used for calibration. Top plate 6.35 x 11.4 x 0.178 cm. Bottom plate 5.72 x 8.89 x 0.203 cm. EDM notches width 0.152 mm, Length 12.7 mm.

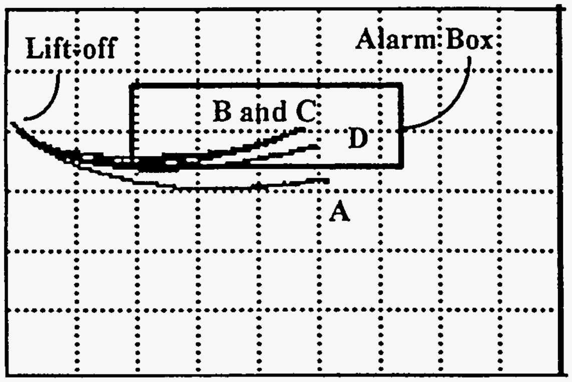

Figure 6: Signals produced on the reference Standard at all four positions. Displayed is the response from a Clear fastener and EDM notches 1.78 mm below the surface.

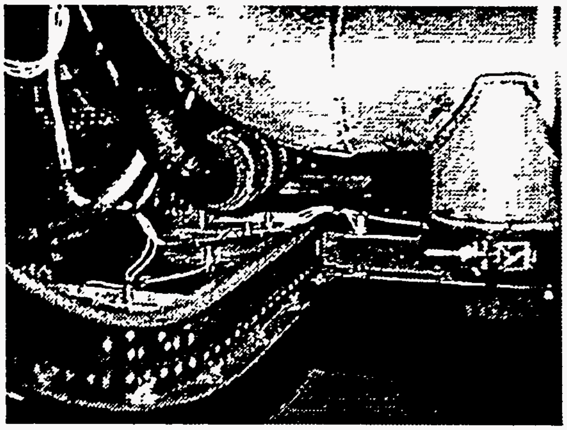

Figure 7: Accelerometer Mounting Detail (Note line of accelerometers at FS 485 and one on longeron at FS 474)

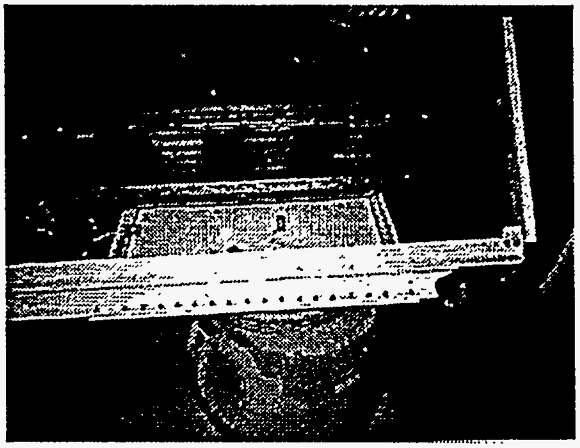

Figure 8: FLIR mounting structure with Accelerometers attached (Note X and Z accelerometers on FLIR Mounting Plate)

Figure 9: Accelerometer on Longeron, Before Structural Enhancement

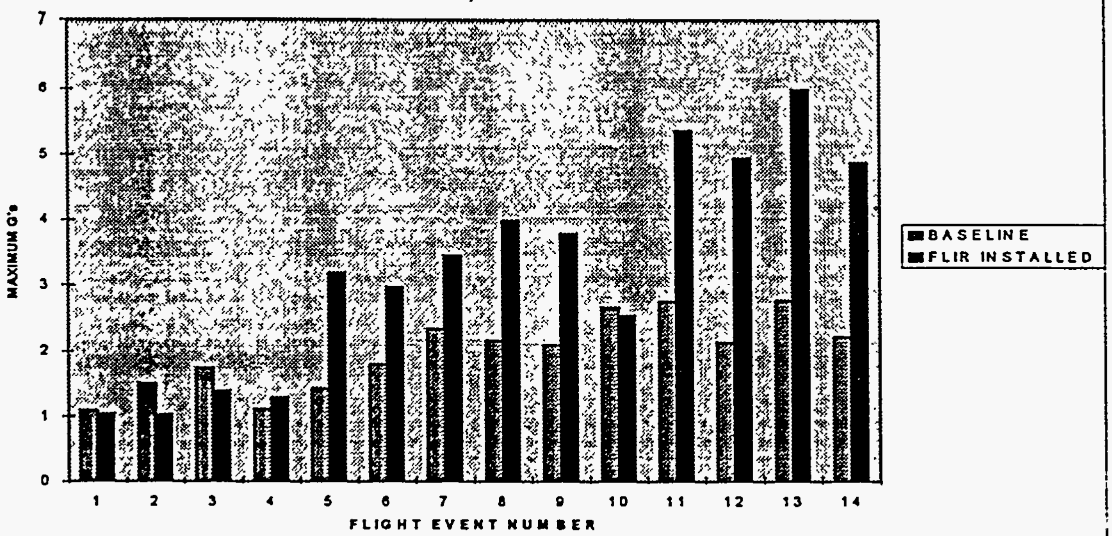

Figure 10: Accelerometer on Stiffener, Before Structural Enhancement

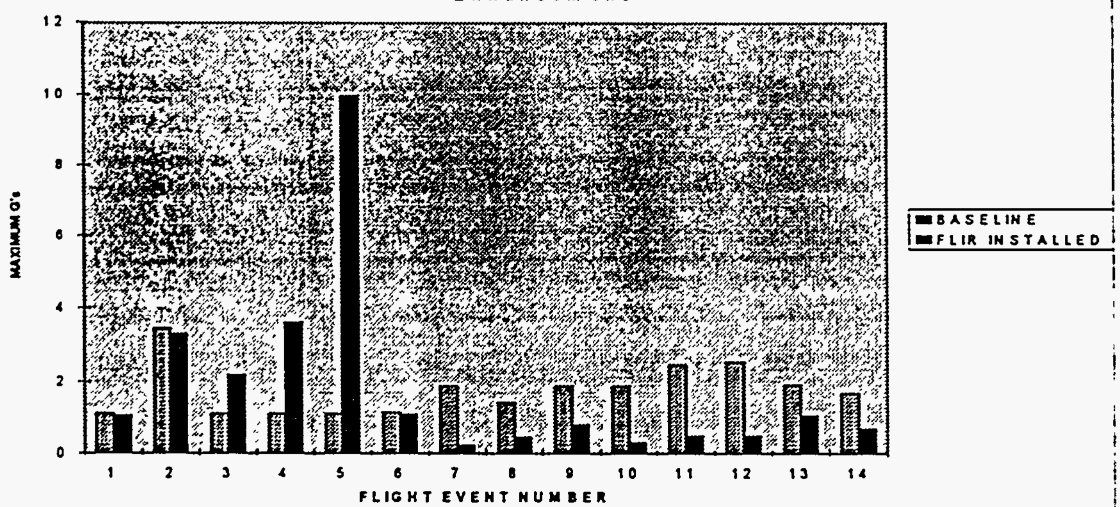

Figure 11: Accelerometer on Stiffener, After Structural Enhancement

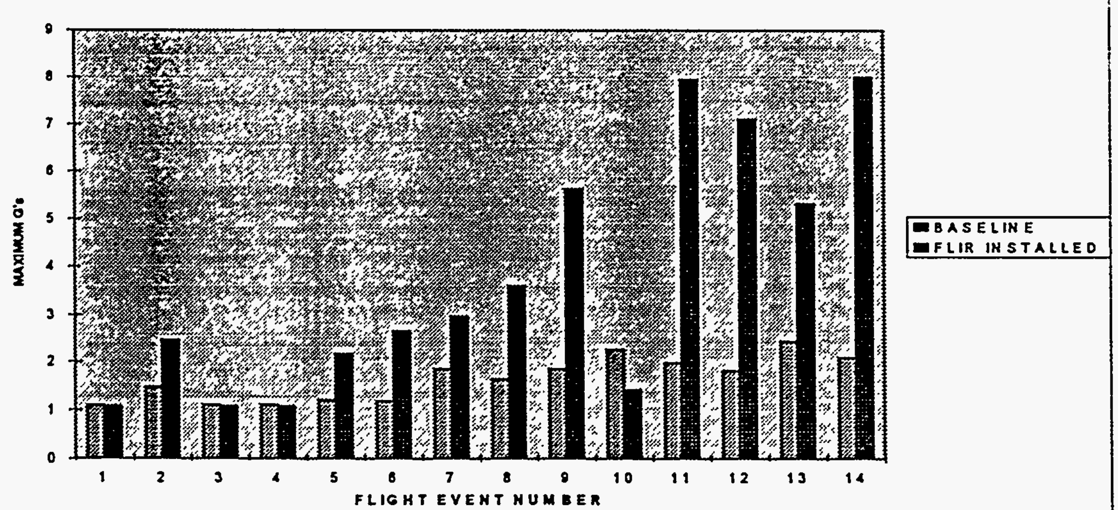

TABLE 1: HISTORICAL DAMAGE ON S/N 1719 WHEEL WELL FAIRING

DATE	DESCRIPTION OF DAMAGE
26 & 27 AUG 97	**EXTENSIVE (15 HRS) NDI OF RIGHT WHEEL WELL FAIRING CONDUCTED:**
	1) 21 SKIN ANOMALIES (CRACKS/CORROSION ORIGINATING FROM FASTENER HEADS IDENTIFIED AS FOLLOWS: A) 8 SKIN CRACKS AT FASTENERS AS NOTED IN ABOVE DISCREPANCY B) CRACKED SKIN ON FASTENER ROW FS 616.5 (THIRD FASTENER OUTBOARD OF FASTENER ROW BL 53.5) C) 2 CRACKS ON FASTENER ROW FS 607.5 (1 FASTENER INBOARD OF FASTENER ROW BL 52, 1 FASTENER OUTBOARD OF FASTENER ROW 42.5) D) 10 SKIN CRACKS ON FASTENER ROW BL 42.5 (9^{TH} AND 10^{TH} FASTENER FORWARD OF FASTENER ROW FS 607.5, 10^{TH}, 11^{TH} & 12^{TH} FASTENER FORWARD OF FASTENER ROW FS 587.5, 9^{TH} & 10^{TH} (CORROSION) FASTENER FORWARD OF FASTENER ROW FS 567.5, 11^{TH} & 12^{TH} FASTENER FORWARD OF FASTENER ROW FS 547.5 FASTENER AT INTERSECTION OF FASTENER ROW BL 42.5 & FASTENER ROW FS 457) 2) TWO ¼" CRACKS VISUALLY OBSERVED EMANATING FROM INBOARD CORNERS OF FORWARD, INBOARD SQUARE CUTOUT ON HAT SECTION ON NEWLY PROCURED FLIR MOUNT DOOR 3) APPROXIMATELY ½" CRACK ON SKIN PANEL AT CORNER INTERSECTION OF FS 491 AND BL 506
27 AUG 97	2.0 HR BASELINE FLIGHT FLOWN
28 AUG 97	2.7 HRS FLOWN WITH FLIR MOUNT AND FLIR INSTALLED. SUBSEQUENT VISUAL DAMAGE NOTED (DUE TO TIME CONSTRAINTS, AN NDI COULD NOT BE PERFORMED TO CHECK FOR INTERNAL DAMAGE): 1) 4 FASTENERS PULLED LOOSE ON FASTENER ROW BL 53.5 BETWEEN FS 491 AND 506 (1^{ST}, 2^{ND}, 3^{RD} & 4^{TH} FASTENER AFT OF FASTENER ROW FS 491.5) 2) 1 FASTENER PULLED LOOSE ON FASTENER ROW 52.0 (1^{ST} FASTENER AFT OF FASTENER ROW FS 491.5) 3) ¼" SKIN PANEL CRACK ON FASTENER ROW BL 52.0 (7^{TH} FASTENER AFT OF FASTENER ROW FS 491.5) REPLACED 5 FASTENERS/STOP DRILLED CRACK. AWAITING STRUCTURAL ENHANCEMENT.

NOTE: IT SHOULD NOT BE ASSUMED THAT THE DEFECTS DETECTED DURING THE INITIAL INSPECTIONS WERE CAUSE BY EARLIER FLIGHT OPERATIONS WITH THE FLIR INSTALLED.

TABLE 2: ACCELEROMETER LOCATIONS (FLIGHTS OF 27-28 AUGUST 97)

CHANNEL NUMBER	ACCEL S/N	LOCATION DESIGNATION	MOUNTING LOCATION TYPE	COMMENTS
1	331	FLIR SUPPORT BRACKET		FLIGHT 1 ONLY
1	331	FLIR - X-DIRECTION		FLIGHT 2 ONLY
2	260	472-55	SKIN (0.040")	
3	416	474-69	LONGERON	
4	395	485-50	SKIN (0.040")	
5	424	485-55	STIFFENER	
6	405	485-69	STIFFENER	
7	399	485-78	STIFFENER	
8	330	MLG INNER DOOR LEADING EDGE		
9	404	516-60	SKIN (0.032")	
10	259	576-60	SKIN (0.032")	
11		FLIR - Z-DIRECTION		FLIGHT 2 ONLY
12		FLIR - Y-DIRECTION		FLIGHT 2 ONLY

TABLE 3: TYPICAL TEST FLIGHT PROFILE

FLIGHT EVENT #	CONDITION	AIRSPEED (KIAS)	ALTITUDE (1000 FT)	COMMENTS
1	NORMAL GROUND IDLE	0	0	
2	GROUND RUNUP	0	0	
3	GEAR EXTENDED, FLAPS 50%	150	4	
4	GEAR UP, FLAPS 50%	150	4	
5	STRAIGHT/LEVEL	200	4	
6	STRAIGHT, 1 BALL OUT, RWD	200	8	RWD=RIGHT WING DOWN
7	STRAIGHT, 1 BALL OUT, LWD	200	8	LWD=LEFT WING DOWN
8	STRAIGHT/LEVEL	225	8	
9	STRAIGHT/LEVEL	250	8	
10	CLIMB	180-160	8-15	
11	MAXIMUM CRUISE	241-247	15	TIT: 1010° C
12	MAXIMUM CRUISE, STRAIGHT, 1 BALL OUT, RWD	245	15	TIT: 1010° C
13	MAXIMUM CRUISE, STRAIGHT, 1 BALL OUT, LWD	245	15	TIT: 1010° C
14	RGHT CONTINUOUS TURN, 30° AOB	250	11	