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AEFA Project No. 87-30



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EVALUATION OF THE PRODUCTION CH-47D ADVERSE WEATHER COCKPIT (AWC) AERIAL REFUELING SYSTEM

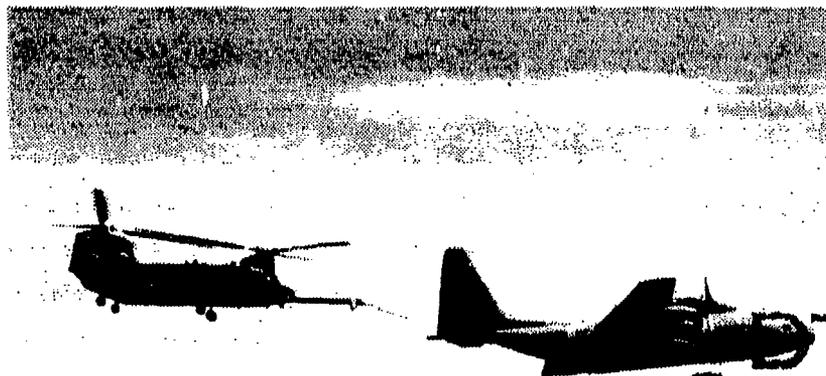
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Final Report



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AVIATION ENGINEERING FLIGHT ACTIVITY
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) An evaluation of the CH-47D Adverse Weather Cockpit (AWC) helicopter with the production aerial refueling system was conducted by the U.S. Army Aviation Engineering Flight Activity (AEFA). The evaluation was conducted at Boeing Helicopters Greater Wilmington, Delaware Flight Test Facility during the period 17 June through 15 July 1988. Eight flights were conducted for a total of 11.9 flight hours, 8.5 of which were productive, with 106 probe-to-drogue contacts and 18,160 pounds of fuel transferred. Level flight performance tests, aerial refueling tests and aerial refueling system tests were conducted by the contractor and were witnessed by AEFA personnel. No drag increment determination could be made from the inconclusive level flight test data. The contractor intends to analytically estimate the external drag of the aerial refueling system. The AEFA evaluation included day, night unaided vision and night aided vision aerial refueling operations using Aviator Night Vision Imaging System (ANVIS-6) night vision goggles with a U.S. Air Force HC-130P tanker aircraft. Tests included a tanker proximity wake turbulence evaluation and evaluation of the handling qualities in the refueling environment including off-center disconnects and non-responsive hose operations. One enhancing characteristic, one deficiency and three shortcomings, one of which was identified on a previous evaluation of the standard CH-47D, were noted. The aerial refueling lighting system is an enhancing characteristic. The requirement to have the battery switch ON in order to single-point refuel on					
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the ground is a deficiency. The inability to select anything other than full bright on the refueling probe light and refueling searchlight during initial filament activation is a shortcoming. The CH-47D AWC helicopter incorporating the Boeing Helicopters production aerial refueling system is suitable for day and night aerial refueling operations. (SDW)



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INTRODUCTION

BACKGROUND

1. The U.S. Army has a mission requirement for extended-range flight capability and intends to support this requirement with the CH-47D Adverse Weather Cockpit (AWC) helicopter modified to accept an aerial refueling system. A feasibility study was begun in November 1984 by the contractor (Boeing Helicopters (BH)) to design, fabricate, install and flight test a prototype aerial refueling system for the CH-47D helicopter. This system included a two-section telescoping refueling probe that was 38 feet, 9 inches long (measured from probe tip to base) when fully extended. The initial feasibility demonstration was conducted by BH at the Boeing Center in Philadelphia, Pennsylvania and the Greater Wilmington, Delaware Flight Test Facility. The U.S. Army Aviation Engineering Flight Activity (AEFA) evaluated the prototype system at the Wilmington Flight Test Facility from 6 through 9 August 1985 (ref 1, app A). Results of the initial flight tests led to the evaluation of the system with the probe fixed at a shorter length of 29 feet, 9 inches (ref 2). The results of these tests indicated that the CH-47D could safely perform refueling operations with the shorter probe and led to the BH design of a production system utilizing a one-piece refueling probe with a length of 29 feet, 7 inches. Accordingly, the U.S. Army Aviation Systems Command (AVSCOM) tasked AEFA to conduct an evaluation of the production aerial refueling system developed by BH for the CH-47D AWC helicopter (ref 3). The tests to be conducted were set forth in the test plan (ref 4).

TEST OBJECTIVES

2. The objective of this test was to evaluate the capability of the CH-47D AWC helicopter to perform day and night aerial refueling operations with the BH aerial refueling system. Additional objectives were to evaluate the effects of the aerial refueling system on the performance and handling qualities of the CH-47D AWC and to provide sufficient data to substantiate an airworthiness release for the Army user.

DESCRIPTION

3. The test helicopter was a production CH-47D (Serial Number 82-23763) modified to incorporate the Collins Integrated Cockpit, Bendix RDR 1301C weather radar, AN/AAQ-16 Forward Looking Infrared system, and BH aerial refueling system. The aerial refueling system consisted of a one-piece probe (29 feet, 7 inches long) mounted on the right side of the aircraft, modifications to the aircraft's pressure refueling system to allow fuel transfer through the probe, a cabin-mounted aerial refueling control panel, an external lighting system installed in the forward pylon for night aerial refueling operations and an aerial refueling lighting system control panel installed in the cockpit. A more detailed description of the CH-47D is contained in the operator's manual (ref 5) and a more complete description of the aerial refueling system is contained in appendix 3.

TEST SCOPE

4. The evaluation of the CH-47D AWC helicopter with the production aerial refueling system was conducted at the BH Wilmington Flight Test Facility during the period 17 June through 15 July 1988. The evaluation consisted of various ground and flight tests conducted by the contractor (including aerial refueling system tests, envelope verification tests, level flight performance and aerial refueling tests), aerial refueling tests conducted by AEFA and aerial refueling training flights (with an AEFA test pilot) for the Army user pilots. AEFA flight test personnel witnessed all contractor ground and flight tests. Eight AEFA flights were conducted for a total of 11.9 flight hours, of which 8.5 were productive, with 106 probe-to-drogue contacts and 18,160 pounds of fuel transferred in flight. Additional user pilot aerial refueling training was conducted at Marine Corps Air Station El Toro, Santa Ana, California between 1 and 4 August 1988. A total of 27.8 flight hours were flown during aerial refueling training of two CH-47D AWC unit pilots. A total of 478 contacts were performed during the AEFA and BH flight tests and the unit training. Prior to performing this evaluation, the flight crews attended initial/refresher aerial refueling training conducted by the 1551st Flying Training Squadron at Kirtland Air Force Base, New Mexico. Ground refueling tests were conducted using a Marine Corps KC-130T tanker and crew from 4th Marine Aircraft Wing, Naval Air Station Glenview, Glenview, Illinois and an Air Force HC-130P tanker and crew from the 9th Special Operations Squadron, Eglin Air Force Base, Florida. The Air Force HC-130P was used for the aerial refueling tests and was under the operational control of the Air Force Flight Test Center, Edwards Air Force Base, California. D Company, 160th Special Operations Aviation Regiment, Fort Campbell, Kentucky provided a UH-60A with flight crew and medic for chase and crash rescue support. The AVSCOM Technology Applications Program Office coordinated the tanker and crash rescue aircraft and flight crews for both the contractor and government flight tests. BH provided a fixed wing chase aircraft and crew, photographic support, test aircraft maintenance, instrumentation, and data reduction support. The 352nd Marine Aerial Refueler Transport Squadron (VMGR-352) located at Marine Corps Air Station El Toro, Santa Ana, California provided a KC-130R tanker to complete the unit pilot aerial refueling training. The limitations contained in the operator's manual (ref 5) and the airworthiness release (ref 6) were observed. Aircraft flight characteristics with the aerial refueling system installed were compared to previous tests of the CH-47D (ref 2). Military specifications MIL-H-8501A (ref 7) and MIL-F-38363B (USAF) (ref 8) were used as guides during the evaluation. The aerial refueling flights were conducted at gross weights from 28,800 pounds to 50,000 pounds and at mid to forward center of gravity. Tanker gross weight during these flights was between 110,000 pounds (light) and 140,000 pounds (heavy). Aerial refueling was performed with unaided vision and with aided night vision imaging system (ANVIS-6) night vision goggles. Refueling was conducted at density altitudes between 3,000 and 6,000 feet and included simulated single-engine, single advanced flight control system refueling operations and off-center disconnects. The general test conditions are presented in table 1.

Table 1. General Test Conditions¹

Test	Average Gross Weight (lb)	Average Center of Gravity (F5)	HC-130P Gross Weight (lb)	Average Density Altitude (ft)	Trim Indicated Airspeed (kt)	Remarks
Level Flight Performance	36,640	328.2	Not Applicable	10,040	81 to 137 KCAS ²	Test conducted by BH. Flown with probe installed and probe removed. RPM varied to maintain constant referred rotor speed.
	35,520	328.6	Not Applicable	4,850	80 to 140 KCAS	
Slope Landings	29,100	317.7	Not Applicable	1,290	0	Test conducted by BH.
	31,400	316.8	111,000	4,270	115	
Tanker Proximity Wake Turbulence Evaluation	47,930	328.3	140,000	4,400	110	100 feet behind tanker left and right wing and fuselage centerline.
	31,000	316.8	110,000	7,930	119	
Daytime Refueling Operations	31,760	316.7	135,000	5,100	105, 110, 115, 120	Included off-center disconnects and failed hose reel automatic take-up system.
	34,670	326.0	145,000	4,440	115	
	48,160	329.0	138,000	4,590	110 and 115	
	33,580	317.9	138,000	11,380	110	
Nighttime Refueling Operations	48,360	328.3	140,000	4,200	110	Test conducted by BH. Night lighting system unfiltered, unaided and aided vision (NVG) ⁴ .
	32,100	317.7	132,000	6,050	110	
Refueling Operations with Single AFCS	48,000	329.0	138,000	4,770	115	Night lighting system with infrared filters, aided vision (NVG).
Refueling Operations with Simulated Single-Engine Failure	31,800	316.6	135,000	6,060	110	#1 AFCS OFF, moderate turbulence. #2 engine beeped back using emergency beep trim.

NOTES:

¹Unless otherwise noted, tests were conducted with both advanced flight control systems (AFCS) ON, 100% rotor speed (225 rpm) in non-turbulent air.

²KCAS: Knots calibrated airspeed.

³BH: Boeing Helicopters.

⁴NVG: Night vision goggles.

TEST METHODOLOGY

5. Flight test techniques are briefly described in the Results and Discussion section of this report. Flight parameters were recorded by the flight test engineer, onboard pulse code modulation recording system, and telemetered to a ground recording station. A listing of the recorded parameters is contained in appendix C. Video and photographic documentation were recorded from the test, tanker, and chase aircraft. Test techniques for the ground tests including static structural tests, static rotor blade-to-probe clearance, probe natural frequency determination, and refueling system functional tests are discussed in appendix D. Methods used to determine refueling system external drag, aircraft vibrations, probe tip loads, tip-path plane to probe/drogue clearance, and receiver to tanker clearance are also discussed in appendix D. Qualitative ratings of the handling qualities and vibrations were based on the Handling Qualities Rating Scale and the Vibration Rating Scale contained in appendix D.

RESULTS AND DISCUSSION

GENERAL

6. An evaluation of the CH-47D Adverse Weather Cockpit (AWC) helicopter equipped with the Boeing Helicopters (BH) aerial refueling system was conducted during day and night aerial refueling operations. Ground functional and in-flight systems tests were performed. Aerial refueling was conducted with a U.S. Air Force HC-130P during the flight tests and initial user pilot training. A U.S. Marine Corps KC-130R was utilized for additional user pilot training. One enhancing characteristic, one deficiency and three shortcomings were noted. The aerial refueling lighting system used for conducting night aerial refueling operations is an enhancing characteristic. The requirement to have the aircraft battery switch ON in order to single-point refuel on the ground is a deficiency. Based on the scope of this evaluation, the CH-47D AWC helicopter incorporating the BH aerial refueling system is suitable for day and night aerial refueling.

DRAG INCREMENT DETERMINATION

7. The contractor, BH, conducted level flight performance testing to determine the change in power required in level flight due to the installation of the aerial refueling system. The test conditions are listed in table 1. The test data were inconsistent; therefore, no drag increment determination could be made from the test data. Because of this, the contractor intends to analytically estimate the external drag of the aerial refueling system.

8. The most likely explanation for the inconsistency is that the power required data were not accurate. The performance data were based on measurements taken from calibrated and uncalibrated ship system instrumentation (app C). The standard CH-47D torque measuring system was instrumented and was the sole source of data for power required. The system was unreliable during flights early in the evaluation but the problem was identified and presumably resolved before commencing with the performance testing. Performance data for the CH-47D AWC with the aerial refueling system should be obtained using an instrumented aircraft with calibrated engines and measured rotor shaft torques.

HANDLING QUALITIES

General

9. The handling qualities of the CH-47D AWC helicopter configured with the aerial refueling system were evaluated during ground and flight operations. Evaluations were conducted at the conditions shown in table 1. The slope landings and high altitude refueling operations were performed by the contractor and monitored by U.S. Army Aviation Engineering Flight Activity (AEFA) personnel. Additional high altitude refueling operations (10,000 feet pressure altitude) were performed during the unit pilot training program conducted by an AEFA test pilot. Procedures for operating the aerial refueling system were recommended by the contractor and evaluated throughout the tests. Additionally, the CH-47D AWC Aerial Refueling System Operator and Crewmember

Supplemental checklist authored by BH was evaluated and changes were recommended. The final version of these two documents will be published and provided to the operating unit by BH.

Ground Handling Characteristics

10. Ground handling characteristics of the CH-47D AWC aircraft fitted with the aerial refueling probe were qualitatively evaluated throughout these tests. Normal procedures for taxi were utilized and included running landings, four wheel and two wheel ground taxi. The clearance between the probe tip and the ground was measured over a level surface with properly serviced landing gear struts and tires. The aircraft gross weight and center of gravity (cg) were 34,020 pounds and fuselage station (FS) 329.1. The clearance was measured at 45.5 inches but should be slightly less at higher gross weights and more forward cg's. Taxi over or near ground obstructions and uneven terrain will further reduce these margins. Pilots and ground guides must be mindful of the potential for probe and/or aircraft damage when ground handling the CH-47D AWC (probe installed) aircraft near obstacles or over uneven terrain. No objectionable probe oscillations were noted during ground operations associated with these taxi tests. The ground handling characteristics of the CH-47D AWC aerial refueling probe equipped aircraft observed during these tests were satisfactory, but the following CAUTION should be placed in the CH-47D AWC Aerial Refueling Procedures Supplement:

CAUTION

Care must be taken when ground handling aircraft equipped with the aerial refueling probe near obstacles or on uneven terrain to avoid contact and possible damage.

11. The only significant probe oscillations observed during ground operations occurred during engine start/runup and shutdown. Probe tip oscillations of approximately ± 3 inches in a random direction at approximately the probe natural frequency were observed when the rotor speed was between 35 and 45 percent (approximately 79 and 101 revolutions per minute). Even at these extreme conditions, probe bending moments of only $\pm 45,000$ inch-pounds vertically and $\pm 30,000$ inch-pounds laterally were observed. These are equivalent to less than 3 percent of the maximum bending moments measured during the static structural test (para 40). The ground handling characteristics of the CH-47D AWC aircraft equipped with the refueling probe were satisfactory.

Slope Landing Characteristics

12. Slope landing characteristics of the CH-47D AWC aircraft equipped with the aerial refueling probe were demonstrated at up to ten degree slope angles in all four directions. Observed characteristics were similar to those of a standard CH-47D helicopter except for the necessity to allow for adequate probe clearance considering the location of the probe and landing gear (para 10). This additional concern is minimized since the probe is in relatively clear view of both pilots during these maneuvers. Within the limited scope of these tests, the slope landing characteristics of the CH-47D AWC aircraft equipped with the aerial refueling probe were satisfactory.

Aerial Refueling Procedures

13. A general description of the aerial refueling procedures is contained in the Air Force Flight Crew Air Refueling Procedures Flight Manual (ref 9, app A). A more detailed description of the aerial refueling procedures evaluated during this test are briefly described here for clarity. The refueling operation is initiated by rendezvous of a tanker and receiver aircraft at a predetermined location, time and track. The tanker and receiver complete their respective rendezvous and join up aerial refueling checklists. The tanker assumes formation lead after overtaking the receiver aircraft on the right, then maintains the desired refueling airspeed and prepares to transfer fuel. The receiver aircraft assumes the left observation position until cleared by the tanker for left refueling drogue contact. The left observation position is approximately 200 feet from the tanker aircraft, off-set on a 45 degree angle such that the tip of the tanker's left horizontal stabilizer is centered on the star emblem which is painted on the fuselage just aft of the paratroop door. Looking across the tanker, the right wing should appear centered on the rudder and only the right aileron should be visible to the receiver pilot. When the tanker gives the receiver clearance to contact the drogue and transfer fuel, the receiver moves down and right to the precontact position. The precontact position is aft of the drogue, with the probe in line with the hose and probe tip 10 to 15 feet behind and centered on the drogue. The receiver then moves forward so that the probe nozzle contacts the drogue (contact position) with a positive rate of closure. Too small a closure rate will result in a soft contact, and the drogue refueling receptacle will not seat properly on the probe nozzle. Approximately 140 pounds of force is required to properly seat the nozzle in the drogue receptacle. After contact, the receiver moves forward, left, and up to the left refueling position to transfer fuel. This position is aft of the left wing tip of the C-130 tanker with the right seat pilot sighting down the left wing fuel dump mast located on the tanker's wing tip. The receiver's vertical position is such that the tabs on the top of the tankers No. 1 engine cowl are barely visible. The C-130 tanker's fuel transfer hose is designed to automatically retract and extend as the receiver aircraft moves fore and aft. Fuel can be transferred when the refueling hose is extended between 56 and 76 feet from the tanker refueling pod. These distances are marked by two, five foot white bands separated by a 10 foot black band on the refueling hose. When fuel transfer is complete, the receiver moves right and down, then straight back to disconnect. Approximately 420 pounds of force is required to unseat the nozzle from the drogue receptacle. The disconnect is made 5 to 10 feet above the contact position so that the drogue drops away from the receiver aircraft refueling probe. The receiver aircraft then moves to the left observation position. Similar procedures are used when refueling from the right drogue. When in the right refueling position, the left seat pilot is sighting down the right wing fuel dump mast.

14. Reference cues on the C-130 tanker utilized by the receiver pilots during aerial refueling operations are essentially the same. However, each refueling tanker flies at its own unique attitude based on gross weight, power settings, trim settings, and refueling drogues vary in their flight characteristics. Therefore, it is imperative that receiver pilots select specific tanker reference cues during the precontact phase of the refueling operation.

15. The Air Force Flight Crew Air Refueling Procedures Flight Manual refers to helicopter refueling procedures for helicopter refueling probes which extend beyond the rotor tip-path. The tip of the aerial refueling probe on the CH-47D AWC is approximately 5 feet 11 inches aft of the forward rotor tip-path. This requires a different precontact position than used by helicopters with aerial refueling probes which extend beyond the tip-path to insure adequate separation between the drogue and rotor. The precontact position used during this evaluation was to align the refueling probe laterally with the refueling hose, probe tip positioned vertically with the center of the drogue, and 10 to 15 feet aft of the drogue. The 10 to 15 feet probe-to-drogue distance, while in the precontact position, allows sufficient clearance between the drogue and rotor during gust upsets in turbulent air conditions or inadvertent receiver low positions. The Air Force T.O. 1-1C-1-20 and the CH-47D AWC Aerial Refueling Procedures Supplement should define the precontact position for the CH-47D AWC as follows: "The precontact position for the CH-47D AWC is the refueling probe laterally aligned with the refueling hose, probe tip positioned vertically with the center of the drogue, and 10 to 15 feet aft of the drogue." The aerial refueling procedures used during this evaluation were satisfactory.

Aerial Refueling Characteristics

General

16. Test aircraft handling qualities during aerial refueling operations were qualitatively evaluated at all normal refueling station-keeping positions for the left and right drogue as well as from both pilot and copilot seats. The effects of tanker wake turbulence on aerial refueling operations were also evaluated with tanker gross weights of 111,000 pounds (light) and 140,000 pounds (heavy). Contacts were accomplished at receiver gross weights from 28,800 to 50,000 pounds. Refueling operations were also evaluated at receiver airspeeds from 105 to 120 knots indicated airspeed (KIAS). The longitudinal cyclic trim (LCT) actuators of the CH-47D AWC were operated in the manual mode with both rotor heads programmed to the normal trim position for the test day refueling altitude and airspeed. The tanker wake turbulence and resultant airspeed fluctuations caused undesirable tip-path-plane motion when the LCT actuators were operated in the automatic mode. The procedure that was used minimized the tip-path-plane motion and provided a more stable refueling platform. This procedure will be described in the CH-47D AWC Aerial Refueling Procedures Supplement. Small probe tip oscillations (approximately ± 2 inches) which were quickly damped were apparent in turbulent air or when excited by flight control inputs. These oscillations did not adversely affect aerial refueling operations. The advanced flight control system (AFCS) of the CH-47D AWC maintained ball-centered trim condition within $\pm 1/4$ ball throughout the refueling task requiring infrequent and minimal pedal applications. Approximately 5 to 10 percent torque reduction was noted between the power required to maintain the precontact position as compared to the observation position. An additional 5 to 10 percent reduction was noted when stabilized in the left aerial refueling position. Slightly more power (approximately 5 percent) was needed when conducting operations on the right drogue. The maximum radial probe tip load observed was 810 pounds and occurred while moving from the contact to the refueling position in turbulent air conditions. Nominal radial

probe tip load during this maneuver was 350 pounds. Little difference was noted between the handling qualities associated with left and right drogue refueling operations.

Tanker Turbulence Evaluation

17. The effect of the turbulence created by the HC-130P tanker on the CH-47D AWC helicopter was evaluated on several flights with tanker gross weight at approximately 111,000 pounds and approximately 140,000 pounds. This evaluation was conducted to determine how the helicopter would react if the aircraft was allowed to get out of the normal refueling station-keeping positions behind the tanker. The evaluation was conducted by stabilizing the test aircraft approximately 100 feet aft and high behind the tanker left wing tip, number one engine, fuselage centerline, number four engine and right wing tip. A vertical sweep was accomplished at each of these lateral positions while maintaining a constant stand-off distance and stopping briefly above the tanker wing, at the refuel drogue, 10 feet below drogue and 30 feet below drogue vertical heights. The turbulence caused an increase in airframe vibration and was perceived as low frequency buffeting. The highest level of vibration was experienced when the helicopter was immersed in the prop wash of any tanker engine regardless of left or right wing locations and was assessed at 6 on the vibration rating scale (VRS) (fig. D-2, app D). Even though vibrations were high, aircraft control was not in question and the aircraft could be easily maneuvered out of the high vibration environment. The helicopter was generally clear of these vibration levels when at heights greater than 10 feet above the drogue and below approximately 20 feet below the drogue. Vibration levels of lesser magnitude were noted when accomplishing these maneuvers behind the tanker wing tips or the fuselage centerline and were rated as VRS 4. Again the helicopter was relatively clear of the vibration when above a vertical height of 10 feet below the wing or below a vertical height of 30 feet below the wing. Aircraft control was maintained at all times during the tanker turbulence evaluation, and the pilot could easily fly out of the tanker turbulence. The handling qualities of the CH-47D AWC equipped with the aerial refueling probe in HC-130P tanker turbulence were satisfactory.

Day, Non-Turbulent Air

18. Day, non-turbulent air refueling operations were conducted at both heavy and light gross weights. A total of 47 drogue engagements were attempted in these conditions, resulting in 43 successful and 4 missed engagements. Operations were conducted on both the left and right drogues and from both pilot seats. A time history plot of representative refueling operations in non-turbulent air is shown in figure E-1, appendix E. In non-turbulent air, the maneuvers requiring lower station-keeping precision, such as observation position and the refueling position, could be accomplished with moderate pilot compensation (Handling Qualities Rating Scale (HQRS) 4) and were no more difficult than other formation flying tasks. The aerial refueling tasks requiring more precision, such as the precontact and moving to contact positions, were accomplished with considerable pilot compensation (HQRS 5). The low gain tasks required approximately $\pm 1/4$ inch control displacements in each of the longitudinal, lateral and thrust axes about every 3 to 5 seconds, while directional inputs were only infrequently required. The higher gain tasks required these same control inputs but were required approximately every 1 to 2 seconds. It was noted that when conducting left drogue

operations from the left pilot seat that the drogue could block the pilots view of the refueling pod and hose markings if a slightly high refueling position was attained. The pilot quickly learned to fly a slightly lower left refueling position (approximately 2 feet) to prevent this loss of station-keeping cue. Otherwise, little difference was noted between handling quality ratings during left or right drogue operations. Low frequency vibrations associated with the tanker wake turbulence were noted at each refueling station-keeping position. The highest vibration level observed while conducting normal operations was VRS 5 when maintaining the precontact position. This level improved to approximately VRS 4 when the receiver aircraft moved to the refueling position. During flights at heavier gross weights, occasionally quick thrust control movements changed the rotor speed sufficiently to cause the pilot or copilot seat vibration absorbers to detune. This condition normally lasted for approximately 15 to 30 seconds (until the absorber retuned) but resulted in an overall increase in pilot perceived vibration levels of about one on the VRS. Additionally, if the pilot allowed the aircraft to fall too far behind the drogue (greater than 15 feet) or stray too far inboard of the drogue (approximately 3 feet) and into the tanker prop wash, overall airframe vibration increased to the VRS 6 level. With practice and adequate pilot concentration, these conditions could be avoided. Overall, handling qualities during aerial refueling operations to both drogues and from both pilot seats in day, non-turbulent air conditions were satisfactory.

Day, Turbulent Air

19. Day, turbulent air refueling operations were conducted at both heavy and light gross weights. Air conditions ranged from light to moderate turbulence. A total of 53 drogue engagements were attempted under these conditions, resulting in 39 successful and 14 missed engagements. A time history plot of representative refueling operations in moderate turbulence is shown in figure E-2. The number of missed engagements was greater during turbulent air flight because the drogue movement (as much as ± 6 feet vertically and laterally) and the decreased aircraft stability due to turbulence made the precontact position more difficult to maintain and the drogue more difficult to engage. Operations were conducted on both drogues and from both pilot seats. In turbulent air, the maneuvering requiring lower station-keeping precision, such as the observation position, and the refueling position could be accomplished with considerable pilot compensation (HQRS 5). The aerial refueling tasks requiring more precision, such as the precontact and movement to contact positions, were accomplished with extensive pilot compensation (HQRS 6). Since the probe tip is approximately 5 feet 11 inches inside the rotor tip-path, establishing the proper precontact position with the drogue approximately 10 to 15 feet beyond the tip of the refueling probe is very important. It is equally important that the pilot utilize the technique of acquiring probe-to-drogue contact during those brief periods of calm air when the drogue is momentarily still or by engaging the drogue at the highest point in its movement arc if the air conditions are such that the drogue is constantly oscillating. Utilizing these techniques will allow adequate safety margin between the rotor blades and the refueling hose/drogue for turbulent air refueling operations. An additional consideration during heavy receiver, high density altitude and turbulent air conditions is the increased transient oscillations of cruise guide indicator values (para 31). Frequent excursions into the yellow arc (100 to 150 percent) and occasional excursions into the red-and-yellow striped band (150 to 200 percent)

were normally associated with either pilot commanded pitch inputs or AFCS responses to gusts. Monitoring of the cruise guide indicator distracts the pilot when his concentration must be directed toward safely engaging the refueling drogue. These conditions can and should be minimized by careful mission planning. The operator's manual (ref 5) states that operation in the red-and-yellow striped band shall be avoided. Decreased gross weight and/or lower altitude lessen high cruise guide indications. The contractor has agreed to provide the user with a planning chart which will establish recommended maximum gross weights versus altitude with consideration given to refueling task power margins and cruise guide indicator activity in turbulent air. This chart has not yet been provided and, therefore, is not included in this report. Overall, handling qualities during aerial refueling operations to both drogues and from both pilot seats in day, turbulent air conditions were satisfactory. The user should be provided recommended gross weight versus altitude planning information for aerial refueling at the earliest possible time.

Night, Unaided Vision

20. Night, unaided vision aerial refueling operations were conducted at heavy gross weight (greater than 48,000 pounds) and in non-turbulent air conditions. The aerial refueling lighting system (para 35) was used and infrared (IR) light filters were not installed. A total of 10 drogue engagements were attempted, all of which were successful and were accomplished to both left and right drogues from both pilot positions. Night refueling operations were no more difficult to perform than day operations particularly since the aerial refueling lighting system adequately illuminated the tanker features used in day procedures. The handling qualities associated with night unaided vision aerial refueling operations were satisfactory.

Night, Aided Vision

21. Night vision goggle (NVG) aided aerial refueling operations were conducted at heavy (approximately 48,000 pounds) and light (approximately 33,000 pounds) receiver gross weights in non-turbulent air conditions. The Aviator Night Vision Imaging System (ANVIS-6) NVG were used during these tests. Tanker lighting was varied but generally was at Air Force regulation minimum lighting for these operations. Probe-to-drogue engagements were accomplished using aerial refueling lighting system white lights at very dim settings and with IR filters installed. A total of 14 engagements were attempted, all of which were successful. Refueling operations at night using NVG were no more difficult than day operations when the refueling light system was used in either the white light or IR filtered light configuration. The drogue and key formation tanker features were adequately illuminated (para 35) with either extremely dim white lights or somewhat brightened IR filtered lighting. The amber light on the aft of the tanker's refueling pod was extremely bright when viewed through NVG. The halo around this light obscured visual references in this general area and the hose markings in particular. When the receiver was within normal refueling range the amber light was out and visual cues were restored. The handling qualities associated with night NVG aided aerial refueling operations were satisfactory. The C-130 tanker refueling pod light indication system should be altered when used in conjunction with night vision goggles.

Non-Responsive Hose Operations

22. Non-responsive hose operations were evaluated during day non-turbulent air conditions. This is an emergency procedure used when the receiver must take on fuel and no other properly operating refueling pod reel is available. Normal contacts were made to both left and right drogues and smooth transitions to the refueling position were accomplished. There was no tendency for the hose to whip or display any other unstable behavior. Probe bending moments were less than those observed during normal refueling operations conducted in turbulent air conditions. Secondary refueling position station-keeping cues were used since the normal hose marking standoff cue was no longer provided. A normal refueling position resulted in a large stable hose loop and provided adequate station-keeping tolerances. When moving to disconnect, a slower than normal deceleration was used to minimize the tendency of the hose and drogue to snap upward to a position higher than the static position. This modification of normal procedures at the disconnect maximized rotor tip-path plane to drogue/hose clearance. The Air Force T.O. 1-1C-1-20 and the CH-47D AWC Aerial Refueling Procedures Supplement should include the following CAUTION:

CAUTION

Movement from the refueling to the disconnect position when performing non-responsive hose refueling operations must be performed slowly to minimize the tendency for the hose and drogue to snap upward at disconnect.

Non-responsive hose operations with the CH-47D AWC equipped with the aerial refueling probe were satisfactory.

Off-Center Disconnects

23. Off-center disconnects were conducted to provide probe loads data (para 30) and to evaluate rotor-to-drogue clearance. Disconnects were accomplished at other than the normal position on both hoses from three relative positions. First a disconnect was made at the normal refueling position height but directly behind the refuel pod. Next, a disconnect was made from the normal refueling position as if the pilot had allowed the tanker to pull away from the receiver. This was considered the most likely and common type of inadvertent disconnect. Lastly, a disconnect was made from the refueling position lateral spacing from the tanker but at a vertical height equal to the normal disconnect position (outboard of the normal disconnect position). No degradation in handling qualities were observed while performing these off-center disconnects. Probe loads are presented in table 4 and discussed in paragraph 30. Rotor-to-drogue clearances were adequate in all cases tested. It was noted during these tests that the drogue had a tendency to slide along the side of the probe tip particularly during slow disengagements. This action could easily damage the drogue chute material making that drogue unstable and unusable for the refueling sortie. Off-center disconnects of the type and magnitude tested showed no unacceptable handling qualities, loads or rotor-to-drogue/hose clearance problems and were satisfactory.

Aircraft Systems Failures

Single AFCS

24. Single-AFCS ON aircraft system failures were evaluated to determine adequacy of handling qualities in accomplishing the aerial refueling mission. Single-AFCS refueling operations were conducted at heavy receiver gross weight, in moderate turbulence and at density altitudes of up to 4800 feet. Each AFCS was failed individually and contacts were made to both the left and right drogue. No qualitative differences were noted during single AFCS operations while performing aerial refueling tasks. The handling qualities of the CH-47D AWC while performing aerial refueling operations with a single AFCS were satisfactory.

Simulated Single Engine

25. Simulated single-engine aerial refueling characteristics were evaluated to determine feasibility and recommended techniques. Specific test conditions are shown in table 1. Single-engine operations were simulated by placing the normal engine trim switch of one engine in the MANUAL position and decreasing the emergency engine trim switch for the same engine until the engine torque reached zero. Rotor speed was maintained by using the normal engine beep trim switch for the other engine. This procedure was used to minimize the time required to regain use of the simulated failed engine should it be necessary to quickly regain power. Approximately 94 percent single-engine torque was required to maintain the observation position on the left side of the tanker at approximately 30,000 pounds receiver gross weight while flying at 110 KIAS and 6100 feet density altitude. A descending diagonal approach was made to the drogue from the observation to the contact position without decreasing power or stopping at the precontact position. This procedure provided satisfactory results and was easily accomplished. Using this procedure, if the receiver aircraft has sufficient power to maintain the left observation position, adequate power should be available to successfully engage the drogue and establish the refueling position. The simulated single-engine procedures and characteristics of the CH-47D AWC aerial refueling equipped helicopter were satisfactory.

IN-FLIGHT CLEARANCES

Rotor-to-Drogue Clearance

26. An in-flight evaluation of flight characteristics and rotor-to-probe clearance was performed at various airspeed and LCT positions. In-flight video was used to determine minimum rotor-to-probe clearance at airspeeds of 105, 110, and 120 KIAS and during dynamic maneuvers simulating movement from precontact to contact. The radius of the drogue was subtracted from the rotor-to-probe clearance to calculate the rotor-to-drogue clearance. Data was recorded with both forward and aft LCT's in manual position programmed at the test refueling airspeed, with the aft LCT at the programmed airspeed while the forward LCT was retracted to the ground (GND) position, and with the aft LCT at the programmed airspeed while the forward LCT was in

the fully extended position. Light gross weight represents worst case (minimum rotor-to-drogue clearance) due to less blade coning. The data is presented in table 2. Calculated rotor-to-drogue clearance was generally greatest with the forward LCT retracted to the GND position. The minimum clearance observed with the LCT's programmed at the aerial refueling airspeed was 6.7 feet. Although more clearance existed with the forward LCT retracted to GND, the potential for forward rotor droop stop contact becomes greater in this position as altitude increases. Additionally, aircraft vibrations were one VRS higher with the forward LCT retracted to the GND position (VRS 4 versus VRS 3) than with the forward LCT programmed at the refueling airspeed. Flight characteristics and probe-to-drogue clearance with the LCT's in the manual position programmed at the refueling airspeed were satisfactory.

Receiver-to-Tanker Clearance

27. Receiver-to-tanker clearance was determined while performing refueling maneuvers. A laser distance measurement system was used from the ramp of the KC-130R to measure distances to a specific point on the CH-47D AWC fuselage. The distance was then calculated from the forward rotor of the CH-47D AWC to the horizontal tail of the KC-130R. This distance represents the approximate minimum distance between the receiver and tanker during refueling operations. A more detailed explanation of how the data was obtained is in appendix D. Minimum distances were determined at the precontact position, contact position (refueling probe inside the refueling drogue), refueling position, and while moving from the contact to refueling position. Also, the minimum distance was determined while maintaining minimum refueling hose length (56 feet of refueling hose extended from the refueling pod) and descending to the disconnect position. Movement to the disconnect position at minimum hose length (56 feet) represents worst case minimum acceptable aerial refueling procedures. Minimum distances while performing aerial refueling maneuvers behind the left and right refueling drogues are presented in table 3.

Table 2. Rotor-to-Drogue Clearance Calculations¹

Forward LCT Position	Airspeed KIAS	Calculated Rotor-to-Drogue Clearance-Static ² (feet)	Calculated Rotor-to-Drogue Clearance-Dynamic ³ (feet)
GND	105	7.58	9.28
GND	110	9.96	9.45
GND	120	9.56	8.21
Trim	105	6.70	6.81
Trim	110	7.14	7.06
Trim	120	6.74	6.74
Fully Extended	105	6.22	6.84
Fully Extended	110	6.85	7.01
Fully Extended	120	7.37	9.75

NOTES:

- ¹Clearances obtained by analysis of video data using known dimensions.
Aft longitudinal cyclic trim (LCT) actuator in manual and programmed at the test airspeed and altitude, 6000 feet pressure altitude, 100% rotor speed, 31,310 pounds average gross weight, 317.9 average center of gravity, non-turbulent air.
- ²Static refers to a stable point at the test airspeed.
- ³Dynamic refers to simulated movement from the precontact to the contact position at the test airspeed.

Table 3. Clearance Between Receiver Forward Rotor and Tanker Horizontal Tail (feet)

Receiver Position	Left Drogue Operations	Right Drogue Operations
Precontact	62.5	53.5
Contact	46.5	41.5
Refueling	35.5	28.5
Moving from Contact to Refueling	34.5	29.5
Moving from Refueling to Disconnect at 56 foot Hose Length (worst case)	31.5	20.5

Receiver-to-tanker clearances are less when performing refueling operations on the right drogue as opposed to the left since the refueling probe is mounted on the right side of the receiver. The minimum clearance observed while operating behind the left drogue was 31.5 feet while the minimum behind the right drogue was 20.5. The minimum clearances occurred while moving from the refueling to the disconnect position while maintaining a 56 foot refueling hose length. Typically the refueling hose should be at mid refueling range (66 feet) or greater while moving to disconnect which provides additional clearance. CH-47D AWC clearance to C-130 tanker aircraft while performing aerial refueling operations behind the left and right refueling drogues was satisfactory.

STRUCTURAL DYNAMICS

Vibrations

28. The CH-47D AWC cockpit vibrations were evaluated in level flight, non-turbulent air conditions as described in appendix D. Cockpit vibrations were evaluated with the refueling probe installed and with the probe removed and were compared to vibration data from a previous report on the CH-47D (ref 10). Data are presented in figures E-3 through E-7. There were small changes in cockpit vibration levels with the removal/installation of the refueling probe but the changes were not perceived by the pilot. With the probe installed, vertical and lateral vibrations at the 3/rev and 6/rev frequencies between approximately 80 and 125 knots calibrated airspeed (KCAS) were slightly higher than with the probe removed. The CH-47D AWC vibration levels with the probe installed or removed were generally higher than those in the CH-47D. The vibrations were objectionable above 140 KCAS in the CH-47D (ref 10) and remain objectionable in the CH-47D AWC above 140 KCAS. These vibrations could become fatiguing to the flight crew if endured over an extended period of time. There are several

configuration differences between the CH-47D AWC and the CH-47D that could account for the change in cockpit vibration levels. Among these are the additional weight and structure for the AWC cockpit modification and the structural modifications at FS 95 and FS 160 for the aerial refueling probe installation. Cockpit vibration levels in the CH-47D AWC above approximately 140 KCAS were objectionable and remain a shortcoming.

29. Cockpit vibration levels in the refueling environment were generally higher than those in stabilized level flight and varied as a function of position relative to the tanker aircraft and the maneuvering conducted behind the tanker. The frequent changes of power setting required to maintain position and to maneuver caused the rotor rpm to change and resulted in the detuning of the pilot or copilot vibration absorbers. In smooth air conditions, vibrations were typically VRS 5 in the precontact position and decreased to VRS 4 in the refueling position. Vibration levels increased in turbulent air conditions due to increased difficulty in maintaining position, the larger and more frequent power changes and the increased buffeting in the tanker wake. The cockpit vibration levels of the CH-47D AWC in the refueling environment did not affect the ability of the crew to perform refueling tasks and were satisfactory.

Structural Loads

30. Probe bending moments and support strut loads (FS 95) were measured during refueling operations. The probe bending moments were used to derive tip loads as described in appendix D. Values for nominal and peak loads observed during refueling operations are shown in table 4 along with design allowable loads and flight test limits. Loads in turbulent air were generally higher than those in smooth air but did not approach any test limitations. All loads were typically highest just after contact while moving to the refueling position. The highest tip load measured during the evaluation was 810 pounds (radially downward to the left) and occurred during flight in moderate turbulence while moving from right drugue contact to the right refueling position. The highest support strut load measured was a 2500 pounds compression force on the lower strut and occurred during the same maneuver as the peak tip load. A time history plot of this maneuver is shown in figure E-8. Off-center disconnects were conducted intentionally to evaluate probe and support loads for out-of-position conditions. These out-of-position conditions generally did not result in bending moments or tip loads higher than those in the refueling position but the disconnect was characterized by greater than normal probe tip oscillations. The highest tip load measured during the off-center disconnects was 400 pounds and occurred when the test aircraft was approximately 10 feet high and outboard of the normal disconnect position. This is an off-center disconnect from the normal refueling position as if the pilot had allowed the tanker to pull away from the receiver. A time history plot of an off-center disconnect is shown in figure E-9. The structural loads observed during refueling operations were all well below flight test limits and were acceptable.

31. Cruise Guide Indicator (CGI) levels are a function of gross weight, cg, airspeed, density altitude and air turbulence. Refueling operations during this evaluation were conducted primarily at 110 KIAS and between 4000 feet and 6000 feet density altitude. A significant effect on CGI levels was evident when the remaining variables were changed. In non-turbulent air, at approximately 31,000 pounds gross weight and with the cg at

Table 4. Structural Loads During Refueling Operations

Parameter	Nominal Load ¹ In Non-Turbulent Air	Nominal Load ¹ in Turbulent Air	Highest Load ² Measured	Flight Test Limit	Ultimate Load ³
Tip Load (lb) ⁴	330	395	810	2250	5445 ⁵
Probe Vertical Bending Moment (in-lb)	70,000 Downward	80,000 Downward	120,000 Downward	None	1,515,000 ⁶
Probe Lateral Bending Moment (in-lb)	60,000 ⁶	75,000 ⁶	200,000 left	None	1,515,000 ⁶
Support Struts at FS 95 (lb)	1000	1200	2500 compression lower strut	15,000	Tension: 24470 (all) Compression: 25,060 (upper and lower), 36,810 (upper middle and lower middle)

NOTES:

- ¹Nominal loads represent an average of the highest loads that occurred during each maneuver. Loads were typically highest at contact or during the move to refueling position.
- ²Highest individual loads did not necessarily occur at the same time.
- ³Ultimate loads represent either an actual value at time of failure or the value for a margin of safety of zero (based on BH stress analysis).
- ⁴Derived from probe bending moments.
- ⁵Static load test failure point. Fragile fitting rated at 2500 lb should preclude loads of this magnitude.
- ⁶Lateral probe bending moments were to the left when operating on right drogue and to the right when operating on left drogue.

FS 317, CGI levels were nominally 40 percent in the observation position and 50 percent in the precontact position. During the run-in (from precontact to contact) and translation to refueling position, CGI level generally increased to 90 percent with occasional spikes to 120 percent. The CGI level would decrease to approximately 50 percent when stabilized in the refueling position. During flight in turbulent air at 48,000 pounds with the cg at FS 329, CGI levels were approximately 50 percent in the observation position and 60 to 70 percent in the precontact and refueling positions. During the run-in and translation to refueling position, CGI spikes to 120 percent were typical and occasional spikes to 160 percent occurred. BH conducted refueling operations in non-turbulent air at 33,580 pounds, with the cg at FS 317.9, at 11,380 feet density altitude to demonstrate the ability to refuel at higher altitudes. CGI levels were approximately 50 percent in the observation position and 80 percent in the precontact and refueling positions. During the run-in and translation to refueling position, CGI spikes to 100 percent were typical and occasional spikes to 125 percent occurred. During the tanker-proximity wake turbulence evaluation (para 17), CGI levels increased as the test aircraft descended to below the wings of the HC-130P. At approximately 36,000 pounds while in the wake turbulence, the CGI levels were typically 60 to 90 percent and spiked up to 100 percent. At 48,000 pounds in turbulent air, CGI levels were typically above 100 percent and occasionally exceeded 200 percent. Although CGI levels were high while maneuvering or while out of position (too far behind or below the tanker) in the refueling environment they did subside when stabilized in any of the normal refueling positions and were acceptable.

HUMAN FACTORS

Aerial Refueling Lights Control Panel

32. Operation of the aerial refueling lights control panel (figs. B-16, B-17 and para 11, app B) was evaluated on the ground in a darkened hangar and in-flight during night visual meteorological conditions (VMC) both unaided (white lights) and aided (NVG using white lights or IR filters). The panel allowed the pilot who was not manipulating the flight controls to control the function of both the refueling probe light and refueling searchlight. Light level control was also provided for both lights through the use of brightness increase/decrease momentary switches. Each time that either light filament switch was cycled to the OFF position and turned back ON, the affected light would again operate at full intensity regardless of the previous level. Since the filament and light level switches were adjacent to each other and of similar shape, it was extremely easy to inadvertently actuate the bulb filament causing the light to return to full bright. This was annoying to the flight crew particularly when conducting NVG refueling operations. If the searchlight is pointed too close to the tanker fuselage, full bright illumination will temporarily blind the C-130 scanner and force delay of refueling operations until his vision is adequately restored. Activation of these lights to full bright also increases the chance of detection by threat land and air forces. The inability to select anything other than full bright on the refueling probe light and refueling searchlight during initial filament activation is a shortcoming and should be corrected prior to operational deployment.

Cabin Aerial Refueling Control Panel

33. Operation of the cabin aerial refueling control panel (figs. B-11, B-12 and para 6, app B) was evaluated during aerial refueling test flights in day and night VMC. Night operations included use while wearing NVG and with unaided vision. Switches and indicator lights were well organized on the panel. All required functions for aerial refueling of the six standard aircraft fuel tanks were available on the one centrally located panel. Automatic and manually terminated refueling operations were easily conducted with logical switch manipulations. The operation of the cabin aerial refueling control panel was satisfactory.

Night Lighting Evaluation

Control Panels

34. The refueling light panel (fig. B-16) and cabin aerial refueling control panel (fig. B-11) were evaluated for night lighting characteristics during night VMC flights while performing the aerial refueling mission. The evaluation was conducted with the crew using NVG and with unaided vision. The aerial refueling lighting system control panel was well lighted, NVG compatible, and was dimmable through the same circuit which controlled the other lower console equipment lighting. No windscreen glare was observed by either pilot which could be attributed to this panel lighting. Although none of the lighting on the cabin aerial refueling control panel, except the press-to-test lights, could be dimmed, it was NVG compatible and no operational difficulties were noted. The NVG and unaided night lighting characteristics of the cabin aerial refueling control panel and aerial refueling lighting system control panel were satisfactory.

Aerial Refueling Lighting System

35. The aerial refueling lighting system was evaluated for night lighting characteristics during night VMC flight while performing aerial refueling tasks. The evaluation was conducted with the crew using NVG and with unaided vision. The refueling lighting system (paras 8 through 11, app B) consisted of a fixed probe illumination light and a movable searchlight, both mounted on the forward portion of the forward transmission cowling (fig. B-15). The installation of this system was required due to the limited up travel of the standard aircraft searchlights, and beam masking of the tanker caused by the refueling probe, Forward Looking Infrared (FLIR) pod and AN/APN-209 standoff mounts. The refueling probe light adequately illuminated the probe tip and drogue during all night conditions tested. The probe light was dimmable with sufficient light level control to conduct unaided vision or NVG aerial refueling operations. The dimming feature and area of illumination were equally acceptable when the probe light was IR filtered. The movable refueling searchlight could be moved through sufficient ranges of elevation and azimuth to illuminate key features of the tanker in the observation, precontact, refueling and disconnect station keeping positions. Light levels were attainable, through the dimming feature, to adequately illuminate tanker references when performing aerial refueling tasks whether using unaided vision or NVG. When using NVG and an IR filtered searchlight beam, adequate brightness control was also attainable. Sufficiently low white light intensities were available to conduct NVG refueling operations

without installing the IR filters on either the probe light or refueling searchlight. The white light intensities were so low during these operations that observers on the C-130 tanker could not see the lights without the aid of NVG. The ability to control the light intensities over this wide range enables the crew to conduct either unaided or NVG aided aerial refueling tasks without configuring the lights with IR filters (approximately 2 manhours required). These lights were also usable during normal landing and ground operations and provided excellent illumination of areas poorly lit by the standard aircraft searchlights due to shadows from the FLIR pod, AN/APN-209 standoffs and the refueling probe. The aerial refueling lighting system is an enhancing characteristic for the conduct of night aerial refueling operations and should be incorporated in future designs.

RELIABILITY AND MAINTAINABILITY

Fuel Transfer System Check Valves

36. Operation of the aircraft fuel system was evaluated throughout these tests. Two check valves that prevent uneven transfer in the standard CH-47D fuel system were removed for the aerial refueling system modification. They were not included because designers felt that the adjacent fuel flow transducers would act as check valves. Uneven fuel transfer was observed on several of the early envelope expansion flights. The proposed solution for this problem was to modify the manifolding and incorporate the check valves (identified as left and right main tank refuel check valves shown in fig. B-9). These check valves and manifolds had to be manufactured and were unavailable for most of these tests. Continued flight test was possible only by electrically closing the gate valves adjacent to these check valves using the cabin aerial refueling control panel. Shortly after the completion of the in-flight refueling tests, the final check valve assemblies were available and were installed during the final probe-off performance flight. Normal fuel transfer was observed during this flight. No adverse effects were noted in refueling system surge pressures due to the check valve installation. Within the limited scope of this evaluation, the fuel transfer system check valves functioned satisfactorily.

Fuel Flow Transducers

37. The operation of the aerial refueling system fuel flow transducers was observed throughout these tests. These transducers (fig. B-9) were installed to provide the refueling operator a positive indication of flow to the individual fuel system tanks and to verify proper operation of the high level shutoff valves. Throughout these tests, the right forward auxiliary and left main fuel flow transducer lights remained illuminated during the primary and secondary fuel shutoff tests. Both valves were replaced, but the left main transducer continued to provide false flow indications. The left main tank transducer was replaced once again and still malfunctioned. These erroneous indications force the operator to assume a high level refuel valve failure and manually override the automatic shutoff system at a lower than filled level (approximately 650 pounds for auxiliary and 1600 pounds for main tanks) to preclude potential fuel tank overpressurization. The poor reliability of the aerial refueling flow transducers is a shortcoming and should be corrected prior to operational deployment of this system.

Single-Point Ground Refueling

38. Single-point ground refueling operations were performed and evaluated throughout these tests. During these ground refueling operations, ground external power was always applied to the aircraft to power the special instrumentation package. Upon completion of the program, the aircraft was deinstrumented and flown back to the user unit home station. Single-point refuel operations were attempted at the first fuel stop on the cross-country flight using standard operator's manual procedures. Power to operate the external single-point refueling panel was not available until the battery switch was placed to the ON position. This is not a normal requirement on CH-47D or CH-47D AWC aircraft. Placing the battery switch to the ON position in the CH-47D AWC aircraft applies power to many of the installed communication/navigation radios and display units. This drain on the battery during single-point ground refueling operations will exceed stored DC power capabilities quickly. During the period of unit pilot aerial refueling training at Marine Corps Air Station El Toro the aircraft battery became discharged resulting in the loss of one day availability while the battery was being deep cycled and recharged. Provisions must be made to perform ground single-point refueling operations without the necessity for energizing the entire group of DC powered equipment controlled by the battery switch. The requirement to have the aircraft battery switch ON in order to single-point refuel on the ground is a deficiency and must be corrected immediately.

AERIAL REFUELING SYSTEM TESTS

General

39. BH conducted several tests to verify that the design, fabrication and installation efforts had produced a refueling system that would operate safely and efficiently. These tests were witnessed and/or the resulting data was evaluated by AEFA personnel. The results of the static structural test and the loads observed during the refueling operations (para 30) indicated that the structural integrity of the probe and external support hardware was adequate. The natural frequencies of the probe installation were determined and were adequately separated from the primary harmonics of the rotor system. The aircraft was refueled through the probe from a fuel truck, a Marine Corps KC-130T tanker and an Air Force HC-130P tanker to verify system operation and compatibility with the tanker aircraft. Flow rates of up to 240 gallons per minute (gpm) were measured while refueling from the KC-130T and up to 155 gpm while refueling from the HC-130P. A maximum allowable surge pressure of 180 pounds per square inch (psi) (as stated in MIL-F-38363, ref 8) was part of the design criteria. Surge pressures during flow stoppage were below 180 psi and were satisfactory. The ground refueling station and aerial refueling control panels functioned properly with one exception: two flow lights (aerial refueling panel) remained on after flow had been confirmed stopped. The minimum blade-to-probe clearance was measured at 16.5 inches. The Army intends to utilize the CH-47D AWC with the probe removed. The removal of the probe and the installation of the hose fitting at FS 160 amount to a change in weight of 280 pounds at FS -17.1. The weight of the entire refueling modification was calculated to be 457 pounds at FS 28.6 and BL 26.4 right. An electromagnetic interference (EMI)

check and probe grounding check were conducted. No EMI was observed and the refueling probe was properly bonded to the airframe.

Static Structural Test

40. BH conducted a static structural test to verify that the probe and external support hardware met or exceeded the design ultimate loads. The frangible fitting designed to break at 2500 pounds normally located at the tip was removed for this test. The probe and external support hardware were mounted on a fixture and a downward load was applied incrementally to the tip until failure of the probe occurred. The probe yielded at approximately 30 inches forward of the support ring located at FS 95. The tip load at the time of failure was 5,445 pounds and the deflection of the tip was 31.5 inches. The external support hardware did not incur any damage during this test. This test was conducted at room temperature conditions, but the strength of the probe will vary with the ambient temperature and relative humidity. A stress analysis conducted by BH concluded that to account for the hot/wet (180 degrees Fahrenheit and 100 percent relative humidity) design conditions, the minimum acceptable failure for a probe tested at room temperature conditions would be 4875 pounds. The results of this test and the loads observed during refueling operations (para 30) indicate that the structural integrity of the probe and external support hardware was adequate.

Natural Frequency Response Tests

41. Accelerometers were mounted near the end of the probe and were used to determine the natural frequency of the probe in the vertical and lateral axes. Natural frequency response tests were conducted on the ground both with and without fuel in the probe fuel transfer tube. The natural frequencies of the probe with fuel in the tube were 4.4 hertz (Hz) vertically and 4.6 Hz laterally. The natural frequencies of the probe with no fuel in the tube were 4.7 Hz vertically and 5.0 Hz laterally. The 1/rev and 3/rev frequencies of the rotor system are 3.75 Hz and 11.25 Hz at 100 percent rotor speed. The natural frequencies of the probe installation were not on or near any of the primary harmonic frequencies of the rotor system.

Functional Tests

42. Initial ground refueling tests were done with a fuel truck to verify system operation and to check for leaks. Refueling through the standard CH-47D single-point connection at a fuel truck pressure of 33 psi resulted in flow rates of up to 168 gpm. Refueling through the probe nozzle at a fuel truck pressure of 35 psi resulted in a flow rate of 150 gpm. Flow rates while refueling from a fuel truck through the single-point connection were satisfactory.

43. The aircraft was also refueled on the ground through the probe nozzle to verify system compatibility with the U.S. Marine Corps KC-130T and the U.S. Air Force HC-130P tanker aircraft. The KC-130T was included in this evaluation because it's fuel transfer system is capable of operating at higher pressures and flow rates than the HC-130P. The CH-47D AWC was positioned behind the tanker aircraft on the ramp and the refueling drogue was reeled out and connected manually to the probe nozzle. Fuel system pressures were monitored and aerial refueling system functions were operated at

the cabin refueling panel during fuel transfer. The initial tests conducted with the KC-130T resulted in surge pressures in the CH-47D fuel system of up to 225 psi when the precheck switch on the cabin refueling panel was placed in the ALL OFF position. These surge pressures were considered unacceptably high so plans were made to modify the panel wiring and the precheck switch. The intended modification was to change the precheck switch function from a simultaneous closing of all shut-off valves to a separate closing of primary shut-off valves and secondary shut-off valves. The primary/secondary shut-off switch on the ground refueling panel was used on subsequent tests with the KC-130T to evaluate operations with the intended modification of the cabin panel precheck switch. Surge pressures during operation of primary and secondary shut-off valves were reduced to 135 psi and 115 psi, respectively. The highest surge pressure measured during closure of the individual gate valves was 175 psi at the probe-hose outlet. A fuel pressure of 53 psi measured at the tanker resulted in the maximum flow rate of 240 gpm with fuel flowing to all tanks. Flow was allowed to continue until the high-level shut-off valves in each individual tank had closed automatically. The highest surge pressure measured during automatic shut-off was 155 psi at the inlet to the left main fuel tank and occurred as the last tank (left main) filled and flow was stopped. Flow rates and surge pressures while refueling from the KC-130T were satisfactory.

44. Ground refueling tests with the U.S. Air Force HC-130P were conducted with the cabin panel precheck modification incorporated. Surge pressures and flow rates were generally lower when refueling with the HC-130P because of the lower operating pressure of the HC-130P fuel transfer system. The highest surge pressure measured during the precheck was 80 psi when the secondary shut-off valves were closed. A fuel pressure of 37 psi measured at the tanker resulted in a flow rate of 155 gpm with fuel flowing to all tanks. The highest surge pressure measured during closure of the individual gate valves was 150 psi at the probe-hose outlet. The highest surge pressure measured during automatic shut-off was 150 psi at the crossfeed and occurred as the last tank (left main) filled and flow was stopped. Flow rates and surge pressures while refueling from the HC-130P were satisfactory.

45. Two check valves were installed in the system subsequent to the functional tests to correct a problem with uneven fuel transfer during flight (para 36). Because the additional manifolds and valves could potentially alter the characteristics of the fuel system during refueling, another ground functional test was conducted. The aircraft was refueled on the ground through the probe and surge pressures and flow rates were found to be similar to those observed during earlier testing without the check valves. After modification of the precheck switch and installation of the check valves the refueling surge pressures were acceptable and the flow rates were satisfactory.

46. A ground functional test was conducted to verify that the jet pumps would evacuate the fuel that remains in the probe, probe hose, crossfeed line and fuel manifolds after refueling through the probe. A total of up to 4.5 gallons can be contained in these areas after refueling. The aircraft was refueled through the probe, the boost pumps were activated and the resultant fuel flow was observed through clear plastic tubing that was installed for this test. After approximately 12 minutes, the fuel was completely evacuated from these areas.

47. The various functions at the ground refueling station panel and the aerial refueling cabin panel were operated throughout the functional tests. The only problem observed was that the left main tank and right forward auxiliary tank flow lights remained on after fuel flow had been confirmed stopped (para 37). This condition remained a problem throughout the entire evaluation.

Static Blade-to-Probe Clearance

48. Measurements were taken on the ground with the rotor blades stopped to determine the minimum vertical clearance between the rotor blades and the probe nozzle. The clearances were a function of forward longitudinal cyclic trim actuator position, cockpit flight controls position, and whether hydraulics were ON and OFF. Results are presented in table 5. The minimum clearance was 16.5 inches and occurred with hydraulics OFF, the forward LCT fully extended, the collective in ground detent, the longitudinal cyclic full forward and the lateral cyclic and directional controls full left. The static blade-to-probe clearance of the CH-47D AWC with the refueling probe installed was satisfactory.

Weight and Balance

49. The refueling probe and external support hardware are removable and the Army intends to utilize the CH-47D AWC with the probe removed. The probe and support hardware were weighed to determine the change in weight and cg for the two configurations. The removable items include the probe, the support ring and the four support struts at FS 95, and the outer half of the support ring at FS 160. The aerial refueling hose (fig. B-8) that extends on the underside of the aircraft from the aft end of the probe to just below the right side dry bay will remain installed. During operation with the probe removed, the forward end of this hose, normally attached to the probe, will be secured to a fitting that replaces the outer half of the support ring at FS 160. The removal of the probe and the installation of the hose fitting at FS 160 amount to a change in weight of 280 pounds at FS -17.1. The weight and cg of the entire aerial refueling modifications was determined using the weight and cg for each component or subsystem. Based on the actual weight of the probe and support hardware and the actual and estimated weights (BH estimation) of additional components, the weight of the aerial refueling system was calculated to be 457 pounds at FS 28.6 and BL 26.4 right.

Electromagnetic Compatibility/Radio Frequency Interference

50. The aerial refueling system was tested for EMI with standard aircraft electrical systems to include communications and navigation systems. No EMI was found to be present during ground or in-flight tests.

Refueling Probe Grounding

51. A refueling probe grounding check was conducted to verify that the probe was properly bonded to the airframe. An ohm-meter was used to measure the continuity between probe nozzle and the probe fuel transfer tube and between the probe nozzle and probe attachment fittings. Electrical resistance was less than one ohm in each case, indicating that the probe was properly bonded to the airframe.

Table 5. Static Blade-to-Probe Clearance

Forward Longitudinal Cyclic Trim Actuator Position	Cockpit Flight Control Position				Hydraulics	Clearance (inches)
	Thrust Control	Longitudinal Cyclic Control	Lateral Cyclic Control	Directional Control		
Ground	Ground Detent	Neutral	Neutral	Neutral	ON	42.5
Full Extend	Ground Detent	Neutral	Neutral	Neutral	ON	41.0
Full Extend	Ground Detent	Full Forward	Full Left	Full Left	ON	20.0
Full Extend	Full Down	Full Forward	Full Left	Full Left	ON	18.8
Ground	Ground Detent	Neutral	Neutral	Neutral	OFF	35.5
Full Extend	Ground Detent	Neutral	Neutral	Neutral	OFF	33.0
Full Extend	Ground Detent	Full Forward	Full Left	Full Left	OFF	16.5

MISCELLANEOUS

Design Considerations For Pressure Refuelable Internal Fuel Tanks

52. The CH-47D aerial refueling system which was developed over the past three years and was tested during this evaluation incorporated many safety/design features that minimize the risks associated with aerial refueling operations. In order to be consistent with the safety/design features incorporated in the production CH-47D AWC aerial refueling system thus far tested, any internal tank aerial refuelable system design should include as a minimum the following features.

a. A check valve system that will prevent internal fuel tanks from continuously filling the crossfeed refuel transfer tube and/or allowing unbalanced fuel transfer between the left and right side aircraft fuel systems.

b. An external vent system for the internal tanks which will prevent fuel or fuel vapors from venting into or near the engine air inlets or being drawn by air flow through the cargo ramp into the cabin area.

c. An automatic high level pressure refuel shutoff system which is redundant and can be prechecked during the initial aerial refueling process.

d. A fuel level indication to provide the crew with backup manual high level pressure refuel shutoff information and the ability to accurately monitor in-flight transfer of the internal fuel.

e. A fuel dump system, as provided in other aerial refuelable helicopters, that allows the crew to rapidly reduce gross weight thereby providing limited range single-engine capability.

Forward Looking Infrared/Aerial Refueling Probe Interface

53. The CH-47D AWC aircraft modified with the aerial refueling system also incorporates a FLIR system mounted beneath the nose to the left of the refueling probe. The FLIR image is displayed on two screens in the cockpit, one on the pilot's console and one on the copilot's console. The FLIR optics are controlled from the cockpit by either the pilot or copilot and are capable of viewing 360 degrees in the horizontal plane and 218 degrees in the vertical plane. The system has a wide and narrow field of view and a "look ahead" feature which aligns the optics with the aircraft longitudinal axis at a preset elevation. The system also has an automatic tracking feature which enables the optics to automatically track an object that has an infrared signature which contrasts with its surroundings.

54. When operating the FLIR in the "look ahead" mode in the wide field of view, the tip of the refueling probe is 13 degrees right of the center of the screen. The tip of the probe is not visible if the FLIR optics are slewed 11 degrees left of the aircraft longitudinal axis. Approximately 25 percent of the screen is obscured when looking 90 degrees right of the aircraft longitudinal axis. In the "look ahead" mode in the narrow field of view the probe is not visible. The FLIR can be slewed 10 degrees right of the

aircraft longitudinal axis before the tip of the refueling probe is visible on the right side of the screen. When looking 90 degrees right of the aircraft longitudinal axis, the probe image fills the entire screen. The automatic tracking feature was used to track a moving object while the aircraft was at a hover. As the aircraft was turned, the refueling probe came between the object and the FLIR optics causing the automatic tracking feature to lose lock and discontinue tracking the object. The impact during a mission scenario of the FLIR's obstructed field of view and disengagement of the automatic tracking feature due to refueling probe interference must be determined by the operational unit. The following NOTE should be placed in the forthcoming CH-47D AWC Aerial Refueling System Operator's Manual Supplement to be published by Boeing Helicopters:

NOTE

The aerial refueling probe limits the FLIR right forward field of view and may cause the automatic track feature to lose lock if the FLIR line of sight is obstructed by the refueling probe.

CONCLUSIONS

GENERAL

55. The following conclusions were reached upon completion of this evaluation of the production CH-47D Adverse Weather Cockpit (AWC) aerial refueling system:

a. The CH-47D AWC helicopter incorporating the Boeing Helicopters aerial refueling system is suitable for day and night aerial refueling.

b. One enhancing characteristic, one deficiency relating to the electrical system, and three shortcomings were identified.

ENHANCING CHARACTERISTIC

56. The following enhancing characteristic of the CH-47D AWC production aerial refueling system was identified: The aerial refueling lighting system (para 35).

DEFICIENCY

57. The following deficiency of the CH-47D AWC production aerial refueling system was identified: The requirement to have the battery switch ON in order to single-point refuel on the ground (para 38).

SHORTCOMINGS

58. The following shortcomings of the CH-47D AWC production aerial refueling system were identified and are listed in decreasing order of relative importance:

a. The inability to select anything other than full bright on the refueling probe light and refueling searchlight during initial filament activation (para 32).

b. The poor reliability of the aerial refueling flow transducers (para 37).

c. Cockpit vibration levels in the CH-47D AWC above approximately 140 knots calibrated airspeed were objectionable (para 28).

RECOMMENDATIONS

59. The enhancing characteristic listed in paragraph 56 should be incorporated in future designs.
60. The deficiency in paragraph 57 must be corrected immediately.
61. The shortcomings listed in paragraph 58 should be corrected prior to operational deployment.
62. Performance data for the CH-47D Adverse Weather Cockpit (AWC) with the aerial refueling system, should be obtained using an instrumented aircraft including calibrated engines and measured rotor shaft torques (para 8).
63. The following CAUTION should be placed in the CH-47D AWC Aerial Refueling Procedures Supplement (para 10):

CAUTION

Care must be taken when ground handling aircraft equipped with the aerial refueling probe near obstacles or on uneven terrain to avoid contact and possible damage.

64. The Air Force T.O. 1-1C-1-20 and the CH-47D AWC Aerial Refueling Procedure Supplement should define the precontact position for the CH-47D AWC as follows: "The precontact position for the CH-47D AWC is the refueling probe laterally aligned with the refueling hose, probe tip positioned vertically with the center of the drogue, and 10 to 15 feet aft of the drogue" (para 15).
65. The user should be provided recommended gross weight versus altitude planning information for aerial refueling at the earliest possible time (para 19).
66. The C-130 tanker refueling pod light indication system should be altered when used in conjunction with night vision goggles (para 21).
67. The Air Force T.O. 1-1C-1-20 and the CH-47D AWC Aerial Refueling Procedures Supplement should include the following CAUTION (para 22):

CAUTION

Movement from the refueling to the disconnect position when performing non-responsive hose refueling operations must be performed slowly to minimize the tendency for the hose and drogue to snap upward at disconnect.

68. Internal tank aerial refuelable system design should include as a minimum the following features (para 52):
 - a. A check valve system that will prevent internal fuel tanks from continuously filling the crossfeed refuel transfer tube and/or allowing unbalanced fuel transfer between the left and right side aircraft fuel systems.

b. An external vent system for the internal tanks which will prevent fuel or fuel vapors from venting into or near the engine air inlets or being drawn by air flow through the cargo ramp into the cabin area.

c. An automatic high level pressure refuel shutoff system which is redundant and can be prechecked during the initial aerial refueling process.

d. A fuel level indication to provide the crew with backup manual high level pressure refuel shutoff information and the ability to accurately monitor in-flight transfer of the internal fuel.

e. A fuel dump system, as provided in other aerial refuelable helicopters, that allows the crew to rapidly reduce gross weight thereby providing limited range single-engine capability.

69. The following NOTE should be placed in the forthcoming CH-47D AWC Aerial Refueling System Operator's Manual Supplement to be published by Boeing Helicopters (para 54):

NOTE

The aerial refueling probe limits the FLIR right forward field of view and may cause the automatic track feature to lose lock if the FLIR line of sight is obstructed by the refueling probe.

APPENDIX A. REFERENCES

1. Final Report, AEFA Project No. 85-09, *Aerial Refueling Evaluation of the CH-47D Helicopter*, August 1985.
2. Final Report, AEFA Project No. 86-18, *Aerial Refueling Evaluation of the CH-47D Helicopter, Phase II*, January 1987.
3. Letter, AMSAV-8, 25 November 1987, subject: Evaluation of the Production CH-47D Adverse Weather Cockpit (AWC) Aerial Refueling System.
4. Test Plan, AEFA Project No. 87-30, *Evaluation of the Production CH-47D Adverse Weather Cockpit (AWC) Aerial Refueling System*, April 1988.
5. Operator's Manual, TM 55-1520-240-10, *Army CH-47D Helicopter*, 10 November 1982 with change 18, 18 March 1988.
6. Letter, AMSAV-E, 14 June 1988 with Revision 2, 27 June 1988, subject: Airworthiness Release (AWR) for Flight Evaluation of the CH-47D Adverse Weather Capability (AWC) Helicopter S/N 82-23763, with Aerial Refueling System.
7. Military Specification, MIL-H-8501A, *Helicopter Flying and Ground Handling Qualities, General Requirements for*, amendment 1, 3 April 1962.
8. Military Specification, MIL-F-38363B (USAF), *Fuel System, Aircraft, General Specification for*, amendments 2 and 3, October 1981.
9. Flight Manual, T.O. 1-1C-1-20, United States Air Force, *Flight Crew Air Refueling Procedures, MC/HC-130, HH-3, and HH-53*, 1 May 1978, with change 7, 1 January 1986.
10. Final Report, AEFA Project No. 82-07, *Airworthiness and Flight Characteristics Test (A&FC) of the CH-47D Helicopter*, February 1984.
11. System Specification CH-47D, Rockwell International drawing number 687-9446-001.
12. AMC Pamphlet, AMCP 706-204, *Engineering Design Handbook, Helicopter Performance Testing*, August 1974.

APPENDIX B. DESCRIPTION

CH-47D ADVERSE WEATHER COCKPIT AERIAL REFUELING SYSTEM

1. The first production aerial refueling system for the CH-47D Adverse Weather Cockpit (AWC) was installed on aircraft S/N 82-23763. The modification included structural rework, installation of a refueling control panel and wiring, installation of aerial refueling lights, fuel system modifications, and installation of an aerial refueling probe. The system allows the six primary fuel tanks and any suitable internal ferry fuel tanks to be fueled in flight. A detailed description of the CH-47D may be found in the operator's manual (ref 5, app A). Additional modification details are provided in the System Specification CH-47D AWC (ref 11).

STRUCTURAL REWORK

2. Structural modifications to the fuselage were incorporated at fuselage station (FS) 95 and 160 (figs. B-1 and B-2). These modifications were necessary to provide adequate load bearing capability for the refueling probe attachment fittings. Additionally, mounting provisions were incorporated for the aerial refueling manifolds located in the forward landing gear dry bays.

AERIAL REFUELING PROBE

3. The aerial refueling probe is made of IMC graphite composite material and is 29 feet 7 inches long (fig. B-3). A detailed drawing of the probe is shown in figure B-4. The diameter and wall thickness are constant with layup comprised of 3 inch wide graphite tape. The mounting rings at FS 95 and 160 are filament wound onto the pre-cured graphite tube. Attachment hardware affixes the probe at FS 95 and 160 (fig. B-5) such that the probe centerline is at waterline -36.0 and right butline 57.75. FS 95 and 160 attachment hardware is shown in figures B-6 and B-7, respectively. The tip of refueling probe extends 16 feet 6 inches forward of the CH-47D AWC nose. Fuel is transferred through a two inch diameter aluminum tube, internally supported by "Dow Ethafoam" spacers, within the probe body. A standard MA2 nozzle is attached to the end of the probe with a frangible fitting designed to shear at 2500 pounds radial load. The frangible fitting incorporates a double flapper valve to stop fuel flow from both sides if the fitting shears. A hose, mounted externally to the lower fuselage of the helicopter, routes fuel into the right forward landing gear dry bay and connects to the existing pressure refueling system (fig. B-8). Copper grounding straps are bonded to the full length of the probe and connected directly to the airframe.

FUEL SYSTEM

Fuel Shut-off Valves and Flow Transducers

4. New gate valves and flow transducers have been added to the existing pressure refueling system (fig. B-9). Five gate valves have been installed, one for each of the main and forward auxiliary tanks and one for internal fuel tank installation. A flow transducer

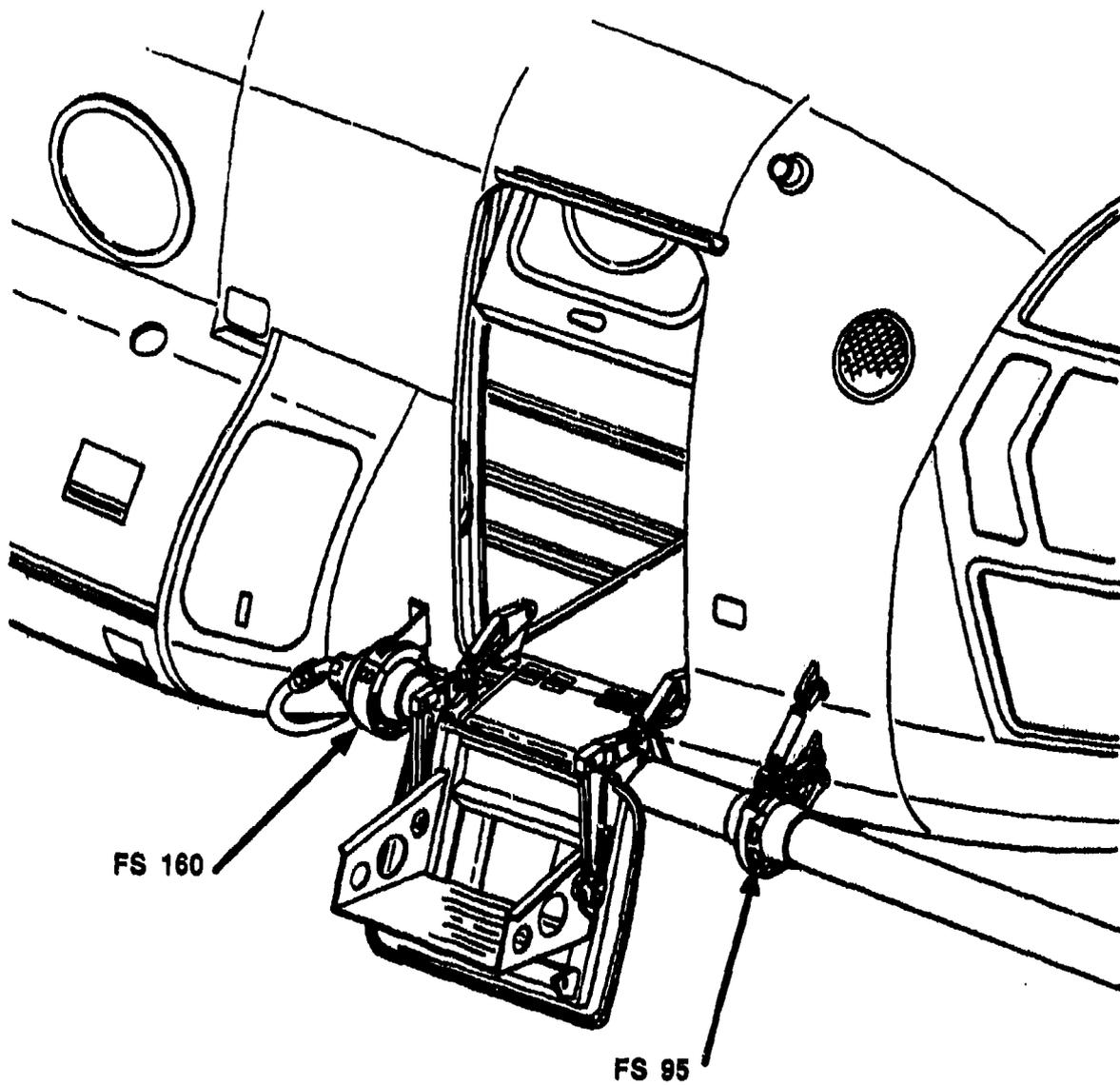


Figure B-1. Refueling Probe Attachment Points

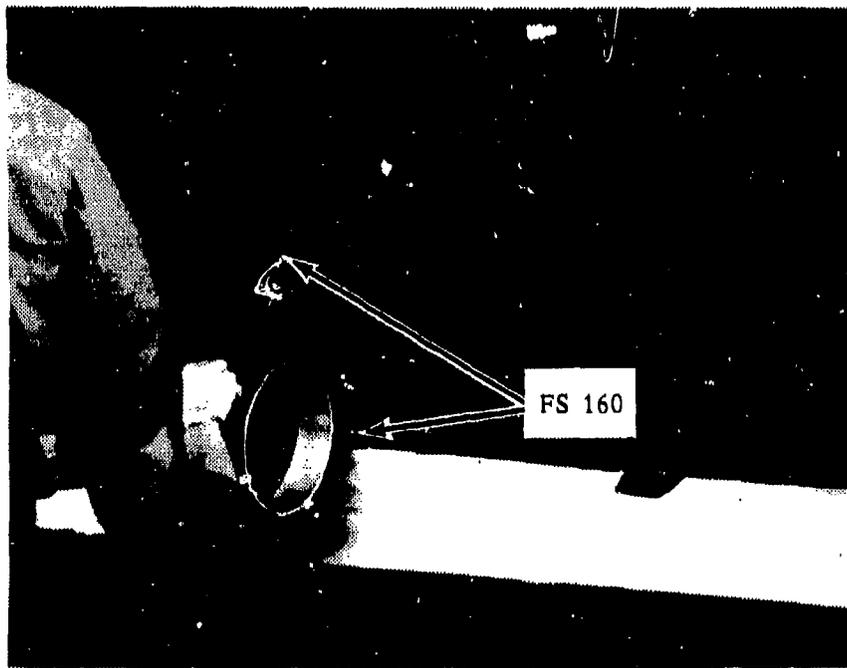
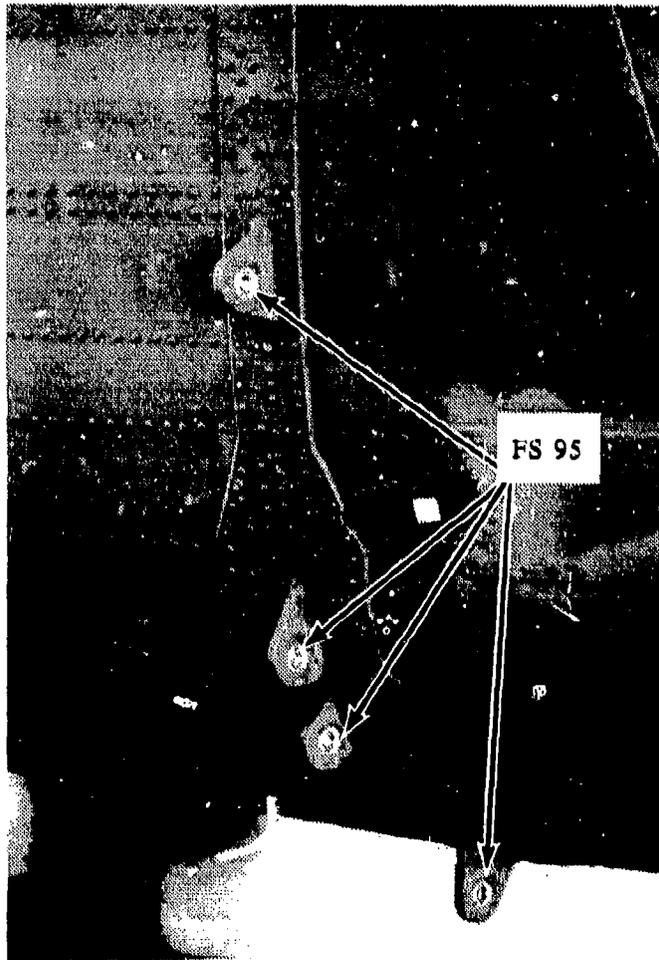
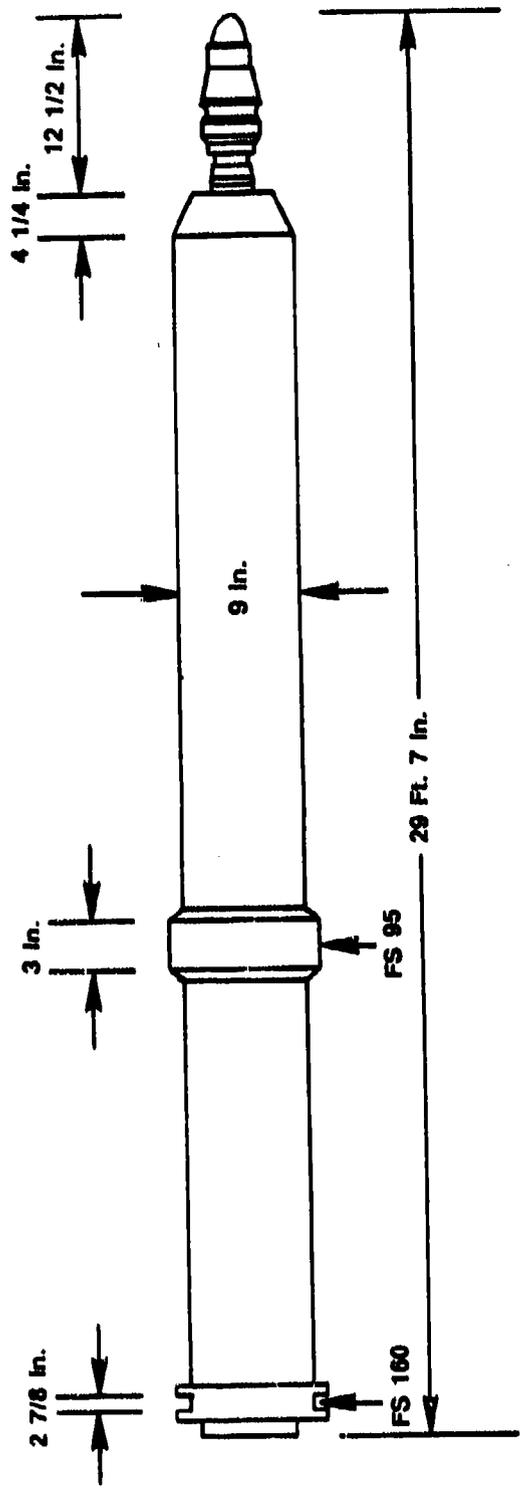


Figure B-2. Refueling Probe Attachment Points



Note: Not drawn to scale

Figure B-3. Aerial Refueling Probe Dimensions

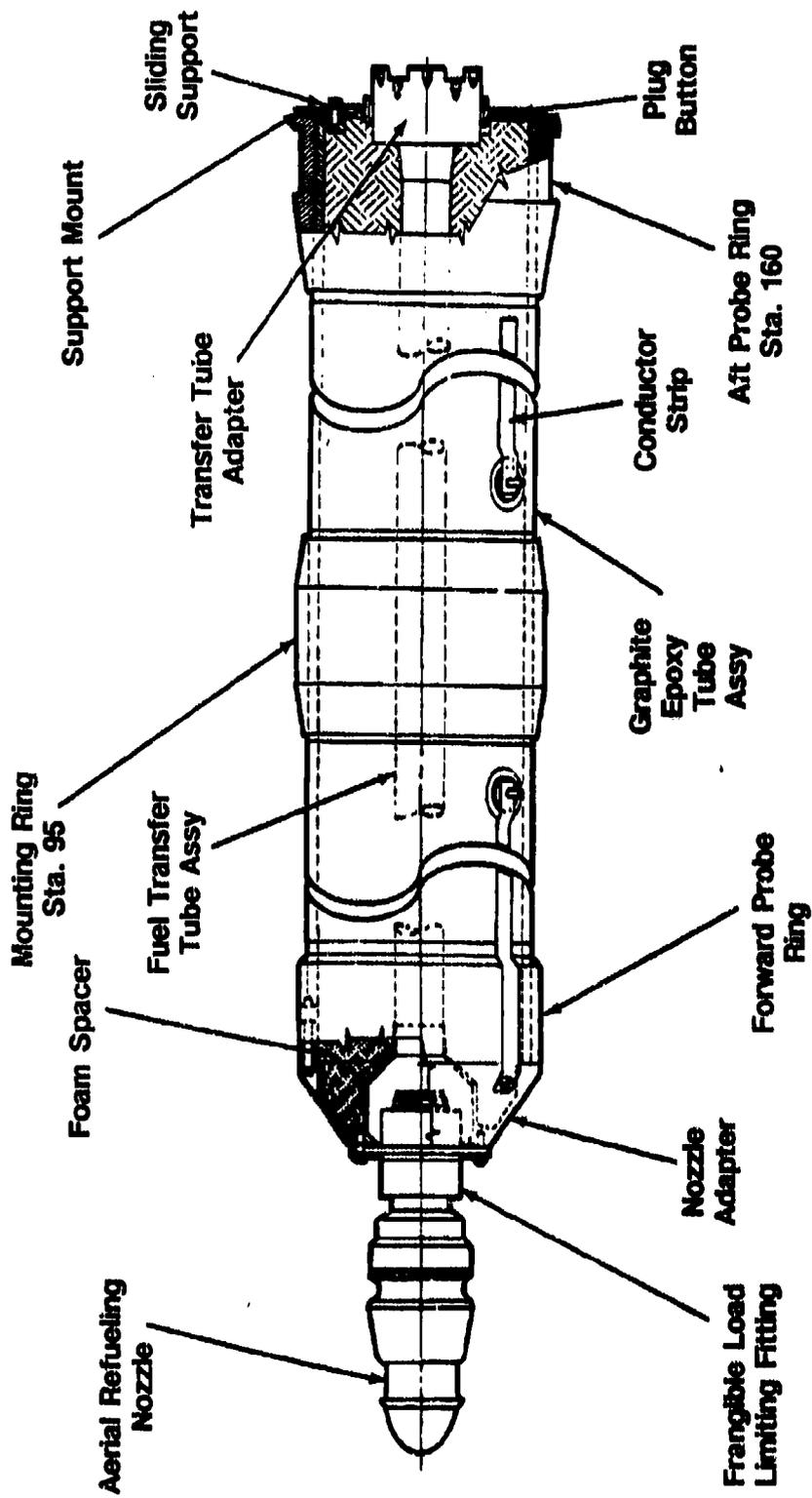


Figure B-4. Aerial Refueling Probe Schematic

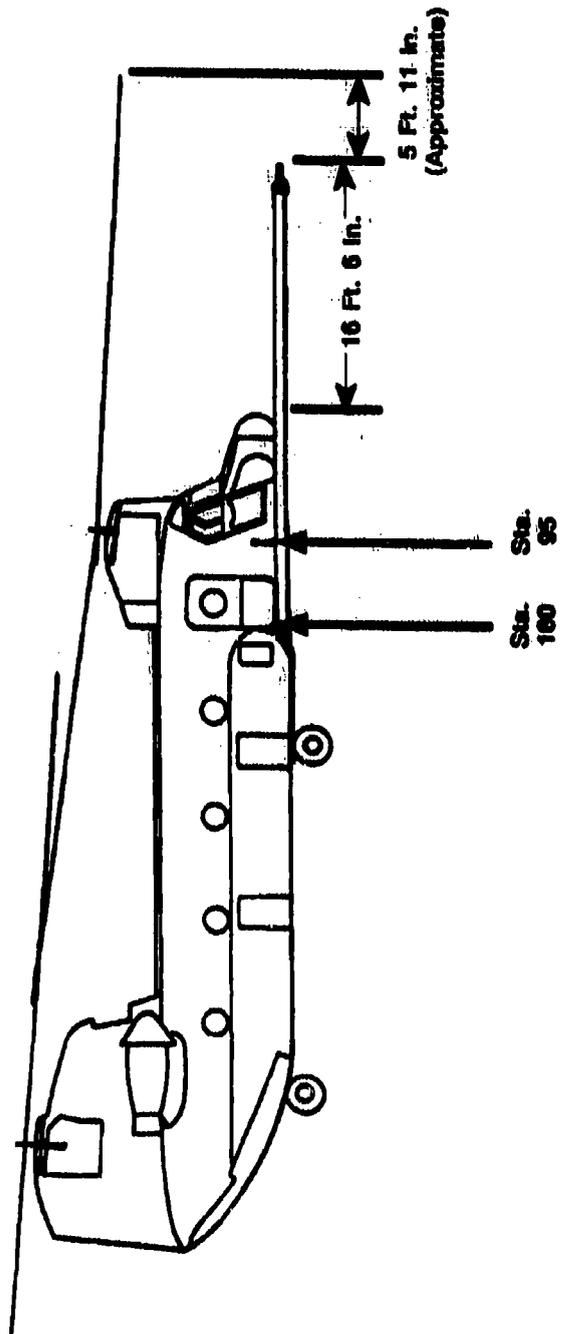


Figure B-5. Aerial Refuel Probe Installation

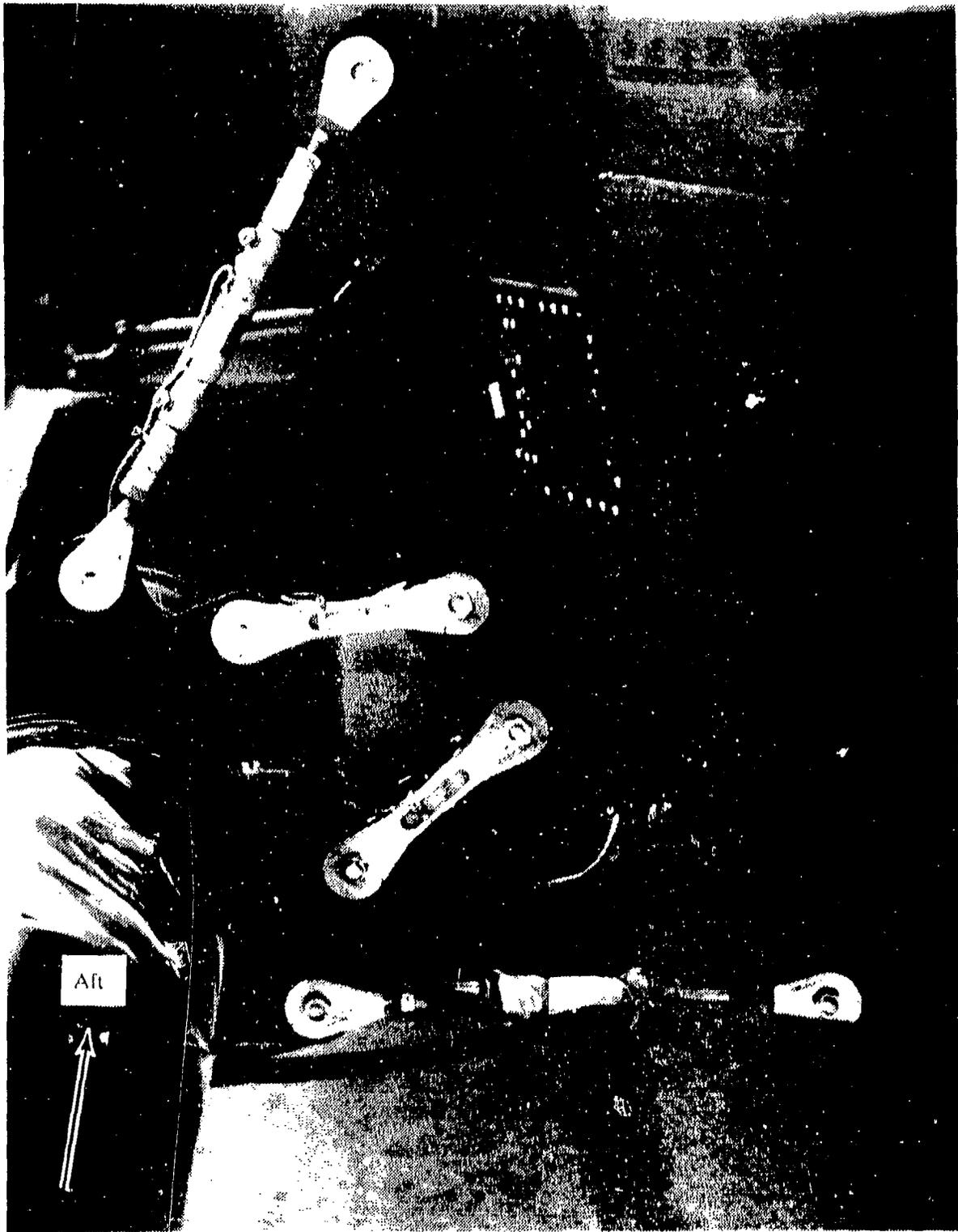


Figure 1. Station 9 - Probe Attachment

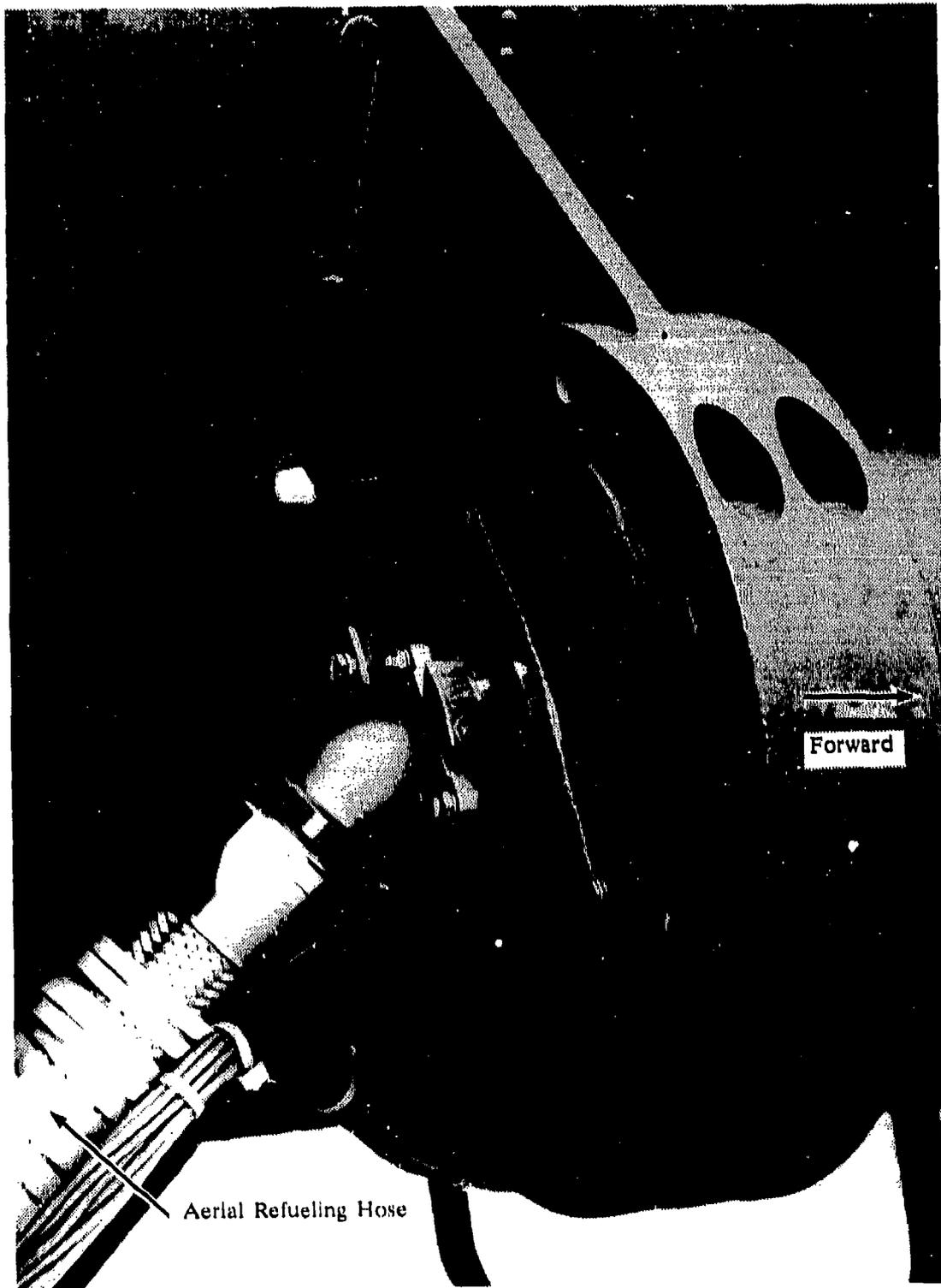


Figure B-7. Station 160 Probe Attachment Ring

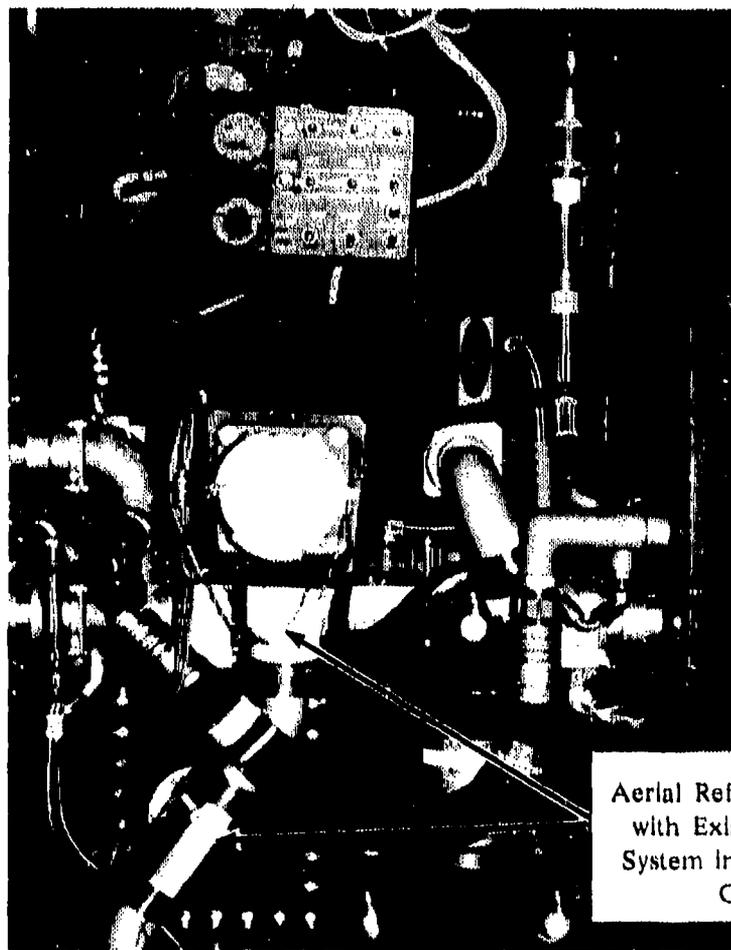
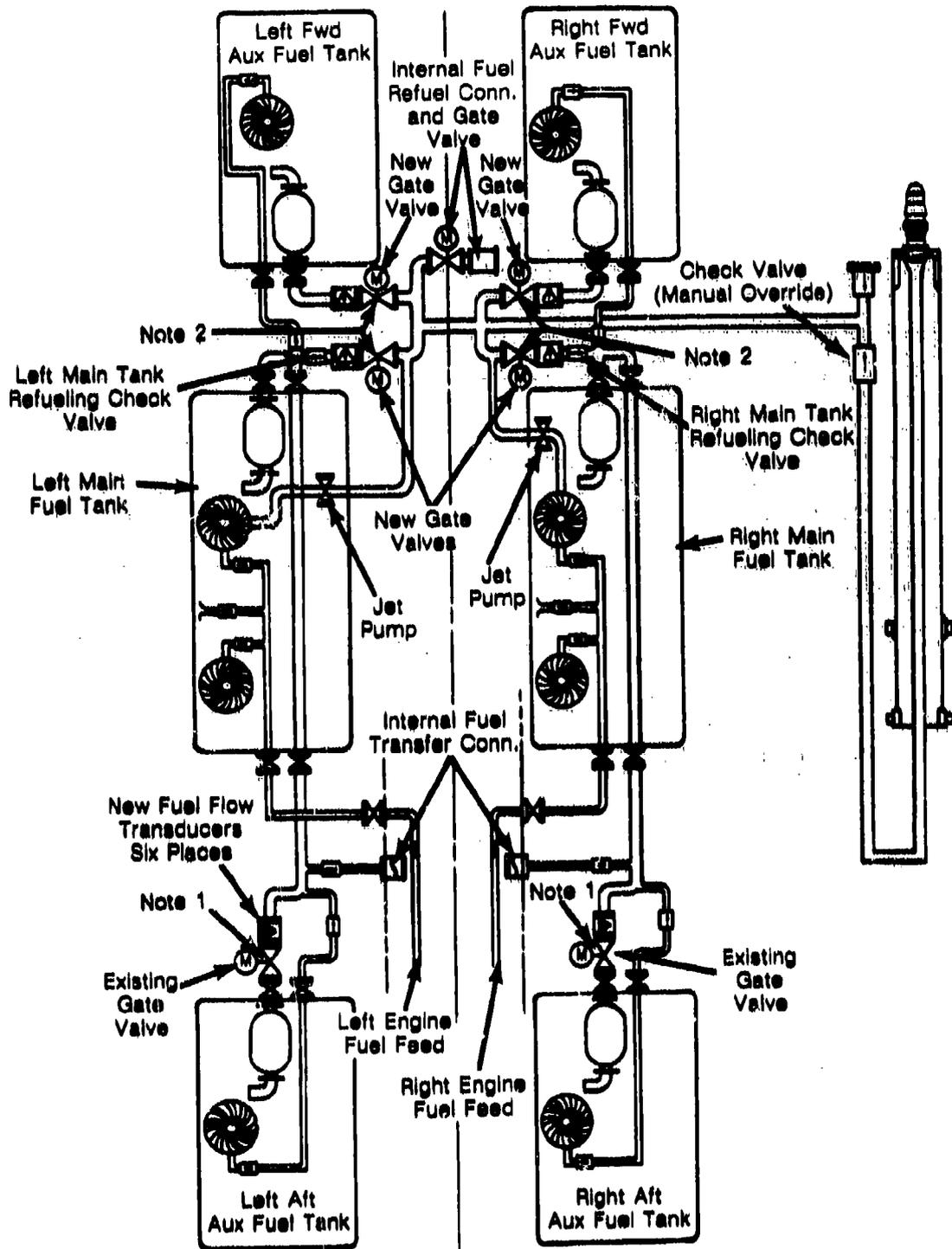


Figure B-8. Aerial Refueling Probe Fuel Line



- Notes:
 1. Commanded Close Refueling Panel Master-Off
 2. Commanded Open Refueling Panel Master-Off

Figure B-9. Aerial Refueling Schematic

is installed at each of the six fuel tanks to monitor fuel flow to that tank. The fuel quantity indicating system has been expanded to permit the flight engineer to verify fuel quantity (except for any internal ferry tanks) at the control panel during refueling operations.

Internal Fuel Provisions

5. An internal refuel connector (fig. B-10) and gate valve are added to the left side of the forward cabin at FS 255 to permit aerial or single-point refueling of the internal ferry tanks. There is no flow transducer or indicator for internal tank(s) servicing.

In-Flight Refueling Control Panel

6. Except for the existing REFUEL STATION switch on the cockpit FUEL CONTROL panel, all aerial refueling controls and indicators are on the IN-FLIGHT REFUEL control panel (fig. B-11) located in the heater compartment (fig. B-12).

a. The MASTER switch has two positions, marked RDY and OFF. It provides power to the refueling system. The refueling control panel will receive power in flight when the REFUEL STATION switch on the cockpit fuel control panel is at ON and the MASTER switch is at RDY. Operation of the panel lights is controlled by a two-position switch marked ON and OFF.

b. Power to operate the panel and refueling system is provided through four circuit breakers marked FUEL QTY IND and REFUEL on No. 1 power distribution panel (PDP) and IN FLT REFUEL and FUEL FLOW XDCRS on No. 2 PDP. All fourteen indicator lights on the panel are press-to-test.

c. Placing the MASTER switch at RDY will cause the TRANSIT light to come on for any refuel valve which is in transit to the commanded position. The transit lights go out when the refuel valves are in the commanded position. The commanded position is determined by the seven REFUEL VALVE POS switches labeled OPEN and CLOSE. The switch is adjacent to the TRANSIT light that it controls. The REFUEL VALVE POS switches will normally be left in the OPEN position. Placing the MASTER switch to OFF or cockpit refuel station switch OFF will close the R and L AFT AUX valves and open the R and L FWD AUX and main valves regardless of the REFUEL VALVE POS switch position. This will allow normal fuel transfer from the auxiliary tanks to the mains tanks.

d. The PRECHECK switch has three positions marked PRI OFF, FLOW, SEC OFF. It tests the automatic high level fuel shutoff system. Fuel flow into the system will be indicated by the illumination of the six FUEL FLOW lights marked FWD AUX, MAIN, and AFT AUX. The lights are in the center section of the control panel. Moving the PRECHECK switch to PRI OFF or SEC OFF stops fuel flow as indicated by the FUEL FLOW lights going out within twenty seconds. If the fuel level shut-off valve fails for any tank, the REFUEL VALVE for that tank can be closed, preventing fuel flow to that particular tank. Closing the main tank fuel valve will prevent fuel flow to both the main and aft auxiliary tanks on that side.

e. Refueling of internal ferry tanks is controlled by a two-position switch marked OPEN and CLOSE. A transit light adjacent to the switch provides the same function as

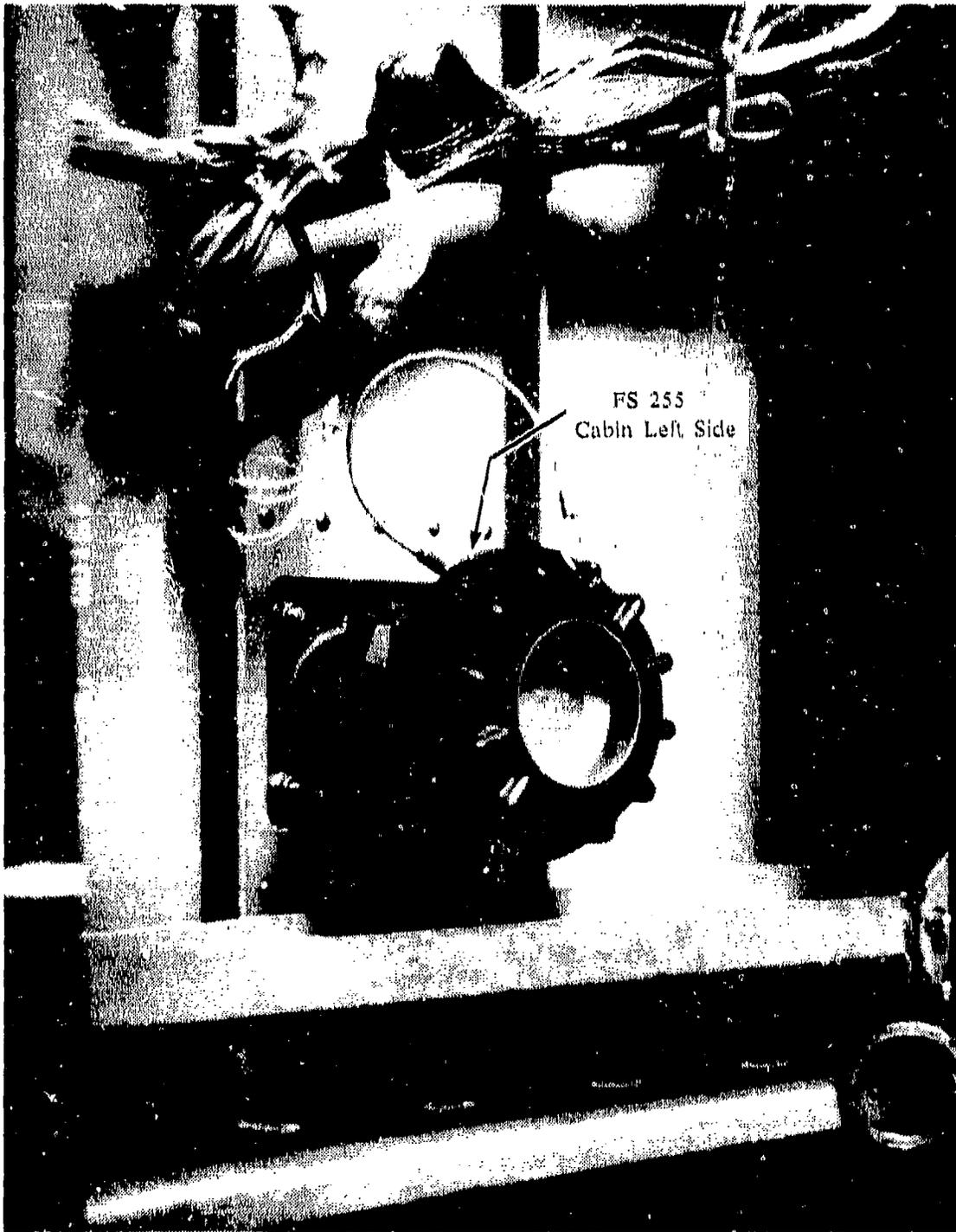


Figure B-10. Internal Refuel Connector

Press-to-Test
Lights (14)

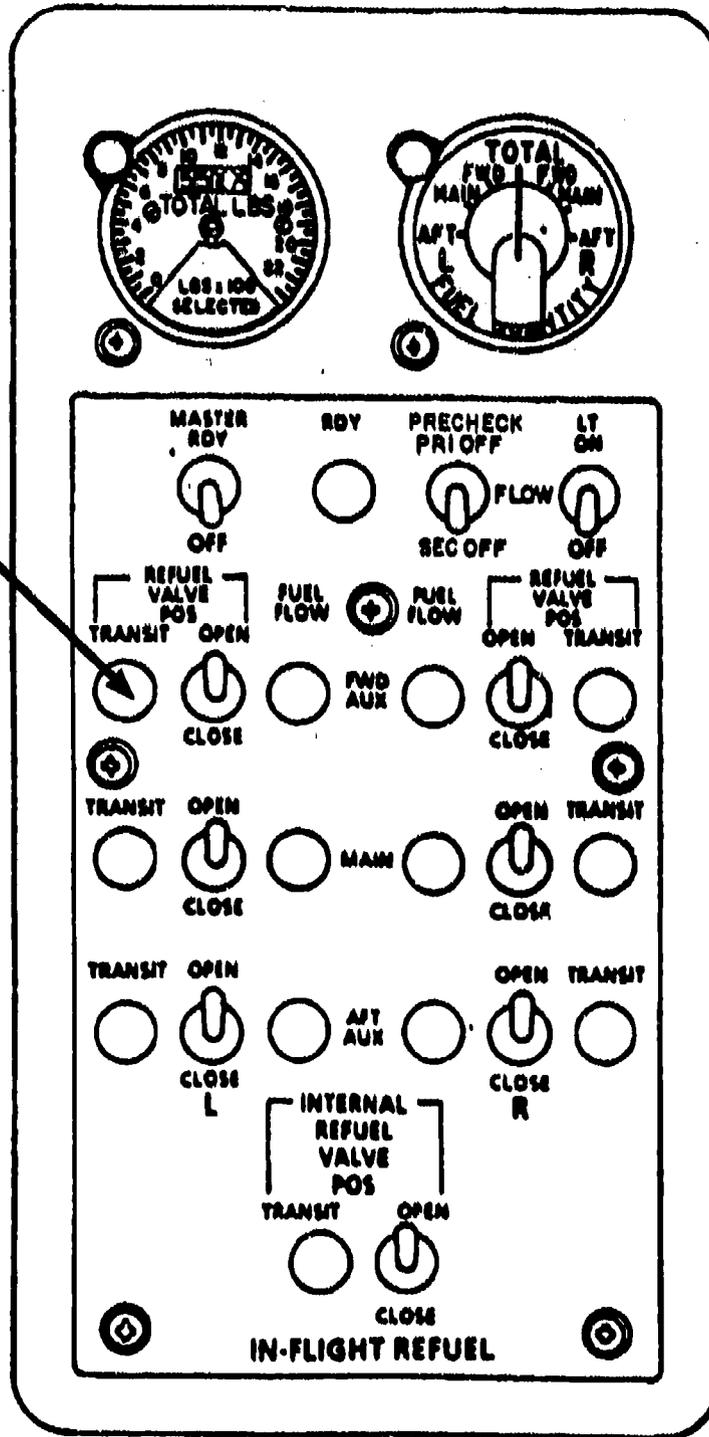


Figure B-11. In-Flight Refueling Control Panel

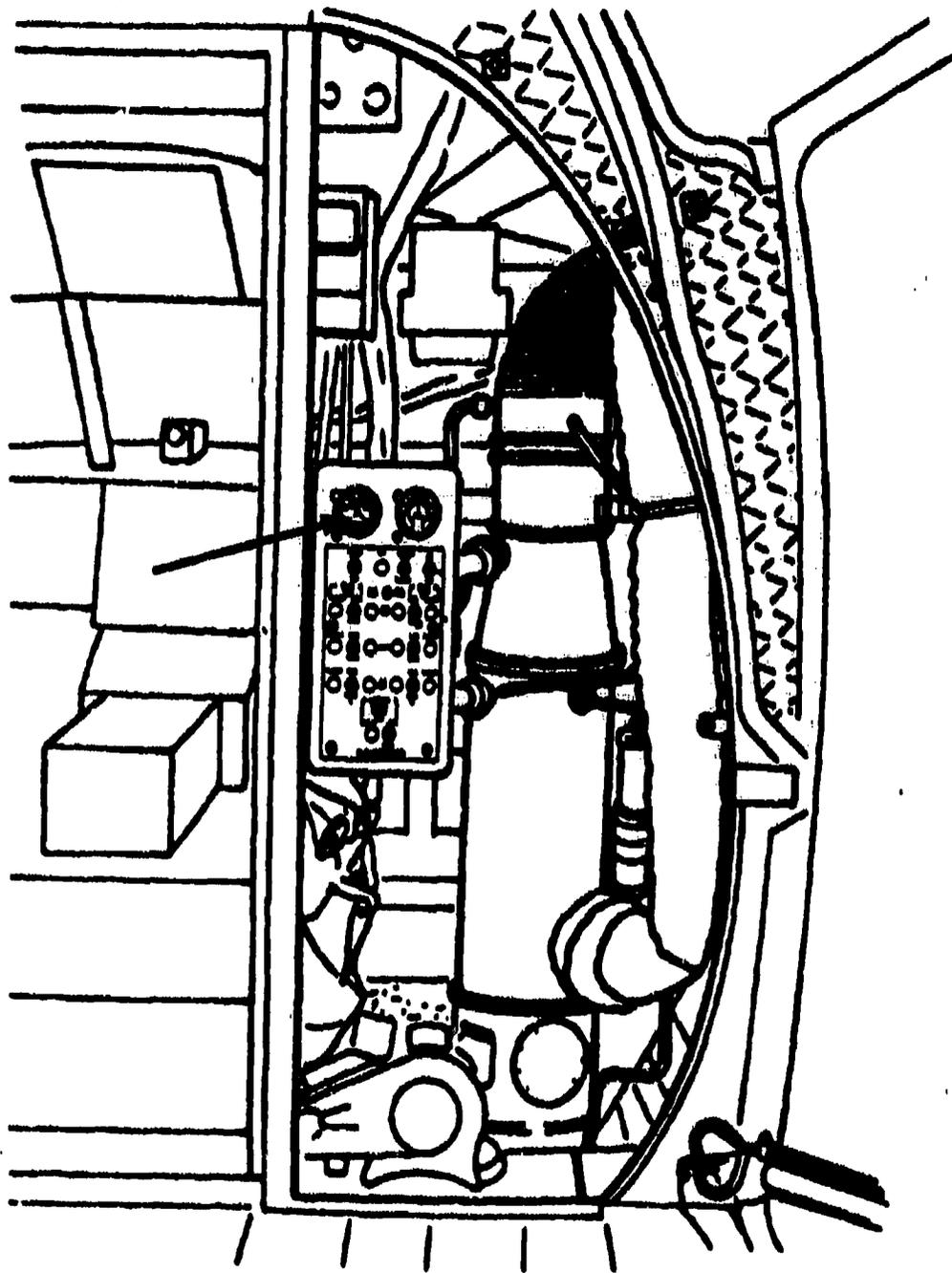


Figure B-12. In-Flight Refueling Control Panel Located in Heater Compartment

the L and R REFUEL VALVE POS switches. A fuel flow indicator is not provided for internal ferry tanks on the control panel.

AERIAL REFUELING MODIFIED POWER DISTRIBUTION PANELS

7. The No. 1 and No. 2 power distribution panels are modified to power the aerial refueling system. Modifications to the panels for lighting and fuel system requirements are shown in figures B-13 and B-14.

AERIAL REFUELING LIGHTING SYSTEM

8. The aerial refueling lighting system consists of a fixed probe light and movable searchlight behind a transparency in the forward pylon (fig. B-15), a lighting control panel in the pedestal console, and two light dimming units on the right hand cabin wall at FS 240. Both the probe light and the searchlight can be manually configured for night vision goggle (NVG) compatible infrared (IR) light by adding an IR filter to each light. The light dimming units provide continuously variable dimming over the entire range of control from full brightness to no light at all. Power for the lighting is provided from No. 2 DC bus through four circuit breakers marked REFUEL LT-PROBE LT CONT, PROBE LT FIL and REFUEL LT-SLT CONT, SLT FIL.

Probe Light

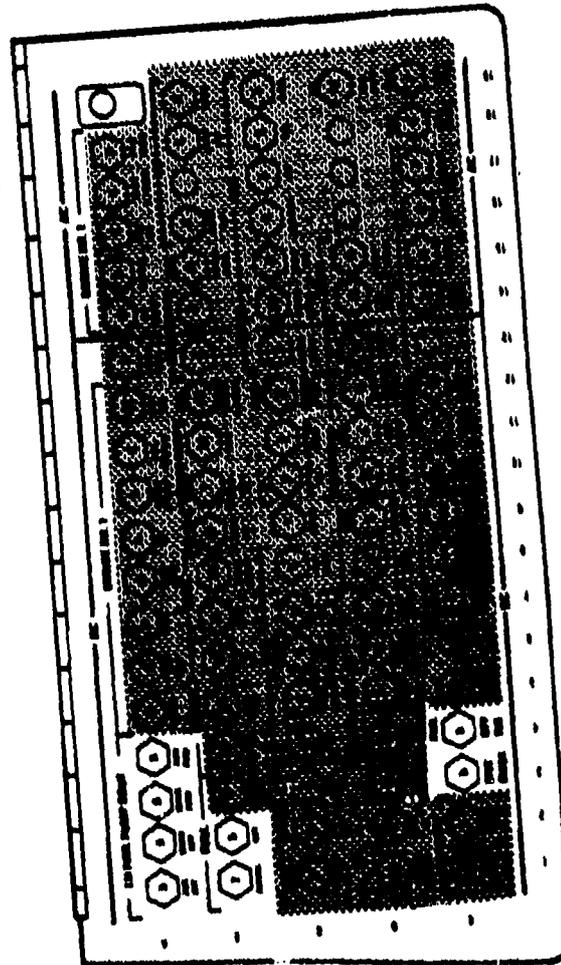
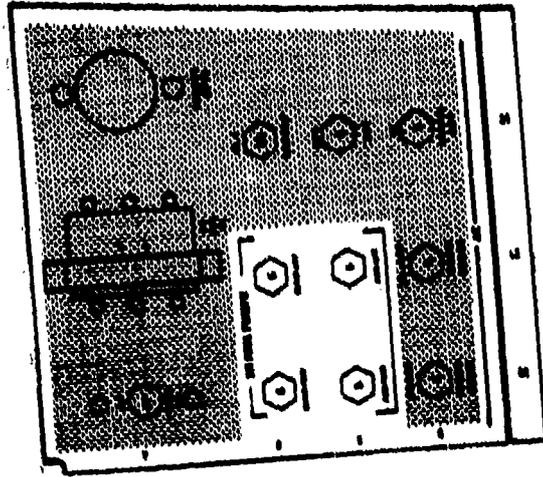
9. The probe light is positioned to illuminate the tip of the refueling probe and the area 40 feet in front of the refueling probe. The 150 watt lamp can be configured for NVG compatible IR output using the same filter as currently used on other CH-47D searchlights.

Movable Searchlight

10. Initial searchlight angle is set to permit illumination of the tanker wing pod or wing/fuselage interface when the helicopter is slightly above normal refueling operation positions. The searchlight may be electrically extended to illuminate the tanker as the helicopter position drops relative to the tanker. The 250 watt lamp can be configured for NVG compatible IR output using the same filter as on other CH-47D searchlights.

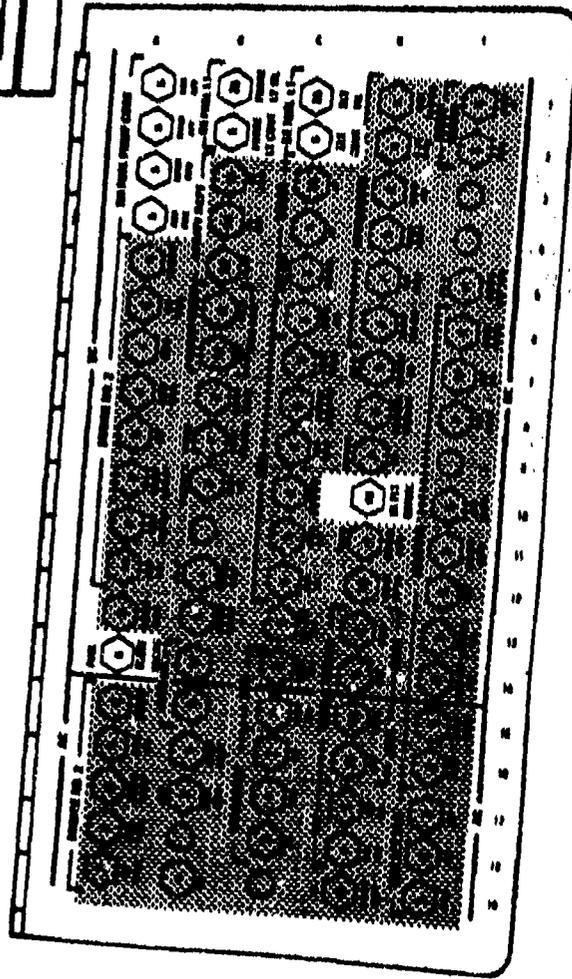
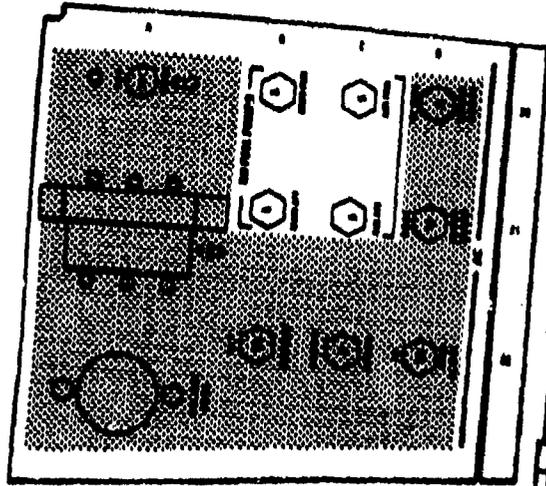
Refueling Lights Control Panel

11. The refueling lights are controlled through a switch panel (fig. B-16) located on the cockpit lower console (fig. B-17). Placing the PROBE LT FIL switch ON turns on the lamp at full brightness. Holding the PROBE LT LVL switch at DIM will dim the light linearly from full bright to completely extinguished in approximately five seconds. Holding the LVL switch at BRT reverses the process linearly from extinguished to full bright in approximately five seconds. A two-position SRCH LT control switch marked ON/RETR provides power to the four-way momentary searchlight position switch. Adjusting the switch R or L will rotate the light 360 degrees clockwise or counterclockwise. Holding the switch from RETR to EXTND will provide 23 degrees of



Note: Top and bottom panels
rotated 90 degrees for clarity.

Figure B-13. No. 1 Power Distribution Panel Aerial Refueling Modification



Note: Top and bottom panels rotated 90 degrees for clarity.

Figure B-14. Ng. 2 Power Distribution Panel Aerial Refueling Modification



Figure B-15. Aerial Refueling Lights

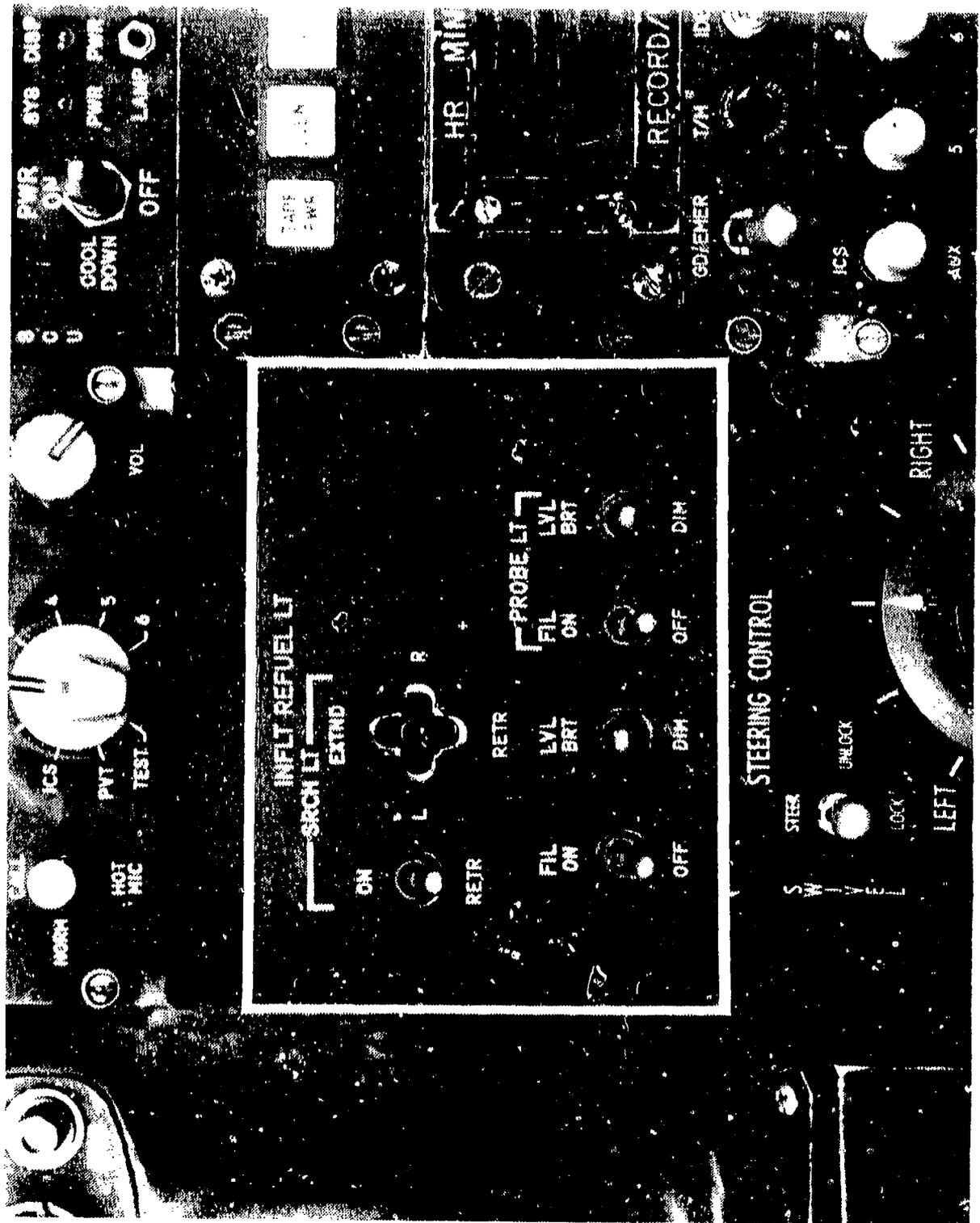


Figure B-16. Aerial Refueling Lights - Control Panel

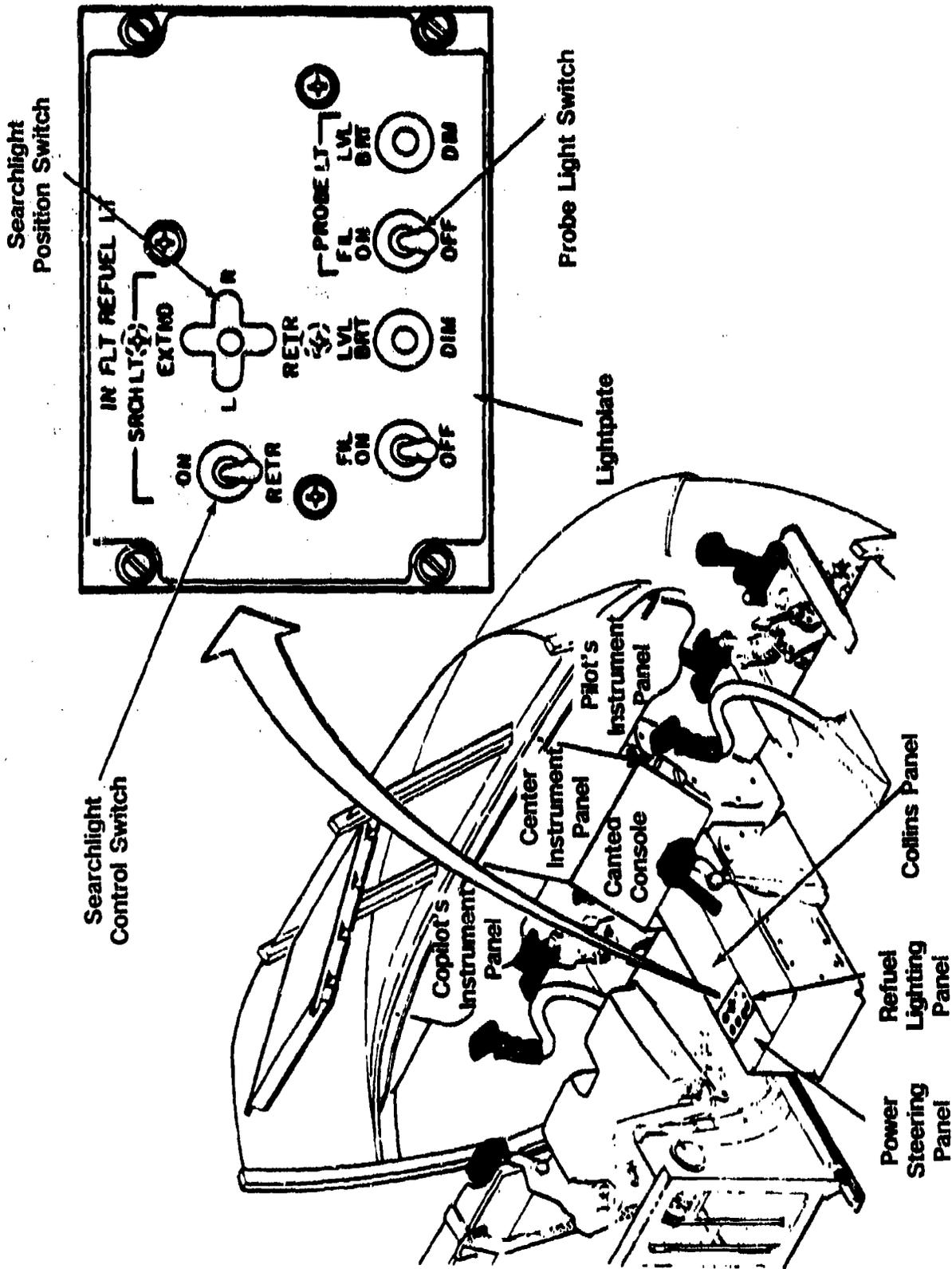


Figure B-17. Aerial Refueling Lights Control Panel Location

rotation in the vertical plane. When the SRCH LT ON/RETR switch is at RETR, the searchlight will fully retract and rotate clockwise until the lamp is centered. The SRCH LT FIL switch is a two-position switch marked ON/OFF. When the switch is at ON, the lamp is turned on at full brightness. Holding the SRCH LT LVL switch at DIM will dim the searchlight lamp linearly from full brightness to completely out in approximately five seconds. Holding the LVL switch at BRT reverses the process linearly from extinguished to full bright in approximately five seconds.

CABIN ENTRANCE DOOR

12. The lower cabin entrance door is the same as on existing helicopters except the support structure and mechanism has been modified by extending the lower hinge assembly to clear the probe when the door is lowered (fig. B-1 and B-18). A door extension/step has been added to provide a step over the probe and fill the gap when the door is open which was created by the extended door hinges. The door extension/step is hinged to the troop commander's seat pallet.

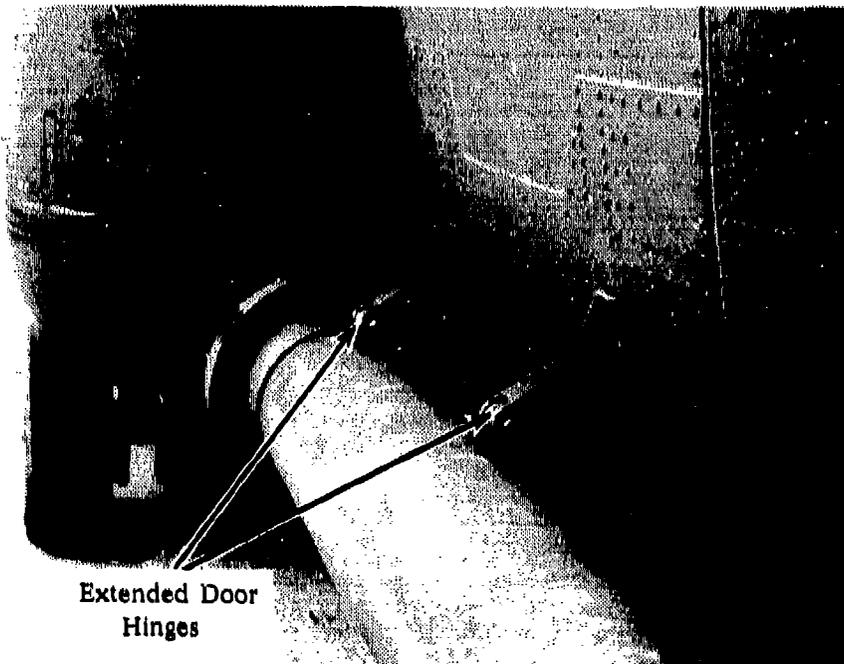
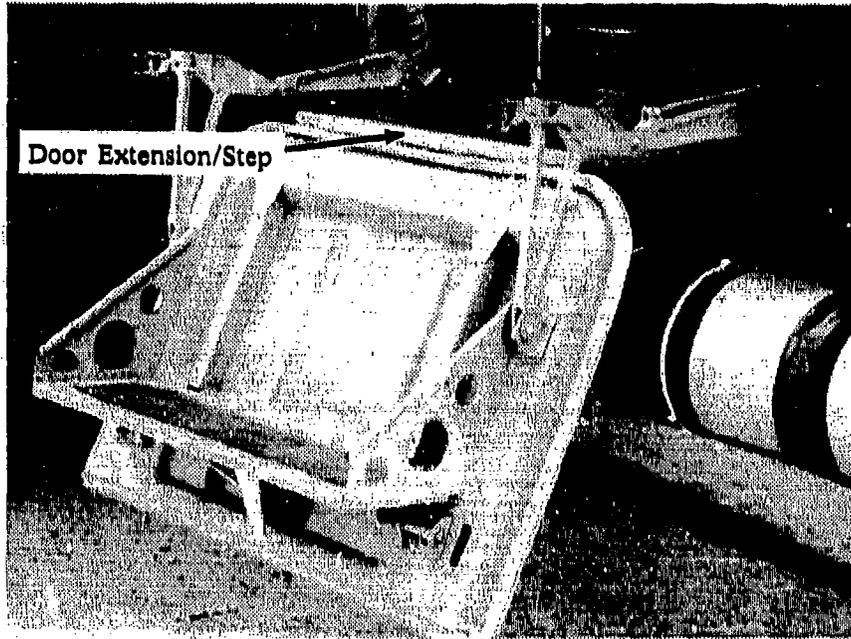


Figure B-18. Cabin Entrance Door

APPENDIX C. INSTRUMENTATION

1. The test instrumentation was installed, calibrated and maintained by Boeing Helicopters. The system included various sensors, signal conditioners, pulse code modulation (PCM) multiplexers, an onboard tape recorder and a telemetry transmitter. A total of 33 parameters were recorded onboard and telemetered to a ground monitoring station.

2. Ship system instrumentation was used to provide electrical input for some parameters. Fuel quantity data were recorded by hand using the ship system fuel quantity gage located on the cabin refueling panel.

3. The parameters displayed on the pilot and/or copilot instrument panels included:

- Airspeed (pilot and copilot systems) (kt)
- Altitude (pilot and copilot systems) (ft)
- Total Air Temperature (deg C)
- Rotor Speed (rpm)
- Engine Torque (%)
 - #1 Engine
 - #2 Engine
- Cruise Guide Indicator
- Fuel Quantity (lb)
- Aircraft Attitude (deg)
 - Pitch
 - Roll
- Aircraft Heading (deg)
- Longitudinal Cyclic Trim Actuator position
 - Forward
 - Aft

4. The PCM parameters measured and recorded during this evaluation were:

- Airspeed (pilot system)* (kt)
- Pressure Altitude (pilot system)* (ft)
- Total Air Temperature (deg C)
- Rotor Speed (rpm)
- Engine Torque* (%)
 - #1 Engine
 - #2 Engine
- Cruise Guide Indicator* (%)
- Aircraft Attitude (deg)
 - Pitch
 - Roll
- Probe Bending Moment FS 90 (in-lb)
 - Vertical
 - Lateral
- Probe Support Strut Tension, FS 95 (lb)
 - Upper Strut
 - Upper-middle Strut

*Ship system

Lower-middle Strut
Lower Strut
Probe Tip Linear Acceleration (g)
Vertical
Lateral
Cockpit Floor Linear Acceleration, Pilot Side, FS 50, BL 33 RT (g)
Vertical
Lateral
Cockpit Floor Linear Acceleration, Center, FS 95, BL 0 (g)
Vertical
Lateral
Longitudinal
Fuel Pressure (psi)
Left main fuel tank inlet
Left aft auxiliary fuel tank inlet
Right main fuel tank inlet
Right aft auxiliary fuel tank inlet
Crossfeed inlet
Crossfeed line
Probe hose output
Left side dry bay manifold
Right side dry bay manifold
Time of day
Event number

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

DRAG INCREMENT DETERMINATION

1. Level flight performance testing was conducted by the contractor in ball-centered flight and the results were analyzed by U.S. Army Aviation Engineering Flight Activity (AEFA) personnel to determine the change in power required for the installation of the aerial refueling system. Data analysis methods used are described in the Army Materiel Command Pamphlet 706-204 (ref 12, app A). Contractor test techniques were evaluated by AEFA personnel and were found to conform with the methods described in reference 12.

VIBRATIONS

2. The output of vibration accelerometers were reduced using a fast Fourier transform method to obtain average vibration amplitudes as a function of frequency. Amplitude at the main rotor harmonic frequencies was then determined.

PROBE TIP LOAD DETERMINATION

3. Probe tip loads were calculated using the longitudinal and lateral bending moments measured at fuselage station 90 and the moment arm to the probe tip (278 inches). Total radial load at the tip was calculated using the following equation:

$$\text{Total radial tip load} = \frac{\sqrt{\text{Vertical bending moment}^2 + \text{Lateral bending moment}^2}}{278}$$

ROTOR-TO-DROGUE CLEARANCE DETERMINATION

4. Vertical clearances between the forward rotor blades and the refueling drogue were obtained by analyzing video recordings of the test aircraft (para 26). The test was conducted with three different longitudinal cyclic trim actuator settings in stabilized level flight to determine the average clearances and during simulated run-in (approach to drogue) maneuvers to determine minimum clearances. Video of the test aircraft was taken from the right side using a fixed-wing chase aircraft. The tapes were analyzed on a video monitor at slow speed and using single-frame advance until the minimum clearance for the specific condition occurred. With the tape stopped at the time of minimum clearance, a photographic print was made for each condition. The probe length and the distance between the rotor disk and the refueling probe tip were measured on the prints and converted to actual values by using the known length of the probe. The radius of the refueling drogue was subtracted from the rotor-to-probe clearance to obtain the rotor-to-drogue clearance.

RECEIVER-TO-TANKER CLEARANCE DETERMINATION

5. The approximate receiver-to-tanker clearance while performing aerial refueling operations was determined in the precontact, contact, refueling, movement from contact

to refueling and movement from refueling to disconnect positions behind the left and right drogue (para 27). An observer using a hand held Laser Distance Measurement System (LDMS) from the cargo loading ramp on the tanker aircraft measured distances to reflective tape targets affixed to the pilot and copilot emergency escape doors. Angles between the receiver's forward main rotor mast and the LDMS were noted for each of the refueling positions. Post-flight measurements were made of the distance between the reflective tape targets and the forward rotor tip-path plane and the distance between the LDMS and that part of the tanker nearest to the receivers forward rotor for the angles corresponding to the refueling positions. These two measurements were summed and subtracted from the LDMS readings to yield the approximate clearance between the receiver and tanker.

AERIAL REFUELING SYSTEM TESTS

Static Structural Test

6. Prior to flight test, Boeing Helicopters conducted a static structural test of a refueling probe and the external probe-support hardware. The probe and external support hardware were mounted on a test fixture and a hydraulic actuator was attached, in series with a load-measuring device, to the tip of the probe. The actuator was used to incrementally increase the tip load until failure of the probe occurred. The same apparatus was used to calibrate the strain gages on the probe used during flight tests.

Natural Frequency Response Tests

7. Accelerometers were mounted near the tip of the probe and were used to determine the natural frequency of the probe in the vertical and lateral directions. Loads were applied manually at the tip to induce oscillation and the cycles of tip movement per second were obtained by analyzing the accelerometer data. The natural frequencies were used to predict aircraft and pilot-induced probe oscillations.

Refueling System Functional Tests

8. Refueling system functional tests were conducted on the ground utilizing a fuel truck, a U.S. Marine Corps KC-130T tanker and a U.S. Air Force HC-130P tanker. Fuel transfer quantities were measured using the truck and tanker totalizers. Fuel flow rates were determined by timing the fuel transfer when refueling from the truck and by a tanker flow meter (ground test equipment) when refueling from the tanker aircraft. During refueling tests, all of the instrumented fuel system surge pressures were monitored via telemetry.

DEFINITIONS

Enhancing Characteristic

9. A characteristic of the test article which will enhance the accomplishment of the mission or is a marked advancement in the state of the art.

Deficiency

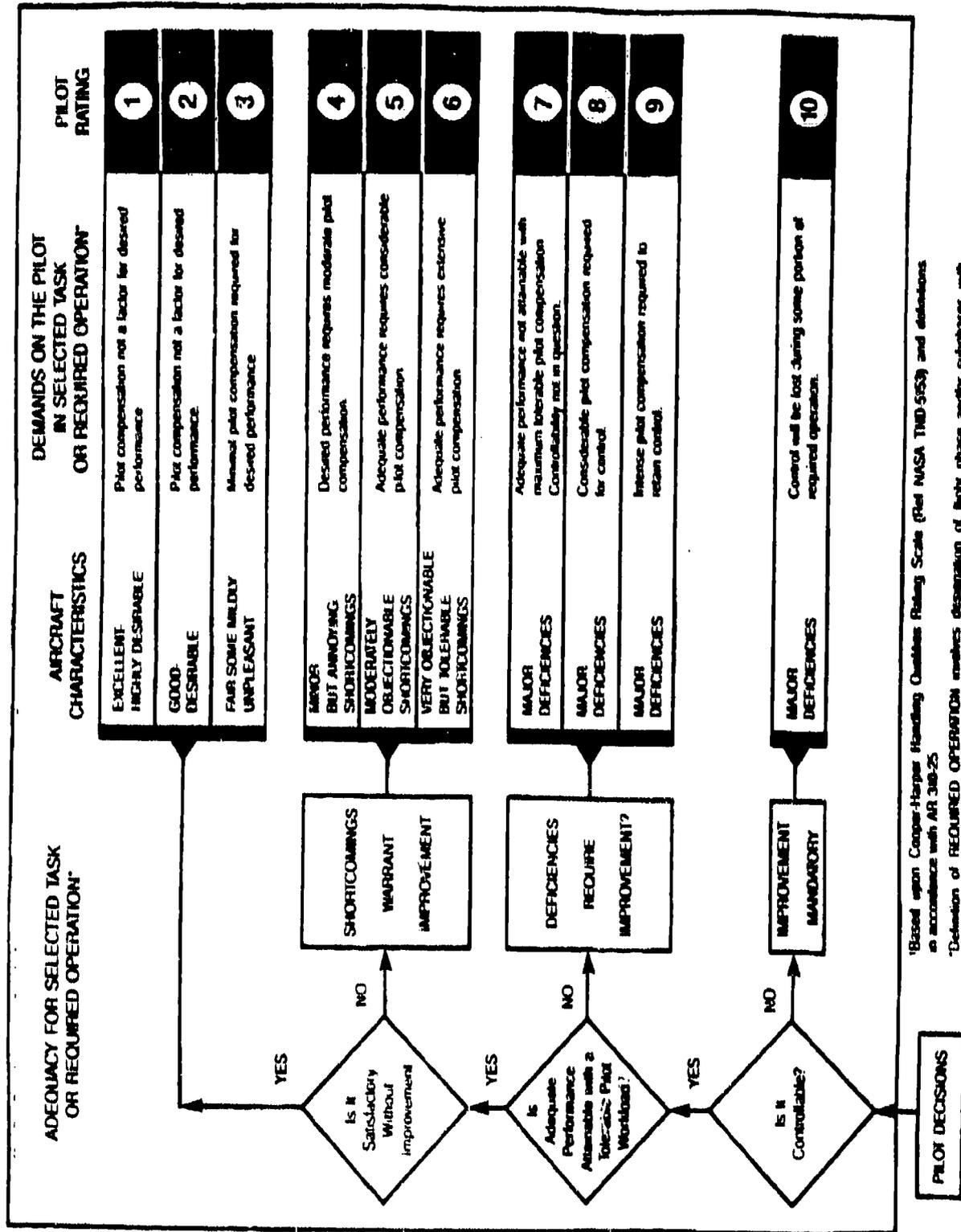
10. A defect or malfunction discovered during the life cycle of an item of equipment that constitutes a safety hazard to personnel; will result in serious damage to the equipment if operation is continued; or indicates improper design or other cause of failure of an item or part, which seriously impairs the equipment's operational capability.

Shortcoming

11. An imperfection or malfunction occurring during the life cycle of equipment which must be reported and which should be corrected to increase efficiency and to render the equipment completely serviceable. It will not cause an immediate breakdown, jeopardize safe operation, or materially reduce the usability of the materiel or end product.

RATING SCALES

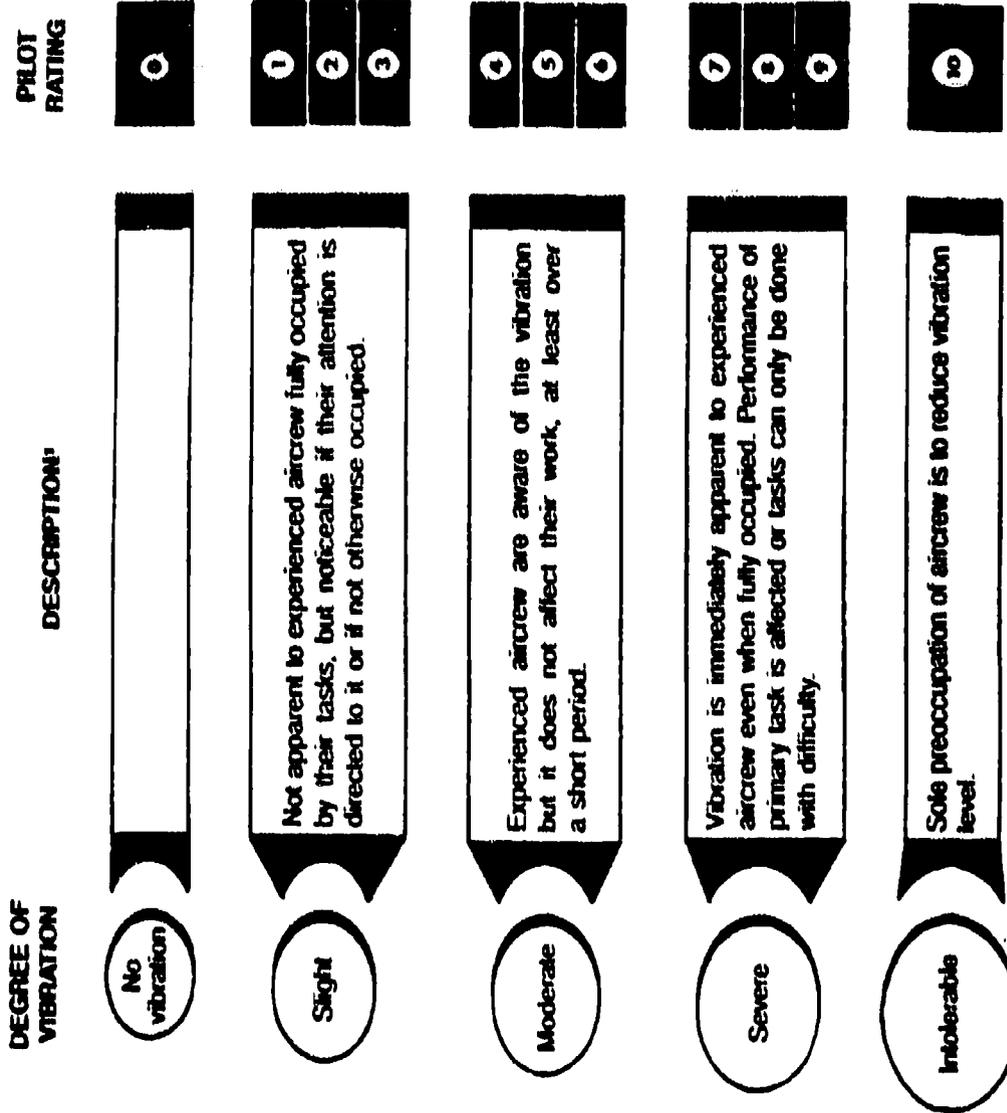
12. The Handling Qualities Rating Scale is presented in figure D-1. The Vibration Rating Scale is presented in figure D-2.



¹Based upon Cooper-Harper Handling Qualities Rating Scale (Ref NASA TMD 5153) and additions in accordance with AR 340-25

²Definition of REQUIRED OPERATION makes designation of flight phase and/or subphases with accompanying conditions

Figure D-1. Handling Qualities Rating Scale



*Based on the Subjective Vibration Assessment Scale developed by the Aeroplane and Armament Experimental Establishment, Boscombe Down, England.

Figure D-2. Vibration Rating Scale

APPENDIX E. TEST DATA

FIGURE	FIGURE NUMBER
Aerial Refueling Operations	E-1 and E-2
Vibration Characteristics	E-3 through E-7
Aerial Refueling Operations, Probe Structural Loads	E-8 and E-9

FIGURE E-1
 AERIAL REFUELING OPERATIONS
 CH-47D USA S/N 82-23763

AVG GROSS WEIGHT (LB)	AVG CG LOCATION		AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	TRIM ROTOR SPEED (RPM)	REFUELING AIRSPEED (KIAS)
	LONG (FS)	LAT (BL)				
31280	318.2(MID)	0.0	6050	12.0	225	110

- NOTES: 1. AIR CONDITIONS: NON-TURBULENT
 2. REFUELING OPERATIONS TO THE LEFT DROGUE
 3. AERIAL REFUELING CONFIGURATION WITH AWC MODIFICATION INCORPORATED

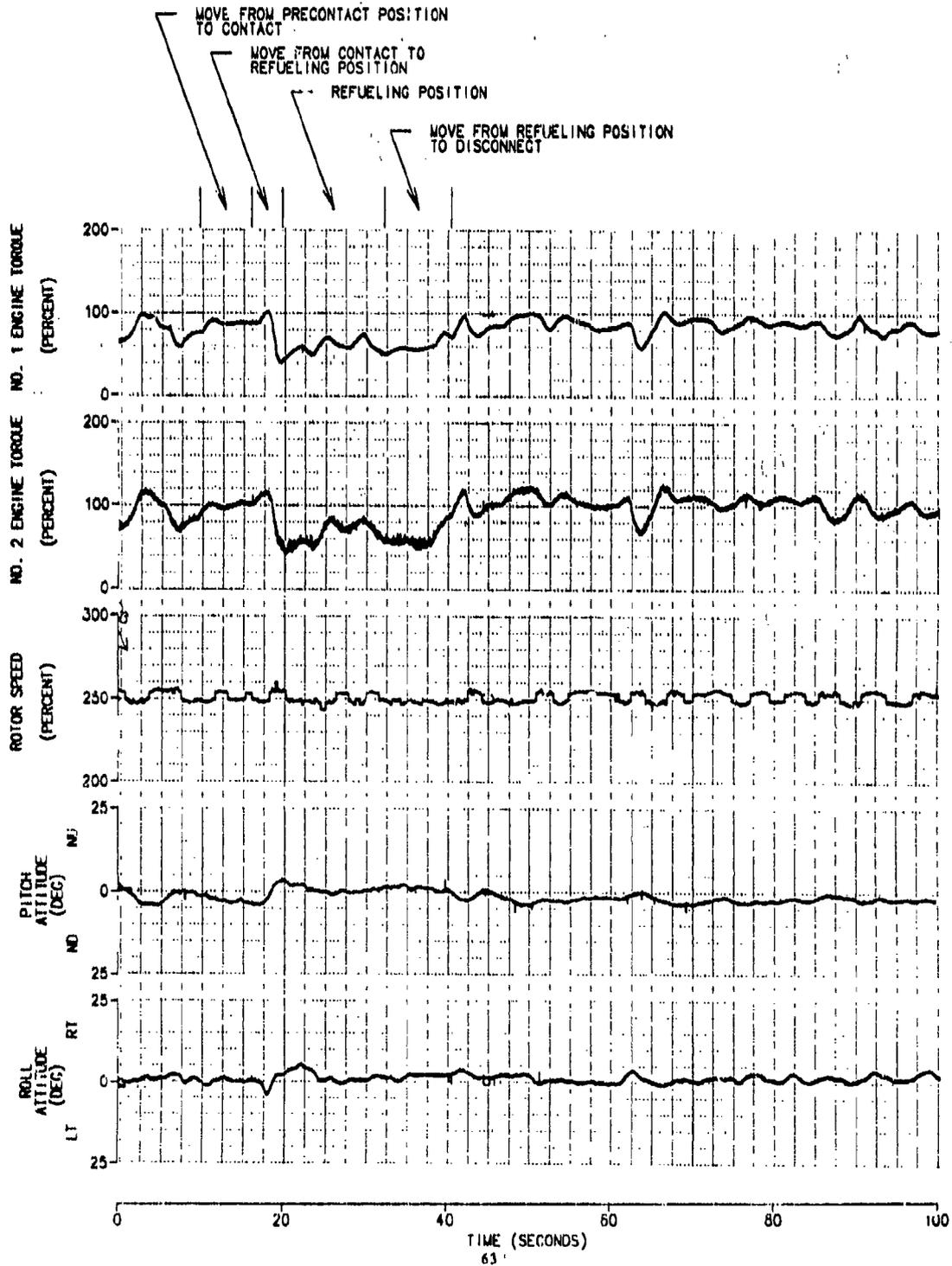


FIGURE E-1 (CONTINUED)
 AERIAL REFUELING OPERATIONS
 CH-47D USA S/N 82-23763

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	TRIM ROTOR SPEED (RPM)	REFUELING AIRSPEED (KIAS)
31280	318.2(MID)	0.0	8050	12.0	225	110

- NOTES: 1. AIR CONDITIONS: NON-TURBULENT
 2. REFUELING OPERATIONS TO THE LEFT DROGUE
 3. AERIAL REFUELING CONFIGURATION WITH AWC MODIFICATION INCORPORATED

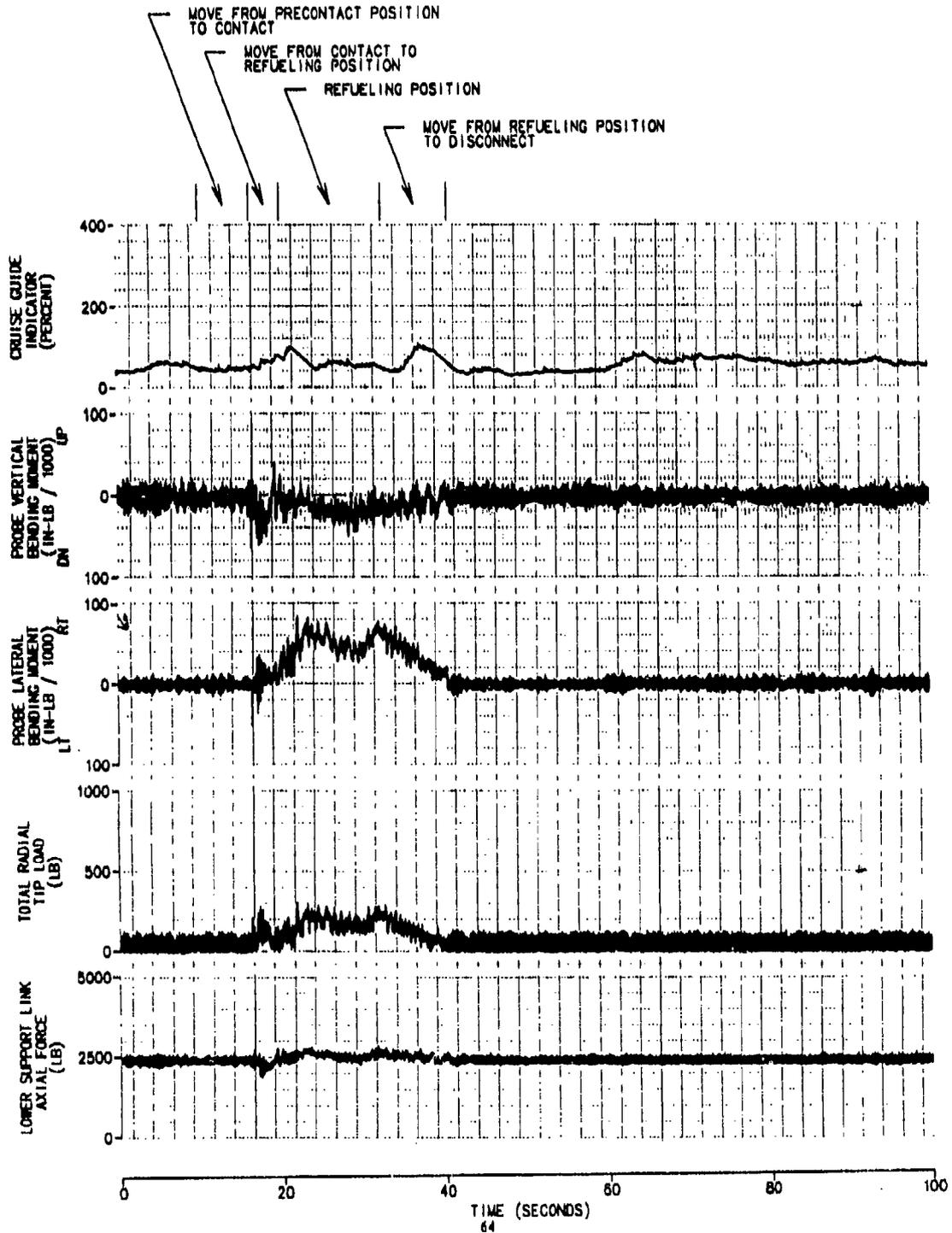


FIGURE E-2
 AERIAL REFUELING OPERATIONS
 CH-47D USA S/N 82-23783

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG O)	TRIM ROTOR SPEED (RPM)	REFUELING AIRSPEED (KIAS)
48160	329.2(MID)	0.0	5100	17.5	225	115

- NOTES: 1. AIR CONDITIONS: MODERATE TURBULENCE
 2. REFUELING OPERATIONS TO THE LEFT DROGUE
 3. AERIAL REFUELING CONFIGURATION WITH AWC MODIFICATION INCORPORATED

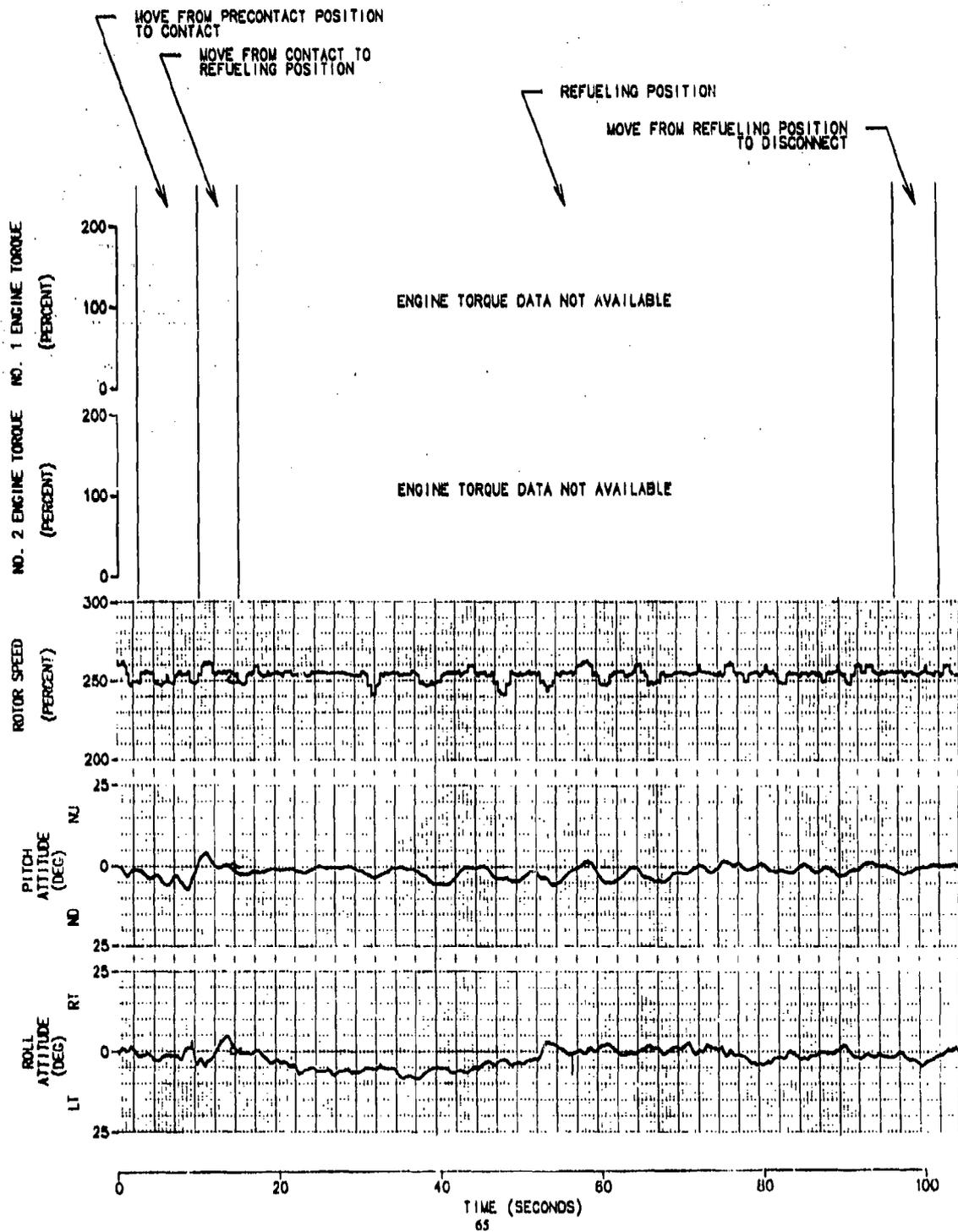


FIGURE E-2 (CONTINUED)
 AERIAL REFUELING OPERATIONS
 CH-47D USA S/N 82-23763

AVG GROSS WEIGHT (LB)	AVG CG LOCATION		AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	TRIM ROTOR SPEED (RPM)	REFUELING AIRSPEED (KIAS)
	LONG (FS)	LAT (BL)				
48180	329.2(MID)	0.0	5100	17.5	225	115

- NOTES: 1. AIR CONDITIONS: MODERATE TURBULENCE
 2. REFUELING OPERATIONS TO THE LEFT DROGUE
 3. AERIAL REFUELING CONFIGURATION WITH AWC MODIFICATION INCORPORATED

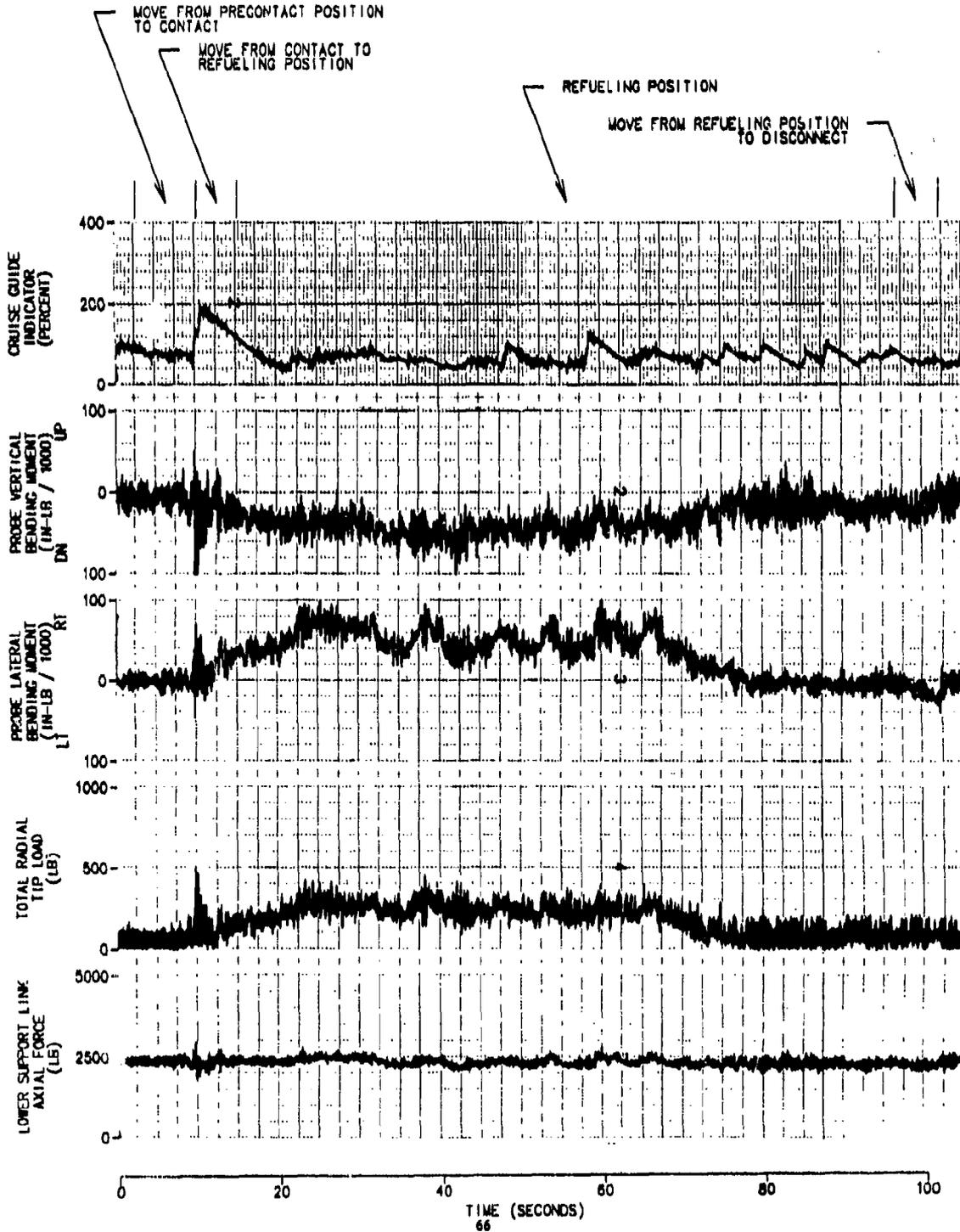


FIGURE E-3
VIBRATION CHARACTERISTICS
CH-47D USA S/N 82-23763

LATERAL VIBRATIONS AT COCKPIT FLOOR, FS 50, BL 33 RIGHT

SYM	AVG GROSS WEIGHT (LB)	AVG CG LOCATION		AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)	AIRCRAFT CONFIGURATION
		LONG (FS)	LAT (BL)				
○	35340	328.4	0.0	5120	23.0	228	PROBE ON
△	35520	328.4	0.0	4830	20.5	226	PROBE OFF

- NOTES: 1. LEVEL FLIGHT
2. AWC MODIFICATION INCORPORATED

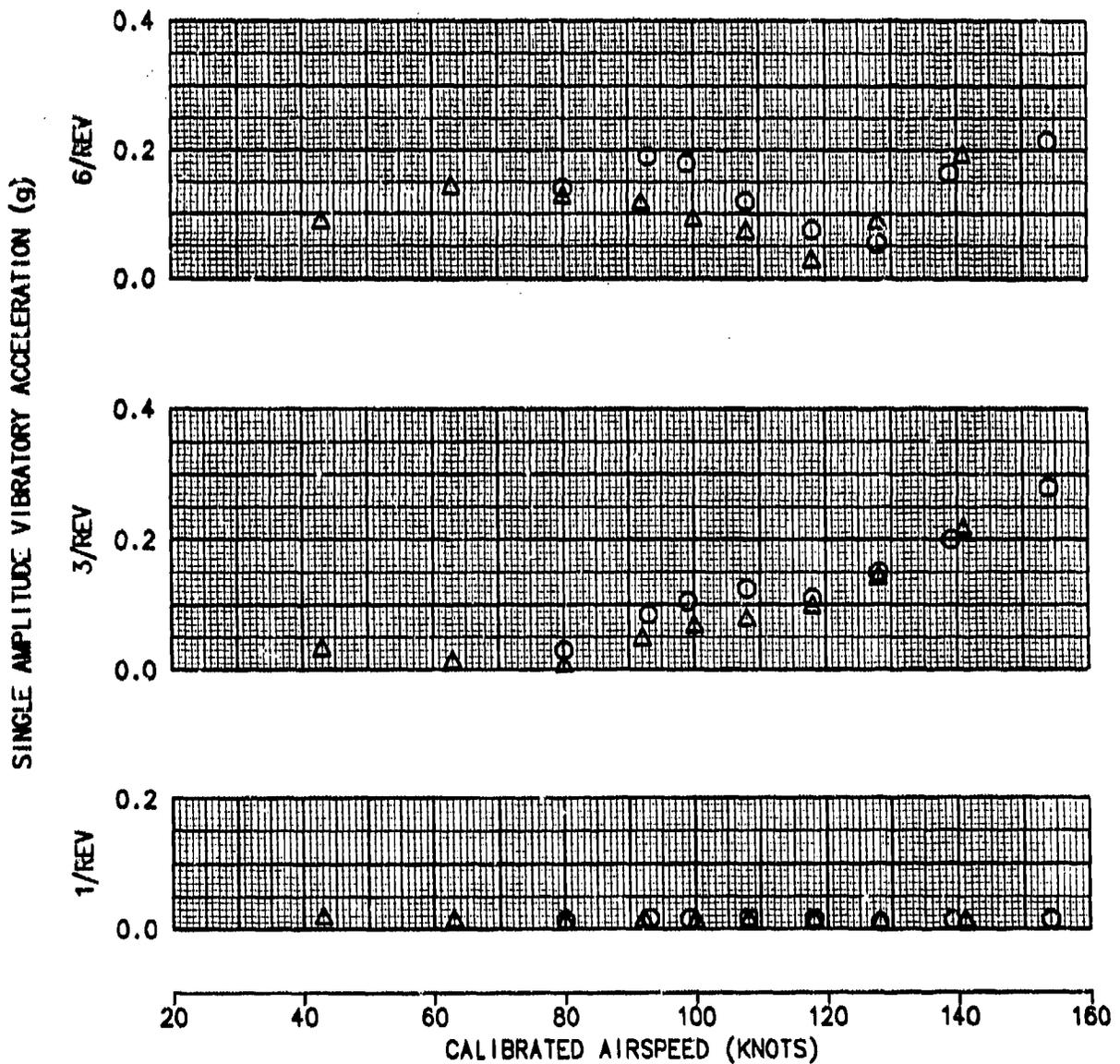


FIGURE E-4
VIBRATION CHARACTERISTICS
CH-47D USA S/N 82-23763

VERTICAL VIBRATIONS AT COCKPIT FLOOR, FS 50, BL 33 RIGHT

SYM	AVG GROSS WEIGHT (LB)	AVG CG LOCATION		AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)	AIRCRAFT CONFIGURATION
		LONG (FS)	LAT (BL)				
○	35340	328.4	0.0	5120	23.0	228	PROBE ON
△	35520	328.4	0.0	4830	20.5	226	PROBE OFF

NOTES: 1. LEVEL FLIGHT
2. AWC MODIFICATION INCORPORATED

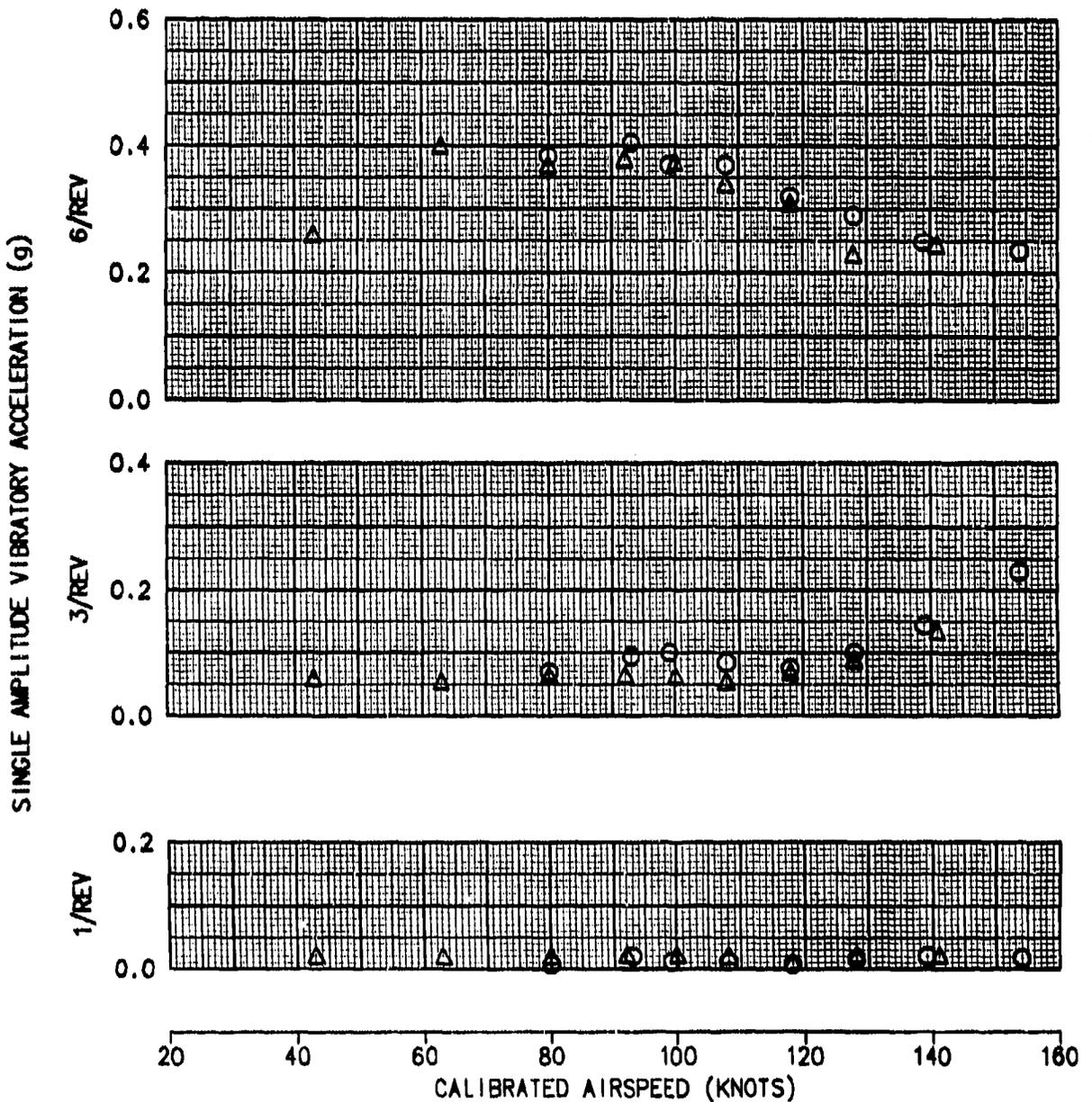


FIGURE E-5
VIBRATION CHARACTERISTICS
CH-47D USA S/N 82-23763

LONGITUDINAL VIBRATIONS AT COCKPIT FLOOR, FS 95, BL 0

SYM	AVG GROSS WEIGHT (LB)	AVG CG LOCATION		AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)	AIRCRAFT CONFIGURATION
		LONG (FS)	LAT (BL)				
⊙	35340	328.4	0.0	5120	23.0	228	PROBE ON
△	35520	328.4	0.0	4830	20.5	226	PROBE OFF

NOTES: 1. LEVEL FLIGHT
2. AWC MODIFICATION INCORPORATED

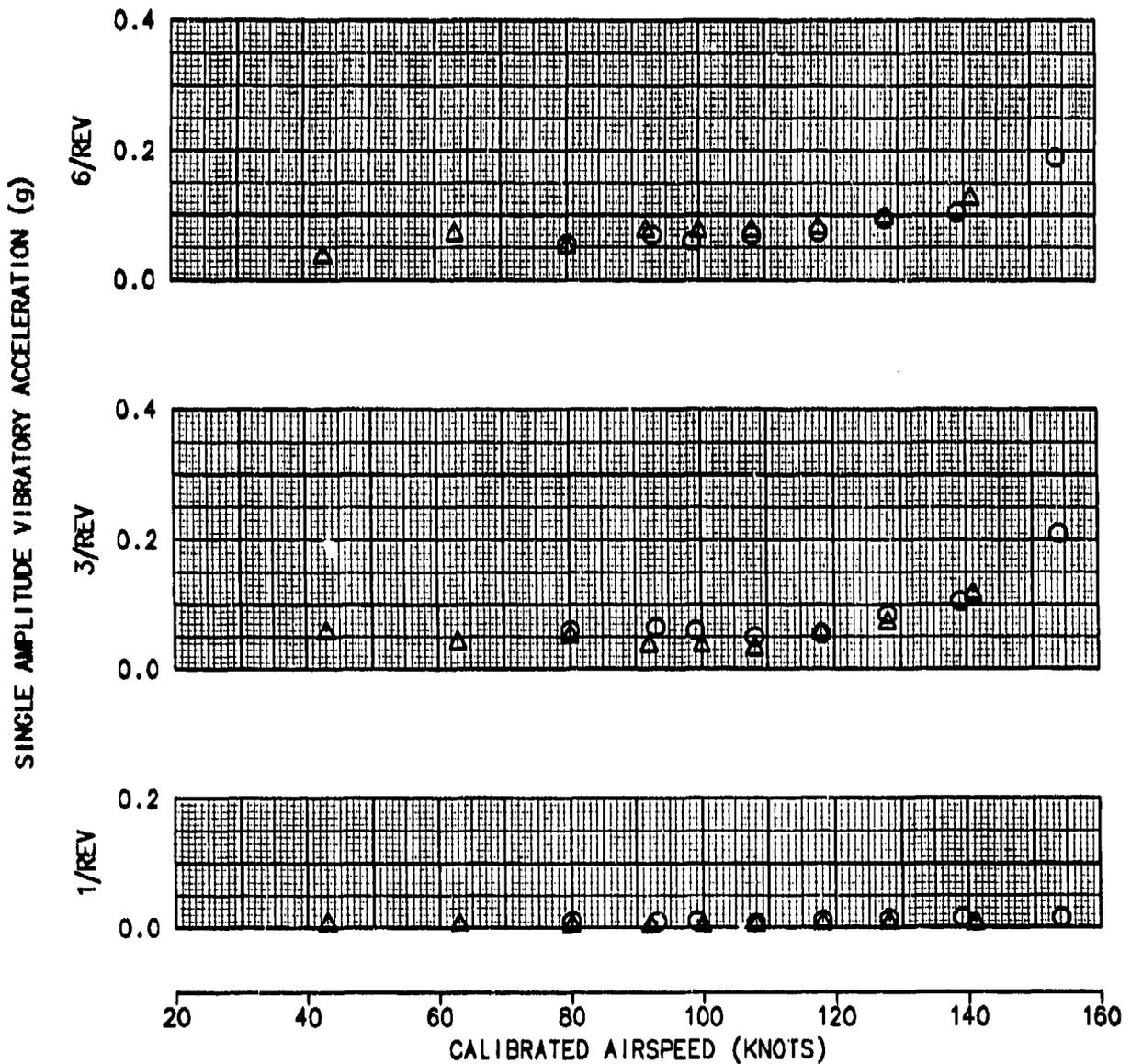


FIGURE E-6
VIBRATION CHARACTERISTICS
CH-47D USA S/N 82-23763

LATERAL VIBRATIONS AT FS COCKPIT FLOOR, 95, BL 0

SYM	AVG GROSS WEIGHT (LB)	AVG CG LOCATION		AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)	AIRCRAFT CONFIGURATION
		LONG (FS)	LAT (BL)				
○	35340	328.4	0.0	5120	23.0	228	PROBE ON
△	35520	328.4	0.0	4830	20.5	226	PROBE OFF

NOTES: 1. LEVEL FLIGHT
2. AWC MODIFICATION INCORPORATED

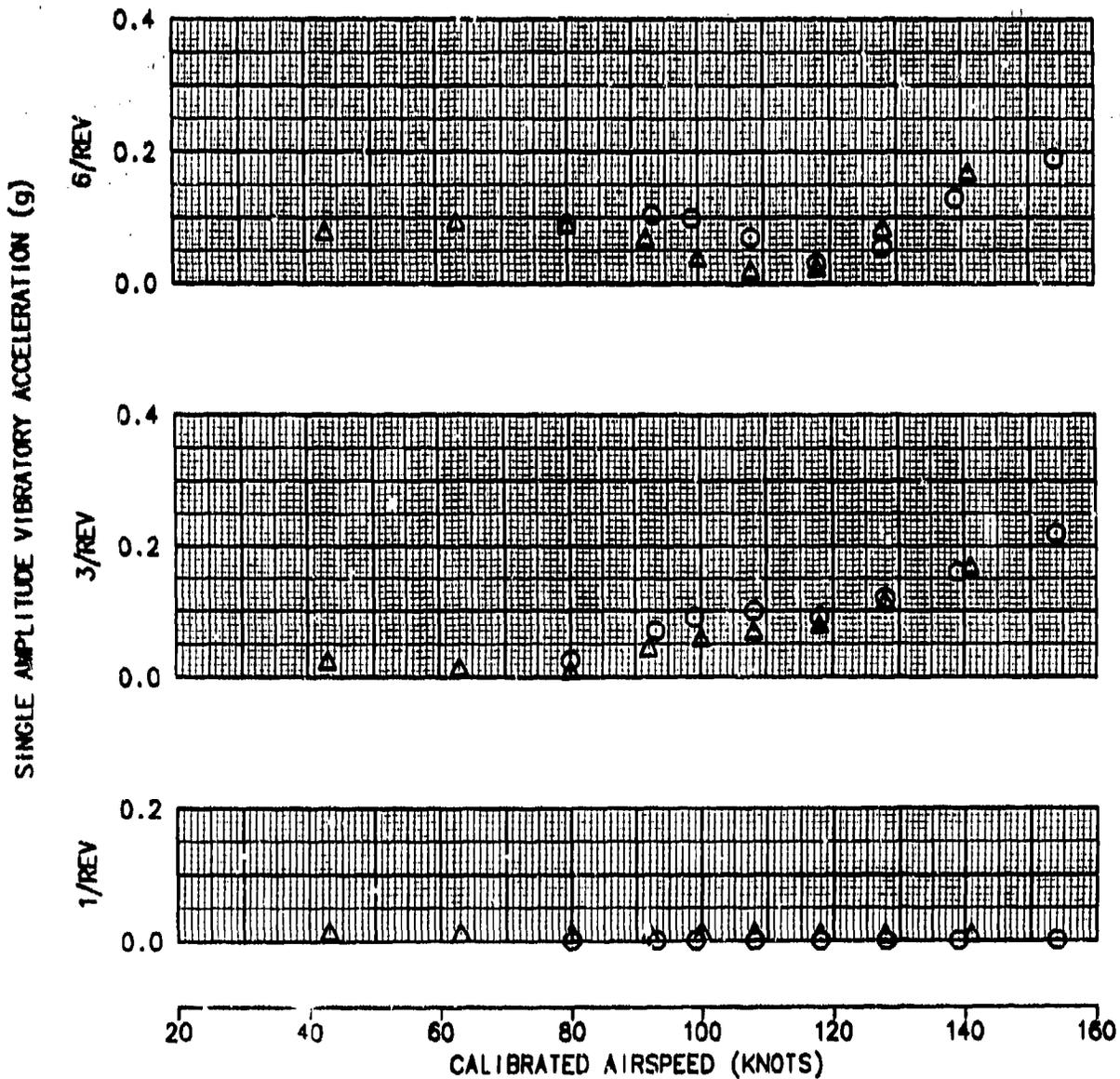


FIGURE E-7
 VIBRATION CHARACTERISTICS
 CH-47D USA S/N 82-23763

VERTICAL VIBRATIONS AT COCKPIT FLOOR, FS 95, BL 0

SYM	AVG GROSS WEIGHT (LB)	AVG CG LOCATION		AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)	AIRCRAFT CONFIGURATION
		LONG (FS)	LAT (BL)				
⊙	35340	328.4	0.0	5120	23.0	228	PROBE ON
△	35520	328.4	0.0	4830	20.5	226	PROBE OFF

- NOTES: 1. LEVEL FLIGHT
 2. AWC MODIFICATION INCORPORATED

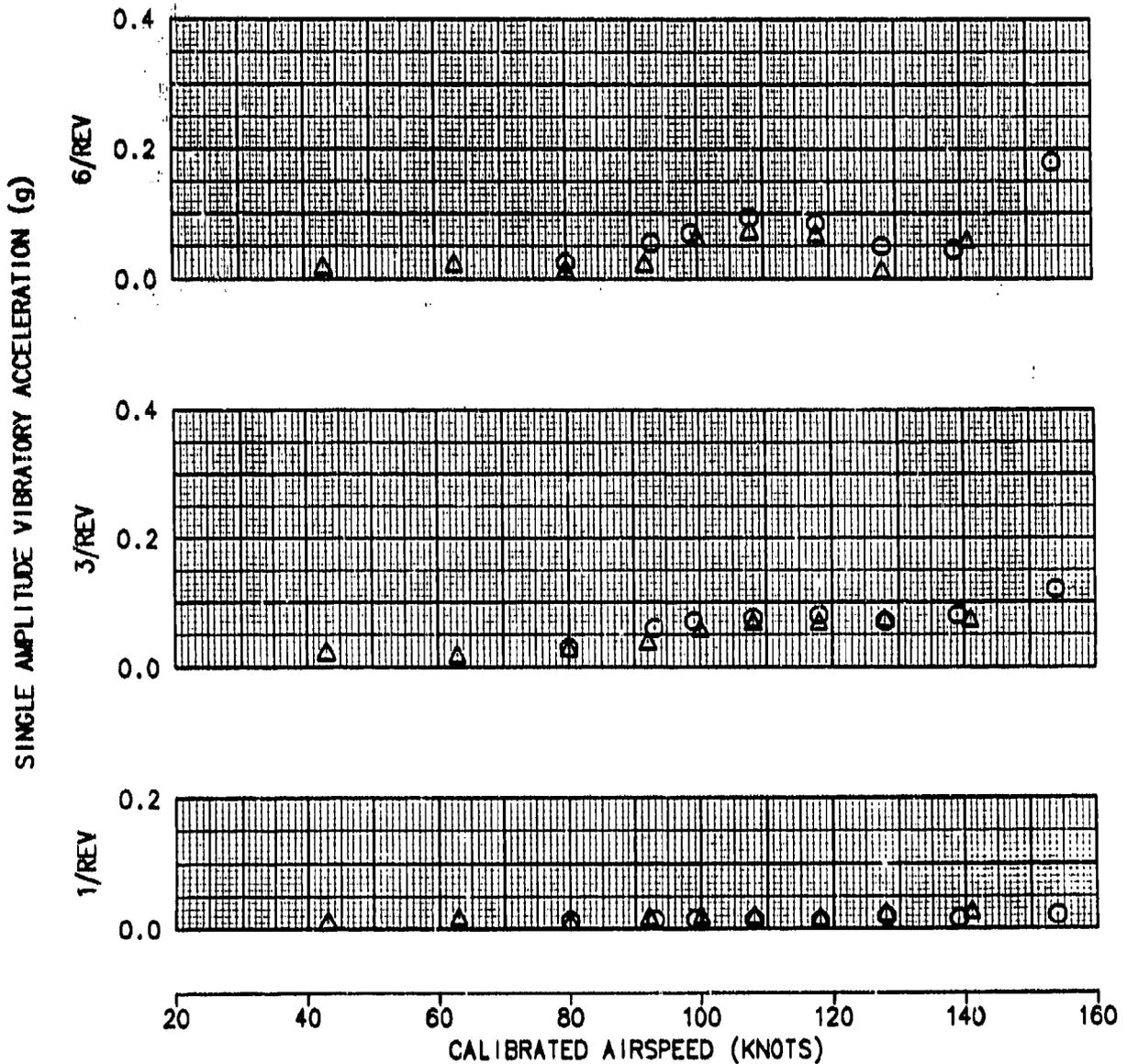


FIGURE E-8
 AERIAL REFUELING OPERATIONS
 PROBE STRUCTURAL LOADS
 CH-47D USA S/N 82-23763

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	TRIM ROTOR SPEED (RPM)	REFUELING AIRSPEED (KIAS)
46660	329.6(MID)	0.0	5100	17.5	225	115

- NOTES: 1. AIR CONDITIONS: MODERATE TURBULENCE
 2. REFUELING OPERATIONS TO THE RIGHT DROGUE
 3. AERIAL REFUELING CONFIGURATION WITH AWC MODIFICATION INCORPORATED

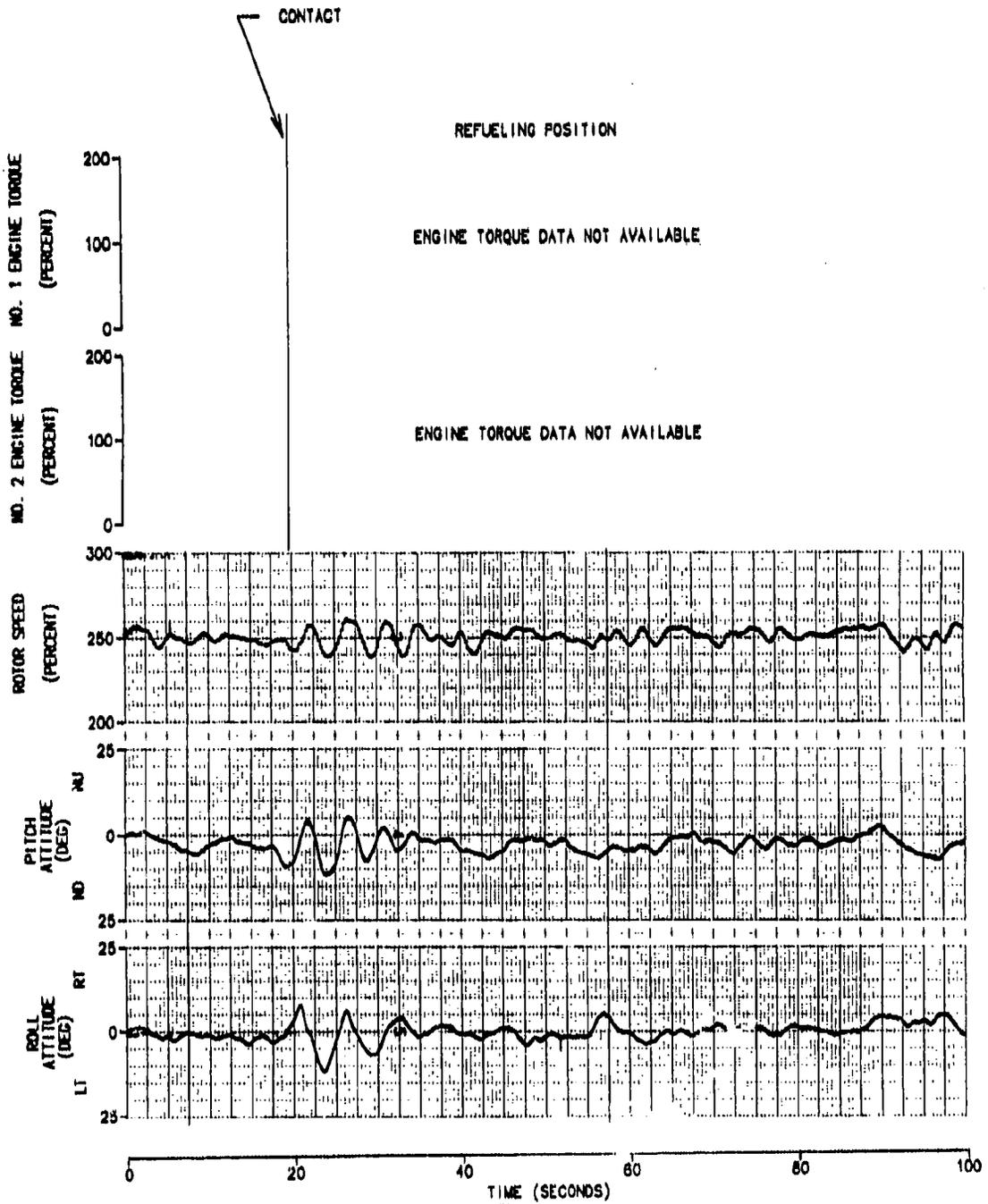


FIGURE E-8 (CONTINUED)
 AERIAL REFUELING OPERATIONS
 PROBE STRUCTURAL LOADS
 CH-47D USA S/N 82-23763

AVG GROSS WEIGHT (LB)	AVG CG LOCATION		AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	TRIM ROTOR SPEED (RPM)	REFUELING AIRSPEED (KIAS)
	LONG (FS)	LAT (DL)				
48660	329.6(MID)	0.0	5100	17.5	225	115

- NOTES: 1. AIR CONDITIONS: MODERATE TURBULENCE
 2. REFUELING OPERATIONS TO THE RIGHT DROGUE
 3. AERIAL REFUELING CONFIGURATION WITH AVG MODIFICATION INCORPORATED

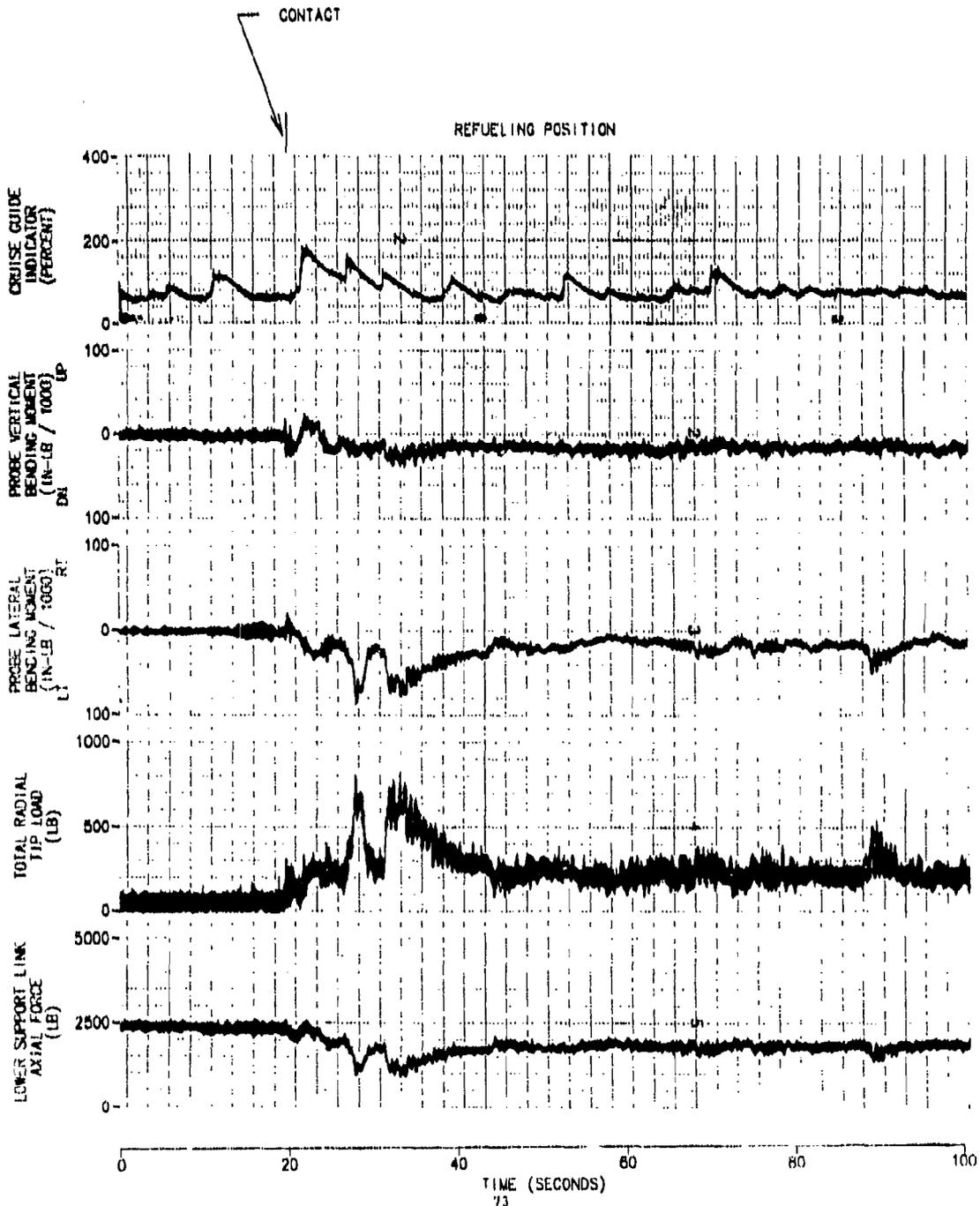


FIGURE E-9
 AERIAL REFUELING OPERATIONS
 PROBE STRUCTURAL LOADS
 OFF-CENTER DISCONNECT
 CH-47D USA S/N 82-23763

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	TRIM ROTOR SPEED (RPM)	REFUELING AIRSPEED (KIAS)
30430	318.3(MID)	0.0	5940	11.0	225	110

- NOTES: 1. AIR CONDITIONS: NON-TURBULENT
 2. REFUELING OPERATIONS TO THE RIGHT DROGUE
 3. AERIAL REFUELING CONFIGURATION WITH AWC MODIFICATION INCORPORATED

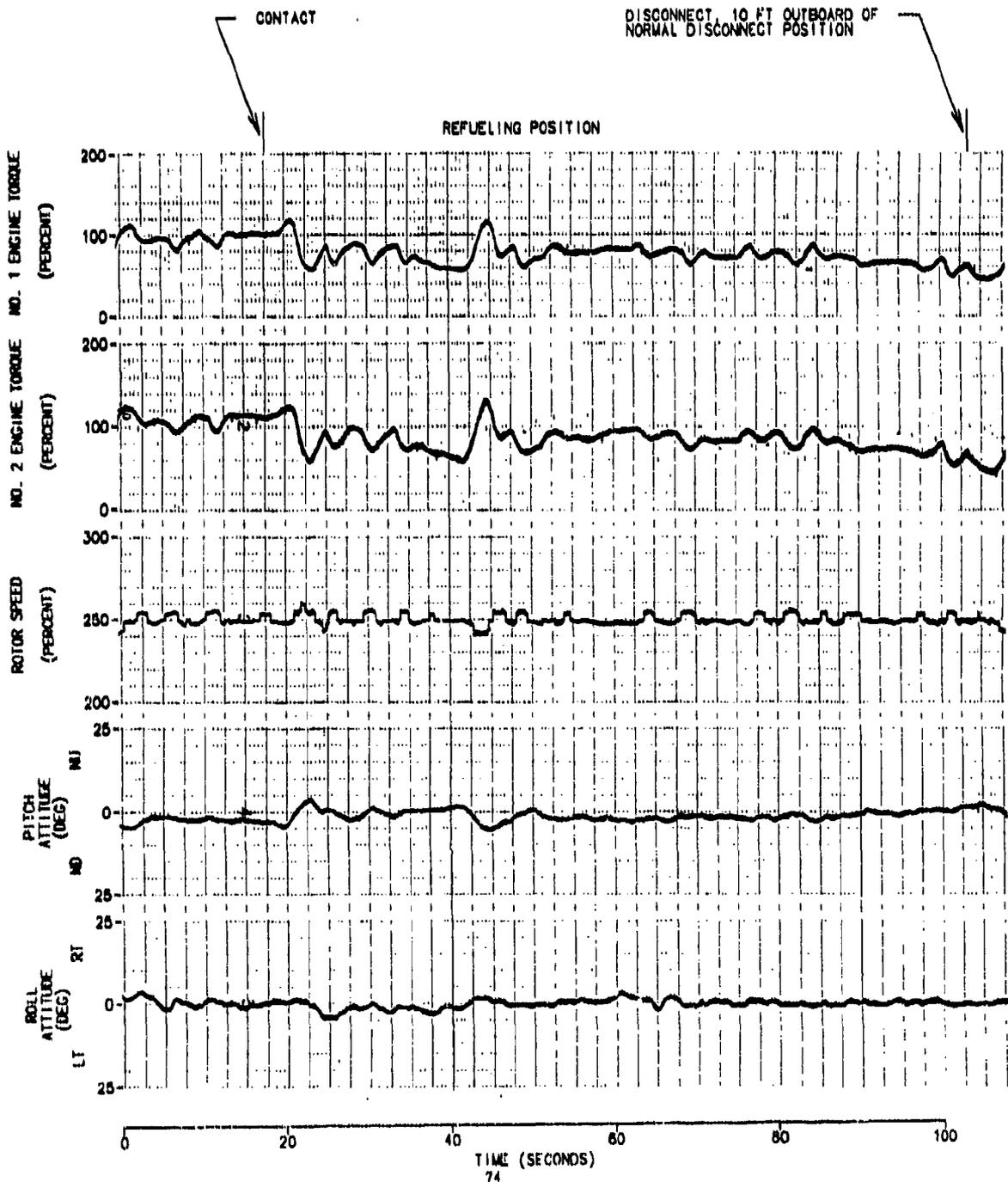
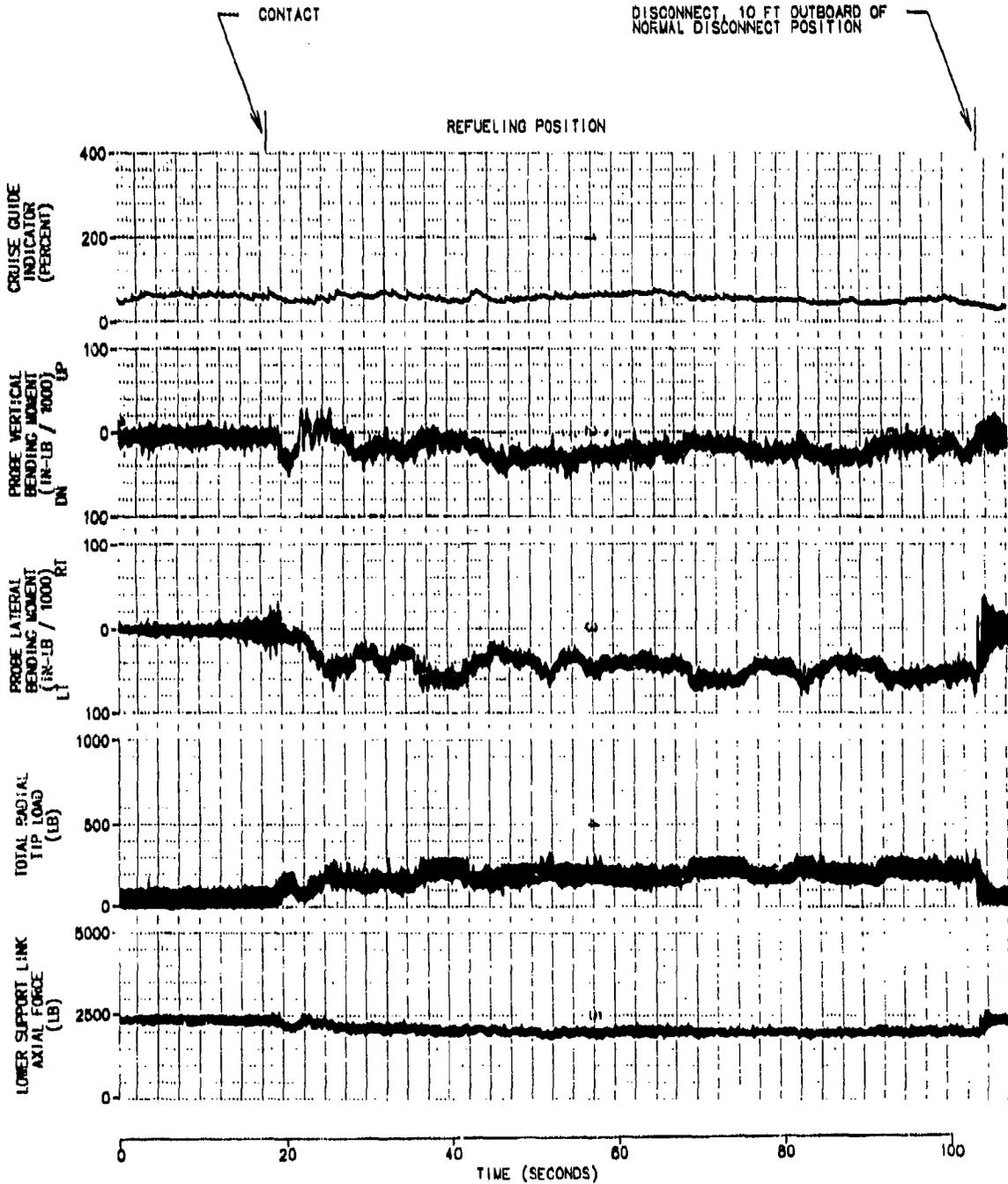


FIGURE E-9 (CONTINUED)
 AERIAL REFUELING OPERATIONS
 PROBE STRUCTURAL LOADS
 OFF-CENTER DISCONNECT
 CH-47D USA S/N 82-23763

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	TRIM ROTOR SPEED (RPM)	REFUELING AIRSPEED (KIAS)
30430	318.3(MID)	0.0	5940	11.0	225	110

- NOTES: 1. AIR CONDITIONS: NON-TURBULENT
 2. REFUELING OPERATIONS TO THE RIGHT DROGUE
 3. AERIAL REFUELING CONFIGURATION WITH AWC MODIFICATION INCORPORATED



DISTRIBUTION

HQDA (DALO-AV)	1
HQDA (DALO-FDQ)	1
HQDA (DAMO-HRS)	1
HQDA (SARD-PPM-T)	1
HQDA (SARD-RA)	1
HQDA (SARD-WSA)	1
US Army Materiel Command (AMCDE-SA, AMCDE-P, AMCQA-SA, AMCQA-ST)	4
US Training and Doctrine Command (ATCD-T, ATCD-B)	2
US Army Aviation Systems Command (AMSAV-8, AMSAV-Q, AMSAV-MC, AMSAV-ME, AMSAV-L, AMSAV-N, AMSAV-GTD)	8
US Army Test and Evaluation Command (AMSTE-TE-V, AMSTE-TE-O)	2
US Army Logistics Evaluation Agency (DALO-LEI)	1
US Army Materiel Systems Analysis Agency (AMXSU-RV, AMXSU-MP)	8
US Army Operational Test and Evaluation Agency (CSTE-AVSD-E)	2
US Army Armor School (ATSB-CD-TE)	1
US Army Aviation Center (ATZQ-D-T, ATZQ-CDC-C, ATZQ-TSM-A, ATZQ-TSM-S, ATZQ-TSM-LH)	5
US Army Combined Arms Center (ATZL-TIE)	1
US Army Safety Center (PESC-SPA, PESC-SE)	2
US Army Cost and Economic Analysis Center (CACC-AM)	1
US Army Aviation Research and Technology Activity (AVSCOM)	3
NASA/Ames Research Center (SAVRT-R, SAVRT-M (Library))	

US Army Aviation Research and Technology Activity (AVSCOM)	2
Aviation Applied Technology Directorate (SAVRT-TY-DRD, SAVRT-TY-TSC (Tech Library)	
US Army Aviation Research and Technology Activity (AVSCOM)	1
Aeroflightdynamics Directorate (SAVRT-AF-D)	
US Army Aviation Research and Technology Activity (AVSCOM)	1
Propulsion Directorate (SAVRT-PN-D)	
Defense Technical Information Center (FDAC)	2
US Military Academy, Department of Mechanics (Aero Group Director)	1
ASD/AFXT, ASD/ENF	2
US Army Aviation Development Test Activity (STEBG-CT)	2
Assistant Technical Director for Projects, Code: CT-24 (Mr. Joseph Dunn)	2
6520 Test Group (ENML)	1
Commander, Naval Air Systems Command (AIR 5115B, AIR 5301)	3
Defense Intelligence Agency (DIA-DT-2D)	1
School of Aerospace Engineering (Dr. Daniel P. Schrage)	1
Headquarters United States Army Aviation Center and Fort Rucker	1
(ATZQ-ESO-L)	
Commander, US Army Aviation Systems Command (AMSAV-EA)	1
Commander, US Army Aviation Systems Command (AMSAV-ECH)	1
Commander, US Army Aviation Systems Command (AMSAV-6)	2
Commander, US Army Aviation Systems Command (AMCPM-SOA)	2