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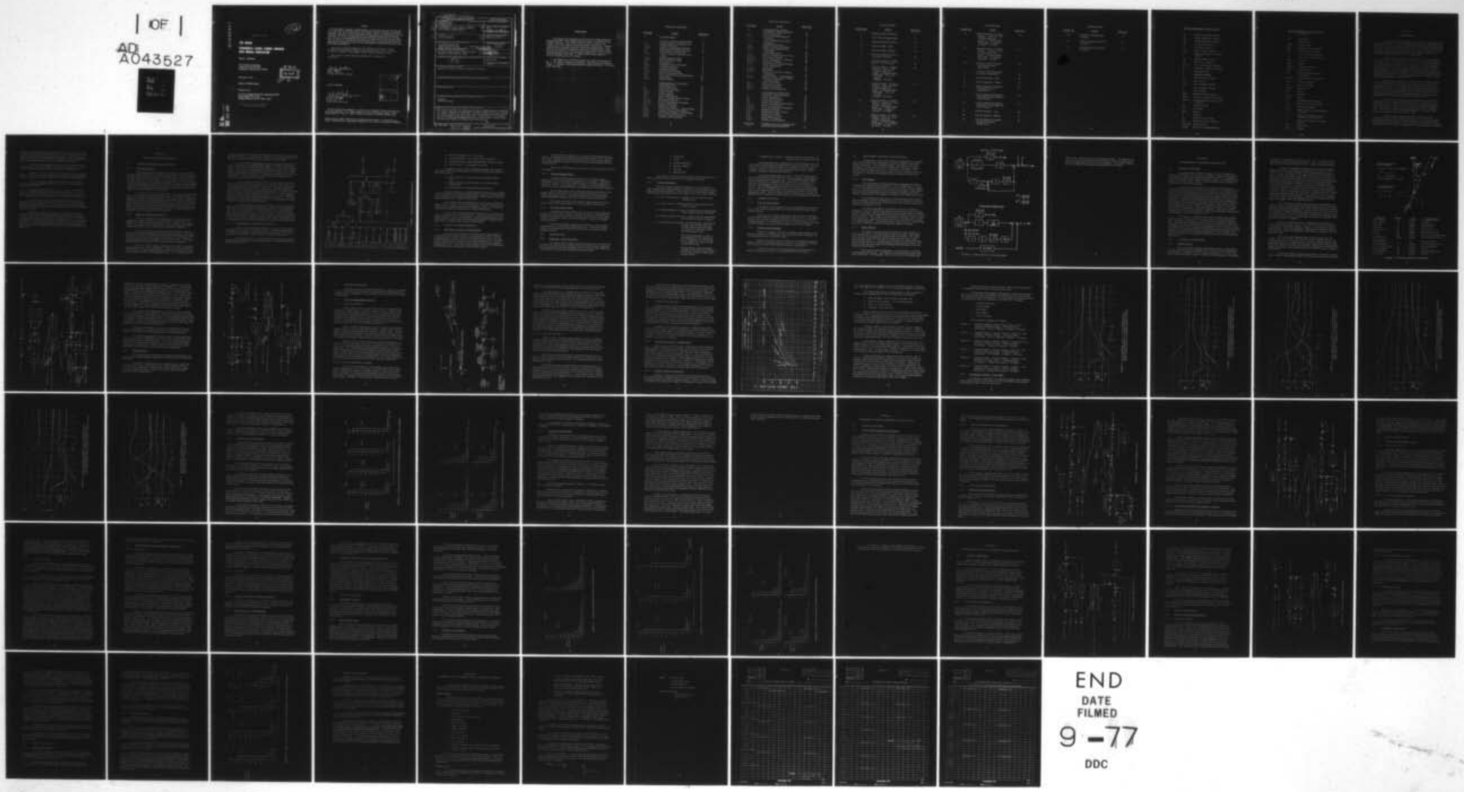

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TEST REPORT

EXPERIMENTAL LATERAL LANDING COMPUTER WITH INERTIAL STABILIZATION

John R. Woloshen

The Bendix Corporation
Flight Systems Division
Teterboro, New Jersey 07608

December 1974

FINAL REPORT A008

Prepared for:

Air Force Flight Dynamics Laboratory/FGT
United States Air Force
Wright-Patterson AFB, Ohio 45433

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This report describes the flight test findings, recommendations, and performance levels achieved on an experimental lateral computer installed on KC-135 No. 53126 at Andrews Air Force Base. The text contained herein also defines the modifications to the system described in AFFDL-TR-71-97. Performance levels are identified throughout the text on analog flight recorder traces and from data tabulated in statistical histogram form.

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FOREWORD

This report was prepared for the Air Force Flight Dynamics Laboratory/FGT, by the Flight Systems Division, The Bendix Corporation, Teterboro, New Jersey under Air Force Contract No. F33615-72-C-1753, data document item A008, Test Report, "Experimental Lateral Landing Computer with Inertial Stabilization". This work was performed in conjunction with other program tasks during the time period January 1972 through December 1974. The Air Force Program Manager was Capt. T. Imrich with Project Engineers, Lt. R.P. Denaro and Lt. B. Kunciw.

The Flight Systems Division effort was under the direction of Mr. F. G. Adams, principal investigator. This report was prepared by Mr. J. Woloshen with supporting data supplied by Messrs. M. Sforza and S. Skaritka.

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ILLUSTRATIONS

ILLUSTRATIONS

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LIST OF SYMBOLS, ABBREVIATIONS

$\hat{\delta}_a$	Aileron Command, Degrees
δ_a	Aileron Deflection, Degrees
δ_R	Rudder Deflection, Degrees
η, ϵ	Localizer Beam Error
ϕ	Roll Angle, Degrees
ϕ_c, ϕ	Roll Command, Degrees
ψ	Runway Heading Error (PSC), Degrees
β_A	Sideslip Angle, Degrees
β_I	Drift Angle, Degrees
$\psi + \beta_I$	Cross Track Angle, Degrees
ω	Frequency, Radians per Second
ζ	Damping Factor
σ	**Standard Deviation**
τ	Time Constant, Seconds
μa	Microamperes
ACC	Alec Computer Capture
τ	Time Constant, Seconds
μa	Microamperes
ADI	Attitude Director Indicator
AFCS	Automatic Flight Control System
ALEC	Advanced Lateral Experimental Computer
CA	Coupling Armed
DA	Drift Angle
DEG	Degrees
$\dot{\phi}$	Roll Rate
F_R	Rudder Force, Pounds
F_W	Roll Wheel Force, Pounds
FD, F/D	Flight Director
FTCM	Full Time Command Modifier

LIST OF SYMBOLS, ABBREVIATIONS
(Continued)

G/S	Glide Slope
h	Altitude, Feet
HDG	Heading Mode
ILS	Instrument Landing System
INU	Inertial Navigation Unit
K	Gain or Relay Designation
Kt	Knot, Nautical Mile Per Hour
LOC	Localizer
MAN	Manual
PB-20D	Autopilot Designation
PSC	Preset Course
RA	Runway Alignment Prior to Touchdown
RFDC	Roll Flight Director Coupled
ROG	Roll Out Guidance
S	Laplace Variable
SYNC	Synchronize
SW	Switch
Sec	Seconds
TRK	Track
V	Indicated Airspeed, Knots
V_A	Axial Velocity of Main Gear
V_G	Total Ground Speed
V_w	Total Wind Velocity with Respect to Ground
Y	Distance from Aircraft c.g. to Runway Centerline, Feet
$\dot{Y}$	Cross Track Velocity, Feet per Second
WL	Wings Level
W/O	Washout

SECTION 1

INTRODUCTION

The Advanced Lateral Experimental Computer was designed and fabricated to provide a means for in-flight evaluation and study of advanced lateral axis control techniques during the final approach and landing phases of flight. This work was accomplished as part of a continuing research and development effort in the general area of low-visibility approach and landing, under the sponsorship of the USAF Flight Dynamics Laboratory (AFFDL), Wright-Patterson Air Force Base, Ohio.

The experimental computer was designed following computer study and analysis efforts in the areas of ILS localizer approach, runway alignment, and roll out guidance. This work included the development of an inertially stabilized ILS localizer configuration; a runway alignment configuration that also employs inertial techniques and uses a forward side-slip control technique; and a configuration to provide a means for roll out guidance, following touchdown. The results of this analysis work and the initial experimental computer implementation are shown in Technical Report AFFDL-TR-71-97, Experimental Lateral Landing Computer with Inertial Stabilization, October 1971.

During the time period since that report was published, flight test development of the experimental approach configurations has been accomplished on a KC-135 test aircraft at Andrews Air Force Base, Maryland. As a result of this flight test work and continuing computer analysis work, the present computer modal configurations differ in some respects from the configurations described in AFFDL-TR-71-97. Another factor that has influenced the present computer configuration was the addition of a manual control capability during this period.

In this report, the present modal configurations are defined and described at a functional block diagram level. Discussions are included that describe system changes resulting from flight test development, configuration improvements, problems encountered during flight test, and a number of other factors that influenced the final configurations. Performance summaries and discussions are included to illustrate overall performance levels in each area.

Section 2 includes discussions that describe the overall lateral axis control system. Many of the areas covered here are essentially pilot oriented, relating to actual techniques and capabilities installed in the KC-135 test aircraft. In this section, discussions are included that describe overall system configurations used during approach, methods used for configuration selection, and the general experimental computer interface on the test aircraft. Other items covered here include a summary of the experimental computer modal sequence and mode engage points, a description of cockpit modal annunciation, and a description of the cockpit instrumentation used for command display purposes.

A functional description of the current Force Wheel Steering configuration is also included since the force wheel configurations are used in conjunction with each of the experimental configurations.

Sections 3, 4, and 5 pertain to the operational modal configurations. In these sections the experimental localizer, runway alignment, and roll out guidance modal configurations are discussed sequentially.

These sections each begin with a general discussion that describes the mode operationally to provide orientation for the functional descriptions that follow.

Following the general discussion, the current modal configurations are defined through use of functional block diagrams. In each case, separate diagrams are included for the automatic and manual control configurations. Discussions in this area relate to these diagrams.

The remainder of these sections are devoted to discussions pertaining to optimization and development of the experimental configurations and flight test results. These discussions summarize problems encountered during the flight test and development phase and the solutions to these problems.

Flight test results are discussed and illustrated through a combination of flight recordings and statistical techniques. During the localizer capture phase, actual flight recordings that reflect the variety of conditions encountered are included. During the localizer track, runway alignment and roll-out phases, system performance levels are shown through use of frequency distributions of key performance parameters. These charts reflect average system performance over approximately 40 approaches.

SECTION 2

OVERALL SYSTEM DESCRIPTION

2.1 LANDING APPROACH CONFIGURATIONS

2.1.1 General Discussion

The Advanced Lateral Experimental Computer can be selected for use during final approach in conjunction with either of the two automatic flight control system configurations presently in use on the KC-135 test aircraft. The general flight control system configuration uses the ALEC to provide lateral axis control display functions, while pitch axis control is accomplished through use of either the autopilot system or the experimental Flight Director/Autopilot Coupled configuration. In either case, the ALEC provides all of the lateral axis control/display functions from the localizer capture point until completion of the landing.

The ALEC can also be selected for use in a manual (display only) mode of operation. In the manual configuration, system operation is analogous to conventional flight director system operation, where steering commands are presented on cockpit displays, while surface control inputs are made manually by the pilot through control wheel movement. In the manual ALEC configuration, steering commands are generated and displayed for pilot reference; however, in this case, pilot inputs are made with the autopilot system engaged through use of the 3-axis Force Wheel Steering Configuration which is available on the test aircraft.

2.1.2 Approach Configuration Selection

Prior to an automatic ALEC approach, the desired system configuration is selected through use of solenoid held "Coupler Arm" and "ALEC Arm" switches which are located on the cockpit overhead control panels. The manual ALEC configuration is selected through operation of a DPDT test switch which is located in the aircraft's J-box area.

These switches are all normally operated with the automatic flight control system disengaged to avoid switching transients. As a safety provision, interlocks are provided that automatically disconnect the flight control system if either of the solenoid held switches in the cockpit are inadvertently operated with the flight control system engaged. The following paragraphs summarize the ALEC system selection procedure.

Prior to an ALEC approach, the ALEC Arm switch is operated with the flight control system disengaged. When this switch is operated, the ALEC system control signal paths are activated in preparation for use of the computer during the final approach phase. As an additional safety feature, the ALEC Arm switch coil (solenoid) is interlocked to ensure that the ALEC computer is ready for use. When basic system interlocks are not satisfied, the solenoid held arm switch will not remain engaged.

The pitch axis configuration to be used during the approach is selected through use of the solenoid held Coupler Arm switch. This switch, which is also operated with the automatic flight control system disengaged, selects the experimental Flight Director/Autopilot Coupled system configuration. When in the normal position, the basic autopilot system configuration is automatically selected. The Coupler Arm switch solenoid is also interlocked, for safety purposes, to ensure that basic Flight Director Coupler System interlocks are satisfied.

Once the ALEC has been selected, the flight control system is then engaged and armed for final approach. Approach mode arming is accomplished through use of either the autopilot system mode control panel or the flight director system mode control panel, depending upon which system has been selected for use during the approach. The selected system will control the aircraft's lateral axis until the localizer capture point is reached. At the localizer capture point, lateral axis circuitry within the flight director and autopilot system computers is bypassed. The ALEC becomes active at this time and provides all of the control/display functions during the final approach and landing phases.

If manual operation is desired, the Manual ALEC test switch is operated prior to the approach with the flight control system disengaged. When this switch is operated, the ALEC will operate in a "display only" mode and provide flight director steering commands for lateral guidance during the final approach phases. With the manual configuration selected, system interlocks are provided to prevent engagement of the automatic approach control modes. Approach arming, in the manual configuration, is accomplished through use of the flight director system mode control panel.

2.2 EXPERIMENTAL COMPUTER INTERFACE

Figure 1, Simplified System Interface, shows the ALEC and its relationship to the major components of the overall experimental lateral axis flight control system. This drawing shows the system in the automatic control configuration, after the localizer capture engage point.

Referring to Figure 1, the ALEC performs lateral axis control/display functions during the final approach phases using input signals from the following sources:

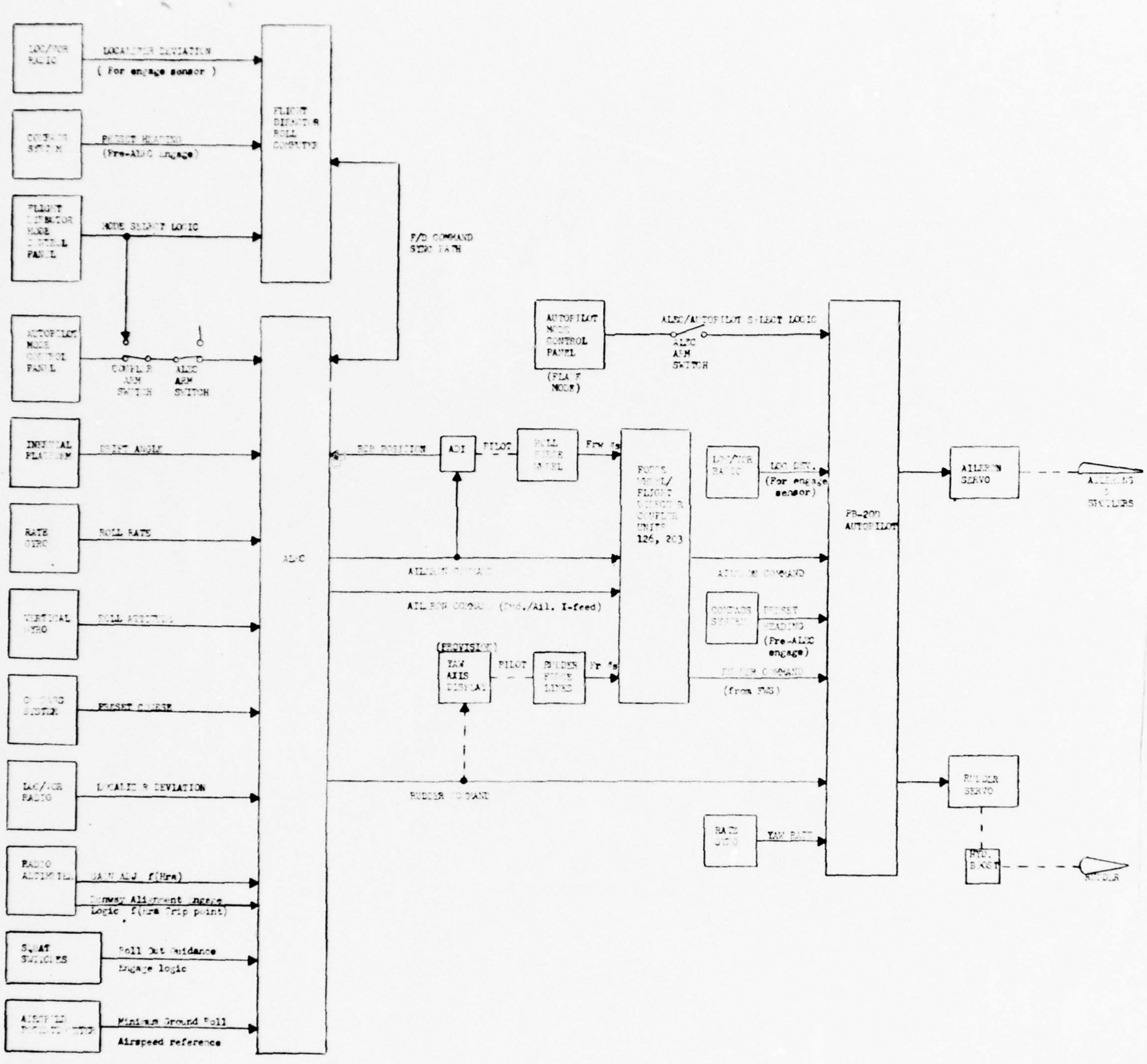


FIGURE 1. SIMPLIFIED SYSTEM INTERFACE

a) Inertial Navigation Unit - Drift Angle
b) LOC/VOR Radios - ILS Localizer Beam Deviation
c) Compass System - Runway Heading Data (Preset Course)
d) Aircraft Gyros - Roll Attitude, Roll Rate

In addition to these control and damping signals, the computer uses signals from the following sources for gain scheduling and mode control logic purposes:

a) Radio Altimeter - Altitude, Runway Alignment Engage Logic
b) Main Landing Gear Squat Switches - Roll Out Guidance Engage Logic
c) Air Data Sensor - Indicated Airspeed Reference

During an approach, the ALEC generates both aileron and rudder commands which are presented on flight director system command displays in the cockpit and also applied through the paths shown (heavy lines) to the autopilot system servo actuator control loops.

In the manual ALEC configuration the basic system interface is also as shown on Figure 1. In the manual case, however, the aileron and rudder channel command paths to the autopilot are opened. The steering command information is applied to the cockpit displays only.

A typical ILS localizer approach using the ALEC for lateral axis control consists of three sequential phases: Localizer capture and track; runway alignment; and roll out guidance. System operation during each of these phases is summarized in the following paragraphs. Detailed discussions will be included in later sections of this report.

2.3 LATERAL AXIS MODE SEQUENCE

2.3.1 Track Mode (Localizer Capture/Track)

The track mode is entered when the localizer capture point for the selected system (Flight Director or Autopilot) is reached. With the autopilot system, localizer capture is initiated when the aircraft reaches a point equivalent to 2.5 degrees localizer beam displacement. The flight director system localizer capture is at a point equivalent to 2.0 degrees displacement error. Prior to the capture point, the aircraft will generally be following heading commands from the selected system.

At the localizer capture point, the system configuration shown in Figure 1 is established through interface switching and the ALEC enters the track mode. In this mode, the ALEC provides all of the necessary lateral axis control/display functions necessary for capture and tracking of the ILS localizer beam.

Yaw axis control during the track mode is provided by the aircraft's yaw damper.

2.3.2 Runway Alignment Mode

During the runway alignment phase, the aircraft's heading is aligned with the runway heading in preparation for touchdown. With the experimental system, the runway alignment mode is normally engaged at an altitude of 150 feet. The engage point is sensed by a variable altitude trip which is set on the copilot's altimeter instrument prior to an ALEC approach.

At the engage point, aircraft heading control is transferred to the rudder channel, while beam error and cross track velocity are zeroed through the aileron channel. The experimental system accomplishes the runway alignment through execution of a forward slide-slip maneuver.

The runway alignment mode remains engaged until the aircraft touches down on the runway where the roll out guidance phase begins.

2.3.3 Roll Out Guidance Mode

The Roll Out Guidance Mode is used for lateral control following touchdown. In this mode, runway centerline tracking is accomplished by transferring localizer beam control from the aileron channel to the rudder channel. The aileron channel is used to maintain a wings-level attitude during this phase.

The roll out guidance engage point is sensed by squat switches mounted on the aircraft's main landing gear struts. The mode remains engaged until manually disconnected by the pilot at the completion of the ground roll phase.

2.4 ANNUNCIATION

2.4.1 Annunciator Drive Provisions

The experimental computer includes annunciator drive provisions to identify the various system modal states and certain warning conditions. The current ALEC annunciation display, which is located in the copilot's instrument panel, includes the annunciations tabulated below:

1. ALEC Arm
2. Track
3. Runway Alignment
4. Roll Out Guidance
5. Warning
6. Manual ALEC

The operation of the annunciation display and the significance of each annunciator will be discussed in the following paragraphs.

2.4.2 Cockpit Annunciation

The ALEC cockpit annunciator display uses a combination of color coding and sequential lighting to identify the various computer modal states and warning conditions. These aspects of the annunciation display will be discussed following a brief description of each annunciator function.

a) ALEC Arm (Amber) - Indicates that the ALEC has been armed for use.

b) Track (Green) - Indicates that the experimental localizer mode is engaged.

c) Runway Alignment (Green) - Indicates that the experimental runway alignment mode is engaged.

d) Roll Out Guidance (Green) - Indicates that the experimental roll out guidance mode is engaged.

e) Warning (Red, Flashing) - During approach, indicates that an input signal validity logic has sensed a problem (loss of signal) from either the LOC radio or the Inertial Navigation Unit.

The warning light may be reset by disengaging the ALEC system and then re-engaging. The ALEC will not re-engage if the signal validity problem still exists.

During landing, indicates that the airspeed has dropped below 80 knots, which is the minimum-rudder-effectiveness speed.

f) Manual ALEC (Amber) - Indicates that the manual ALEC configuration has been selected for use.

The annunciator color coding used for ALEC annunciation is consistent with other annunciation displays used in the test aircraft. The general rule here is that amber denotes "arm" conditions, green denotes "engage" conditions, and red or red-flashing denotes potential "danger" conditions requiring immediate pilot attention.

The following light sequence is used. The ALEC ARM annunciator is lighted whenever the ALEC arm switch is engaged. This light remains on throughout an ALEC approach. The TRACK, RUNWAY ALIGNment, and ROLL OUT GUIDANCE mode annunciators are lighted and extinguished sequentially through the approach as each system mode is entered. The WARNING annunciator will light whenever a validity failure occurs. When the WARNING annunciation is on, previously engaged mode logic will be dropped and the system will automatically enter a wing-level attitude hold mode. When the manual ALEC configuration is selected, the MANUAL ALEC annunciator will light and remain on throughout the approach.

2.5 COMMAND DISPLAYS

2.5.1 Roll Command Display

A standard FD-109 flight director system Attitude Director Indicator (ADI) is used to display ALEC roll axis commands during the final approach phases.

Beginning at the ALEC engage point, the ADI roll command bar is positioned through use of signals generated within the ALEC. The flight director roll steering commands, which are normally used to drive the command display, are synchronized by ALEC circuitry to prevent activation of ADI warning flag circuitry within the flight director roll computer.

2.5.2 Rudder Command Display

The ALEC includes provisions to generate rudder steering commands for display on a suitable yaw axis command indicator during the runway alignment and roll out guidance modes.

Initial work with the yaw axis display was accomplished using an isolated single-cue command indicator; however, this display was not suitable for use in the test-aircraft flight instrument configuration.

A three-cue (pitch, roll, yaw) flight director indicator is presently being procured for use in conjunction with the ALEC system.

2.6 FORCE WHEEL STEERING CONFIGURATIONS

The lateral axis force wheel steering configuration is an integral part of the overall ALEC configuration in both the automatic and manual modes of operation. In the automatic modes, pilot inputs can be made through the roll and yaw force wheel channels to modify and/or augment automatic system performance (i.e., supervisory override). In the manual ALEC configuration, the force wheel steering capability is used as the means for closure of the displayed lateral steering command error signals.

2.6.1 Roll Channel

The roll channel force wheel steering configuration is shown in functional block diagram form in Figure 2. In this configuration, transducers in the aircraft's control wheels are used to generate electrical signals which are proportional to pilot control wheel (force) inputs. These signals are processed through displacement and integral gain paths to generate attitude commands which are applied to the system roll attitude control loop.

In the displacement gain path, an electrical dead-band circuit is used to establish a minimum breakout force level of 3.6 pounds. Force inputs greater than this level are considered to be valid control inputs and are passed by the dead band circuit.

The integral gain path is controlled by a force level detector. Integration of the force wheel input signals occurs when the input force level exceeds 5.2 pounds. When the input level is less than this value, a feedback path is closed around the integrator that causes the integrator output to return to null reference. This removes any steady state bank angle reference due to force wheel inputs and thus allows the system to return to the lateral computer command reference. In the manual mode, where automatic control is not used, the aircraft will return to a "wing-level" attitude reference.

2.6.2 Rudder Channel

The rudder force wheel steering channel is shown in Figure 2. In this configuration, electrical signals proportional to pilot rudder pedal forces are processed to generate rudder surface commands. The rudder force breakout is determined by spring loading within the sensor units (approximately 22 lbs.). A lag-filter is included in the displacement gain path to provide pilot/servo loop decoupling on a high frequency basis. The rudder channel operates using only the displacement gain path in all of the automatic control modes.

In the manual ALEC configuration, an integral path is activated at runway alignment engage. The integrator output represents steady-state rudder deflections. The integrator, then, acts to relieve the steady-state

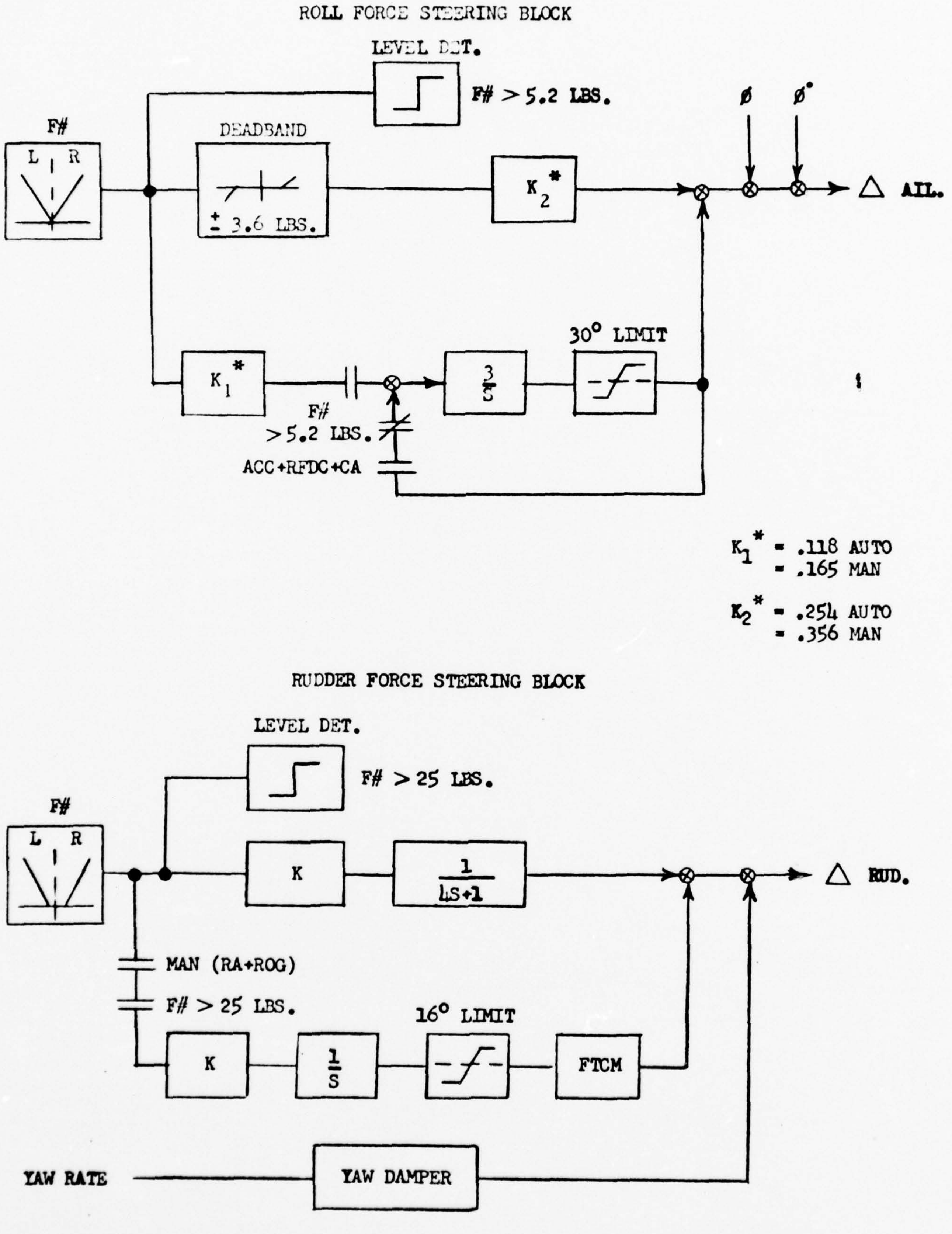


FIGURE 2. FORCE WHEEL CONFIGURATIONS

rudder forces required during the alignment maneuver. The integral gain path remains active through the roll out guidance mode to maintain the established rudder deflection at a reference position. The amount of deflection can be updated by the pilot through additional force inputs.

SECTION 3

EXPERIMENTAL LOCALIZER CONFIGURATION

3.1 GENERAL DISCUSSION

The experimental, inertially damped, localizer configuration uses the standard ILS localizer beam for guidance control during approach and landing. Capture and tracking of the localizer beam is accomplished in the conventional manner using aileron/bank control. A conventional yaw damper is used for rudder control. A typical ALEC localizer approach is described in the following paragraphs.

The localizer capture phase of the approach is entered automatically when the aircraft reaches a point equivalent to 2.5 degrees (187.5 μa) localizer beam displacement. Prior to this point, the aircraft is generally following a heading track that will result in an intercept of the localizer beam at a predetermined intercept angle and range from the localizer transmitter. During the capture maneuver, bank angles of as much as 25 degrees are common as the aircraft turns toward the runway heading and finally establishes a ground track along the center of the localizer beam. At the completion of the capture phase, roll attitude and cross track velocity will be approximately zero. When crosswinds are present, a crab-angle will have been established to counteract wind drift. The capture phase is considered to be completed when the aircraft has established a stable ground track along the center of the localizer beam.

The localizer track phase of the approach begins when localizer displacement, roll angle, and cross track velocity are all approximately zero. In crosswind conditions, a crab-angle will be present to counteract drift. With the experimental system, the localizer track phase extends to an altitude of 150 feet where the runway alignment mode is engaged. (Tracking of the localizer beam continues until touchdown; however, for discussion purposes, since somewhat different control techniques are employed, the runway alignment phase will be discussed separately.) The localizer track phase is considered to be completed when the aircraft reaches the alignment engage point.

3.2 FUNCTIONAL DESCRIPTION

3.2.1 <u>Aileron Channel</u>

The experimental automatic and manual localizer configurations are shown in functional block diagram form in Figures 4 and 5 respectively. In both of these configurations, ILS localizer beam data (ϵ) is used as the outer control loop guidance signal. Localizer track damping is accomplished through use of an inertial "cross track angle" term, $(\psi + \beta_I)$, which is generated by summing inertial "drift angle", (β_I), with preset course, (ψ). These terms are defined in Figure 3, Lateral Aircraft Geometry.

In Figure 3, drift angle is defined as the angle in the lateral plane between the instantaneous ground speed vector and the aircraft reference line. Since the algebraic sum of heading and drift angle, $(\psi + \beta_I)$, or cross track angle, is the angle between the aircraft's instantaneous ground track and the beam centerline, it is also a measure of the velocity across the beam centerline. In this respect the cross track angle term is equivalent to beam rate, a derived term often employed for localizer track damping in systems that do not use inertial damping. Cross track angle, however, unlike beam rate, is relatively noise free and is also insensitive to localizer beam disturbances. It also provides a reliable measure of cross track velocity in crosswind and windshear conditions. When crosswinds are present, the heading term will be equal to the drift angle term when the cross track velocity is zero (i.e. when tracking the localizer beam center). Since these terms are of opposite sign, cancellation occurs when the aircraft is on track and at the appropriate crab-angle for the wind condition present.

Referring to the localizer mode functional block diagrams, the localizer beam error term and the cross track angle term are summed to generate a bank command signal, $(\hat{\phi})$. At the capture point, the resulting bank command signal is applied to and processed through a Full Time Command Modifier (FTCM) circuit that limits the maximum command rate to 4.5 degrees/second. This circuit provides command smoothing and limits the maximum roll rate (e.g., during capture) to prevent wing buffet when large error signals are applied.

After rate limiting, the bank command signal is applied to a variable bank angle limiter circuit. The limit value, which is controlled as a function of an altitude reference voltage, is ± 25 degrees during the capture phase. Later in the approach, beginning at an altitude of 850 feet, the limit is decreased with altitude to a final value of ± 5 degrees at an altitude of 80 feet.

The limited bank command signal is then summed with roll attitude, (ϕ), and roll rate, $(\dot{\phi})$, which are the roll attitude loop control and damping terms, to generate an aileron surface command signal. This signal is displayed on the flight director system Attitude Director Indicator (ADI) roll command bar and, in the automatic configuration, simultaneously applied through the control display coupler to the aileron surface actuator control loop.

Referring to Figure 4, during the localizer track phase, the automatic localizer configuration includes several provisions for processing and

Ground Speed Resolved in Runway Coordinates:

$$\dot{Y} = V_G \sin(\psi + \beta_I) = V_o \sin(\psi + \beta_A) - V_w$$

$$\approx V_G / 57.3 \, (\psi + \beta_I)$$

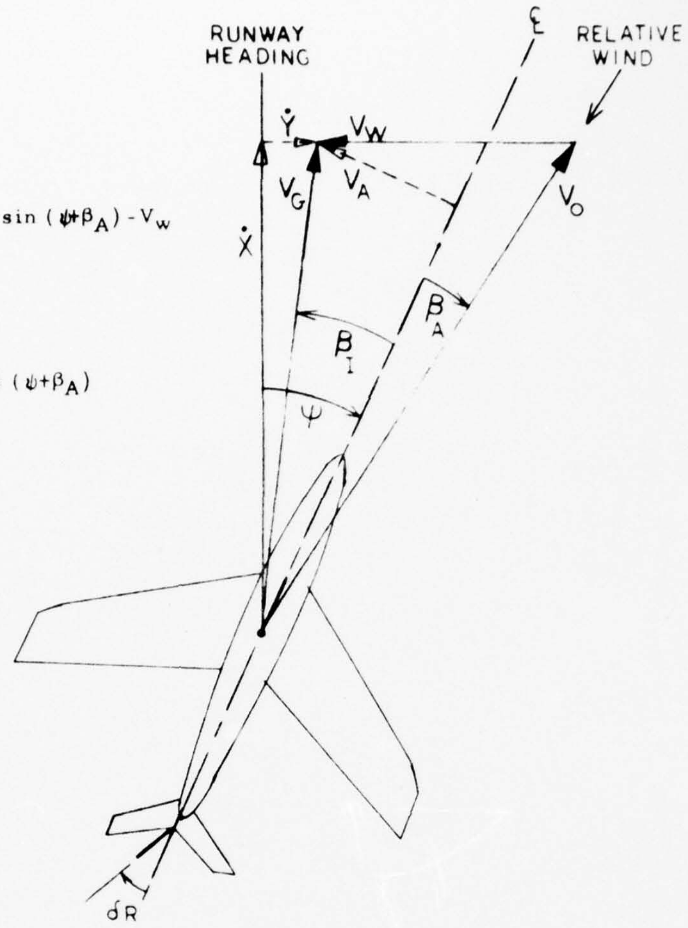
$$\beta_I = 0 \text{ on ground roll}$$

$$\dot{X} = V_G \cos(\psi + \beta_I) = V_o \cos(\psi + \beta_A)$$

Ground Speed Resolved in Aircraft Coordinates:

$$V_A = V_G \sin \beta_I$$

$$\approx V_G / 57.3 \, \beta_I$$



PARAMETER	SYMBOL	UNITS	DEFINED POSITIVE
Aileron deflection	δa	Degrees	Producing positive roll
Rudder deflection	δR	Degrees	Left Rudder
Beam Error	λ	Degrees	Plane right of beam
Roll attitude	ϕ	Degrees	Right wing down
Heading error (PSC)	ψ	Degrees	Nose right of runway
Sideslip	β_A	Degrees	Relative wind from right
Drift angle	β_I	Degrees	Ground speed vector right of nose
Cross track angle	$\psi + \beta_I$	Degrees	Plane moving right of reference
Distance from c.g. to runway centerline	Y	Feet	Plane right of runway
Cross track velocity	$\dot{Y}$	Ft./Sec.	Plane moving right of runway
Axial velocity of main gear	V_A	Ft./Sec.	Plane moving to right
Total ground speed	V_G	Ft./Sec.	Forward
Total wind velocity	V_w	Ft./Sec.	Wind from right of runway
True airspeed	V_o	Ft./Sec.	Forward

FIGURE 3. LATERAL AIRCRAFT GEOMETRY

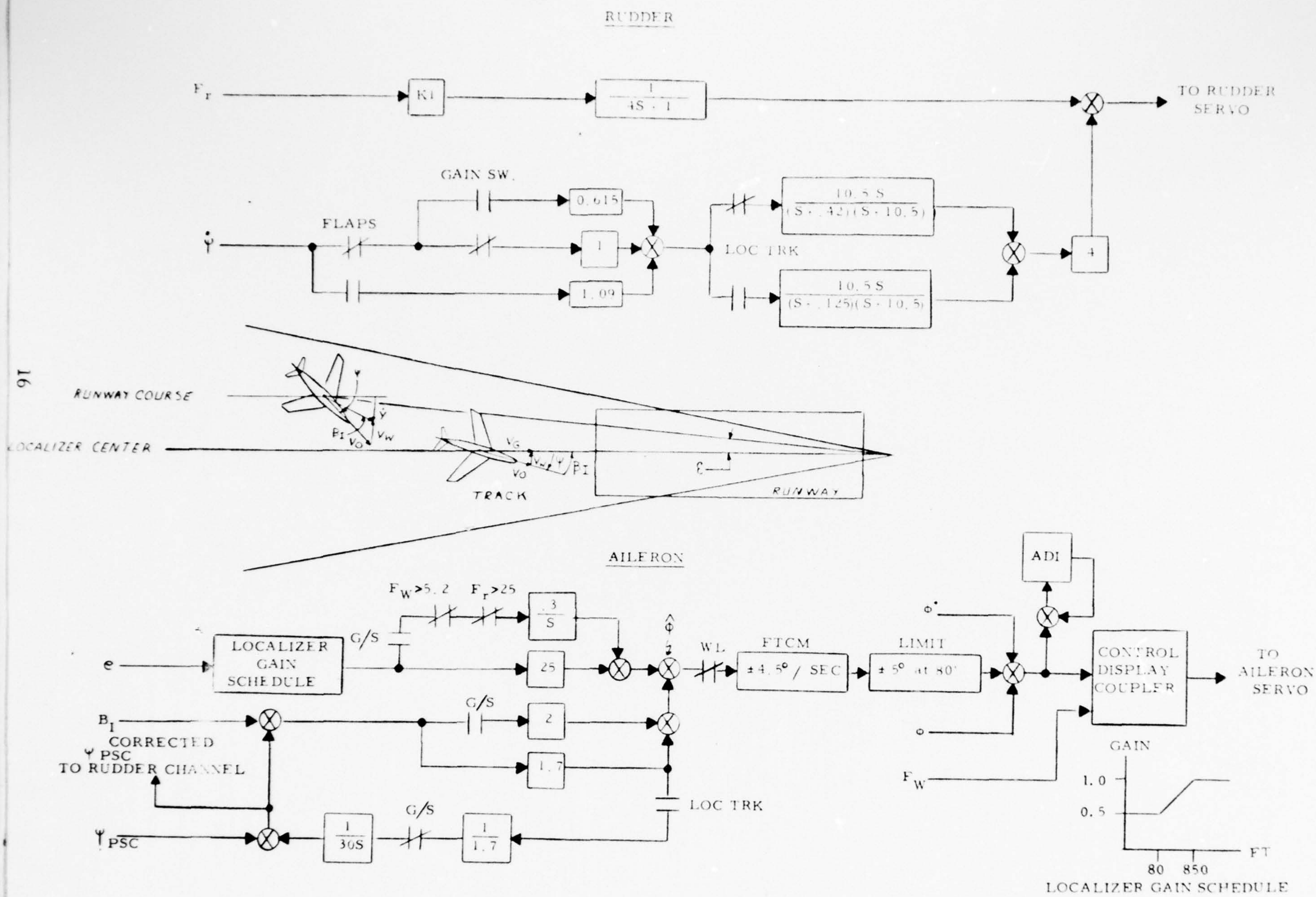


FIGURE 4. LOCALIZER MODE-AUTO

updating the system command reference signals. Beginning at localizer track, the cross track angle damping term is updated (i.e., washed out) to remove steady-state signal source errors which can result in localizer tracking offsets. The washout circuit, which has a 30 second time-constant, is functionally equivalent to a high-pass filter. The washout circuit output is summed with the preset course term, which is then used in the cross track angle computation. Later in the approach, this same term is used in the runway alignment and roll out guidance computations. After this summation, the heading term is referred to as "corrected preset course", (ψ_{psc} corrected). At the glide slope capture point, the washout function is disabled (memory retained) and the cross track angle gain is increased to the value required for the later approach stages.

At the glide slope engage point, an integrator begins to operate on the localizer beam error signal which results in the closure of any long-term beam tracking errors that may be present. Note that logic is provided to disable the integrator when pilot inputs are being applied to either the roll or yaw axes. (Force level detectors are used to sense pilot inputs.) These provisions prevent false beam integration during periods of time when pilot supervisory override inputs are being made.

Beginning at an altitude of 850 feet, the localizer beam error term is desensitized as a function of altitude to compensate for the effect of beam convergence as the aircraft nears the localizer transmitter.

The manual configuration shown in Figure 5 is functionally identical to the automatic configuration except that, in the manual case, beam integration is not used after glide slope. (The cross track angle washout remains active throughout the approach.) For manual, the roll attitude commands are applied to the cockpit display only and closed by the pilot through use of the roll axis Force Wheel Steering configuration.

3.2.2 Rudder Channel

During the localizer capture and track phase of an approach, the ALEC rudder command/display computation is inactive and in a synchronized mode.

The rudder configurations shown in Figures 4 and 5 reflect the aircraft's yaw damper configuration and the rudder channel of the force wheel steering configuration. Both the yaw damper and the force wheel steering configuration shown, however, are part of the overall ALEC system localizer configuration.

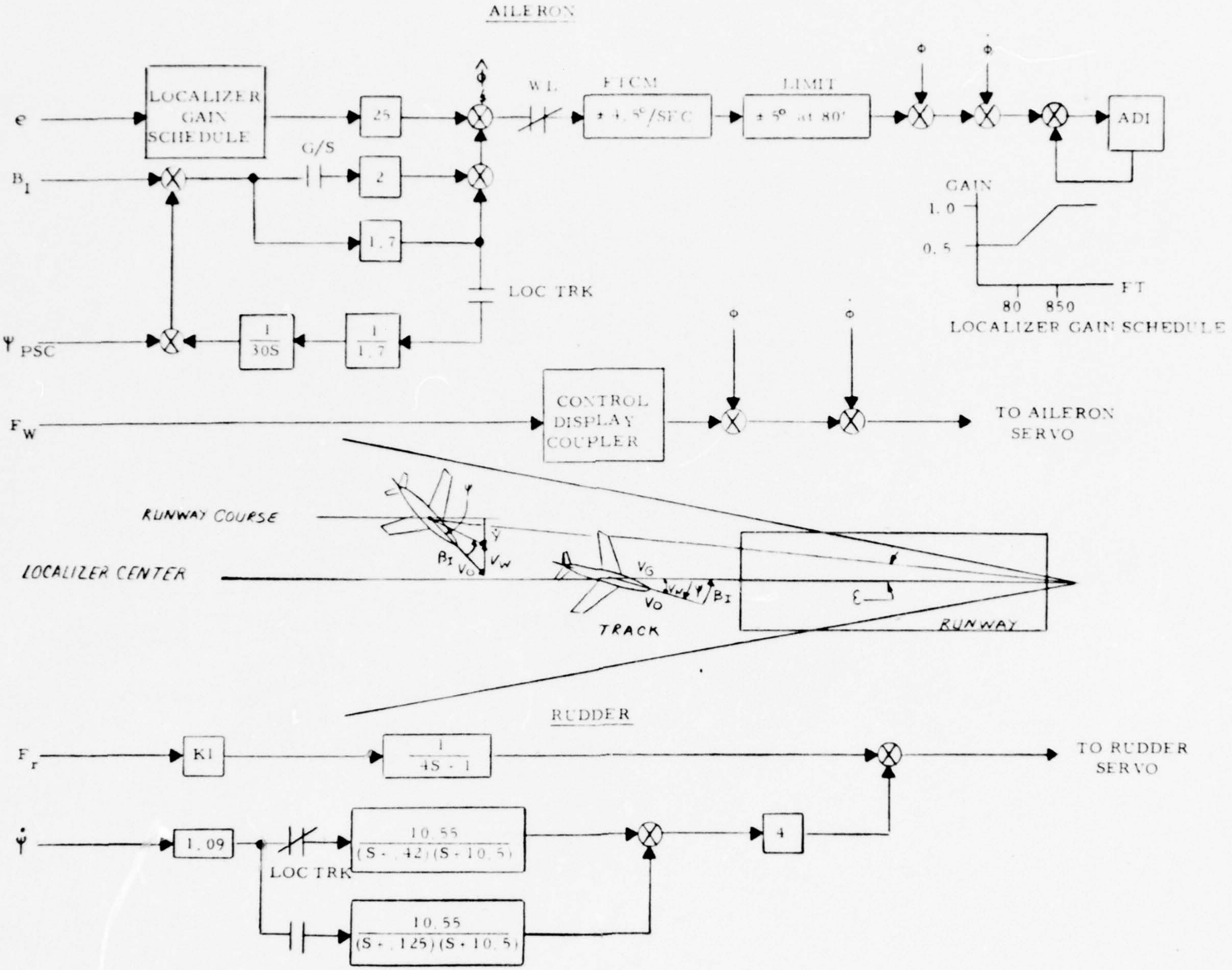


FIGURE 5. LOCALIZER MODE-MANUAL

3.3 SYSTEM OPTIMIZATION

During the course of the ALEC development, a number of problems were encountered in flight test that led to improvements and changes to the original system configuration. These changes will be discussed in the following paragraphs.

3.3.1 Effect of Compass System Errors

3.3.1.1 Performance Effects

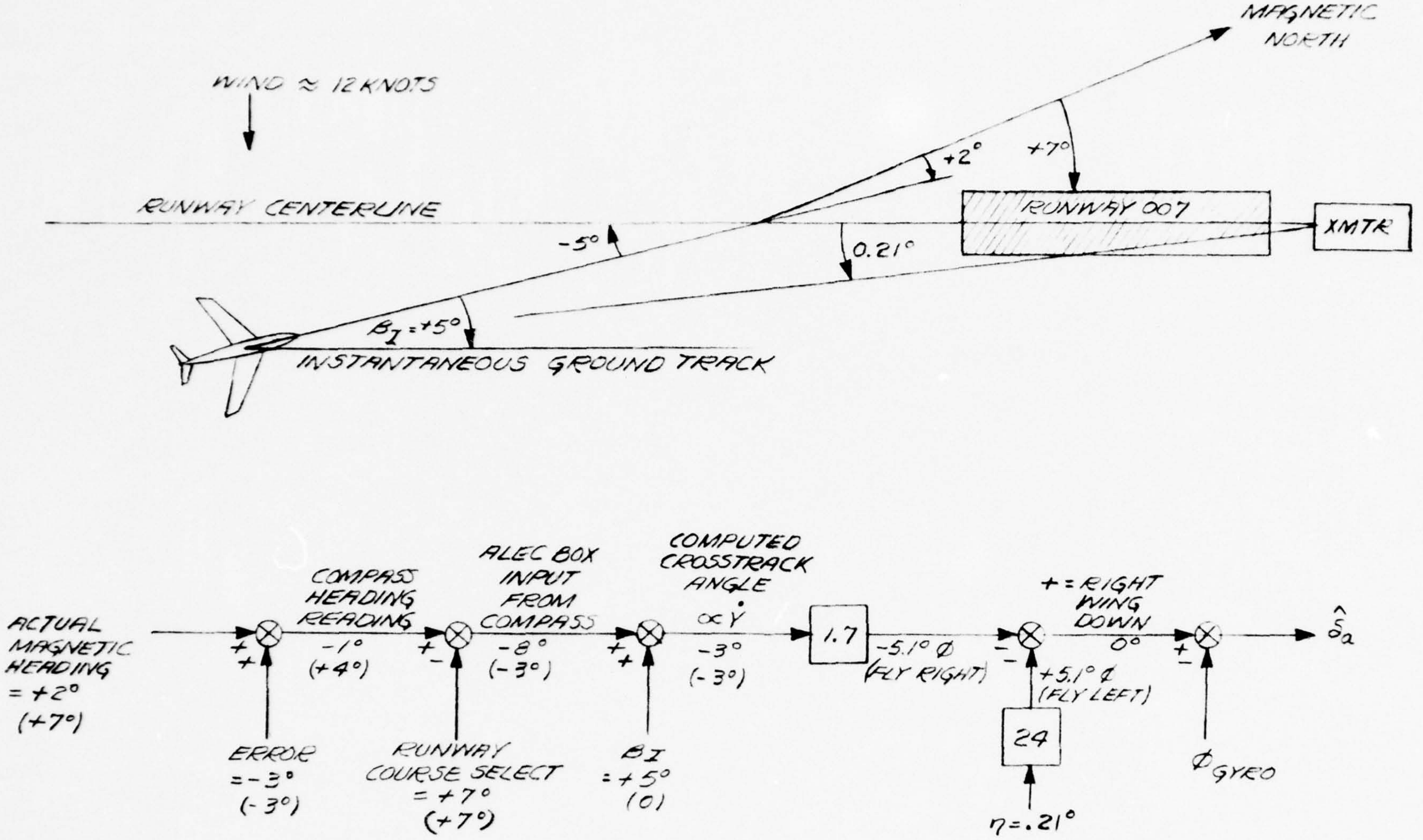
Initial flight test of the experimental localizer configuration revealed that compass offsets of as much as plus or minus 3 degrees could occur during routine system operation. Since the original configuration did not include a heading washout circuit, the heading offset could only be cancelled in the signal chain by a steady localizer beam error until the localizer beam integrator could operate to return the aircraft to beam center. To illustrate this effect, Figure 6, shows the signal chain conditions present for the case of a 3 degree compass error.

With a compass offset present, at the completion of the localizer capture maneuver, the aircraft would establish a position offset from the center of the beam proportional to the amount of compass offset. This condition would be maintained until 15 seconds after glide slope engage when beam integration was initiated. At typical capture ranges, the offset would be present for one to two minutes before the integration point was reached.

Although the use of beam integration ultimately brought the aircraft on track, the technique was found to be generally unsatisfactory because of gain scheduling required during an approach on the cross track angle term. (The cross track angle gain must be significantly increased prior to alignment to a value that is too high for use during the capture phase.) Integration of the error generally resulted in only partial cancellation because, when the cross track angle gain was raised at alignment, the magnitude of the offset was increased as well. The overall effect here was an undesirable roll motion at the runway alignment engage point.

3.3.1.2 Error Compensation Techniques

In view of these problems, several changes were made to the system configuration. First, a washout circuit was added to the localizer track configuration to update the heading reference as soon as the track phase is reached. The washout circuit presently operates on the cross track angle term during the period of time from localizer track until glide slope capture. Initially, a 60 second time constant was used to avoid



PARENTHESES REFER TO THE NO WIND CONDITION

FIGURE 6. EFFECT OF COMPASS ERROR ON LOCALIZER TRACKING

reduction in overall damping; however, this value was reduced during flight test to 30 seconds to allow faster updating of the cross track angle term.

A second change to the configuration moved the cross track angle gain switching point from the runway alignment engage point to the glide slope engage point,as presently used.In effect, this allows for removal of any cross track angle errors remaining after the washout update period by the beam integrator prior to the more critical runway alignment point. Increase of the gain at this time also increases system damping during the glide slope phase of the approach. The integration initiation point was also moved to the glide slope engage point to allow more time for error integration.

Initial flight tests using the washout circuit were conducted using manual switching to control the operation of the washout circuit. Following these tests, an automatic switching circuit was designed and installed to activate the washout circuit at the completion of the localizer capture maneuver. In the present configuration, the washout circuit is activated when the beam error signal has reached a value of less than .2 degrees beam displacement error and the aircraft's roll attitude is at a value of less than 2.0 degrees. The washout continues to operate while these conditions are satisfied until the glide slope engage point is reached. At glide slope, the washout is disabled, the cross track angle gain increased, and beam integration begins.

3.3.1.3 Summary of Results

Addition of the cross track angle washout circuit has resulted in improved system performance during the early localizer track phase when compass offsets are present. In most cases, compass system errors are closed before the beam integration point (glide slope engage) is reached. Although some reduction in damping results from use of the washout circuit no changes in system performance have been noted other than the improvement in overall tracking performance.

Since the cross track angle gain is increased through use of an easy-on circuit, and the cross track angle errors are removed prior to the increase through operation of the washout, the switching point is generally undetectable in flight.

The present washout configuration has one notable drawback, in that, sufficient time must occur from the localizer track point to the glide slope point to allow removal of the major portion of errors that are present. Further improvements are possible here for the relatively close in capture cases where this time interval is short (i.e., 30 seconds or less). Several possible improvements are suggested in the summary and conclusions at the end of this section.

It should also be noted here, that the updated heading term generated through use of the washout, is also used in the runway alignment and roll out configurations as the primary heading reference signal. This application is more critical and is based on certain premises regarding the nature of the cross track angle errors. This application, however, has no effect on the localizer track configuration discussed here, and will be discussed in greater detail in the runway alignment section of the report.

3.4 FLIGHT TEST RESULTS

In this section, Localizer mode performance will be discussed. Since performance considerations differ somewhat, the localizer capture and track phases will be discussed separately. In these discussions, the capture phase begins when the aircraft reaches a point equivalent to 2.5 degrees localizer displacement; includes the initial turn to the runway heading; and, ends when the aircraft has established a stable track along the center of the localizer beam. Localizer tracking performance is discussed from an altitude of 1000 feet to an altitude of 250 feet, just prior to the initiation of the runway alignment phase of the approach.

In addition to discussions pertaining to overall system performance levels, a number of flight recordings are included to illustrate performance in the capture phase. For the track phase, a statistical approach was used to measure system performance levels over a number of approaches. In this case, frequency distributions of key performance parameters are included for reference.

3.4.1 Performance Criteria - Capture Phase

System performance during the capture phase can be discussed from a number of points of view; however, since the objective here is the establishment of a "localizer track" condition, the nature of the beam error closure characteristic is of primary interest. When considered in view of the conditions present during the capture, this characteristic can be used as a qualitative measure of system capture performance. In this regard, the ideal localizer capture is accomplished asymptotically with no overshoot or undershoot of the beam zero reference. Performance where tendencies to overshoot the beam reference exist can be regarded as "under-damped", while, conversely, "over-damped" performance is characterized by undershoot of the beam reference and slow error closure.

3.4.2 Localizer Capture Performance

In general, flight test performance levels obtained with the experimental localizer configuration have been in agreement with performance levels predicted through analog computer studies. Figure 7 shows the range of conditions (intercept angle, range from transmitter, wind) over which zero

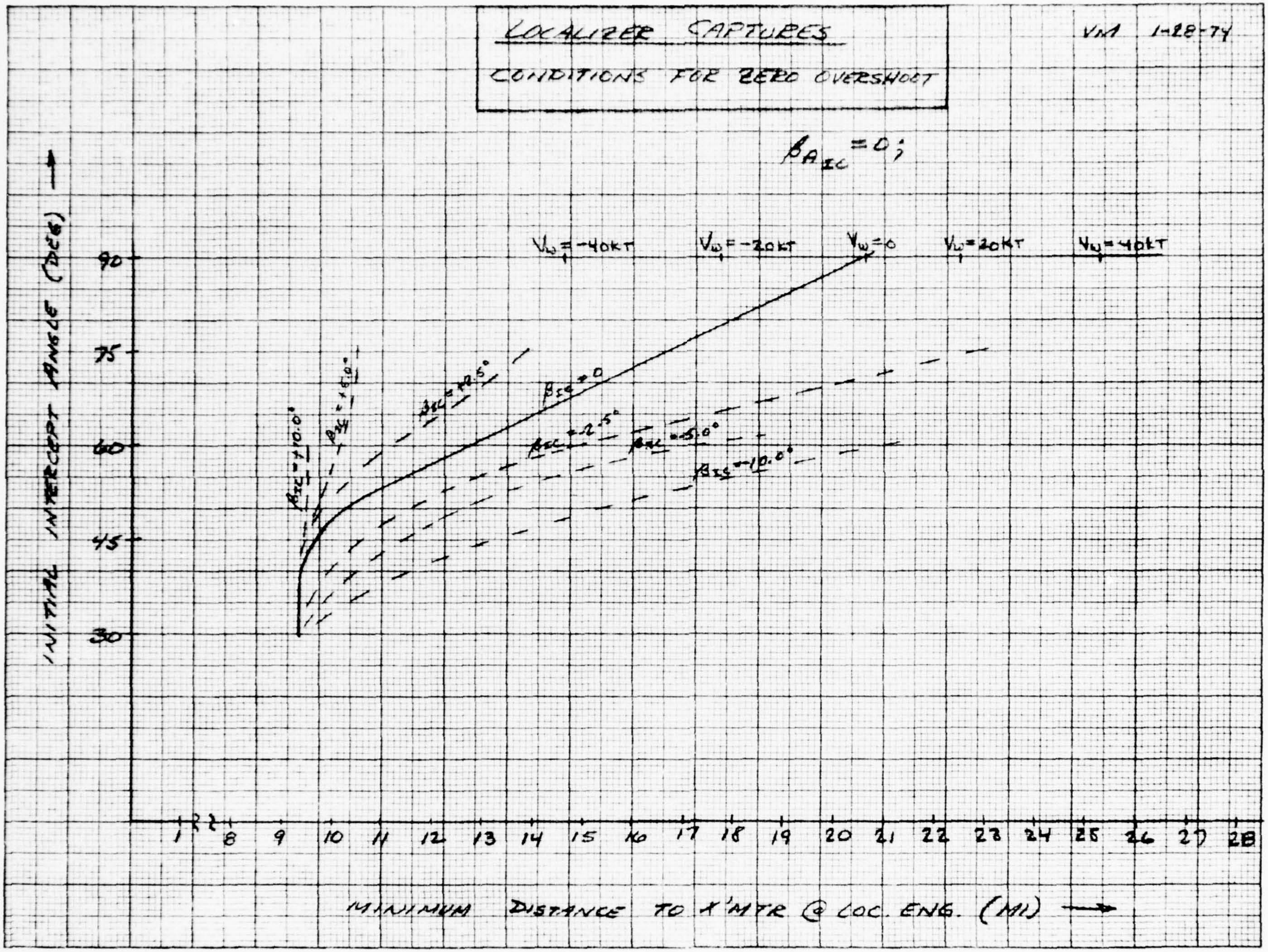


FIGURE 7. LOCALIZER CAPTURES CONDITIONS FOR ZERO OVERSHOOT

overshoot captures can be made with the experimental localizer configuration. The data shown in Figure 7 is based on analog computer study results.

The experimental localizer configuration has been evaluated extensively during flight test over the following range of conditions:

1. Intercept angle - 25 to 60 degrees heading error
2. Range from transmitter - 10 to 15 nautical miles
3. Wind - zero to ± 25 knots
4. Airspeed - 160 to 140 knots

These conditions represent those most frequently encountered during routine KC-135 operation and can therefore be regarded as typical capture conditions. The configuration has also been evaluated on a limited number of occasions at extreme capture conditions. In these cases, captures have been made at intercept angles from 10 to 90 degrees; at capture ranges of 8 to 25 nautical miles; and in winds of ± 40 knots.

Localizer captures over the range of typical capture conditions are made with little or no overshoot of the beam zero reference. Many of the captures made in this range are ideal asymptotic captures. At the relatively close-in/high-intercept-angle conditions within this range, some beam overshoot occurs, but is not excessive (typically 1/4 to 1/2 degree beam displacement) and damps quickly. Second overshoots generally do not occur.

At the extreme capture conditions, in the long range cases, (i.e., greater than 15 miles), at typical capture angles, (25 to 60 degrees), the system exhibits a somewhat overdamped response. Undershoot of the beam center occurs but is not excessive or regarded as objectionable from an operational point of view. At these ranges, however, captures can be made without overshoot at intercept angles of up to 90 degrees.

Capture performance at ranges less than the nominal range of values is severely limited by beam geometry and aircraft turn radius constraints. Note that in Figure 7 capture data is limited to ranges beyond approximately 9.2 miles from the localizer transmitter. In general, at ranges less than this value, beam overshoots of varying magnitudes will occur, regardless of capture angle. This point, then, represents an operational limit. With the present system configuration, shallow angle captures (i.e. less than 25 degrees) cannot be accomplished at the close ranges since the computation causes the aircraft to turn towards the beam reference to establish the system nominal capture angle. (This angle is determined by localizer and cross track angle gains within the computer.)

Several methods for improving close range capture performance are suggested in the summary and conclusions section.

To illustrate system capture performance, flight test recordings that represent the range of conditions encountered have been selected and are included in Figures 8 through 13. For convenience, the following lateral axis parameters have been reproduced from the actual recordings:

.... Localizer Deviation

.... Preset Course

.... Drift Angle

.... Roll Attitude

.... Aileron Position

The following recordings are included:

Figure 8 - Flight Recording-Localizer Capture-July 16, 1974
45 Degree Intercept, Range: 13 Nautical Miles
Drift Angle: Zero to 2 Degrees, Airspeed: 155 Knots

Figure 9 - Flight Recording - Localizer Capture - August 13, 1974
42 Degree Intercept, Range: 14 Nautical Miles
Drift Angle: Zero to 2 Degrees, Airspeed: 160 Knots

Figure 10 - Flight Recording - Localizer Capture - January 28, 1974
42 Degree Intercept, Range: 7.9 Nautical Miles
Drift Angle: 5 Degrees, Airspeed: 165 Knots

Figure 11 - Flight Recording - Localizer Capture - March 29, 1974
35 Degree Intercept, Range: 18 Nautical Miles
Drift Angle: 2 to 4 Degrees, Airspeed: 155 Knots

Figure 12 - Flight Recording - Localizer Capture - January 9, 1974
90 Degree Intercept, Range: 19 Nautical Miles
Drift Angle: 10 Degrees, Airspeed: 150 Knots

Figure 13 - Flight Recording - Localizer Capture - January 9, 1974
45 Degree Intercept, Range: 12 Nautical Miles
Drift Angle: 10 Degrees, Airspeed: 142 Knots

3.4.3 Performance Criteria - Track Phase

The localizer track phase of an approach begins at the completion of the capture maneuver when the aircraft has established a stable ground track along the center of the localizer beam.

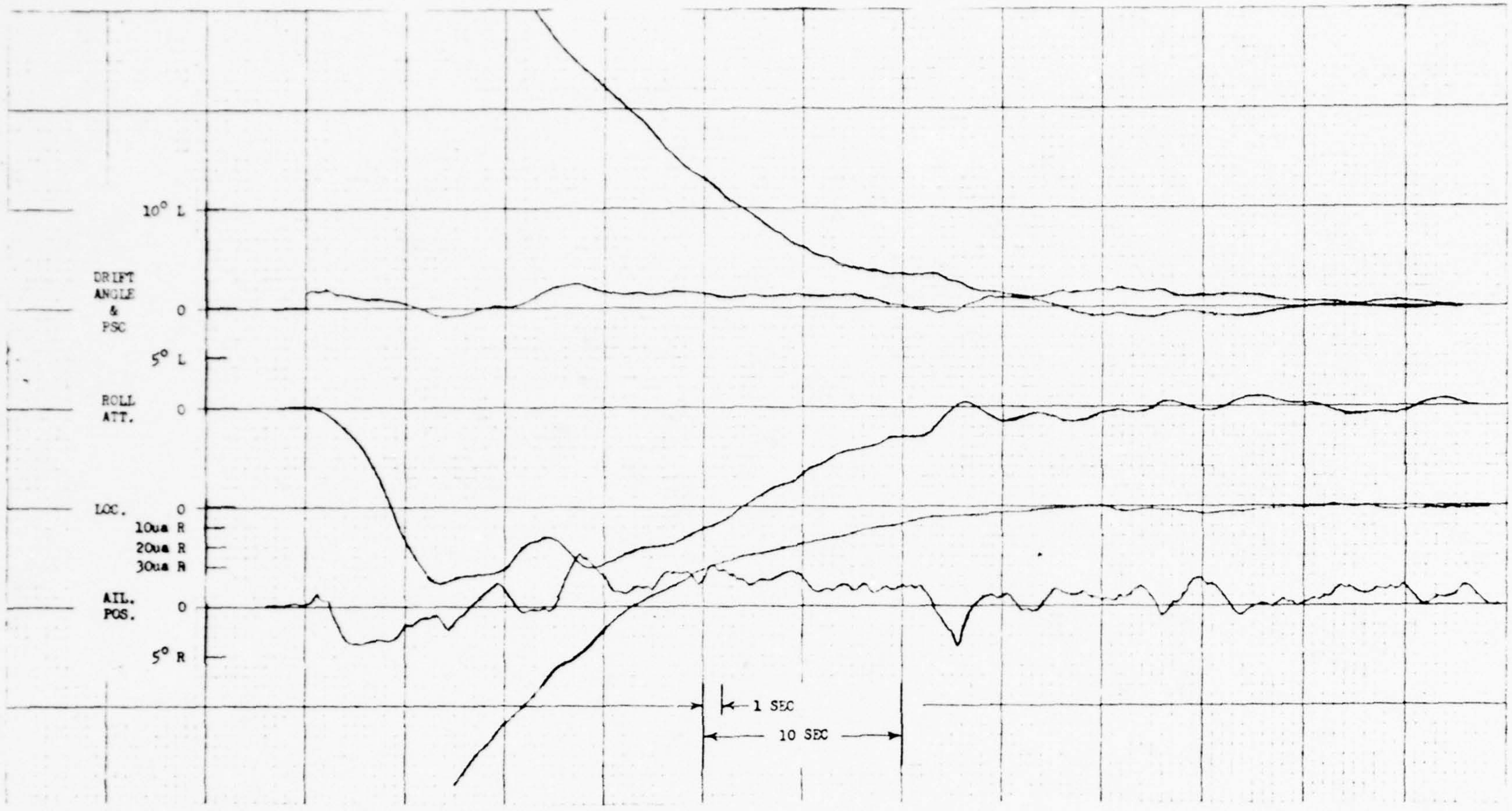


FIGURE 8. ALEC CAPTURE, JULY 16, 1974 APPROACH NO. 4
45 DEGREE INTERCEPT, 13 MILES FROM RUNWAY
DRIFT ANGLE ZERO TO 2 DEGREES, SPEED 155 KTS.

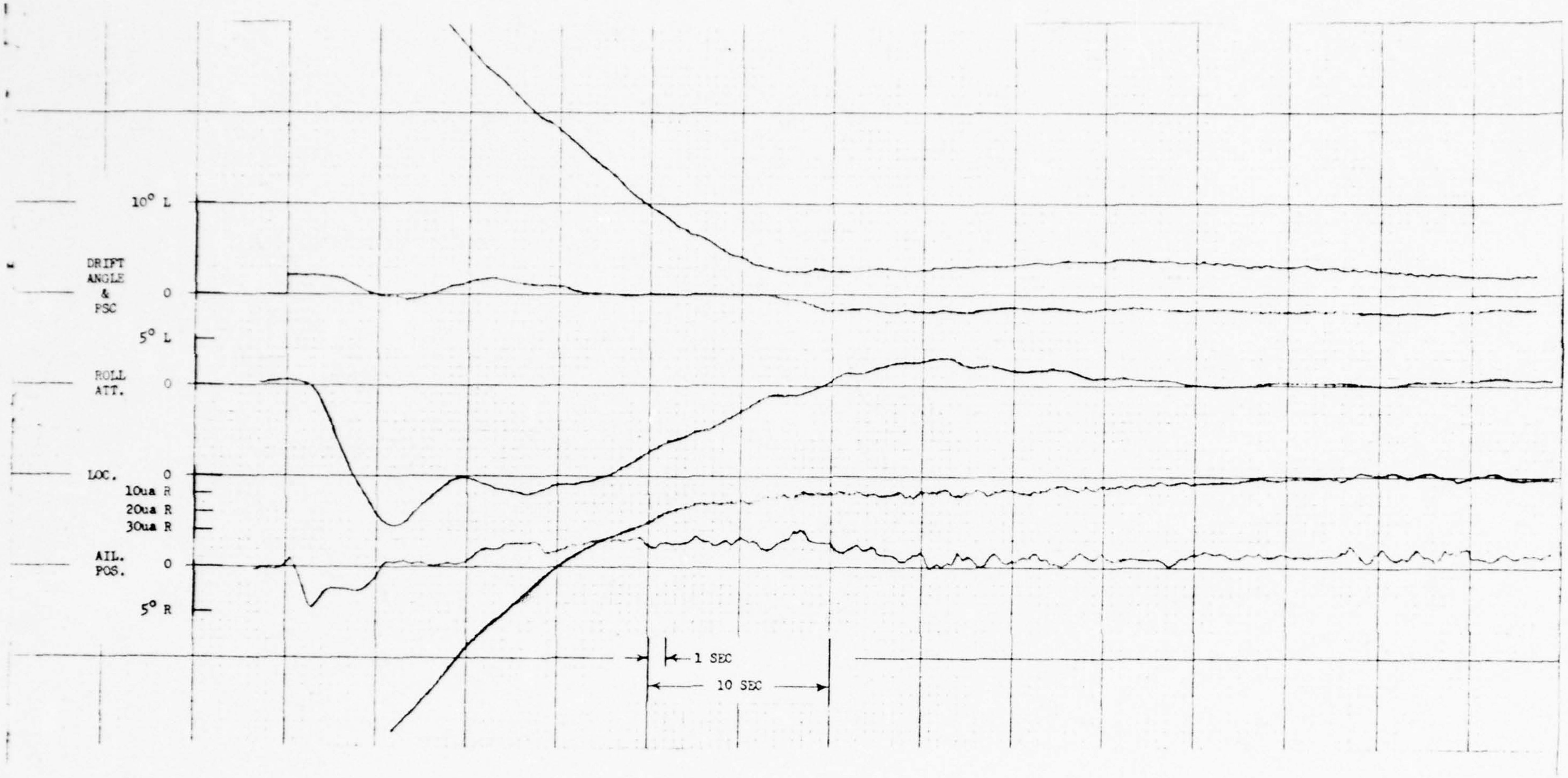


FIGURE 9. ALEC CAPTURE, AUGUST 13, 1974 APPROACH NO. 1
42 DEGREE INTERCEPT, 14 MILES FROM RUNWAY
20 KT. HEADWIND-2 DEG. R DRIFT ANGLE, SPEED: 160 KTS.

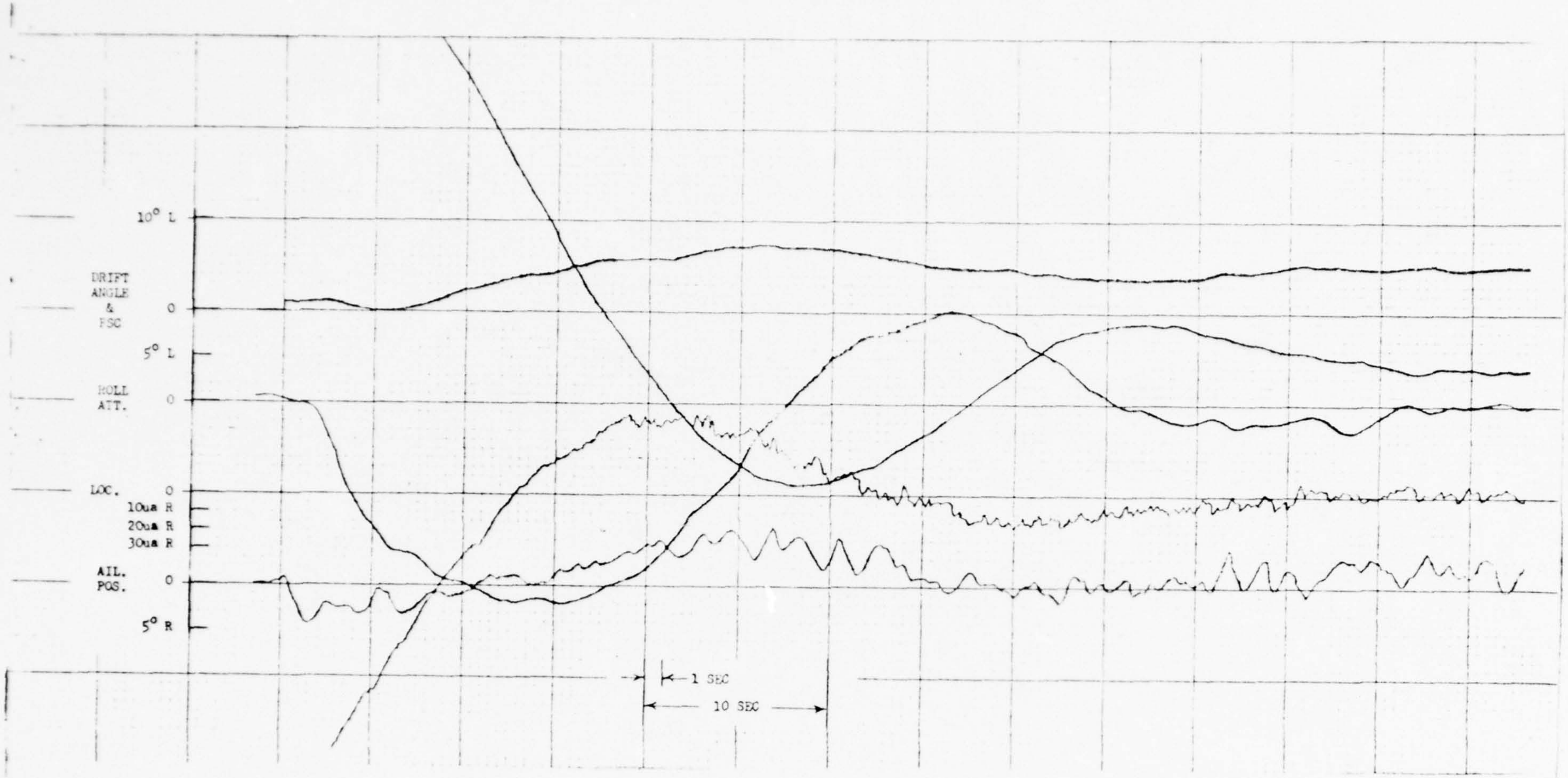


FIGURE 10. ALEC CAPTURE, JANUARY 28, 1974 APPROACH NO. 1
42 DEGREE INTERCEPT, 7.9 MILES FROM RUNWAY
DRIFT ANGLE: 5 DEGREES L, SPEED: 165 KTS.

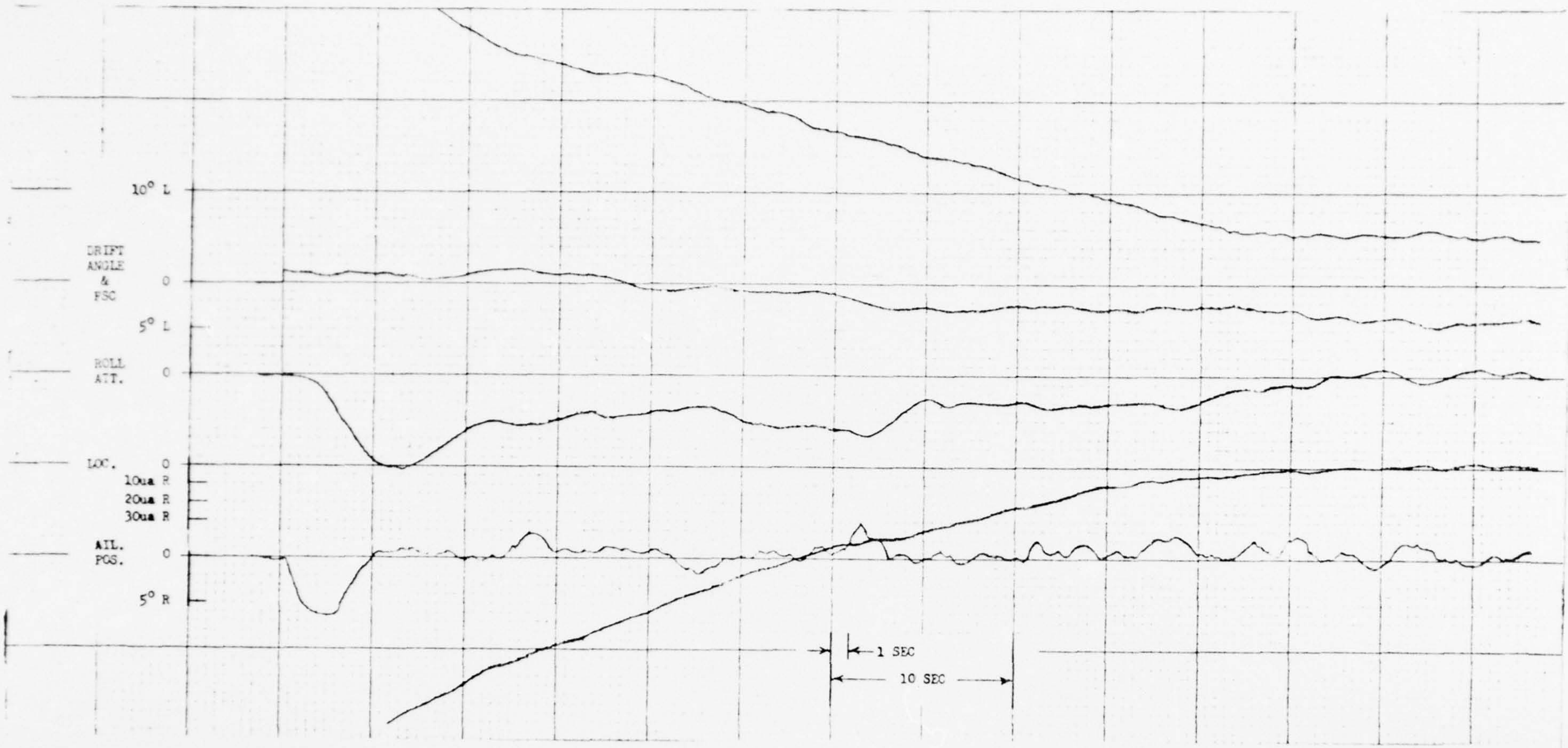


FIGURE 11. ALEC CAPTURE, MARCH 29, 1974, TINKER AFB APPROACH
35 DEGREE INTERCEPT, 18 MILES FROM RUNWAY
DRIFT ANGLE: 2-4 DEGREES R, SPEED: 155 KTS.

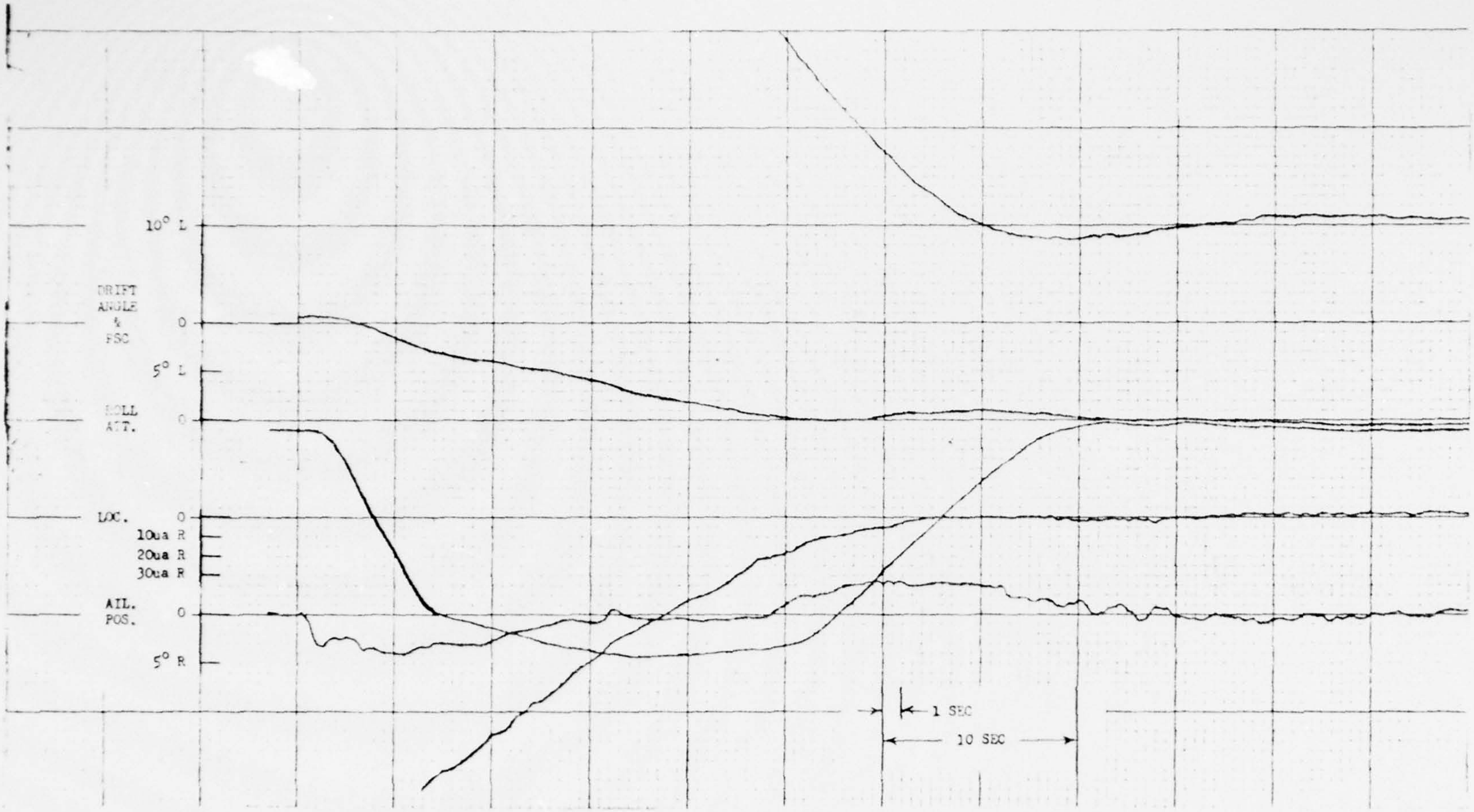


FIGURE 12. ALEC CAPTURE, JANUARY 9, 1974 APPROACH NO. 4
90 DEGREE INTERCEPT, 19 MILES FROM RUNWAY
30 KT. HEADWIND-10 DEG. R DRIFT ANGLE, SPEED 150 KTS.

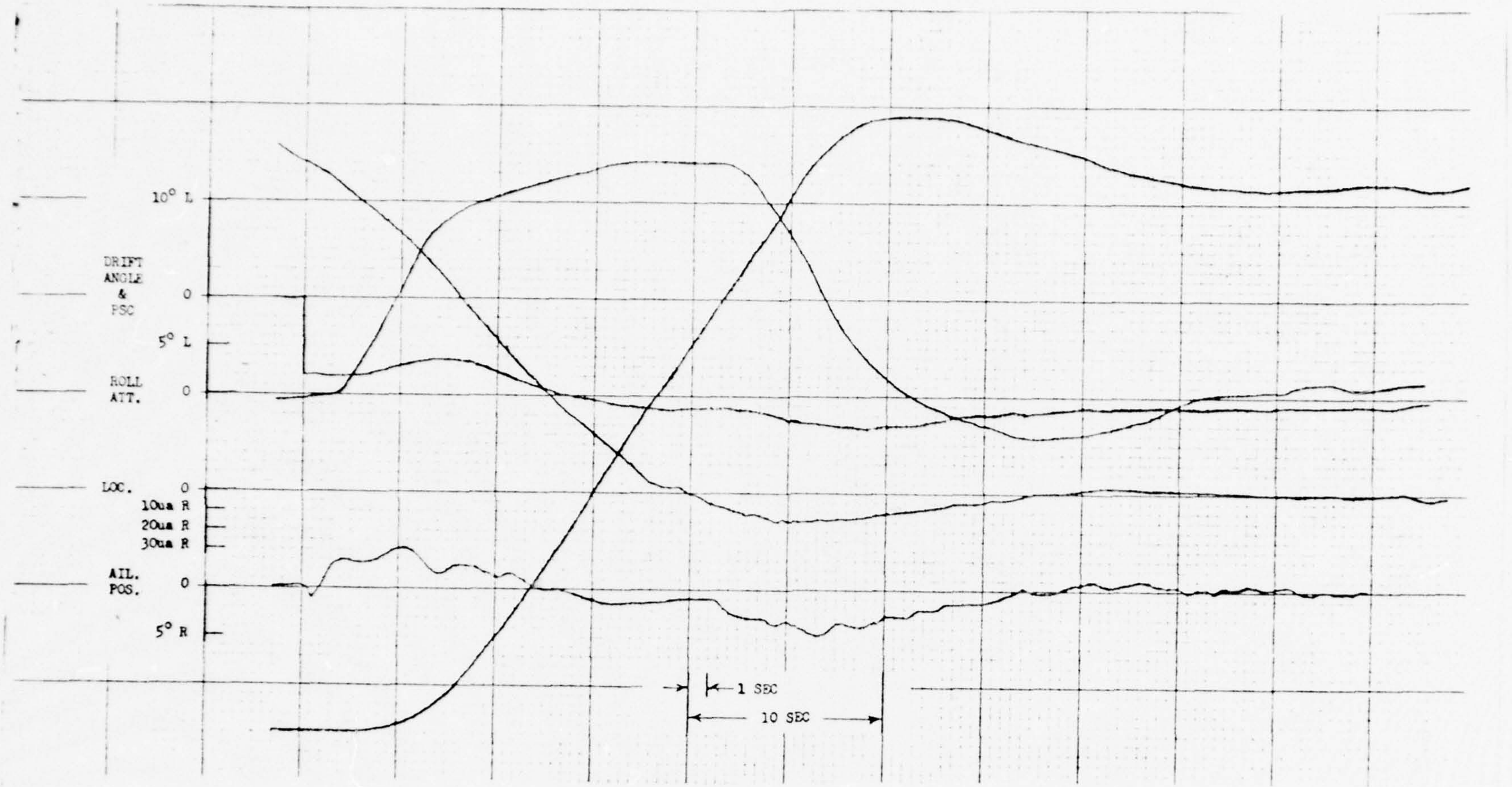


FIGURE 13. ALEC CAPTURE, JANUARY 9, 1974 APPROACH NO. 6
45 DEGREE INTERCEPT, 12 MILES FROM RUNWAY
DRIFT ANGLE: 10 DEG. R, SPEED: 142 KTS.

During the track phase, the ability of the system to maintain track over a range of constant as well as changing wind conditions is of primary concern from a performance point of view. Another factor here is the ability of the system to compensate for long-term tracking errors. These errors, which can arise due to signal source offsets, as an example, generally result in steady-state localizer tracking offsets.

Generally speaking, localizer beam displacement errors can be used during the track phase as an overall measure of system performance. Under ideal performance conditions, localizer displacement error would be zero throughout the approach localizer track phase.

3.4.4 Localizer Track Performance

In actual operation, during the localizer track phase, airplane motions and localizer beam displacement errors are generally small. Visual performance observations are usually made from raw data displayed on the Horizontal Situation Indicator. On this indicator, 1 bar-width is equivalent to a 15 μa localizer beam displacement. Since one degree of localizer displacement is equal to 75 μa, the bar-width is a relatively small increment. Generally, performance within ± 1 bar-width is considered good. At touchdown, 15 μa (1 bar-width) is equivalent to approximately 30 feet displacement from the runway centerline.

With the experimental system, observed localizer tracking performance is generally within the ± 1 bar-width range. In most cases, tracking errors are not detectable through use of cockpit instrumentation in the later stages of the approach.

To illustrate system performance during the localizer track phase, Figure 14 includes localizer deviation frequency distribution charts that reflect measured system performance levels over approximately 40 approaches. Drift angle frequency distributions are shown in Figure 15 to identify the nature of the wind conditions encountered during the data runs.

The data shown in Figure 14 reflects system tracking performance during the most critical portion of the localizer tracking phase, from an altitude of 1000 feet to an altitude of 250 feet, prior to initiation of the runway alignment maneuver. This portion of the approach, after glide slope engage, is most subject to wind shear conditions. Localizer tracking data to touchdown is also presented in this same form in the runway alignment data section of this report.

The data shown in Figures 14 and 15 were obtained by sampling the localizer deviation and drift angle parameters at the 1000, 750, 500, and 250 foot altitude points. Raw data were obtained for this purpose using the aircraft's in-flight recorder system. The appropriate data points were identified through use of a recorder marker channel during each approach.

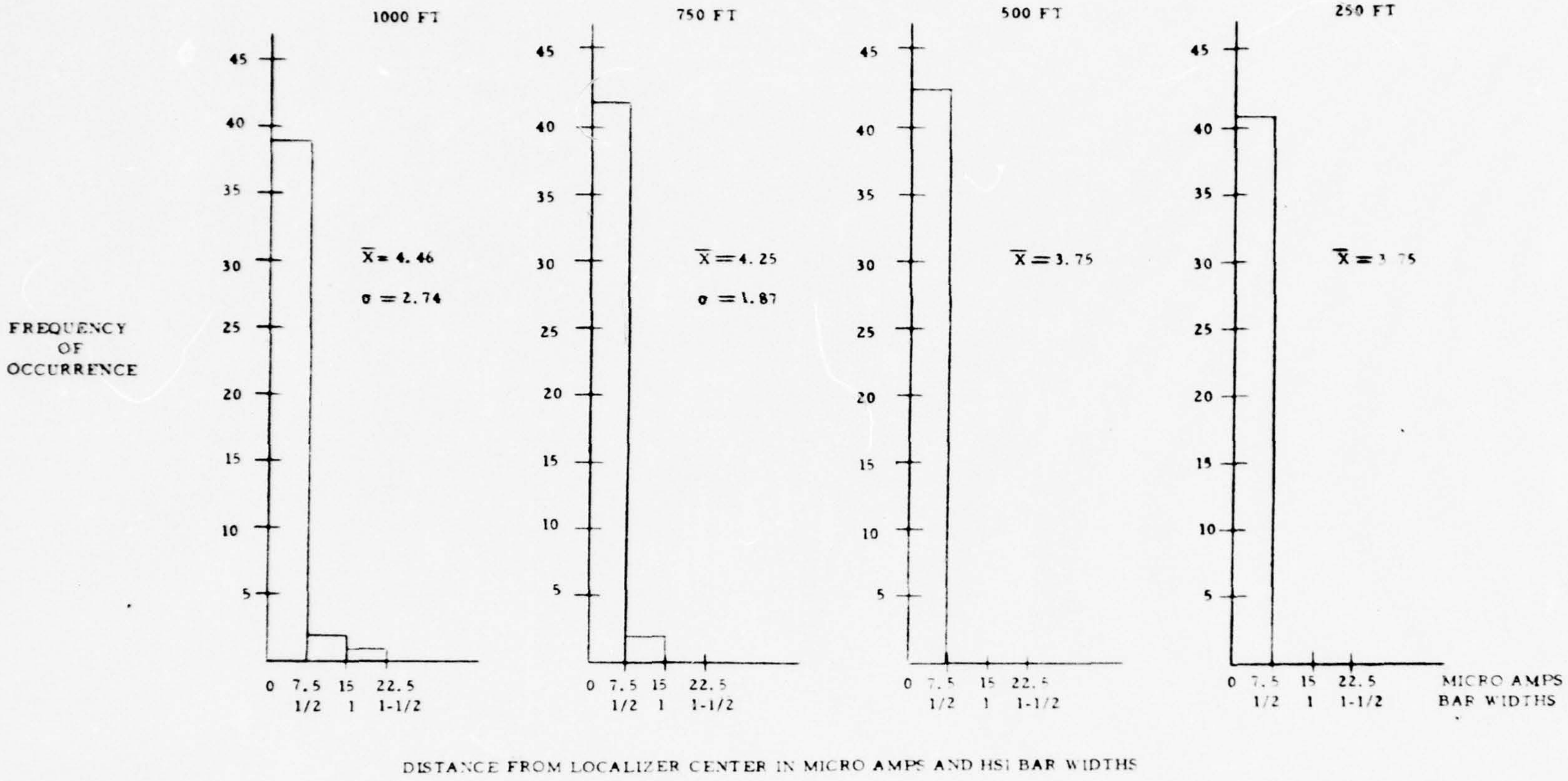


FIGURE 14. LOCALIZER TRACK FREQUENCY DISTRIBUTION, LATERAL DISPLACEMENT

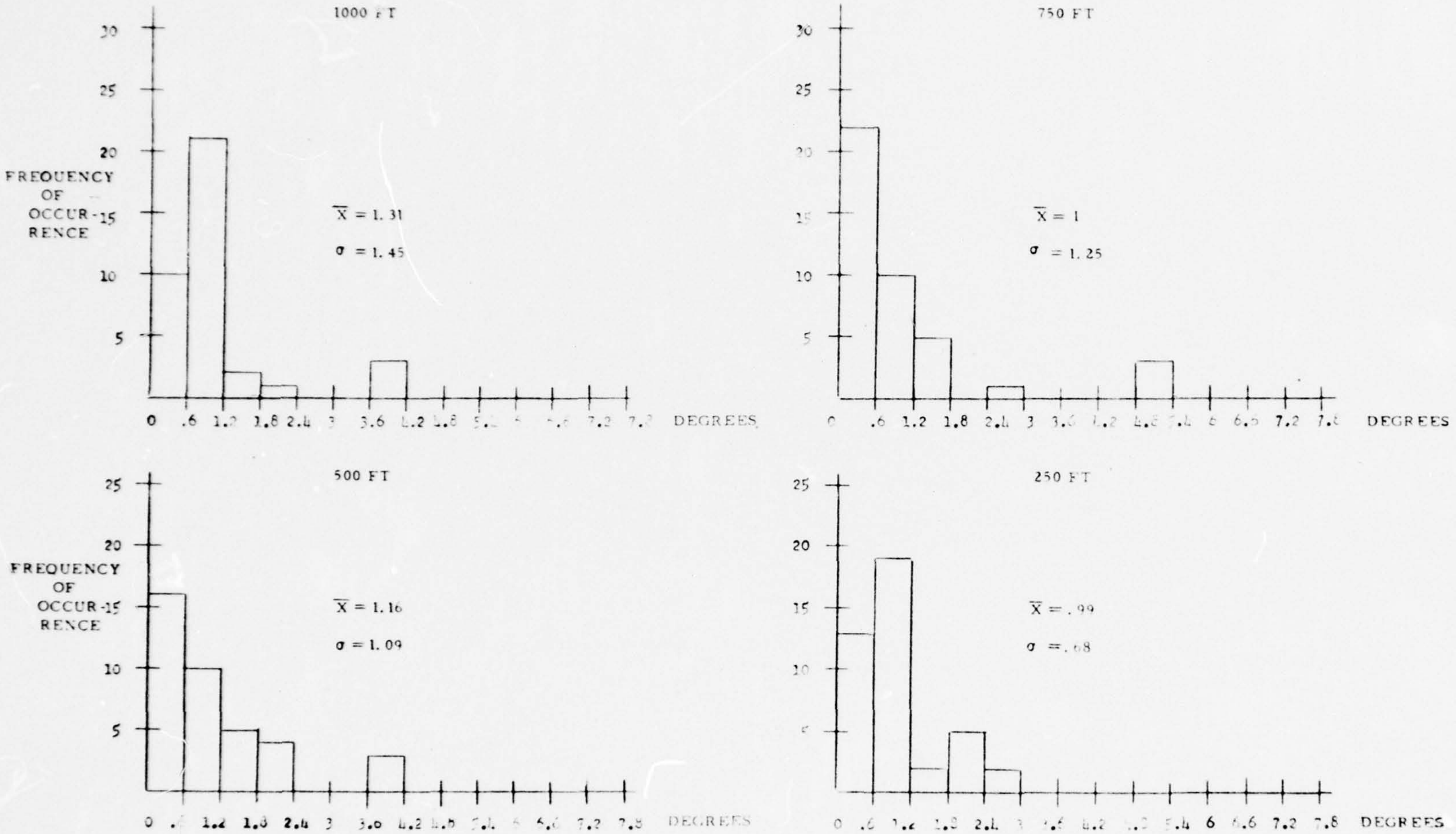


FIGURE 15. LOCALIZER TRACK DRIFT ANGLE FREQUENCY DISTRIBUTION

The frequency distributions were plotted using standard statistical techniques. Appendix A includes a more detailed discussion of the data acquisition and processing techniques employed.

In conclusion, the experimental system has exhibited good tracking characteristics over a wide range of crosswind, windshear, and turbulence conditions.

3.4.5 Summary and Conclusions

Flight test results obtained using the experimental system configuration for capture and tracking of the ILS localizer beam have been in close agreement with predicted performance based on analog computer study results.

One area of interest during the localizer phase was the use of the inertial cross track angle term for system damping. In this regard, flight test results have confirmed that adequate track damping can be obtained throughout the range of KC-135 airspeeds and approach conditions through use of an inertial damping term, cross track angle, which is generated by summing inertial drift angle with runway heading error.

The wind data conveyed by this term has proven to be of value during both the capture and track phases of an approach. Localizer captures can be made without overshoot of the beam reference over a wide range of external conditions. Tracking performance is enhanced by the fact that the sum of drift angle and heading error effectively represents a commanded crab-angle which is established immediately after capture of the localizer beam in crosswind conditions. Moreover, this crab-angle reference is automatically updated as the approach progresses, since changes in wind conditions are instantaneously reflected in the drift angle term before tracking errors develop.

Typical tracking performance is within ± 1 bar-width (± 15 μa) HSI raw localizer deviation.

Although system performance is generally satisfactory, improvements can be made in several areas. Preliminary computer study work has been accomplished in some of the following areas, while others have been expanded to the hardware design stage.

In the localizer capture phase, preliminary studies indicate that the system optimum performance window can be increased substantially through use of range information in the capture computation. In the current configuration, for example, beam desensitization, which is accomplished through use of a radio altitude desensitizer, only extends to a range of five miles. In the capture range, then the system Y to $\dot{Y}$ gain relationship is essentially a function of range. This, of course, results in varying capture characteristics as a function of range. Improvements here can be obtained through linearization of the Y to $\dot{Y}$ gain relationship, possibly using DME information. Another approach might involve the implementation of an exponential capture law, to obtain captures at any range in minimum time and without overshoot of the beam reference.

Several aspects of capture performance can be improved through modification to the existing system configuration. For example, computer studies have shown that the overall system roll response characteristic can be improved through the addition of circuitry to provide rudder coordination during turns. With the present configuration, lack of turn coordination results in a non-linear roll response characteristic that increases the amount of time required to reach maximum bank angle during the capture phase. At the close range conditions, a small improvement in turn rate would have a measurable effect on overall capture performance.

Close range capture performance could also be improved by allowing small angle intercepts at these conditions without turning towards the localizer beam. This could be accomplished by sensing and blocking commands toward the center of the beam, thus allowing the aircraft to penetrate to a point where the command polarity was toward the runway heading.

In the localizer track phase, the combination of the cross track angle washout and localizer beam integration appears to give satisfactory results with regard to tracking performance (i.e., long-term error closure with signal source offsets). During recent flights, however, continuing study of the nature of the cross track angle errors (offsets) that occur frequently in actual operation has indicated that the nature of these errors is more complex than was previously believed. In recent analysis, both the compass system and the inertial drift angle terms appear to contribute significantly to the total steady-state cross track angle error present at any given time, rather than the compass system alone. Since the cross track angle washout is currently used to update the compass heading signal for use in the runway alignment and roll out guidance modes, additional study should be performed in this area.

In this same general area, it would be desirable to develop a cross track angle washout control logic technique that allows sufficient time for removal of cross track angle errors under all capture conditions. With the present control logic, under relatively close in capture conditions, the washout may not have adequate time to operate before the glide slope point is reached. A possible improvement here might involve the addition of an amplitude sensor on the cross track angle term. This would override the glide slope logic that presently disables the washout circuit when cross track angle errors are still present at the glide slope point. It is also possible that system gains could be established which would allow the washout to continue to operate after glide slope capture, in conjunction with the beam integrator.

SECTION 4

EXPERIMENTAL RUNWAY ALIGNMENT CONFIGURATION

4.1 GENERAL DISCUSSION

4.1.1 Forward Side-Slip Alignment Technique

Runway alignment prior to touchdown is necessary under crosswind conditions in order to zero the aircraft's heading for smooth transition into the ground roll phase of the landing. The experimental configuration accomplishes the alignment in a manner consistent with conventional pilot technique for the KC-135 aircraft through execution of a forward side-slip maneuver. Essentially, this involves lowering the upwind wing to counteract drift, while simultaneously applying rudder control inputs to zero runway heading errors and thus align the aircraft with the runway. With the experimental system, the alignment maneuver is generally initiated prior to flare engage at an altitude of approximately 150 feet.

The forward side-slip runway alignment maneuver is one of two classical maneuvers generally considered for use as a lateral axis control technique in preparation for landing under crosswind conditions. The alternative maneuver, which is generally referred to as a "decrab" maneuver, basically involves the rapid application of rudder at a point just prior to touchdown to align the aircraft with the runway while maintaining a wing-level attitude through aileron control. The forward side-slip maneuver, which is performed at a higher altitude, involves slow control inputs and is the preferred method of alignment for the test aircraft.

From a control point of view, the forward side-slip involves simultaneous and coordinated control of the aircraft's roll and yaw axes. The following paragraph will illustrate the sequence of events that occurs during this phase of an approach.

During a typical approach under crosswind conditions, the aircraft will be tracking the localizer beam with wings level and zero side-slip. At this time, a runway heading error (crab angle) will be present to counteract the crosswind component. Beginning at the alignment initiation point (typically an altitude of 150 feet) heading error will be removed (zeroed) over a period of 5 to 10 seconds through rudder control. During this same period of time, a wing low roll attitude will be established through aileron control inputs to counteract drift. During the alignment maneuver, the aircraft will continue to track the localizer beam. Under constant wind conditions, the following steady state conditions will be present at the completion of the transition to the alignment mode. The aircraft will be on localizer track with zero runway heading error, zero drift, and banked slightly into the wind. Steady state rudder and aileron surface deflections will be present to maintain the forward side-slip condition. These conditions will then be maintained through flare until touchdown.

4.1.2 Control Considerations during Alignment

The purpose of the runway alignment maneuver, of course, is to align the aircraft with the runway heading in preparation for the ground roll phase of the landing. Although runway alignment is an important requirement under crosswind conditions, it is equally important during this approach phase to maintain precise localizer tracking as the aircraft nears the runway. The runway alignment maneuver, then, must be accomplished in a manner that has minimal effect on localizer tracking performance.

The transition from the standard localizer tracking configuration (crabbed) to the forward side-slip is a critical phase of the alignment and must be accomplished through precisely coordinated rudder and aileron/bank control to avoid lateral drift and the resultant localizer tracking errors. In addition to command coordination, surface command and error closure rates are particularly critical during the transition period. The runway heading error must be closed relatively fast but without overshoot of the zero reference. The effects of aerodynamic coupling between the aircraft's yaw and roll axes must also be considered during alignment. As an example, high yaw axis control rates will result in assymetrical lift forces which, during alignment, will tend to restrict lowering the upwind wing to establish the necessary bank angle into the wind.

In the roll axis, adequate roll control must be provided to offset the effects of crosswinds while limiting bank angles to safe limits. With the KC-135 aircraft, bank angle control near touchdown is critical since an angle of approximately 7 degrees will cause the engine nacelles to drag on the runway.

4.2 FUNCTIONAL DESCRIPTION

4.2.1 Rudder and Aileron Channels

The experimental automatic and manual runway alignment mode configurations are shown in functional block diagram form in Figures 16 and 17, respectively.

Referring to Figure 16, at the runway alignment engage point, the rudder computation channel becomes active and operates to close existing runway heading errors. Rudder/heading loop damping is provided by the aircraft's yaw damper configuration which operates in parallel with the experimental computer in the alignment mode. The rudder channel computation is also used to generate bank angle and aileron surface command signals which are applied to the aileron channel through independent cross-feed paths.

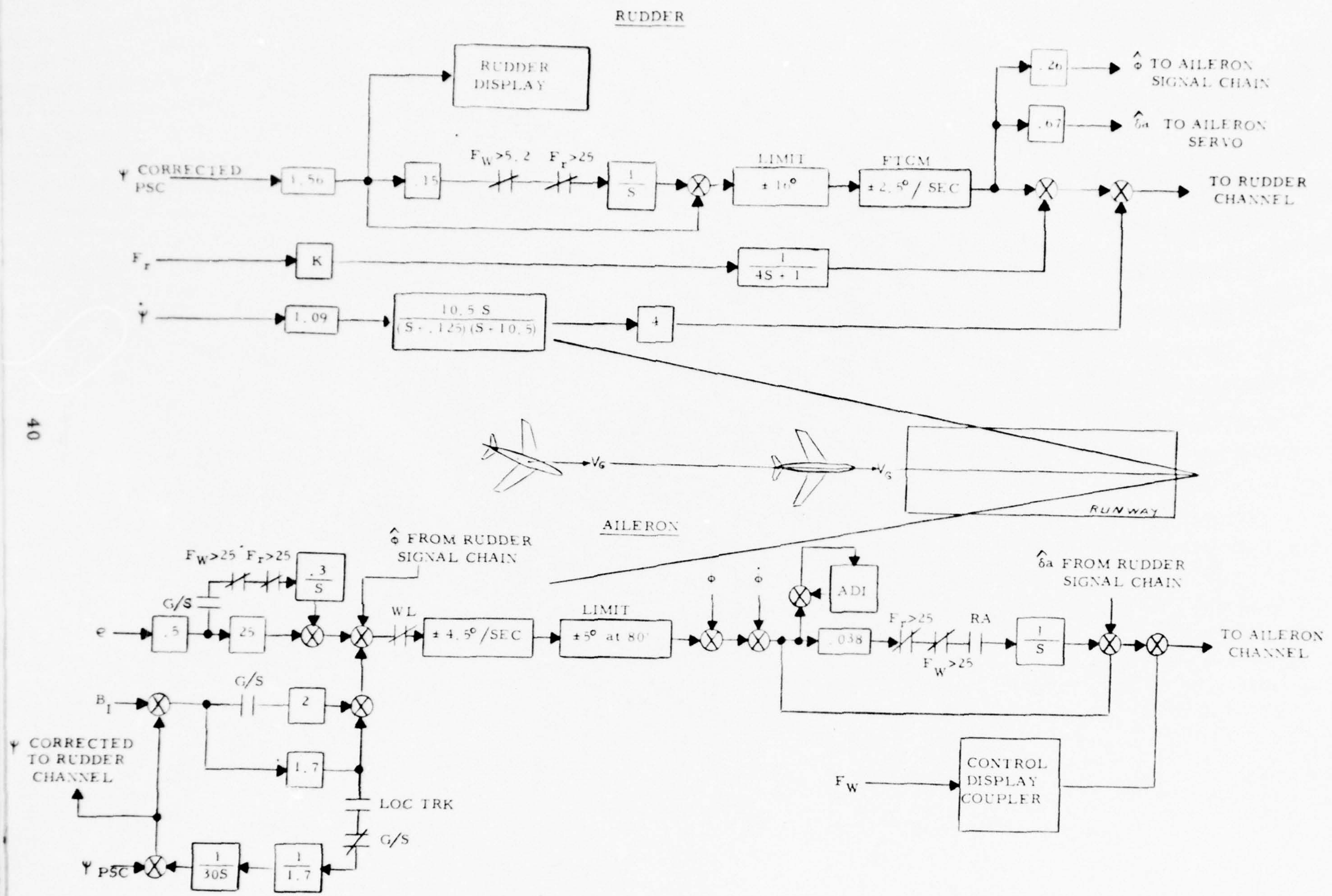


FIGURE 16. RUNWAY ALIGNMENT-AUTO

The heading error term (ψ_{psc} corrected, from aileron channel) is made available for display on cockpit instrumentation and processed through displacement and integral gain paths. The resulting rudder position command signal is then amplitude limited to ± 16 degrees and rate limited to a maximum of ± 2.5 degrees/second before being applied to the rudder surface servo-actuator control loop. The amplitude and rate limited rudder command signal is also applied through cross-feed paths to the aileron channel bank and aileron command control loops.

Aileron channel computations during the alignment maneuver are based on localizer beam error and cross track angle as during the localizer capture and track phases. During the alignment, however, the rudder command cross-feed signals from the computer's rudder channel are now active and operate to generate a wing-low attitude command into the wind and the steady-state aileron command required to maintain the forward side-slip condition. In addition, an integrator now operates on the computed aileron servo command signal to ensure command closure. In effect, this integrator augments the rudder/aileron surface command cross-feed signal to ensure that adequate steady-state aileron surface displacement is maintained for command closure. Note that the variable bank angle limiter will reach a value of ± 5 degrees at the 80 foot altitude point to prevent excessive bank angle at touchdown.

Referring to Figure 17, the basic alignment computations used for manual operation are functionally similar to those employed in the automatic configuration. For manual alignment, runway heading error is displayed on the cockpit yaw axis command display. Command closure is accomplished by the pilot through use of the rudder channel force wheel steering configuration. The heading error term is then amplitude and rate limited, as in the automatic configuration, and applied through the rudder/bank command cross-feed path to the aileron channel bank command loop.

In the manual ALEC alignment mode, an integral gain path is added to the basic rudder channel force wheel steering configuration. The output of this integrator is proportional to the amount of steady-state rudder surface deflection and is used to generate the steady-state bank command signal that is required in the aileron channel bank command computation.

In the aileron channel, command display computations are based on the localizer beam error and cross track angle terms, plus the bank command cross-feed signal from the rudder channel.

4.2.2 Runway Alignment/Roll Out Guidance Transition

When the aircraft reaches the touchdown point, the transition from the runway alignment to the roll out guidance mode occurs. At this point, the rudder channel integrator will be holding an output proportional to the amount

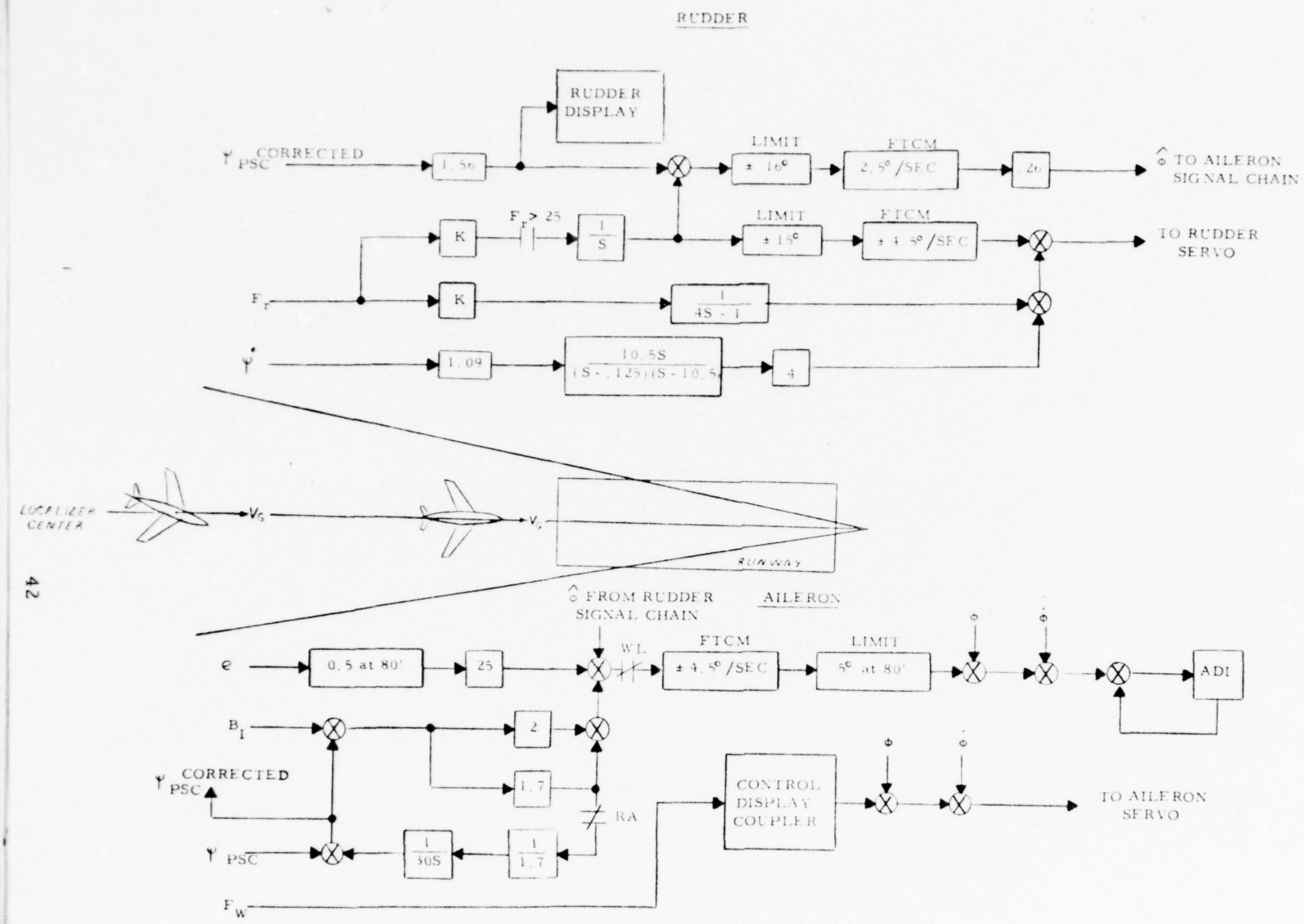


FIGURE 17. RUNWAY ALIGNMENT-MANUAL

of steady-state rudder surface deflection. In the automatic case, this output will also result in a steady-state aileron deflection through the rudder/aileron command cross-feed path. At the completion of the runway alignment phase (i.e. touchdown) the rudder channel integrator holds memory and remains in the signal chains. The rudder and aileron surface positions established during the alignment maneuver, then, are retained and serve as an operating point reference during the roll out guidance mode which is entered at touchdown.

4.3 SYSTEM OPTIMIZATION

4.3.1 Effect of Compass System Errors

4.3.1.1 Performance Effects

During the flight test phase of the system development it was found that compass offsets of as much as 3 degrees could occur during routine system operation. Since the compass system preset course term is used in each of the ALEC control configurations, significant effects were noted in each of the system modes. The effect of such errors has been discussed in the localizer section of this report along with a discussion of a means used to minimize the effects of offset errors on localizer tracking performance. In that case, a washout circuit was implemented which would remove steady-state offset errors between the localizer track point and the glide slope capture point.

During the runway alignment phase, the general effect of compass errors was a general misalignment of the aircraft with the runway by an amount equal to the offset error. In the alignment mode, runway heading error is used as the primary rudder control signal, therefore, the rudder channel would operate to position the aircraft to the offset heading, rather than the runway heading. Generally, landings could be made in this manner, however, overall performance characteristics were less than optimum. Landing with a heading error generally caused less than optimum performance to occur during the roll out mode, as well. This effect will be discussed in greater detail in the roll out guidance section of the report.

4.3.1.2 Error Compensation Techniques

To minimize the effects of compass system offsets on alignment performance, the configuration was changed to allow use of an inertially updated heading reference during alignment in lieu of the heading data obtained directly from the aircraft's compass system.

Essentially, this was accomplished through use of the heading signal correction established during the localizer track phase of the approach. During the localizer track phase, a washout circuit is used to update the system cross track angle term which is the sum of compass heading and inertial drift angle. In this configuration, the output of the washout is summed with the compass heading signal. Any error in the compass signal will be updated to the accuracy level of the drift angle signal. The heading signal generated in this manner (ψ_{psc} corrected) is used during the alignment as the runway heading reference. The corrected heading term is also used in the roll out guidance configuration as a damping term.

4.3.1.3 Summary of Results

During the initial flight tests using this signal, heading offsets of approximately 4 degrees were inserted prior to several of the approaches to test the concept under actual conditions. During each of these approaches, the aircraft aligned to the correct runway heading which, of course, was the desired result.

Based on these tests, the technique appeared to be a valid method for minimizing the effect of compass system errors on runway alignment performance and was, therefore, adopted for use.

With the present configuration, an improved heading reference is obtained in the manner described under most conditions. Several drawbacks, however, exist with the configuration as described. First, since the corrected heading signal is generated during the localizer track phase of the approach, sufficient time must occur between the initiation of the track phase and the glide slope engage point to allow the heading to be updated by the washout circuit, which has a 30 second time constant. This problem was discussed briefly in the localizer mode summary and conclusions section of this report along with several possible methods for improvement. When sufficient time does not occur, of course, a portion of the heading offset error will remain uncorrected. After glide slope engage, the beam integrator will close any tracking error that results from the residual heading error; however, when the alignment point is reached, the error will again become apparent.

The second drawback concerns the nature of the offset conditions in the localizer track phase. The configuration essentially relies on a reliable and accurate drift angle signal. As mentioned in the localizer section, summary and conclusions, continuing investigations of the factors that cause the frequently encountered cross track angle errors have indicated that the inertial drift angle term also contributes to the offset conditions, rather than the compass signal alone. In certain cases, then, the quality of the corrected heading signal may be somewhat worse than the uncorrected heading itself. This would occur when the compass system was correct, and an offset existed due to drift angle. Present data indicates that the inertial platforms used as a drift angle source have small alignment (heading) errors that are reflected in the drift angle output. From flight data these errors appear to be less than 1 degree in magnitude, and it appears that these errors can be corrected through precise platform alignment.

4.3.2 Rudder/Aileron Crossfeed Alignment Configuration

4.3.2.1 Background

The runway alignment configuration described in the preceding section of this report differs in several respects from the original runway alignment configuration that is described in Technical Report AFFDL-TR-71-97. The major differences, which are primarily the result of flight test development and manual control considerations, will be discussed in the following paragraphs.

The original configuration included a 20 second washout that operated on the aileron channel heading term beginning at the alignment engage point. The runway heading error was zeroed through the rudder channel, as in the present configuration. During the time period required to close the runway heading error, the washout circuit in the aileron channel was also acting to remove the aileron channel heading reference. When the actual aircraft heading was zeroed, after approximately 5 seconds, the output of the washout circuit resulted in the necessary wing-low attitude command. This output would then decay with a 20 second time constant. It was assumed that the alignment engage point would be at or near the flare engage point, or 10 to 15 seconds before touchdown, so that only small changes in the washout output would occur.

The present configuration was designed in view of several additional requirements which were established following the initial flight tests using the original configuration. The following capabilities were found to be necessary. It was found desirable to initiate the alignment at a higher altitude than was originally planned. In view of this, the alignment configuration would have to be capable of maintaining the forward side-slip for greater periods of time than the 20 second time constant permitted.

Another consideration pertained to the runway alignment/roll out guidance transition. Under constant crosswind conditions, it was found necessary to maintain the alignment rudder and aileron positions during the roll out guidance phase. The original configuration included provisions to maintain rudder position after touchdown but did not include provisions to do so in the aileron channel. The configuration transferred to a wing level control mode, with a neutral aileron control surface reference, at touchdown. Since the aircraft generally touches down with a bank angle, transfer to the wing-level reference in this manner generally resulted in rapid removal of the upwind aileron. This was undesirable, since care must be taken to avoid raising the up-wind wing under crosswind conditions.

A final consideration pertained to the current contract requirement to implement a manual control capability. The washed out heading approach was not suited to manual operation, since it did not provide a steady-state bank command.

With these considerations in mind, additional computer studies were performed to develop an alignment configuration with the desired capabilities. The current configuration design is based on a relationship that exists between the amount of rudder and the amount of bank and aileron required during alignment. The amount of bank and aileron required were found to be approximately proportional to rudder position which led to the current configuration that uses rudder/aileron channel crossfeeds to generate the wing-low attitude command and an aileron position command.

4.3.2.2 Advantages

The rudder command crossfeed techniques allows the alignment mode to be engaged at any altitude during the approach and is compatible with manual control techniques, since a hard attitude command reference is provided. During the ground roll transition, the use of separate aileron and bank crossfeeds allows the aileron position crossfeed to remain active without effect to the command display, which will be in a wing level reference mode in roll out. In this manner, the desired aileron position reference is retained, and wing level control is accomplished about this surface position.

4.3.3 Addition of Roll Rate to Display Computation

The display computation was improved through addition of a roll rate term. Since the rate term is part of the basic aileron command computation, command/display discrepancies were sometimes noted before this term was included in the display computation.

4.3.4 Heading Closure - 100% Alignment

The original configuration included provisions for an 80% alignment rather than closure to 100% of the runway heading. This was to avoid saturation of the bank command limiter circuit which, in that configuration, was partially saturated by the portion of the command signal required to generate the steady-state aileron deflection required during side-slip. In effect, a portion of the ± 5 degree limit value was used for aileron deflection and a portion was used for actual bank command. This approach resulted in an effective limit considerably lower than the ± 5 degree value and allowed the limiter to be saturated by a crosswind of approximately 20 knots. Use of the 80% alignment was a means to extend the crosswind operational range of the system.

With the present configuration, since the aileron portion of the crossfeed signal is applied downstream of the bank command limiter, saturation of the limiter is not a problem. In the present configuration, a 100% alignment is used. This is an advantage over the previous configuration, since even small heading errors at touchdown will have an adverse effect on roll out performance.

4.3.5 Flight Test Optimization - Gains and Control Rates

The remainder of the development work with the present configuration involved the establishment of optimum system gains and control rates. The gains and command rates were arrived at through flight tests using analog computer data as a reference for in flight adjustment of system parameters. Particular attention was given to the establishment of system gains that provided proper transition from localizer track to forward side-slip. In brief, this involved tailoring of the rudder/aileron crossfeed gains to obtain coordinated rudder/aileron bank control during the transition period. The alignment rate was also found to be a critical factor in establishing optimum performance levels. In this regard, the heading/rudder gains and the rudder channel Full Time Command Modifier rate were adjusted to allow the alignment to be performed with minimum yaw/roll coupling. The system gains shown in the runway alignment mode functional block diagrams reflect the system gains arrived at in this manner.

4.4 FLIGHT TEST RESULTS

4.4.1 Performance Criteria

The runway alignment maneuver is initiated at an altitude of 150 feet and continues until touchdown. During alignment, aircraft heading errors are zeroed through rudder action and a wing-low attitude into the wind is established to counteract drift. Localizer tracking continues throughout the alignment maneuver. During the alignment phase, the key overall performance parameters are heading, drift, and localizer beam displacement.

4.4.2 System Performance

Since one objective during alignment is closure of the aircraft's heading error, the ability to close this error and the nature of the closure characteristic is one performance consideration. The experimental configuration has been evaluated extensively at flight conditions where initial crab angles varied over a range of zero to approximately 8 degrees and on some occasions were as high as 10 to 20 degrees. The system generally closes heading errors within 5 to 10 seconds after initiation of the maneuver with no overshoot of the zero reference.

The drift angle closure characteristic with the experimental configuration closely matches the heading characteristic. Generally, these parameters close at the same rate and converge at zero at the same time.

As the aircraft nears the touchdown point, localizer tracking becomes increasingly important. The ability of the system to track the localizer beam during alignment is a prime overall system performance consideration as well as a measure of alignment performance. Localizer track performance during alignment is generally very good. In the majority of cases, tracking errors are less than 10 μa beam displacement and barely measurable through use of cockpit instruments. Touchdowns are generally within 10 - 15 feet of the runway centerline.

To illustrate system performance during the alignment maneuver a statistical approach has been used. The techniques employed are essentially the same as used in the localizer track phase of the approach.

Figure 18 shows localizer deviation frequency distribution charts that reflect measured system performance over approximately 40 approaches. The data presented here is essentially an extension of the localizer track data presented in Section 3.4.4. The data points were taken at 100, 50, and approximately "zero" feet above touchdown (zero= touchdown-1 second).

Figures 19 and 20 show frequency distributions for heading and drift angle at the same data points. When evaluating this data, consideration should be given to the following factors.

At the 100 foot data point, the transition to the alignment mode is still in process since this point is approximately 5 seconds after mode engagement. At the 50 foot data point, the alignment transition is generally completed. For this reason, the 50 foot data point is a more reliable measure of system heading and drift closure. The final data point, TD-1, occurs 1 second before touchdown.

When considering the magnitude of heading errors, it should be noted that the preset course data shown at each data point is uncorrected heading error from the aircraft's compass system. Since this is uncorrected heading data, it is subject to normal compass system errors.

4.4.3 Summary and Conclusions

Flight test results obtained through use of the experimental alignment configuration have been in general agreement with performance levels predicted through analog computer studies.

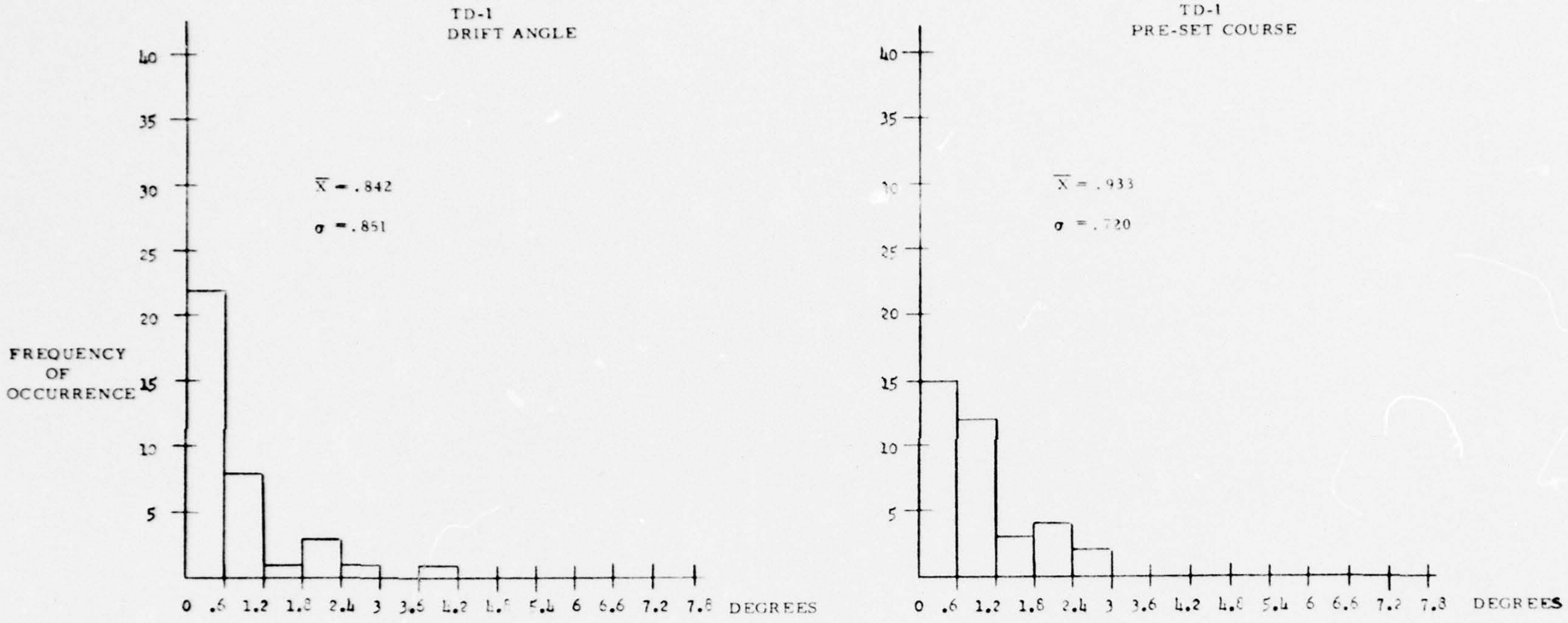


FIGURE 18. RUNWAY ALIGNMENT FREQUENCY DISTRIBUTION

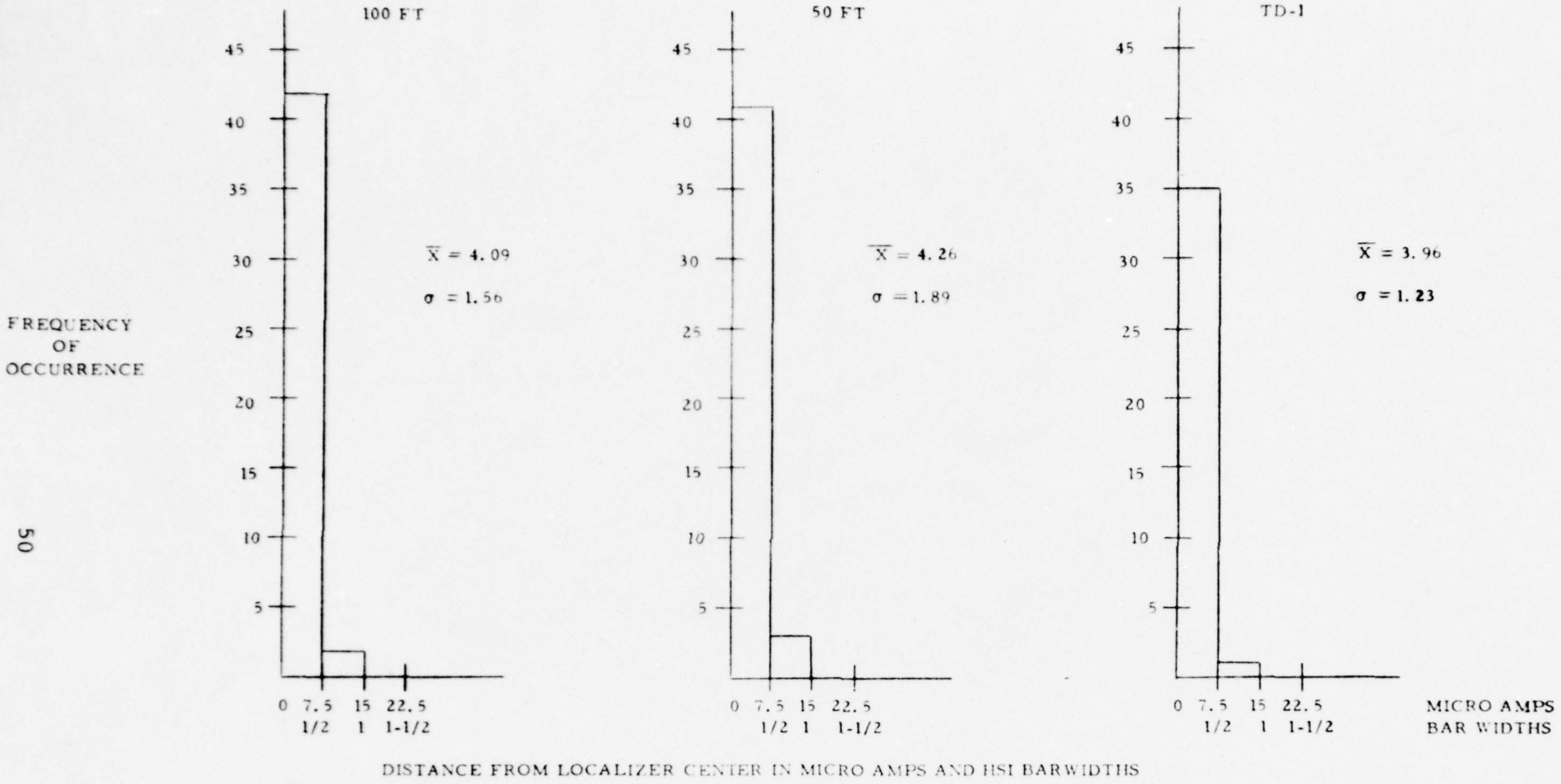


FIGURE 19. RUNWAY ALIGNMENT FREQUENCY DISTRIBUTION, LATERAL DISPLACEMENT

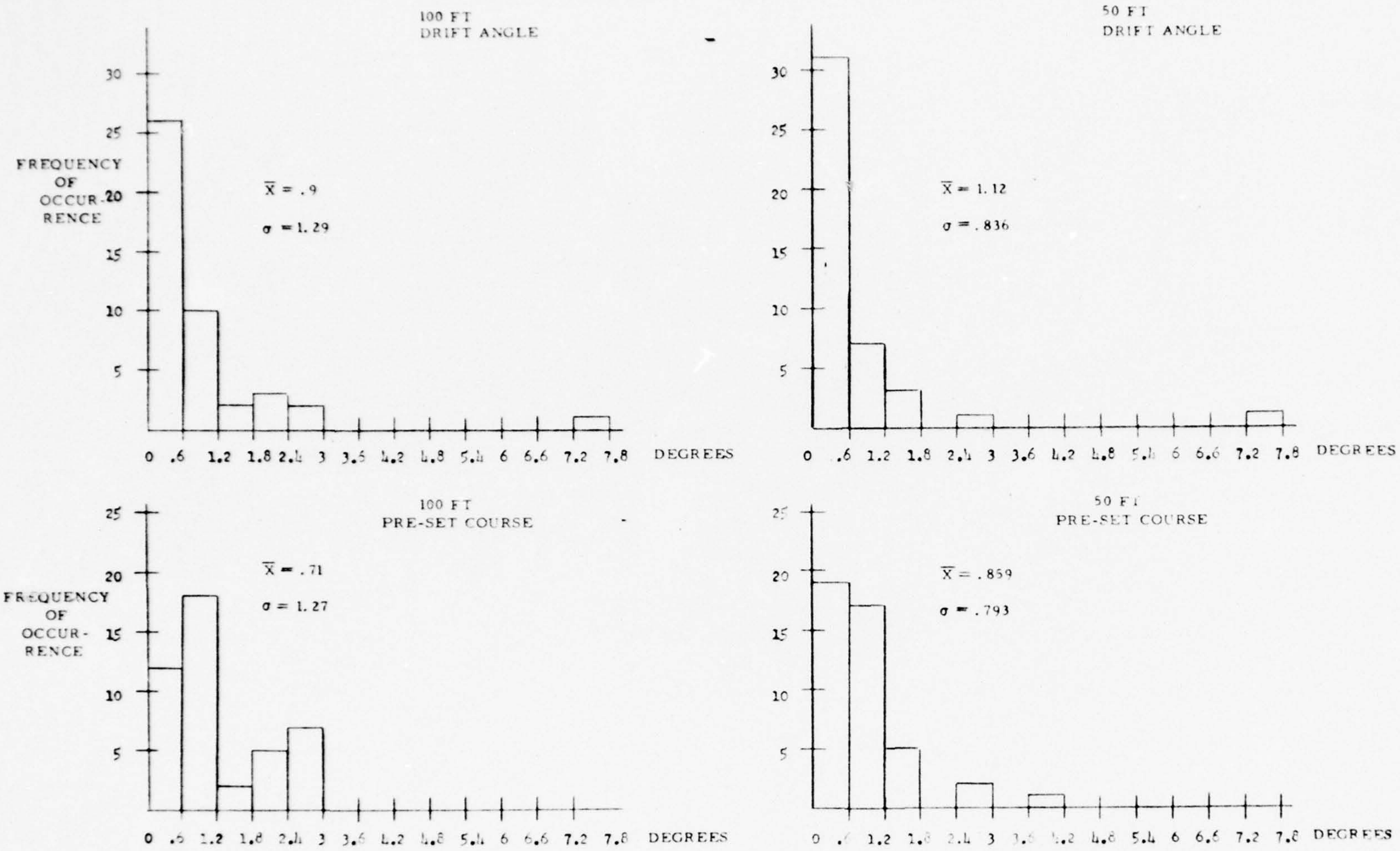


FIGURE 20. RUNWAY ALIGNMENT FREQUENCY DISTRIBUTION

The system is capable of good alignment performance over a wide range of crosswind conditions. No further improvements are anticipated in this area since performance is satisfactory in all respects.

SECTION 5

EXPERIMENTAL ROLL OUT GUIDANCE CONFIGURATION

5.1 GENERAL DISCUSSION

Lateral control of the aircraft while on the ground during landing or takeoff is necessary to maintain runway centerline tracking. At speeds above 80 knots, control is accomplished through the rudder.

The experimental roll-out guidance configuration performs control/display computations necessary for tracking the runway centerline during landing roll-out or during takeoff/touch-and-go maneuvers. The configuration is designed to provide automatic directional control at speeds above the 80 knot, minimum rudder effectiveness airspeed. Provisions are included for either automatic or manual (display only) operation.

During landing, the mode is engaged at touchdown (sensed by main landing gear squat switch closure) and remains operative until manually disconnected by the pilot. During takeoff, the mode is engaged automatically when the airspeed reaches 80 knots. In this case, the mode is disconnected automatically when the rotation point, which is sensed by the aircraft's Rotation/Go-Around computer, is reached. A back-up disconnect is also provided when the landing gear squat switches open.

5.2 FUNCTIONAL DESCRIPTION

The experimental automatic and manual roll out guidance configurations are shown in functional block diagram form in Figures 21 and 22, respectively. In these configurations, directional control is accomplished through the rudder channel while the aileron channel operates to maintain a wing-level reference.

The controlling signals in the roll out guidance mode are localizer beam error (ϵ) and runway heading error (ψ_{psc} corrected). The localizer signal is the system control reference for steering to the runway centerline. The runway heading term provides track damping, in conjunction with the aircraft's yaw damper, which is also active in the roll out guidance mode.

Referring to Figure 21, Roll Out Guidance - Auto, the localizer beam error and runway heading error terms are summed and applied to the rudder channel display when the roll out guidance (ROG) mode is engaged. The combined control and damping terms are then applied to an amplitude limiter that limits the maximum rudder command to ± 15

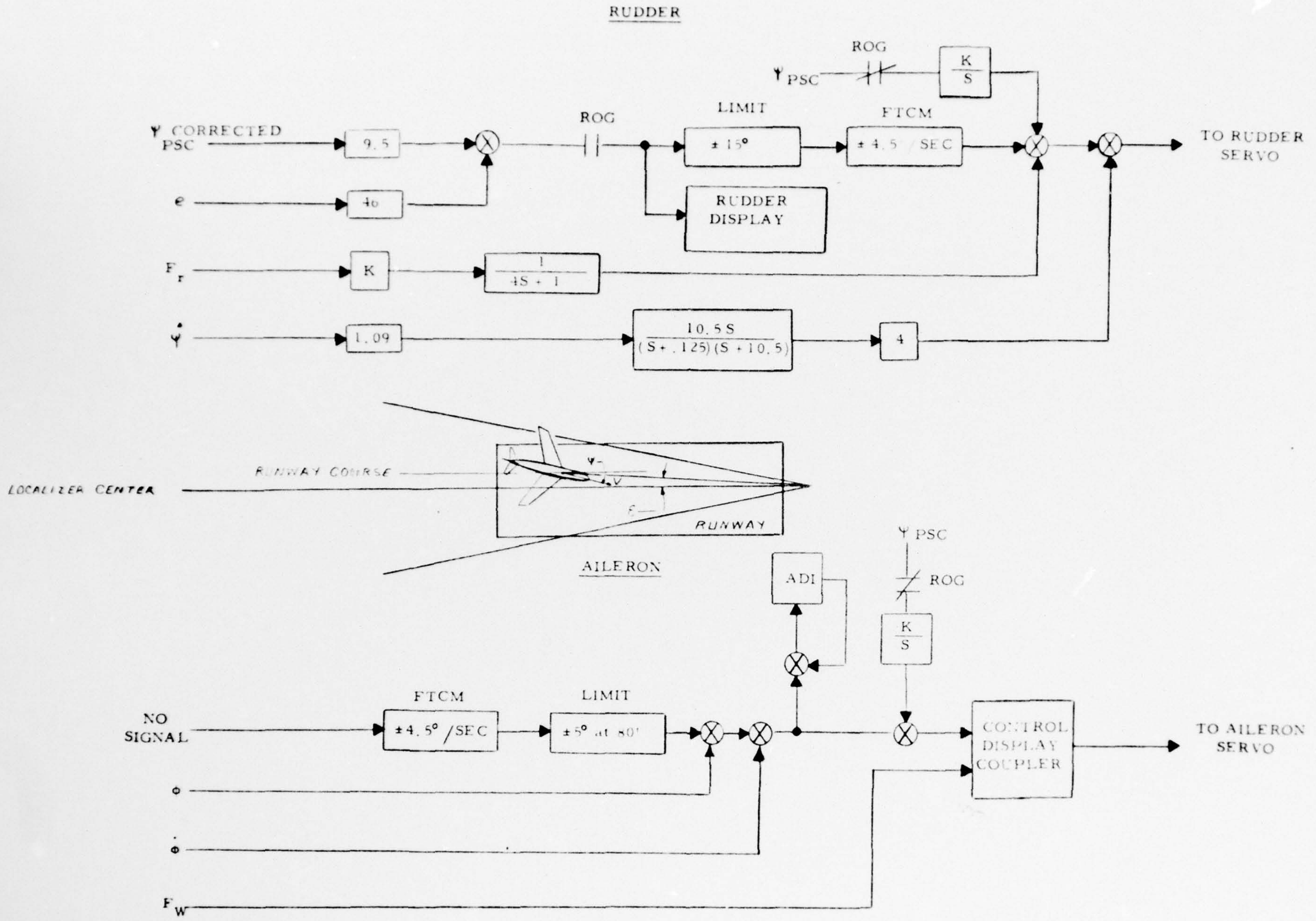


FIGURE 21. ROLL-OUT GUIDANCE-AUTO

degrees and to a Full Time Command Modifier (FTCM) that limits the command rate to ± 4.5 degrees/second. These circuits serve to limit the rudder surface displacement and rudder command rate to acceptable values. The FTCM circuit also performs a command smoothing function at the mode engage point to prevent rapid (transient) surface displacement. The limited command signal is then summed with the runway alignment mode integrator output, and then applied to the rudder servo actuator control loop. The runway alignment integrator is used as a rudder surface position reference in the roll out guidance mode. The integrator retains the output signal developed during alignment.

In the aileron channel, the roll attitude and roll rate terms operate to maintain a wings-level roll attitude during the roll out guidance mode. The runway alignment integrator remains in the signal chain (no input applied) to provide an aileron surface position reference. Wing level control is accomplished about this reference position.

In the manual configuration shown in Figure 22, the rudder channel control and damping terms are summed and applied directly to the rudder command display. Error closure is accomplished by the pilot through use of the rudder channel force wheel steering configuration. The yaw damper is also operational in this configuration.

In the aileron channel, the attitude loop signals are applied to the ADI roll command bar for wing level reference. Aileron control is accomplished by the pilot through use of the roll force wheel steering configuration.

5.3 SYSTEM OPTIMIZATION

5.3.1 Effect of Compass System Errors

5.3.1.1 Performance Effects

In the roll-out guidance phase of the approach, compass system runway heading offset errors generally result in runway centerline tracking offsets. In this mode, heading signal offsets can only be cancelled in the signal chains by a proportional amount of beam error signal. The amount of actual offset is determined by the effective beam to heading gain ratio. Since the effective beam gain varies as the aircraft nears the localizer transmitter, due to convergence of the beam, heading offsets generally do not result in constant tracking offsets in terms of lateral displacement from the runway centerline. As an example, a 2 to 3 degree heading offset will cause the aircraft to track approximately 30 feet off the runway centerline during the initial part of the roll out. The magnitude of the tracking offset will then gradually

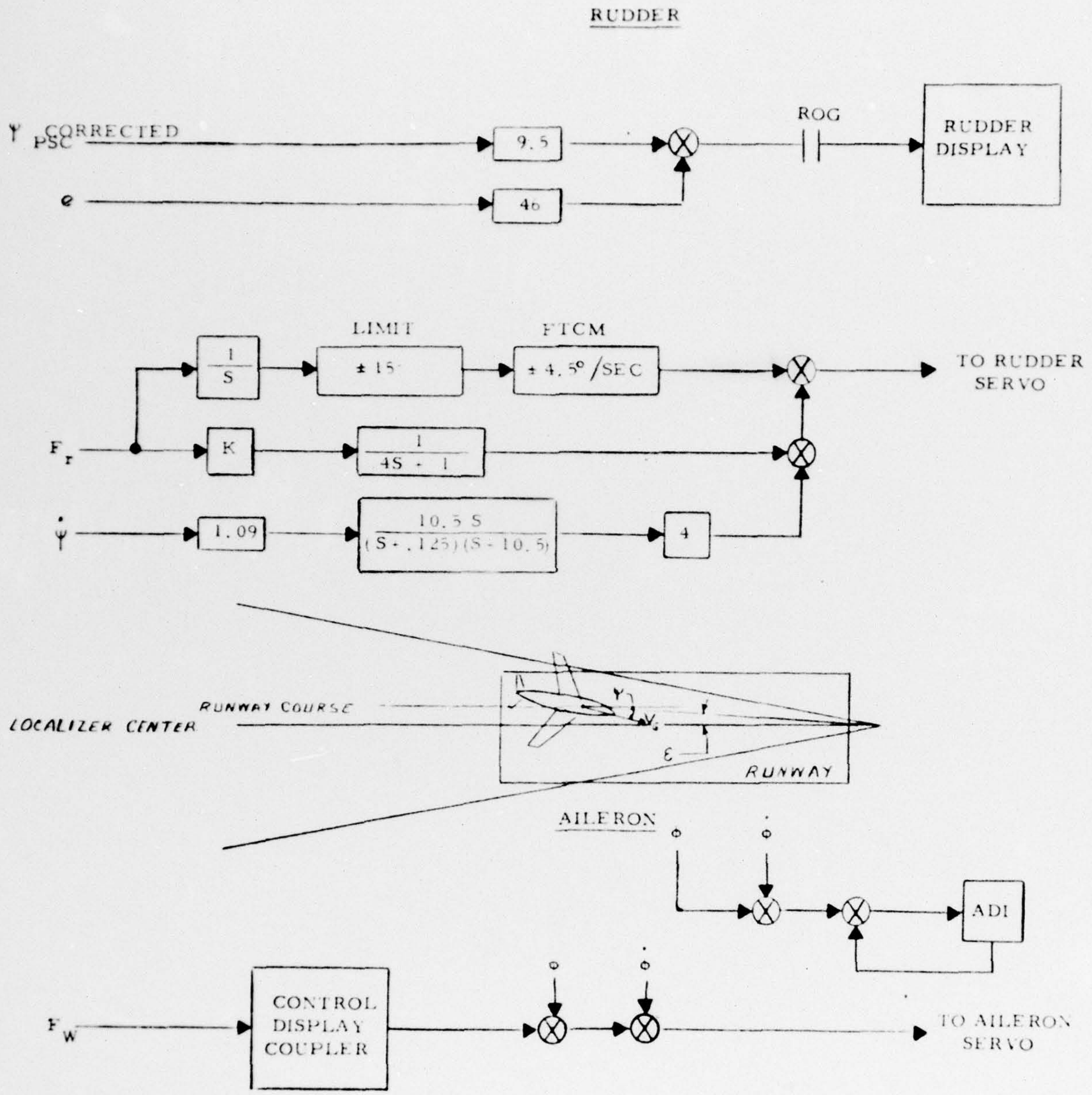


FIGURE 22. ROLL-OUT GUIDANCE-MANUAL

decrease as the aircraft nears the localizer transmitter and the effective beam gain increases.

5.3.1.2 Error Compensation Technique

To minimize the effect of heading offsets, a washout circuit was added to the heading term that is used in the roll out guidance computation and evaluated during a number of flights. In this configuration, the roll out guidance heading term was applied to the washout circuit input in flight at an altitude of 50 feet. Since the aircraft should be fully aligned at this altitude, it was assumed that the heading at this point would be the heading at touchdown. In effect, the washout circuit would update the heading reference to accept this heading as the actual runway heading. Later in the development, however, the roll out configuration was changed to allow use of the inertially corrected heading signal. The heading washout circuit discussed in this paragraph was disabled and is not included in the block diagrams.

5.3.1.3 Summary of Results

The primary drawback to use of the washout circuit was that the heading established during alignment was not, in all cases, the actual runway heading (i.e. when the compass errors during alignment causes the aircraft to align to an incorrect heading). Under these conditions, in the roll out mode, the system would attempt to maintain this incorrect heading reference. This resulted in an initial tracking error which remained until sufficient time elapsed for the heading error to washout during the roll out maneuver.

With the present configuration, the inertially updated heading signal is used in lieu of this washout configuration. The technique used to obtain this signal is discussed in the runway alignment section of this report in the discussion of heading offset effects.

Test results to date indicate that an improved, although not always exact, runway heading reference is obtained through use of the inertially corrected heading term.

5.3.2 Configuration Improvements

The roll-out guidance configuration described in this report differs in several respects from the original configuration which is described in Technical Report AFFDL-TR-71-97. These differences, which are primarily the results of system flight test development and manual control consideration, will be discussed briefly in the following paragraphs.

The general configuration shown in the roll out guidance functional block diagrams is similar from a functional point of view to the configuration described in AFFDL-TR-71-97. It should be noted, however, that the present configuration includes a separate roll out guidance signal chain; while, in the previous configuration portions of the runway alignment signal chain were used for roll out guidance. The essential difference here is that separate command limiters (amplitude and rate) are provided which allows independent adjustment of the limit values.

From a control point of view, the present configuration includes several provisions which were not in the original configuration. One difference, in this regard, is the aileron command signal from the rudder integrator which is used as a surface position reference in the roll out guidance mode. This provision was added following initial flight tests with the original configuration and has the dynamic effect of preventing " wing lift" during the roll out phase under crosswind conditions.

Another difference pertains to the rudder control technique used following touchdown. The original configuration employed a surface "washback" technique that gradually removed the rudder surface commands established during alignment. The present configuration retains the rudder surface position established during alignment as an operating point reference during the roll-out guidance mode. This signal determines both the rudder position operating point and the aileron surface operating point, through the rudder/aileron crossfeed path.

Flight test development of the roll out configuration has been conducted on a continuing basis with the overall objective of establishing system gains and control rates to optimize performance.

Primary areas of interest, in this regard, have been improving the tightness of centerline tracking and establishing an optimum centerline closure characteristic in cases where the aircraft does not touch down on the centerline.

5.4 FLIGHT TEST RESULTS

5.4.1 Performance Criteria

The roll-out guidance mode is entered at touchdown and remains operative during landing until disconnected by the pilot at the completion of the landing ground roll. In takeoff or touch-and-go cases, the roll-out mode is terminated at the rotation point.

In the roll-out guidance mode, localizer beam displacement errors are zeroed through rudder action while a wing-level attitude is maintained through aileron control. Since the rudder is used as the means for directional control, the mode is effective only at airspeeds above the 80 knot minimum rudder effectiveness speed. During landing, the system is normally disconnected when this speed is reached.

From a performance point of view, the ability of the system to track the localizer beam under crosswind conditions is the primary measure of performance. Although, in most cases, the aircraft will touchdown at or near the runway centerline, consideration must also be given to the system error closure characteristics for cases when touchdowns are made off the centerline. In this regard, operationally, the preferred characteristic is a gradual closure of the centerline tracking error, rather than a rapid turn and capture maneuver. This type of control characteristic is desirable in that it eliminates tire scrubbing and reduces tendencies for wing-lift under crosswind conditions.

In general, then, tight tracking is desired when the aircraft touches down on the centerline and a gradual closure is desirable in cases where touchdown is off the centerline.

5.4.2 System Performance

During the development of the experimental roll-out guidance configuration system gains and control rates were established to obtain the desired closure characteristics while maintaining relatively tight tracking capability.

The present configuration exhibits the desired "gradual closure" characteristic in cases where touchdown is off the centerline, however, this was accomplished through some reduction in centerline tracking performance, particularly under engage conditions where heading errors are present. In general, however, tracking performance has been satisfactory under all wind conditions encountered.

To illustrate system performance in the roll out guidance mode, a statistical approach has been used. The techniques used are essentially the same as during the earlier approach phases for localizer track and runway alignment performance data.

Figure 23 shows localizer deviation frequency distribution charts that represent measured system performance over approximately 40 data runs. The data points shown here represent the system performance levels obtained in the final approach and roll-out guidance phases. The following points are shown: Runway threshold, touchdown -1 second, 3000 feet, and 5000 feet. The latter two points are measured from the runway threshold. The touchdown data point varies over a range from 1800 to 2400 feet from threshold. The roll-out guidance mode is normally entered several seconds after touchdown.

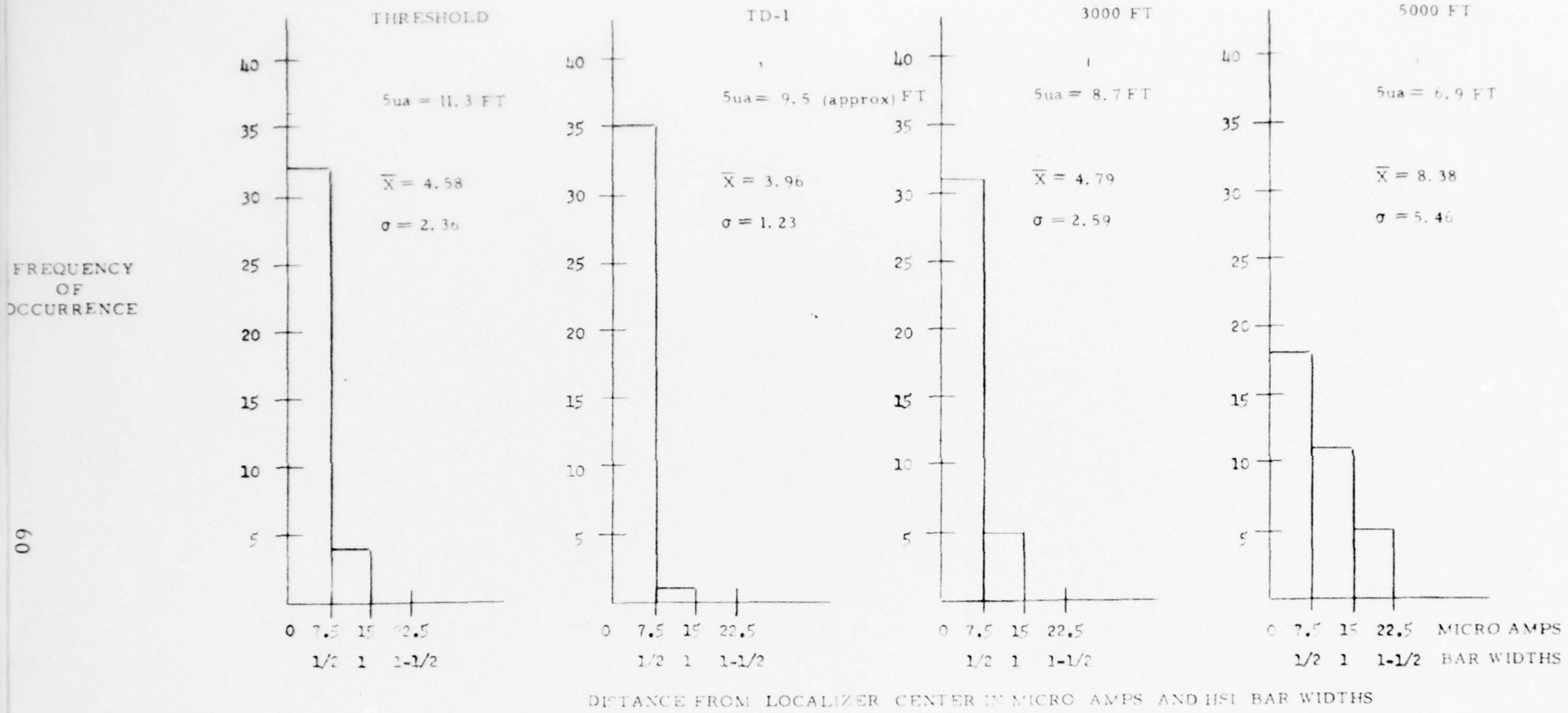


FIGURE 23. ROLL-OUT GUIDANCE FREQUENCY DISTRIBUTION, LATERAL DISPLACEMENT

5.4.3 Summary and Conclusions

Flight test results in the roll-out guidance mode have been in general agreement with performance levels predicted through analog computer study results.

During flight test, system gains and command rates were adjusted to obtain desired performance characteristics. In general, these adjustments resulted in good error closure characteristics under conditions where touchdowns are made off the localizer beam centerline. In these cases, system gains and command rates are such that gradual closure of the centerline error occurs without abrupt or excessive rudder surface motion.

Centerline tracking has been generally satisfactory under all conditions encountered; however, it is felt that further improvements here could be obtained through use of higher control loop gains. With the present configuration, however, system gains cannot be increased further without causing excessive rudder control.

In conclusion, it is presently felt that roll out guidance performance can be improved using essentially the same configuration through additional development work in this area.

During the later development stages, a configuration change was implemented to allow further optimization of system performance but was not evaluated due to time limitations. In brief, the surface command limiter was modified to permit selection of the limit value. The general objective here was to provide a means to allow higher control loop gains to be used, but at the same time prevent excessive rudder displacement in the cases where touchdown was off the centerline and thus retain the gradual error closure characteristic. The limiter would act to restrict the amount of rudder displacement to a relatively small value and thus limit the error closure rate. Additional data on roll-out guidance configurations is included in Final Report A007, "Landing and Takeoff Roll-Out Augmentation".

APPENDIX A

SUMMARY OF DATA ACQUISITION AND ANALYSIS TECHNIQUES

The following paragraphs discuss the methods of data acquisition and data reduction used to prepare the statistical charts presented in the various system performance sections of this report.

Data Acquisition

A total of 45 automatic landing approaches were performed for data purposes at Dulles Airport in Virginia on a Category II ILS localizer beam. Each of these approaches was recorded using a 24 channel visicorder oscillograph, which is currently available on the test aircraft. The following lateral axis parameters were recorded:

.... Localizer Deviation

.... Drift Angle

.... Heading Error (Preset Course)

.... Roll Attitude

.... Aileron Position

.... Rudder Command

.... Rudder Position

.... Roll Command

.... Roll Force Sensor

.... Yaw Force Sensor

.... Ground Speed

.... Integrated Ground Speed (Distance from Threshold)

.... Localizer Capture, Runway Alignment, and Roll Out Guidance Logic

During each approach, the following data points were identified through use of a manually operated recorder logic channel: 1000, 750, 500, 250, 200, 150, 100, 50, and touchdown altitude less one second as well as runway range from threshold in 1000 foot increments during rollout guidance.

Data Reduction

The following information was tabulated on data forms prepared to aid in data reduction: (Sample data form for each condition are shown in Figures 24 through 26.)

.... Runway Location, Data Flight Number, Date of Flight

.... Localizer Displacement (μa); Drift Angle (Degrees) at the 1000, 750, 500, and 250 foot Altitude Points

.... Runway Alignment: Localizer Displacement (μa), Drift Angle (Degrees), Preset Course (Degrees) at 200, 100, and 50 foot Altitude Points

.... Roll Out: Localizer Displacement (μa) at Runway Threshold and 1000, 3000, and 5000 foot ranges from Threshold

After completion of the data tabulation, the data for each of the parameters shown was used to plot histograms (i.e., frequency distributions). The boundaries of the histogram cells were set up with consideration to the overall range of the parameters, the magnitude, and the accuracy of measurement. In the case of the localizer deviation charts, consideration was also given to correlation of the data with visual observations made through use of cockpit instrumentation. Since the Horizontal Situation Indicator (HSI) raw localizer deviation bar is commonly used to monitor in-flight performance, a scale was chosen that corresponds to the unit of measurement used on that indicator (i.e., 1 bar-width = 15 μa displacement error).

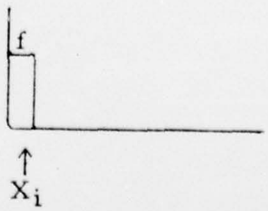
In preparing the localizer displacement histograms, absolute values were used without regard to direction (left, right) of the displacement errors.

The number of samples in each case is approximately 40. This number varies slightly between each histogram, since in some cases minor recording difficulties occurred. Because of these problems on certain runs, some of the data points could not be obtained.

In general, the data shown should be interpreted as illustrative rather than definitive of system performance levels, because of the relatively small sample size. A larger sample would have been desirable, however, this was not possible because of scheduling limitations.

From the histograms, in cases where the distributions appeared to be approximately Gaussian, the mean and standard deviation were calculated using standard statistical techniques. The following formulas were used for these calculations.

Mean: $$\overline{X} = \frac{\Sigma x_i f_i}{n}$$



Where: $\overline{X}$ is the mean.

X_i is the class mark.

f is the frequency.

n is the number of samples.

Standard Deviation:

$$\sigma = \left[\frac{\Sigma(X_i-\overline{X})^2 f_i}{n}\right]^{1/2}$$

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FIGURE 24

Runway Location ____________
Data Flignt No. ____________
Runway No. ____________
Date of Flight ____________

By ____________

Title LOCALIZER TRACK DATA SHEET

	APPROACH #1									APPROACH #6					
h	μa		β	Range	Angle	Lt/Rt				μa		β	Range	Angle	Lt/Rt
1000'															
750'															
500'															
250'															
Capture Conditions															
	APPROACH #2									APPROACH #7					
1000'															
750'															
500'															
250'															
Capture Conditions															
	APPROACH #3									APPROACH #8					
1000'															
750'															
500'															
250'															
Capture Conditions															
	APPROACH #4									APPROACH #9					
1000'															
750'															
500'															
250'															
Capture Conditions															
	APPROACH #5									APPROACH #10					
1000'															
750'															
500'															
250'															
Capture Conditions															

NOTE: (1) If data is not included on any approach, indicate why.

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FIGURE 25

Runway Location ____________

Data Flight No. ____________

Runway No. ____________

Date of Flight ____________

By ____________

Title RUNWAY ALIGNMENT DATA SHEET

		APPROACH #1							APPROACH #8						
h	μa		β		ψ	Δt			μa		β		ψ	Δt	
200'															
100'															
50'															
T. D. $^{-1}$															
		APPROACH #2							APPROACH #9						
200'															
100'															
50'															
T. D. $^{-1}$															
		APPROACH #3							APPROACH #10						
200'															
100'															
50'															
T. D. $^{-1}$															
		APPROACH #4													
200'															
100'															
50'															
T. D. $^{-1}$															
		APPROACH #5													
200'															
100'															
50'															
T. D. $^{-1}$															
		APPROACH #6													
200'															
100'															
50'															
T. D. $^{-1}$															
		APPROACH #7													
200'															
100'															
50'															
T. D. $^{-1}$															

NOTE: (1) Δt = time to close error within 10%.

(2) If data is not included on any approach, indicate why.

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FIGURE 26

Runway Location ____________
Data Flight No. ____________
Runway No. ____________
Date of Flight ____________

By ____________

Title ROLL-OUT GUIDANCE DATA SHEET

THRESHOLD TO LOCALIZER TRANSMITTER DISTANCE

	APPROACH #1	APPROACH #6
"x" from		
Threshold	µa	µa
0'		
1000'		
3000'		
5000'		
	APPROACH #2	APPROACH #7
0'		
1000'		
3000'		
5000'		
	APPROACH #3	APPROACH #8
0'		
1000'		
3000'		
5000'		
	APPROACH #4	APPROACH #9
0'		
1000'		
3000'		
5000'		
	APPROACH #5	APPROACH #10
0'		
1000'		
3000'		
5000'		

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