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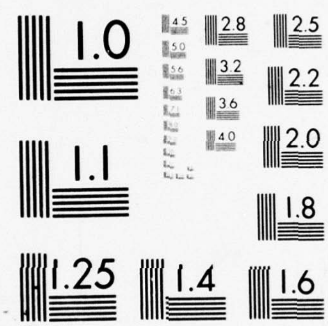

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FLIGHT EVALUATION
ROSEMOUNT LOW-RANGE ORTHOGONAL AIRSPEED SYSTEM WITH 853G SENSOR.

9 FINAL REPORT,

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PROJECT PILOT

11 MARCH 1977

12 26p.

UNITED STATES ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

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Model 853G sensor

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Rosemount low range orthogonal airspeed system with a Model 853G sensor installed above the main rotor was evaluated by the United States Army Aviation Engineering Flight Activity at Edwards Air Force Base, California, in August 1976. The system repeatably measured airspeed in the direction of the relative wind. However, the system had excessive perturbations in the axis perpendicular to relative wind, which must be corrected prior to the system becoming operational.

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INTRODUCTION

BACKGROUND

1. Standard aircraft pitot-static airspeed systems are inadequate for low forward airspeed (below 40 knots) sensing in helicopters, and are inoperable in crosswind or downwind flight conditions. The United States Army Aviation Engineering Flight Activity (USAAEFA) conducted tests on several low-speed omnidirectional systems during USAAEFA Project No. 71-30 (refs 1 through 6, app A). The United States Army Avionics Laboratory, Fort Monmouth, New Jersey, is currently developing a lightweight doppler navigation system (LDNS) which requires inputs from an airspeed system that will operate reliably in the low-speed nap-of-the-earth (NOE) flight regime. In May 1975, the United States Army Aviation Systems Command (AVSCOM) directed USAAEFA to evaluate two systems for the Avionics Laboratory (ref 7) and a test plan was prepared by USAAEFA (ref 8). Subsequently, the Avionics Laboratory requested that two additional systems be tested. One of those systems was the Rosemount low range orthogonal airspeed system with a Model 853G sensor.

TEST OBJECTIVES

2. The objective of this evaluation was to define the operating characteristics of the Rosemount low-airspeed system in an NOE flight environment for possible use with the LDNS. Specific objectives were to define:

a. Airspeed range in which system is effective.

b. Impact of flight direction on accuracy.

c. Optimal display characteristics.

DESCRIPTION

3. The system tested was manufactured by Rosemount, Inc. of Minneapolis, Minnesota. It consisted of an airspeed and altitude sensor, an airspeed transducer, an altitude transducer, and an airspeed and direction indicator. A detailed description of the system is provided in appendix B.

4. The sensor is a hemispherically capped cylindrical tube approximately 3/4 inch in diameter and 15 inches long. It senses differential pressures in the longitudinal and lateral axes. It was mounted vertically on a stationary platform which was attached to a standpipe placed inside the hollow main rotor shaft. The installation

placed the sensor above the main rotor plane of rotation. The aircraft used in this evaluation was an NUH-1M helicopter, SN 63-8684. A detailed description of the aircraft is contained in the operator's manual (ref 9, app A).

TEST SCOPE

5. The Rosemount system was evaluated in August 1976 at Edwards Air Force Base, California. A total of 3 hours were flown, of which 1.8 hours were productive. Flight conditions were within the limitations imposed by the operator's manual and the safety-of-flight release (ref 10, app A). Testing was limited to 40 knots at various azimuths. Angle of attack effects were not investigated.

TEST METHODOLOGY

6. The Rosemount system was tested to 40 knots near the ground, using the calibrated pace vehicle technique. Wind speed and direction were measured and added vectorially to the pace vehicle readings to obtain aircraft true airspeed. The true airspeed was then converted to calibrated airspeed for a direct comparison with Rosemount airspeed outputs.

7. Previous testing on a similar Rosemount system (ref 5, app A) indicated that optimal results would be obtained by mounting the sensor on a relatively long (18 inches) adaptor above the main rotor mast. This was the only configuration evaluated during this test.

RESULTS AND DISCUSSION

GENERAL

8. The performance of the Rosemount system in all cardinal azimuths in the horizontal plane was similar. The system measured forward, rearward, and lateral airspeeds adequately in the direction of the relative wind, but showed undesirable perturbations in the axis perpendicular to the relative wind. The sensor was mounted above the main rotor throughout the evaluation. All tests were flown at approximately 7000 pounds gross weight, mid center of gravity, and main rotor speed of 324 rpm.

SYSTEM PERFORMANCE IN FORWARD AND REARWARD FLIGHT

9. The performance of the Rosemount system in forward and rearward flight is shown in figure 1, appendix D. The longitudinal airspeed output was essentially linear, steady, and repeatable throughout the range of the transducer capsule, ±40 knots. Position error for the 50-foot skid height data was typically less than 4 knots, and could be nearly eliminated by a slight gain adjustment in the transducer output circuitry.

10. The lateral airspeed output of the system during forward and rearward flight was erratic, with random perturbations as great as 24 knots. This phenomenon was consistent throughout the test.

SYSTEM PERFORMANCE IN SIDEWARD FLIGHT

11. The system characteristics in sideward flight were similar to those during forward and rearward flight, as shown in figures 1 and 2, appendix D. The lateral airspeed output was essentially linear, steady, and repeatable throughout the range of the transducer capsule (±40 knots). The lateral position error in sideward flight was typically less than 4 knots and could be nearly eliminated by a slight gain adjustment. Also, similar to longitudinal flight, the off-axis output (longitudinal in the case of lateral flight) displayed erratic behavior, which should be corrected.

12. The perturbations noted in the flight test data appear to occur when a high proportion of the flow is tangential to the pressure ports of a given axis. A time history of this phenomenon is shown in figure A. In response to inquiries by USAAEFA, Rosemount conducted additional wind tunnel tests on a system similar to the model tested by USAAEFA. Sample results are shown in figure B. Wind tunnel data of the off-axis perturbations show trends similar to flight test data, though of a much smaller magnitude. Viewing figures A and B together, it can be concluded that the greater tangential perturbations in the flight test data are caused by turbulence. The off-axis perturbations must be corrected before the

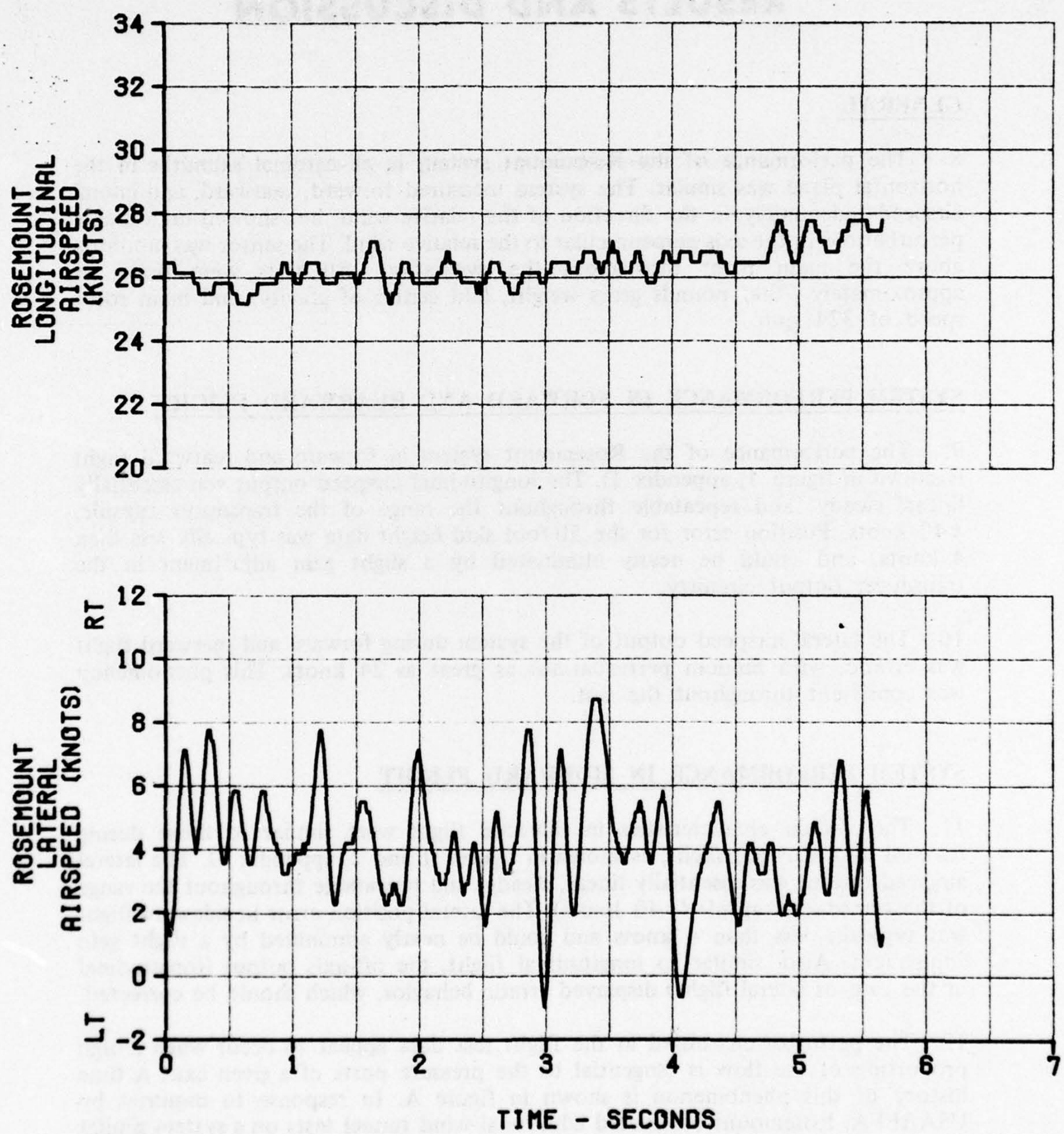


Figure A. Rosemount System Perturbations During Forward Flight.

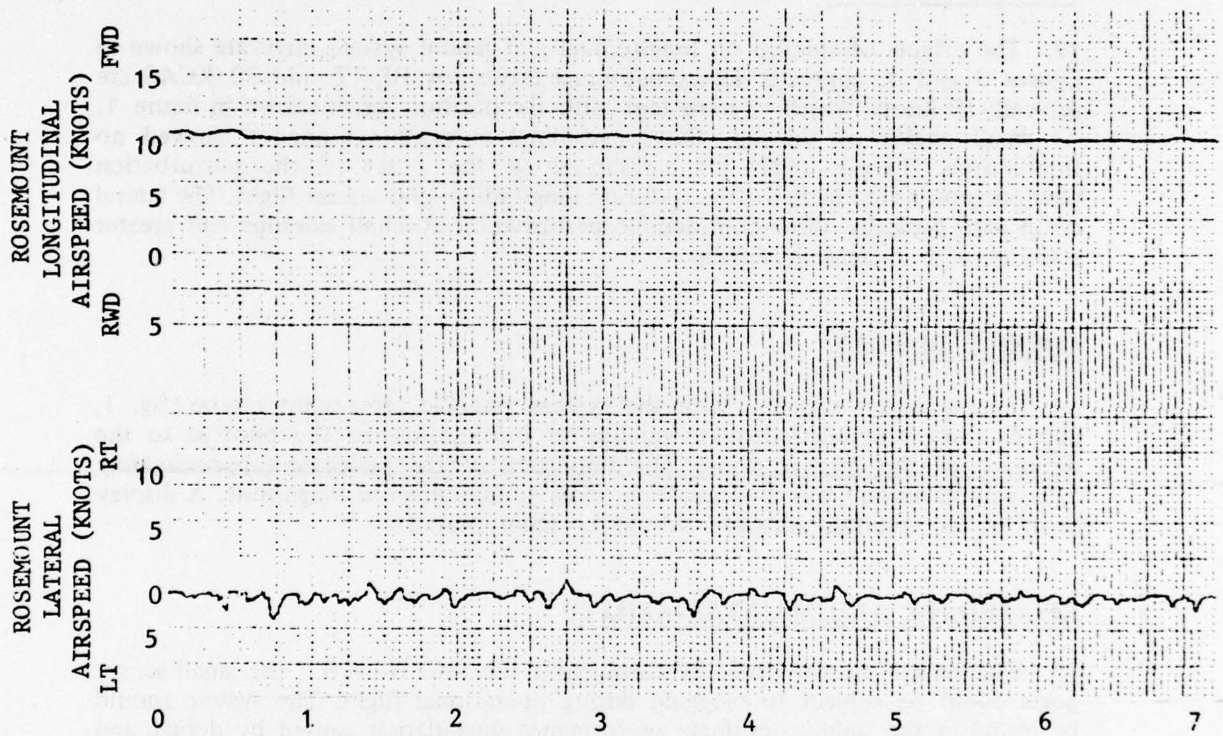


Figure B. Rosemount System Perturbations During Wind Tunnel Testing.

system can be used either as part of a navigation system or as an engineering flight test reference. During the wind tunnel testing, Rosemount experimented with different diameters and lengths of tubing to vary the damping characteristics of the system. Some success was noted in the reduction of the perturbations and in the increase of off-axis accuracy.

SIDESLIP EFFECTS

13. The effects of sideslip on longitudinal and lateral system error are shown in figures 3 and 4, appendix D. Longitudinal errors for 10, 17, and 30 KCAS are typically 5 knots, which is consistent with the position error shown in figure 1. At small angles of sideslip, the longitudinal airspeed component showed no fluctuations. Larger angles of sideslip show the onset of the perturbation phenomenon noted in the off-axis during longitudinal and lateral flight. The lateral error data typically show considerable perturbation at small sideslips and greater stability with increasing sideslip.

COCKPIT DISPLAY

14. The indicator supplied with the system was the cross-pointer type (fig. 1, app B), and provided adequate qualitative information to the pilot as to the direction of the relative wind. The resolution of the indicator (approximately 1/8 inch/10 knots) was inadequate to easily obtain airspeed magnitude. A display showing the resultant airspeed should be incorporated.

RELIABILITY AND MAINTAINABILITY

15. The sensor operated reliably throughout the test. However, the small sensor ports could be subject to clogging during operational flight. The system should be tested in the field to evaluate performance degradation caused by debris, and to evaluate the sensor deice capability.

16. A diaphragm in an airspeed transducer capsule ruptured before the first flight, and the pressure altitude and rate-of-climb elements of the system were inoperable during the test. No cause was determined for either failure.

ADDITIONAL SYSTEM FEATURES

17. The pressure altitude and rate-of-climb outputs were not tested; however, several features of the system should be noted. Airspeed is measured with the aircraft axes as a reference, and rate-of-climb is computed with the earth axis as a reference. If this system is to be used as a navigation input, the difference in

reference axes must be considered. Additionally, rate of climb is obtained by differentiating pressure altitude, and cannot be used directly as a vertical airspeed component because airspeed output in the horizontal plane is calibrated airspeed. If the Rosemount system is to be used in the LDNS, provisions should be made to convert the system airspeed outputs to true airspeed.

CONCLUSIONS

18. The Rosemount low-airspeed system with the sensor mounted above the main rotor repeatably measured airspeed in the direction of the relative wind to the limits tested (paras 9 and 11).

19. Excessive perturbation occurs in the system output for the axis perpendicular to the relative wind (para 12).

20. The cockpit indicator, while giving adequate relative wind direction information, did not have adequate resolution to easily determine resultant airspeed (para 14).

RECOMMENDATIONS

21. The perturbations and inaccuracies in the axis of tangential flow must be corrected (para 11).

22. A display should be added to the cockpit indicator showing the resultant airspeed (para 14).

23. Additional field testing should be conducted to evaluate performance degradation caused by debris and to evaluate the sensor deice capability (para 15).

24. Provisions should be made for the system output to be in true airspeed for possible use with the LDNS (para 17).

APPENDIX A. REFERENCES

1. Final Report I, US Army Aviation Systems Test Activity (USAASTA), Project No. 71-30, *Flight Evaluation, Elliott Low-Airspeed System,* September 1972.

2. Final Report II, USAASTA, Project No. 71-30, *Flight Evaluation, Aeroflex True Airspeed Vector System, Low-Airspeed System,* March 1973.

3. Final Report III, USAASTA, Project No. 71-30, *Flight Evaluation, Pacer Systems, Inc., LORAS II Low-Airspeed System,* March 1974.

4. Final Report IV, USAASTA, Project No. 71-30, *Flight Evaluation, J-TEC Airspeed System, Low-Airspeed Sensor,* April 1974.

5. Final Report V, USAAEFA, Project No. 71-30, *Flight Evaluation, Rosemount Orthogonal Low-Airspeed System, Low-Airspeed Sensor,* November 1974.

6. Final Report VI, USAAEFA, Project No. 71-30, *Flight Evaluation, Elliott Dual-Axis Low-Airspeed System, LASSIE II, Low-Airspeed Sensor,* September 1975.

7. Letter, AVSCOM, AMSAV-EQI, 12 May 1975, subject: AVSCOM Test Request Number 75-17, Flight Evaluation of Two Low-Airspeed Sensing Systems.

8. Test Plan, USAAEFA, Project No. 75-17, *Flight Evaluation of Two Low-Airspeed Sensing Systems,* September 1975.

9. Technical Manual, TM 55-1520-220-10, *Operator's Manual, Army Model UH-1C/M,* November 1968 with changes 1 through 4.

10. Letter, AVSCOM, DRSAV-EQA, 6 May 1976, subject: Safety-of-Flight Release for Rosemount Probe Installed on UH-1M.

APPENDIX B. SYSTEM DESCRIPTION AND THEORY OF OPERATION

GENERAL

1. The Rosemount orthogonal airspeed system consists of a Model 853G orthogonal airspeed sensor, a Model 542AM-1 air data transducer, a Model 1241 barometer altitude transducer, and an indicator. The system components are shown in photo 1.

Sensor

2. The 853G airspeed sensor is a hemispherically capped cylindrical tube approximately 3/4 inch in diameter and 15 inches long, and is shown in detail in figure 1. In the test installation, the sensor was mounted vertically on an 18-inch adaptor atop a nonrotating platform above the main rotor hub, as illustrated in figure 2. The sensor has four sets of four pressure ports drilled into the surface of the tube, gaining access to the four chambers within the tube. Two sets of ports are aligned in the fore-aft direction, and two in the left-right direction. An additional set of ports is located below the orthogonal ports for sensing static pressure, which is used to determine pressure altitude and vertical velocity.

3. The sensor is heated for deicing and to vaporize surface and internal moisture. The heater uses 150 watts in still air and 275 watts in flight. Heaters are available to operate on either 28 VDC or 115 VAC.

Air Data Transducer

4. The function of the 542AM-1 transducer is to convert the differential pressure from the sensor to a voltage, which may be interpreted as airspeed by an indicator or other instrumentation. Inside the unit is a fore-aft capsule and a right-left capsule. Pressures from the sensor are input on opposite sides of the capsule, moving a sensing diaphragm stretched between fixed capacitor plates. The differential capacitance between the sensing diaphragm and the capacitor plates is converted electronically to a high-level DC voltage signal (linear with pressure) by signal conditioning circuitry. Rosemount currently makes three different capsules: ±40 knots, ±100 knots, and ±120 knots. The system tested used a ±40-knot capsule for both axes.

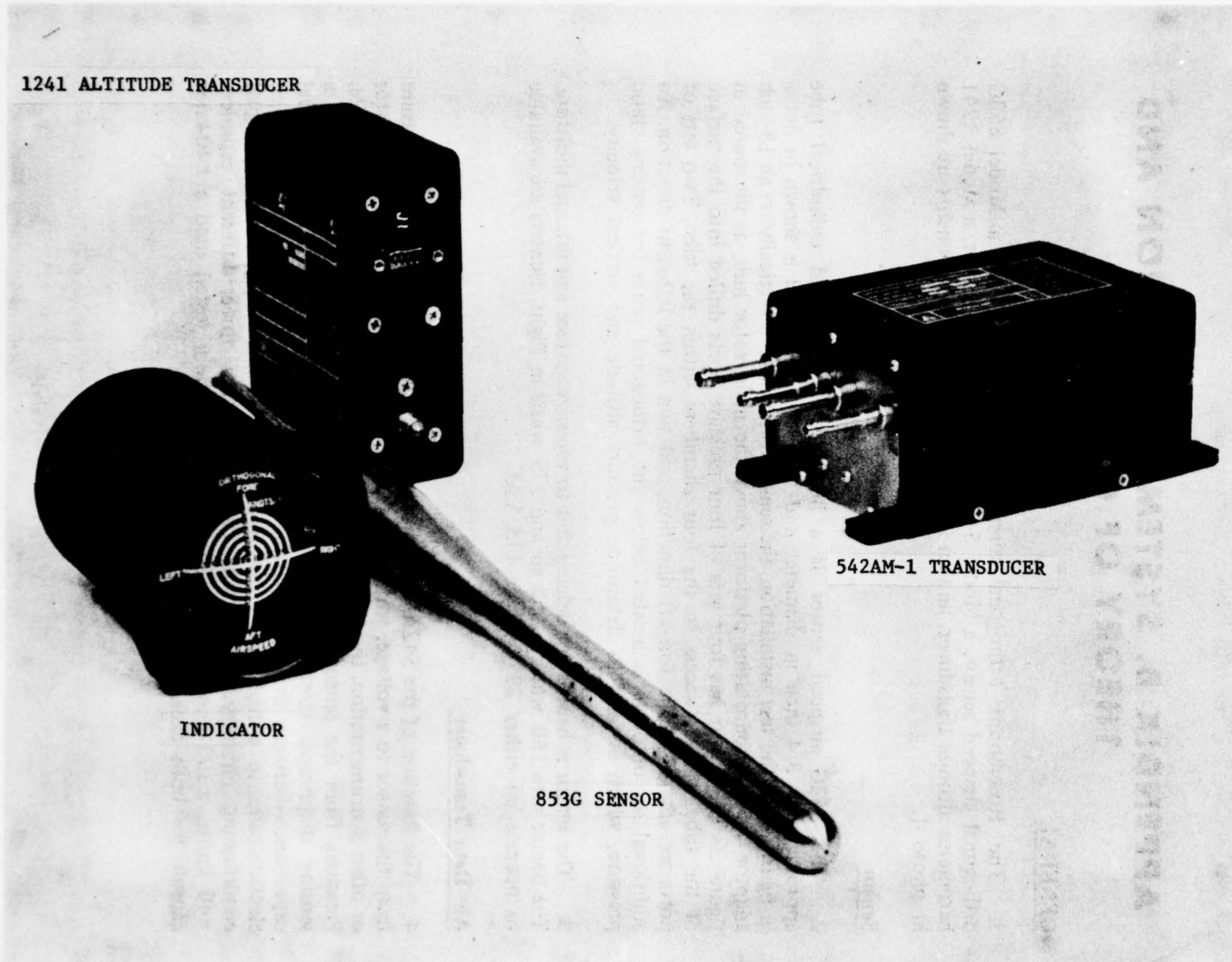


Photo 1. Rosemount Orthogonal Airspeed System.

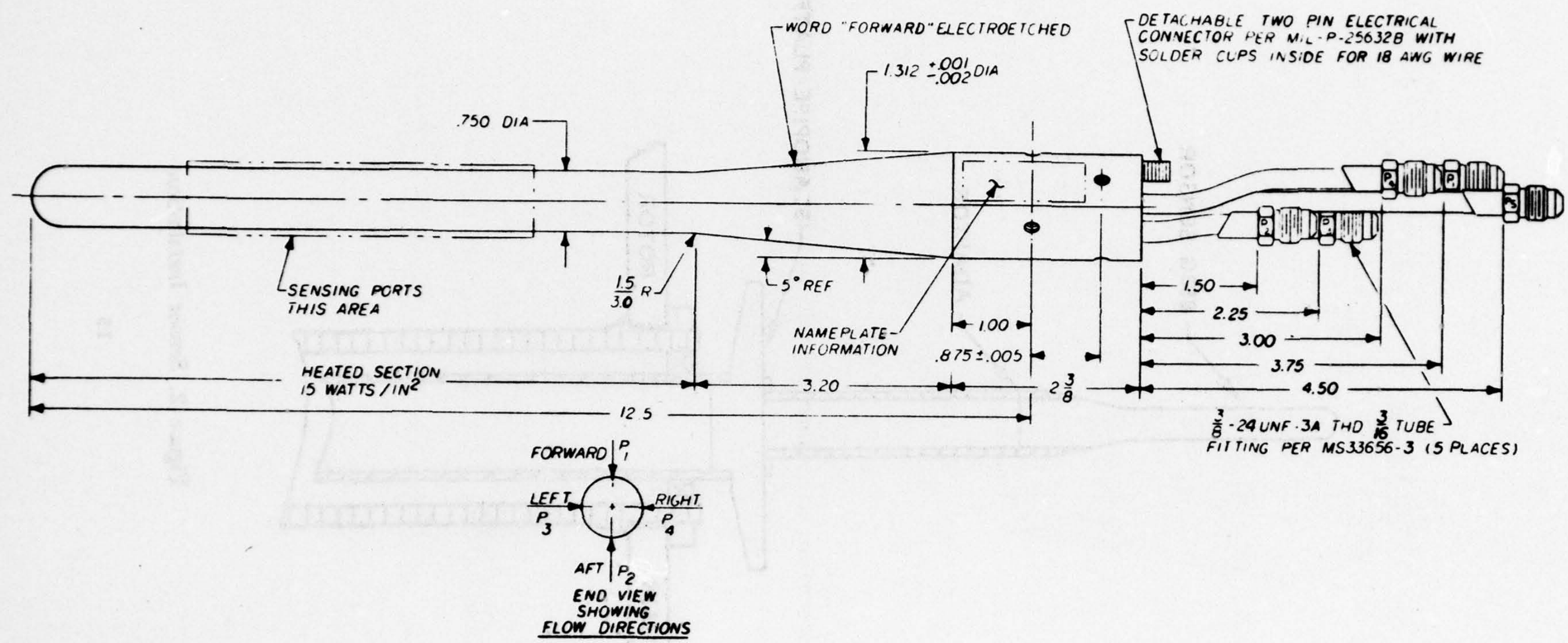


Figure 1. Model 853G Sensor.

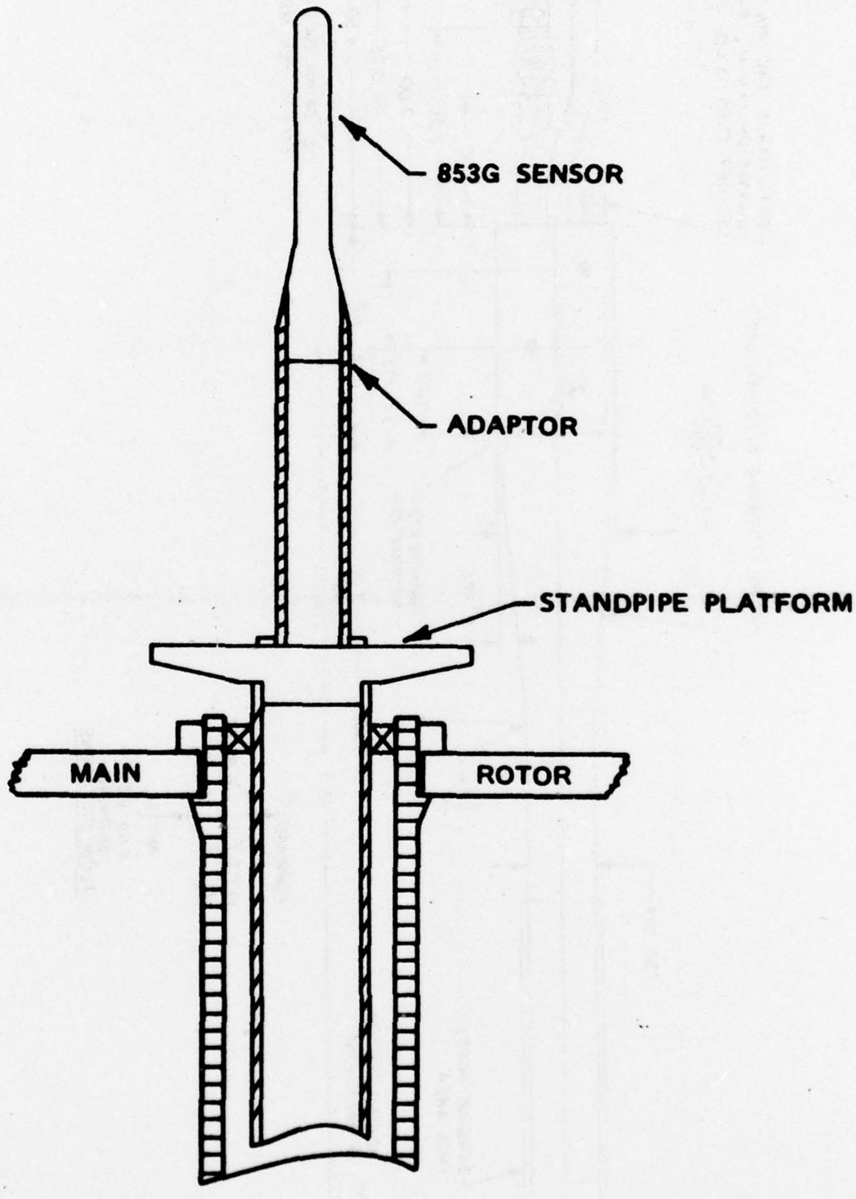


Figure 2. Sensor Installation

5. **Dynamic pressure (q) attributable to longitudinal and lateral velocity is proportional to the pressure differential along those axes.**

$$q_x = A(P_1 - P_2) \tag{1}$$

$$q_y = A(P_4 - P_3) \tag{2}$$

Where:

A is a calibration constant

The relationship between dynamic pressure and calibrated airspeed is defined by the equation:

$$V_{cal} = \left\{ \frac{2\gamma}{\gamma-1} \left(\frac{P_o}{\rho_o}\right) \left[\left(\frac{q}{P_o}\right) + 1) ^{\frac{\gamma-1}{\gamma}} -1 \right] \right\}^{1/2} \tag{3}$$

Where:

γ **= specific heat ratio of air ~ 1.4**

P_o **= standard-day, sea-level pressure**

ρ_o **= standard-day, sea-level density**

This equation can be represented by the transfer function:

$$V_{cal} = K_1 + K_2 \left[q/(1 + K_3 q)\right]^{1/2} \tag{4}$$

Where:

K_n **are constants required to make the equation valid**

The error introduced by the use of this function rather than equation 3 is ±0.0007 percent over the range of 10 to 150 knots.

6. **The transfer function is applied to the DC voltage in a function module within the air data transducer unit. This allows the transducer output to be proportional to airspeed.**

7. A temperature compensation circuit is also included in the transducer to eliminate errors caused by temperature variation.

8. Rosemount has also developed a transducer that will combine dynamic and static pressures with temperature and output longitudinal and lateral airspeeds in units of true airspeed. This would probably be more useful if the system is to be incorporated into a navigation system.

Barometer Altitude Transducer

9. The 1241 altitude transducer converts static pressure from the sensor to a voltage proportional to pressure altitude. The transfer function used is:

$$H_P = K_1 \left(\frac{1}{P_S}\right)^{K_2} \qquad (5)$$

The transducer also has a module to differentiate the altitude signal to obtain rate of climb.

Cockpit Indicator

10. The cross-pointer indicator has a display in the form of concentric circles 10 knots apart with zero located at the geometric center. The horizontal pointer moves up with increasing forward airspeed; the vertical pointer moves in the direction of lateral aircraft motion. The intersection of the two pointers will show resultant vector airspeed. There is no indicator for pressure altitude or rate of climb.

APPENDIX C. TEST INSTRUMENTATION

1. The following parameters were recorded on board the test helicopter on magnetic tape and were displayed on the instrument panel.

Time of day
Engineer event
Pilot event
Run number
Test boom altitude
Test boom airspeed
Radar altimeter
Outside total temperature
Angle of attack
Angle of sideslip
Rotor speed
Pitch attitude
Roll attitude
Magnetic heading
Fuel used counter
Fuel temperature
Rosemount longitudinal airspeed
Rosemount lateral airspeed
Rosemount pressure altitude[1]
Rosemount rate of climb[1]

2. The following parameters were hand-recorded on the ground.

Wind speed and direction
Pace vehicle speed and direction
Ambient temperature

[1]Not displayed in the aircraft.

APPENDIX D. TEST DATA

INDEX

FIGURE 1

SYSTEM PERFORMANCE IN FORWARD AND REARWARD FLIGHT

NUH-1M USA S/N [illegible] ROSEMOUNT ORTHOGONAL AIRSPEED SYSTEM MODEL 853

AVG GROSS WEIGHT (LB)	AVG CG LOCATION (FS)	AVG DENSITY ALTITUDE (FEET)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)	AVG CT	SKID HEIGHT (FEET)
7000.	131.8 (MID)	3710.	24.0	324.	0.0039	50.

NOTES: 1) GROUND PACE VEHICLE METHOD
2) SYMBOLS DENOTE MEAN VALUES
3) VERTICAL LINES DENOTE RANGE OF ROSEMOUNT DATA
4) SHADED SYMBOLS DENOTE 5 FOOT SKID HEIGHT

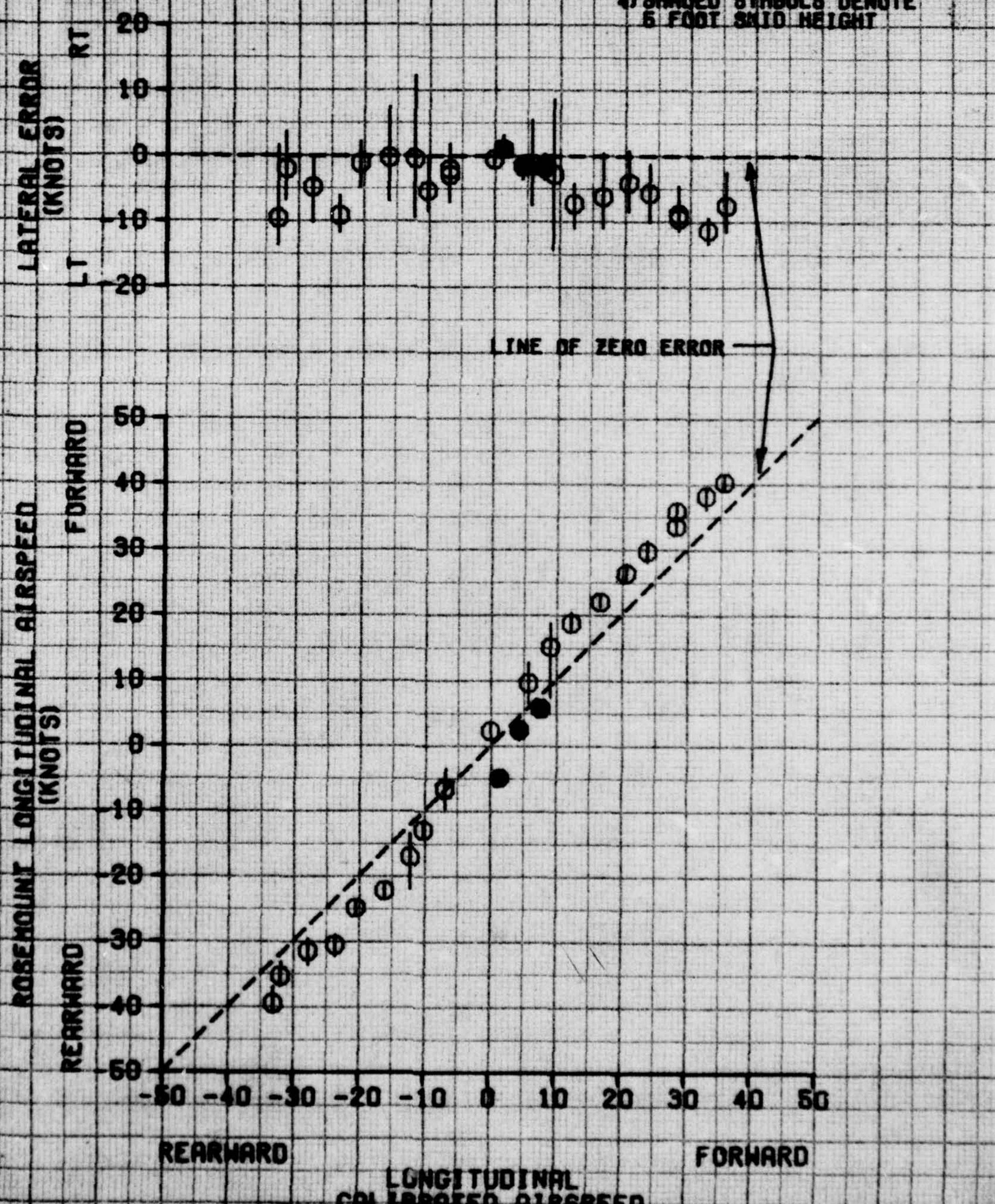


FIGURE 2

SYSTEM PERFORMANCE IN SIDEWARD FLIGHT

NUH-1M USA S/N [illegible] ROSEMOUNT ORTHOGONAL AIRSPEED SYSTEM MODEL 850

AVG GROSS WEIGHT (LB)	AVG CG LOCATION (FS)	AVG DENSITY ALTITUDE (FEET)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)	AVG CT	SKID HEIGHT (FEET)
8950.	131.7 (MID)	3900.	25.5	324.	0.0039	50.

NOTES: 1) GROUND PACE VEHICLE METHOD
2) SYMBOLS DENOTE MEAN VALUES
3) VERTICAL LINES DENOTE RANGE OF ROSEMOUNT DATA

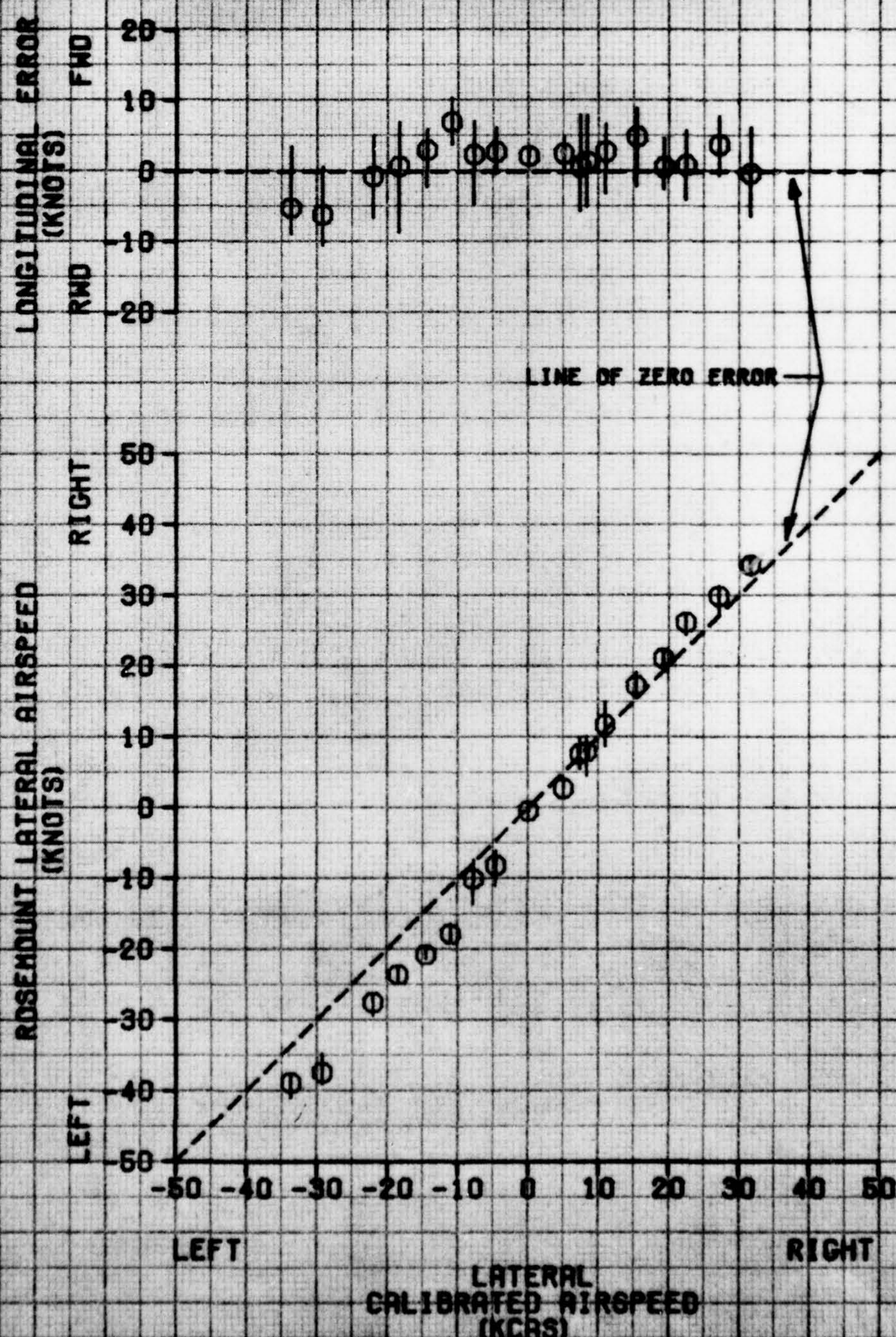


FIGURE 3

SIDESLIP EFFECTS ON LONGITUDINAL AIRSPEED ERROR

NUH-1M USA S/N [illegible] ROSEMOUNT ORTHOGONAL AIRSPEED SYSTEM MODEL 853

AVG GROSS WEIGHT (LB)	AVG CG LOCATION (FS)	AVG DENSITY ALTITUDE (FEET)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)	AVG CT	SKID HEIGHT (FEET)
[illegible]	131.7 (MID)	3900.	26.0	324.	0.0038	50.

NOTES: 1) GROUND PACE VEHICLE METHOD
2) SYMBOLS DENOTE MEAN VALUES
3) VERTICAL LINES DENOTE RANGE OF ROSEMOUNT DATA

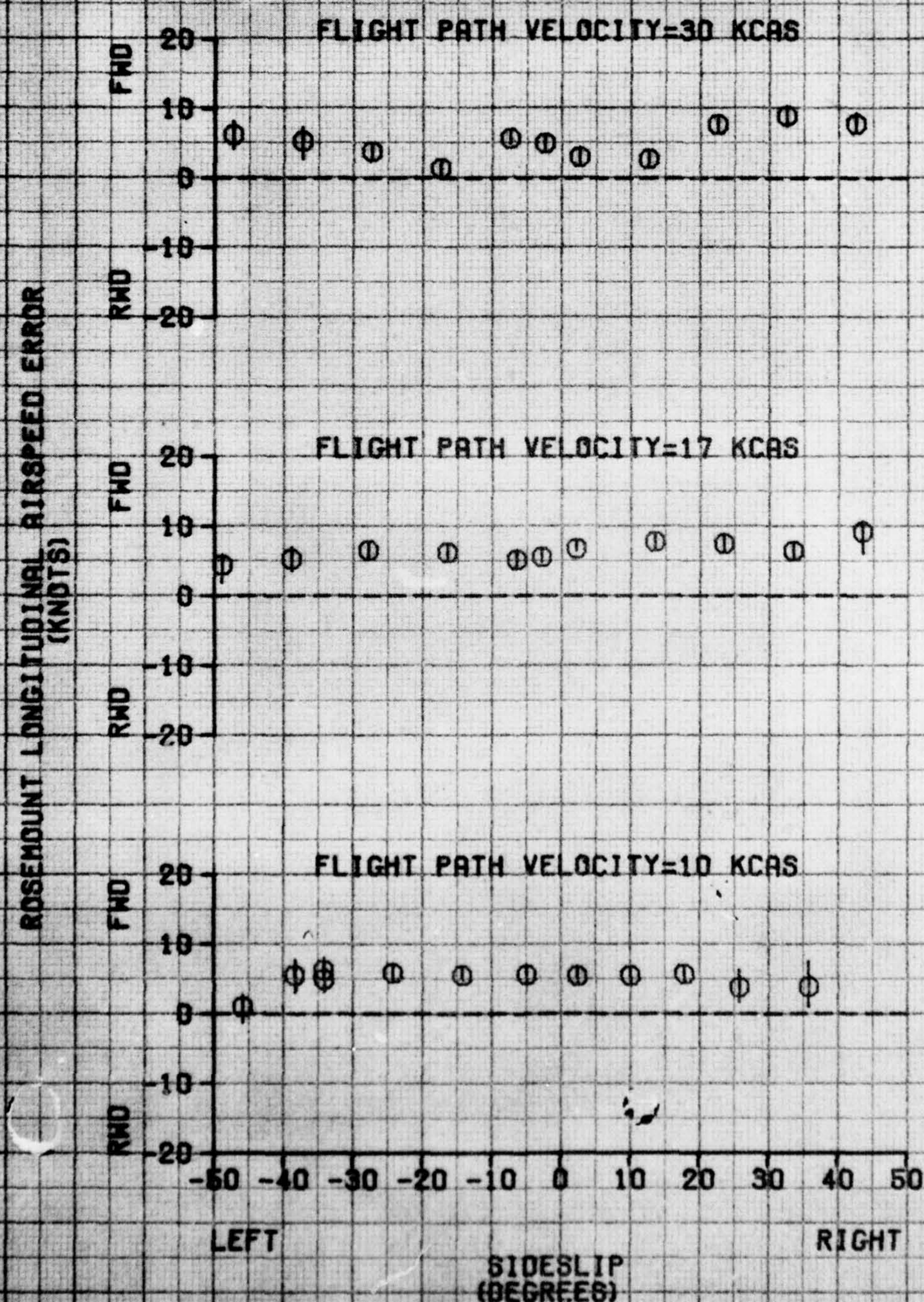


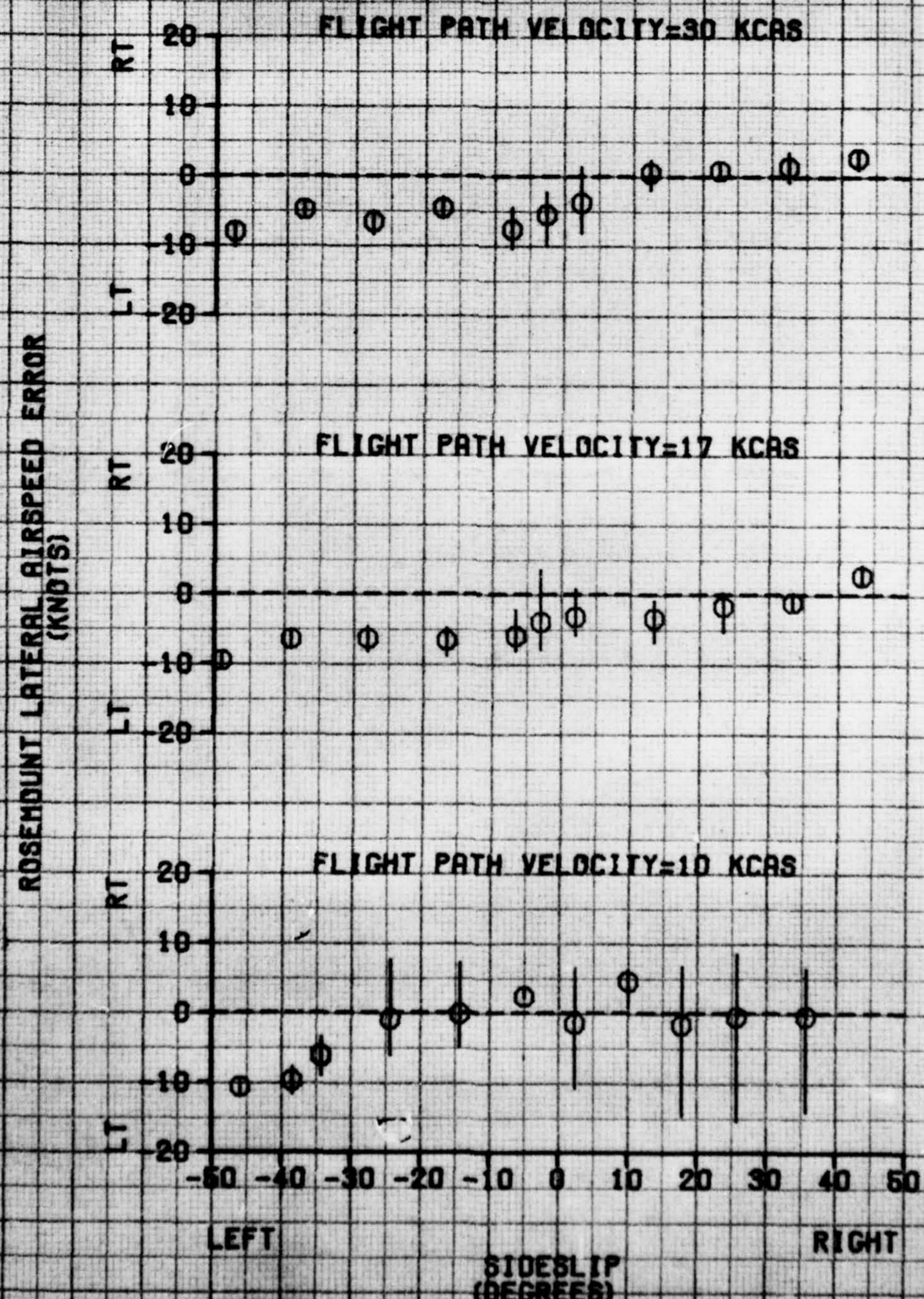
FIGURE 4

SIDESLIP EFFECTS ON LATERAL AIRSPEED ERROR

NUH-1H USA S/N 68-0084 ROSEMOUNT ORTHOGONAL AIRSPEED SYSTEM MODEL 853

AVG GROSS WEIGHT (LB)	AVG CG LOCATION (FS)	AVG DENSITY ALTITUDE (FEET)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)	AVG CT	SKID HEIGHT (FEET)
8060.	131.7 (MID)	3900.	26.0	324.	0.0036	50.

NOTES: 1) GROUND PACE VEHICLE METHOD
2) SYMBOLS DENOTE MEAN VALUES
3) VERTICAL LINES DENOTE RANGE OF ROSEMOUNT DATA



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