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THE INFLUENCE OF RADIO ALTIMETER ERRORS ON PILOT PERFORMANCE DURING THE FINAL APPROACH AND LANDING PHASE OF AN RPV MISSION

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16. Abstract

Due to the fact that remotely piloted vehicles (RPV's) are currently being flown from fixed base control centers, kinesthetic and real world peripheral vision cues are absent (figs. 1, 2). The absence of these cues complicates the piloting task, particularly during the final approach and landing phase of a mission. The pilot's task is further complicated by errors in the displayed altitude information. To determine the influence of these errors on pilot performance during the final approach and landing phase of a mission, an experiment was conducted in which pilot subjects were asked to fly a fixed base simulation of a Piper PA-30 aircraft, using degraded altitude information. For this experiment, the chevron component of the display configuration shown in figure 3 was driven by a radio altimeter. Four altimeters were used, each with a different error characteristic, but within the range specified for the Sperry series of radio altimeters. The resulting displays were presented to four pilot subjects in accordance with a Latin square design. Each pilot subject was instructed to execute final approaches and landings starting from an initial distance of 9,000 ft (2,743 m) from the runway threshold, and an initial altitude of 500 ft (152 m).

Results indicate that for the range of errors considered, there is no significant difference in landing performance that can be attributed to errors in altitude information.

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SUMMARY

Due to the fact that remotely piloted vehicles (RPV's) are currently being flown from fixed base control centers, kinesthetic and real world peripheral vision cues are absent (figs. 1, 2). The absence of these cues complicates the piloting task, particularly during the final approach and landing phase of a mission. The pilot's task is further complicated by errors in the displayed altitude information. To determine the influence of these errors on pilot performance during the final approach and landing phase of a mission, an experiment was conducted in which pilot subjects were asked to fly a fixed base simulation of a Piper PA-30 aircraft, using degraded altitude information. For this experiment, the chevron component of the display configuration shown in figure 3 was driven by a radio altimeter. Four altimeters were used, each with a different error characteristic, but within the range specified for the Sperry series of radio altimeters. The resulting displays were presented to four pilot subjects in accordance with a Latin square design. Each pilot subject was instructed to execute final approaches and landings starting from an initial distance of 9,000 ft (2,743 m) from the runway threshold, and an initial altitude of 500 ft (152 m).

Results indicate that for the range of errors considered, there is no significant difference in landing performance that can be attributed to errors in altitude information.

INTRODUCTION

As part of a continuing effort to determine the display requirements for remotely piloted vehicles (RPV's), an experiment was conducted to determine the influence of radio altimeter errors on pilot performance during the final approach and landing phase of a mission. A recent study (ref. 1) established that the display of state variables shown in figure 3, was an effective configuration for RPV pilots. In the configuration shown, the basic display consisted of a perspective image of terrain and runway, a horizon bar and an aircraft symbol. Pilot opinion and experimental evidence indicated that pitch attitude, glide slope information and a chevron combined with digital readouts of airspeed, altitude and vertical velocity were the most useful additions to the basic display. The chevron which is a sensitive indicator of altitude and sink rate is shown separately in figure 4. It enables the RPV pilot to control these variables with the precision necessary for successful landings. In the experiment described in reference 1, the values of altitude and sink rate displayed by the chevron were assumed to be free of errors. In the present study, radio altimeter accuracy was subjected to a series of degradations in the range indicated by the instrument specifications. The contaminated altitude output was then used to drive the chevron display, and pilot performance was measured as a function of altimeter accuracy.

RADIO ALTIMETERS

Four radio altimeters were used in the experiment. Each altimeter had a different error characteristic within the range specified for the Sperry series of instruments. Each instrument consists of a receiver transmitter unit, an antenna and an altitude indicator. A variety of models is available to suit a wide range of operating conditions. All of the basic altimeter circuitry is housed in the receiver transmitter unit (fig. 5). Several antenna models may be selected to suit particular installation problems (fig. 6). The indicator component provides the display which the pilot uses to control aircraft altitude (fig. 7).

EQUIPMENT AND METHOD

Aircraft Description

A Piper PA-30 aircraft was simulated for this experiment. This aircraft was chosen because it is currently being used at NASA's Flight Research Center for RPV flight test experimentation. It is a low-wing monoplane, powered by two Lycoming, four cylinder, aircooled engines, each capable of delivering 160 rated horsepower. Figure 8 gives the principal dimensions. The airplane has a wing span of 35.98 ft (10.97 m), a wing area of 178 ft^2 (16.54 m^2), an aspect ratio of 7.3, and a mean aerodynamic chord of 5 ft (1.52 m) (ref. 2). The airplane has the standard three-control system. The horizontal tail is the all-movable type with a control deflection range of 4° to -14°. The tail has a trailing edge tab which moves in the same direction as the tail, with a deflection ratio (tab deflection to tail deflection) of 1.5. The control deflection on each aileron is from 14° to -18°. The rudder control deflection range is ±27° (ref. 2).

Simulator and Vehicle Model

The Piper PA-30 aircraft was simulated on a Systems Engineering Laboratory (SEL) 840 digital computer. The final approach model is based on available data from FRC's simulation model and references 2, 3. The model consists of the rigid body, six degrees of freedom equations of motion that are perturbation equations in the stability axis system (ref. 3). After passage through a digital to analog converter (DAC), the output from the SEL 840 computer was used to drive a visual flight attachment via an Applied Dynamics, Inc. (ADI) 256 analog computer. The output from the SEL 840 computer was also used to drive an Evans & Sutherland (E & S) LDS-2 display generator, which was mounted in parallel with the visual flight attachment. The E & S display generator was used to superimpose geometric representations of state variables on the pictorial scene of terrain and runway generated by the visual flight attachment. The visual flight attachment used in this experiment was a General Precision Systems (GPS) model. The essential components of this attachment are a servo driven television camera, an optical probe and a TV monitor (ref. 4). A fixed base simulator consisting of a pilot's cab equipped with a conventional cockpit display, and augmented with the GPS visual scene, was used to assess the importance of the E & S generated displays in assisting RPV pilots to execute the final approach and landing phase of a mission.

EXPERIMENTAL DESIGN

The chevron component of the display configuration shown in figure 3 was driven by a radio altimeter. Four altimeters were used, each with a different error characteristic. The resulting displays were presented to four pilot subjects in accordance with a Latin square design. If a Latin square with four displays is used, the error mean square will have only six degrees of freedom. To obtain an estimate of error with a larger number of degrees of freedom, the experiment was replicated using eight Latin squares. Each Latin square was then treated as a block in a randomized block design, with the square X display sum of squares corresponding to the block X treatment sum of squares in a randomized block design.

In the applications to which the Latin square has been typically applied in psychology, physiology and drug research, each row of a square corresponds to a single subject with the columns corresponding to successive periods or tests. This is the procedure followed in the present design, where the element in a given Latin square gives the performance measure obtained during a test run with the corresponding display.

Each pilot subject was instructed to execute final approaches and landings starting from an initial distance of 9,000 ft (2,743 m) from the runway threshold, and an initial altitude of 500 ft (152 m). For each series of runs, the Latin square design assures that a pilot subject never encounters the same order of presentation more than once, and that the order effect, whether it be practice, fatigue, boredom, etc., is independent of particular displays.

During each run the following performance measures were taken for subsequent statistical evaluation: sink rate at touchdown, rms of sink rate and rms of stick activity.

RESULTS AND DISCUSSION

Sink Rate at Touch Down

Subsequent to the learning phase, the mean sink rate at touch down for all subjects and all error conditions was 2.26 ft/sec (0.69 m/s).

The influence of altimeter errors on pilot performance may be seen by tabulating the sink rate at touch down for each error condition. In the following matrices of performance measures, S denotes subject, L the Latin square and C the error condition. Condition 1 is an error free condition; conditions 2, 3 and 4 represent 1σ errors of 2, 4 and 6 ft, respectively. The elements of the matrices are measures of sink rate at touch down in ft/sec.

S = 1

L \ C =	1	2	3	4
1	2.90100	2.65500	3.80100	3.22500
2	3.62600	2.68600	2.29900	3.85300
3	3.40200	3.71300	3.98100	3.63200
4	2.75400	7.17100	3.63500	3.04100
5	2.73900	2.54800	3.35700	4.07900
6	2.43400	1.31500	2.37100	2.78600
7	3.54500	2.04700	3.68000	3.36900
8	3.77700	3.00600	2.19800	3.42600

S = 2

L \ C =	1	2	3	4
1	2.42600	4.67200	1.98200	2.17000
2	1.99500	3.20200	2.37000	3.42500
3	0.72400	2.37400	2.25700	1.62800
4	1.90300	2.15200	1.84600	2.99700
5	1.82500	1.30300	1.94000	2.36000
6	1.13200	1.74600	1.36400	0.91900
7	1.42000	2.14700	2.97800	0.78200
8	1.98000	3.55300	1.84300	1.41200

S = 3

L \ C =	1	2	3	4
1	2.02600	1.69200	2.58500	4.00600
2	2.21800	1.57500	2.69500	2.48100
3	0.69200	2.36300	2.02700	2.29000
4	1.10400	1.21000	2.11900	3.68900
5	0.79200	1.57000	2.98100	2.83100
6	0.76500	1.29100	1.37200	2.25100
7	1.14700	0.13800	2.59200	4.14700
8	0.89700	2.10000	2.12400	0.72600

S = 4

L \ C =	1	2	3	4
1	5.42900	2.40200	2.51700	5.02200
2	0.92600	0.44200	1.01300	2.98100
3	1.39200	1.44900	0.59200	1.55800
4	0.95900	1.77600	1.04500	3.32100
5	0.90900	2.79300	2.40700	0.12200
6	0.37700	1.09600	2.45200	0.60700
7	1.19800	2.01400	0.75600	1.81800
8	1.20200	2.09000	0.83300	3.19500

The computed value of the variance for the error contaminated displays was 2.74. An error variance of 1.4 gave rise to an F ratio of 1.96. For a significance level of 0.05, the critical value of F for a display variance with 3 df and an error variance with 9 df is 3.86, and it is evident that the experimental value is not statistically significant.

rms Values of Sink Rate

The chevron component of the display configuration shown in figure 3, appeared on a head-up display at an altitude of 100 ft (30.48 m). To assess the influence of altitude error on pilot performance, as measured by rms values of sink rate, this parameter was computed during the final 100 ft (30.48 m) of altitude. The mean rms value of sink rate for all subjects and all error conditions was 5.99 ft/sec (1.83 m/s).

As in the case of sink rate at touch down, the rms values of sink rate are tabulated for each error condition. In the matrices of performance measures, S again denotes subject, L the Latin square and C the error condition. Conditions 1, 2, 3 and 4 again represent 1σ errors of 0, 2, 4 and 6 ft, respectively. The elements of the following matrices are rms values of sink rate, calculated during the final 100 ft (30.48 m) of altitude.

S = 1

C =	1	2	3	4
L = 1	5.24700	7.20600	6.53400	8.42700
2	6.04700	6.31700	7.11600	5.74800
3	6.46900	10.54700	7.23300	6.20100
4	5.78800	5.44100	5.75500	4.83300
5	5.45300	6.89900	7.39500	5.34400
6	6.97000	7.01800	6.13400	7.10900
7	5.98100	8.24100	5.53400	6.94700
8	6.48100	7.58600	7.74400	6.37300

S = 2

C =	1	2	3	4
L = 1	6.35900	6.79200	6.25700	6.01100
2	6.43600	6.64800	6.23900	6.31500
3	6.61500	5.97700	6.27700	5.93600
4	6.17200	6.30500	6.48200	5.90100
5	5.94000	6.15200	6.56500	6.43600
6	5.61900	6.26000	5.93800	6.17900
7	5.85600	5.88400	5.54700	4.58900
8	5.80300	6.07800	5.86600	5.93900

S = 3

C =	1	2	3	4
L = 1	7.01200	6.41400	6.99000	6.79100
2	6.43400	7.04600	6.83800	6.05300
3	6.17700	6.54500	6.60200	6.58900
4	6.03600	7.00400	6.92600	6.81400
5	5.98400	6.60800	6.72700	6.49600
6	5.74200	6.52700	5.01200	6.22700
7	5.81000	5.88800	6.39400	6.18200
8	5.16300	7.07000	6.23900	6.71900

S = 4

C =	1	2	3	4
L = 1	4.54600	4.66400	5.30800	4.46900
2	4.61300	4.42200	4.39300	4.69000
3	4.79300	5.45200	3.67800	3.89700
4	4.82200	4.70800	5.88000	4.44800
5	4.24600	4.37900	4.93800	4.46100
6	4.46500	5.08500	3.77000	3.94700
7	6.00200	5.78800	4.77600	4.24600
8	6.25200	5.64500	6.40700	5.05300

The computed value of the variance for displays, each with a different error characteristic, was 2.05. An error variance of 0.63 gave rise to an F ratio of 3.25. For a significance level of 0.05, the critical value of F for a display variance with 3 df and an error variance with 9 df is 3.86. It is evident that the experimental value obtained on the basis of rms values of sink rate measures is not statistically significant.

rms Values of Stick Activity

In order to determine the influence of radio altimeter error on pilot work load, as measured by rms values of stick activity, this parameter was measured during the final 100 ft (30.48 m) of altitude. The mean rms value of stick activity for all subjects and all error conditions was 0.33 in.

As in the case of sink rates, the rms values of stick activity are tabulated for each error condition. In the matrices of performance measures the same notation applies in this case as in the preceding two cases, and the range of error conditions is the same. The elements of the following matrices are rms values of stick activity measured during the final 100 ft (30.48 m) of altitude.

S = 1

L \ C	1	2	3	4
1	0.27100	0.11300	0.10600	0.13700
2	0.11200	0.12800	0.14500	0.12100
3	0.11200	0.20000	0.13800	0.14500
4	0.18900	0.05200	0.14800	0.15500
5	0.13100	0.12700	0.15000	0.26000
6	0.15500	0.14400	0.14300	0.16400
7	0.16600	0.16900	0.13300	0.14100
8	0.18400	0.17500	0.18800	0.16000

S = 2

L \ C	1	2	3	4
1	0.27100	0.29100	0.15000	0.34300
2	0.30600	0.30100	0.31100	0.40900
3	0.32000	0.36700	0.32000	0.35200
4	0.40400	0.30100	0.37600	0.37700
5	0.41900	0.40200	0.36900	0.37700
6	0.48800	0.43500	0.44500	0.44300
7	0.45500	0.46800	0.48900	0.23700
8	0.20400	0.19000	0.51100	0.22900

S = 3

L \ C	1	2	3	4
1	0.33300	0.31300	0.29400	0.31800
2	0.30000	0.32100	0.25700	0.32400
3	0.36800	0.31500	0.31000	0.29600
4	0.36700	0.30000	0.30800	0.30100
5	0.34500	0.27400	0.29600	0.23700
6	0.27800	0.25600	0.30900	0.25300
7	0.19800	0.17200	0.12600	0.12300
8	0.19300	0.10700	0.11900	0.15900

S = 4

L \ C	1	2	3	4
1	0.36200	0.52200	0.41100	0.52200
2	0.34800	0.45900	0.42600	0.69500
3	0.45300	0.43000	0.69800	0.67100
4	0.54600	0.54500	0.57100	0.59300
5	0.61600	0.65200	0.53900	0.60600
6	0.40200	0.39600	0.77800	0.67700
7	0.41100	0.63100	0.50700	0.90800
8	0.30300	0.24100	0.63100	0.71500

The computed value of the variance of stick activity for all error conditions was 0.017. An error variance of 0.026 gave rise to an F ratio of 0.654. As in the preceding two cases, the critical value of F for a significance level of 0.05 is 3.86. It is evident that the variation of workload with altitude error, as measured by rms values of stick activity, is not statistically significant.

CONCLUSION

Statistical evaluation of the data obtained indicates that for the range of errors considered there is no significant difference in landing performance that can be attributed to errors in altitude information.

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3. Koziol, Joseph S., Jr.: Simulation Model for the Piper PA-30 Light Maneuverable Aircraft in the Final Approach. TSC Technical Memorandum, July 1971.

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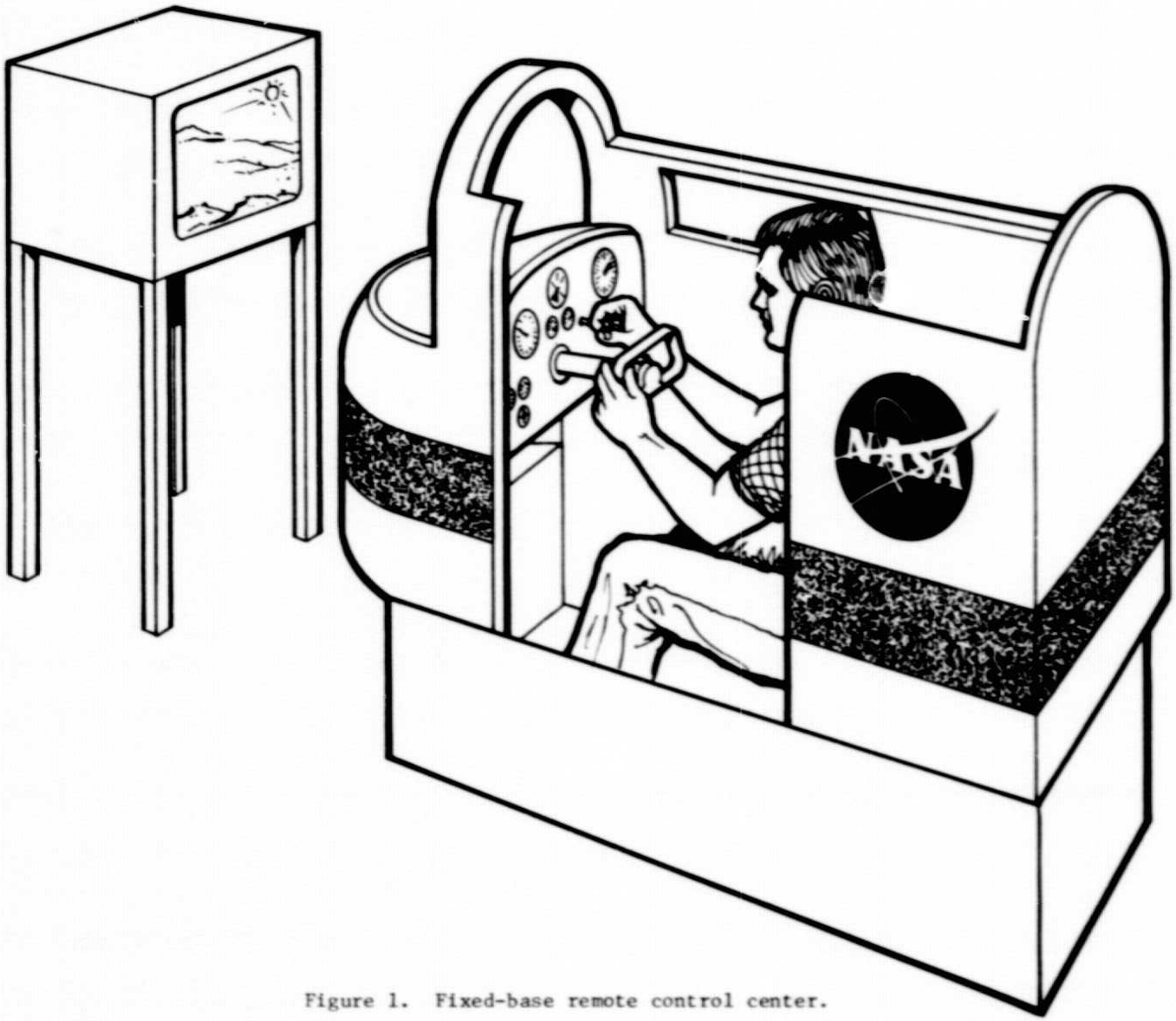

Figure 1. Fixed-base remote control center.

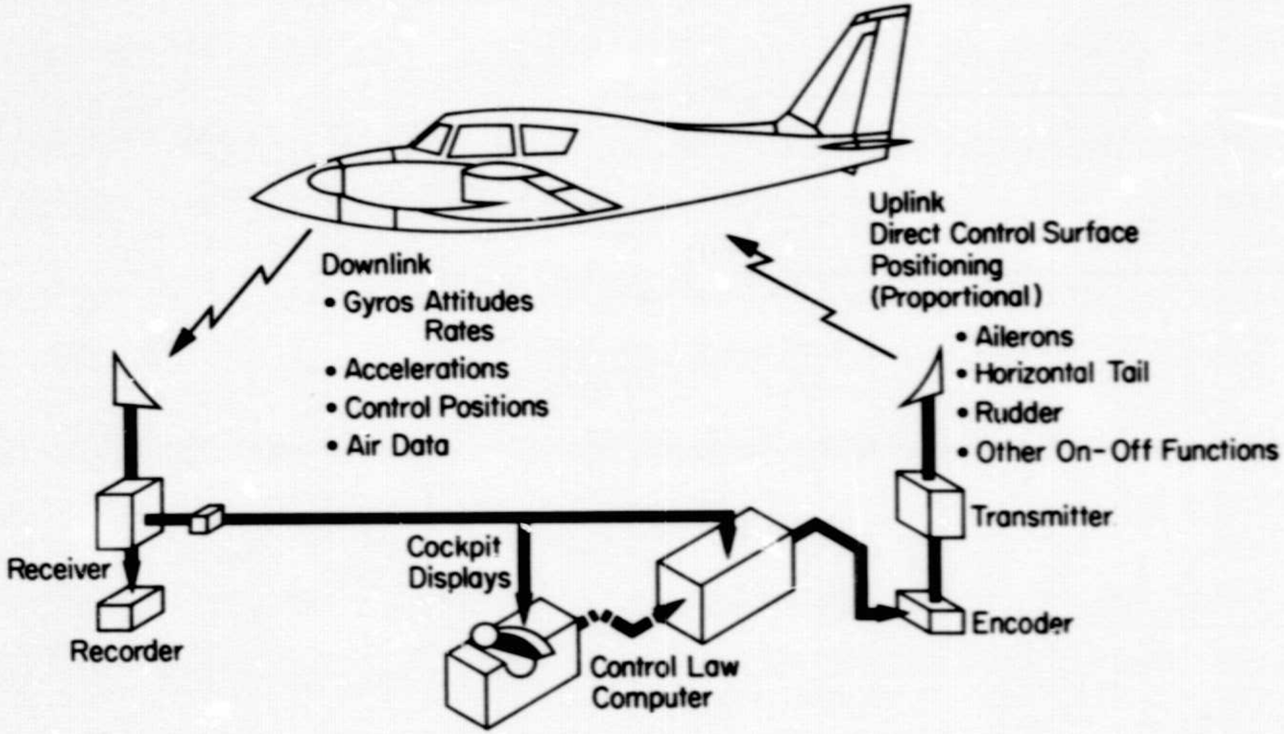

Figure 2. Avionics link used in the National Aeronautics and Space Administration's remotely piloted research vehicle.

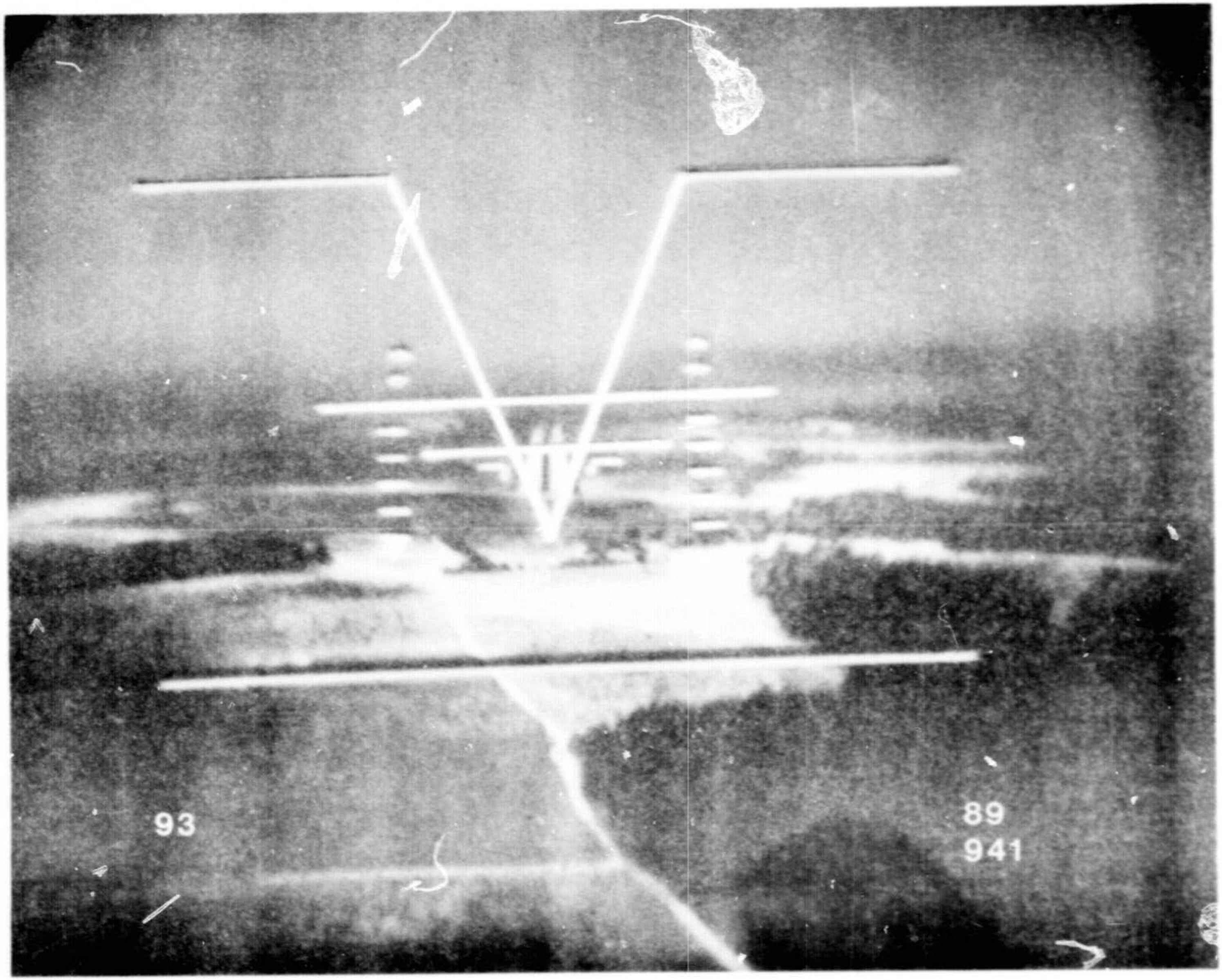

Figure 3. Display configuration D_4.

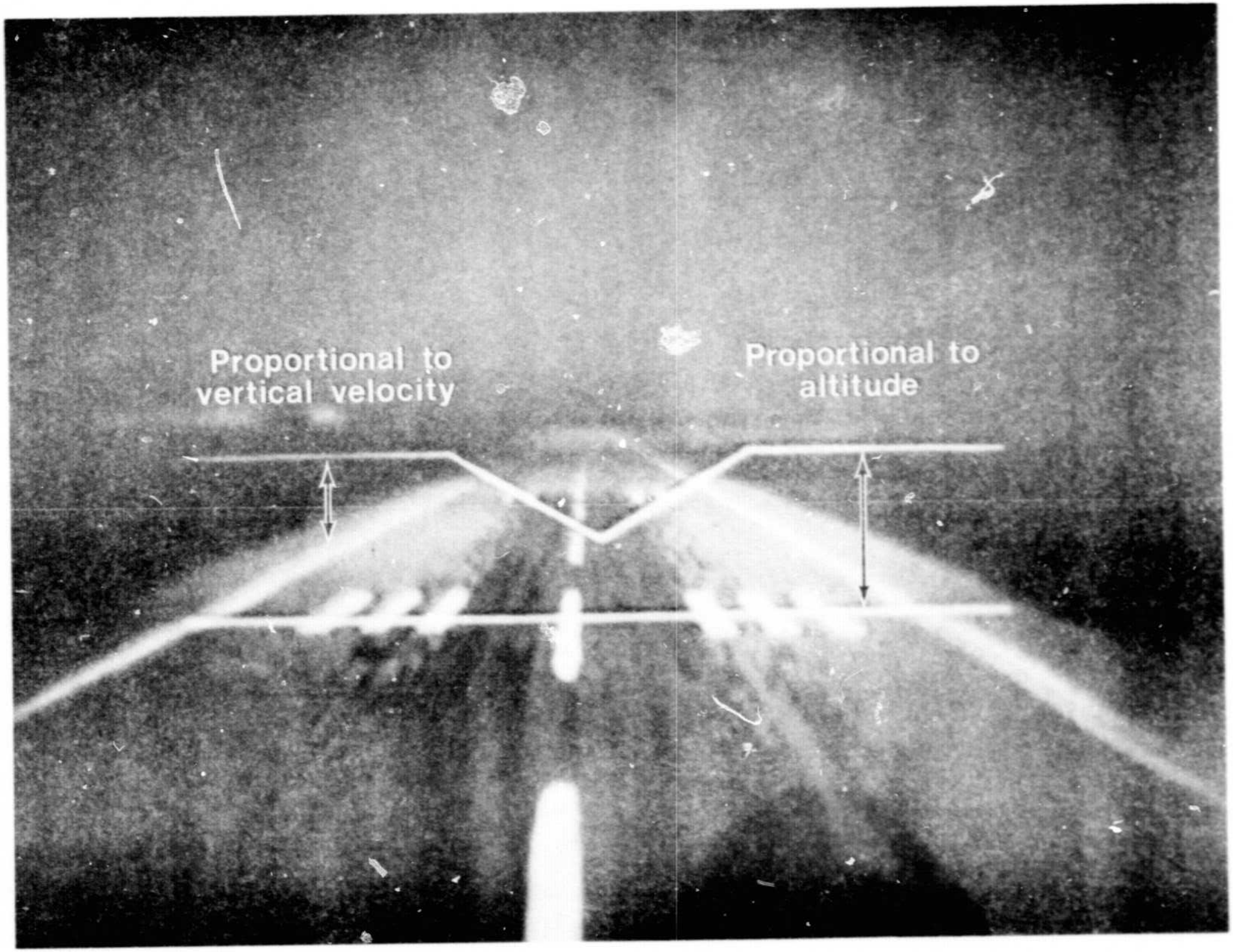

Figure 4. Chevron characteristics.

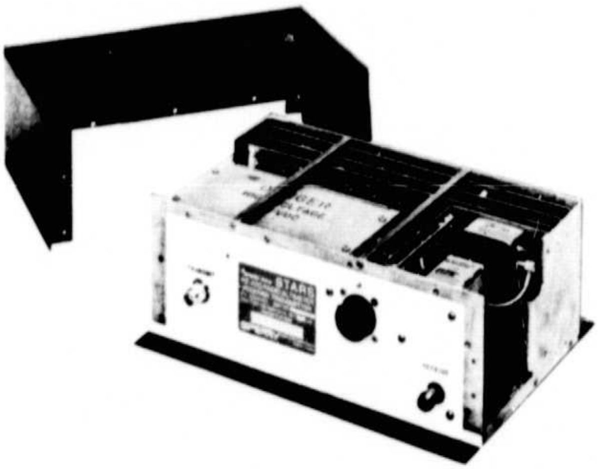

Figure 5. Receiver transmitter unit.

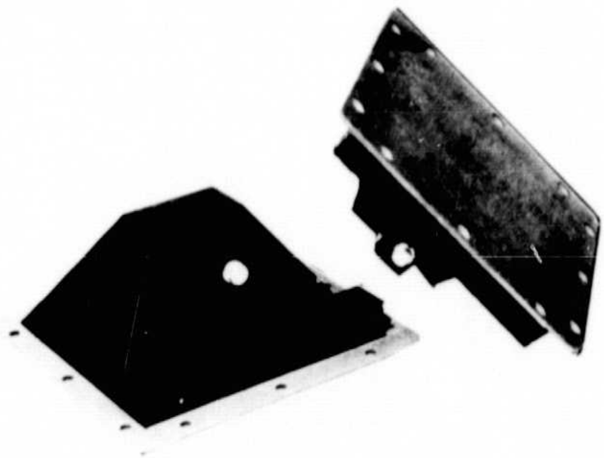

Figure 6. Antenna unit.

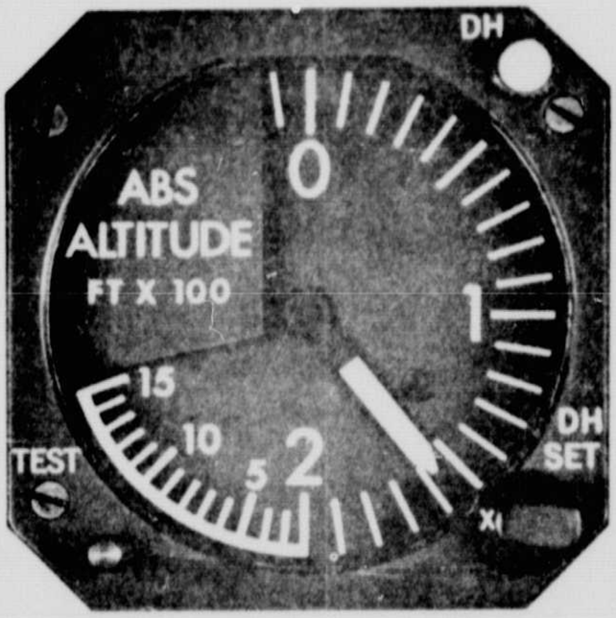

Figure 7. Radio altimeter indicator.

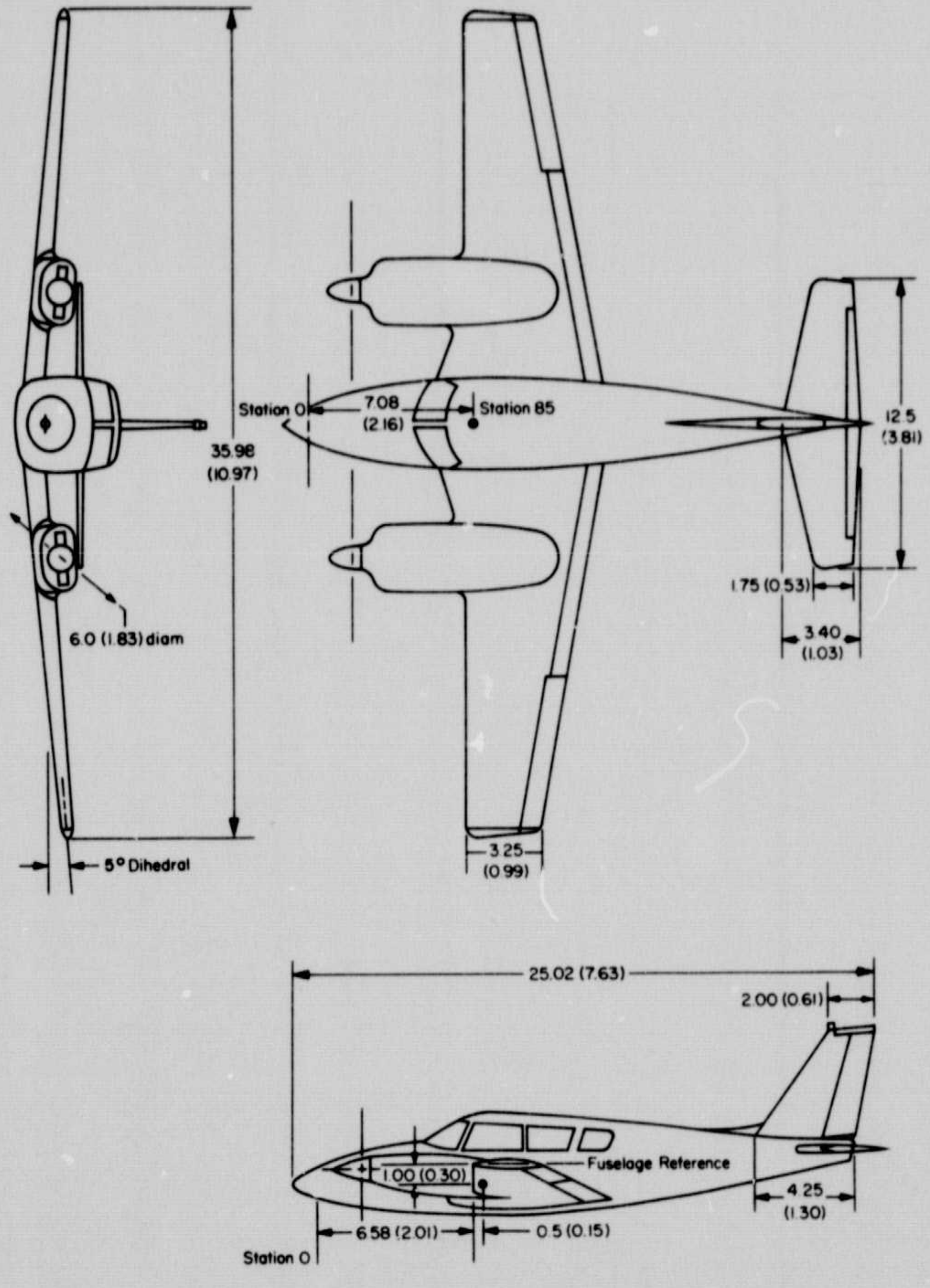

Figure 8. Three-view drawing of airplane. All dimensions are in feet (meters).