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US ARMY
AVIATION
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FLIGHT CHARACTERISTICS TEST OF THE UH-60A WITH TAIL BOOM MOUNTED STRAKE

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FINAL REPORT

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US ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523 - 5000

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cyclic control displacement (increase in control margin) required in right sideward flight. There was a minor improvement in longitudinal cyclic pilot workload in left and right sideward flight to 15 KTAS. The pilot did not detect a significant difference in flying qualities with the strake installed. This test reflected little change with the strake installed. Also previous US Army Aviation Engineering Flight Activity performance and flying qualities evaluations of the UH-60A helicopter without a tail boom mounted strake have found no control margin or power required problems with sideward flight. Consequently, no further strake testing should be conducted on the UH-60A helicopter. The UH-1H helicopter, which has a documented problem with tail rotor control margins during hover and sideward flight, should be considered a candidate for a tail boom strake evaluation.

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INTRODUCTION

BACKGROUND

1. The Aerostructure Directorate, US Army Aviation Research and Technology Activity, has shown that the installation of a strake (i.e., a spoiler attached to the upper left shoulder of the tail boom) on a helicopter can result in improved sideward flight capability and reduction of tail rotor power required in hover and sideward flight. These results were obtained from tests conducted in NASA Langley's 4x7 meter wind tunnel using two-dimensional tail boom cross sections. Preliminary flight tests of the strake mounted on an OH-58A helicopter have confirmed that there may be an improvement in hover and sideward flight capability due to the strake. The effects of a strake on the UH-60A was expected to be much more significant because the tail boom cross sectional area is larger and the main rotor disk loading is much higher than that of the OH-58A helicopter. As a result, the US Army Aviation Systems Command (AVSCOM) requested the US Army Aviation Engineering Flight Activity (USAAEFA) to conduct a flight characteristics test of the UH-60A helicopter with a tail boom mounted strake installed (ref 1, app A).

TEST OBJECTIVE

2. The objective of this test was to evaluate the effect of a strake mounted on the tail boom of the UH-60A helicopter.

DESCRIPTION

3. The UH-60A Black Hawk helicopter is a twin-turbine, single main rotor helicopter capable of transporting cargo, 11 combat troops, and weapons during day, night, visual meteorological conditions, and instrument meteorological conditions. Conventional wheel-type landing gear are provided. The main and tail rotors are both four-bladed. Manual main rotor blade and tail pylon folding capabilities are provided for air transportability. A moveable horizontal stabilator is located on the lower portion of the tail rotor pylon. The helicopter is powered by two T700-GE-700 turboshaft engines having an installed thermodynamic rating (30 minute) of 1553 shaft horsepower (shp) (power turbine speed of 20,900 rpm) each at sea level, standard day static conditions. Installed dual engine power is transmission limited to 2828 shp. A more detailed description of the UH-60A helicopter is available in the Prime Item Development Specification (PIDS) (ref 2, app A), appendix B and the operator's manual (ref 3).

4. The test helicopter, JUH-60A US Army S/N 82-23748, is a sixth year production Black Hawk which incorporates the External Stores Support System fixed provisions and the modified production stabilator schedule. The test aircraft also incorporated reoriented airspeed probes and engineering change proposal 0252 which upgraded the airspeed system with the production restrictors, one piece spacer blocks, and fairings.

5. The tailboom strake is comprised of four 0.063 inch (in.) 6061-T6 aluminum alloy sections each 3.0 in. in height, 2.5 in. in width at the base, and 40 in., nominally, in length. When fastened end to end to the left side of the UH-60A tailboom, the four sections run from fuselage station 485 to 643 and are offset from the vertical axis of the aircraft by approximately 40 degrees (deg). The base of the strake is curved to prevent chaffing the rivet heads of the UH-60A tailboom surface and is fastened by means of aircraft structural screws anchored through self locking nut plates. The 3.0 in. high aerodynamic surface of the strake is oriented 90 deg from the base so as to be normal to the UH-60A tailboom skin at the point of installation. The strake was manufactured and installed by USAAEFA. Photographs of the test helicopter tailboom strake and tufting as well as a more detailed description of the tailboom strake and its installation are included in appendix B.

TEST SCOPE

6. Flight testing was conducted at Edwards Air Force Base, California (2302 feet elevation). A total of 8 flights were conducted between 14 January 1986 and 19 August 1986 for a total of 6.9 flight hours of which 2.0 were productive (flown 11 through 19 August 1986). Productive flights were limited to low speed flight characteristics in right (90 deg azimuth) and left (270 deg azimuth) sideward flight. USAAEFA calibrated and maintained all the test instrumentation and performed all required maintenance on the helicopter. Flight restrictions and operating limitations observed during the evaluation are contained in the operator's manual (ref 3, app A) and the airworthiness release (ref 4). Testing was conducted at the conditions shown in table 1 in accordance with the test plan (ref 5) approved by AVSCOM.

Table 1. Test Conditions¹

Flight	Strake	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)
1	OFF	20200	347.2	3730
2 ²	ON	20180	347.1	3600
3	ON	20390	347.0	3420

NOTES:

¹Normal utility configuration, main rotor speed of 258 rpm, and mid lateral center of gravity location; Boost, Stability Augmentation System, Flight Path Stabilization and Trim - ON, Pitch Bias Actuator electrically disconnected at 2.7 in.

²Flight aborted when surface winds exceeded 5 knots.

TEST METHODOLOGY

7. A detailed listing of the test instrumentation is contained in appendix C. Established flight test techniques and data reduction procedures were used (ref 6, app A) and are described in appendix D. The flight test data were obtained from test instrumentation displayed on the instrument panel and recorded by onboard magnetic tape recording equipment.

RESULTS AND DISCUSSION

GENERAL

8. Tests were conducted to evaluate low speed flight at the conditions presented in table 1 to determine the performance and handling qualities of the UH-60A helicopter both with and without the strake installed. Testing was performed at speeds up to approximately 45 knots true airspeed (KTAS) in left and right sideward flight. A calibrated pace vehicle was used as a speed reference. The helicopter was flown in-ground effect at a wheel height of approximately 15 feet. The low speed flight test data are presented in figures 1 through 3, appendix E. The "I" bars denote the minimum and maximum excursions of control positions, engines and tail rotor torques, and tail rotor impress angles during the stabilized data points. The "I" bars are included to indicate pilot workload. Testing was terminated after three productive flights when no significant improvement in performance or handling qualities was noted with the strake installation.

PERFORMANCE

9. The performance of the UH-60A helicopter was compared with and without the strake during hover and sideward flight up to 45 KTAS (fig. 1, app E) while maintaining approximately the same ratio of weight over sigma. Engine torque required for left sideward flight was the same with and without the strake installed. Engine torque required for hover and right sideward flight was slightly higher (15 to 50 ft-lb) with the strake installed. Tail rotor torque required was the same (strake installed or uninstalled) during hover and left sideward flight up to 35 KTAS. From 35 to 45 KTAS left sideward flight and from 5 to 20 KTAS and 35 to 45 KTAS in right sideward flight there was a slight reduction (0 to 30 ft-lb) of tail rotor torque required with the strake installed. Power required variations as a result of the strake installation were inconsistent and not significant. The UH-60A helicopter's overall performance during hover and sideward flight to 45 KTAS was essentially unchanged by the strake installation.

HANDLING QUALITIES

10. Handling qualities data with and without the strake installed were compared during sideward flight up to 45 KTAS (fig 1, app E) to determine the effects of the strake on flight control margins. The directional control positions were similar for hover and sideward flight up to 35 KTAS left and right. From 35 to 45 KTAS left, sideward flight there was up to a 0.3 in. increase

of right pedal required (decrease in control margin) with the strake installed. At speeds of 35 to 45 KTAS right sideward flight there was up to a 0.25 in. decrease of left pedal required (increase in control margin). Longitudinal cyclic control positions were similar during flights with the strake installed and uninstalled. Lateral cyclic positions were similar for hover and left sideward flight up to 35 KTAS. From 35 to 45 KTAS left sideward flight there was a requirement for up to 0.2 in. of additional left cyclic (reduction of control margin) with the strake installed. Right sideward flight required approximately 0.3 to 0.4 in. less right cyclic (increase in control margin) control with the strake installed. Flying qualities (as determined by flight control excursions, annotated by "I" bars on figs. 2 and 3, app E) were compared for flight with the strake installed and uninstalled during sideward flight. Directional control excursions were similar up to 35 KTAS during left sideward flight. At 35 to 45 KTAS left sideward flight, the directional pedal excursions were reduced by +0.5 in. to +0.3 in. when the strake was installed. Longitudinal cyclic excursions were reduced when the strake was installed during hover and left and right sideward flight to 15 KTAS (by +0.5 to +0.2 in.). Longitudinal cyclic excursions were also decreased by +0.8 to +0.6 in. during flight at 15 to 45 KTAS left sideward flight with the strake installed. There was no change in longitudinal cyclic control excursions during right sideward flight above 15 KTAS. There were no changes in lateral or collective control excursions noted with the strake on or off. The strake installation on the UH-60A helicopter had no significant effect on flight control margins. A slight improvement in longitudinal cyclic workload during left and right sideward flight to 15 KTAS was noted. The pilot did not detect a significant difference in handling qualities with or without the strake installed.

11. The Aerostructure Directorate, US Army Aviation Research and Technology Activity expected improvements in hovering performance and flying qualities with reduced pedal requirement in sideward flight (as indicated in ref 7, app A) for a strake installation on the UH-60A helicopter. Since no significant improvements were noted, testing was terminated after three productive flights. Since this test reflected little change with the strake installation and since previous USAAF performance and handling qualities reports on the aircraft have found no control margin or power required problems during sideward flight, no further strake testing should be considered on the UH-60A. The UH-1H helicopter which has a documented problem with tail rotor control margins during hover and sideward flight (ref 8) might be a much better candidate for a tail boom strake evaluation.

12. Early termination of the test precluded compliance testing to the PIDS requirements (ref 2, app A) with the strake installed.

CONCLUSIONS

13. The overall performance and handling qualities of the UH-60A helicopter during hover and sideward flight to 45 KTAS was essentially unchanged by the installation of the strake.

a. The overall performance of the UH-60A helicopter was essentially unchanged by the installation of the strake (para 9).

b. There was no significant effect of the strake installation on the UH-60A helicopter flight control margins, except for a slight reduction in right cyclic control displacement (increase in control margin) required in right sideward flight (para 10).

c. There was a minor reduction in longitudinal cyclic workload during left and right sideward flight to 15 KTAS. The pilot did not detect a significant difference in overall handling qualities with the strake installed (para 10).

RECOMMENDATIONS

14. The following recommendations are presented regarding the flight characteristics of the UH-60A helicopter with a tail boom mounted strake:

a. No further strake testing should be conducted on the UH-60A (para 11).

b. The UH-1H helicopter has a documented problem with tail rotor control margins during hover and sideward flight and should be considered for a tail boom strake evaluation (para 11).

APPENDIX A. REFERENCES

1. Letter, AVSCOM, AMSAV-ED, undated, Subject: Flight Characteristics Test of the UH-60A with Tail Boom Mounted Strake, USAAEFA Project 85-07.
2. Prime Item Development Specification, Sikorsky Aircraft Division, DARCOM CP-2222-S1000F, 18 December 1981.
3. Technical Manual, TM 55-1520-237-10, *Operator's Manual, UH-60A Helicopter*, Headquarters Department of the Army, 21 May 1979 with change 37 dated 17 July 1986.
4. Letter, AVSCOM, AMSAV-E, 31 July 1986, subject: Release of UH-60A BLACKHAWK Helicopter S/N 82-23748 to Conduct a Flight Evaluation of the UH-60A Helicopter with Tail Boom Strake Installed and Two (2) Light Weight Video Cameras Installed on the Stabilator, USAAEFA Project No. 85-07.
5. Test Plan, USAAEFA Project No. 85-07, *Flight Characteristic Test of the UH-60A with Tail Boom Mounted Strake*, June 1985.
6. Flight Test Manual, Naval Air Test Center, FTM No. 101, *Helicopter Stability and Control*, 10 June 1968.
7. Letter, National Aeronautics and Space Administration, Langley Research Center, 14 December 1984, subject: Request for Flight-Test Investigation of Tail Boom Strake on UH-60 BLACKHAWK.
8. Final Report, USAASTA Project No. 71-18, *Tail Rotor Performance and Translational Flight Handling Qualities Tests UH-1H Helicopter*, January 1972.
9. Final Report, USAAEFA Project No. 84-28, *Flight Evaluation of the UH-60A Helicopter with the Pitch Bias Actuator (PBA) Locked and Centered*, to be published.
10. Final Report, USAAEFA Project No. 86-01, *Level Flight Performance Evaluation of the UH-60A Helicopter with the Production External Stores Support System and Ferry Tanks Installed*, to be published.

APPENDIX B. DESCRIPTION

GENERAL

1. The Sikorsky UH-60A (Black Hawk) is a twin turbine engine, single main rotor helicopter capable of transporting 11 combat troops plus a crew of three. It is equipped with three nonretractable conventional wheel-type landing gear. A movable horizontal stabilator is located on the lower portion of the tail rotor pylon. The main and tail rotors are both four-bladed with a capability of manual main rotor blade and tail pylon folding. The cross-beam tail rotor with composite blades is attached to the right side of the pylon and is canted 20 deg upward from the horizontal. The primary power plants for the UH-60A helicopter are two General Electric T700-GE-700 front drive turboshaft engines, each rated at 1553 shaft horsepower (shp) (30 minute limit) at a power turbine speed of 20,900 revolutions per minute (rpm) (sea level, standard day, installed). A complete description of the aircraft is contained in the operator's manual (ref 3, app A).

BASIC AIRCRAFT INFORMATION

2. General data of the UH-60A helicopter are as follows:

Gross Weight

Maximum gross weight	20,250 lb
Empty weight	Approximately 10,620 lb
Primary mission gross weight	16,324 lb
Fuel capacity (measured)	360 gal

Main Rotor

Number of blades	4
Diameter	53 ft, 8 in.
Blade chord	1.73/1.75 ft
Blade twist	-18 deg (equivalent)
Blade tip sweep	20 deg aft
Blade area (one blade)	46.7 sq ft
Airfoil	
section (root to tip designation)	SC1095/SC1095R8
thickness (percent chord)	9.5 percent
Main rotor mast tilt (forward)	3 deg

Tail Rotor

Number of blades	4
Diameter	11 ft

Blade chord	0.81 ft
Blade twist (equivalent linear)	-18 deg
Blade area (one blade)	4.46 sq ft
Airfoil	
section (root to tip designation)	SC1095/SC1095R8
thickness (percent chord)	9.5 percent
Cant angle	20 deg

Gear Ratios

	<u>Input rpm</u>	<u>Output rpm</u>	<u>Ratio</u>
Engine to main rotor	20,900.0	257.9	81.0419
Engine to tail rotor	20,900.0	1189.8	17.5658
Tail rotor to main rotor	1189.8	257.9	4.6136

STRAKE INSTALLATION

3. The UH-60A tailboom strake (photos 1 and 2) is comprised of four 0.063 in. AL ALY 6061-TG sections, FED SPEC QQ-A-250/11 stock, each 3.0 in. in height, 2.5 in. in width at the base, and 40 in., nominally, in length. When fastened end to end to the left side of the UH-60A tailboom the four sections run from fuselage station 435 to 643 and are offset from the vertical axis of the aircraft by approximately 40 deg. The base of the strake sections which fasten to the tailboom skin employ a curvature across their width which is more severe than that of the tailboom in order that the strake sections may ride above existing tailboom rivet heads and prevent rivet chaffing. The radius of curvature for the sections are 2.5 in. and 3.0 in. for the two rear sections and two forward sections, respectively. Both ends of each strake segment are chamfered at 0.50 in. x 45 deg. The free edge along the base of the strake (uppermost edge when mounted onto the tailboom) has been modified with a slight 0.50 in. radius reflex to prevent chaffing of the aircraft skin along the length of the strake. The transition from the base of the strake to the 90 deg extension also utilizes a 0.50 in. radius of curvature. Additionally, slight cutaways exist in the forward most and two aft segments to allow for clearance of existing rivet patterns along bulkheads within the tailboom. The radius of each corner in all cutaways is 0.125 in. Blind rivets along the tailboom at the points of attachment of the strake were

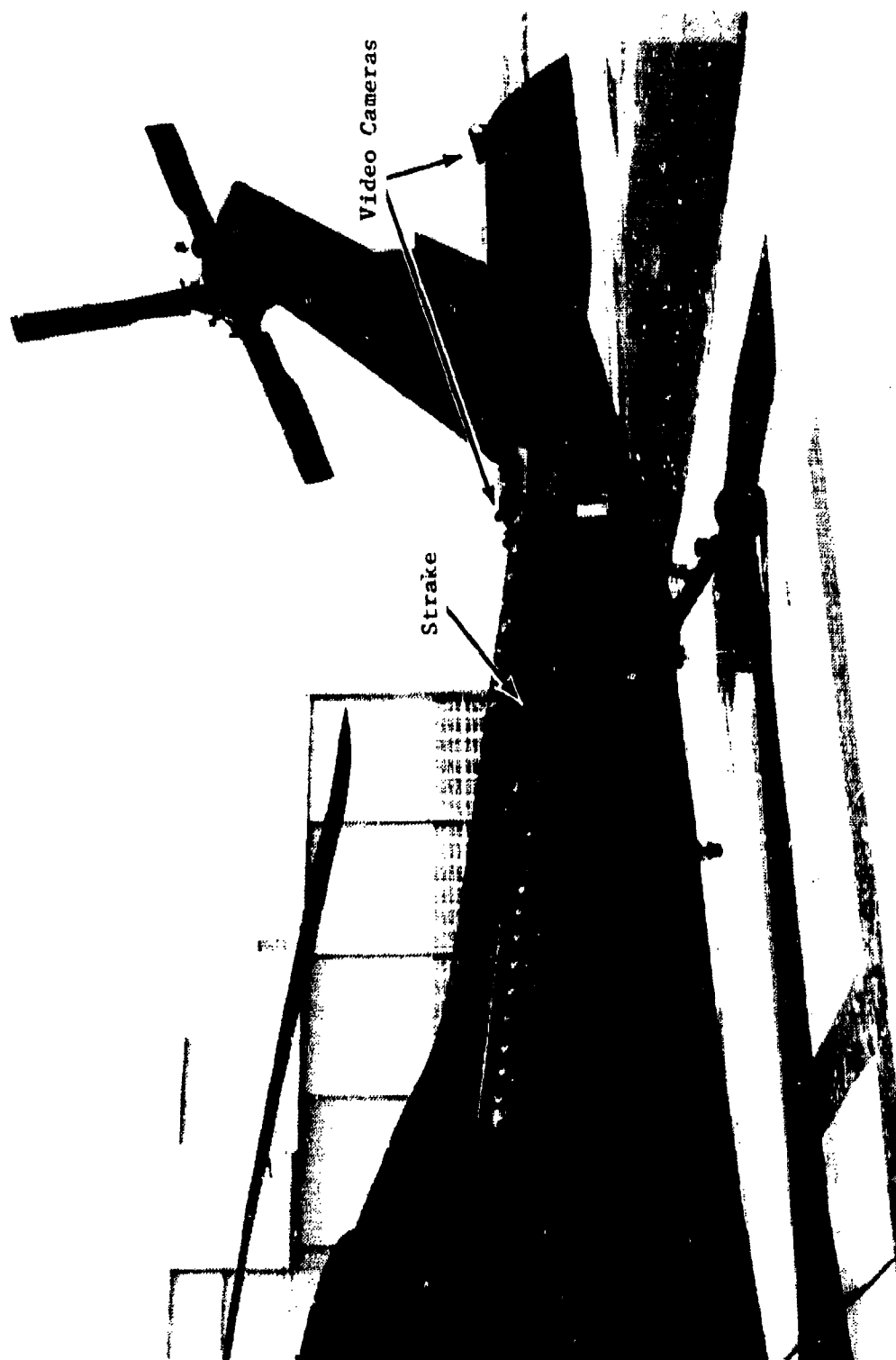


Photo 1. Left Side View of Tail Boom Mounted Strake, Tufts and Stabilator
Mounted Cameras

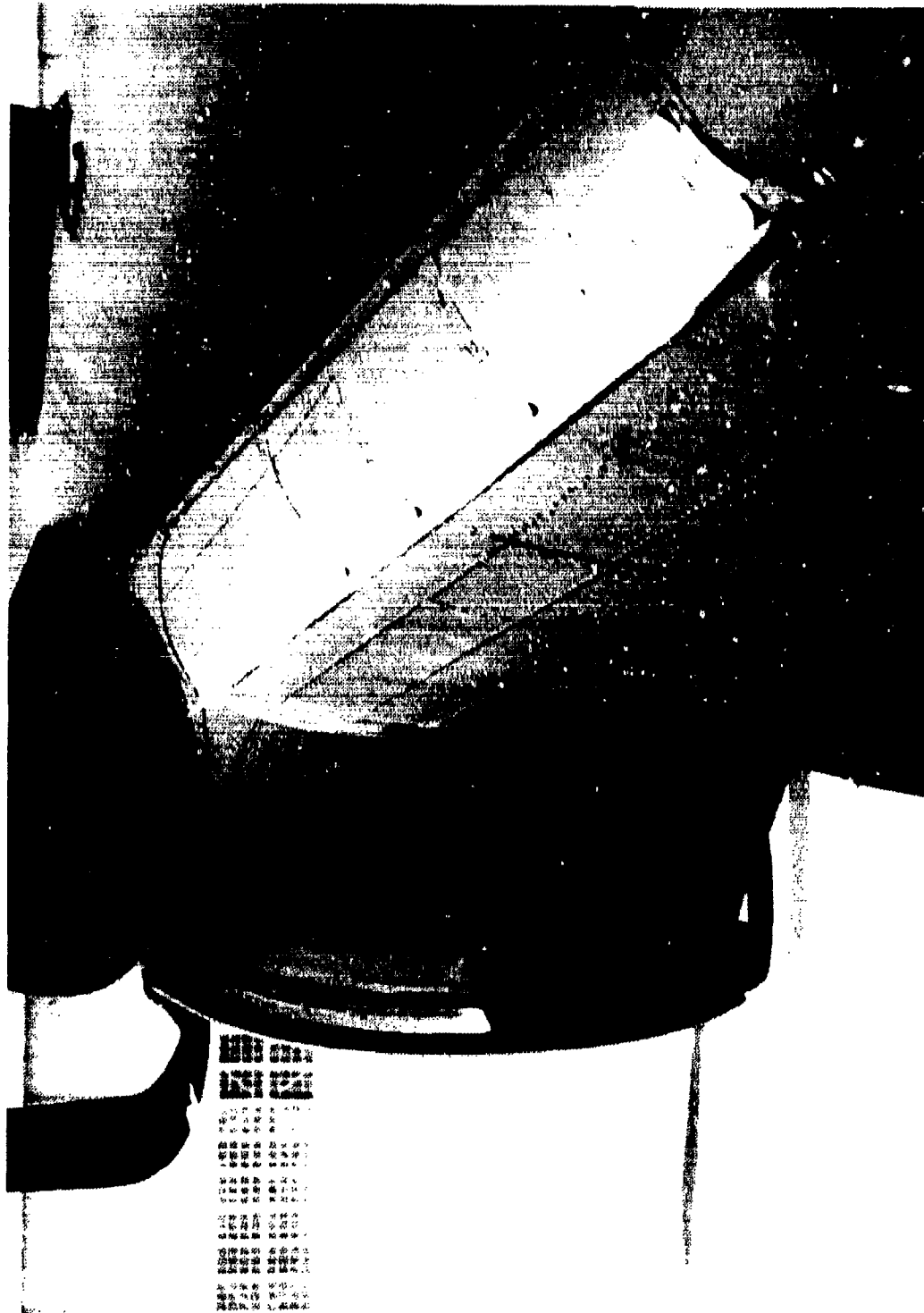


Photo 2. Close-up of Tail Boom Mounted Strake (Looking Forward Left Side)

periodically replaced by stainless steel self-locking nut plates, (D.A. 500-83-V-N248), which are fastened with AN426 AD3-6 solid aluminum rivets where work space permitted, and DLA 500-85-M-Y734 blind aluminum rivets elsewhere. The strake is secured with MS-27039 1/7 10/32 in. aircraft structural screws. The longest span between successive nut plates is 5 in. The ends of each strake segment extend no more than 2.25 in. from the closest nut plate, with the only exception being the forward end of the forward segment, where the closest nut plate is 4.75 in. aft. The strake was manufactured and installed by the US Army Aviation Engineering Flight Activity.

APPENDIX C. INSTRUMENTATION

GENERAL

1. The test instrumentation was installed, calibrated and maintained by US Army Aviation Engineering Flight Activity personnel. A swiveling pitot-static tube and angle of attack and side-slip vanes were installed on a test boom 162 in. forward of the nose of the aircraft and 29 in. to the right of centerline. Also installed were two video cameras, one mounted at each stabilator tip, for the purpose of monitoring the aerodynamic behavior of the tailboom tufting during testing (photo 1, app B). Each camera assembly weighed approximately 2.7 lb. Images were recorded on tape adjacent to the engineer's station and observed in real time using a video monitor nearby. Equipment required only for specific tests was installed when needed and is discussed in the section on special equipment (para 2). Data was obtained from calibrated instrumentation and displayed or recorded as indicated below.

Pilot Position

Altitude (radar-dual range)*
Rotor speed (sensitive)
Engine torque* **
Turbine gas temperature (T4.5)* **
Engine gas generator speed * **
Control positions
 Longitudinal
 Lateral
 Pedal
 Collective
Stabilator position
Event switch

Copilot/Engineer Station

Rotor speed*
Engine torque* **
Total air temperature
Fuel used (totalizer)
Ballast cart position
Time code display
Run number
Event switch

*Ship system/not calibrated

**Both engines

Digital Pulse Code Modulation Data Parameters

Altitude (radar)
Total air temperature
Rotor speed
Engine torque**
Turbine gas temperatures (T4.5)**
Engine gas generator speed**
Engine power turbine speed**
Engine fuel flow**
Engine fuel used**
Engine fuel temperature (at fuel used transducer)**
Auxiliary Power Unit (APU) fuel used
APU fuel temperature (at fuel used transducer)
Tail rotor shaft torque
Tail rotor impress pitch
Stabilator position
Ballast cart position
Control positions
 Longitudinal
 Lateral
 Pedal
 Collective
Stability augmentation system output position
 Longitudinal
 Lateral
 Directional
Control mixer input position
 Longitudinal
 Lateral
 Directional
Aircraft attitude
 Pitch
 Roll
 Yaw
Aircraft angular rate
 Pitch
 Roll
 Yaw
Linear acceleration
 Center of gravity normal
 Center of gravity lateral
 Center of gravity longitudinal
Time of day
Run number

**Both engines

Data status words
Pilot event
Engineer event

SPECIAL EQUIPMENT

Ground Pace Vehicle

2. A vehicle utilizing a calibrated fifth wheel to determine accurate ground speed was used in conjunction with wind speed and direction to provide a precise true airspeed reference for the test aircraft during low speed tests.

Weather Station

3. A portable weather station, consisting of an anemometer, sensitive temperature gage, and barometer, was used to record wind speed, wind direction, ambient temperature, and pressure altitude during low speed tests.

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

AIRCRAFT RIGGING

1. A flight controls engineering rigging check was performed on the main and tail rotors during a previous test program conducted by the US Army Aviation Engineering Flight Activity (USAAEFA) (ref 9, App A). The rigging data are presented in table 1.

AIRCRAFT WEIGHT AND BALANCE

2. A weighing accomplished during a previous test program conducted by USAAEFA was used as a reference for all strake testing (ref 10, app A). The aircraft was weighed in the instrumented condition with full fuel and oil onboard. In addition, the movable ballast system, the external stores support system (ESSS) wings with fairings and racks, four external fuel tanks, and load ballast at various fixed locations was installed during the weighing. With the weight of fuel, the weight of the ESSS, the weight of the external tanks, and the weight of fixed ballast subtracted from the total weight, the basic weight was 11918.8 pounds with the longitudinal center of gravity (cg) at fuselage station (FS) 356.5 (ballast cart cg FS 301). To this weight was added 5.5 pounds to account for remote video cameras located at FS 698.0 and 60.0 pounds to account for the video monitoring/recording equipment with support rack located at FS 278.0. The basic aircraft weight was therefore modified to 11,984.3 lb with a longitudinal cg at FS 356.3. This basic weight and cg was used in all subsequent strake testing.

3. The fuel weight for each flight was determined prior to engine start and following engine shutdown by using external sight gages to evaluate fuel volume and by measuring the specific weight of the fuel. Lead weights were secured inside the aircraft at fixed locations and within the movable ballast cart to adjust the weight and cg for test purposes. The ballast cart had a maximum capacity of 2664 lb and a total travel of 72.7 in. (FS 301 to FS 373.7). To maintain the desired weight during low speed testing, ballast was added periodically at FS 324.5 as fuel was burned at time intervals convenient to the orderly completion of test points. To maintain cg, the ballast cart was moved as required. The desired test weight was varied as required at the beginning of each flight to maintain a consistent gross weight over sigma ratio.

Table 1. Main and Tail Rotor Rigging Information

Main Rotor Rigging

Flight Control Position				Swashplate Tilt (Degrees)		Collective Blade Pitch at the Root (Degrees)
Collective	Longitudinal	Lateral	Pedal	Longitudinal	Lateral	
Low	*	*	*	-8.7	-2.1	9.6
High	*	*	*	-4.2	-3.3	24.3
Low	AFT	LT	*	-9.4	-7.4	8.8
High	AFT	LT	*	-9.2	-7.6	24.0
Low	FWD	RT	*	11.0	7.2	9.3
High	FWD	RT	*	17.3	6.5	23.4
High	AFT	LT	LT	-11.3	-7.7	23.6
Mid	AFT	LT	*	-11.7	-7.5	16.6
Mid	FWD	RT	*	-15.6	6.2	15.5
Mid	*	*	*	-7.4	-2.6	17.0

Tail Rotor Rigging

Flight Control Position		Collective Blade Pitch at the Root (Degrees)
Collective	Pedal	
Mid	LT	15.1
Mid	RT	16.2
Mid	MID	0.9
Low	MID	8.2
High	MID	7.6
High	LT	15.4
High	RT	7.5
Low	RT	16.5
Low	LT	7.3

*Indicates appropriate control was pinned.

TEST TECHNIQUES

4. Conventional test techniques were used during the conduct of the handling qualities tests. Detailed descriptions of the test techniques are contained in reference 6, appendix A.

APPENDIX E. TEST DATA

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Low Speed Flight Characteristics	
Strake Installed/Uninstalled Comparison	1
Strake Uninstalled Parameter Excursions	2
Strake Installed Parameter Excursions	3

FIGURE 1
LOW SPEED FLIGHT CHARACTERISTICS
STRAKE ON/OFF COMPARISON
LM-99A USA 3/4 82-23748

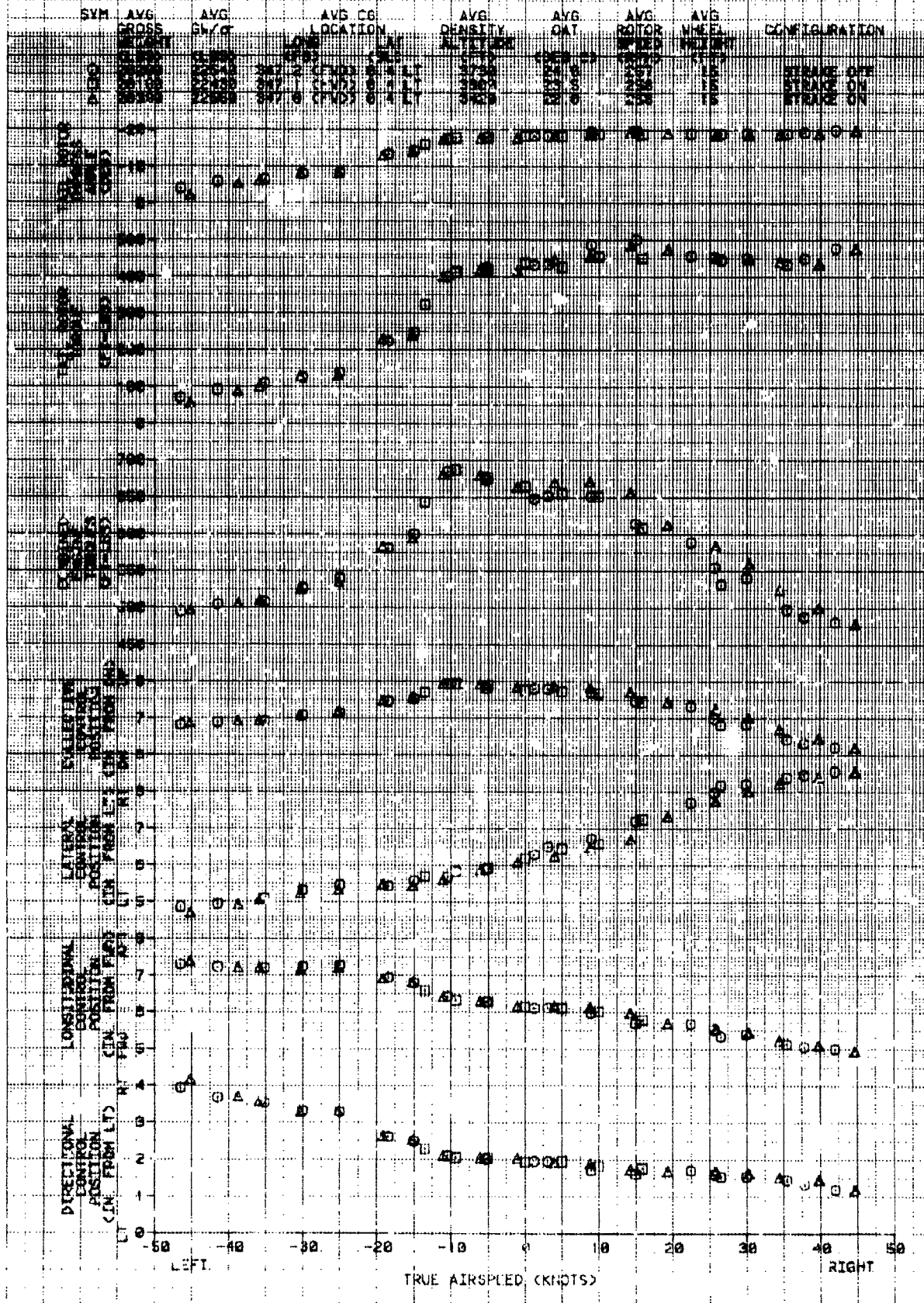


FIGURE 2
LOW SPEED FLIGHT CHARACTERISTICS
STRAKE OFF PARAMETER EXCURSIONS
UH-60A USA 6/4 82-28748

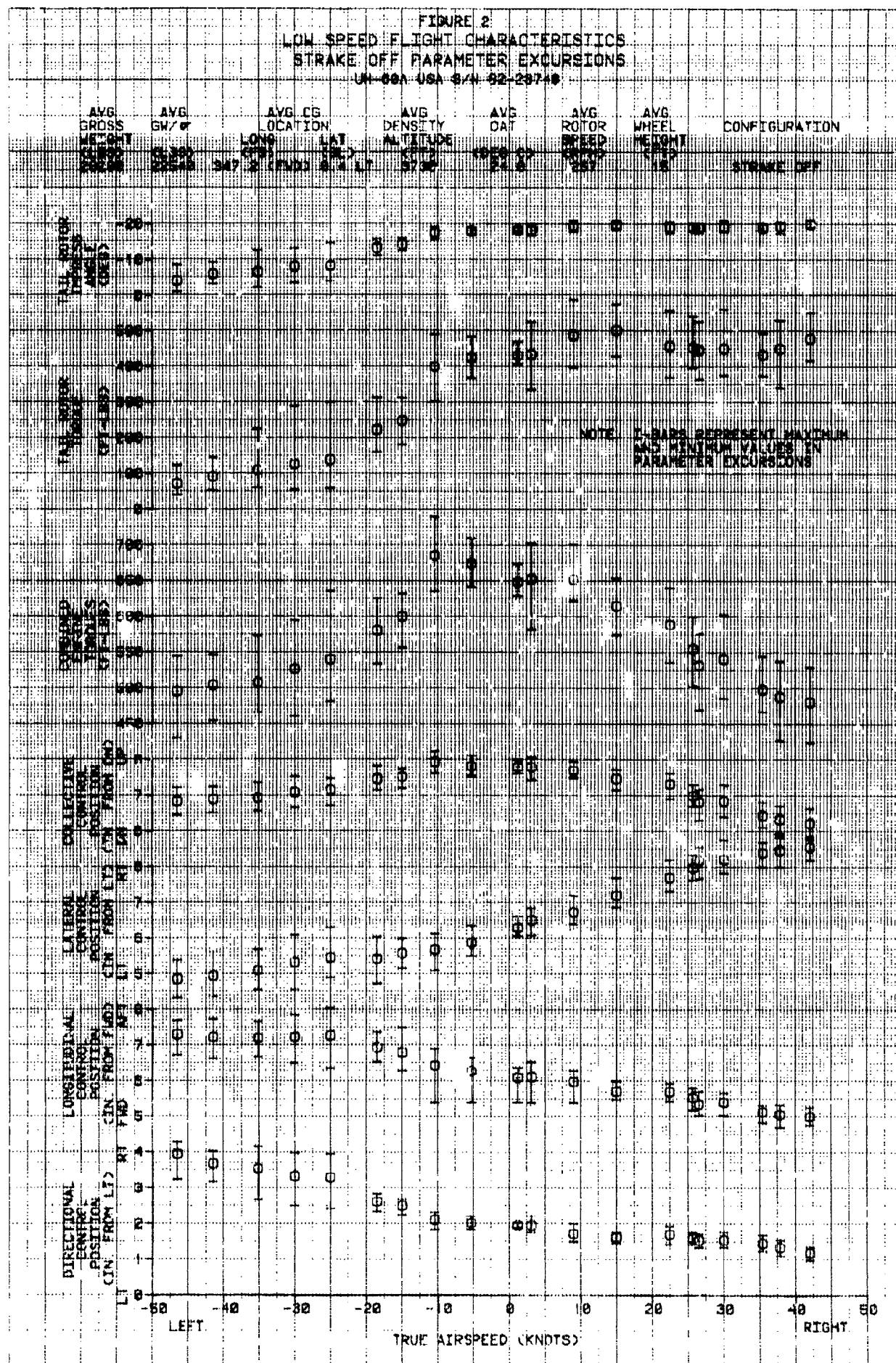
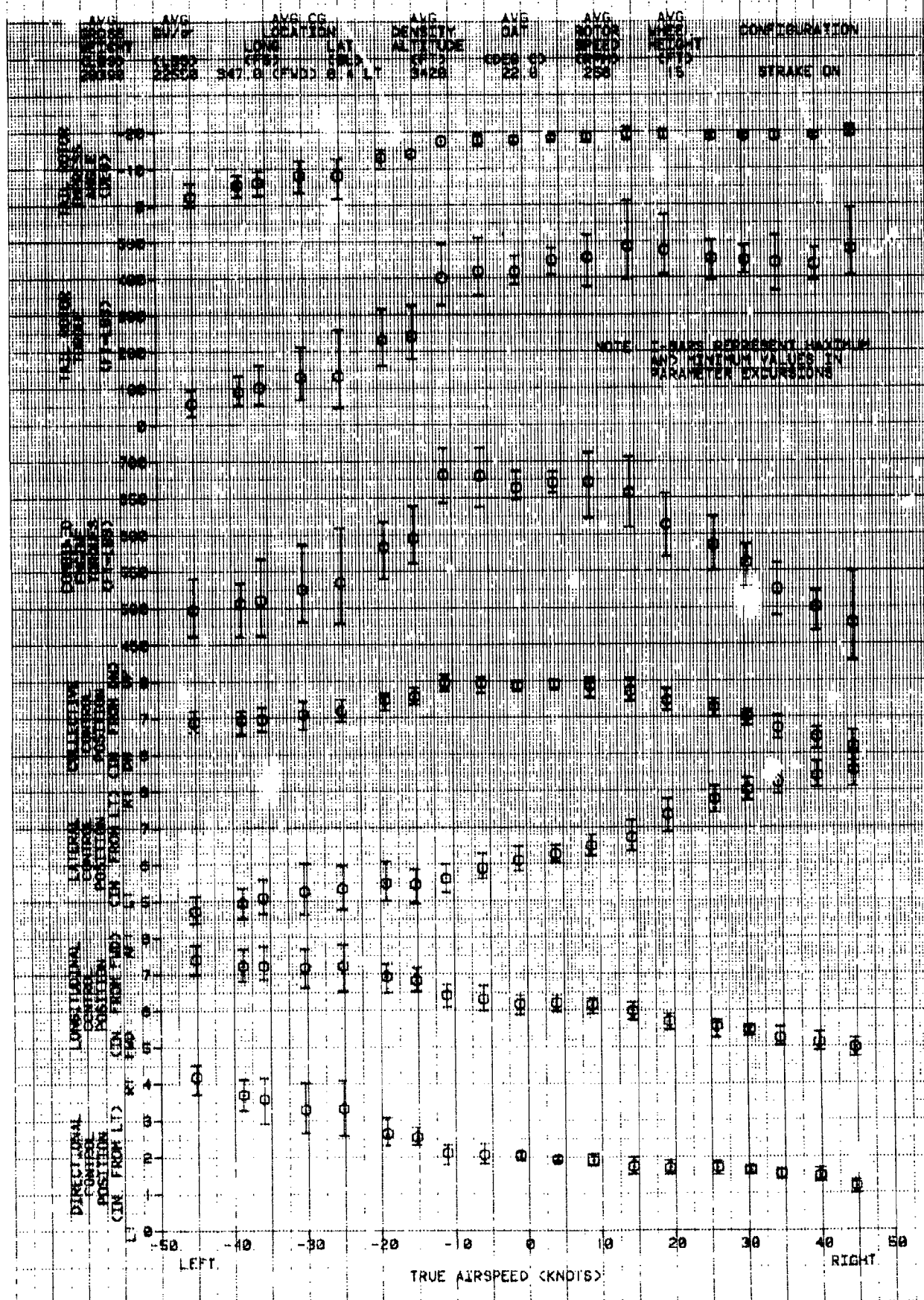


FIGURE 9
LOW SPEED FLIGHT CHARACTERISTICS
STRAKE ON PARAMETER EXCURSIONS
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