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SUMMARY

As part of a cooperative effort with NASA's Flight Research Center (FRC) a two part investigation was conducted to determine the display requirements for the final approach and landing phase of a remotely piloted vehicle (RPV) mission, and to assess the relative merits of several possible display configurations. The objective of the first part of the investigation was to obtain subjective assessments of several display configurations, and to select the most promising display concepts for subsequent evaluation in terms of performance measures. A basic display consisting of a perspective image of terrain and runway, a horizon bar and an aircraft symbol was used, and guidance symbology was added to the basic display configuration with the object of determining the most effective manner of displaying selected state variables. Initial results suggested that as guidance symbology is added to the basic display, pilot acceptance tends to increase. A point of diminishing returns is eventually reached, however, when additional information produces too much clutter, and makes it difficult for the pilot to process the displayed information.

The results of the first part of the study suggested 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. Their effectiveness in assisting pilots to make safe RPV landings was the object of the second part of the program. Here, the influence of the various display configurations on pilot performance during the final approach and landing phase of an RPV mission was evaluated.

Results indicate that there is no significant difference in landing performance that can be attributed to a particular display configuration. Pilot opinion, however, strongly suggested that although approximately equal performance could be achieved with each of the displays, the use of display configuration D_4, which incorporated the chevron, gave the RPV pilots greater assurance of success during the final approach and landing phase of an RPV mission. Moreover, the consistency of landing performance achieved with the display D_4, has led FRC to consider implementing this configuration in the forthcoming Firebee investigation. In addition to the basic display augmented with digital readouts of airspeed, altitude and altitude rate, configuration D_4 contained pitch attitude and glide slope information plus the chevron.

INTRODUCTION

The overall objective of the remotely piloted vehicle program is to develop an aeronautical research tool that is well suited to aerodynamic research; to obtain high angle-of-attack data up to and including post-stall, prespin conditions, and to assess advanced control systems under these conditions.

In one of its more important applications, the RPV program represents an attempt to reduce the cost and the danger involved in testing high performance aircraft. The lack of full-scale flight test data for these aircraft is due to the risk involved in testing such aircraft. The average loss of one aircraft per spin flight test program with advanced fighters costing from $15M to $18M each makes these tests very expensive. The RPV approach offers a very attractive potential for performing large scale flight testing of hazardous tasks at low risk and relatively low cost (ref. 1).

In addition to its use as an aeronautical research tool, the RPV concept has a potential military application as an air-to-air combat weapon. In this role, the RPV can execute sustained high g maneuvers that a human pilot could not tolerate, and avoids exposure to the hazards of aerial combat. A variety of other applications has been suggested. Among these are crop dusting, weather modification and pollution monitoring. For a more detailed list of potential applications see figure 1.

As presently constituted, the NASA remotely piloted vehicle program calls for the building and flight testing of three 3/8 scale models of the F-15 fighter aircraft. The first vehicle is for basic subsonic tests; the second vehicle is a backup to the first, and a third vehicle is for special follow-on tests, possibly at supersonic speeds to determine if aerodynamic or control system modifications are necessary, and to develop a horizontal landing capability (ref. 1). The vehicles will be air-launched from a B-52 aircraft at 45,000 ft (13,716 m) and recovered initially by mid-air parachute snatch (fig. 2). Later in the program horizontal landings will be attempted. A pilot will fly the vehicle from a fixed-base simulation cockpit using standard flight instruments and a TV display which are driven by telemetered flight data (figs. 3,4).

A preliminary phase of the RPV program, which is currently under way at FRC, involves the use of a Piper PA-30 aircraft for final approach and landing tests. It is the object of the present study to simulate this aircraft on a fixed base simulator in order to assess the advantage of supplementing the conventional cockpit display with graphic overlays of selected state variables. With this object in mind, a two part investigation was conducted to determine the display requirements for the final approach and landing phase of an RPV mission, and to assess the relative merits of several possible display configurations. As indicated previously, the purpose of the first part of the investigation was to make a subjective assessment of several display configurations, and to select the most promising display concepts for subsequent evaluation in terms of performance measures. A basic display consisting of a perspective image of terrain and runway, a horizon bar and an aircraft symbol was used. Guidance symbology was added to the basic display configuration, with the object of determining the most effective manner of displaying selected state variables. Pilot opinion suggested that pitch attitude, glide slope information and a chevron combined with digital readouts of airspeed, altitude and vertical velocity were the most useful addition to the basic display. The second part of this study was devoted to the measurement of the influence of the various display configurations on pilot performance during the final approach and landing phase of an RPV mission.

Although the display requirements for the final approach and landing phase of an RPV mission do not differ significantly from conventional jet transport display requirements, the manner in which information is displayed to the RPV pilot assumes greater importance. Based on experience to date, FRC pilots give much the same pilot rating on the fixed base simulator as in the real RPV aircraft. However, they complain of more exhaustive workload on the simulator, because of the extreme concentration and eye focusing on instruments required to obtain the same quickening cues normally obtained from outside vision and inertial motion cues.

As the RPV program progresses to a more advanced stage, the information required by the pilot will increase. Of critical importance at high angles of attack, in the region of stall, will be the display of incipient spin indicators, such as yaw rate and sideslip rate. The possibility of information loss from gyro sensors during certain maneuvers will have to be considered. Likewise, the possibility of subjecting the vehicle to excessive structural loads can be avoided by displaying "g" load information to the pilot or, alternately, by displaying the output of strain gauges mounted at high bending moment locations, or points of suspected high stress concentration. Finally, turbulent aerodynamic conditions may excite the flexural and torsional oscillations of the wings and fuselage. These in turn may induce flutter, which can lead to structural failure. The RPV pilot must be made aware of such conditions by providing him with appropriate display information.

DISPLAY CONFIGURATIONS FOR SUBJECTIVE EVALUATION

The display configurations considered for subjective evaluation are shown in figures 5 through 10. The basic configuration I shown in figure 5 consisted of a pictorial view of terrain and runway, which was generated by the Life Sciences General Precision Systems (G.P.S.) visual attachment. Superimposed on the pictorial scene was a horizon bar and an aircraft symbol, both of which were generated by an Evans & Sutherland LDS-2 display generator. In addition, the basic display contained digital readouts of airspeed and altitude. The airspeed readout was in knots and appeared at the top left-hand region of the display. The digital readout of aircraft altitude was in feet and was presented at the top right-hand area of the display. Finally, pitch attitude information was presented in the form of broken lines at one degree intervals.

In addition to the information displayed in the basic configuration shown in figure 5, configuration II provided a digital readout of altitude rate in feet per minute. This was located immediately beneath the digital readout of aircraft altitude as shown in figure 6.

Configuration III provided the pilot with roll information as shown in figure 7. Each short line represented a roll angle of 5°, and each long line a roll angle of 10°.

The glide slope and localizer window shown in figure 8 marks the difference between display configuration III and configuration IV. Configuration IV provided the pilot with glide path and localizer errors. By maintaining the aircraft symbol in the middle of the window, the pilot could remain on a specified glide slope.

Configuration V contained the chevron shown in figure 9. A more detailed description of the information contained in the chevron and the implications of changing chevron geometry are given in figure 10. In this particular display, the chevron was designed to facilitate the landing operation. At an altitude of 98 ft (30 m), it was superimposed on the display configuration shown in figure 8, and provided a measure of wheel height above the runway and the vertical velocity of the aircraft. If the pilot initiated flare when the point of the chevron which indicated the vertical velocity of the aircraft touched the ground reference line, and then continued to pitch up just enough to keep the point of the chevron on the reference line, a touchdown with a vertical velocity of 2 ft/sec (0.6 m/sec) could be achieved (ref. 2).

Subsequent to the initiation of flare, all information was removed from the display, except the chevron, and the display assumed the form shown in figure 10. It was hoped that by adopting the procedure of removing distracting symbols that were no longer being used, the pilot would be able to concentrate more fully on the landing operation.

Pilot Comments

Airspeed indication– The location of the digital readout of airspeed did not meet with pilot approval. Since pilots are accustomed to look down for airspeed information, they would prefer to have this data at the left-hand side of the horizon bar or the lower left-hand region of the display.

Altitude readout– As in the case of airspeed indication the location of the digital readout of altitude did not meet with pilot approval. Pilots would prefer to have this information displayed on the right-hand side of the horizon bar or the lower right-hand region of the display.

Display of altitude rate– Pilot opinion indicates that a location of digital readout of altitude rate beneath the altitude readout is satisfactory. However, larger incremental changes in this state variable would be preferred. In this connection, it was felt that changes in readout should only be made when the sink rate increases by 50 ft/min (15 m/min).

Roll information– The displayed roll information was not used by the RPV pilots.

Horizon bar– The horizon bar is considered very useful in RPV work.

Attitude information– The presentation of attitude information in the form of pitch lines at one degree intervals met with good pilot acceptance. It was suggested that the present form of the display be retained for future research. It was considered unnecessary to number the pitch angles.

Glide slope and localizer display– The glide slope information contained in the glide slope and localizer window was considered to be extremely useful. However, pilots felt that glide slope information should be presented in a different way, possibly in the form of an unbroken line.

The chevron– Because it provides an integrated display of wheel height above the runway and vertical velocity, it is expected that the chevron will play a very important role in assisting pilots to control remotely piloted vehicles, particularly during the final approach and landing phase. It appears that in landing RPVs from a remote control center, pilots don't perceive the altitude with sufficient precision when they are getting low, and feel that the information contained in the chevron display would provide the assistance necessary to overcome this defect. The large scale of the chevron used in this study was considered to be just right (fig. 9). It gave the necessary information in a rather dramatic form prior to the initiation of flare. In this study, all display information, except the chevron, was removed at the initiation of flare (fig. 10). This procedure was not liked by the pilots who stressed the importance of attitude information subsequent to flare (in

RPV work). Evidently there is a tendency on the part of pilots to land the RPV too fast and to lose precise attitude control.

In RPV work, the pilots would like greater sensitivity of glide slope and localizer displays to changes in aircraft motion. As a means of implementing greater display sensitivity to aircraft motion, the pilots expressed a preference for a gain control on the instrument panel, which would bring the sensitivity under the control of individual pilots.

DISPLAY CONFIGURATIONS FOR QUANTITATIVE EVALUATION

On the basis of pilot opinion, four display configurations were selected for evaluation in terms of performance measures. These are shown in figures 11 through 14. Configuration D_1, shown in figure 11, consisted of a pictorial view of terrain and runway. Superimposed on the pictorial scene was a horizon bar and an aircraft symbol. In addition, D_1 contained digital readouts of airspeed (knots), altitude (feet), and altitude rate (feet/min). In accordance with pilot opinion, the digital readouts were located at the lower left-hand and lower right-hand regions of the display. With the exception of pitch attitude information, configuration D_2 was the same as configuration D_1. As shown in figure 12, attitude information was presented in the form of pitch lines at one degree intervals. Pilot opinion indicated that it was unnecessary to number the pitch angles.

In addition to the information displayed in configuration D_2, configuration D_3 contained glide-slope information. At the request of the pilots, the glide-slope and localizer window which was used for subjective evaluations was replaced by a glide-slope line as shown in figure 13. The fourth and final configuration of the series for quantitative evaluation was D_4. As can be seen in figure 14, this configuration was the same as D_3 with the chevron superimposed.

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 FRC 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 15 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. 3). The airplane has the standard three-control system. The horizontal tail is of 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. 3).

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 the NASA Edwards Flight Research Center simulation model and references 3,4.

The model consists of the rigid body, six degrees of freedom aircraft equations of motion that are basically linear perturbation equations in the stability axis system (ref. 4). Where they are considered essential, some of the non-linear cross coupling terms have been included. 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 digital 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 provide overlays of state variables on the pictorial scene of terrain and runway provided 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. 5). 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 an RPV mission.

EXPERIMENTAL DESIGN

The four display configurations selected for evaluation were presented to four pilot subjects in accordance with a Latin Square design. In the situations to which the Latin Square design 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 four runs, the Latin Square design assures that a pilot 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; distance from runway threshold at touchdown; rms of sink rate; rms of stick activity and rms of altitude error. See Table 1 for results.

CONCLUSIONS

Statistical evaluation of the data obtained indicates that there is no significant difference in landing performance that can be attributed to a particular display configuration. However, pilot opinion stressed the fact that although approximately equal performance could be achieved with each of the displays, the use of display configuration D_4 gave the RPV pilots greater assurance of success in controlling the dependent variables during the final approach and landing phase of a mission.

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TABLE 1.– ANALYSIS OF VARIANCE RESULTS

Dependent variable	Source	F Ratio and df	Significance level	Critical value
RMS Sink rate	Display	1.05 (3,9)	0.05	3.86
RMS Stick activity	Display	2.19 (3,9)	0.05	3.86
RMS Altitude error	Display	1.07 (3,9)	0.05	3.86
Sink rate at touchdown	Display	0.72 (3,9)	0.05	3.86
Range at touchdown	Display	1.69 (3,9)	0.05	3.86

FOREST FIRE DETECTION

FOREST FIRE FIGHTING

LOGGING

MAIL DELIVERY

FREIGHT DELIVERY

TRAFFIC INSPECTION/MONITORING/COUNTING

SEARCH/AID IN REMOTE AREAS

WEATHER SENSING

AGRICULTURAL DUSTING

AGRICULTURAL INSPECTION

POLICE SURVEILLANCE/SEARCH

POLICE PURSUIT/INTERDICTION

WEATHER MODIFICATION (CLOUD/FOG SEEDING, CYCLONE BUSTING)

POLLUTION MONITORING (AIR, GROUND, WATER, NOISE)

DISASTER/DANGER WARNING (SMALL CRAFT WARNINGS, CYCLONE WARNINGS – BANNER OR LOUDSPEAKER)

AERONAUTICAL AND SENSOR RESEARCH

FISH & WILDLIFE DETECTION, MONITORING, COUNTING, HERDING, STOCKING

TERRAIN MAPPING, SURVEYING, GEODETIC WATER SHED

COMMUNICATION RELAY (ON THE SPOT NEWS, TV, DATA)

TOW VEHICLE FOR GLIDING FREIGHTERS, SPORT AIRCRAFT, PERSONAL AIRCRAFT

REFUELING VEHICLE

SNOW AND PRECIPITATION MEASUREMENT

TEMPORARY BEACON (AIRCRAFT, RESCUE WORK, DANGER AREA)

PIPE AND POWER LINE INSPECTION

ADVERTISING (SKYWRITING/TYPING, BANNER TRAILING)

Figure 1 Civil uses of RPVs.

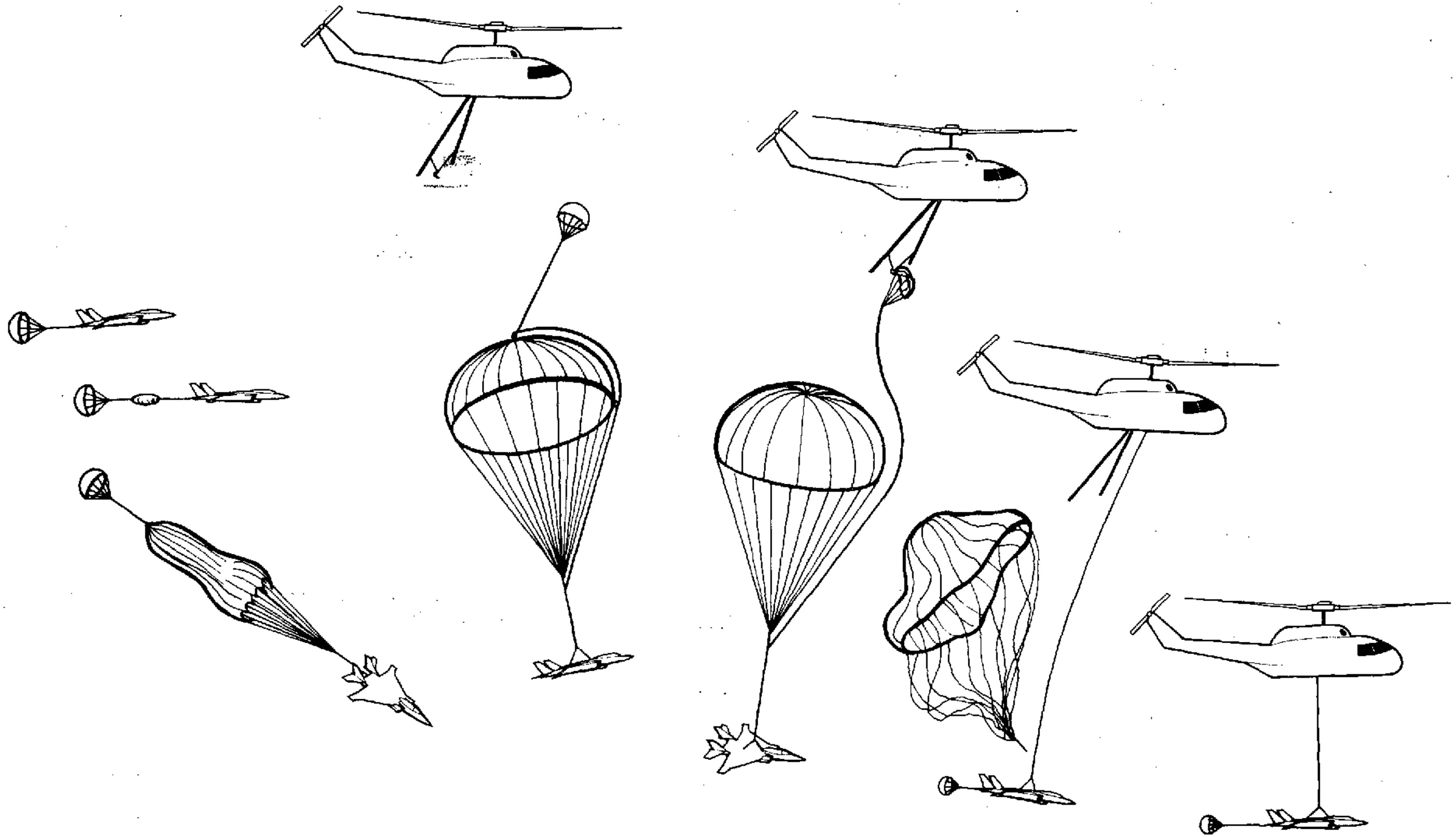

Figure 2 RPV recovery system.

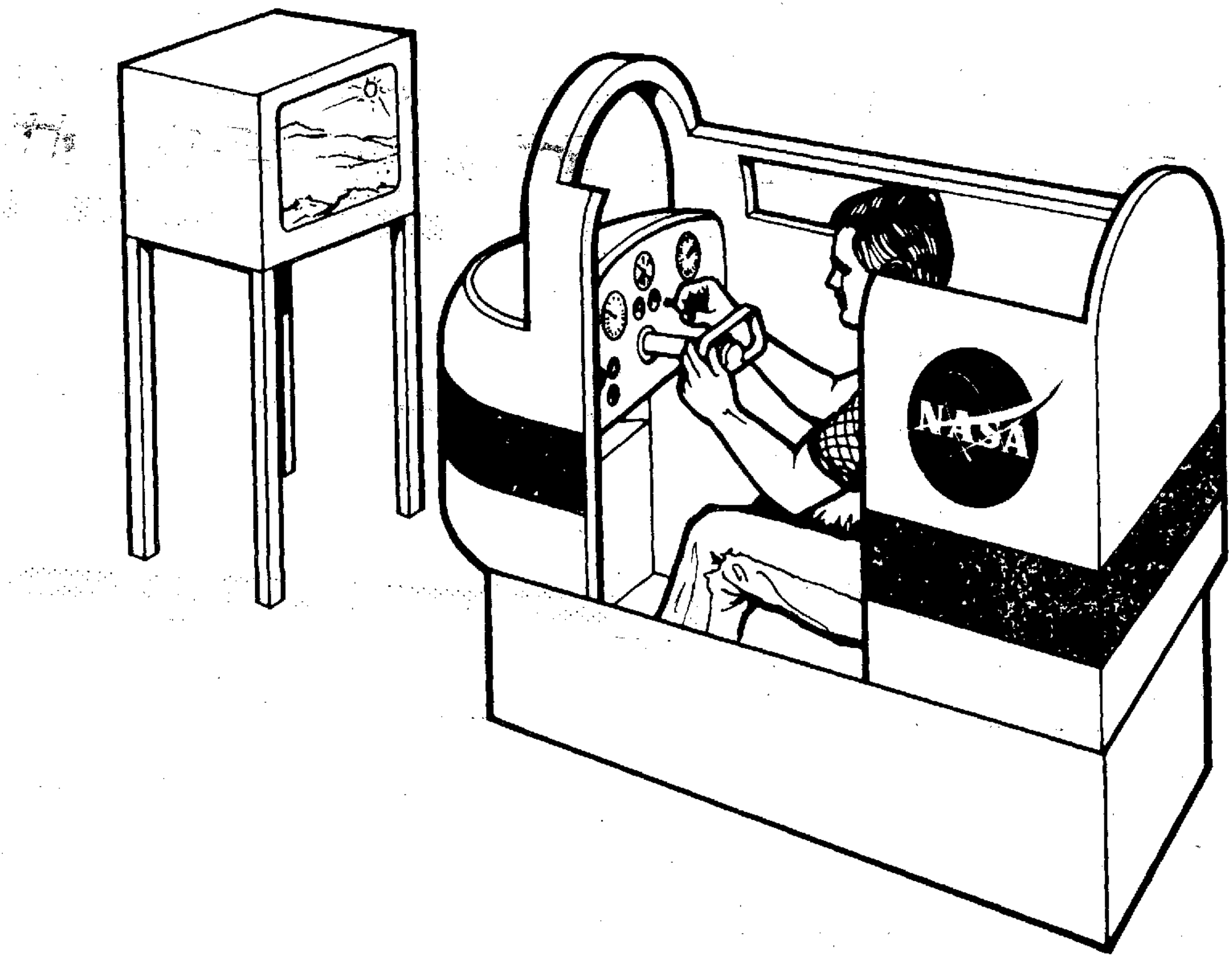

Figure 3 Fixed-base remote control center.

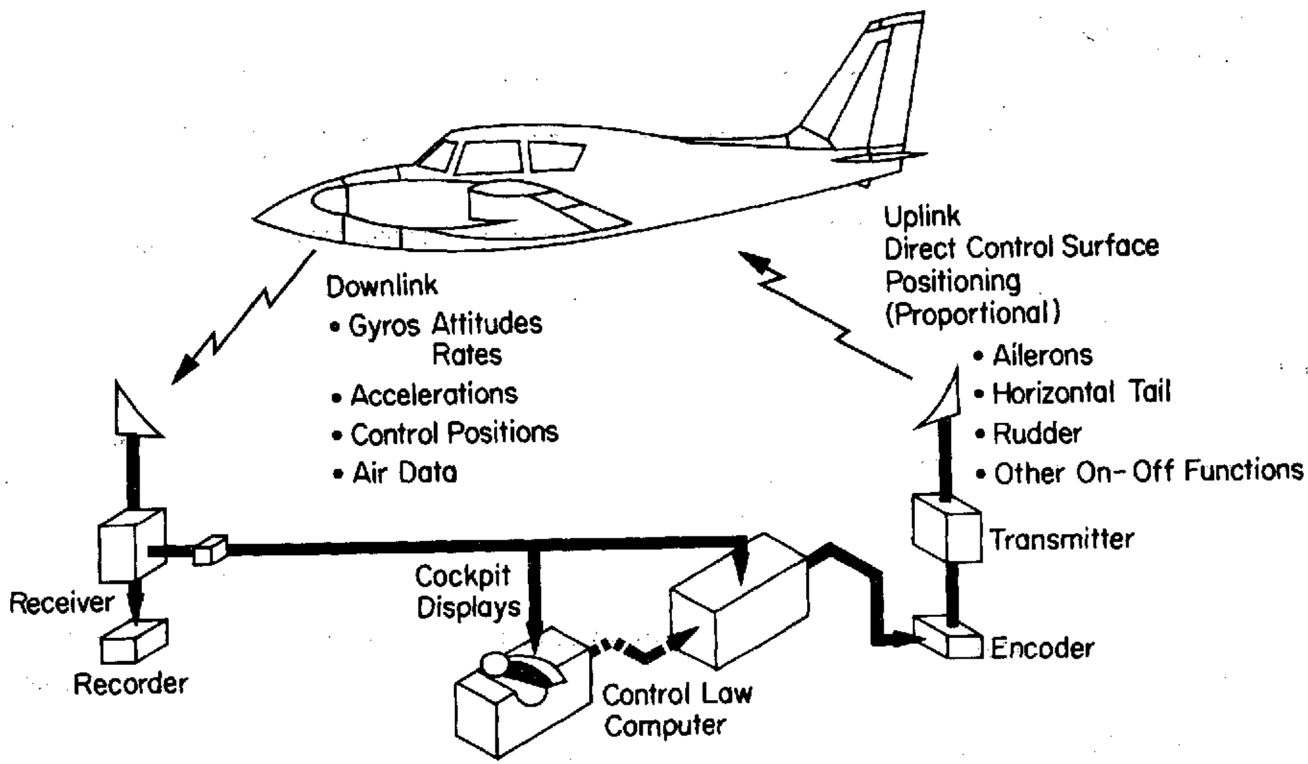

Figure 4 Avionics link used in the National Aeronautics and Space Administration's remotely piloted research vehicle.

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Figure 5 Display configuration I.

Figure 6 Display configuration II.

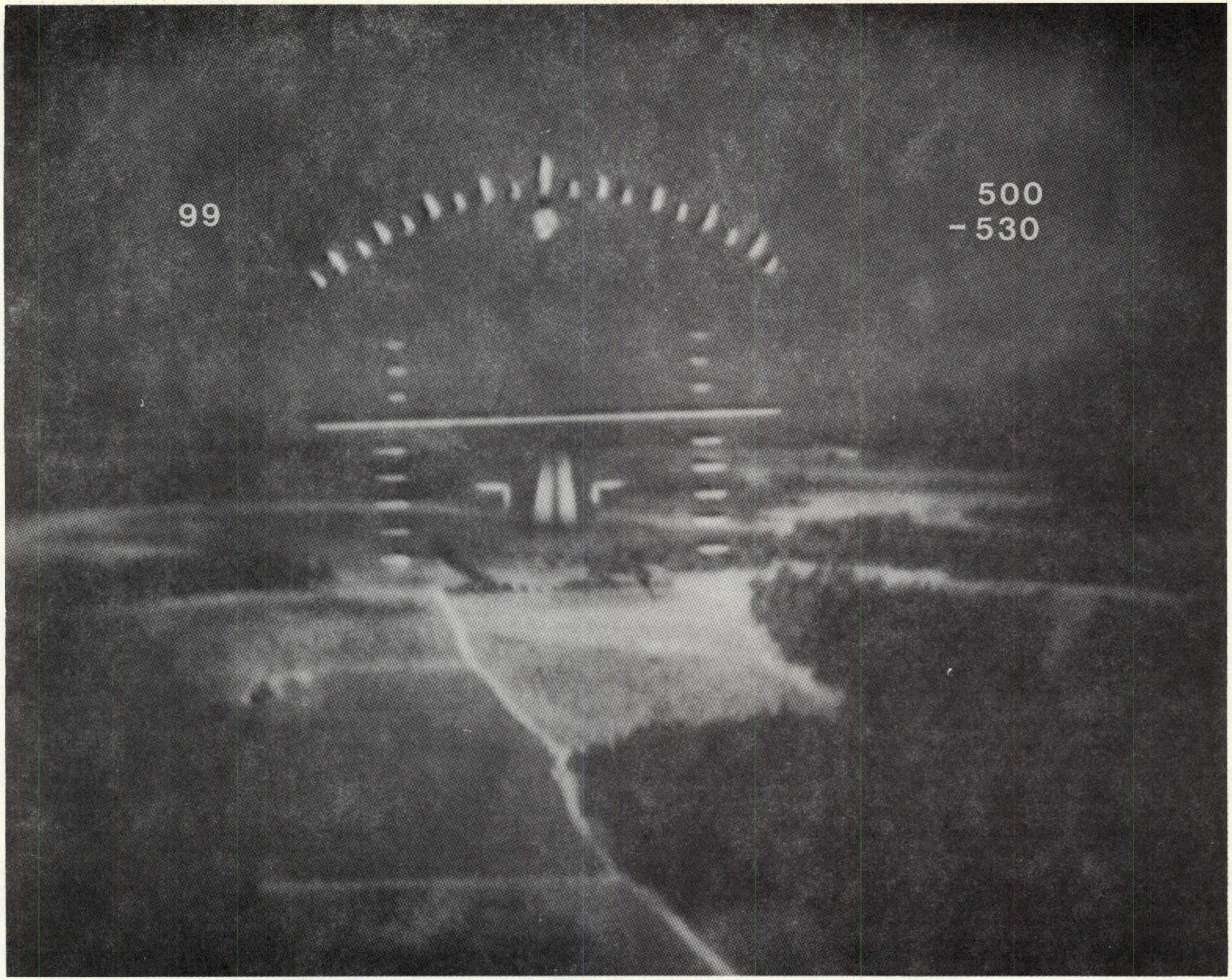

Figure 7 Display configuration III.

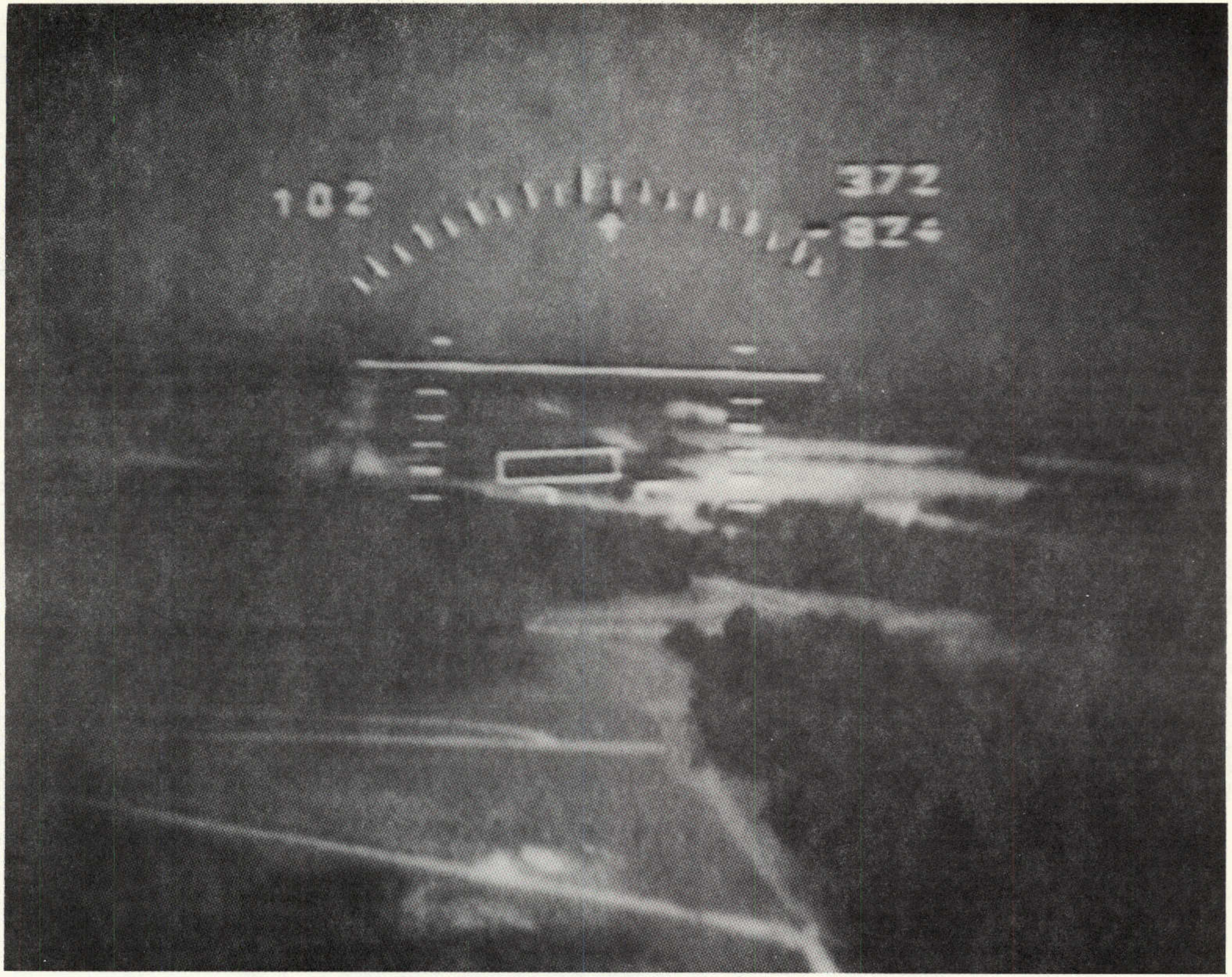

Figure 8 Display configuration IV.

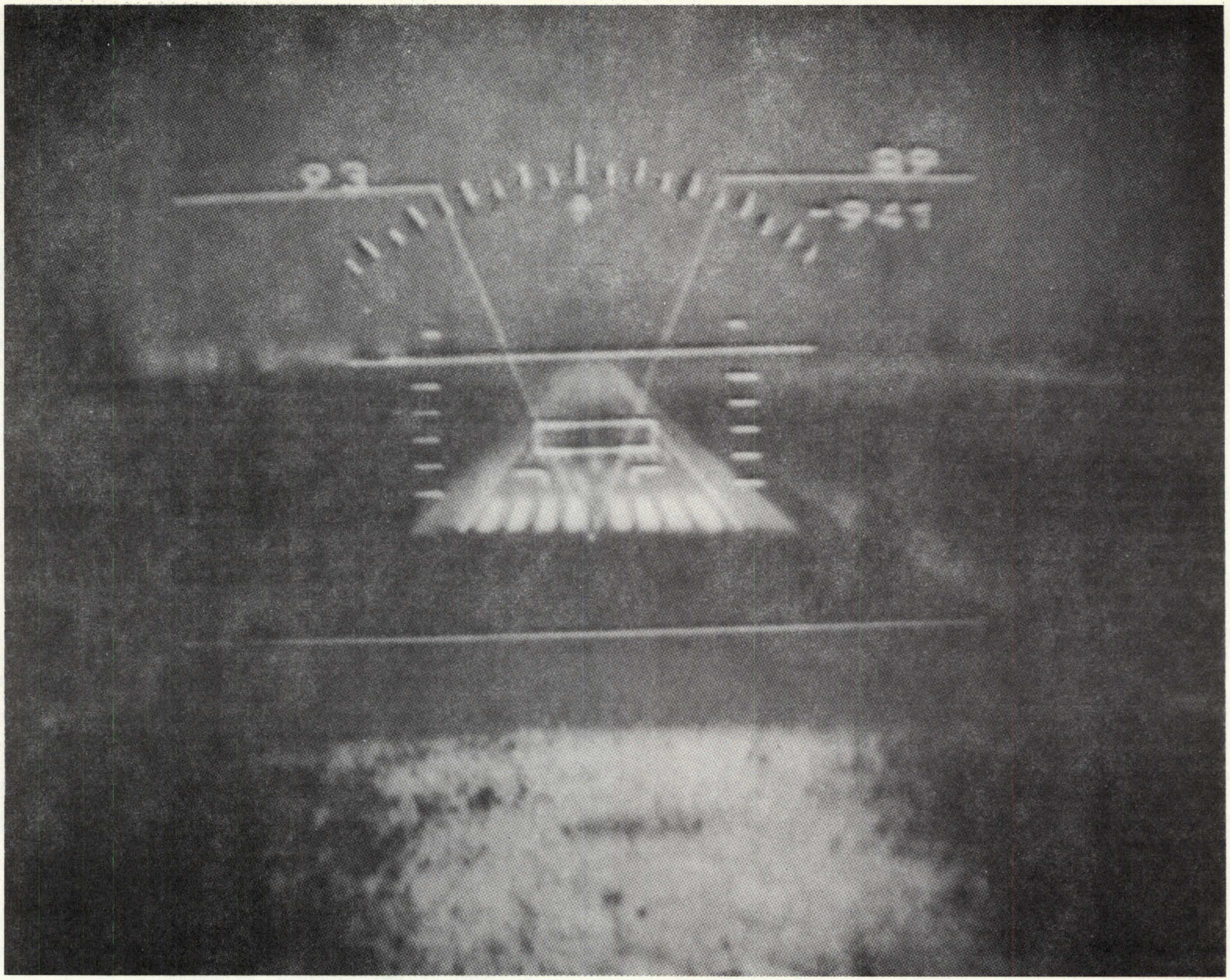

Figure 9 Display configuration V.

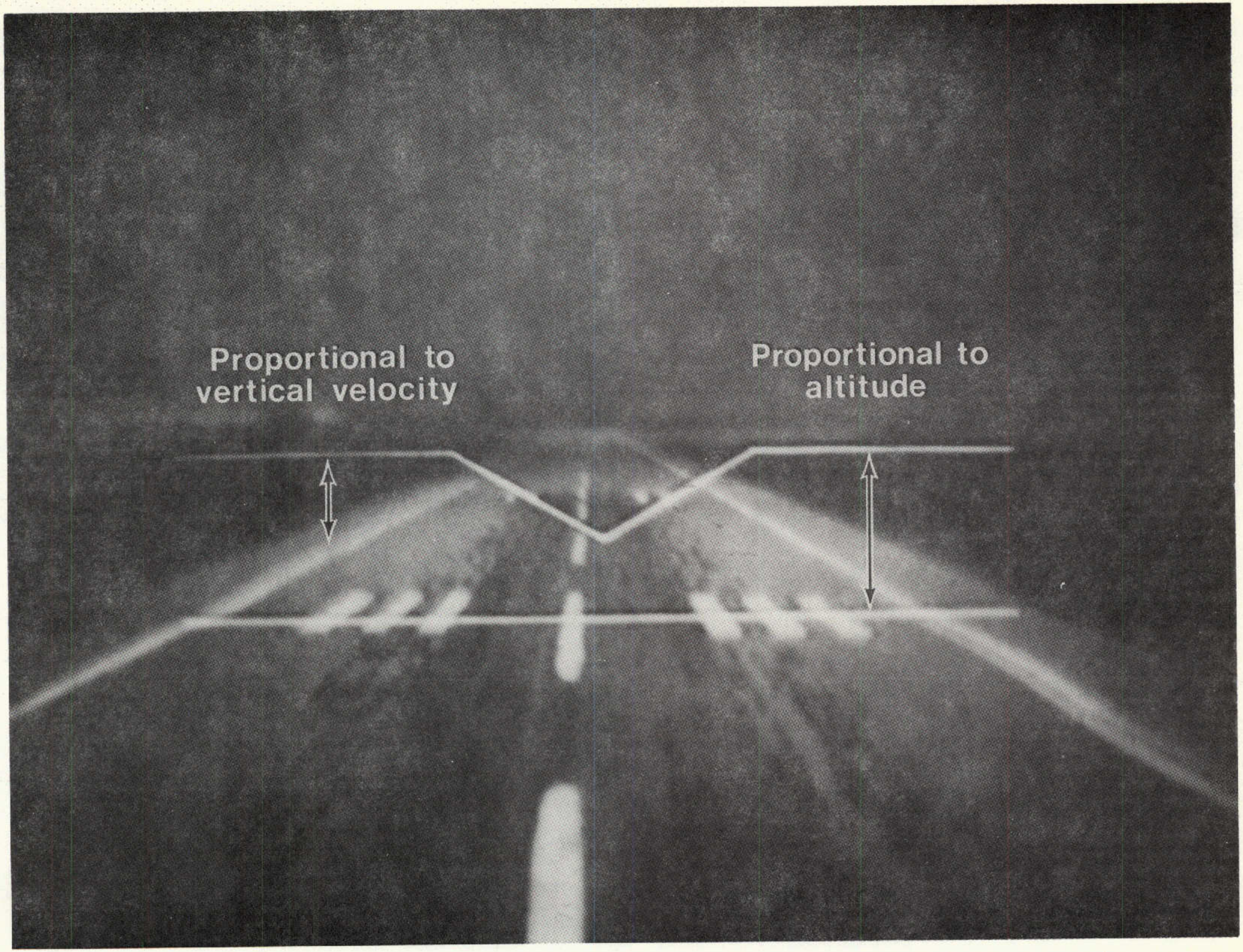

Figure 10 Chevron characteristics.

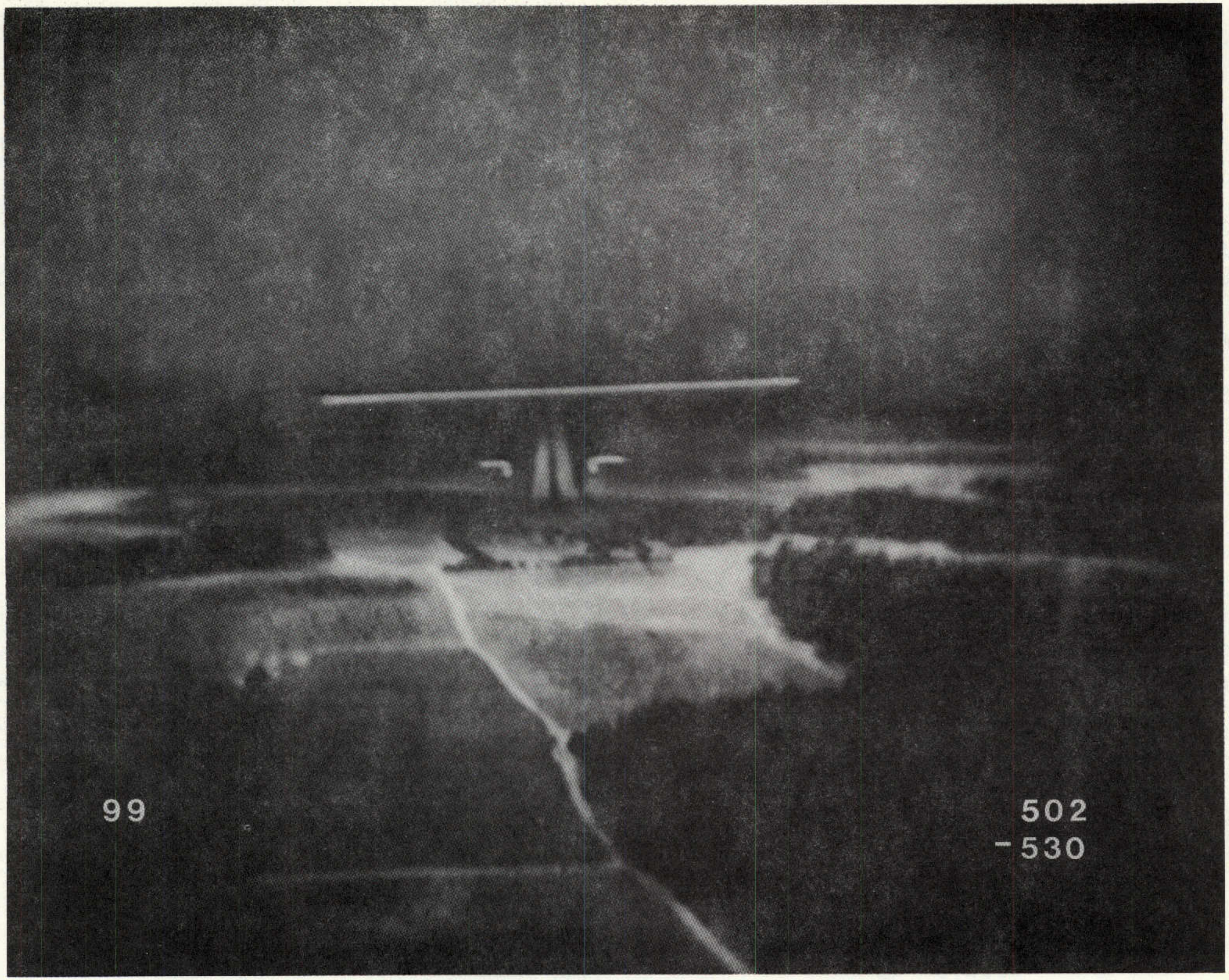

Figure 11 Display configuration D_1.

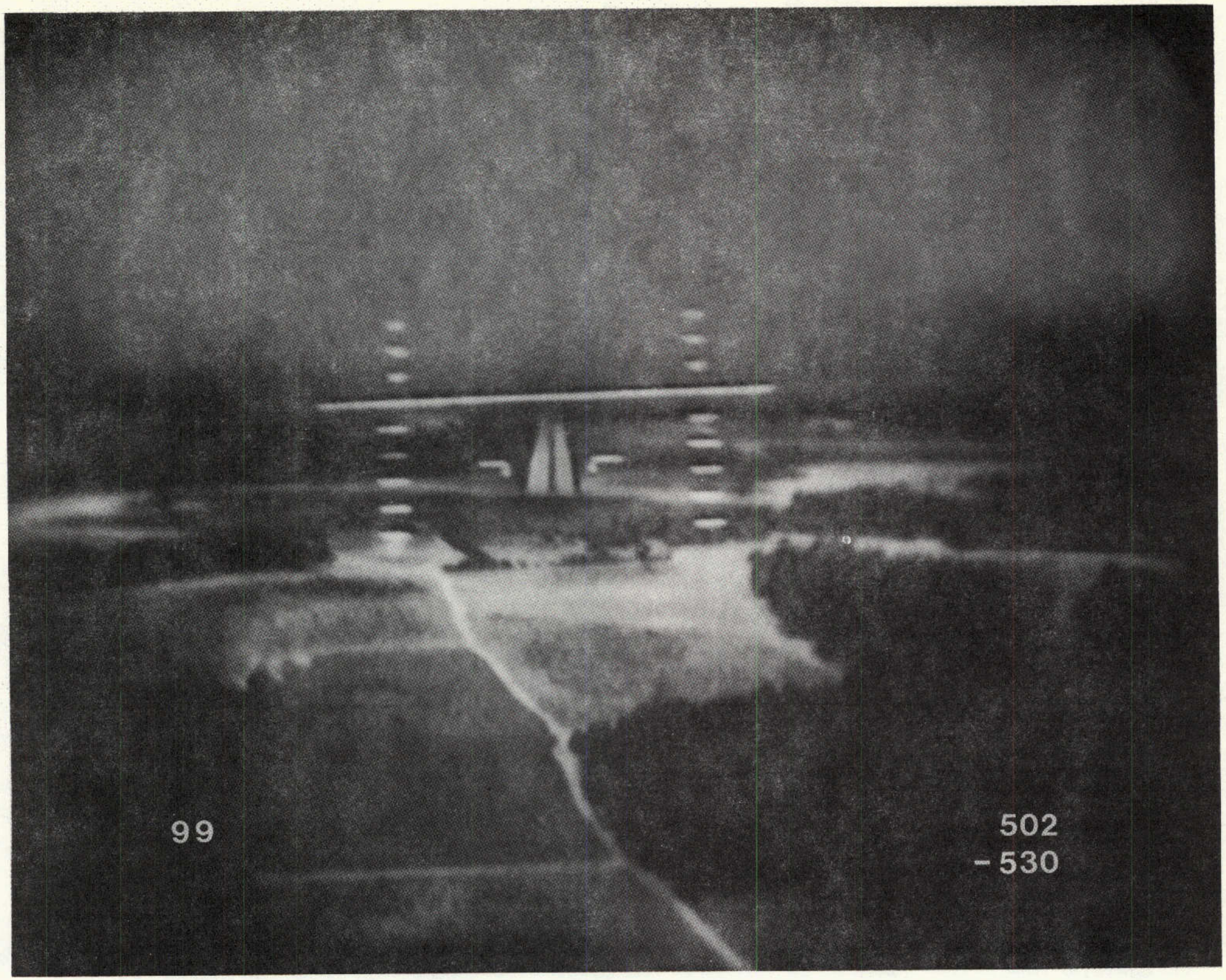

Figure 12 Display configuration D_2.

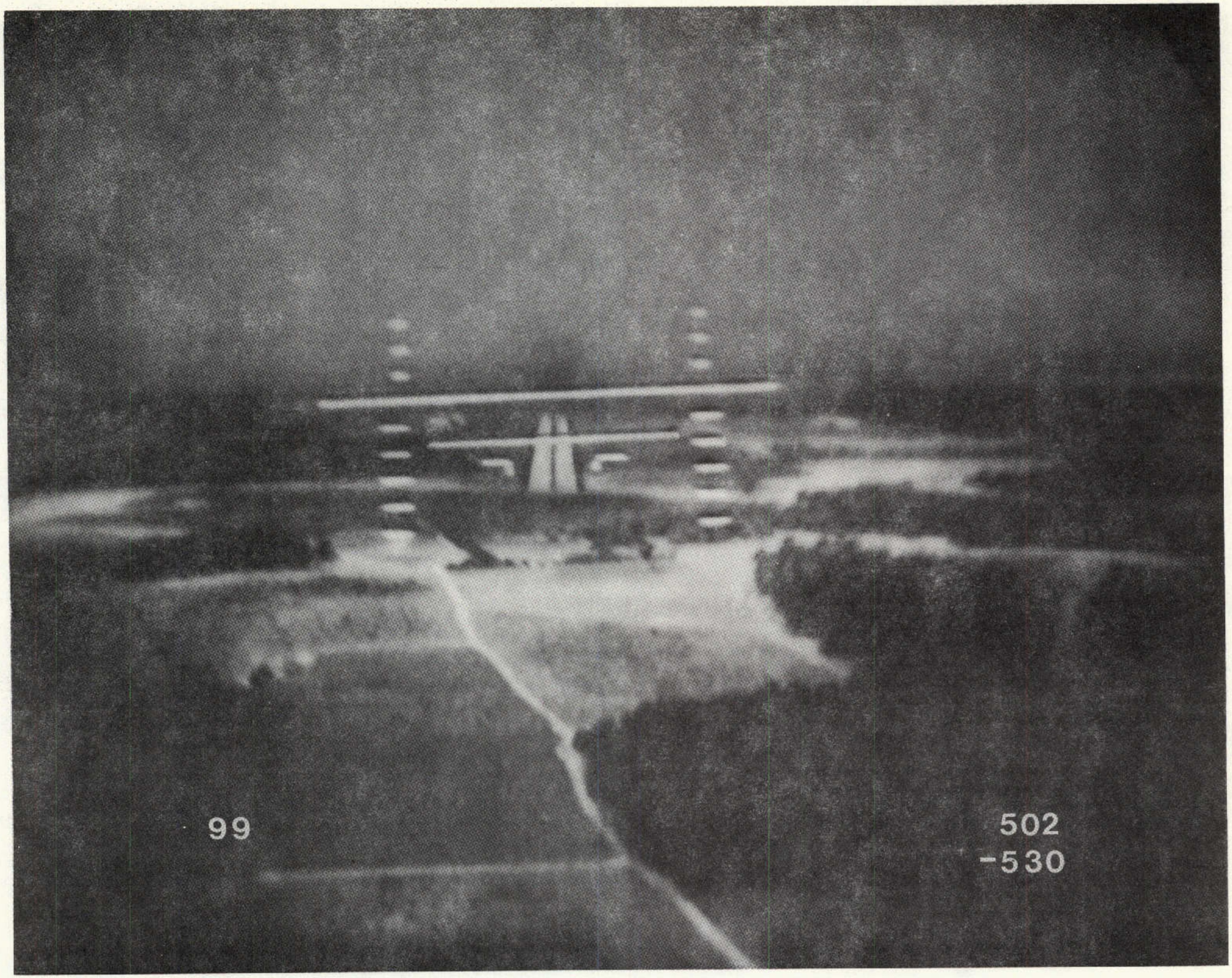

Figure 13 Display configuration D_3.

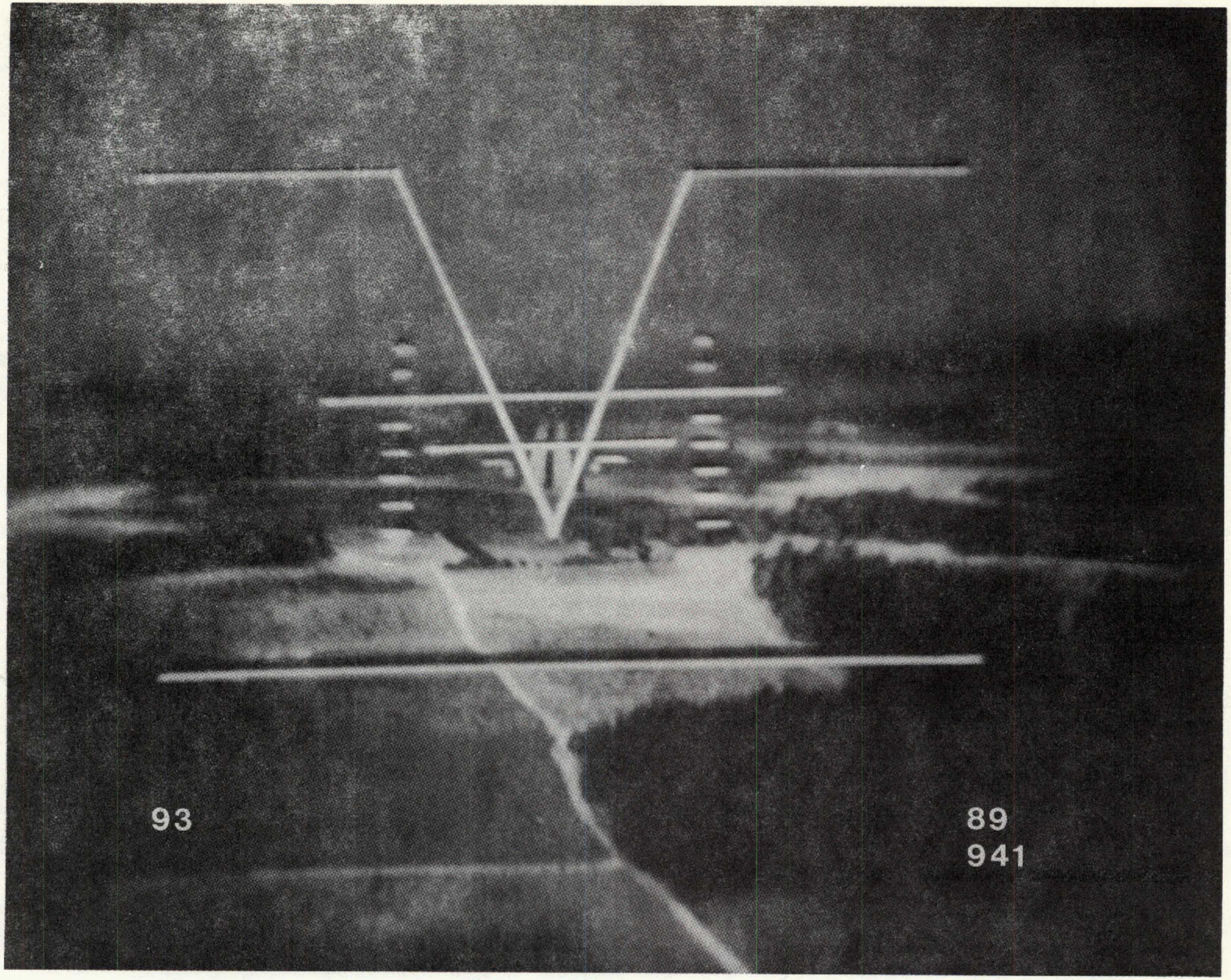

Figure 14 Display configuration D_4.

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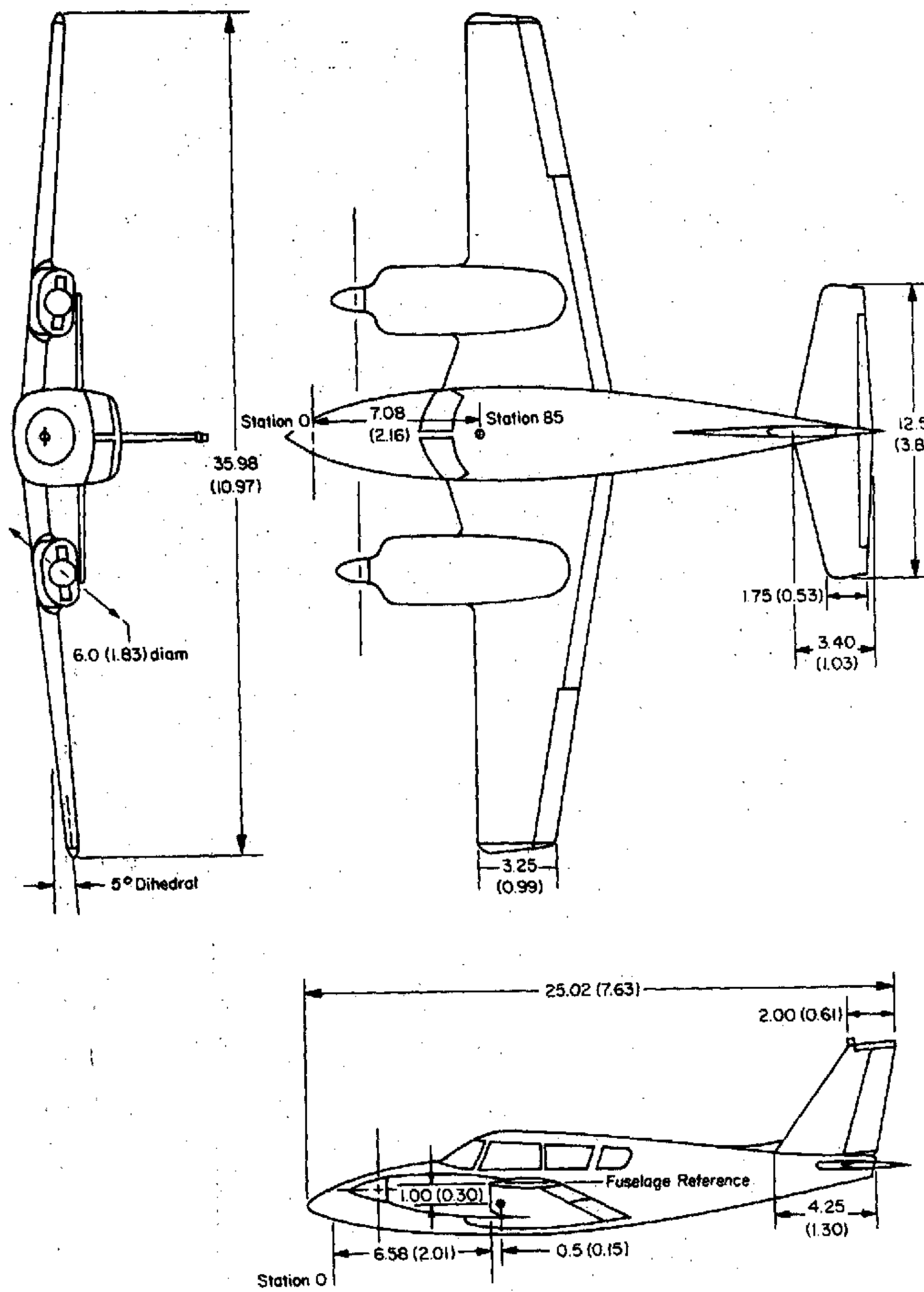

Figure 15 Three-view drawing of airplane. All dimensions are in feet (meters).