CURRENT RESEARCH ON ADVANCED COCKPIT DISPLAY SYSTEMS

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Presented at the 25th Flight Mechanics Panel Meeting of the Advisory Group for Aeronautical Research and Development

Munich, Germany
October 12-14, 1964

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C.

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ABSTRACT

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Current cockpit-display philosophy is discussed in terms of the pilot's informational requirements. Pilots' scan patterns obtained through the use of an eye-position camera and a ground-based simulator are depicted for a conventional display system and for two advanced concepts. Preliminary results of some flight-test and ground-simulation evaluations of advanced concepts, such as totally integrated displays and indirect pilot viewing systems, are discussed.

Author

INTRODUCTION

With the increased performance of flight vehicles, additional and more exacting control requirements are being placed on the pilot, including an increasing demand for all-weather operation. As a result of this increased workload, effective utilization of the pilot can be achieved only through effective design of the pilot—vehicle interface, the displays. These displays must provide the proper information in the proper form. The information required can be divided into two categories, depending upon the utilization. The first category--information required by the pilot to assess the vehicle's situation with respect to either a desired end point or some vehicle limit--is conventionally displayed in the form of the quantitative values of vehicle performance and attitude. The second category--information required by the pilot to ascertain what control inputs to make--is usually in the form of the direction and magnitude of error of the control parameter from a preplanned or desired condition. Although the parameters involved are generally the same, optimization of a display unit for either category usually cannot be accomplished without adversely affecting the display's capability in the other category.

Traditionally, displays have been designed to present the information required for the piloting task but not necessarily in a manner that has made optimum utilization of the pilot's sensory capabilities. The recent development of a reasonably light and accurate eye-movement camera and the use of other instrumentation now affords a means of obtaining quantitative information that may be applied toward optimizing the pilot's display in terms of both the mission and the pilot's workload. The camera records both the scene being viewed and the exact fixation point of the eye on that scene. The data are in the form of a real-time 16 mm movie of the display system with a superimposed white spot indicating the pilot's eye

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position. Figure 1 shows an eye-position recording camera being worn by a pilot during a simulator flight.

Pilot's display requirements have been studied in many investigations, for example, those of references 1 to 6. The NASA Flight Research Center, Edwards, Calif., recently initiated a program to investigate the effectiveness of several displays envisioned for vehicles in the next generation performance range, such as the X-15 airplane. Although the X-15 is flown only during visual-flight conditions, the precision required of the pilot is such that the entire mission, except for the final approach and landing, is flown solely with reference to instruments. Consequently, the display technology involved in this program is directly applicable to all-weather flight in high-performance aircraft.

This paper presents the results of the Flight Research Center program to date and considers the effectiveness of some existing cockpit displays and several of the new approaches to displays that are designed to more effectively utilize the capabilities of the human pilot. First, the improvement of conventional displays is discussed, then integrated displays and indirect visual displays are considered, and, finally, the use of auxiliary channels for providing information is examined.

DISCUSSION

Conventional Display Techniques

In this paper, the term "conventional display technique" refers to pilot displays that utilize the quantitative display of individual parameters grouped together in a logical fashion. A display system of this type has several advantages, one of which is that the information is carried along multiple channels; consequently, individual component failures result in only partial loss of information to the pilot. Although the display of individual parameters provides adequate control information for single-axis control, it does not fulfill the requirements for assessment of the vehicle situation, since a number of individual quantities must be read and mentally integrated to determine the vehicle situation. To gather these bits of information from individual parameters, the pilot must continually scan the display panel.

Figure 2 shows a conventional display panel, that of the X-15 airplane, which provides fixed scales with moving-pointer indicators. Superimposed on the panel is the pilot's scan pattern as recorded by the eye-movement camera during the first 40 seconds of a simulation of an X-15 launch. The pilot's task is primarily that of longitudinal control, as evidenced by the high level of concentration on pitch angle and angle of attack. On the simulator he did not monitor the airplane subsystems as he might in actual flight. Although the pilots have flown X-15 missions within acceptable limits with this display, some shortcomings are apparent when it is considered how rapidly control quantities change during a mission.

Increased information.- One of the primary approaches being followed in an attempt to improve conventional display systems is to increase the information content on individual instruments in order to reduce the pilot's scan pattern. Figure 3 shows this approach applied to the attitude indicator. As shown in the photo on the left, an early version of the attitude indicator displayed only two parameters qualitatively, pitch and roll. In a later version (photo on the right) three axes of attitude, pitch, roll, and heading, are displayed quantitatively and flight-director needles are superimposed on the instrument face. In addition, mounted near the main display are a vertical null pointer and a turn and bank indicator.

Improved design.- Another current approach to the improvement of conventional display systems is in instrument design. Much effort is being spent in attempting to design individual cockpit instruments so that they will be more legible and the display more meaningful in terms of the pilot's information requirements (refs. 1 and 2). Figure 4 illustrates the application of this type of effort to the X-15 display panel. Through the use of moving vertical tapes as flight-parameter display units, it is possible to group the instruments so that they have a common fixed reference line, as shown in the upper center portion of the panel. Although the same number of quantities are displayed, the physical scanning task is considerably reduced as a result of reducing both the vertical separation and the horizontal spacing.

This "advanced" display system has undergone a preliminary evaluation by the X-15 pilots on the fixed-base X-15 simulator, and the flight control parameter section will be installed in the X-15 aircraft next spring. The results of the simulator evaluation are indicated in figure 5, a representative time history in which pilot performance with the conventional X-15 display panel and the advanced display system is compared. The pilot's control task immediately after engine light until completion of the boost phase is primarily longitudinal. The profile is flown by making an initial pullup at constant angle of attack to a pre-set pitch angle. This pitch angle is held constant for a given length of time, then a push-over at zero normal acceleration is maintained until the rate of climb approaches zero. At the predetermined altitude, the velocity is stabilized until engine burnout.

As indicated in figure 5, the pilot's overall performance with the advanced display was not appreciably different from that with the conventional panel. Two significant factors must be considered, however. First, the evaluation pilots had several thousand hours of experience with the conventional display and only 5 to 10 hours with the advanced panel. Second, the pilot's workload was decreased by the reduction of the physical scan requirements. This reduced workload is illustrated in figure 6, a comparison of the pilot's scan pattern for the conventional and the advanced display concepts during the first 40 seconds of the simulated X-15 mission. The pilot's scanning track is indicated by lines superimposed on photographs of the display panels, and the number of samples and average fixation time for several parameters are shown in the tabulation. The scanning task with the advanced panel was obviously simpler than with the conventional display, and the average dwell time was lower.

In general, the pilots indicated that they were able to perform a pre-planned mission equally well with either display system, but that during rapidly changing, unanticipated maneuvers the moving-tape display made rapid gross assessment of the whole panel difficult. Thus, this display would be less desirable than the fixed scale—moving pointer indicators for recovering from unusual attitudes.

Integrated Displays

One of the most promising of the advanced display techniques is the integrated flight display on which the individual parameters are symbolically represented in a manner that satisfies the information requirements for both assessment and control. In a system of this type, the required scan pattern is substantially reduced. The overall situation is continuously and pictorially presented and requires little or no mental integration by the pilot. In most instances, the format chosen is representative of the real world; consequently, the pilot can maintain visual-flight techniques during instrument flight conditions.

Contact analog.- Figure 7 illustrates an integrated display system, known generally as a contact analog (refs. 3 to 5). This display is basically a computer system that receives electrical signals from the vehicle's sensors and converts this information into a symbolic picture of the real world. The resulting pilot display is a television picture consisting of a representation of the sky, ground, and horizon drawn in perspective. All elements move in six degrees of freedom identical to the corresponding elements of the real world. Since the contact analog display system is based on a standard television technique, it lends itself readily to the superposition of additional information on the screen in the form of null indicators for prime control parameters or quantitative numerical information. Figure 8 shows a display in which the contact analog format is used as a basis for totally integrating the flight-parameter display for a hypersonic aircraft. The qualitative assessment information is presented in the standard contact analog pictorial form, while the precise control information is displayed as null indicators or command cursors.

Figure 9 is a time history taken during a comparative evaluation of the contact analog display and the conventional X-15 display panel on the X-15 fixed-base simulator. The data are for the atmospheric reentry portion of an X-15 flight, a regime that requires a complex multiple-axis control task during a period of rapidly changing aerodynamic parameters. A preliminary evaluation of the data indicates that the pilot's control precision in damping the vehicle's oscillations was improved when he used the contact analog display.

Figure 10 depicts the pilot's scan pattern while using the conventional display and the contact analog system during the boost phase of an

X-15 flight. As shown, the pilot is able to obtain the required flight-control information from the contact analog display with considerably less scanning. It should be noted that the pilot had only about 1 hour of experience on the contact analog system but had flown the conventional display system for many hours. Consequently, it can be inferred that the level of performance with the contact analog will increase as pilot familiarity with the system increases.

The scaling of the contact analog display computer does not readily yield adequate range and resolution for consideration as a visual landing display; however, since the system uses a television format, the required resolution can be obtained by blending with a real-world picture as it is seen by either a closed-circuit television camera or other electronic means, such as radar or infrared sensors.

Television display system.- To evaluate the capabilities of indirect visual display systems for approaches and landings, a flight-test program (ref. 7) was conducted by the NASA Ames Research Center to provide in-flight data on the feasibility of using a television system as a primary pilot display. The results of this program indicate that approaches and landings are feasible when a television picture of the outside world is used as a reference; however, standard monocular television does not yield adequate information for complete visual control through touchdown. Additional information such as vernier altitude must be provided during the last few feet before touchdown, or the pilot must use a power-attitude technique until contact is made.

A more extensive flight program is planned by the Flight Research Center to evaluate several different television techniques as they are applied to the navigation, approach, flare, and touchdown phases of flight. It is anticipated that some combination of the television displays to be investigated will provide an improvement over those previously studied. The program will be flown in a small transport airplane that has been modified to provide the pilot with a complete set of aircraft controls in the aft cabin. The only display available will be the television system under evaluation. The three concepts (fig. 11) to be evaluated are (1) a monocular display with manual pilot control over the camera look angle, (2) a panoramic display utilizing multiple cameras and monitors, and (3) a system that will provide the pilot with a three-dimensional picture. It is anticipated that the most promising of these systems will be further tested in a high-performance fighter-type aircraft.

Heads-up display.- A major shortcoming of the conventional display technique is that the procedures required for the pilot to fly with this system are incompatible with visual-flight techniques. This incompatibility becomes especially undesirable when a transition from instrument techniques to visual-flight procedures must be accomplished at a critical time, such as breaking out of the overcast on a low-visibility approach. A display system that permits the pilot to use a consistent technique for either instrument or contact flight is shown in figure 12. This approach to an integrated flight display is referred to as the "heads-up" concept.

With this technique, only the information lacking in the visual world need be presented, since the display is viewed as a collimated overlay against the real world. The information can vary from simply an indication of velocity and altitude for visual approaches and landings to the complete contact analog or television-type picture for approaches during low visibility. This concept lends itself readily to the low-visibility approach, since the pilot receives information in a form that will blend smoothly into the real world when it is acquired, with no transition in technique or visual accommodation necessary.

A study by Sperry Gyroscope Co., as part of the Flight Research Center program, provided the background design information necessary for consideration of this type of system as a primary flight display. The final report from the study (ref. 6), although specifically for application to spacecraft, includes normalized design charts for heads-up display equipment as well as an indication of the effects of the interaction of this technique with more conventional panel displays. Display equipment is now being procured that will permit flight-test evaluation of the capabilities of this type of system applied to the landing of vehicles with low lift-drag ratios.

Auxiliary Information Channels

During flight utilizing the standard instrument-panel displays, the pilot's central vision is the primary channel for information. Examination of the pilot's scanning requirements for a conventional display (fig. 2) indicates that it would be highly desirable to develop methods of information display that will not further saturate this channel. The effects of providing additional inputs to the pilot through auxiliary or nonstandard channels, such as the visual periphery or auditory senses, are discussed in the following sections.

Peripheral displays.- The first of two peripheral systems studied utilized the pilot's peripheral field of vision capability to distinguish gross position and to discriminate colors as a secondary means of providing information. A short flight-test program was flown in a T-33 airplane to demonstrate the feasibility of flight application of this minimum-attention display technique. The indicator was a bright-orange ball suspended across the top of the instrument panel (left photo, fig. 13) which displayed approach velocity within a range of ±2 knots. For this range, the ball moved the full width of the instrument panel. During the turn from the base leg of the pattern to final approach, the pilot was able to concentrate fully on alining the aircraft with the runway for final approach, while simultaneously obtaining a positive indication of airspeed within ±1 knot.

The second system tested (right photo, fig. 13) was a paravisual display utilizing the pilot's peripheral capability to discern the direction and frequency of flicker. During the flight program on an F-104 airplane, several different parameters were displayed on this instrument. In every instance, the paravisual unit was driven so that the rate and direction of rotation were proportional to the error from a desired condition. As shown in figure 13, even though the display unit was mounted approximately 60° from the pilot's central field of view, the error indications were readily apparent. During the display of the different parameters, when the instrument was used to display error in position, such as altitude, the pilot was unable to determine the magnitude of the error with enough precision for smooth control. However, when the displayed parameter responded directly to the control input, such as angle of attack or normal acceleration, the smoothness and precision of control was limited only by the scaling of the display unit.

Auditory displays.- A second technique being examined is the auditory display of flight dynamics. Previous studies in this area have resulted in a system known as Flybar, or flying by auditory reference (ref. 8). This sytem provides the capability of determining airspeed, bank angle, and turn rate through an auditory display. A feasibility study has been completed at the Flight Research Center, and a more comprehensive program is now underway to determine what, if any, additional advantages can be obtained through the display of flight information to the pilot by auditory means. These studies will examine in detail several of the unique characteristics of the auditory channel, such as lateralization and the selective filtering capability known as the "cocktail party effect." Present indications are that, through the proper choice of coding, multiple parameters may be simultaneously displayed so that the pilot can perceive and control each individually, even in the presence of normal radio communications.

Indirect Viewing System

As the performance of flight vehicles continues to increase, aerodynamic heating makes the structural aspects of large canopies less desirable. Consequently, in future vehicles, a pilot may find that his view of the outside world is obtained through an indirect viewing system. Depending upon the type of viewing system chosen, the design requirements for the cockpit display may be drastically changed.

To provide the pilot with the capability of visual-flight control, several optical viewing systems are being considered. These systems, as shown in figure 14, provide the pilot with a unity-magnification, undistorted, wide field of view. A flight-test program (ref. 9) conducted with the overlapping monocular system mounted in an L-19 (top photo), a relatively low-performance aircraft, proved that approaches and landings could be made both during the day and at night using only the optical system for visual reference. The undesirable features pointed out by these flight tests, such as the lack of a vehicle reference and the wide objective spacing with the resulting exaggerated stereoscopic vision, have been eliminated in a second system (center photo) now being constructed for testing in a high-performance aircraft. Since the pilot is required to keep his head close to the eyepiece in this type of viewing device, the new optical system will incorporate a "heads-up" type display in the field of view to provide the required flight-control information. A slightly different concept in indirect viewing systems (lower photo) replaces the eyepiece with a spherical mirror and results in a long eye relief and large exit pupil system. A system of this type makes it unnecessary to maintain the eye close to the eyepiece and thus permits the pilot to use a standard instrument-panel display in a normal manner.

CONCLUDING REMARKS

In considering the most effective utilization of the human pilot's capabilities in the control of advanced flight vehicles, it is apparent that the standard "round dial" moving-pointer display panel has serious limitations. These limitations are primarily in terms of scan requirements placed on the pilot by the individual display of parameters and in the resulting sampled data obtained from this scanning. With a display system of this type, the more complex the task, the more time-consuming and difficult it is for the pilot to obtain a complete frame of information. Consequently, he is forced to make decisions based on data that are behind real time.

It is quite feasible to reduce the pilot's scan-pattern requirements through the use of advanced instrument design concepts, as shown by the advanced X-15 display panel. Further, it appears feasible to display selected prime parameters continuously through an auxiliary channel, such as the auditory or peripheral senses.

Perhaps the most promising approach to the reduction of the scan task, in terms of preserving visual techniques and for ease of interpretation, is the totally integrated, electronically generated system. However, to achieve the full capability of this type of display, it becomes a necessarily complex electronic system and, as such, will require a great deal of effort to insure the reliability necessary in a primary flight control display.

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SYMBOLS

a_n	normal acceleration, g units
g_i	instantaneous resulting gravity vector
h	altitude, ft
h_i	inertial altitude, ft
q	dynamic pressure, lb/sq ft
r	turn rate (body axis)
V	velocity, ft/sec
V_i	inertial velocity, ft/sec
α	angle of attack, deg
β	angle of sideslip, deg
θ	angle of pitch, deg
θ_c	pitch-angle command
φ	angle of roll, deg
ψ	angle of yaw, deg

A dot over a quantity indicates the first derivative with respect to time.

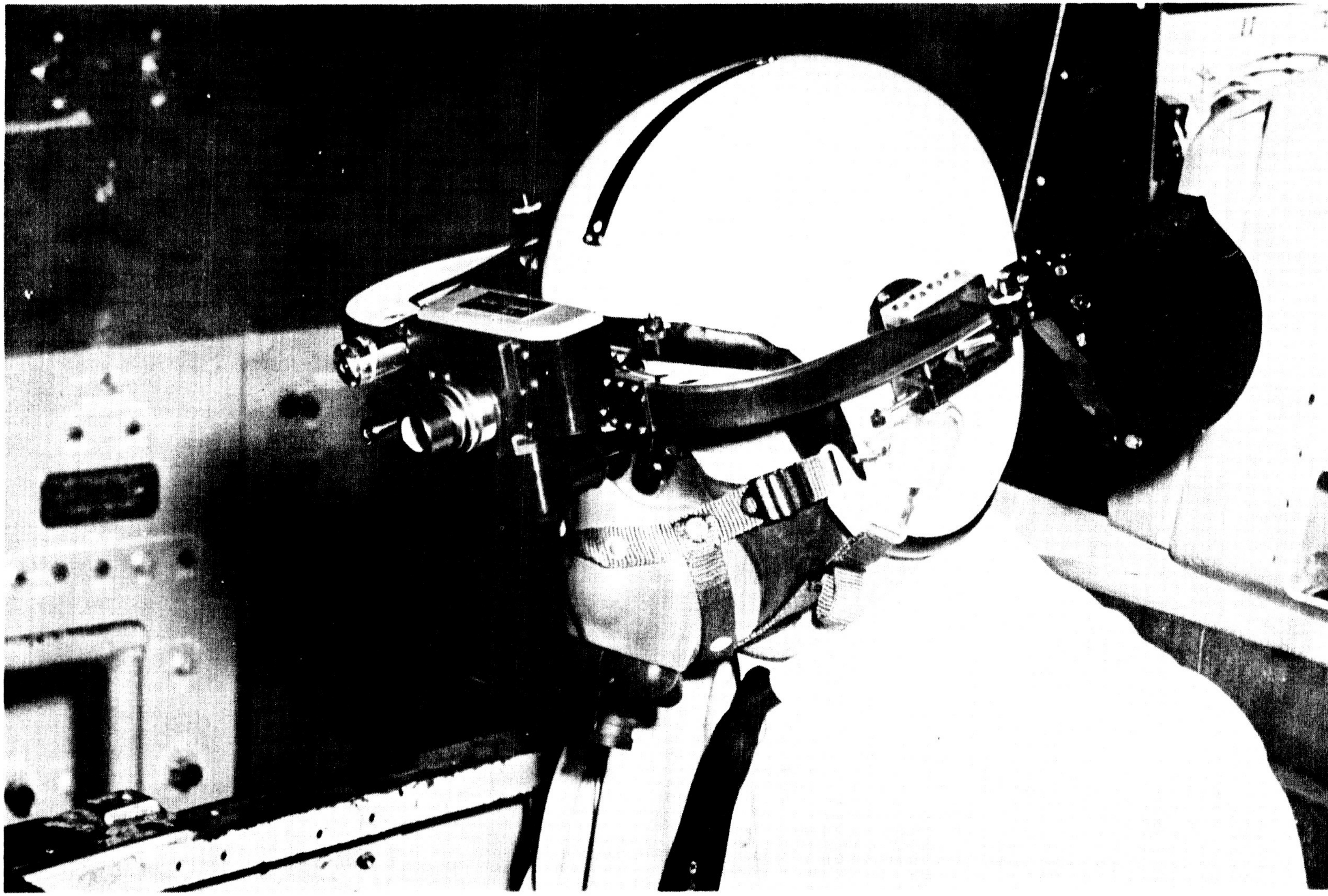


Figure 1.- Eye-position recording camera.

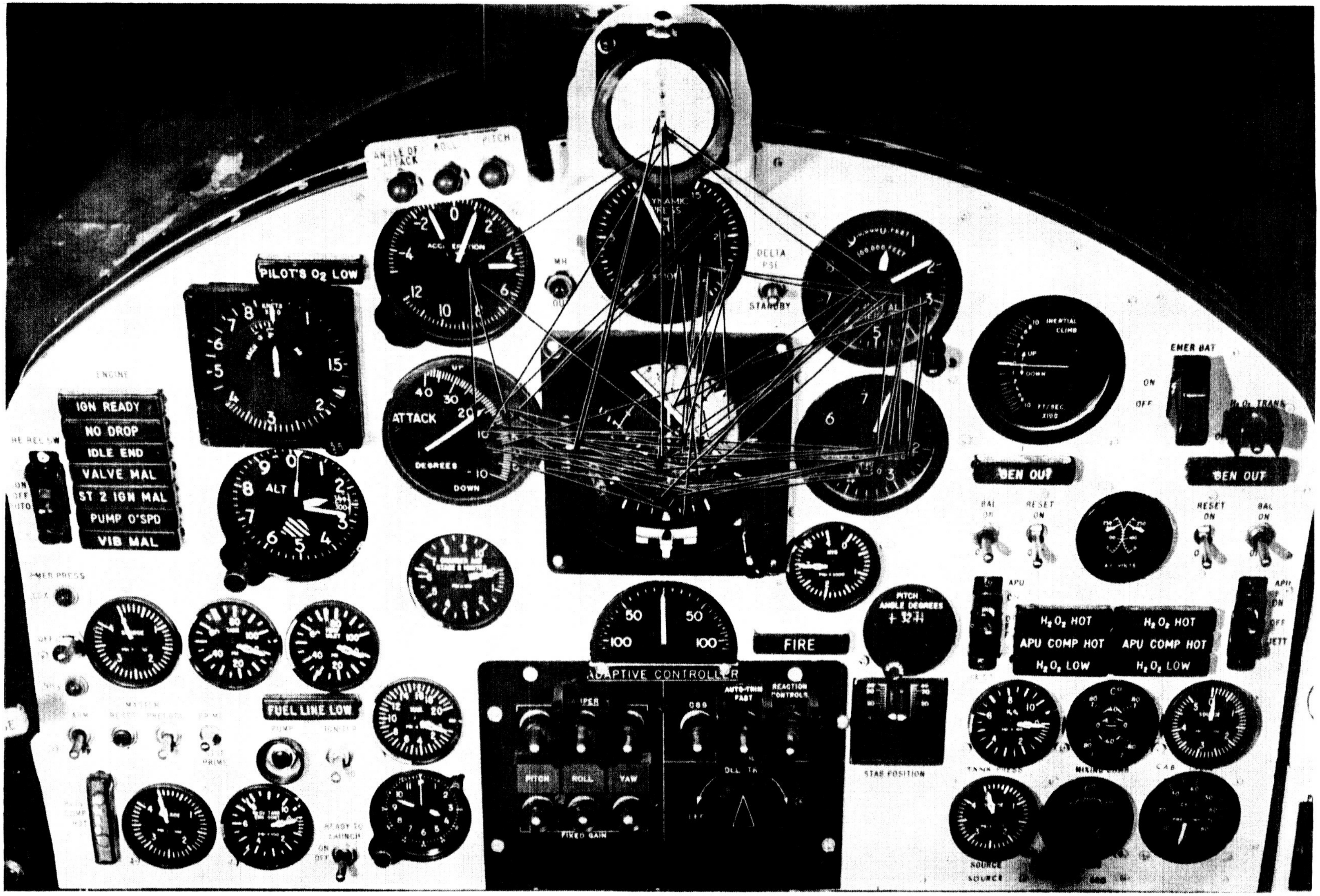
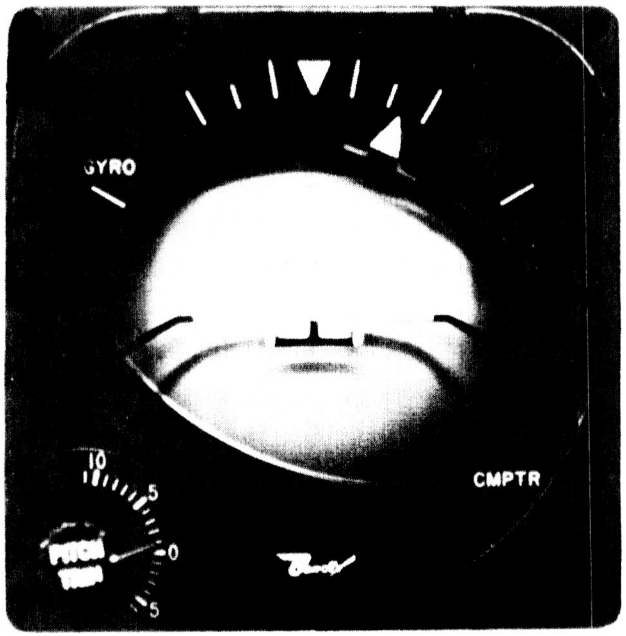


Figure 2.- Conventional display panel with superimposed pilot scan pattern.

Two-axis



Parameters displayed

Two-axis	Advanced three-axis
θ	θ
φ	φ
	ψ
	θ_c
	r
	g_i
	Localizer glide path

Advanced three-axis

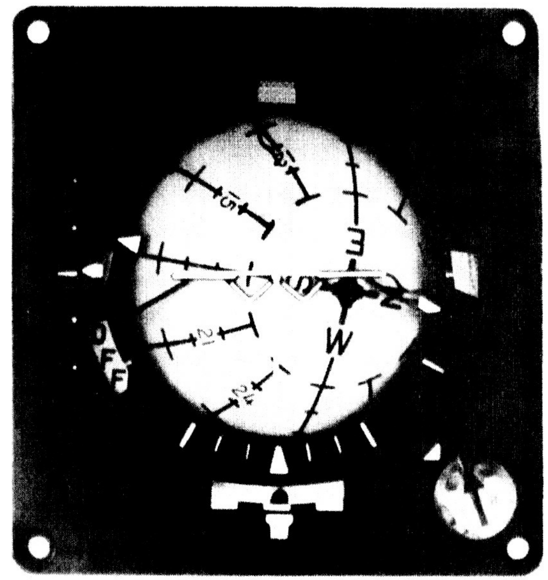


Figure 3.- Comparison of information content of two different types of attitude indicators.

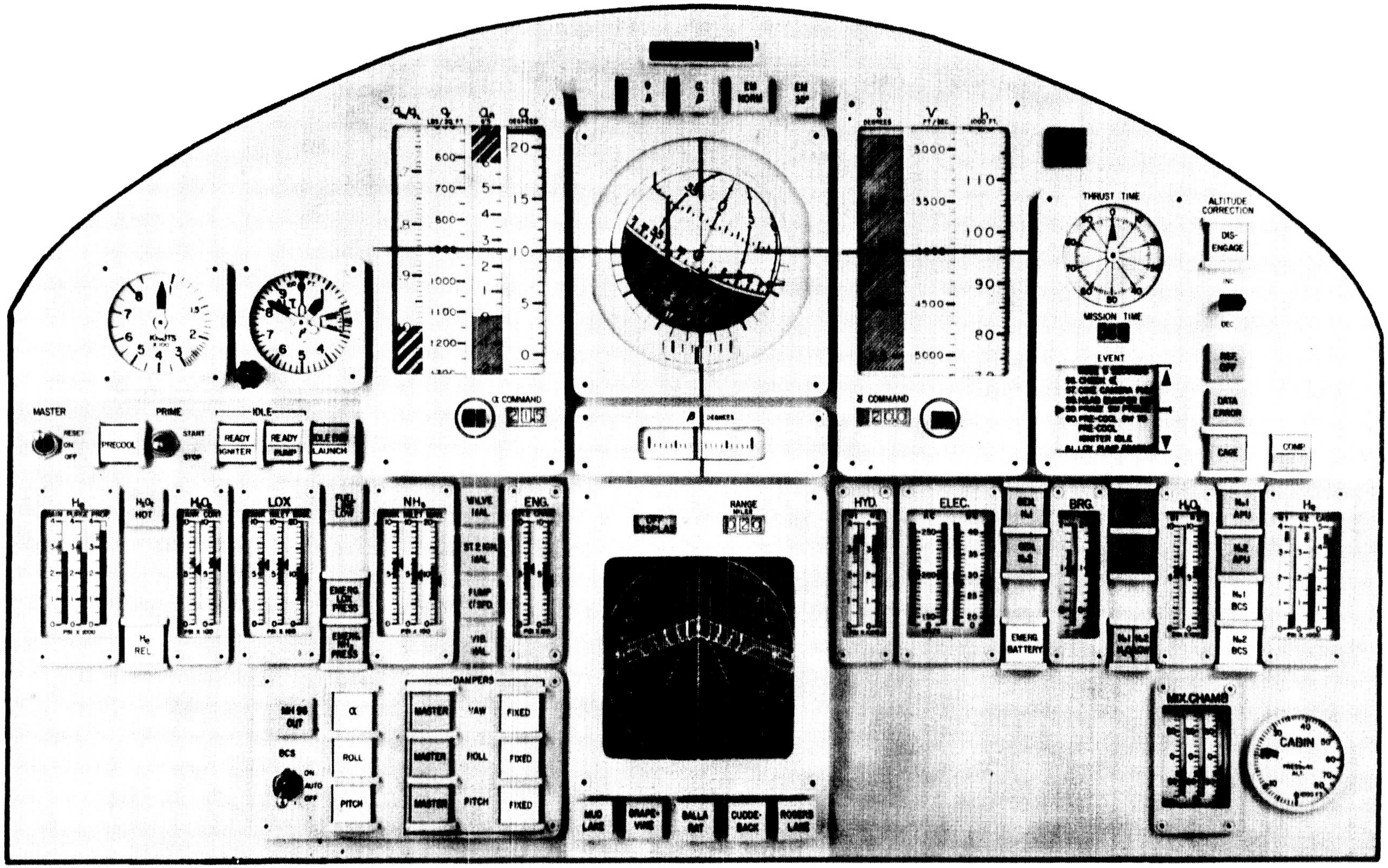


Figure 4.- Advanced version of the X-15 display panel.

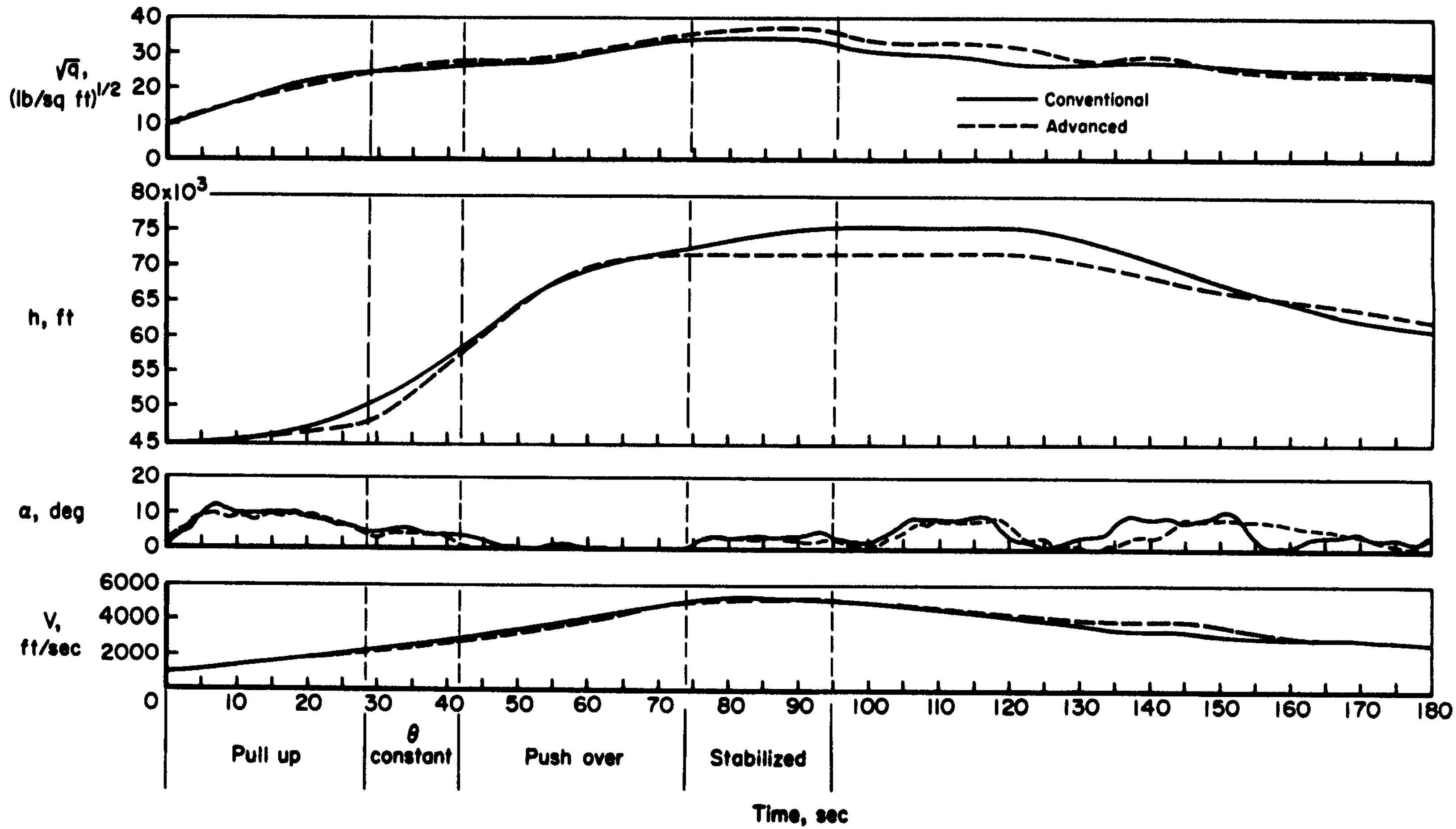
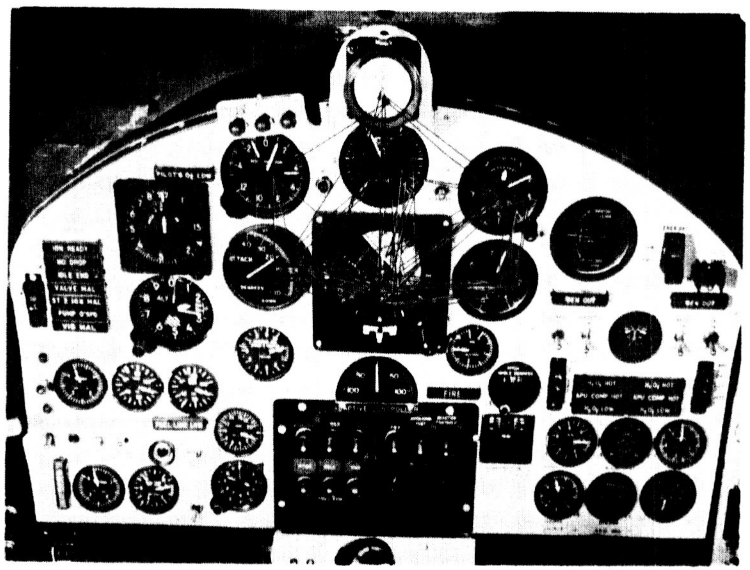


Figure 5.- Pilot performance with conventional and advanced display systems. X-15 ground-based simulator.

Conventional			Advanced	
Samples	Average time, sec	Parameter	Samples	Average time, sec
10	0.66	α	15	0.53
3	.63	a_n	4	.53
2	.50	V_t	2	.50
7	.45	h_t	5	.45

Conventional



Advanced

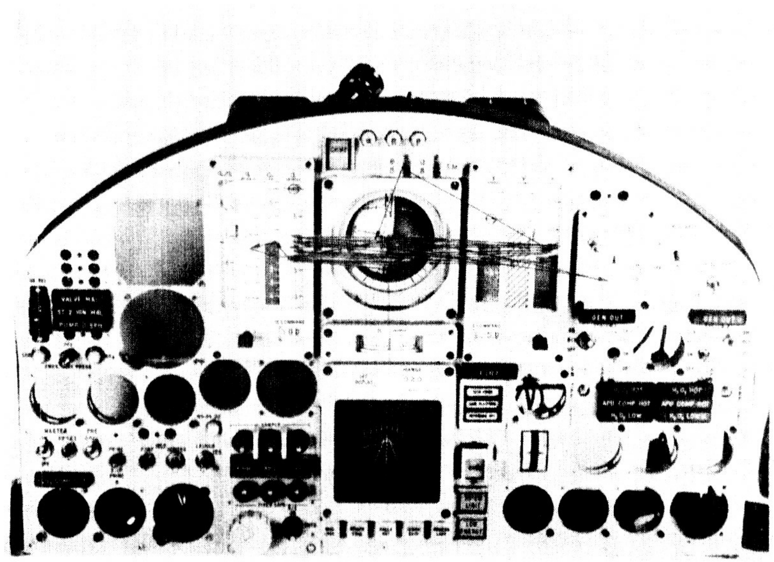


Figure 6.- Pilot scan patterns with the conventional and the advanced X-15 display panels. X-15 ground-based simulator.

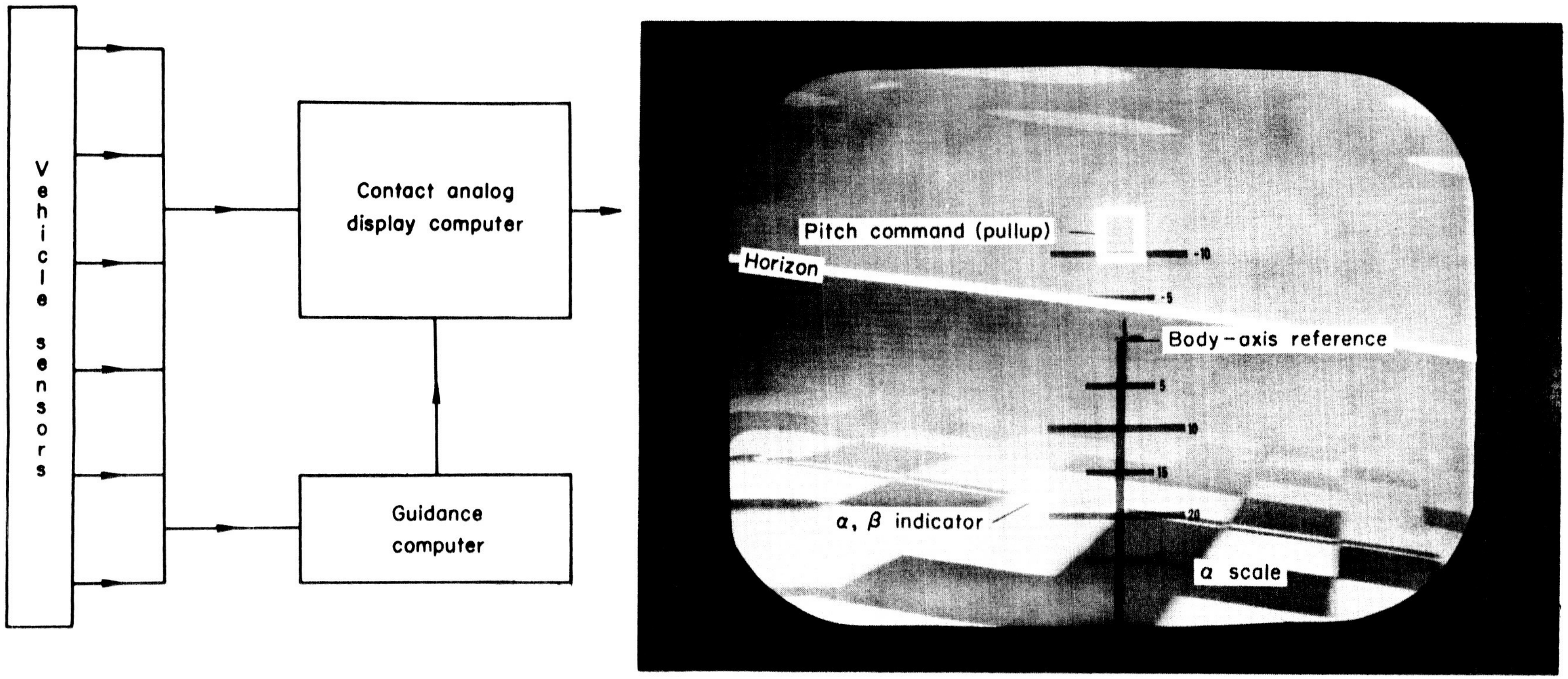


Figure 7.- Contact analog display system.

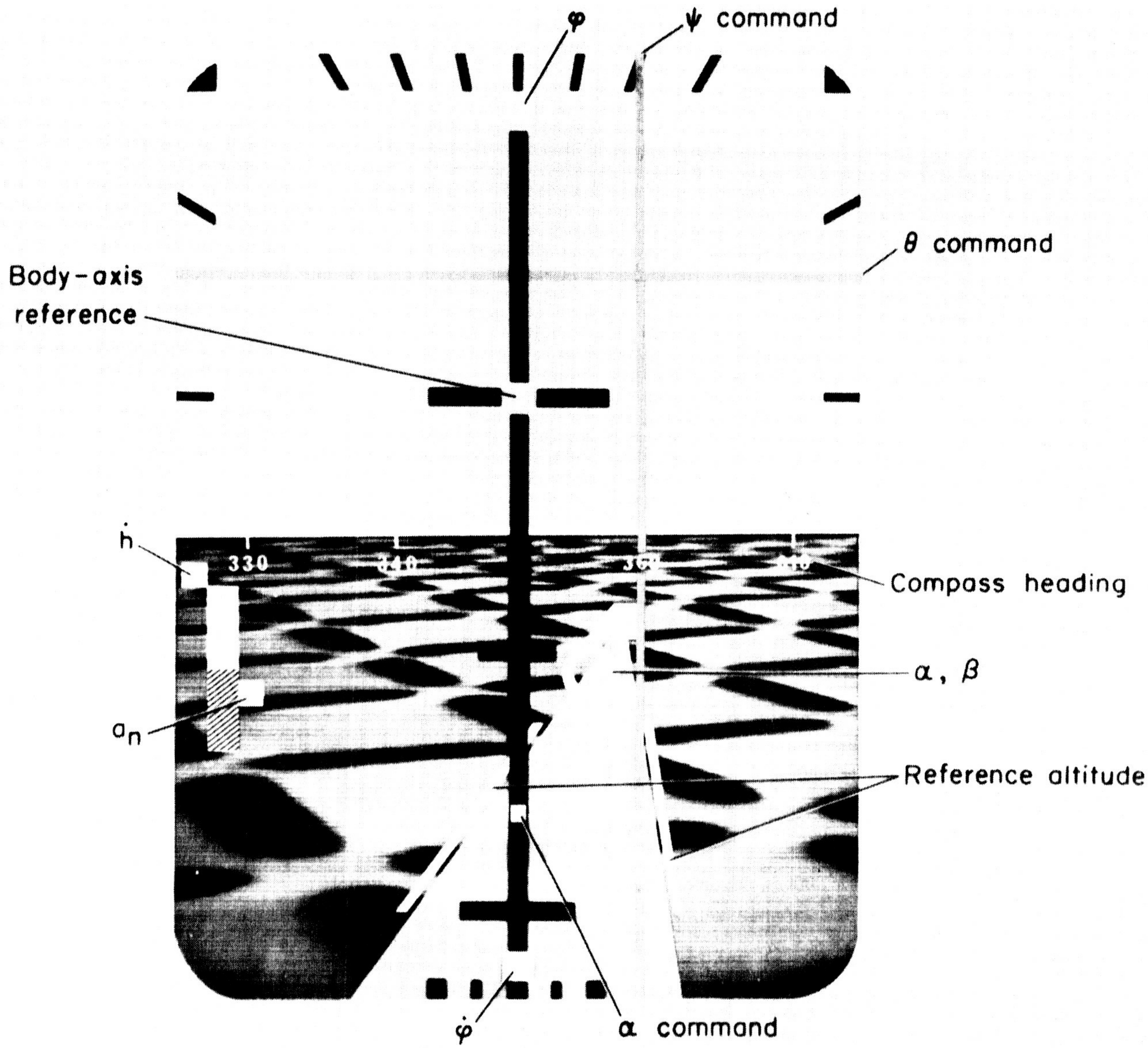


Figure 8.- Totally integrated display for a hypersonic vehicle.

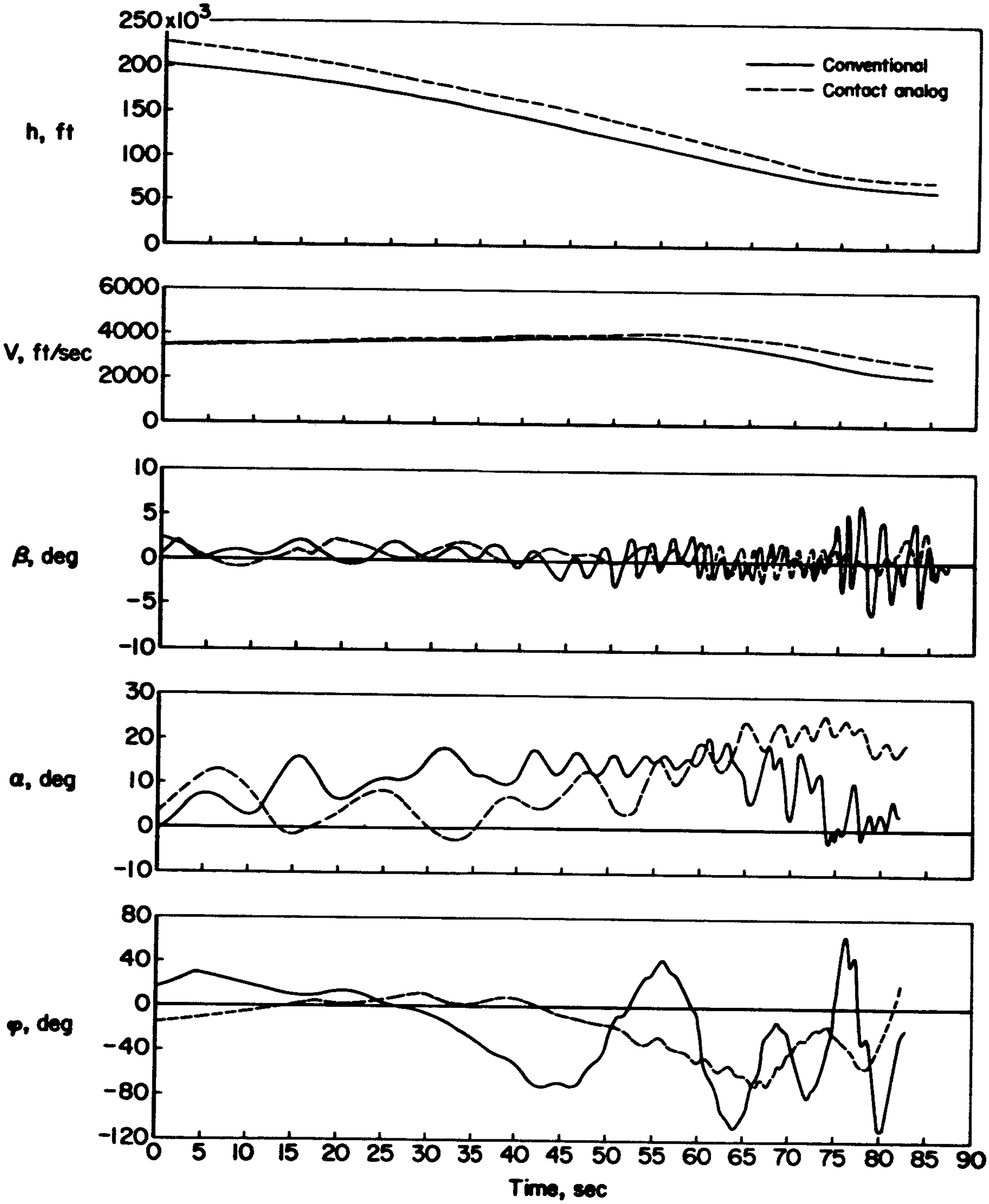


Figure 9.- Pilot performance during a simulated X-15 reentry using the conventional X-15 display panel and the contact analog display system.

Conventional

Contact analog

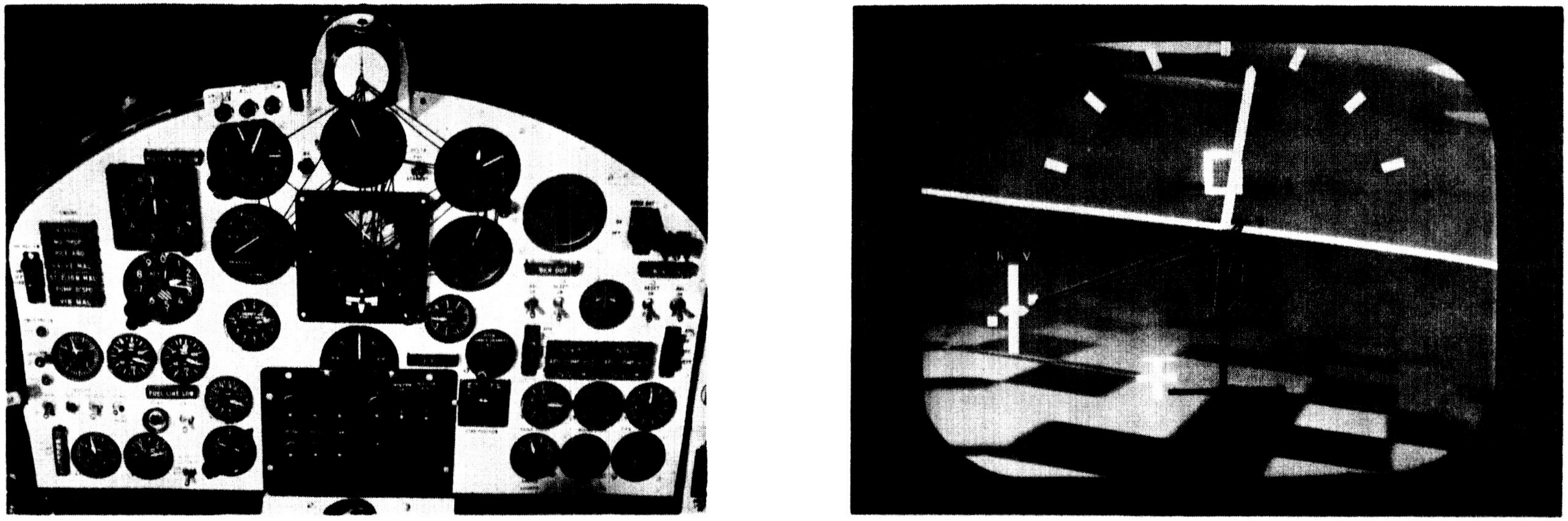


Figure 10.- Pilot's scan pattern during X-15 simulator flights using the conventional X-15 display panel and the contact analog display system.

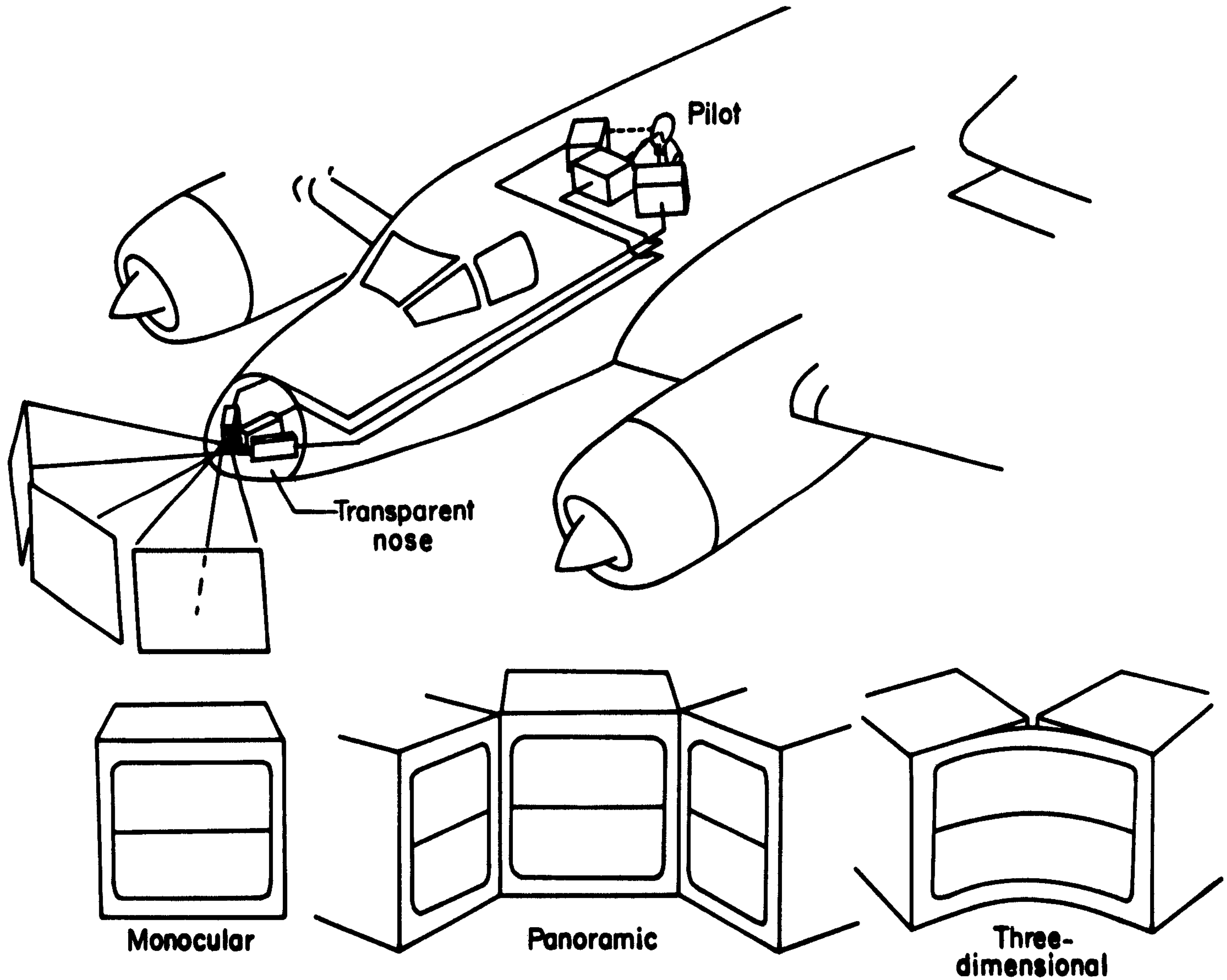


Figure 11.- Closed-circuit television systems to be evaluated in the Flight Research Center program.

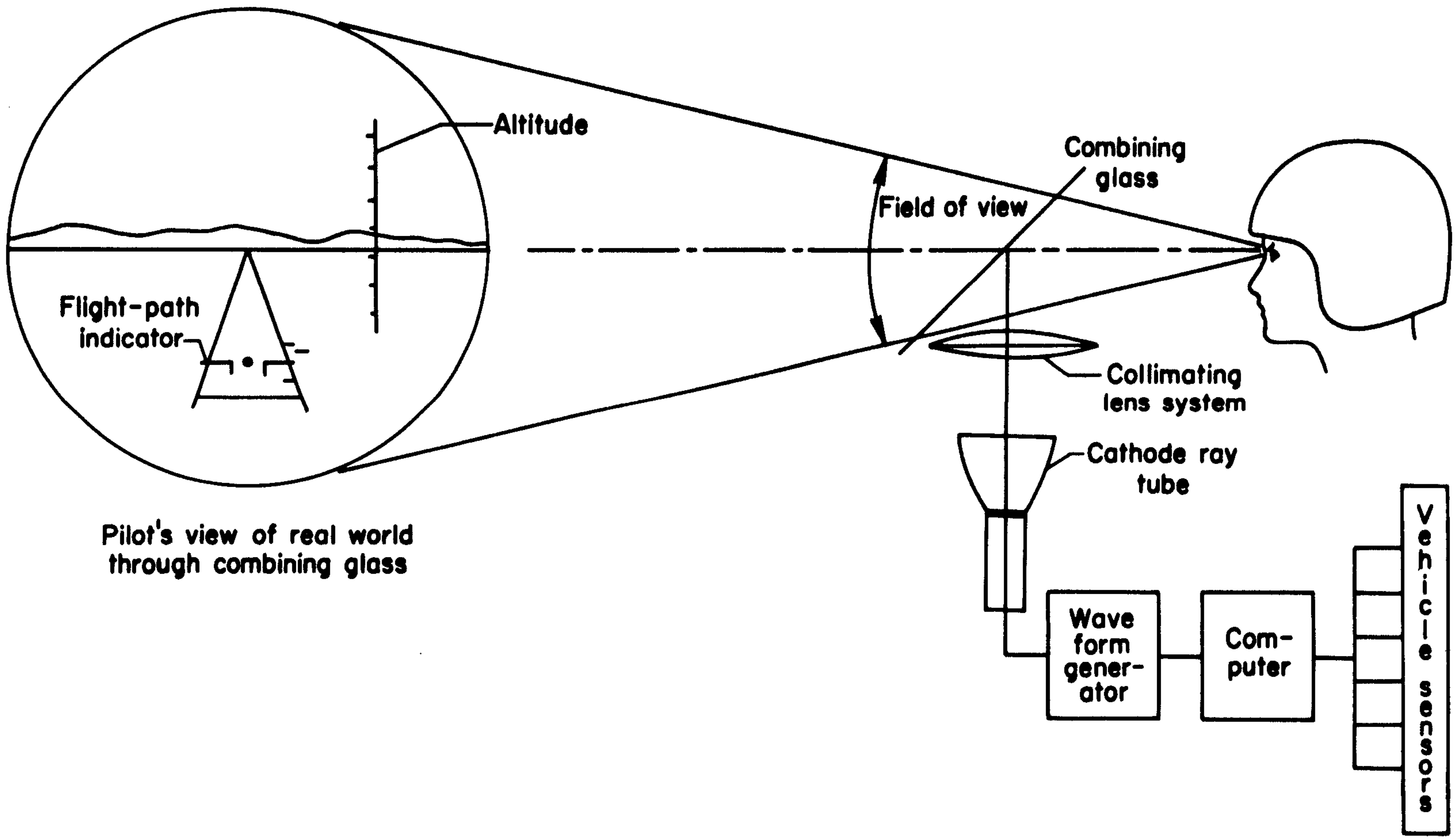
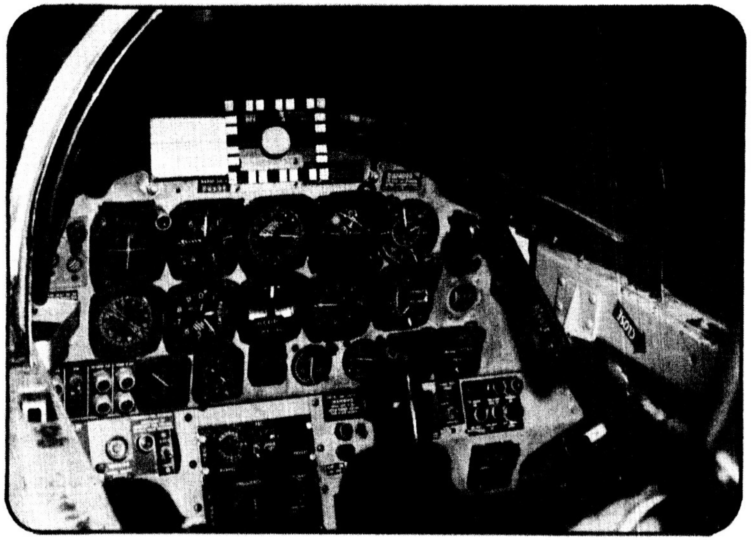


Figure 12.- Heads-up display technique.

Minimum attention



Paravisual

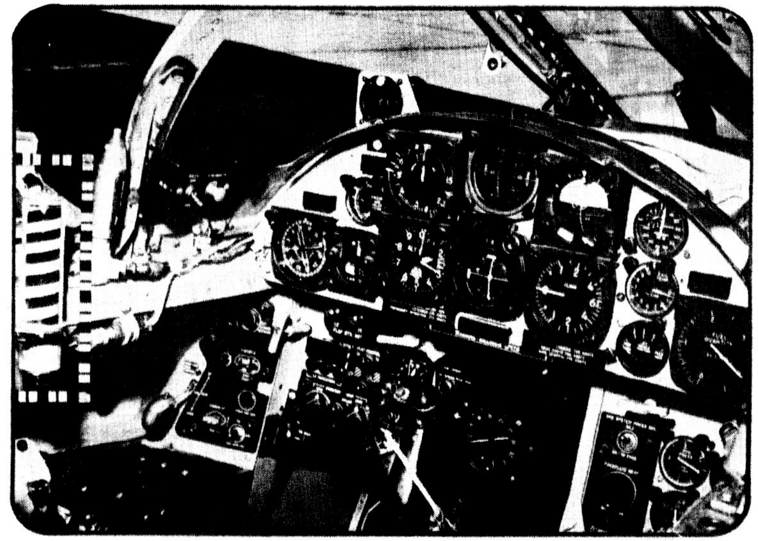
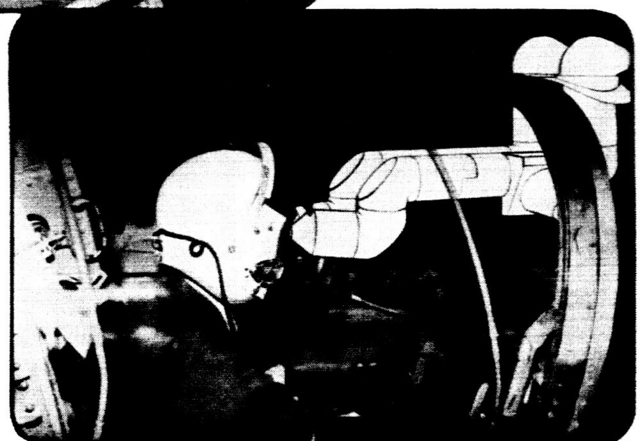
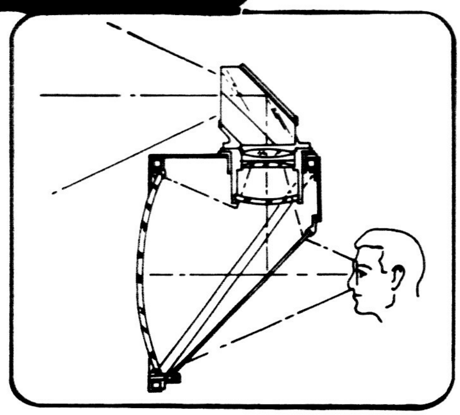


Figure 13.- Peripheral display devices.

L-19 system



F-104B system



Spherical-mirror viewing system

Figure 14.- Optical viewing systems.