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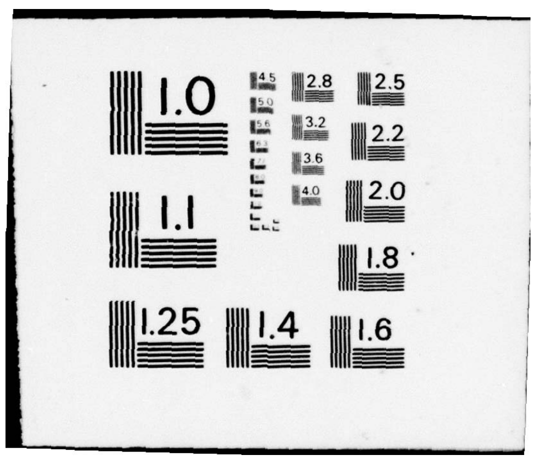
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AVIATION RESEARCH LABORATORY

INSTITUTE OF AVIATION
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

TECHNICAL REPORT

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ADVANCED INTEGRATED AIRCRAFT DISPLAYS AND AUGMENTED FLIGHT CONTROL: SCIENTIFIC FINAL REPORT

STANLEY N. ROSCOE

ARL-76-17/ONR-76-4
NOVEMBER 1976

Contract: N00014-76-C-0081
Work Unit Number: NR 196-133

PREPARED FOR

ENGINEERING PSYCHOLOGY PROGRAMS
AND AERONAUTICS PROGRAMS
OFFICE OF NAVAL RESEARCH

AVIATION RESEARCH LABORATORY

University of Illinois at Urbana-Champaign
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Savoy, Illinois
61874

Technical Report

ARL-76-17/ONR-76-4

November 1976

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER ARL-76-17/ONR-76-4	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Advanced Integrated Aircraft Displays and Augmented Flight Control. Scientific Final Report		5. TYPE OF REPORT & PERIOD COVERED Scientific Final, 1973-76 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Stanley N. Roscoe		8. CONTRACT OR GRANT NUMBER(s) N00014-76-C-0081
9. PERFORMING ORGANIZATION NAME AND ADDRESS Aviation Research Laboratory Institute of Aviation University of Illinois, Savoy, IL 61874		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 196-133
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research (Code 455) 800 North Quincy Street Arlington, Virginia 22217		12. REPORT DATE November, 1976 13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) ARL-76-17/ONR-76-4		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

Final scientific rept. 1973-1976

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

39p.

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Flight Displays	Flight Director Displays	Quickening
Pursuit Displays	Cockpit Instrumentation	Unburdening
Display Symbology	Compensatory Displays	Flight Control
Human Factors	Contact Analog Displays	Cockpit Workload
Attitude Displays	Predictor Displays	(Cont. on Reverse)

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

The Aviation Research Laboratory of the University of Illinois has investigated integrated computer-generated symbolic displays and computer-augmented flight control for the Office of Naval Research. The research was directed toward (1) the isolation of minimum sets of visual image cues sufficient for spatial and geographic orientation in the various ground-referenced phases of representative flight missions, (2) the generation and spatially integrated presentation of computed guidance commands and fast-time flight path predictors,

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

406171 LB

19. Key Words Cont.

Pilot Workload
Computer-Generated Displays
Computer-Augmented Control
Manual Flight Control
Performance Control System
Control Authority
Frequency-Separated Displays
Aviation Psychology

20. Abstract Cont.

and (3) the matching of the dynamic temporal relationships among these display indications for compatibility with computer-augmented flight performance control dynamics, both within each ground-referenced mission phase and during transitions between phases. The investigative program drew selectively upon past work done principally under ONR sponsorship or partial sponsorship, including the ANIP and JANAIR programs.

CONTEXT

The Aviation Research Laboratory of the University of Illinois has investigated synthetic-imaging displays and computer-augmented flight control for the Office of Naval Research. Mr. Gerald Malecki, Assistant Director, Engineering Psychology Programs, was the technical monitor of the research. Professor Stanley N. Roscoe was the principal investigator during the initial phase of study and experimental apparatus development; Professor Robert C. Williges served as principal investigator while Professor Roscoe was on academic leave during 1975-76.

The research was directed toward (1) the isolation of minimum sets of visual image cues sufficient for spatial and geographic orientation in the various ground-referenced phases of representative flight missions, (2) the generation and spatially integrated presentation of computed guidance commands and fast-time flight path predictors, and (3) the matching of the dynamic temporal relationships among these display indications for compatibility with computer-augmented flight performance control dynamics, both within each ground-referenced mission phase and during transitions between phases. The investigative program drew selectively upon past work done principally under ONR sponsorship or partial sponsorship, including the ANIP and JANAIR programs.

During Phase I of the contract, the Aviation Research Laboratory systematically investigated the relationships between the movement of the controls and the response of the airplane and demonstrated substantial improvement in pilot performance as a consequence of their reorganization. By the completion of Phase I, all planned control modifications, specifically the digital control system, were incorporated into the GAT-2 simulator, and both a real-time visual scan converter and a peripheral device for linear coordinate transformation were designed, fabricated, and integrated with the simulation facility (Daly, Collins, and Ruby, 1975).

To study experimentally the effectiveness of alternate sets of visual cues the Aviation Research Laboratory developed a highly versatile computer-generated display system to present dynamic pictorial images either on a head-down, panel-mounted CRT or on a head-up television projection to a large screen mounted in front of the pilot's windshield on the Link GAT-2 simulator. Due to the great flexibility of the pictorial display, visual cues and flight status information can be manipulated experimentally. Experimentation was conducted to isolate the visual cues sufficient for approach and landing (Eisele, Williges, and Roscoe, 1976).

The incorporation of predictive indications of successive future states into the contact analog scene was programed for computer generation during Phase II (Artwick, 1976). Studies were conducted to determine the number and temporal spacing of flight path predictors to be integrated into the forward-looking flight view (Gallaher, Hunt, and Williges, 1976).

Determination and software implementation of command guidance symbology compatible with the synthetic forward-looking contact analog and predictive flight path presentations were also undertaken with the ultimate objective to develop a reconfigured cockpit with integrated sensor- and computer-generated imaging displays and computer-augmented controls applicable to advanced Naval aircraft.

TECHNICAL DISCUSSION

Issues and Principles

The controls and displays that make it possible for a pilot to fly a modern airplane involve a great deal of computer processing between control inputs, airplane responses, and display indications. However, generalizable principles to guide the airplane designer in his application of computers have not been followed; indeed, they have never been formally developed and explicitly stated. For example, while semi-automatic "fly-by-wire" control systems give the pilot more direct command of flight performance than do conventional controls, the relationship between the pilot's control inputs and airplane responses have not been arrived at by the application of either rationally or empirically derived principles.

Furthermore, military airplanes much of the time still demand moment-to-moment manipulation of angular and linear accelerations, a method of control that requires the pilot to perform complex transformations between input and output variables that shift in range and sensitivity both gradually during a mission phase and abruptly from phase to phase. Studies performed by the Calspan Corporation (Lebacqz and Aiken, 1975) suggest that the difficulty of flying with manual control systems that require complex input/output transformations can be offset by the proper transformation and integration of displayed information; conversely, the difficulty of flying with displays of unrelated raw information can be eased through control augmentation.

Although there unquestionably is a tradeoff between improvements in displays and improvements in controls, as advanced by the Calspan investigators, it is evident that an improvement in either is always beneficial and that the greatest benefit comes from the matching of display and control systems to minimize pilot transformation requirements. The optimum display/control system is one that provides the pilot ease of control, but with sufficient manual control authority for flexible response to changing tactical requirements, and at the same time allows him to maintain continuous geographic, topographic, and situational orientation to recognize immediately that a relevant change has occurred in the flight situation.

Despite the absence of formally stated principles for computer application to achieve the optimum display/control system, several investigators within the US Navy or supported by ONR over the past 30 years have advanced systematic analytical treatments and some formal experimentation relevant to the subject. The first investigator to address the subject analytically was Williams (1947/71) who developed a conceptual framework for the organization of information required for instrument flight, analyzed the manipulations involved in flight control, and recommended desirable characteristics for flight displays. Williams was followed by Birmingham and Taylor (1954); Ritchie (1960); Carel (1965); Kelley (1968); Roscoe (1968; 1974); Johnson and Roscoe (1972); Kraus and Roscoe (1973); Roscoe and Williges (1975); Ince, Roscoe and Williges (1975); Beringer, Williges, and Roscoe (1975); Roscoe, Eisele, and Bergman (1975); and Eisele, Williges, and Roscoe (1976).

Throughout the papers just cited, there is ample evidence that the complexity of manual control transformations can be simplified through computer assistance in many ways to make the task of flying the airplane more straightforward (Roscoe, Eisele, and Bergman, 1975). Control systems can be designed to require pilot inputs at any level in the control-order hierarchy as appropriate to the phase of a mission or even to the immediate flight situation encountered. Predictor and command guidance displays can readily integrate information in a manner that elimiates many transformations that would otherwise be required of the pilot. To advance such currently feasible applications with confidence requires the explicit statement of human engineering principles of computer application to flight control and display system design.

Approach

The proper approach to any system design problem is first to determine the functions the system must perform to accomplish its mission and then the best distribution of those functions between the people in the system and automatic devices. For example, if control of the six degrees of freedom of the aircraft constitutes the functions under consideration, it is necessary at the outset to decide on a basis for distributing control authority and responsibility for these functions between the pilot and the automated portions of the control system.

Control augmentation. At least in theory, it would be possible to give the pilot authority over position, rate, acceleration, or rate of change of acceleration with respect to any or all of the six degrees of freedom. The farther along this list his authority extends, the greater his responsibility for coordinating moment-to-moment control movements. As his control authority shifts in the opposite direction, the system becomes increasingly automatic, and his direct control responsibilities diminish (Roscoe and Kraus, 1973; Roscoe, Eisele, and Bergman, 1975).

The essential problem is that of determining the point at which the pilot should interface with semiautomatic controls to minimize the difficulty and attention demands of his control task without depriving him of the minimum essential control authority to counter any reasonably likely flight contingency. To the extent that he can be removed from the inner loops of control, where he performs principally transforming functions, he will be unburdened of the routine of repetitive manipulation, and his performance will be more precise and less variable.

The Aviation Research Laboratory has systematically investigated the relationships between the movement of the controls and the response of the airplane and demonstrated substantial improvement in pilot performance as a consequence of their reorganization. Initial investigations by Kraus (Roscoe and Kraus, 1973) showed that placing bank angle and vertical speed under direct pilot control not only yielded reliable improvements in altitude and course holding but also reduced navigation procedural errors by 90 percent. The configuration was called the Performance Control System (PCS). Subsequent equipment developments and experiments by Bergman (1974, 1976) showed similar performance benefits in flight.

Although simulator and flight research using the PCS system at ARL supported the contention that a pilot's enroute navigation performance is improved when the order of control that the pilot performs is reduced, this principle is complex and has additional implications for other flight tasks. Subsequently, the simulated PCS system was modified to investigate reduced orders of control of airspeed, rate of climb, bank angle, aircraft side-slip, and heading during approaches to landings. In addition, the ability to provide discrete vertical (glideslope) and crosscourse (localizer) displacements was investigated by incorporating direct lift and sideforce controls representative of those employed in control configured airplanes.

Integrated pictorial displays. Computer image generation (CIG) technology is now capable of presenting real-time dynamic projections of complex scenes in true picture-plane perspective. Early advocates of CIG vertical-situation flight displays assumed that all information essential to the pilot for orientation and control is available from a clear view of the outside world; hence, if highly literal dynamic images of the world as viewed from the cockpit were generated, the pilot would have the best possible forward-looking display. This belief fostered the investment of a great deal of money and effort in the procurement and programing of giant computers and display devices to generate such scenes. A more promising alternate approach has been to isolate "essential" or, more appropriately, sufficient visual cues from the contact view that the pilot can use effectively and incorporate them into a highly stylized skeletal contact scene (Eisele, Williges, and Roscoe, 1976).

Within the framework of the skeletal perspective view of the contact scene, it is possible to embed both command guidance indications and some representation of the airplane's projected flight path. These three types of indication represent, respectively, what Professor A. C. Williams of the University of Illinois referred to as orientation information, indices of desired performance, and indices of actual performance. A contact analog normally represents the situation at the present time, whereas command guidance may be presented as a function of time, and a flight-path predictor display is, by definition, a representation of successive future states of the system.

Pursuit versus compensatory steering. When the pilot's task is to null an error arising from a discrepancy between his actual position or course and his desired position or course, two forms of presentation have traditionally been used: pursuit and compensatory. Pursuit displays, also called "following" or "true-motion" displays, have two indices, one representing the pilot's own airplane and the other representing the target or desired position or course; both symbols move against a common scale or reference system. Compensatory, or relative motion, displays have only one moving index with the direction and distance between it and a fixed reference index representing the error (Johnson and Roscoe, 1972).

Various embodiments of the two arrangements have been compared by many investigators in many experiments involving a wide range of tasks. Despite the fact that most steering guidance displays call for compensatory tracking, with no critical exception the experiments show pursuit tracking to be consistently superior by about two to one on average, with the ratio of superiority increasing with task complexity. Resistence to the adoption of the pursuit steering arrangement has been based on the fact that a "pure" pursuit display is mapped in earth rather than airplane coordinates, thereby rendering it "outside-in" rather than "inside-out" and consequently creating tradeoff problems between scale factors and fields of view.

Fortunately the benefits of pursuit steering are not limited to the "pure" pursuit arrangement; various hybrid arrangements yield the same benefits without incurring the difficulties, the most thoroughly tested of which is the "frequency separation" principle studied at the University of Illinois (Johnson and Roscoe, 1972; Roscoe and Williges, 1975; Ince, Williges, and Roscoe, 1975; Beringer, Williges, and Roscoe, 1975). A frequency-separated display, by somewhat arbitrary definition, is one in which both symbols move, the one representing the airplane moving in response to the "higher frequency" acceleration and rate components of the airplane's response which are not normally displayed directly, and the symbol or symbols representing the outside world moving in their customary manner to indicate the "lower frequency" rate and position components of the airplane's response to which pilots are accustomed.

Flight path prediction. If the pitch and bank angles of the airplane are represented by fixed indices relative to a moving horizon line, the momentary vertical flight path angle may be represented by an airplane symbol that is displaced vertically as a function of the angle of attack (Roscoe, Eisele, and Bergman, 1975). The airplane symbol thus becomes, in effect, a velocity vector symbol (see Figure 1). If two successively smaller airplane symbols are displaced and rotated relative to the initial airplane symbol by terms that approximate, respectively, rates of change in flight path angles and rates plus accelerations in flight path angles, an effective approximation of the curvilinear projection of the flight path can be effected with proper scaling (also shown in Figure 1).

Although the frequency-separated flight path projection thus achieved is an imprecise approximation when the airplane is maneuvering, the errors of projection decrease as the airplane approaches the desired flight path and the pilot resumes a steady state of flight, at which point the projection is correct. Fortunately, errors in approximation while the pilot is maneuvering onto the desired course, vertical gradient, final approach path, or weapon-delivery run are generally of little consequence, their main effect being to cause the pilot to capture his desired flight path more or less rapidly. Furthermore, all approximations are improved by scaling as a function of speed.

Command guidance. Computed guidance commands can be embedded in a perspective contact scene in many ways, the choice of which depends upon both the complexity and the precision of the flight path control required

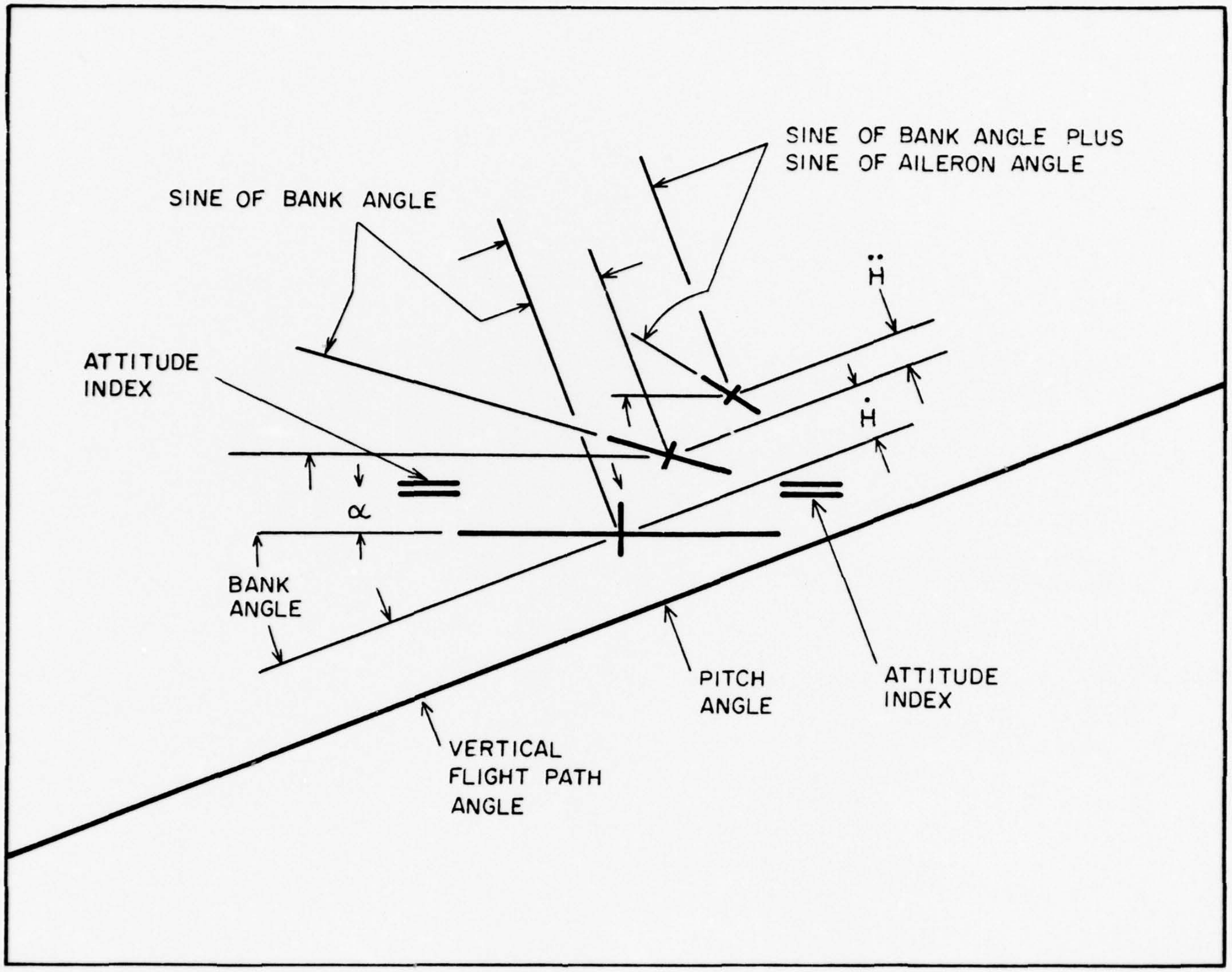

Figure 1. Flight path predictor in all airborne modes.

(Roscoe, Eisele, and Bergman, 1975). If a flight path predictor is to be used, the resulting display, by definition, becomes a hybrid pursuit display, and for any flight maneuver that can be reduced basically to a tracking task, a simple indication of horizontal and vertical angles to turn through, represented by a steering dot or small circle toward which the predictor is constantly driven by the pilot, will yield the ultimate in manual tracking precision. Such a display is appropriate to takeoff, enroute and terminal area navigation, and air-to-air interception and attack.

Ground-referenced maneuvers, ones defined in three dimensions relative to specific surface objects, such as approaches to airport runways and terrain following or avoidance in the vicinity of a target, can also be reduced to tracking tasks, but some of the potential contributions of the pilot can be lost in the process. In such cases, curvilinear command guidance indications, as represented, for example, by the "highway in the sky" concept, offer the pilot a perspective view of his desired position as a function of time and/or distance, which in turn may allow him to make better use of his flight path predictor.

Figure 2 illustrates the application of ground-referenced command guidance to the ILS approach to an airport runway; the airplane is clearly to the left and above the path defined by the localizer and glide path beams. Informal simulator studies at the University of Illinois have shown this type of guidance to facilitate the use of the flight path predictor. Although curvilinear guidance paths have not been simulated to date, their contributions relative to compensatory steering dot commands would be expected to be even greater.

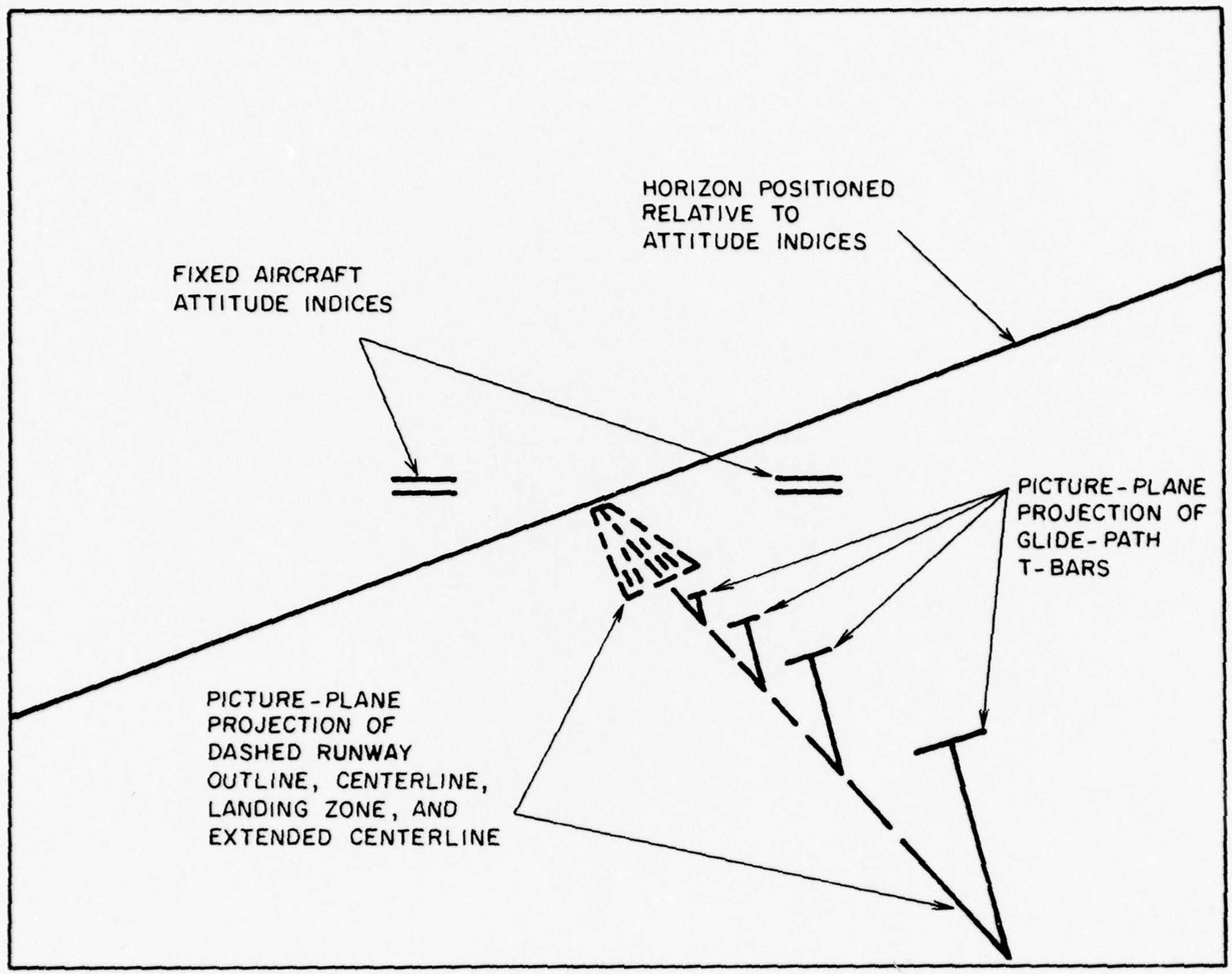

Figure 2. Basic position and attitude indications in landing approach.

Rate fields as flight directors. The main advantage of pictorial displays is the instant orientation afforded by the fact that relationships among various items of information are presented directly; the requirement for transformations by the pilot is minimized. However, the price of pictorial display is often a reduction in the scale or sensitivity of presentation of flight variables that require close and timely attention for precise control. For flight maneuvers such as weapon delivery or zero-visibility takeoffs and landing, indices of desired and actual performance must be presented with high sensitivity and with virtually no sensing or filtering lags.

One excellent method of presenting computer-assisted flight direction of critical variables, such as airspeed, pitch and roll rates, angle of attack, and vertical flight path gradient, is the use of prominent rate-field movement along the edges of pictorial imaging displays. Rate-field movement (or apparent movement) can be achieved in many ways, such as "barber pole" displays, strips of streaming dots or bars, traveling sine waves, and moiré pattern generators, to name but a few. Several applications of the rate-field principle have been developed into commercially available flight instruments, and some have been tested (Swartzendruber, Ince, Williges, and Roscoe, 1971).

The chief advantages of rate fields as flight directors are that any movement from a steady motionless state attracts attention, and nulling the error-indicating motion is relatively easy if the required control action is to oppose the motion; it is far more difficult to learn to null an error by following the motion, and control reversals occur frequently. The rate field motion need not, and normally should not, be linearly related to the magnitude of error; usually a logarithmic relationship is in order. Another advantage of rate fields as flight directors is that they can provide prominent, sensitive indications for at least three dimensions of control simultaneously without creating a cluttered appearing display or requiring any actual scales.

Program Phases

The research program conducted for ONR at the Aviation Research Laboratory was a combined effort in which computer assistance was applied to both aircraft controls and displays to reduce both pilot error and workload thereby increasing the aircraft-pilot system performance. The program consisted of two phases. The major efforts in Phase I were performed in a Link GAT-2 light twin-engine simulator. Phase II research was conducted exclusively in the Link GAT-2 simulator. The general program plan was to optimize computer-augmented controls used in a landing approach during Phase I and to optimize a computer-generated landing display during Phase II.

To anticipate the display research planned for Phase II, approximately one-third of the effort during Phase I was directed toward software and hardware modifications of the existing computer-generated landing display at the Aviation Research Laboratory and to experiments to determine cues essential in the approach to a landing. Likewise, approximately one-third of the effort during Phase II was devoted to modification and upgrading of the Phase I computer-augmented control system for use in connection with the computer-generated display system.

Phase I accomplishments. The main thrust of Phase I was to modify the existing performance control system used in the Link GAT-2 simulator at the Aviation Research Laboratory to allow investigations of various automated control modes used in the landing approach. These modifications apply the principle of reducing the control order to additional phases of flight involving changes in aircraft configuration. Based on a detailed analysis and computer simulation of the transitional flight modes in the complete landing approach, performance control modifications were designed to allow all transitions to occur smoothly.

Four related efforts took place during Phase I, the first of which was supported by the Air Force Office of Scientific Research and involved measurement of the effects of the existing PCS upon control precision and procedural compliance while pilots flew a complex three-dimensional area navigation mission in a Beechcraft Twin Bonanaza. The second was a review of forward-looking pictorial displays and manual control augmentation systems (supported by ONR and reported by Roscoe, Eisele, and Bergman, 1975). The third involved hardware acquisitions and software modifications to the existing computer-generated display system in support of the fourth effort, a parametric experimental study of various combinations of visual cues in a static approach-to-landing scene (Eisele, Williges, and Roscoe, 1976).

The flight experiment served both as a partial validation of previous findings from simulator experiments by Kraus (Kraus and Roscoe, 1972; Roscoe and Kraus, 1973) and in addition revealed certain deficiencies and objectionable features of the existing PCS when vertical maneuvers are required during complex terminal area navigation procedures. System modifications to correct the deficiencies and eliminate the objectionable features were determined and incorporated (Daly, Collins, and Ruby, 1975).

The hardware acquisitions and developments and the software modifications for the computer-generated display system also involved several parallel efforts during Phase I. The system now includes three major new elements: a matrix multiplier designed and developed by graduate student Robert A. Ruby; a raster scan converter designed and developed by graduate student Douglas J. Collins; and one commercial procurement, an Advent color TV projection system. With these additional elements, the display system in the GAT-2 is complete with respect to hardware.

Phase II accomplishments. The work remaining on the research facility during the first year of Phase II was the development, checkout, and experimental optimization of a computer software program to provide (1) the dynamic real-time imagery generation for a contact analog display of essential visual cues for landing (Artwick, 1976) and (2) a frequency-separated fast-time prediction of projected flight path (Gallaher, Hunt, and Williges, 1976). In parallel with the computer software development effort, a series of optimization pretests was conducted in the Link GAT-2/Raytheon 704 simulation facility to establish the specific ranges of values and time and scaling constants for the frequency-separated fast-time prediction of the projected flight path presentation to assure its compatibility with computer-augmented control.

Flight variables considered in these exploratory optimization studies included instantaneous flight path deviation from desired approach path, heading relative to runway orientation, vertical flight path angle, horizontal and vertical rates of approach or departure to or from desired flight path, bank and pitch altitudes, roll and pitch rates and accelerations, aileron position, and prediction intervals and ranges as a function of distance to the touchdown aiming point. Subsequent formal experimental investigation of such a large number of variables over sufficient ranges of values no doubt would be facilitated by the use of an appropriate central composite RSM experimental design.

Application to Standard Mission Phases

The results of the research performed under this program are generalizable to a wide range of display and control system applications for future Naval aircraft. The practical embodiment of the various display principles formulated and tested in this and related programs at the Aviation Research Laboratory is illustrated in the series of figures that follow. Each shows an integrated computer-generated display configuration for a standard phase of a representative flight mission. Weapon delivery configurations, not shown, would appear essentially the same as the "Enroute Course and Altitude Intercept" display but with appropriate differences in guidance computations.

Although the display principles and symbolic configurations embodied in the illustrations have all received some form of experimental validation in one context or another, there has not been a systematic evaluation in a total-mission, integrated-system context. Such an evaluation would necessarily involve not only the measurement of absolute and comparative pilot performances of the individual flight and navigation tasks encountered in the various mission phases but also a similar consideration of the ease or difficulty of transitions from phase to phase and among the associated display and control modes.

Furthermore, although the use of rate-field motion as a primary means of flight-direction has received some formal experimental study, the few relevant experiments have not included a systematic determination of the most compatible direction of motion relationships or the range of motion rates that can be used effectively. Nor has there been any systematic consideration of the advantages or possible necessity of differential coding of rate-field configurations to prevent misidentification of what is being presented in each display mode. These and possibly other display and control system considerations will require systematic study prior to an eventual determination of total system effectiveness and acceptability.

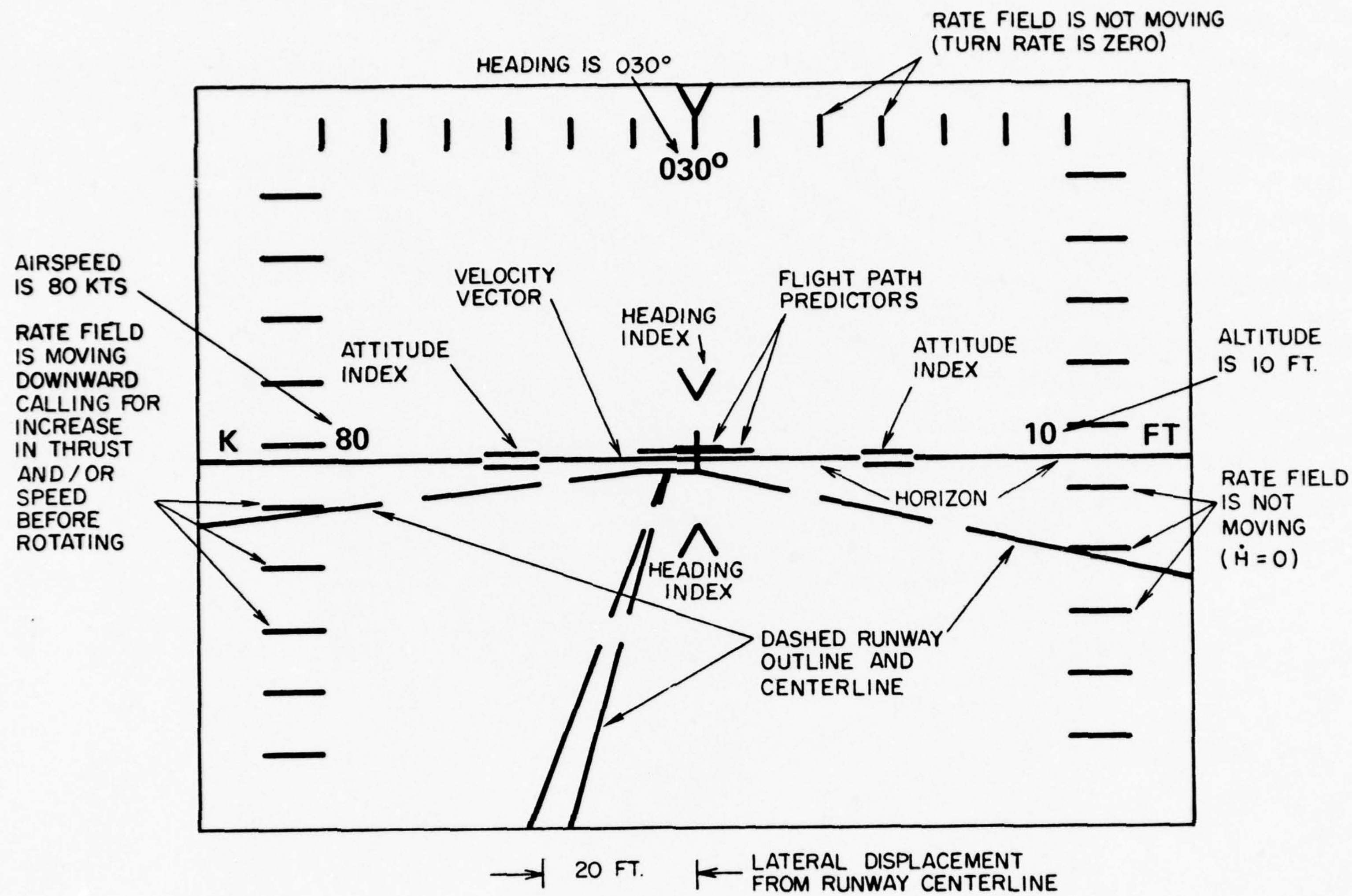

Figure 3. Takeoff roll before rotation.

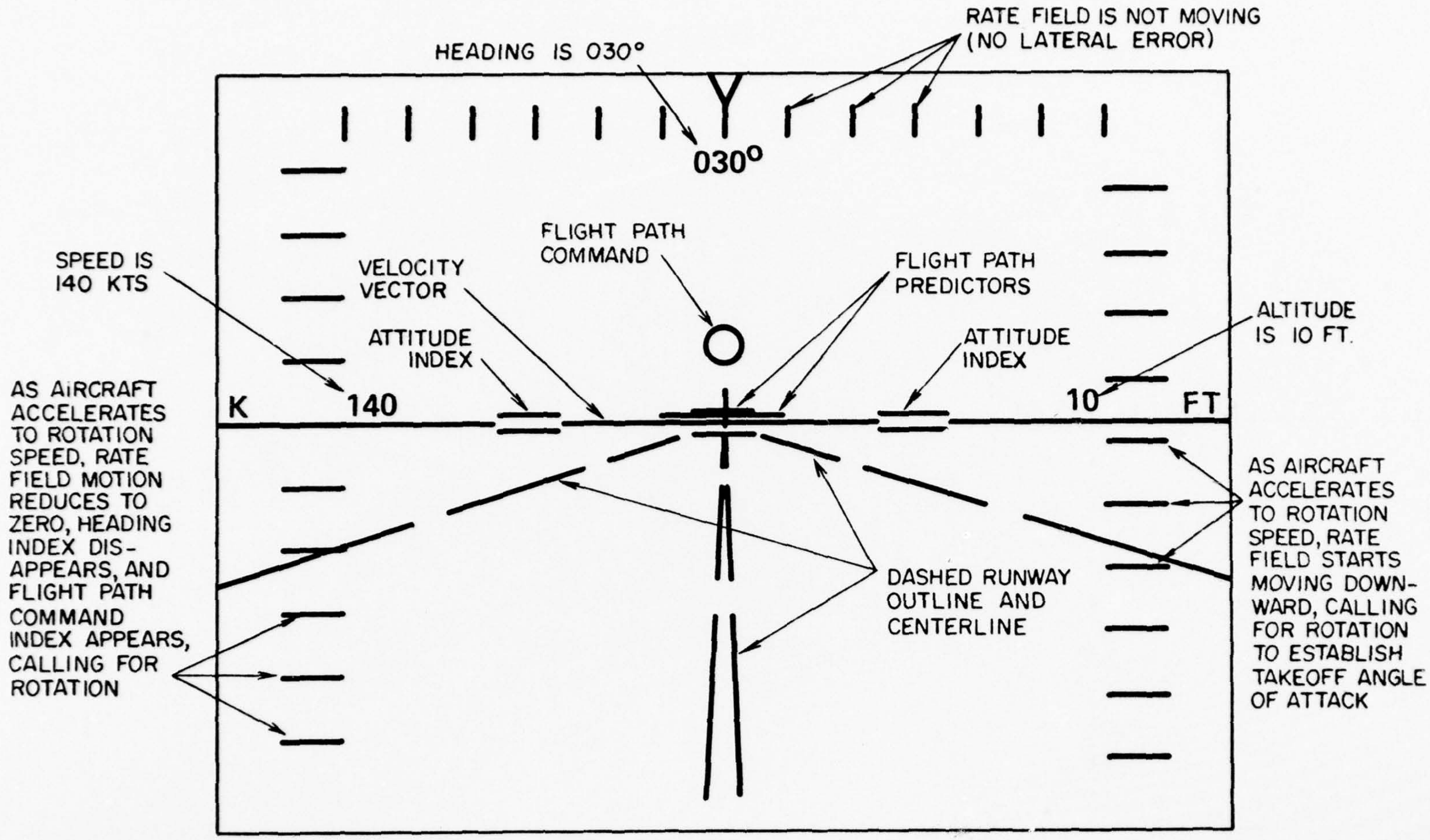

Figure 4. Takeoff roll immediately before rotation.

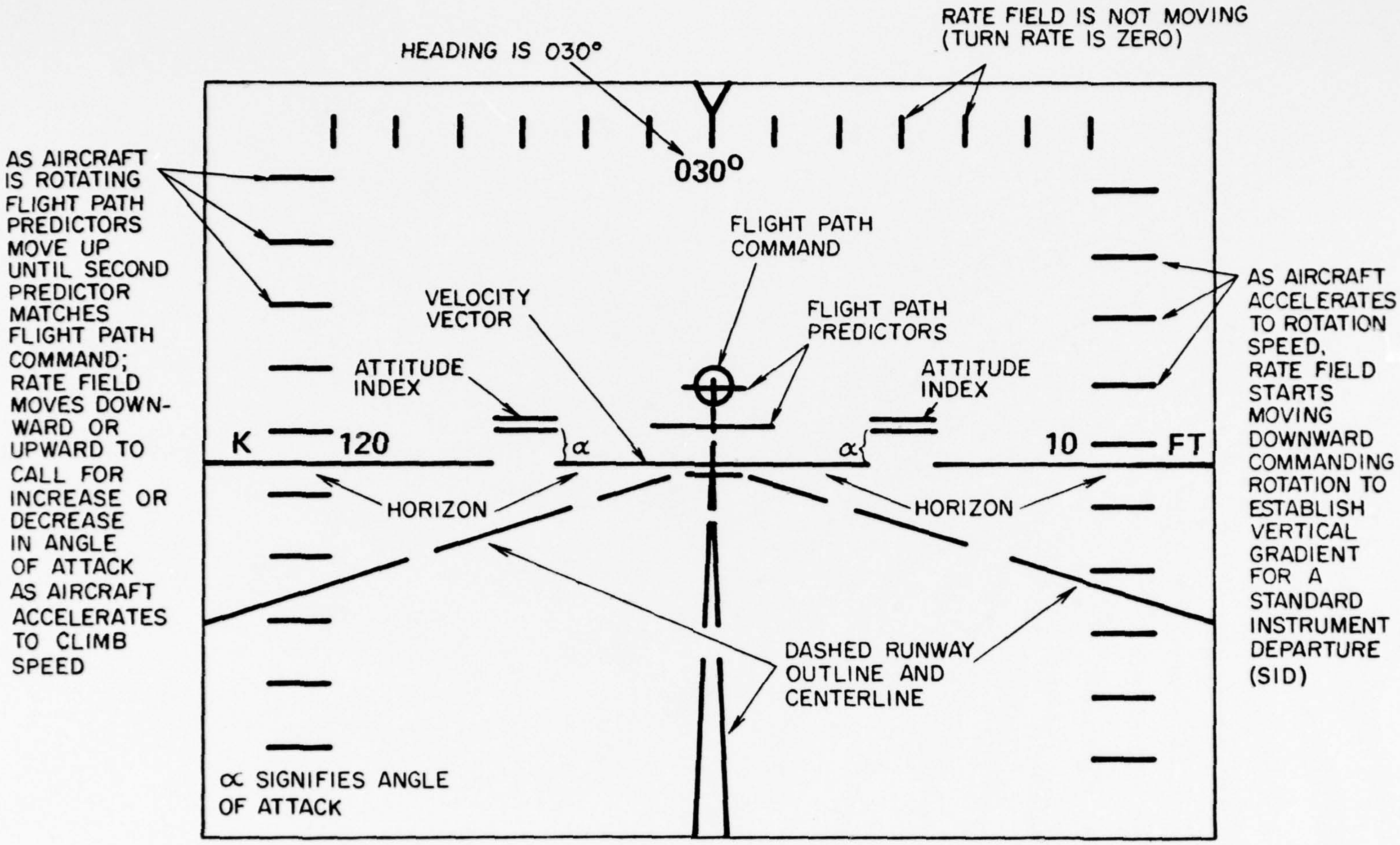

Figure 5. Takeoff roll during rotation but before liftoff.

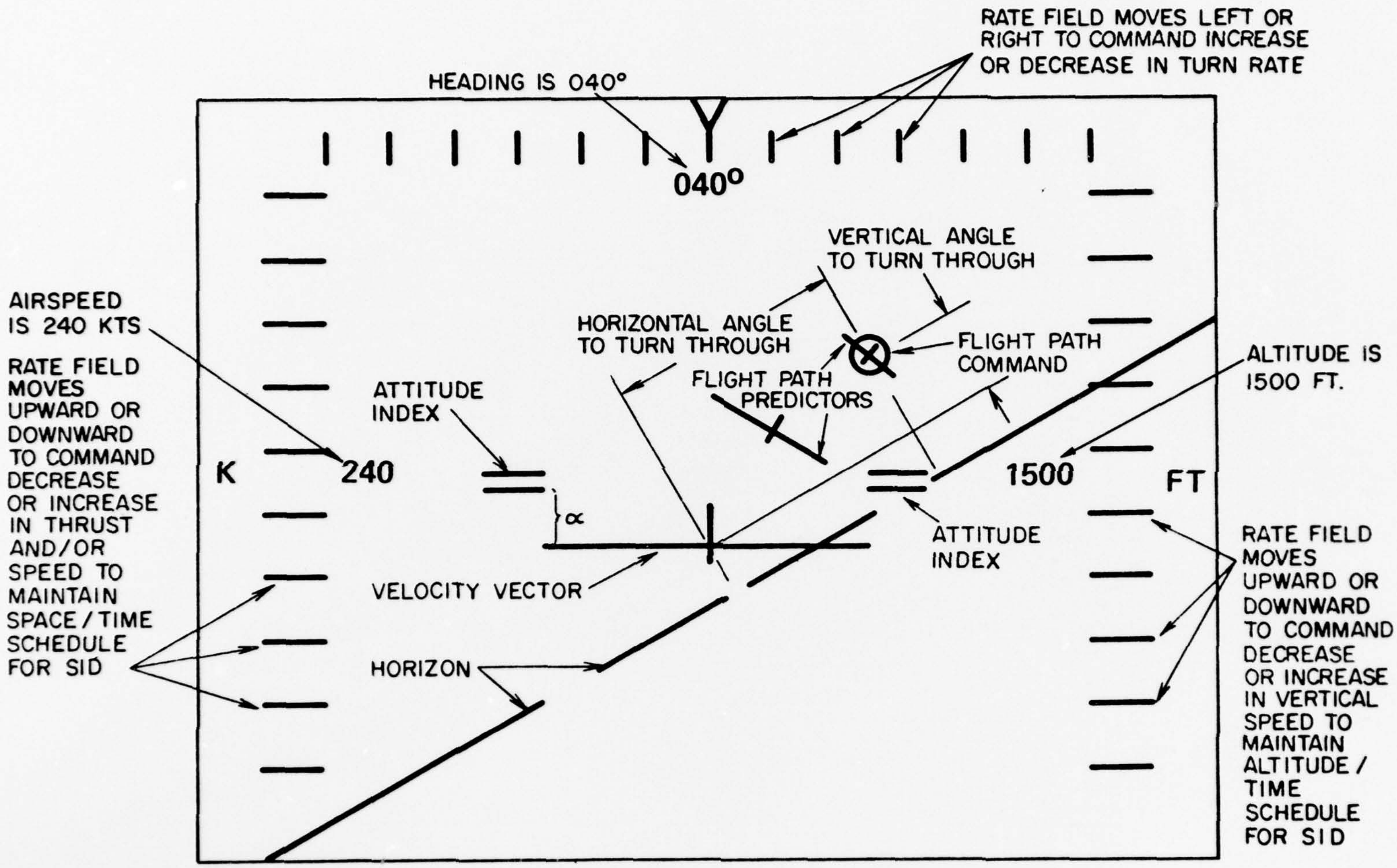

Figure 6. Standard instrument departure - climbing turn to command course and altitude.

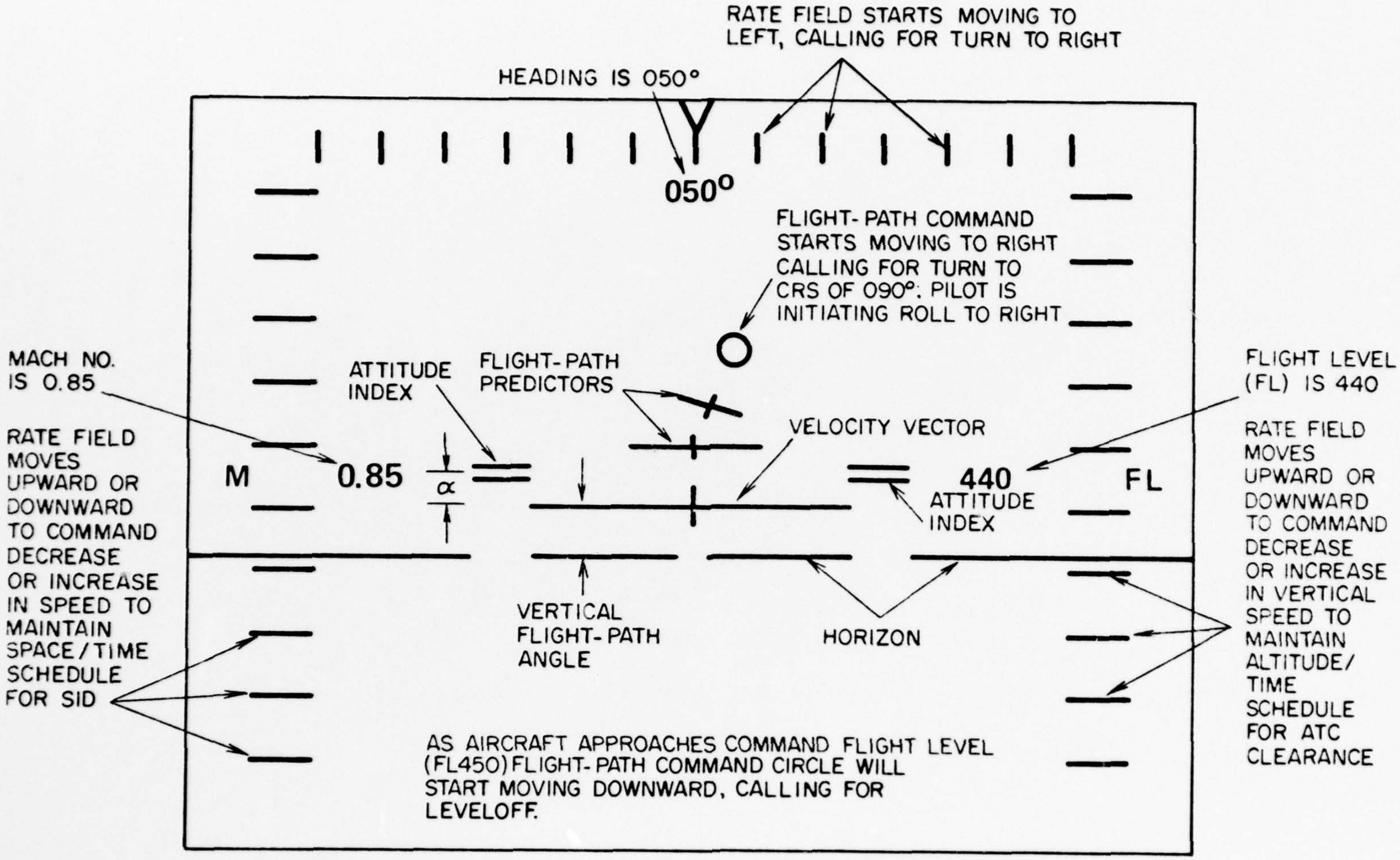

Figure 7. Enroute course and altitude intercept (or air-to-air intercept).

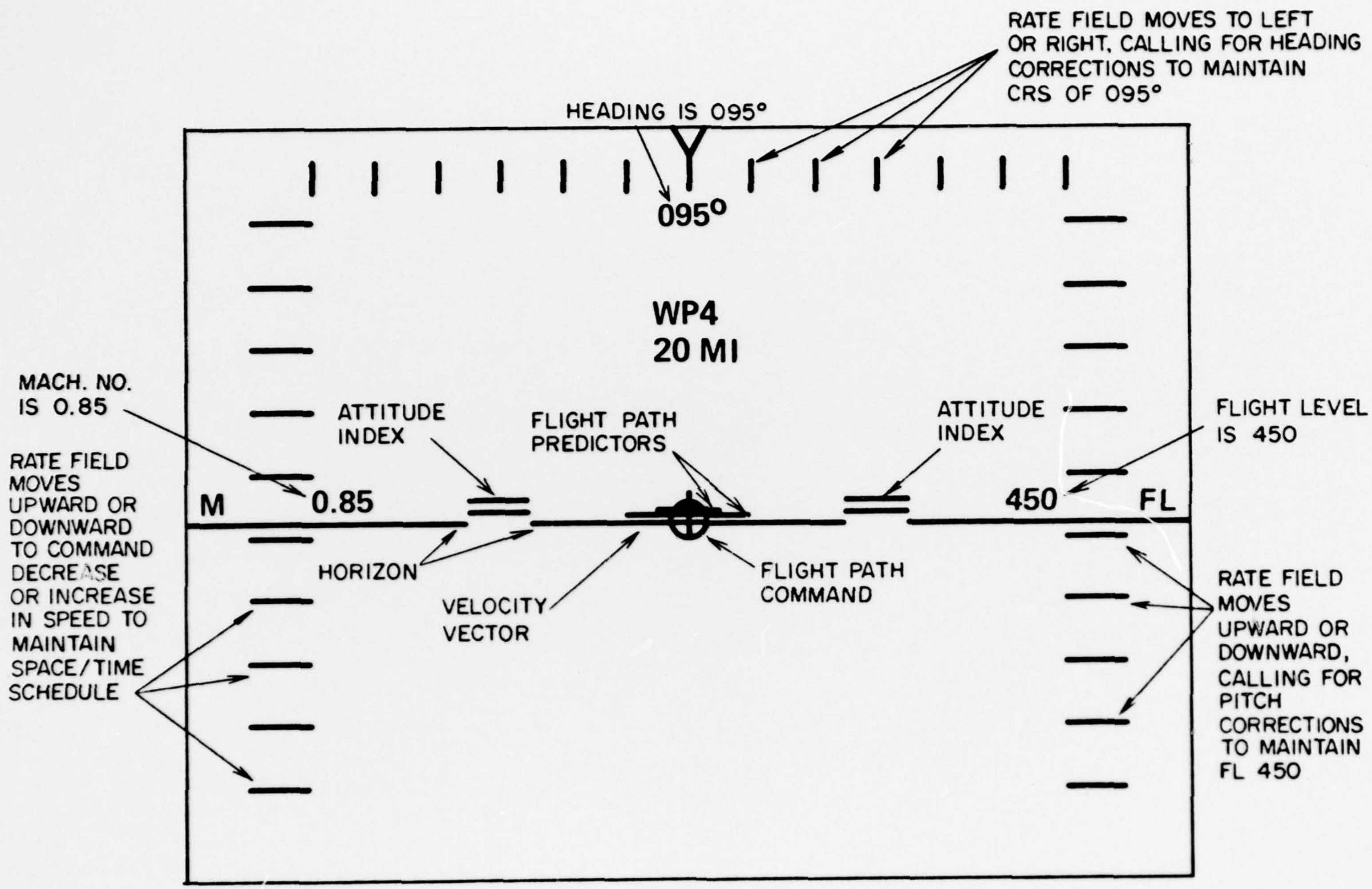

Figure 8. On-course cruise.

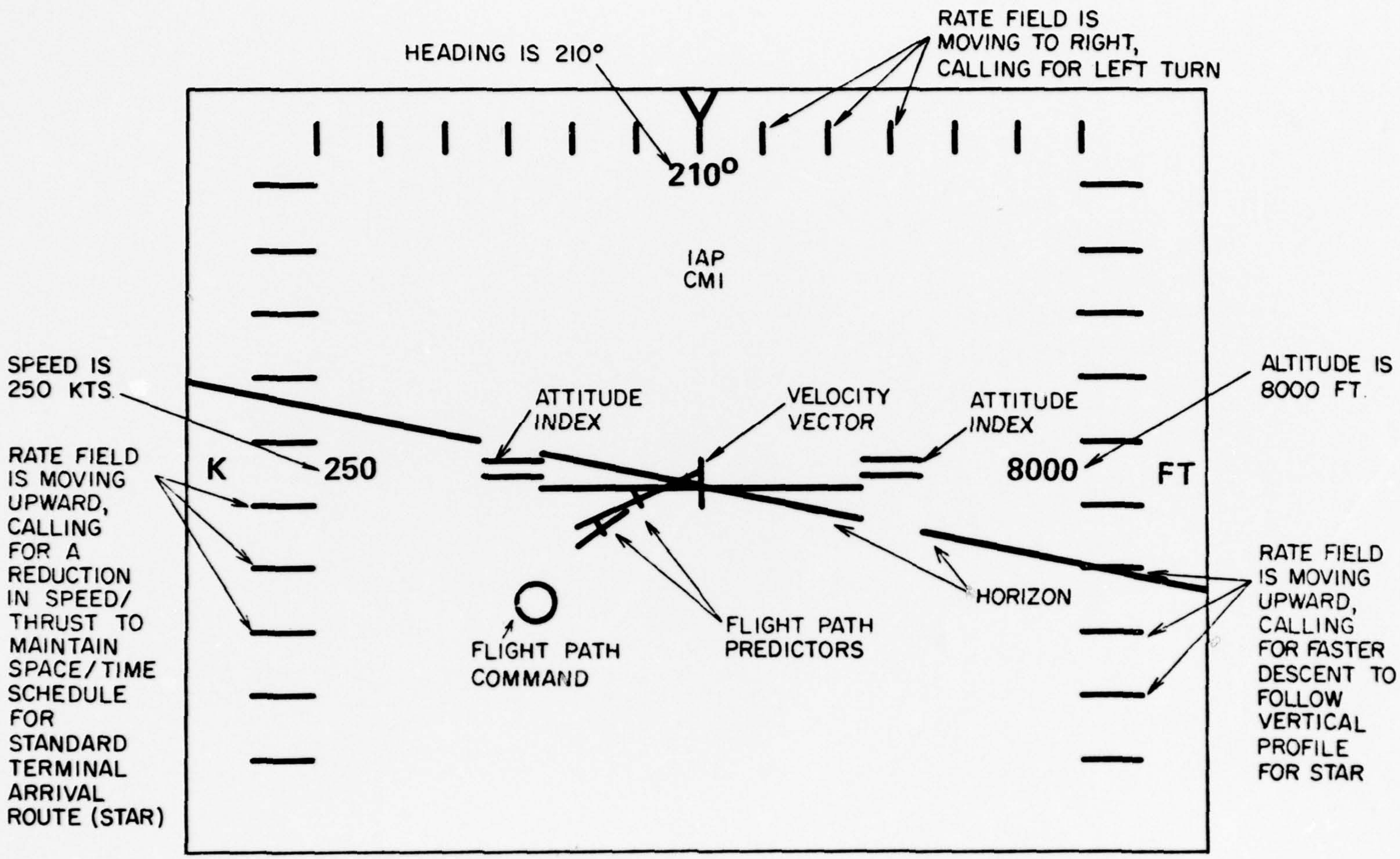

Figure 9. Entering descending turn from IAP (Initial Approach Point of "high gate") to FAF (Final Approach Fix or "low gate").

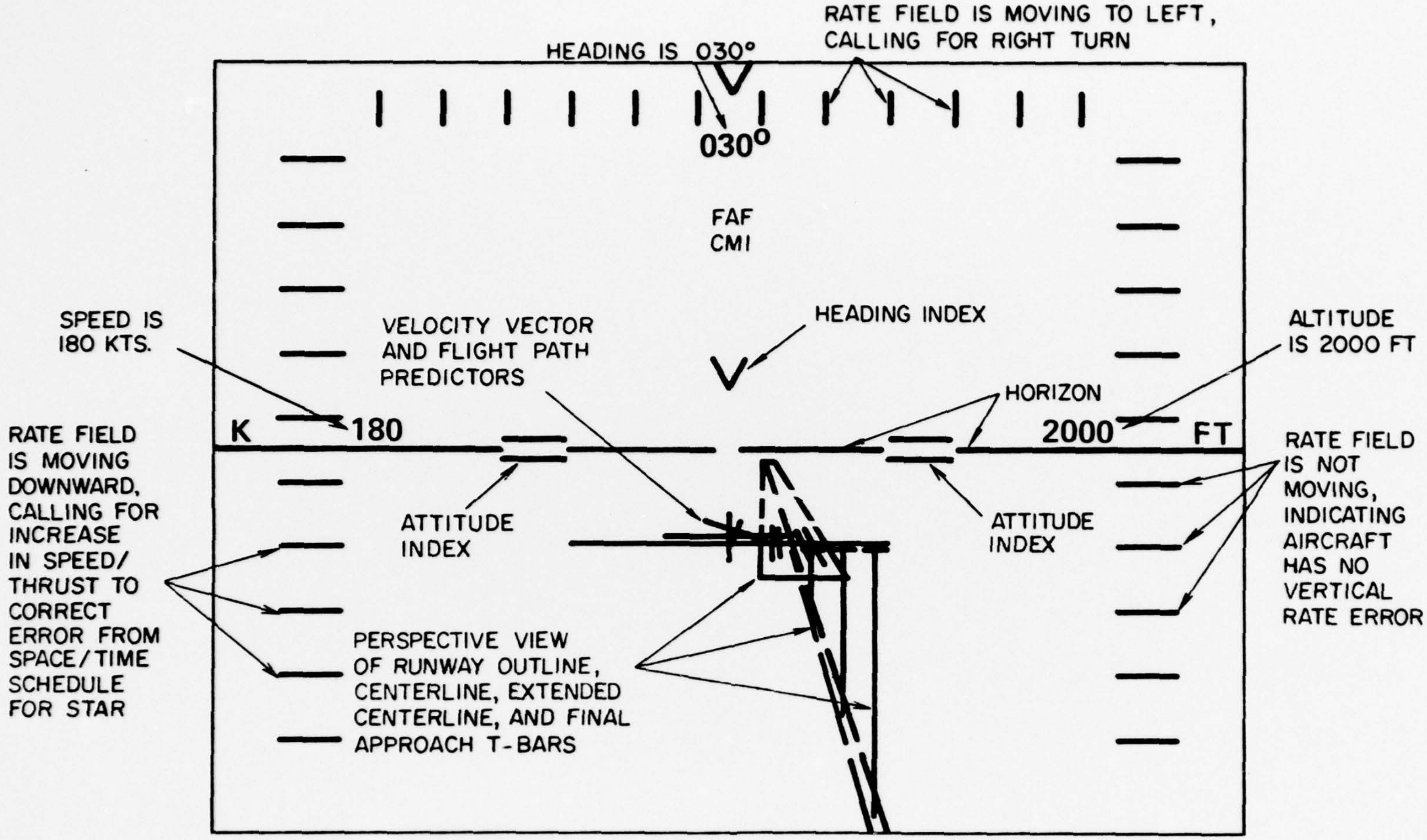

Figure 10. Entering final approach at FAF (low gate), on glide slope, left of localizer.

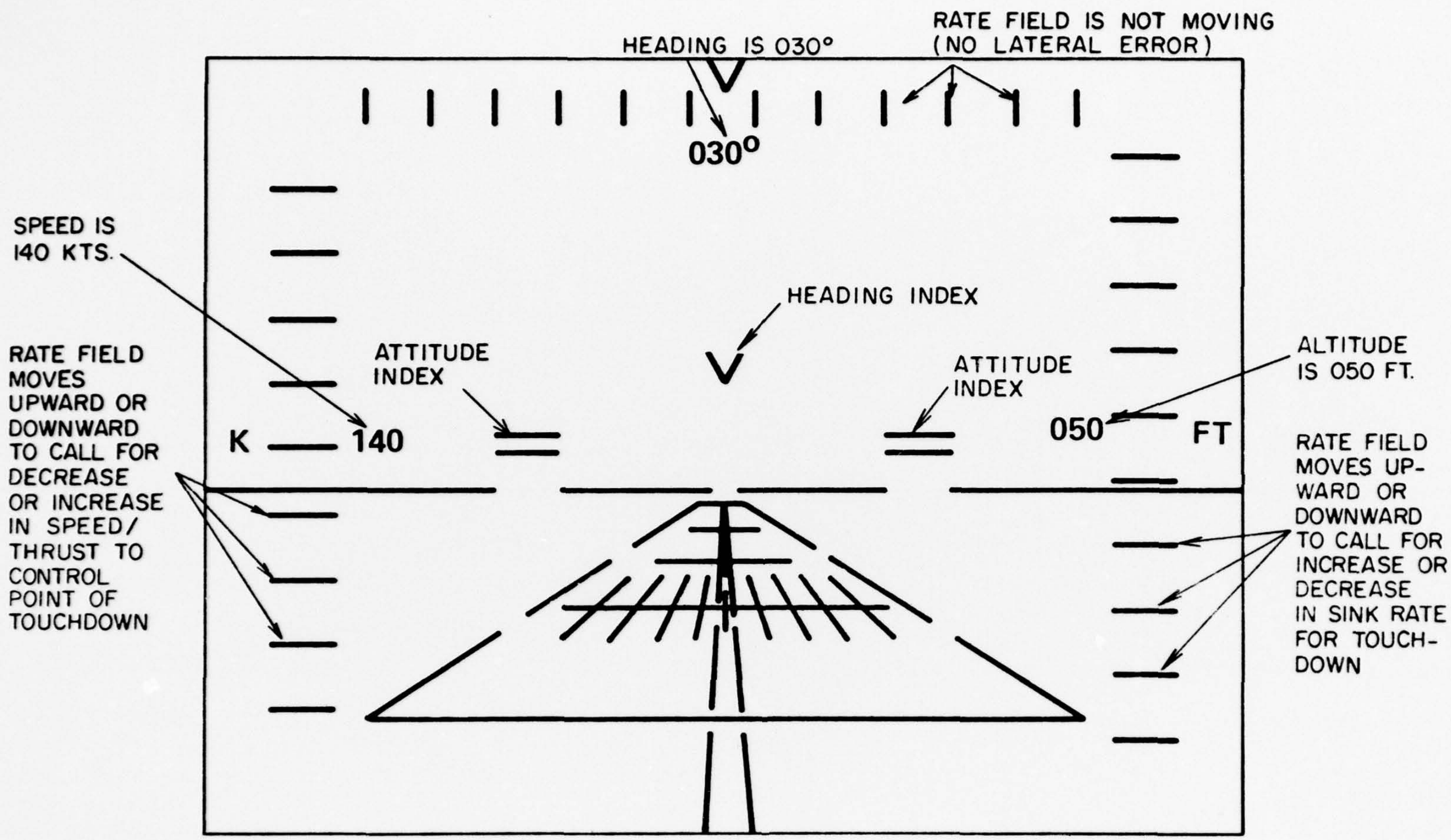

Figure 11. Initation of flare on short final approach to landing.

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Roscoe, S. N., Eisele, J. E., and Bergman, C. A. Advanced integrated aircraft displays and augmented flight control, Volume I. Scientific findings. Savoy, Ill.: University of Illinois at Urbana-Champaign, Aviation Research Laboratory TR ARL-75-12/ONR-75-2/I, 1975.

Daly, D., Collins, D. J., and Ruby, R. A. Advanced integrated aircraft displays and augmented flight control, Volume II: Appendices, Savoy, Ill.: University of Illinois at Urbana-Champaign, Aviation Research Laboratory TR ARL-75-12/ONR-75-2/II, 1975.

This integrative report is divided into two volumes. Volume I introduces a classification of aircraft displays and controls, reviews problems that have plagued their evolution, and advances the pilot's task hierarchy as a conceptual framework within which available information can be abstracted, integrated, and applied to the design of displays and controls. In particular, Volume I constitutes a bringing together and integration of the findings from the various historical lines of investigation associated with quickening and unburdening, contact analog displays, predictor displays, frequency-separated displays, and performance control systems.

Volume II contains reports detailing the hardware efforts. Hardware specific to Phase II simulation and experimentation was designed. built, and installed. Volume II describes equipment necessary to continuing research on computer-augmented controls and computer-generated displays. Appendix A by Dennis W. Daly reports the design and installation of a digital control system for reduced order, decoupled control of an aircraft simulator. A real-time scan converter for computer-generated visual simulations is described by Douglas J. Collins in Appendix B. Another hardware development applicable to computer-generated visual simulations, a peripheral device for linear coordinate transformation, is detailed by Robert A. Ruby in Appendix C.

Artwick, B. A. A versatile computer-generated dynamic flight display. Savoy, Ill.: University of Illinois at Urbana-Champaign, Aviation Research Laboratory TR ARL-76-5/ONR-76-1, 1976.

This report describes a real-time, dynamic, computer-driven visual display program which is written in the Fortran programming language. Versatility, efficiency, and ease of use are stressed in the software development, resulting in an easy to program dynamic display which can be implemented economically with a bare minimum of graphics hardware and a sixteen-bit mini-computer which has Fortran capabilities. Modular structure is stressed and speedup methods are discussed including the use of a matrix multiplier. A unique frame synthesizing feature is described in detail. Sample data base structures and display images conclude the report.

Gallaher, P. D., Hunt, R. A., and Williges, R. C. A regression approach to generate aircraft predictor information. Savoy, Ill.: University of Illinois at Urbana-Champaign, Aviation Research Laboratory TR ARL-76-11/ONR-76-2, 1976.

A predictor display shows the human operator future consequences of his immediate control inputs. A contact analog aircraft display is described in which an airplane-like predictor symbol depicts future airplane position and orientation. The standard method for obtaining the predictor information is to use a complete, fast-time model of the controlled vehicle. An alternative approach is presented in this paper in which least-squares, first-order, linear approximations for each of the six degrees of freedom of aircraft motion are calculated. Thirteen variables representing changes in positions and rate of change of positions were selected as parameters for the prediction equations. Separate sets of equations were determined for 7, 14, and 21 seconds prediction times and continuous, one-second, and three-second control neutralization times. The advantages and disadvantages of this regression approach are discussed.

Eisele, J. E., Williges, R. C., Roscoe, S. N. The isolation of minimum sets of visual image cues sufficient for spatial orientation during aircraft landing approaches. Savoy, Ill.: University of Illinois at Urbana-Champaign, Aviation Research Laboratory, TR ARL-76-16/ ONR-76-3, 1976.

An experimental investigation of synthetic imaging displays was directed toward the isolation of minimum sets of visual cues sufficient for spatial orientation in ground-referenced aircraft landing approaches. Thirty-two flight instructors viewed static computer-generated airport scenes TV-projected onto a large screen viewed from the cockpit of a twin-engine general aviation trainer. Judgments of lateral and vertical deviations from a three-degree approach to landing aim point in the display were made to 32 combinations of four contact analog cues: runway outline, runway touchdown zone, runway centerline, and ground plane texture; and one guidance cue: glidepath-localizer symbol. The views of each cue set were generated from 27 different positions in three-dimensional space. Dependent measures were response choice and response latency. The most accurate glidepath and course deviation judgments were made when the guidance cue glidepath was in the set. When only contact analog cues were present the best judgments of spatial orientation consistently were made when the runway outline was present. For a majority of the 27 spatial positions and 32 cue combination sets, the presence of a ground-plane texture grid increased the response latency and the probability of incorrect judgment.

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