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STOL TACTICAL AIRCRAFT INVESTIGATION–EXTERNALLY BLOWN FLAP

Volume V

Flight Control Technology

Part II

Simulation Studies/Flight Control System Validation

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FOREWORD

This report was prepared for the Prototype Division of the Air Force Flight Dynamics Laboratory by the Los Angeles Aircraft Division, Rockwell International. The work was performed as part of the STOL tactical aircraft investigation program under USAF contract F33615-71-C-1760, project 643A0020. Daniel E. Fraga, AFFDL/PTA, was the Air Force program manager, and Garland S. Oates, Jr., AFFDL/PTA, was the Air Force technical manager. Marshall H. Roe was the program manager for Rockwell.

This investigation was conducted during the period from 10 June 1971 through 9 December 1972. This final report is published in six volumes and was originally published as Rockwell report NA-72-868. This report was submitted for approval on 9 December 1972.

This technical report has been reviewed and is approved.

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ABSTRACT

The basic objective of the work reported herein was to provide a broader technology base to support the development of a medium STOL Transport (MST) airplane. This work was limited to the application of the externally blown flap (EBF) powered lift concept.

The technology of EBF STOL aircraft has been investigated through analytical studies, wind tunnel testing, flight simulator testing, and design trade studies. The results obtained include development of methods for the estimation of the aerodynamic characteristics of an EBF configuration, STOL performance estimation methods, safety margins for takeoff and landing, wind tunnel investigation of the effects of varying EBF system geometry parameters, configuration definition to meet MST requirements, trade data on performance and configuration requirement variations, flight control system mechanization trade data, handling qualities characteristics; piloting procedures, and effects of applying an air cushion landing system to the MST.

From an overall assessment of study results, it is concluded that the EBF concept provides a practical means of obtaining STOL performance for an MST with relatively low risk. Some improvement in EBF performance could be achieved with further development - primarily wind tunnel testing. Further work should be done on optimization of flight controls, definition of flying qualities requirements, and development of piloting procedures. Considerable work must be done in the area of structural design criteria relative to the effects of engine exhaust impingement on the wing and flap structure.

This report is arranged in six volumes:

Volume I - Configuration Definition

Volume II - Design Compendium

Volume III - Performance Methods and Takeoff and Landing Rules

Volume IV - Analysis of Wind Tunnel Data

Volume V - Flight Control Technology

- Part I - Control System Mechanization Trade Studies
- Part II - Simulation Studies/Flight Control System Validation
- Part III - Stability and Control Derivative Accuracy Requirements and Effects of Augmentation System Design

Volume VI - Air Cushion Landing System Trade Study

This volume (V-II) presents the final results of a flight simulation study program which evaluated the flying qualities of an EBF MST in the STOL mode. The study investigated normal and failure operation characteristics in the takeoff, landing and waveoff modes with and without external disturbances. In addition to validating the flight control systems, the study defined safe speed margins, examined the effects of approach path variations and evaluated the touchdown dispersions resulting from failures and external disturbances.

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LIST OF SYMBOLS

SYMBOL	DIMENSION*[1]	DEFINITION
b	ft.	wing span
C	lb.	chord force
$\bar{c}$	ft.	mean aerodynamic chord
c.g.		center of gravity
c.p.		center or pressure
C_D		nondimensional total drag $D/\bar{q}S$
C_L		nondimensional total lift $L/\bar{q}S$
C_ℓ		nondimensional rolling moment $\mathscr{L}/\bar{q}Sb$
C_{ℓ_p}		nondimensional roll damping derivative $d\mathscr{L}/dp \cdot 1/\bar{q}Sb$
C_m		nondimensional pitching moment $M/\bar{q}S\bar{c}$
C_N		nondimensional normal force $N/\bar{q}S$
C_n		nondimensional yawing moment $\eta/\bar{q}Sb$
C_{n_r}		yawing damping derivative $d\eta/dr \cdot 1/\bar{q}Sb$
C_Y		nondimensional side force $Y/\bar{q}S$
D	lb.	total drag
g	ft./sec.^{2}	acceleration of gravity
h	ft.	altitude above terrain
$\dot{h}$	ft./sec.	altitude rate
i	rad.	horizontal stabilizer incidence angle
I	slugs - ft.^{2}	moment of inertia about the X, Y, Z body axis
L	lb.	total lift
$\mathscr{L}$	lb.-ft.	rolling moment
ℓ_H	ft.	tail arm distance
M	lb.-ft.	pitching moment
N	lb.	normal force
n	lb.-ft.	yawing moment
$\dot{p}$	rad./sec.^{2}	angular roll acceleration
p	rad./sec.	angular roll rate
ψ	deg.	heading angle
$\dot{q}$	rad./sec.^{2}	angular pitch acceleration
q	rad./sec.	angular pitch rate
$\bar{q}$	lbs./ft.^{2}	dynamic pressure $1/2\ \rho V^2$
$\dot{r}$	rad./sec.^{2}	angular yaw acceleration
r	rad./sec.	angular yaw rate
S	ft.^{2}	wing reference area
T_{PE}	lb.	thrust per engine
t	sec.	time
V	ft./sec.	true airspeed

*[1] - dimension as noted unless otherwise indicated

LIST OF SYMBOLS (contd.)

SYMBOL	DIMENSION	DEFINITION
V_{SL}	ft./sec.	minimum speed at which two thirds maximum allowed touchdown sink rate can be maintained with one engine out. At $\delta_F = 65°$, $V_{SL} = 113$ FPS
V_{STO}	ft./sec.	minimum speed at which level flight can be maintained with one engine out. At $\delta_F = 46°$, $V_{STO} = 123$ FPS.
$\dot{V}_X$	ft./sec.^{2}	acceleration along the positive X body axis
V_X	ft./sec.	X body axis velocity
$\dot{V}_Y$	ft./sec.^{2}	acceleration along the positive Y body axis
V_Y	ft./sec.	Y body axis velocity
$\dot{V}_Z$	ft./sec.^{2}	acceleration along the positive Z body axis
V_Z	ft./sec.	velocity along the Z body axis
w	lb.	aircraft weight
X	ft.	linear displacement
Y	lb.	side force
$\dot{\alpha}$	rad./sec.	angle of attack rate
α	rad.	angle of attack
β	rad.	angle of sideslip
Δ		increment due to power
δ	rad.	angular deflection of an undefined control surface
δ_a	rad.	differential aileron and/or roll spoiler deflection angle
δ_e	rad.	elevator deflection angle
δ_F	rad.	flap deflection angle
δ_H	rad.	horizontal stabilizer deflection angle
δ_{sp}	rad.	direct lift control (DLC) spoiler deflection angle
ϵ	rad.	downwash angle
ϕ	rad.	aircraft bank angle
ω_{ph}	rad./sec.	longitudinal phugoid mode frequency
ω_{sp}	rad./sec.	longitudinal short period frequency
θ	rad.	aircraft pitch attitude
ζ_{ph}		phugoid mode damping ratio
ζ_{sp}		short period damping ratio

SUBSCRIPTS

$(\ )_{\not P}$	power off
$(\ )_{\not T}$	tail off
$\dot{\alpha}$	angle of attack rate
α	angle of attack
β	angle of sideslip

SUBSCRIPTS (contd.)

C	when used in conjunction with a force it references the wing chord; when used in conjunction with a displacement it refers to the pilot's column.
δ	control surface deflection
g	gust
MX	peak magnitude in the X body axis direction
MY	peak magnitude in the Y body axis direction
MZ	peak magnitude in the Z body axis direction
p	roll rate
q	pitch rate
r	yaw rate
TD	touchdown
TRIM	initial trim or command condition
U, V, W	orthogonal aircraft body axis components
YE	Y direction in the earth reference axis system

LIST OF ABBREVIATIONS AND ACRONYMS

CT	Continuous turbulence
CW	Crosswind
DEG	Degrees
DLC	Direct lift control
DOF	Degrees-of-freedom
EBF	Externally blown flap
EO	One engine-out operation
Flt.	Flight
FPS	Feet per second
Ft.	Feet
GM	Gross maneuver
IFR	Instrument flight rules
LDG	Lateral-directional gust
LG	Longitudinal gust
MST	Medium STOL transport
NO	Normal operation
P	Pitch augmentation
PM	Pitch maneuver
PR	Pilot rating
R	Roll augmentation
RAD	Radians
Rnwy	Runway

LIST OF ABBREVIATIONS AND ACRONYMS

SEC	Seconds
SP	Speed parameter = $\bar{q}S/T_{PE}$
STOL	Short takeoff and landing
TCS	Thrust control system
VFR	Visual flight rules
VSTOL	Vertical and/or short takeoff and landing
Y	Yaw augmentation

Section I

INTRODUCTION

Short takeoff and landing transports offer tactical advantages not presently available in conventional transports or helicopters. Conventional transports provide mission capabilities upwards of several hundreds of miles at speeds approaching the speed of sound but require conventional takeoff and landing flight paths and runways due to their dependence upon aerodynamic lift for all flight phases. Helicopters offer small field takeoff and landing capability but are limited in payload capacity, mission radius, and speed because of their dependency on powered lift. The STOL/VSTOL concept incorporates some of the advantages of both conventional transport and helicopter design concepts by providing short field, medium range, high speed mission capability in one vehicle. STOL technology has been under development for several years and many design criteria have been made available during this period of development. However, to assure the feasibility of a low risk vehicle based on current tactical application requirements several areas in design depend on the development of additional design criteria.

A low cost method for developing such preliminary design criteria is the utilization of a flight simulation program. To this end, a flight simulation program has been conducted to provide data which will assist in assessing the feasibility of a low risk EBF medium STOL transport. The study objectives were: (1) validation of the pitch, roll, and yaw flight control systems for operation in the takeoff, landing, and wave-off areas of the flight profile by assessing the piloted handling qualities of this vehicle during both normal and augmentation and engine failure modes with and without external disturbances, (2) assessment of the influence of engine failures and external disturbances on safe speed margins and runway size requirements and (3) definition of the sensitivity of the augmented and unaugmented aircraft flight characteristics, as measured by pilot opinion to variations of aerodynamic coefficients.

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Section II

TECHNICAL APPROACH

GENERAL

The approach used to achieve the objectives of this portion of the STOL Tactical Aircraft Investigation utilized piloted handling qualities evaluation techniques, analysis of piloted time history data, and other control analyses techniques as may be necessary to fully define STOL handling qualities. MIL-F-83300 provides the basis for evaluating the flying quality characteristics of the baseline system.

The study evaluated a 6 DOF MST model and its associated control and augmentation systems under simulated STOL flight conditions during the landing, takeoff and waveoff flight phases. Simulated disturbances from the vehicle's intended flight path included discrete and continuous turbulence gust models, crosswind and critical engine failure effects. Piloted handling qualities were examined using a 2 DOF motion simulator in the longitudinal and lateral-directional axes for a variety of control inputs ranging from small to those resulting in operation near the aircraft's maneuver limits.

EVALUATION MANEUVERS

The study utilized maneuvers typical of the STOL flight phases being investigated and consistent with the requirements of MIL-F-83300. The flight phase maneuvers involved include Category B for takeoff climb, and Category C for the landing approach and waveoff/go-around decision. The maneuvers evaluated were designed to provide both single and multiple axes control evaluations.

TAKEOFF AND CLIMB

The takeoff maneuver was initiated from the runway just after liftoff and terminated at 1000 feet altitude. The initial trim at takeoff was at the maximum climb rate for the full power lift-off speed and flap setting. This maneuver is illustrated in Figure 1. At an altitude of 500 feet, the aircraft was trimmed to level flight to evaluate longitudinal control. Subsequent to leveling off, a 90 deg right heading change was accomplished for evaluation of lateral-directional control. Upon completion of the heading change the aircraft was again trimmed to maximum climb angle. This maneuver required two pitch control changes and one combined pitch and roll maneuver for harmony. Gust and/or fan failure conditions were introduced at various times during the maneuver to evaluate control under upset conditions.

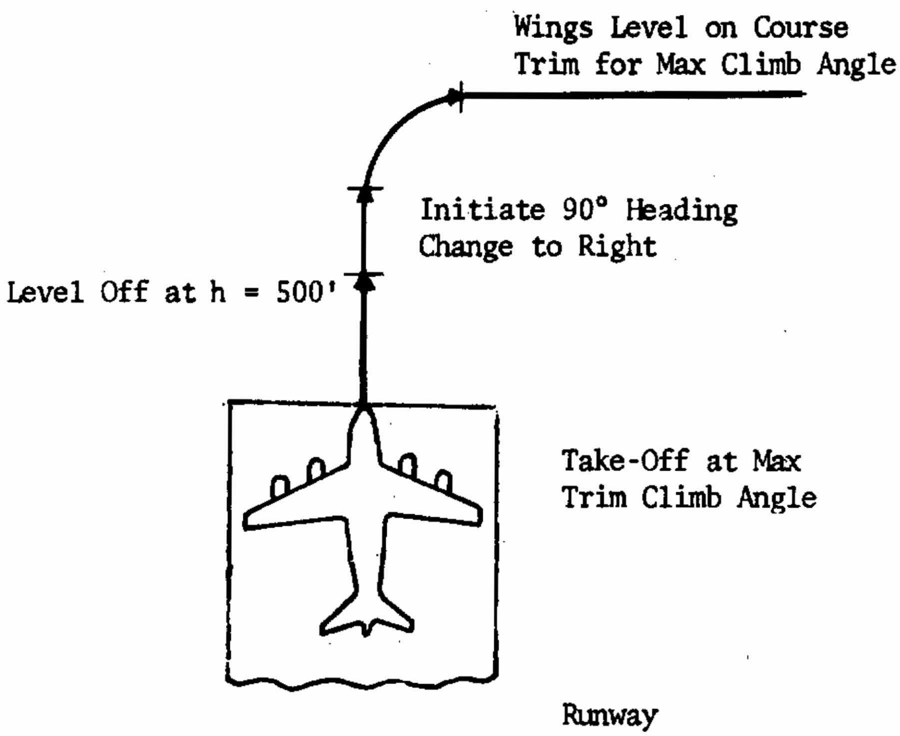


Figure 1. Take-Off and Climb Evaluation Maneuver

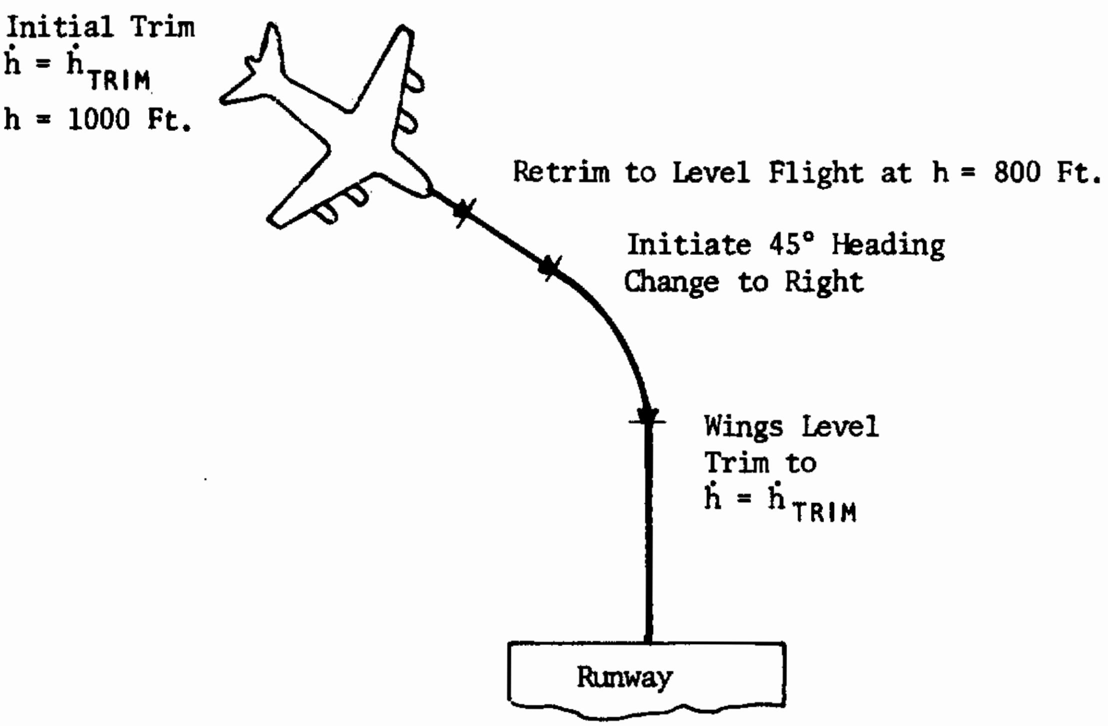


Figure 2. Landing Approach Evaluation Maneuver

LANDING APPROACH

Initial trim for this maneuver is at 10 feet/second or greater rate of descent. As in the case of the takeoff maneuver there are two pitch control changes and a combined pitch and roll maneuver. The maneuver is defined in Figure 2. The heading change to the right has been selected to create a worst case situation with loss of the right hand outboard fan.

WAVEOFF/GO-AROUND

With the aircraft trimmed and stabilized for a landing approach, an engine failure is introduced. After recovery from the engine failure transient a decision is made to waveoff depending on altitude at the time. The control commands defined for this maneuver include two pitch control commands. The first occurs simultaneous with the waveoff decision while the flaps are retracting and the speed is being stabilized. The second occurs when the aircraft is trimmed to a 3-degree climb angle. Combined pitch, roll and yaw control inputs are required for recovery from the fan out transient. This maneuver is described in Figure 3. Additional control evaluation commands can be initiated by applying crosswinds, longitudinal or lateral-directional discrete and/or continuous gust inputs to provide independent control evaluations. The study also utilized normal operation waveoffs in the presence of external disturbances.

UPSET CONDITIONS

In addition to the maneuvers previously described, a number of aircraft disturbances were applied at various times during the maneuvers. These disturbances affect the equilibrium of the aircraft, thus requiring a pilot control response. Such disturbances available in the program include loss of a single fan, continuous and discrete type gust turbulence models and crosswinds.

All of the upset conditions are introduced directly into the model equations and can be triggered at any time during the course of a maneuver. They are introduced by switching functions located at the Simulation Operator's station. Utilization of this technique for introduction of the failure precluded anticipation of its introduction by the Evaluation Pilots.

This section describes the effects of the upset conditions on the simulated model, the areas in each of the maneuvers in which the upsets were evaluated and the criteria used to establish the gusts available in the program.

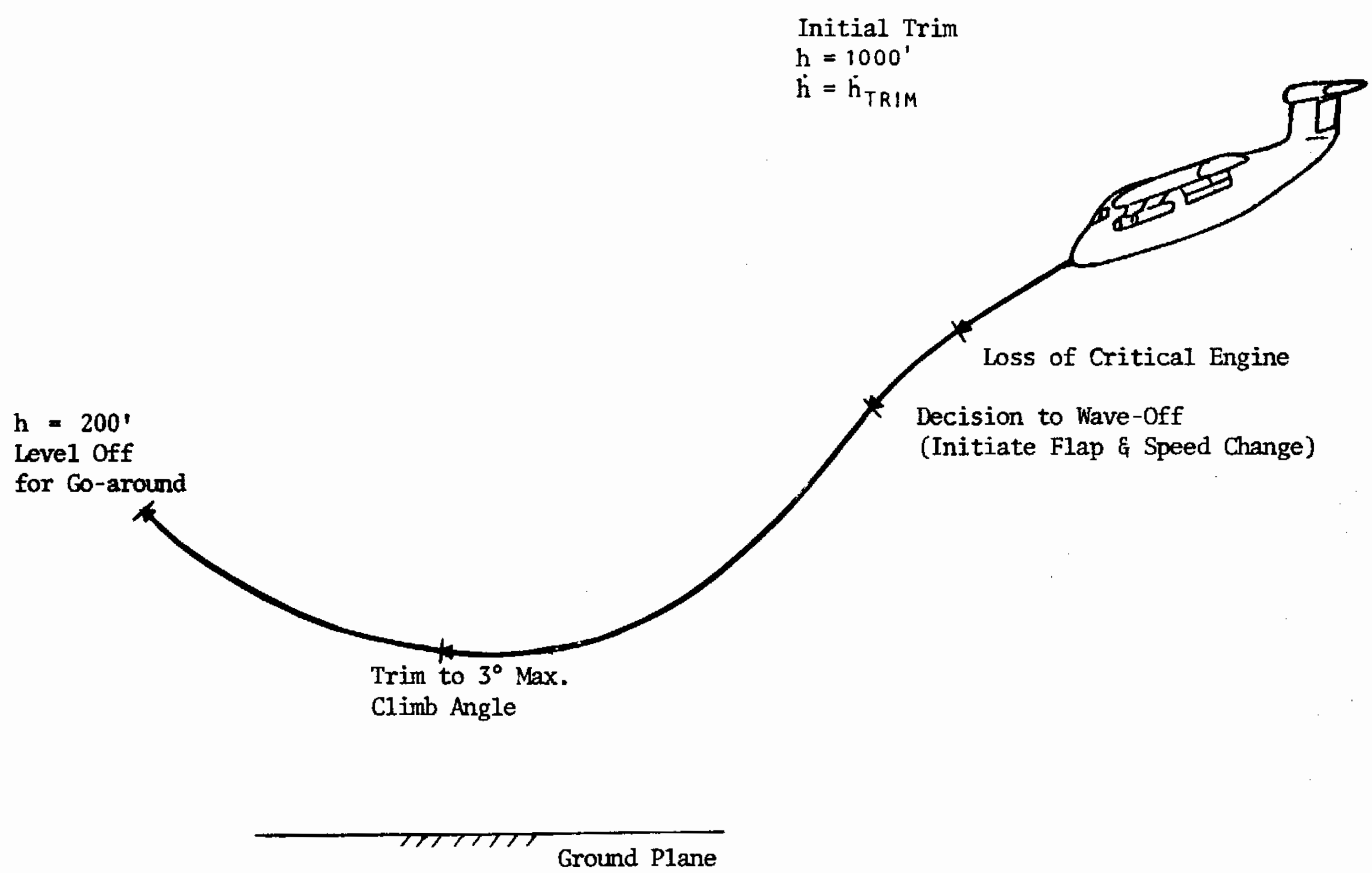


Figure 3. Wave-Off Decision After Loss of Critical Engine

CRITICAL ENGINE FAILURE

The model simulates loss of the right hand outboard fan. Introduction of this failure creates rolling, pitching and yawing moments as well as a lift loss and a drag increment. The resulting forces and moments appear in three axes with the greatest control compensation required in the roll axis. Thus the piloted evaluation of this condition is basically an evaluation of simultaneous control required in all axes to varying degrees and an evaluation of the effect of thrust loss.

Pilot opinion and time history data were obtained for this failure at a variety of points along the various maneuvers. The effect of this failure was evaluated during the required heading change when the right wing is down. This situation simulates a worst case condition for fan failure. The second area in which the failure was introduced was during the wings level portions of the various maneuvers at a range of altitudes to investigate the effect of altitude on fan failure.

DISCRETE GUSTS

Discrete gusts in conformance with requirements of MIL-F-8785B were utilized during piloted evaluations. Gusts were formulated for each of three axes and utilize scales and intensities based on an average altitude of 500 feet consistent with Category C requirements. To permit examination of worst case conditions, thunderstorm turbulence (Dryden scales) was selected for both longitudinal and lateral-directional gust magnitudes. Gust frequencies were tuned to the natural frequencies of the aircraft flight dynamic characteristics. Longitudinal gusts were defined in terms of the short period frequency and the lateral-directional gusts were defined in terms of the dutch roll frequency. Three gust frequencies were evaluated at one flight condition to determine the gust frequency which presents the most severe control problem. The three frequencies evaluated are the undamped natural frequency, one half the natural frequency and twice the natural frequency. The results of this evaluation determined the gust frequency mode which was utilized to establish the gust disturbances for other flight conditions evaluated.

Application of the longitudinal gust to the model results in changing drag and lift forces and introduces a pitching moment. The effect of this gust on handling qualities was evaluated during descent and climb modes of the various maneuvers. Gust inputs subsequent to having trimmed for a fan failure were also evaluated.

The lateral-directional gusts result in a change in rolling and yawing moments. These gusts were evaluated during the required heading change both for normal and fan out operation. The sign of the gust was selected to create the most difficult control problem.

CONTINUOUS GUSTS

A continuous random gust model of the Dryden form consistent with the requirements of Reference 2 was simulated for evaluation of piloted control. This model utilizes three orthogonal gust components introduced simultaneously. The gust model equations, mechanization and a sample time history are described in detail in Section III of this report. These were introduced during both longitudinal and lateral-directional pilot control commands to evaluate their effect on pilot control. The effect of these gusts on each maneuver was examined.

CROSSWIND LANDING

This disturbance consisted of applying a 90-degree crosswind during the entire landing approach or waveoff. It is based on the crosswind requirement of MIL-F-83300, and was applied parallel with the terrain. It was evaluated during the landing approach maneuver both with and without an engine failure condition. The effects of crosswind size up to a maximum of 30 knots were evaluated.

DATA EVALUATION

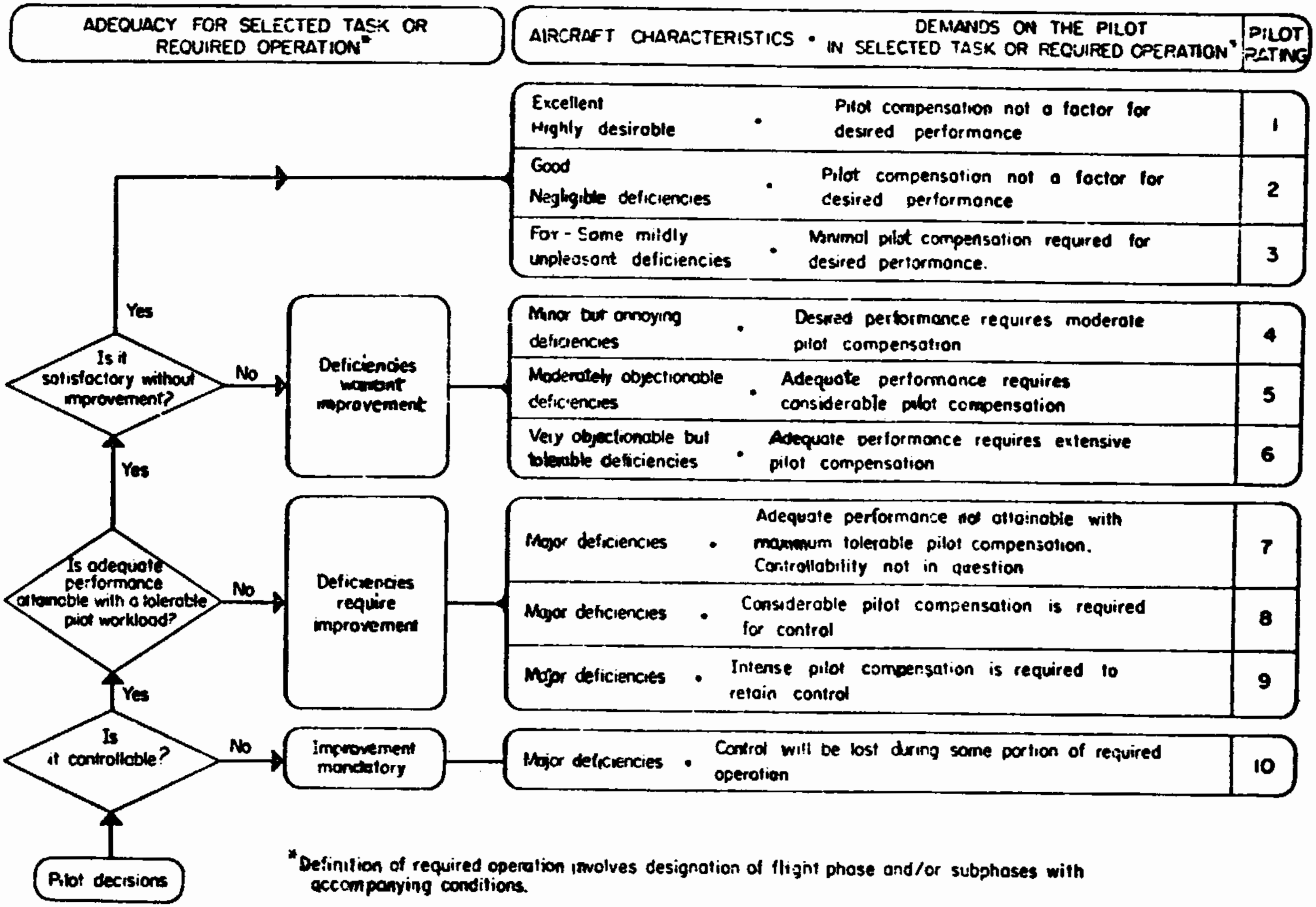
Evaluation methods include interpretation of pilot opinion and utilization of recorded time history data for assessment of pilot technique and measurement of the degree of control. These evaluation techniques are applied during all phases of the study. They are utilized during validation and verification of the baseline configuration handling qualities with the requirements of the applicable military specifications, evaluation of appropriate control techniques under upset and normal operating conditions and evaluation of parameter variation effects on handling qualities.

PILOT RATINGS

Pilot evaluation utilized the Cooper-Harper pilot rating system discussed in Reference 3. For convenience, this rating scale and its interpretation is presented in Figure 4.

TIME HISTORY DATA

To assist in establishing control techniques, determining safety margins, dispersion patterns, and verifying handling qualities, time history data and digital printout of maximum and minimum values of appropriate parameters were recorded. These were recorded on a "when needed" basis. Recording equipment sufficient to record up to 16 parameters simultaneously was available on a standby basis. Table I lists the minimum parameters which were available for recording. This table also identifies parameters for which the computer monitored maximum and minimum values and the run



*Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions.

Figure 4. Handling Qualities Rating Scale

TABLE I

PARAMETERS AVAILABLE FOR RECORDING

TIME HISTORY AND MIN/MAX DIGITAL PRINTOUT

*Altitude Rate (feet/sec)	*Normal Acceleration (g)
*True Velocity (feet/sec)	*Altitude Error (feet)
*Heading (degrees)	*Lateral Error (feet)
Thrust (pounds)	Column Position (inches)
*Flight Path Angle (degrees)	Wheel Position (degrees)
*Angle of Attack (degrees)	Pedal Position (inches)
Aircraft Attitude (degrees)	Rudder Position (degrees)
*Pitch Rate (deg/sec)	Aileron Position (degrees)
*Horizontal Stabilizer Position (Degrees)	Speed Parameter
*Elevator Position (degrees)	Axial Acceleration (feet/sec^2)
*DLC Spoilers (degrees)	Angle of Attack Rate (deg/sec)
*Lateral Acceleration (g)	Gust Disturbances
*Sideslip (degrees)	Altitude (feet)
*Yaw Rate (deg/sec)	Horizontal Range (feet)
*Roll Rate (deg/sec)	Lateral Range (feet)
*Bank Angle (deg)	

*Maximum and minimum values also available in the form of a digital printout

POINT OF TOUCHDOWN DIGITAL PRINTOUT

Bank Angle	Side Velocity
Heading	Sink Rate
Pitch Attitude	True Velocity
X Error	Lateral Acceleration
Y Error	Normal Acceleration

time at which they occurred. To simplify the data analysis task and facilitate identification of dispersion patterns for the landing approach, the computer was programmed to record certain parameters at the point of touchdown. These are also shown in Table I.

VERIFICATION AND VALIDATION

Definition of flight control system requirements consistent with level 1 and level 3 handling qualities were established for each of the three maneuvers specified and the various disturbances considered. Level 1 requirements for the air vehicle and control system were established by defining the augmentation loops and gains necessary to obtain median pilot ratings of three or better for normal operation. Control system requirements consistent with level 3 handling qualities were defined by evaluating engine-out characteristics in terms of pilot ratings with augmentation on and off. Acceptable handling qualities for this case were considered to be established, when median pilot ratings of nine or better were obtained.

In addition to defining control system requirements, by verification of handling qualities with MIL specification requirements, the approach utilized during this portion of the study defined augmentation system reliability requirements. Study results which indicated an unsafe condition after loss of the outboard engine, during discrete gusts or continuous turbulence with the unaugmented vehicle, resulted in a fail-operational requirement for the augmentation system. Study results which indicated that the unaugmented vehicle, subsequent to losing an engine or when operating in turbulence, had minor and/or major deficiencies but was not considered unsafe, resulted in a fail-safe requirement on the augmentation system.

EVALUATION OF SPEED MARGIN

Subsequent to verification of the compliance of the simulation model with MIL-F-83300 requirements, the effect of speed margins on handling qualities and flight safety were examined. Using the level 3 control system configuration, this portion of the study obtained pilot ratings for trim speeds approaching the critical fan failure stall speed. The maneuver and upset conditions utilized in this portion of the study, were selected on the basis of the pilot ratings obtained during the previous tests. Only those maneuvers and upset conditions considered most severe were selected. The initial evaluation was obtained for an incremental trim speed change of 0.2 V_{SL} or V_{STO}.

The method of obtaining pilot ratings for speed margin evaluation was as follows. The aircraft was trimmed to the speed margin to be evaluated. The evaluation pilot was asked to fly a specified maneuver at the trimmed speed either with or without crosswinds and/or continuous gusts. During the course of the maneuver the engine failure transient was introduced. Upon recovering from this transient, an additional upset condition was introduced in the form of discrete gust. The pilot was asked to evaluate the controllability of the aircraft in terms of the Cooper-Harper rating system.

An incremental change of ±0.1 V_{SL} was made for the subsequent trim point depending on whether or not an unsafe condition existed. In the event an unsafe condition existed at the initial trim point, the next trim point for evaluation was increased by 0.1 V_{SL}. In the event a safe condition existed at the initial trim point, the next trim point evaluated was reduced by 0.1 V_{SL}. The safe speed margin for this maneuver and series of upset conditions was defined when a number of pilots with average abilities fully recovered from the most critical transients at the trimmed speed being evaluated.

SENSITIVITY TO VARIATIONS IN MST VEHICLE PARAMETERS

The sensitivity of the flight control system to variations in some of the more important stability and control derivatives was evaluated using conventional dynamic analysis techniques in conjunction with pilot ratings. These data provide a basis for determining accuracy requirements of STOL aerodynamic coefficients for a given control system configuration. They also provide a range of coefficient values considered to be acceptable in terms of handling qualities for the baseline configuration under consideration.

In the longitudinal axis, these data define the change in stability and control parameters, such as ω_{sp}, ζ_{sp}, ω_{ph}, and ζ_{ph} with changes in aerodynamic coefficients. Similar comparisons are made for the coefficients in the lateral-directional axes. The effect of these coefficient variations are plotted and presented as a portion of the final study results. The pilot opinion ratings for aerodynamic coefficient variations are also plotted to show the range of values of a given coefficient which results in typical level 1, 2, or 3 handling qualities. These data in conjunction with coefficient estimation analytical techniques and wind tunnel or flight test data provide a method of establishing estimation technique accuracy requirements.

The techniques utilized for piloted evaluation of aerodynamic coefficients produced a pilot rating of the vehicle and flight control system for each value of each aerodynamic coefficient investigated. Typically each aerodynamic coefficient was examined at three values: The baseline value, and at least two multiples of the baseline value. The multiples selected for evaluation, above and below baseline values, were determined on an individual basis for each coefficient. These were selected proportional to the influence of each coefficient upon such stability and control parameters as frequency, damping, and time constants. The aerodynamic coefficients evaluated included M_V, $M_{\dot{\alpha}}$, M_q, M_δ, X_V in the longitudinal axis and L_p, L_β, L_r, L_{δ_a}, N_p, N_β, N_{δ_a}, N_{δ_r}, Y_β, Y_r in the lateral-directional axes.

The maneuver selected for this evaluation was that rated most difficult during validation of the baseline vehicle. The normal operation case with gust or crosswind disturbances were rated for each coefficient value. In the case of discrete gust disturbances, for longitudinal coefficients, the most severe longitudinal gust disturbance was applied. For the lateral-directional coefficient evaluations, a discrete lateral-directional gust was introduced as a disturbance. These disturbances, introduced during execution of the maneuver assure that the pilot ratings are obtained under simulated conditions comparable to those encountered in actual flight.

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Section III

MST MODEL

GENERAL

The MST simulation provided full six-degree-of-freedom capability throughout the STOL flight regime. Aerodynamic coefficients, where necessary, vary for normal and critical engine failure operation. Additionally they vary for thrust, speed and flap deflections.

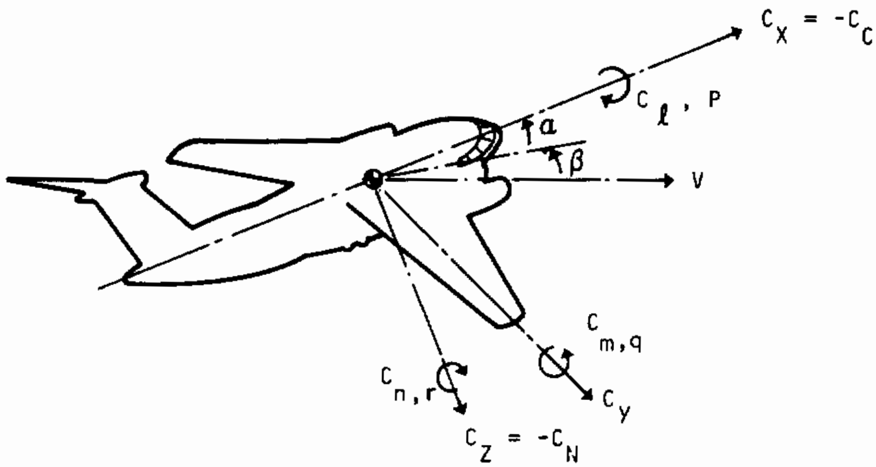
The simulated model includes equations of motion, control and augmentation system equations, aircraft position, crosswind and discrete and continuous gusts equations. The hardware necessary for the study includes a moving base transport evaluation cockpit, evaluation pilot operated controllers and switches, instrument and through-the-windshield visual displays. This section defines the model used to achieve the program objectives. A detailed description of the digital computer programs and analog mechanizations utilized in this study is presented in Reference 4.

SIGN CONVENTION

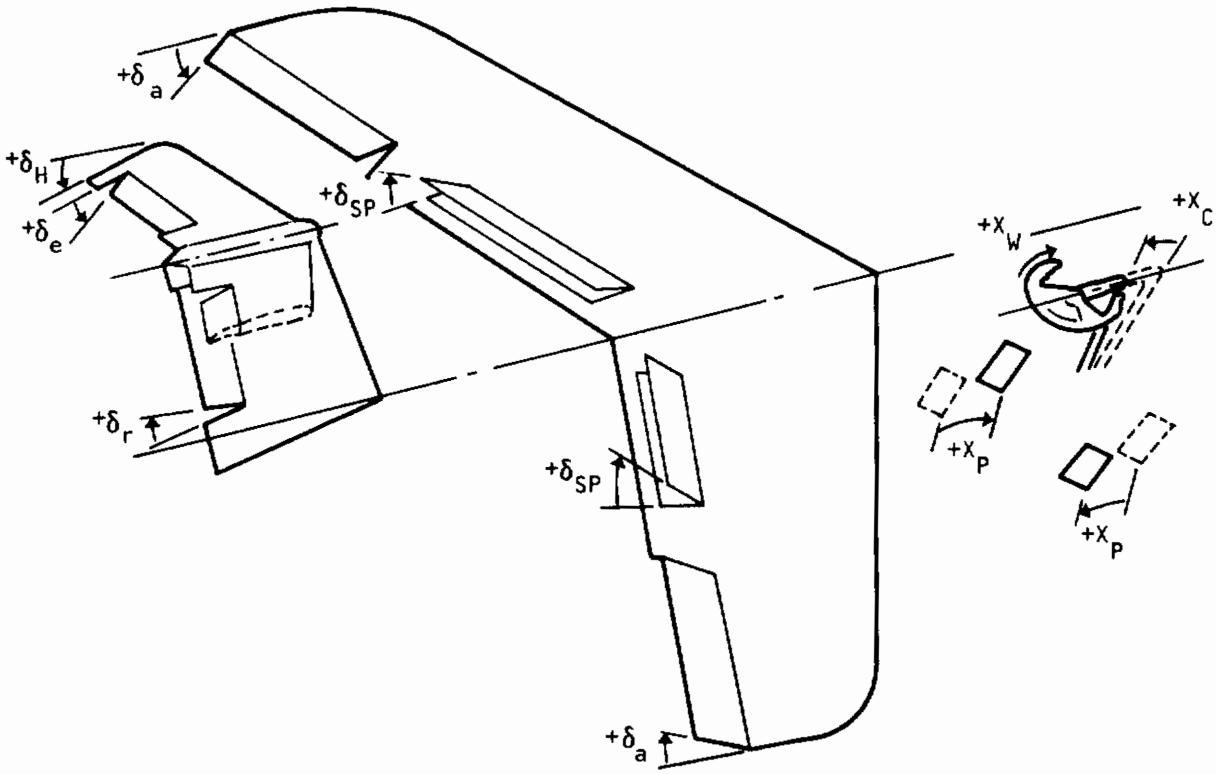
The sign convention associated with the MST is defined in the body axis system. The positive sense for forces, moments, pilot controllers and control surface deflections are identified in Figure 5.

EQUATIONS OF MOTION

The model includes full six-degree-of-freedom equations written in terms of force and moment coefficients normalized to thrust per engine. The equations are presented in Figure 6. They utilize the closed aerodynamic loop coupling terms normally associated with body axis coefficients. The aerodynamic force and moment coefficients on the right side of these equations include the effect of losing the right hand outboard engine. The failure characteristics for yaw and rolling moments are summed into these equations as individual terms. The pitching moment; normal force and axial force failure contributions are introduced by converting a number of coefficients in each equation from a normal operation value to one for engine failure. Positive sense for these equations is as indicated in the figure. The negative signs multiplying the aerodynamic coefficients of the normal and axial force equations convert the lift and chord force coefficients respectively to forces positive along the positive Z and X axes.



BODY AXIS SYSTEM



SENSE OF POSITIVE DEFLECTIONS

Figure 5. Simulation Model Sign Convention

NORMAL FORCE (+DOWN) -1*(NZOT + NZAT*ALP+NZDHT*DH+NZDET*DE+NZDAT*AXLDA+NZDST*DS + NZGND

$$\frac{W}{g T_{PE}}\left(\dot{V}_z - V_x q + V_y p - g\cos\theta\cos\phi\right) = -1\cdot\left(\left[\frac{N_{TOT}}{T_{PE}}\right]_{\alpha=0} + \left[\frac{N_{TOT\alpha}}{T_{PE}}\right]\alpha + \left[\frac{N_{TOT\delta_H}}{T_{PE}}\right]\delta_H + \left[\frac{N_{TOT\delta_e}}{T_{PE}}\right]\delta_e + \left[\frac{N_{TOT\delta_a}}{T_{PE}}\right]|\delta_a| + \left[\frac{\Delta N_{DLC}}{T_{PE}}\right]\delta_{sp} + \left[\frac{\Delta N_{TOT}}{T_{PE}}\right]^{\#2}_{GND}\right)$$

AXIAL FORCE (+FWD) -1*(DOT + DAT + DDST*DS + DDAT*AXLDA + DGND

$$\frac{W}{g T_{PE}}\left(\dot{V}_x + V_z q - V_y r + g\sin\theta\right) = -1\cdot\left(\left[\frac{C_{TOT}}{T_{PE}}\right]_{\alpha=0} + \left[\frac{C_{TOT}}{T_{PE}}\right]_{\alpha} + \left[\frac{C_{TOT_{DLC}}}{T_{PE}}\right]\delta_{sp} + \left[\frac{C_{TOT\delta_a}}{T_{PE}}\right]|\delta_a| + \left[\frac{\Delta C_{TOT}}{T_{PE}}\right]^{\#2}_{GND}\right)$$

PITCHING MOMENT (+UP) MOT + MAT*ALP +MADTT*ADOT+MQT*Q +MDHT*DH +MDET*DE + MGND

$$\frac{I_y}{\bar{c} T_{PE}}\left[\dot{q} + \left(\frac{I_x - I_z}{I_y}\right) r p - \frac{I_{xz}}{I_y}(r^2 - p^2)\right] = \left[\frac{M_{TOT}}{T_{PE}\bar{c}}\right]_{\alpha=0} + \left[\frac{M_{TOT\alpha}}{T_{PE}\bar{c}}\right]\alpha + \left[\frac{M_{TOT\dot{\alpha}}}{T_{PE}\bar{c}}\right]\dot{\alpha}\frac{\ell}{V} + \left[\frac{M_{TOT q}}{T_{PE}\bar{c}}\right] q\frac{\ell}{V} + \left[\frac{M_{TOT\delta_H}}{T_{PE}\bar{c}}\right]\delta_H + \left[\frac{M_{TOT\delta_e}}{T_{PE}\bar{c}}\right]\delta_e + \left[\frac{\Delta M_{TOT}}{T_{PE}\bar{c}}\right]^{\#2}_{GND}$$

SIDE FORCE (+RIGHT) YBT*BETA+YRT*R*LH/V+YDRT*DR

$$\frac{W}{g T_{PE}}\left(\dot{V}_y - V_z p + V_x r - g\cos\theta\sin\phi\right) = \left[\frac{Y_{TOT\beta}}{T_{PE}}\right]\beta + \left[\frac{Y_{TOT r}}{T_{PE}}\right]\frac{r\ell_V}{V} + \left[\frac{Y_{TOT\delta_r}}{T_{PE}}\right]\delta_r$$

YAWING MOMENT (+NOSE RIGHT) NOT + NBT*BETA+NRT*R*B/(2*V)+NPT*P*B/(2*V)+NDAT*DA+NDRT*DR

$$\frac{I_z}{b T_{PE}}\left[\dot{r} - (\dot{p} - q r)\frac{I_{xz}}{I_z} - p q\left(\frac{I_x - I_y}{I_z}\right)\right] = \left[\frac{N_{TOT}}{T_{PE} b}\right]^{\#1}_{\alpha=0} + \left[\frac{N_{TOT\beta}}{T_{PE} b}\right]\beta + \left[\frac{N_{TOT r}}{T_{PE} b}\right]\frac{r b}{2V} + \left[\frac{N_{TOT p}}{T_{PE} b}\right]\frac{p b}{2V} + \left[\frac{N_{TOT\delta_a}}{T_{PE} b}\right]\delta_a + \left[\frac{N_{TOT\delta_r}}{T_{PE} b}\right]\delta_r$$

ROLLING MOMENT (+RIGHT) LOT + LBT*BETA+LRT*R*B/(2*V)+LPT*P*B/(2*V)+LDAT*DA+LDRT*DR

$$\frac{I_x}{b T_{PE}}\left[\dot{p} - (\dot{r} + p q)\frac{I_{xz}}{I_x} - q r\left(\frac{I_y - I_z}{I_x}\right)\right] = \left[\frac{\mathcal{L}_{TOT}}{T_{PE} b}\right]^{\#1}_{\alpha=0} + \left[\frac{\mathcal{L}_{TOT\beta}}{T_{PE} b}\right]\beta + \left[\frac{\mathcal{L}_{TOT r}}{T_{PE} b}\right]\frac{r b}{2V} + \left[\frac{\mathcal{L}_{TOT p}}{T_{PE} b}\right]\frac{p b}{2V} + \left[\frac{\mathcal{L}_{TOT\delta_a}}{T_{PE} b}\right]\delta_a + \left[\frac{\mathcal{L}_{TOT\delta_r}}{T_{PE} b}\right]\delta_r$$

#1 APPLIES TO ENGINE OUT CONDITION ONLY

#2 APPLIES TO GROUND EFFECTS ONLY

Figure 6. Body Axis System Equations of Motion - 6 DOF MST Simulation

CONTROL EQUATIONS

The control equations utilized for the pitch, roll, yaw and thrust control systems simulate hardware design requirements by inclusion of comparable transfer functions. These transfer functions simulate system dynamic response, maximum travel and system rates, and in some cases signal shaping and limiting which has been found necessary as a result of MST program Part I studies. The system dynamic response characteristics which have been defined for these systems are comparable to the system mechanization concepts being considered for the control system trade studies (Task 10b). For example, in the unaugmented mode the MST model systems represent the all mechanical control concept of Task 10B. With augmentation on but zero pilot command gains these systems represent the mechanical plus stability augmentation configuration of Task 10b. In addition, the evaluation pilot's controller in each system was mechanized to provide force characteristics comparable to the level 1 requirements of MIL-F-83300. The primary flight controls, augmentation, trim systems and thrust control systems are discussed in detail below.

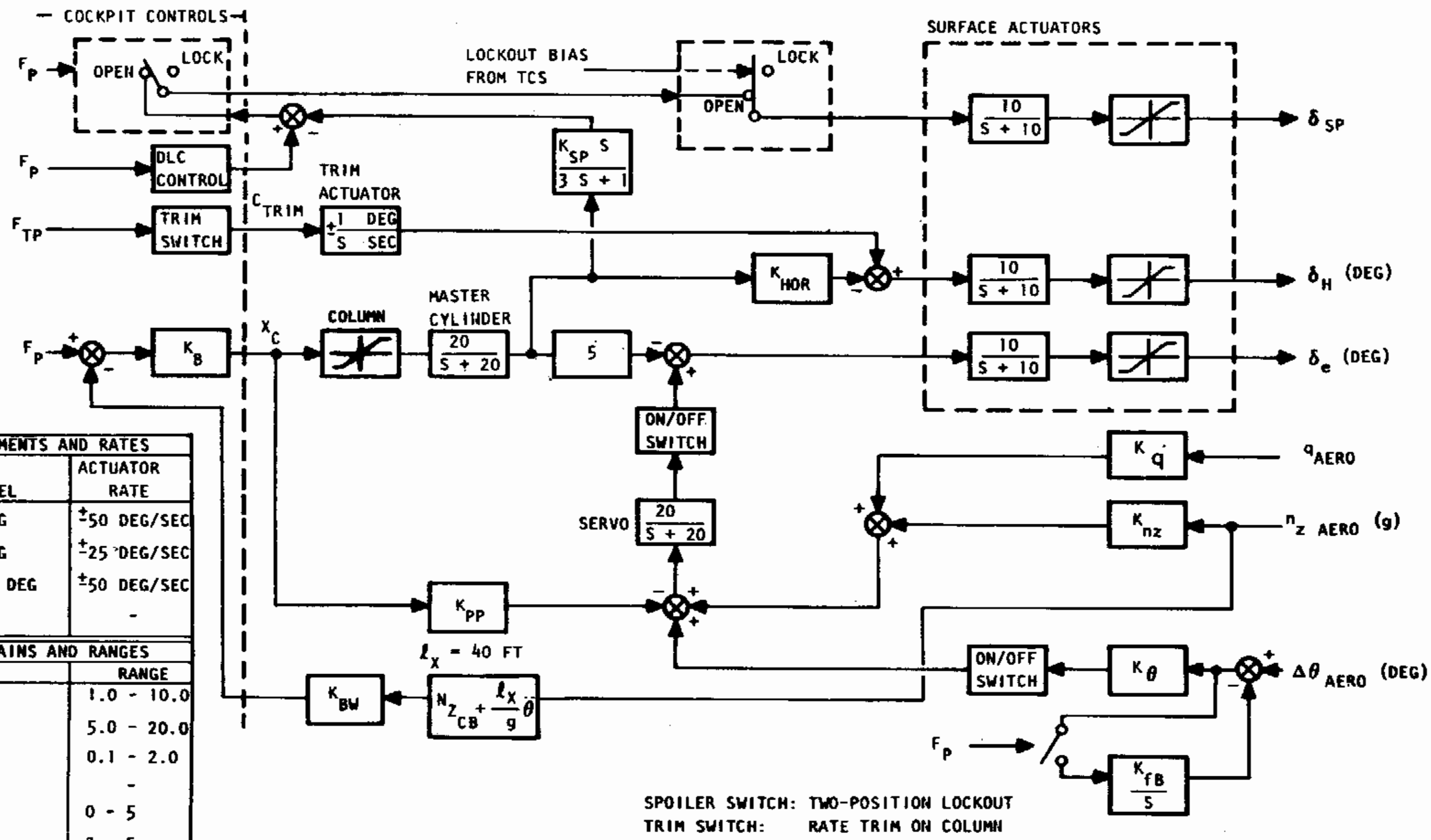
PITCH FLIGHT CONTROL AND AUGMENTATION SYSTEM

The flexibility of the pitch control system mechanization offers a large number of control system configurations which were evaluated to define the final configuration. This system is described in Figure 7. As shown in this figure, the pilot's column controls the horizontal stabilizer, elevator and direct lift spoilers. The horizontal stabilizer responds to pilot column inputs and pitch trim commands. The primary pitch trim system consists of a trim actuator connected in series with the column. The pilot's trim inputs are through a rate trim button on the wheel.

In addition to responding to the pilot inputs, the elevators respond to control/stability augmentation system inputs. A pilot-controlled manually operated spoiler lockout switch is provided on the center console. This is a two-position switch which, when in the locked position, closes the spoilers and holds them closed regardless of column or spoiler control knob position. This mode is selected for takeoff, waveoff, and after engine failure. In the normal position, and the throttles at other than full power, the spoilers are at 50 percent of full travel and respond to column inputs through a washout with a three-second time constant. An interlock has been provided between the thrust control system (TCS) and the spoiler control system. This interlock system provides automatic spoiler positioning as a function of thrust command and is described more fully in the description of the TCS system. The spoiler (DLC) control knob is located on the pilot's right hand wheel grip and gives the pilot direct control of the two inboard spoilers.

All augmentation level switches shown are selectable by the computer operator; they are not included as pilot command functions.

In addition to rate and acceleration stability augmentation, a control stick steering loop has been provided which performs an attitude hold function



DISPLACEMENTS AND RATES		
	TRAVEL	ACTUATOR RATE
δ_e	±25 DEG	±50 DEG/SEC
δ_H	±20 DEG	±25 DEG/SEC
δ_{SP}	(0-60) DEG	±50 DEG/SEC
X_C	±5 IN.	-
NOMINAL GAINS AND RANGES		
	NOM	RANGE
K_q	1.66	1.0 - 10.0
K_{nz}	10.1	5.0 - 20.0
K_θ	0.5	0.1 - 2.0
K_{FB}	50 V/V	-
K_{PP}	2	0 - 5
K_{HOR}	4	2 - 5
K_{SP}	24	5.0 - 30.0
K_B	0.166 IN./LB	-
K_{BW}	10 LB/g	-

Figure 7. Pitch Flight Control and Augmentation System

when the pilot is not applying a force to the column. The attitude feedback gain is a function of cockpit control force, and is zero with control force applied. Thus the command-response relationship when a control force is applied is a rate command system.

ROLL FLIGHT CONTROL AND AUGMENTATION SYSTEM

The roll axis control system includes the control wheel, wheel feel system, trim control and the stability/control augmentation system. This system is described in Figure 8. The primary roll flight control system includes master cylinder and control surface actuator lags comparable to those of a hydro-mechanical system. A series trim system is operated by a thumb switch on the pilot's controller. The control/stability augmentation system is authority limited to 50 percent of full roll control authority.

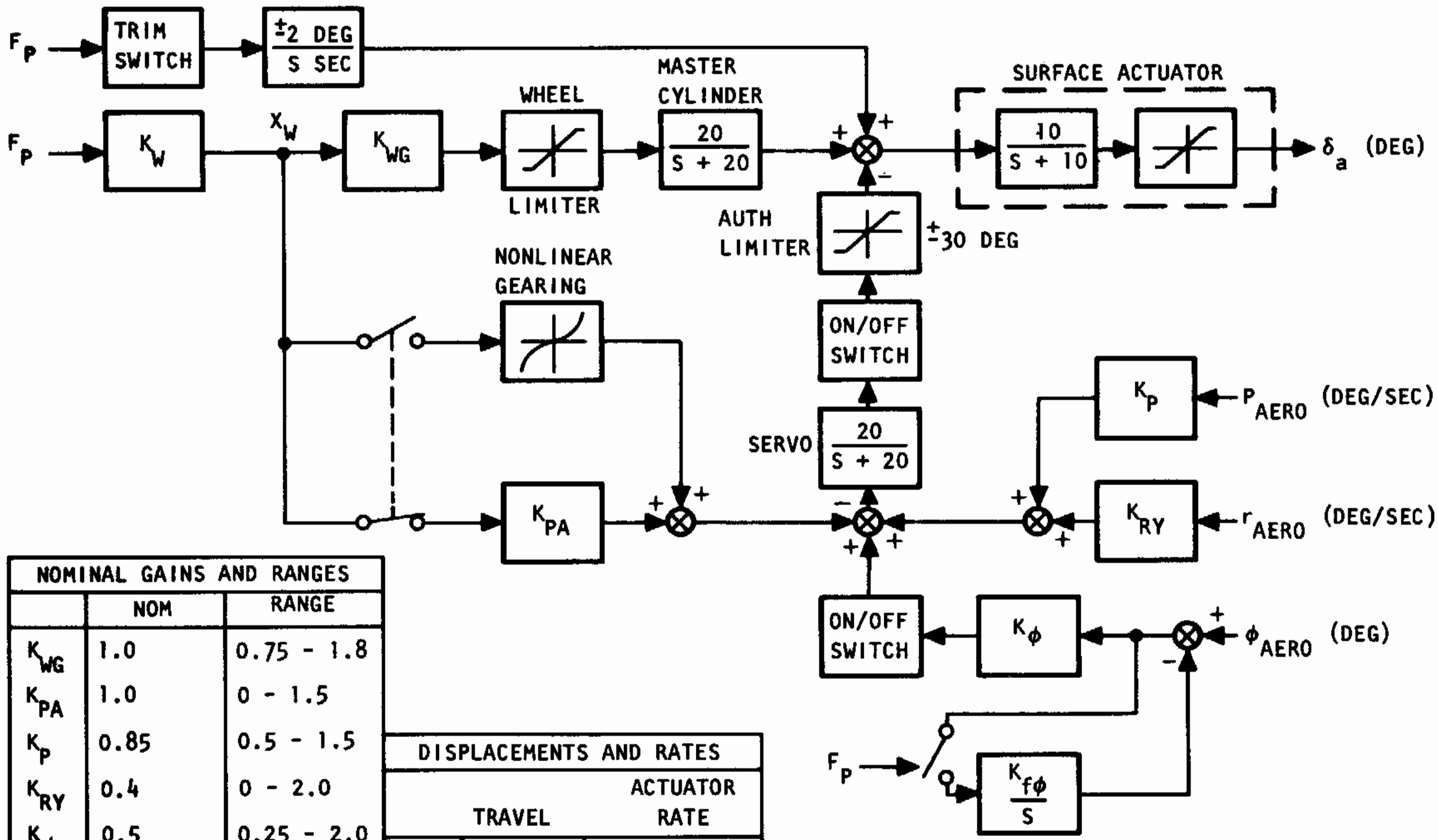
YAW FLIGHT CONTROL AND AUGMENTATION SYSTEM

As in the case of the pitch and roll control systems, the yaw control system, defined in Figure 9, permits a lot of flexibility in establishing the final configuration. This system utilizes a rate trim command located on the center console which is connected in series with the pilot's pedal input. The basic stability augmentation includes yaw rate damping and lateral acceleration feedback loops. Because of the high Ny feedback gains typically found desirable in STOL configurations, in combination with high roll due to rudder deflection, the authority of this feedback loop has been limited. Normal operation in the yaw rate damper loop includes the washout shown. The no-washout mode (NWO) is selectable by the computer operator and is not a pilot command function.

THRUST CONTROL AND ENGINE FAILURE MECHANIZATION

The thrust control mechanization consists of the pilot-to-computer control link and the switching and logic necessary to trigger and simulate an engine failure. The control system dynamic response to a pilot input is represented by a 0.1 second lag. This is described in Figure 10. A single switch at the computer console provides the signal which triggers an engine failure by adjusting appropriate aerodynamic coefficients. The rate at which an incremental change in the aerodynamic coefficients takes place is through a 0.1 second lag.

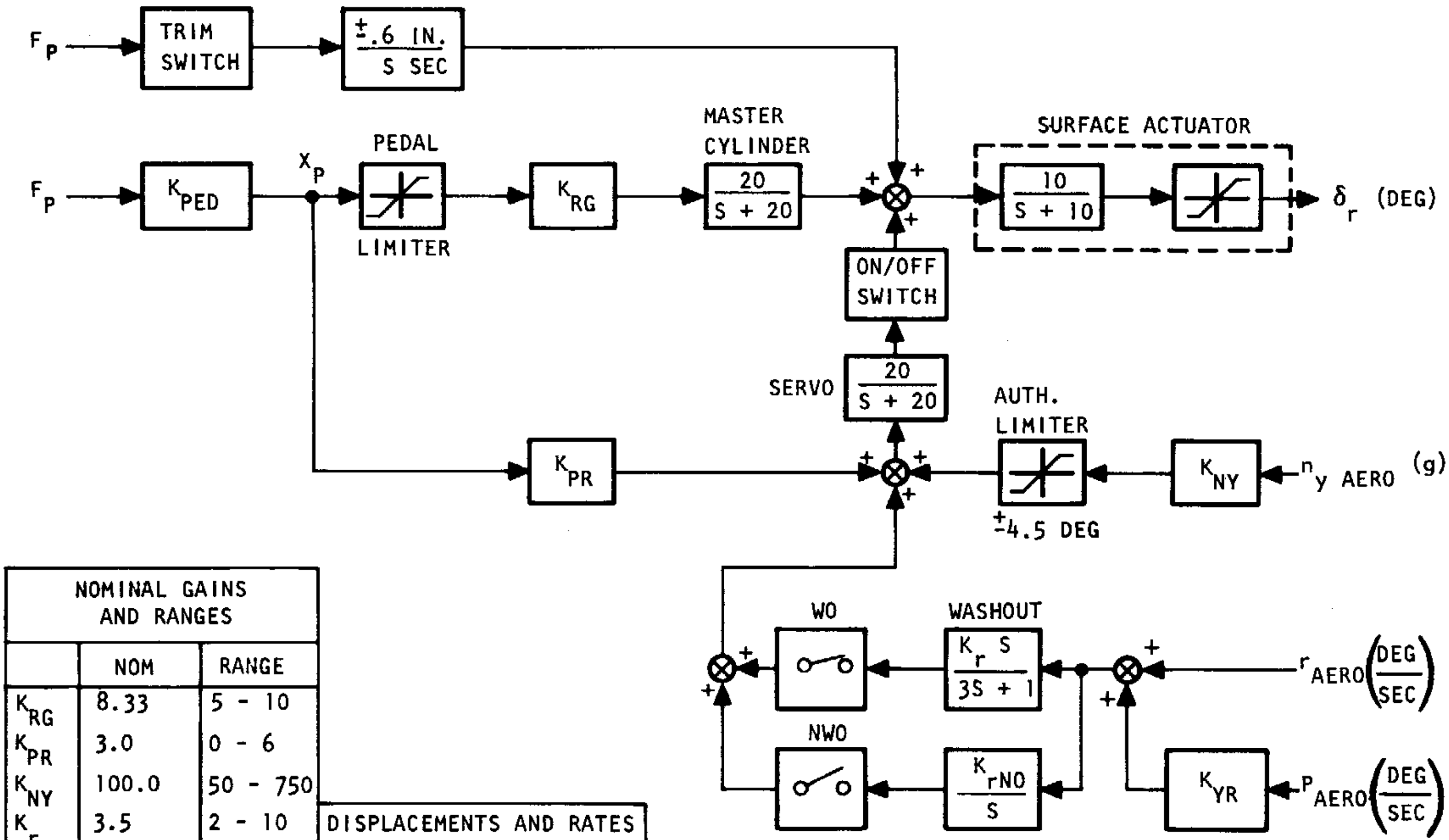
An interlock from this system to the spoiler control system provides automatic spoiler locking capability when full throttle is commanded by the pilot. With the pilot's switch in the open position and full throttle applied, the system energizes the spoiler lockout actuator driving the spoilers to the fully closed position. When the throttles are retracted



NOMINAL GAINS AND RANGES		
	NOM	RANGE
K_{WG}	1.0	0.75 - 1.8
K_{PA}	1.0	0 - 1.5
K_P	0.85	0.5 - 1.5
K_{RY}	0.4	0 - 2.0
K_ϕ	0.5	0.25 - 2.0
$K_{f\phi}$	50.0 V/V	-
K_W	4 DEG/LB	±25 LB/DEG

DISPLACEMENTS AND RATES		
	TRAVEL	ACTUATOR RATE
	±60 DEG	±50 DEG/SEC
X_W	±60 DEG	-

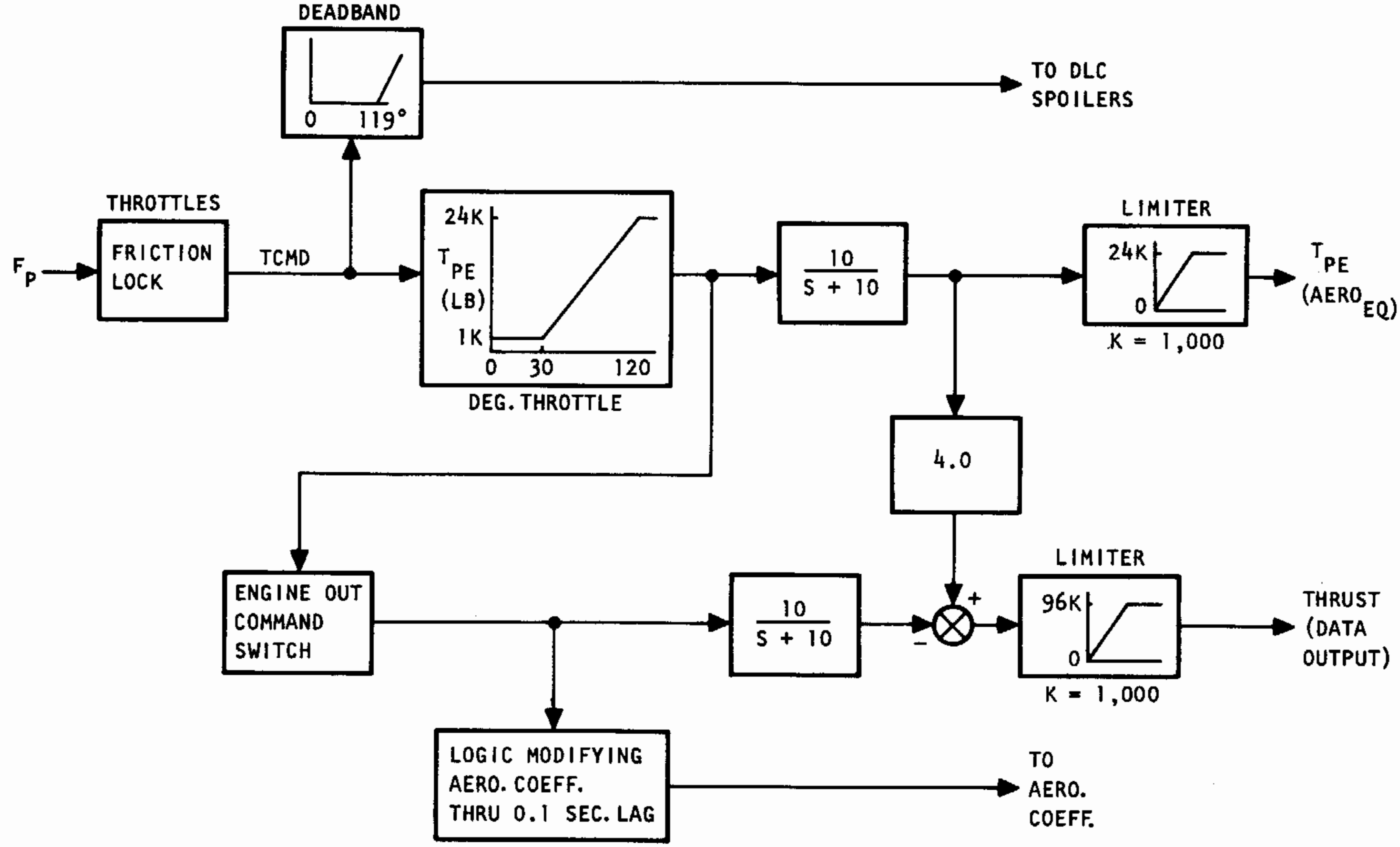
Figure 8. Roll Flight Control and Augmentation System



NOMINAL GAINS AND RANGES		
	NOM	RANGE
K_{RG}	8.33	5 - 10
K_{PR}	3.0	0 - 6
K_{NY}	100.0	50 - 750
K_r	3.5	2 - 10
K_{rNO}	1.75	1 - 5
K_{YR}	0.0	0 - 3
K_{PED}	0.05 $\frac{IN}{LB}$	-

DISPLACEMENTS AND RATES		
	TRAVEL	ACTUATOR RATE
δ_r	±25 DEG	±50 DEG/SEC
X_P	±3 IN.	-

Figure 9. Yaw Flight Control and Augmentation System



THROTTLES - 4 REQD, MAX BREAKOUT = 3 LB

ENGINE-OUT COMMAND - ON/OFF SWITCH, ON COMPUTER CONSOLE

Figure 10. Thrust Control System (TCS) and Engine Failure Mechanization

from the full power position the spoilers return to their "open" operating mode and respond to column position.

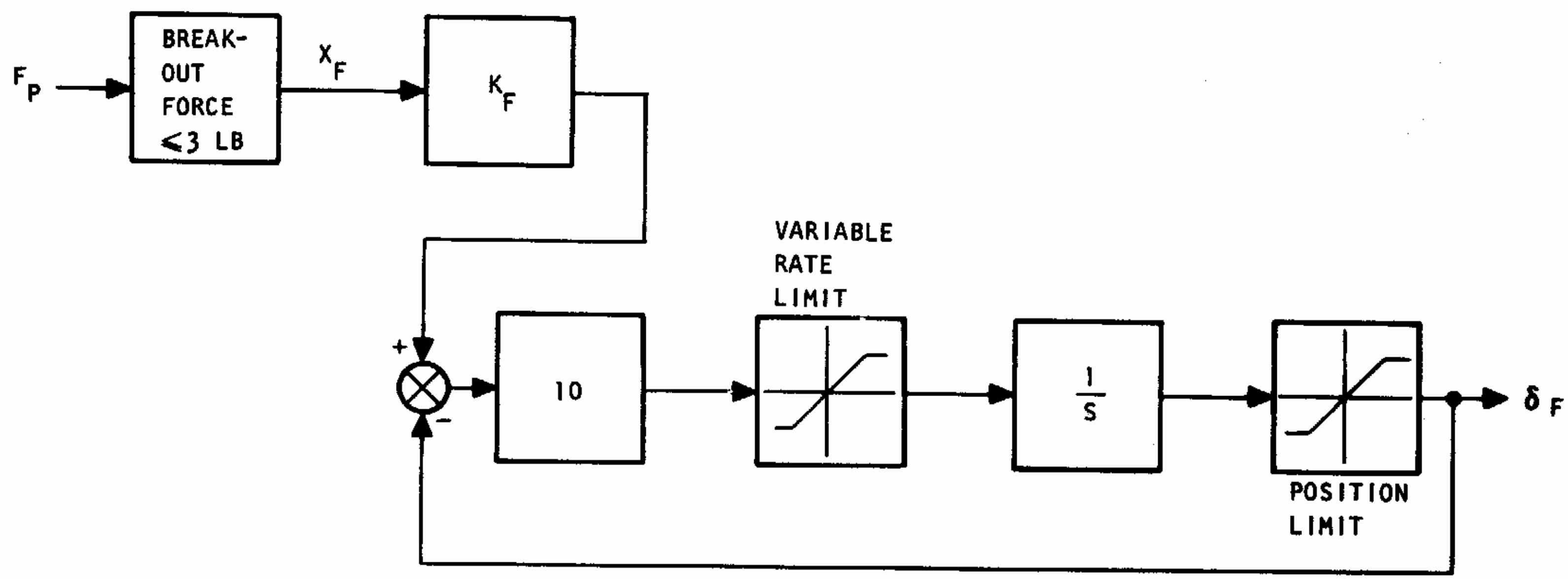
FLAP CONTROL SYSTEM

The flap control system provides pilot control of simulation model flap position. It is utilized during simulation testing of the waveoff characteristics. In practice the pilot positions the flap handle to the commanded position and the flap deflects at the maximum defined rate of the actuator to the commanded position. The simulated system utilizes a variable flap rate which is controlled by the computer operator. The system is defined in Figure 11.

AERODYNAMIC COEFFICIENTS

The aerodynamic coefficients as used in the equations of motion are plotted in terms of $\bar{q}S/T_{PE}$. The values for coefficients and the ranges of independent variables which were programmed into the six-degree-of-freedom model are defined in Figures 12 through 40 and Tables II, III, and IV. These data define all of the coefficients in the equations of Figure 6. Some of these coefficients are computed from a number of curves in these figures. The equations for computing these coefficients are identified in Figures 12, 16, 22, 26, and 38.

The independent variables for these coefficients are $\bar{q}S/T_{PE}$ and δ_F. The range of steady state $\bar{q}S/T_{PE}$ for this investigation varies from 0.75 to 6.0 depending on the trim condition selected. These are the values shown in Figures 13 through 40. The curves shown in these figures represent the data as they are programmed in the model. The actual points programmed appear on these figures as symbols. The computer program interpolates linearily between these points as indicated by the straight line connections of the symbols. The original curves were documented in Reference 6. The initial MST simulation model functional tests disclosed a need to extend the speed parameter range to avoid program "bombing" during pilot controlled throttle or T_{PE} transients. These transient effects were on the order of tenths of a second while the computer integration interval was on the order of milliseconds. This program "bombing" would have resulted in a simulation model impact on the study results. The problem was negated by extending the speed parameter range for the aerodynamic coefficient function generators and look-up tables out to 50. This permitted the digital computations to continue during the fractional second transients which occurred from large throttle step inputs. The values selected at $\bar{q}S/T_{PE}$ = 50 were either straight line extensions of the data of Figures 13 through 40 or asymptotes depending upon the coefficient. These values are listed in Table II.



DISPLACEMENT AND RATES				
	DISPL. (DEG)		RATE (DEG/SEC)	
SYMBOL	NOM.	RANGE	NOM.	RANGE
X_F	-	0 - 100	-	-
δ_F	-	23 - 93	2.5	2.5 - 20
K_F	0.7	0.5 - 1.4	-	-

Figure 11. Flap Position Control System

NZOT = NTPE - NITPE * EPSI

$$\left(\frac{N_{TOT}}{T_{PE}}\right)_{\alpha=0} = \left(\frac{N}{T_{PE}}\right)_{\substack{\alpha=0\\ \Phi}} - (57.3)\left(\frac{N_i}{T_{PE}}\right)(\epsilon)_{\alpha=0}$$

NZAT = NATPE + NITPE * (1-DEPSI)

$$\left(\frac{N_{TOT\,\alpha}}{T_{PE}}\right) = (57.3)\left(\frac{N_\alpha}{T_{PE}}\right)_{\substack{\alpha=0\\ \Phi}} + (57.3)\left(\frac{N_i}{T_{PE}}\right)\left(1 - \frac{d\epsilon}{d\alpha}\right)$$

NZDET = NITPE * DALDH

$$\left(\frac{N_{TOT\,\delta e}}{T_{PE}}\right) = (57.3)\left(\frac{N_i}{T_{PE}}\right)\left(\frac{\partial\alpha}{\partial\delta}\right)_H$$

NZDAT = KL * LDAT

$$\left(\frac{N_{TOT\,\delta_A}}{T_{PE}}\right) = K_{\mathcal{L}}\left(\frac{\mathcal{L}_{TOT\,\delta_A}}{T_{PE}\,b}\right)$$

NZDST = KS * NTPE

$$\left(\frac{\Delta N}{T_{PE}}\right)_{\delta_{SP}} = K_S\left(\frac{N}{T_{PE}}\right)_{\Phi,\alpha=0}$$

Figure 12. Normal Force Coefficient Equations

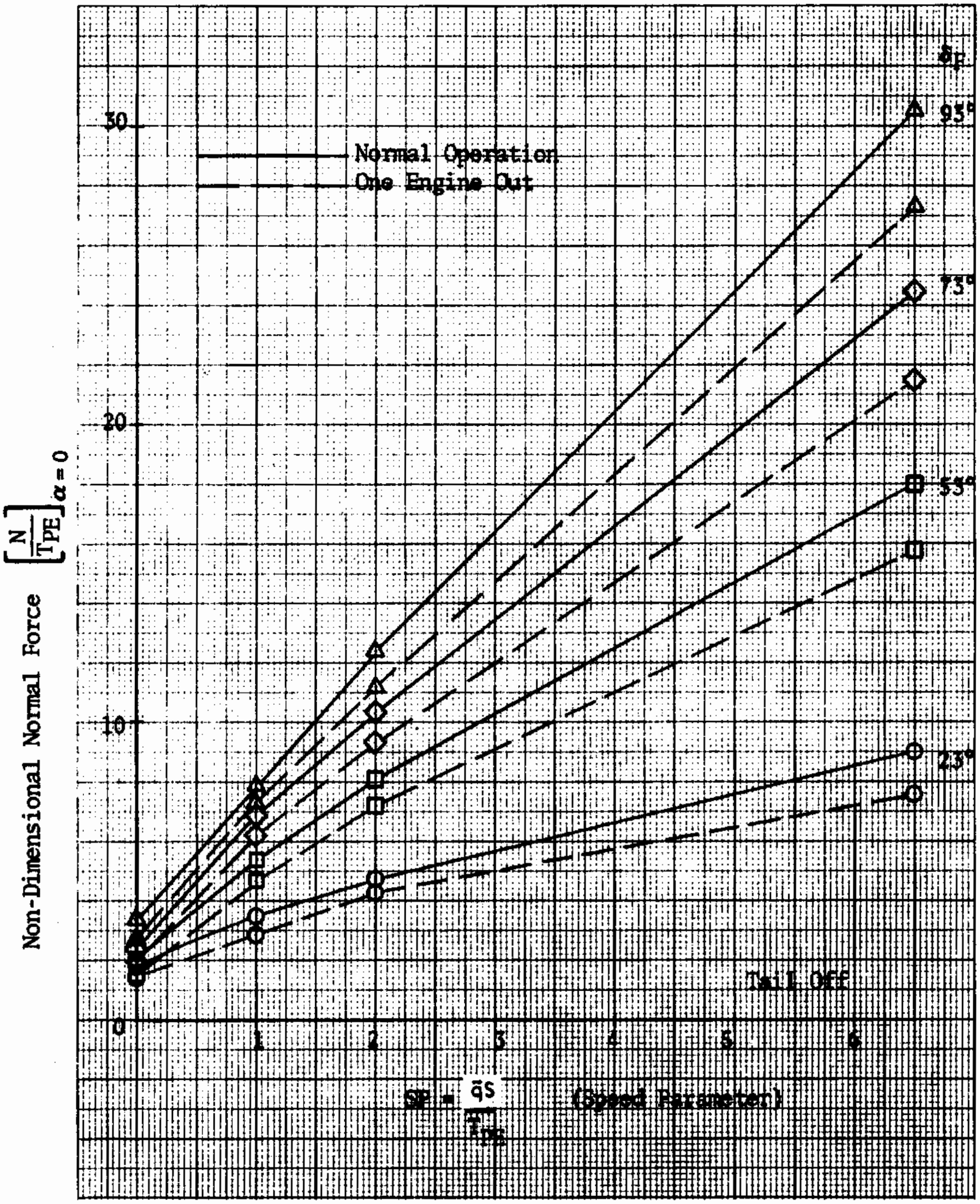


Figure 13. Lift Versus Speed Parameter Effect of One Engine Failure

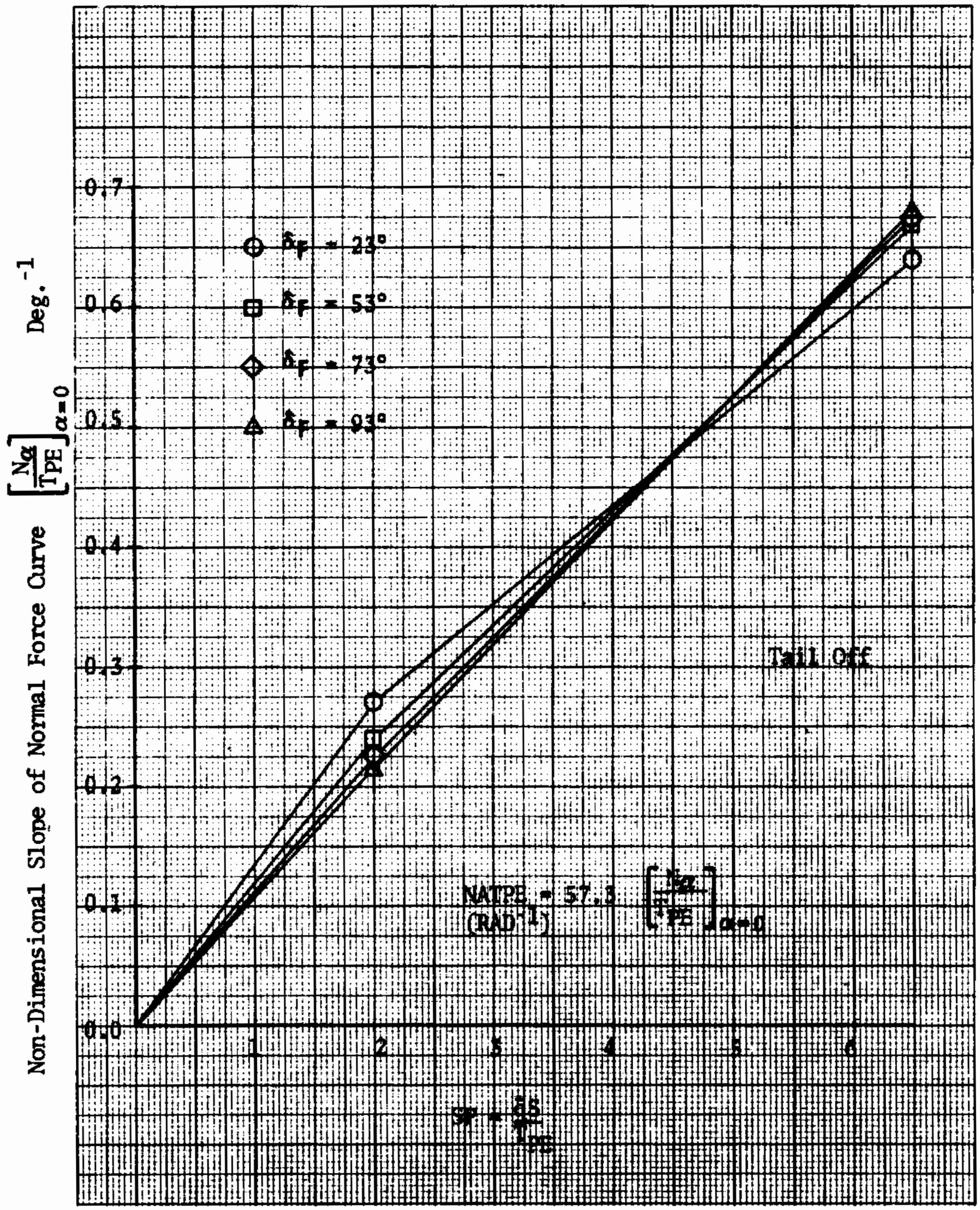


Figure 14. Slope of Normal Force Versus Speed Parameter

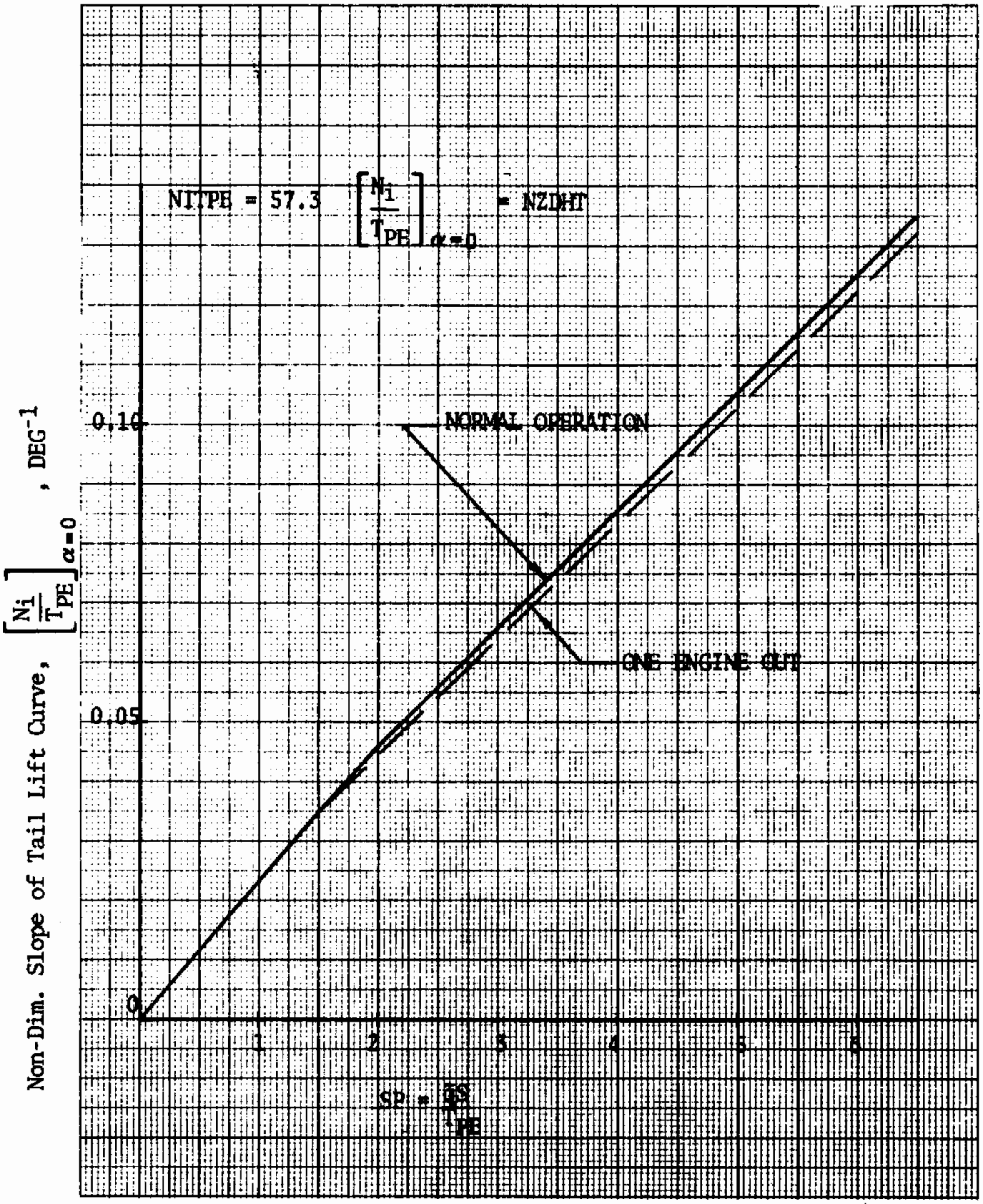


Figure 15. Tail Lift Effectiveness Versus Speed Parameter

$$DOT = CDO * SP + DELCT + NITPE * (DH\text{-}EPSI) * EPSI$$

$$\left(\frac{C_{TOT}}{T_{PE}}\right)_{\alpha=0} = (C_D)_{\beta\Phi,\,\alpha=0} \frac{\bar{q}}{T_{PE}/S} + \left(\frac{\Delta C}{T_{PE}}\right)_{\bar{\Phi},\,\alpha=0} + (57.3)\left(\frac{N_i}{T_{PE}}\right)[i - (\epsilon)_{\alpha=0}]\,(\epsilon)_{\alpha=0}$$

$$DAT = DELCD * SP + KD * DELNT * ALP - NTPE * ALP$$

$$\left(\frac{C_{TOT}}{T_{PE}}\right)_{\alpha} = (C_D - C_{D\ \alpha=0})_{\beta\Phi} \frac{\bar{q}}{T_{PE}/S} + K_D\left(\frac{\Delta N}{T_{PE}}\right)_{\bar{\Phi},\,\alpha=0}\alpha - \left(\frac{N}{T_{PE}}\right)_{\bar{\Phi},\,\alpha=0}\alpha$$

$$EPSI = EPSI00 + KEPSI * (NTPE/SP)$$

$$(\epsilon)_{\alpha=0} = \epsilon_{0,0} + K_\epsilon\left[\left(\frac{N}{T_{PE}}\right)_{\bar{\Phi},\,\alpha=0} \Big/ \frac{\bar{q}S}{T_{PE}}\right]$$

$$DELNT = NTPE - (CLIFPO) * SP$$

$$\left(\frac{\Delta N}{T_{PE}}\right)_{\bar{\Phi},\,\alpha=0} = \left(\frac{N}{T_{PE}}\right)_{\bar{\Phi},\,\alpha=0} - (C_L)_{\beta\Phi}\frac{\bar{q}}{T_{PE}/S}$$

Figure 16. Axial Force Coefficient Equations

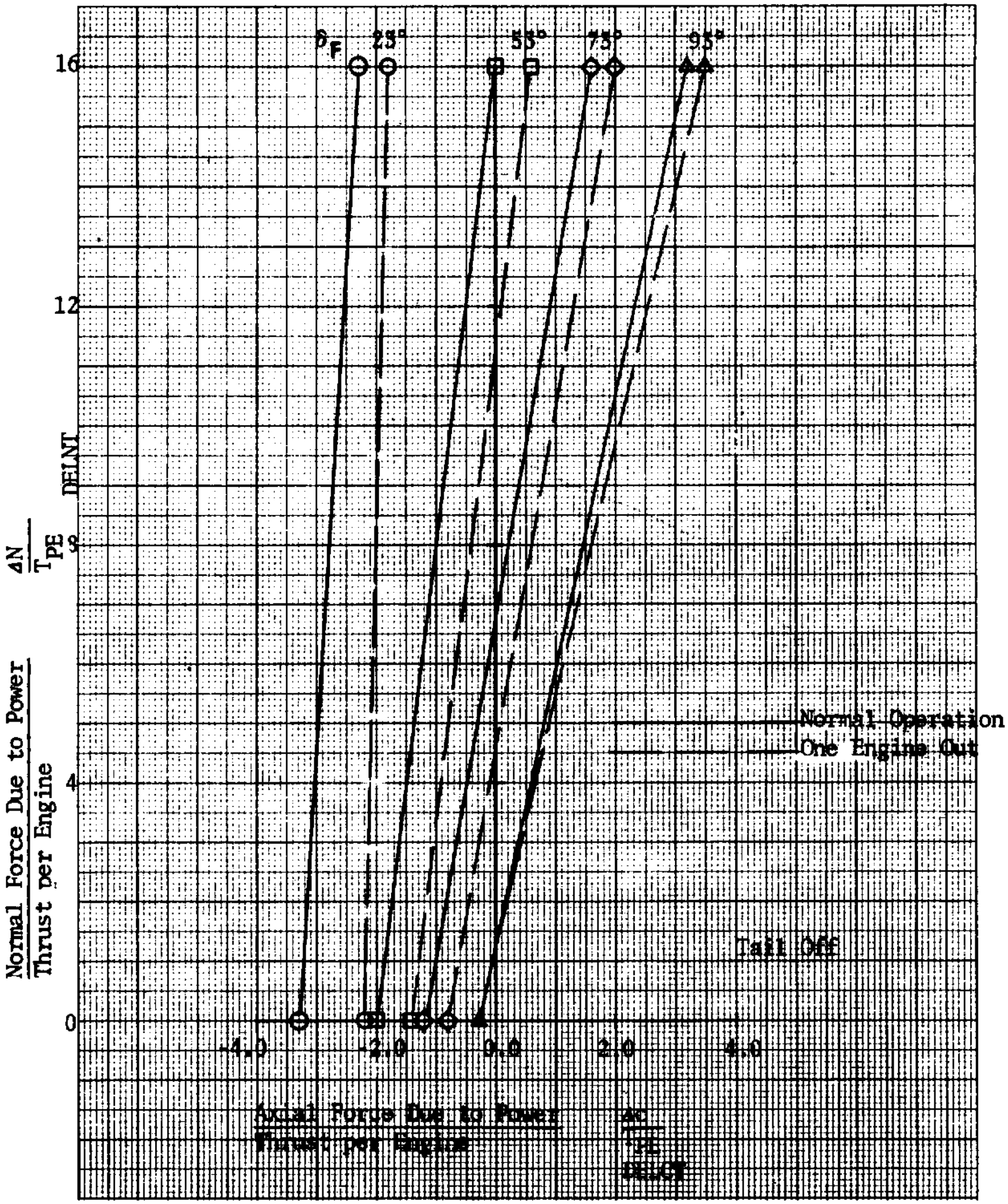


Figure 17. Drag Effects at $\alpha = 0°$
Effect of One Engine Failure

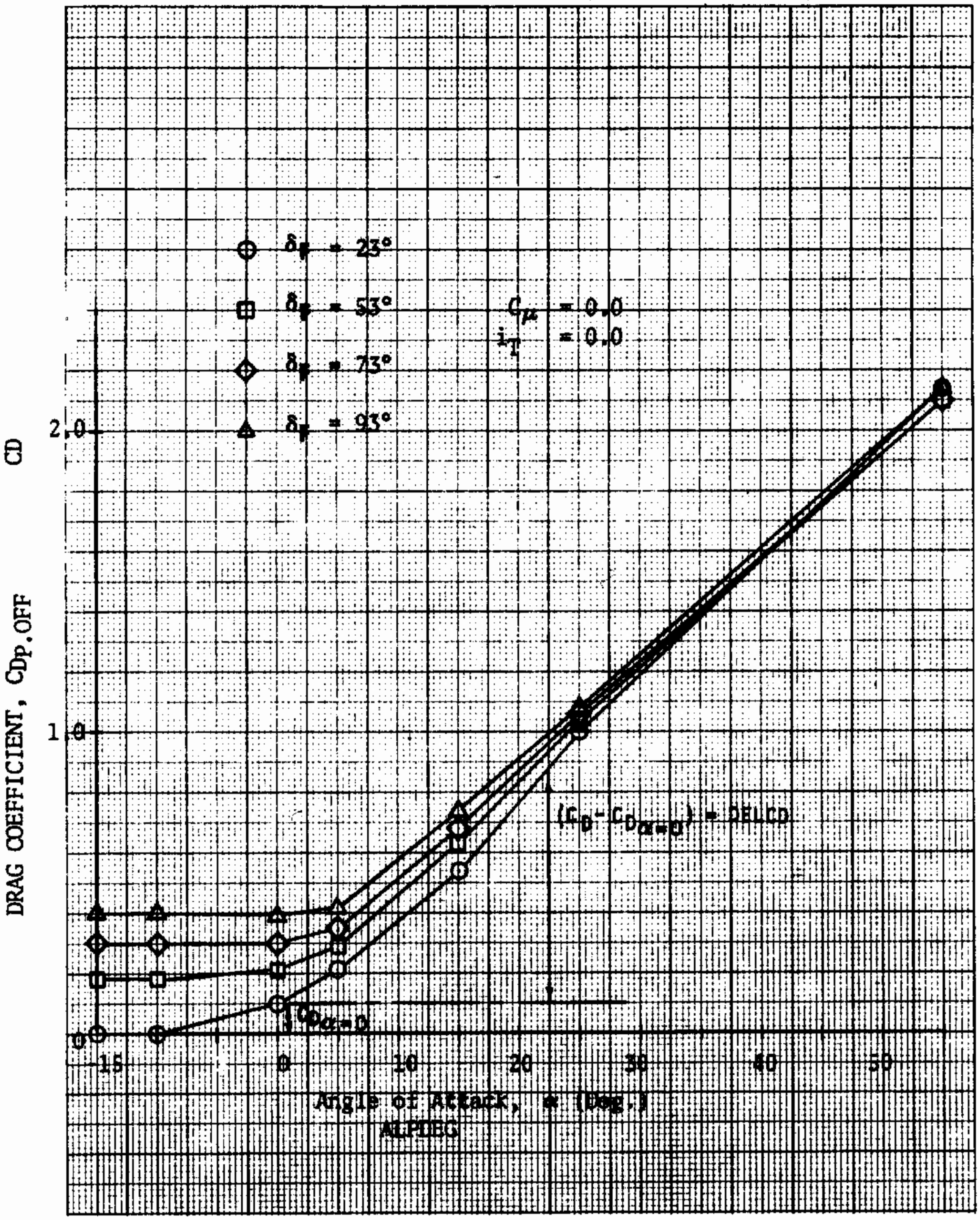


Figure 18. Power Off Drag Versus Angle of Attack

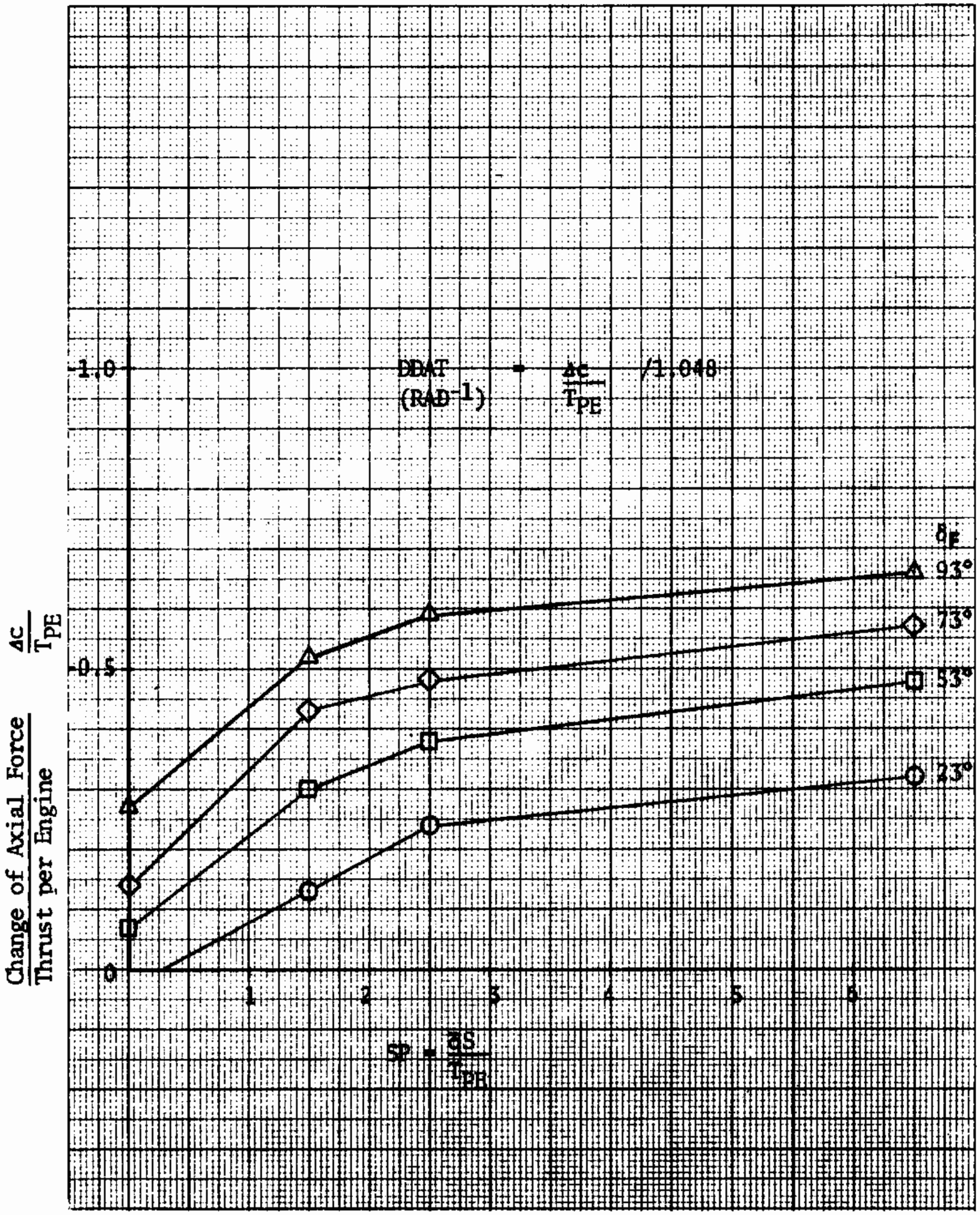


Figure 19. Axial Force Change Due to Full Roll Control

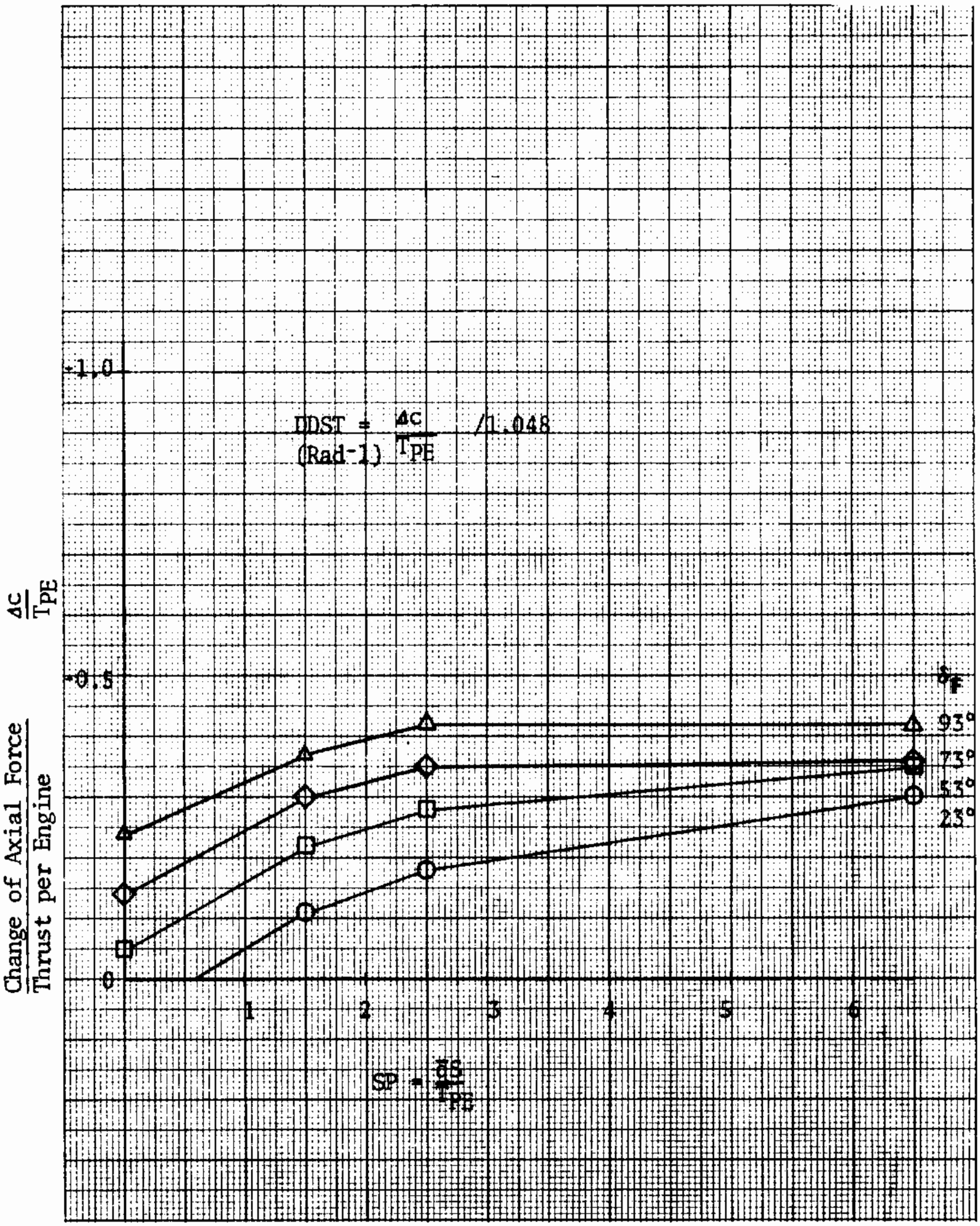


Figure 20. Axial Force Change Due to Full D.L.C. Application

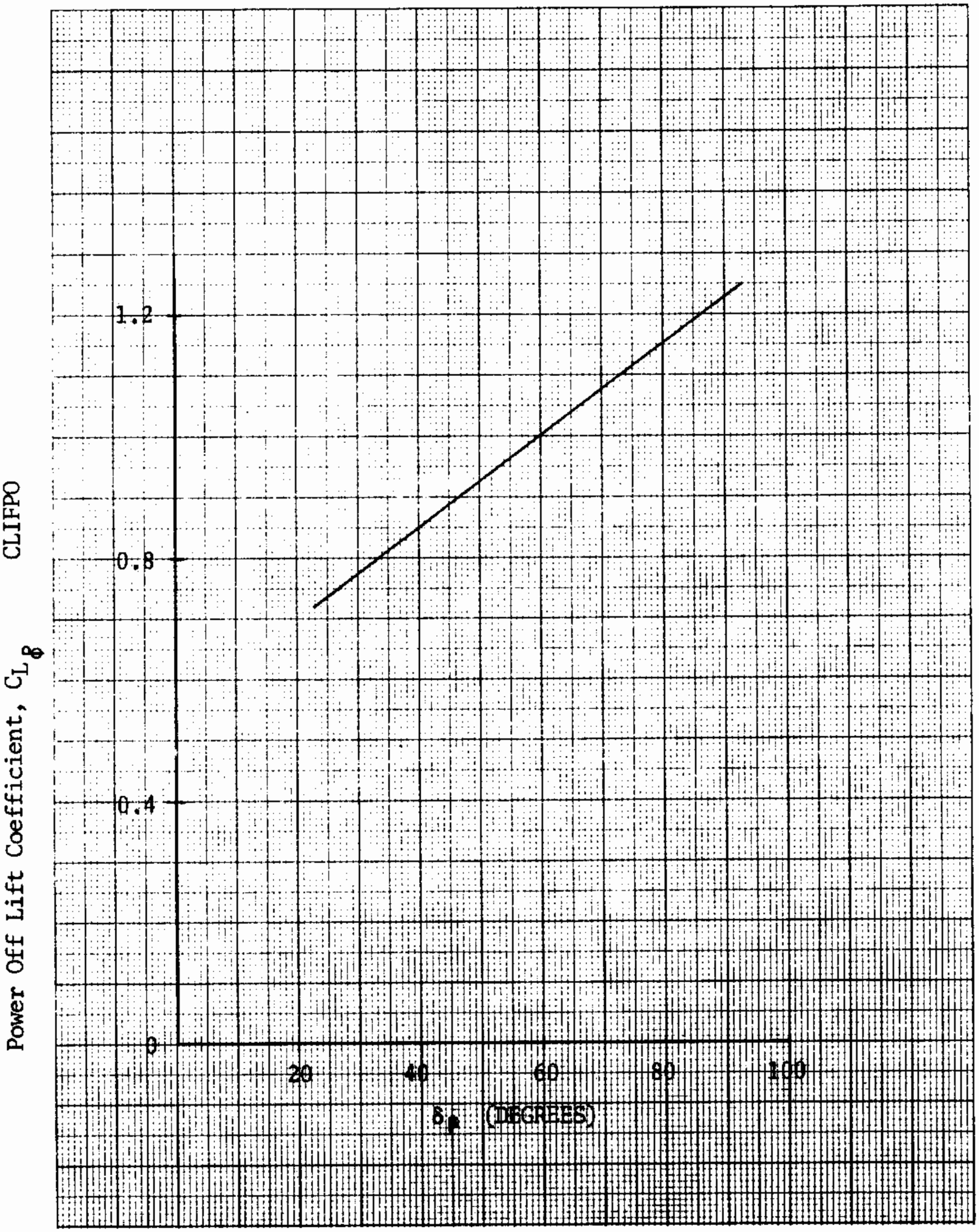


Figure 21. Power Off Lift Versus Flap Position

MOT = NTPE * (XCPC - XCGC) - NITPE * (XH/C-XCGC) * EPSI

$$\left(\frac{M_{TOT}}{T_{PE}\,\bar{C}}\right)_{\alpha=0} = \left(\frac{N}{T_{PE}}\right)_{\Phi,\alpha=0}\left[\frac{X_{CP}}{\bar{C}} - \frac{X_{CG}}{\bar{C}}\right]_{\Phi,\ \alpha=0} - 57.3\left(\frac{N_i}{T_{PE}}\right)\left[\frac{X_H}{\bar{C}} - \frac{X_{CG}}{\bar{C}}\right](\epsilon)_{\alpha=0}$$

MAT = NATPE * (XACC - XCGC) - NITPE * (XH/C - XCGC) * (1 - DEPSI)

$$\left(\frac{M_{TOT\alpha}}{T_{PE}\,\bar{C}}\right) = (57.3)\left(\frac{N_\alpha}{T_{PE}}\right)_{\Phi}\left[\frac{X_{AC}}{\bar{C}} - \frac{X_{CG}}{\bar{C}}\right]_{\Phi} - (57.3)\left(\frac{N_i}{T_{PE}}\right)\left[\frac{X_H}{\bar{C}} - \frac{X_{CG}}{\bar{C}}\right]\left(1 - \frac{d\epsilon}{d\alpha}\right)$$

MQT = - NITPE * (LH/C)

$$\left(\frac{M_{TOT\dot{\theta}}}{T_{PE}\,\bar{C}}\right) = -57.3\left(\frac{N_i}{T_{PE}}\right)\frac{\ell H}{\bar{C}}$$

MDHT = NITPE* (XH/C- XCGC)

$$\left(\frac{M_{TOT\ i}}{T_{PE}\,\bar{C}}\right) = 57.3\left(\frac{N_i}{T_{PE}}\right)\left[\frac{X_H}{\bar{C}} - \frac{X_{CG}}{\bar{C}}\right]$$

MDET = MDHT * DALDH

$$\left(\frac{M_{TOT\ \delta e}}{T_{PE}\,\bar{C}}\right) = -57.3\left(\frac{N_i}{T_{PE}}\right)\left[\frac{X_H}{\bar{C}} - \frac{X_{CG}}{\bar{C}}\right]\left(\frac{\partial\alpha}{\partial\delta}\right)_H$$

MADTT = - NITPE * LH/C * DEPSI

$$\left(\frac{M_{TOT\dot{\alpha}}}{T_{PE}\,\bar{C}}\right) = -57.3\left(\frac{N_i}{T_{PE}}\right)\frac{\ell H}{\bar{C}}\left(\frac{d\epsilon}{d\alpha}\right)$$

Figure 22. Pitching Moment Coefficient Equations

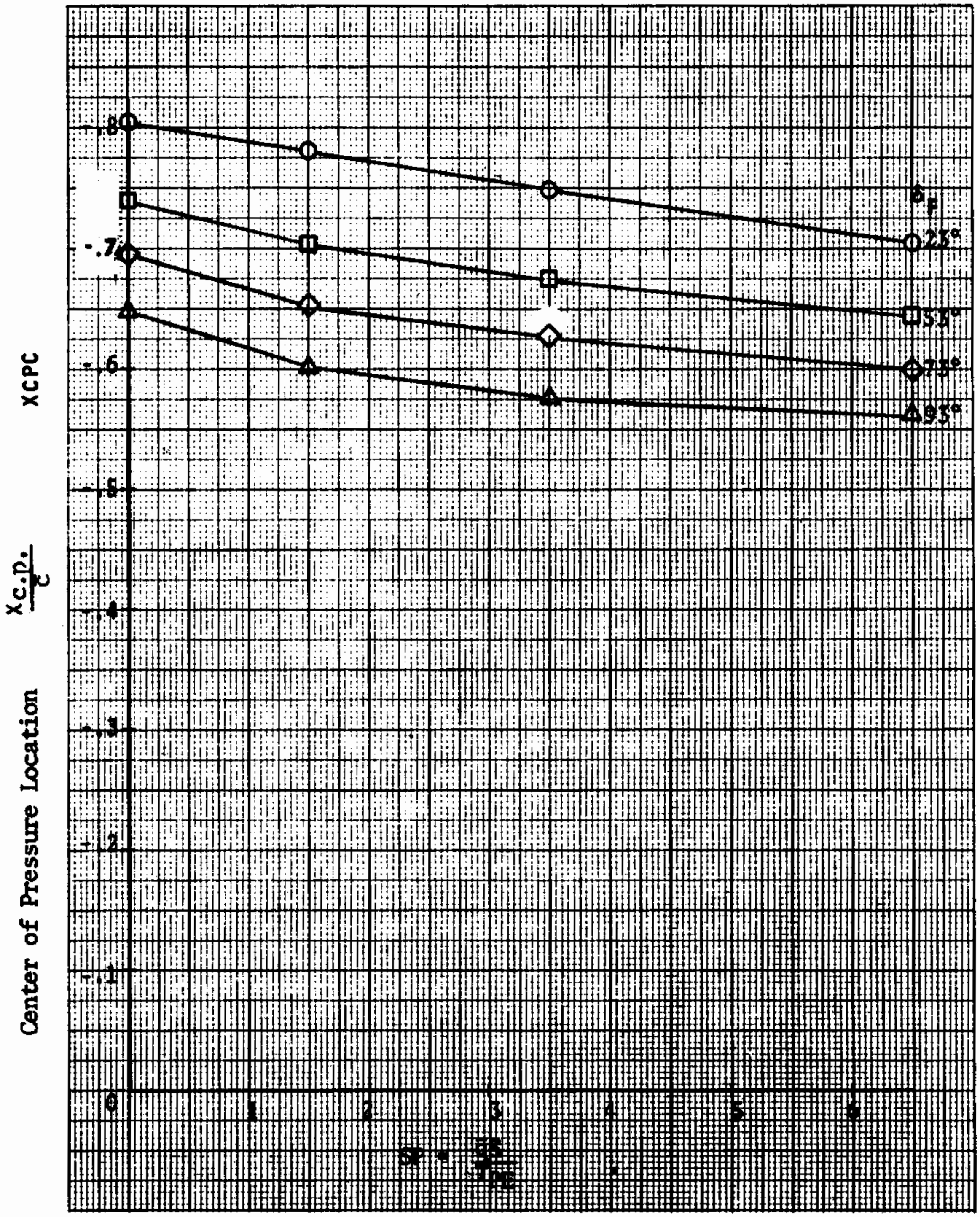


Figure 23. C.P. Location Versus Speed Parameter

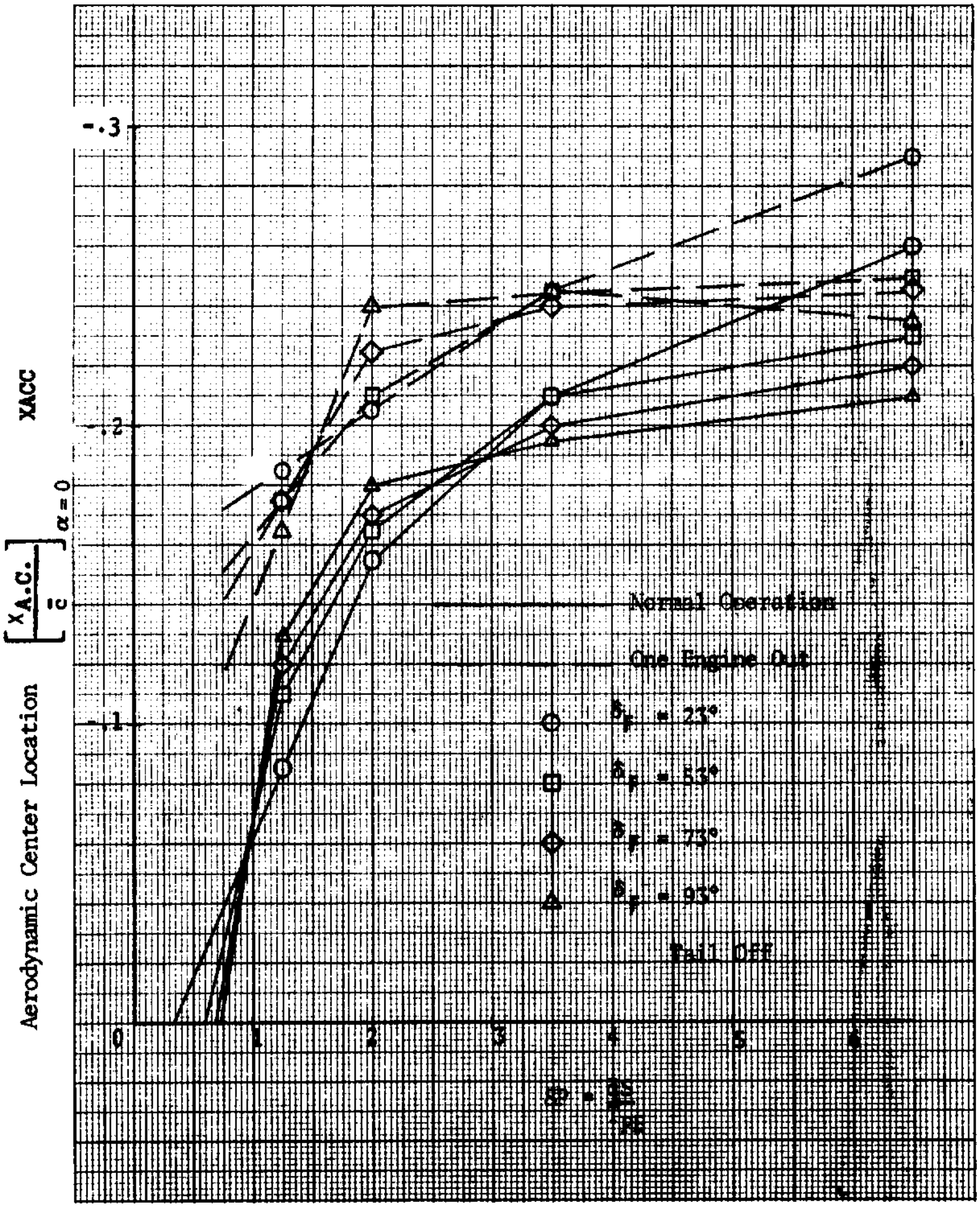


Figure 24. A.C. Location Versus Speed Parameters

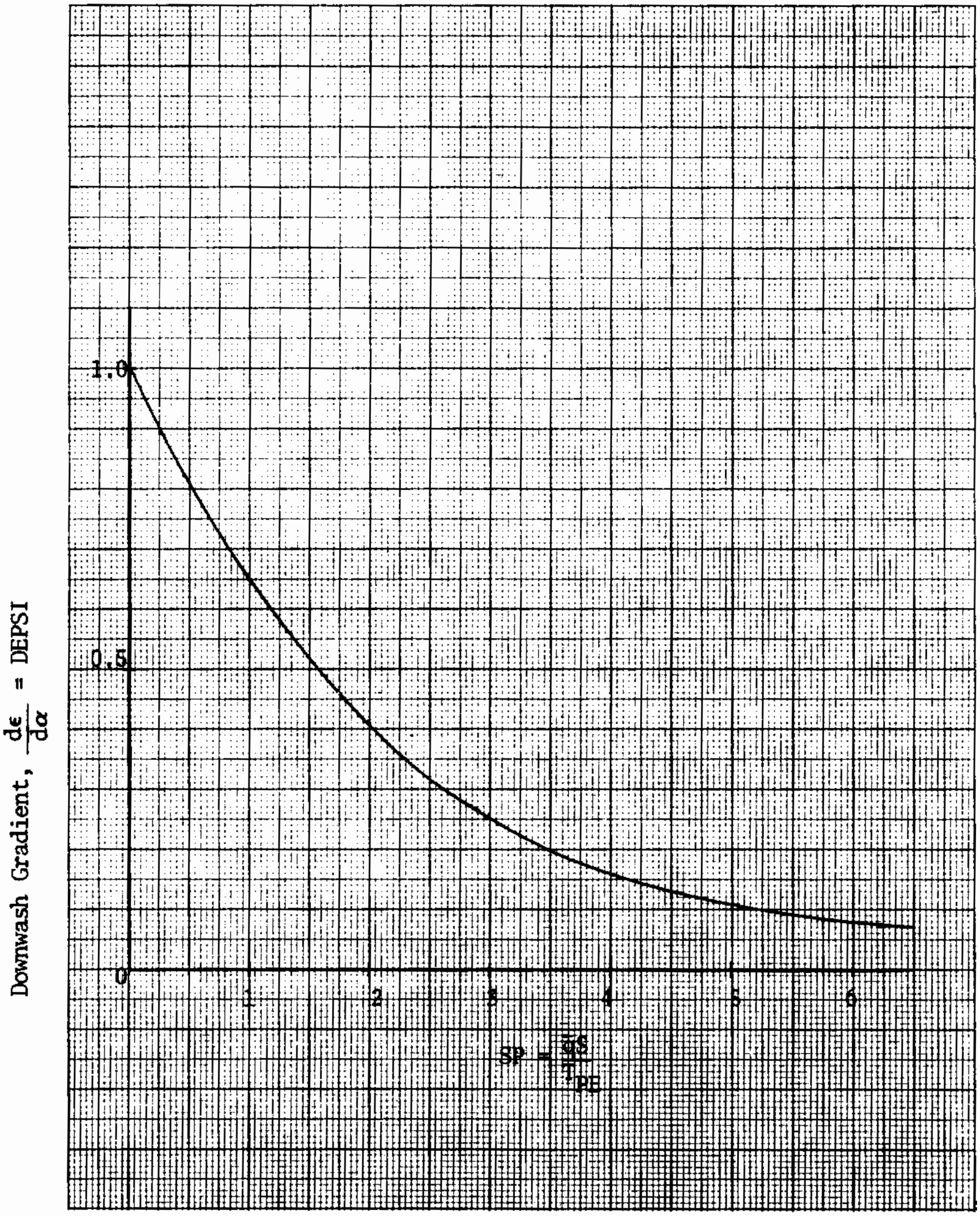


Figure 25. Downwash Gradient Versus Speed Parameter

SIDE FORCE: YRT = YAVTPE * 2 * LVB

$$\left(\frac{Y_{TOTr}}{T_{PE}}\right) = 57.3\left(\frac{Y_{\alpha v}}{T_{PE}}\right)\frac{\ell_v}{b/2}$$

YDRT = YAVTPE * DALDV

$$\left(\frac{Y_{TOT\delta R}}{T_{PE}}\right) = 57.3\left(\frac{Y_{\alpha v}}{T_{PE}}\right)\left(\frac{\partial \alpha}{\partial \delta}\right)_v$$

YAWING MOMENT: NDRT = -LVB * YAVTPE * DALDV

$$\left(\frac{N_{\delta R}}{T_{PE} b}\right) = -\frac{\ell_v}{b} 57.3\left(\frac{Y_{\alpha v}}{T_{PE}}\right)\left(\frac{\partial \alpha}{\partial \delta}\right)_v$$

NDAT = KN * LDAT

$$\frac{N_{TOT\delta a}}{T_{PE}\, b} = K_N\left(\frac{\mathcal{L}_{TOT\delta a}}{T_{PE} b}\right)$$

ROLLING MOMENT: LDRT = ZVB * YAVTPE * DALDV

$$\left(\frac{\mathcal{L}_{TOT\delta R}}{T_{PE}\, b}\right) = \frac{Z_v}{b} 57.3\left(\frac{Y_{\alpha v}}{T_{PE}}\right)\left(\frac{\partial \alpha}{\partial \delta}\right)_v$$

Figure 26. Lateral - Directional Coefficient Equations

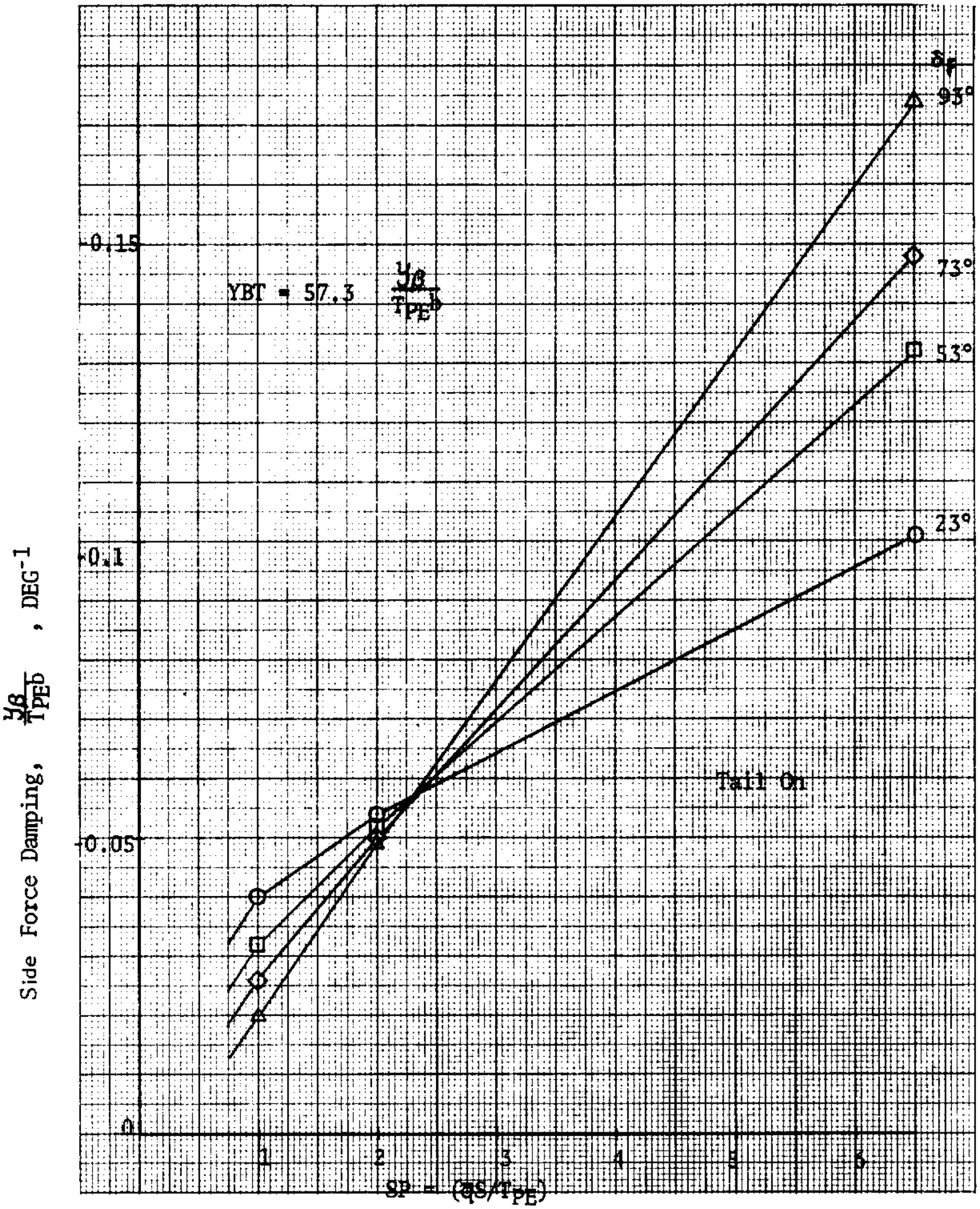


Figure 27. Side Force Damping Versus Speed Parameter

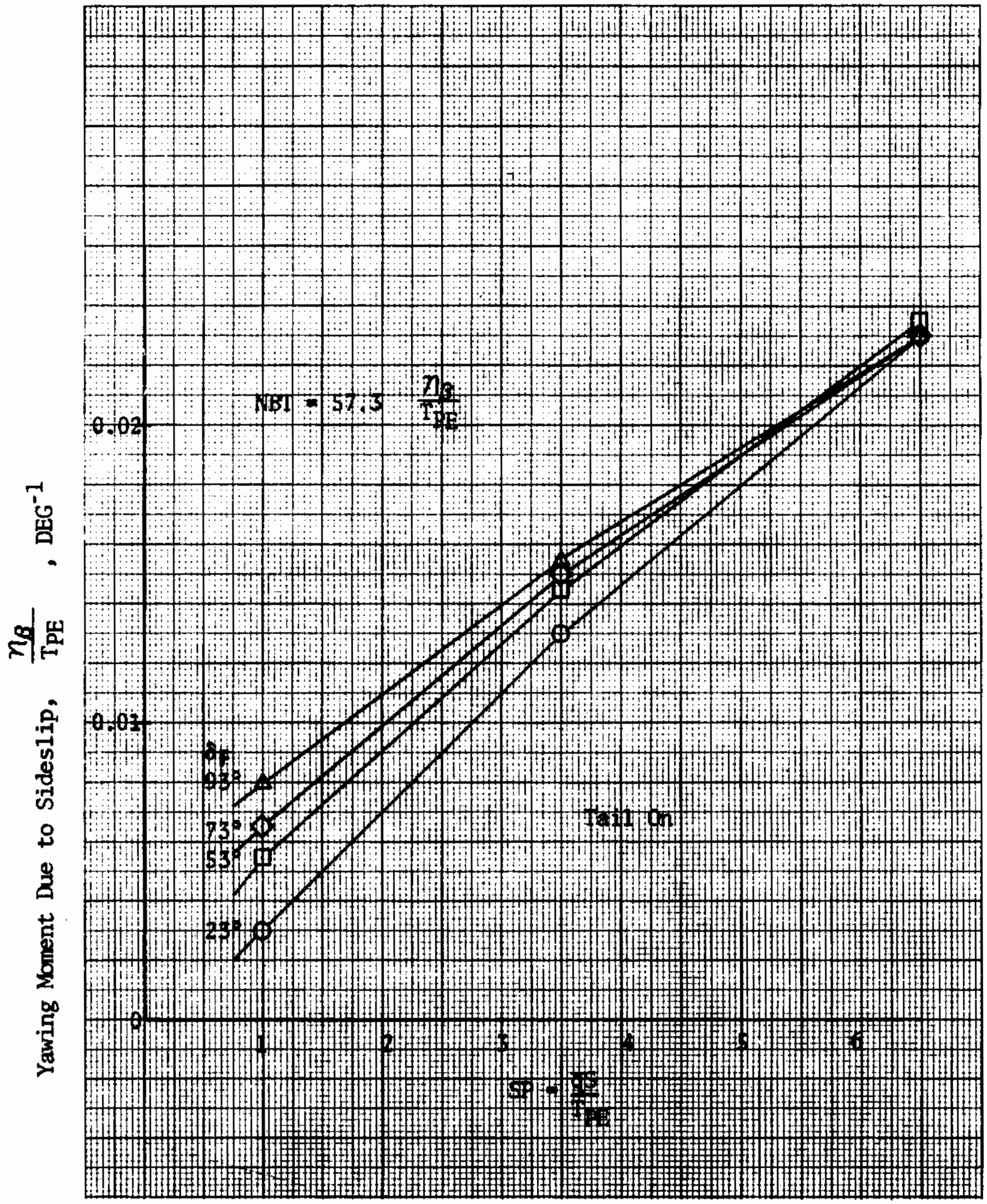


Figure 28. Yawing Moment Due to Sideslip Angle

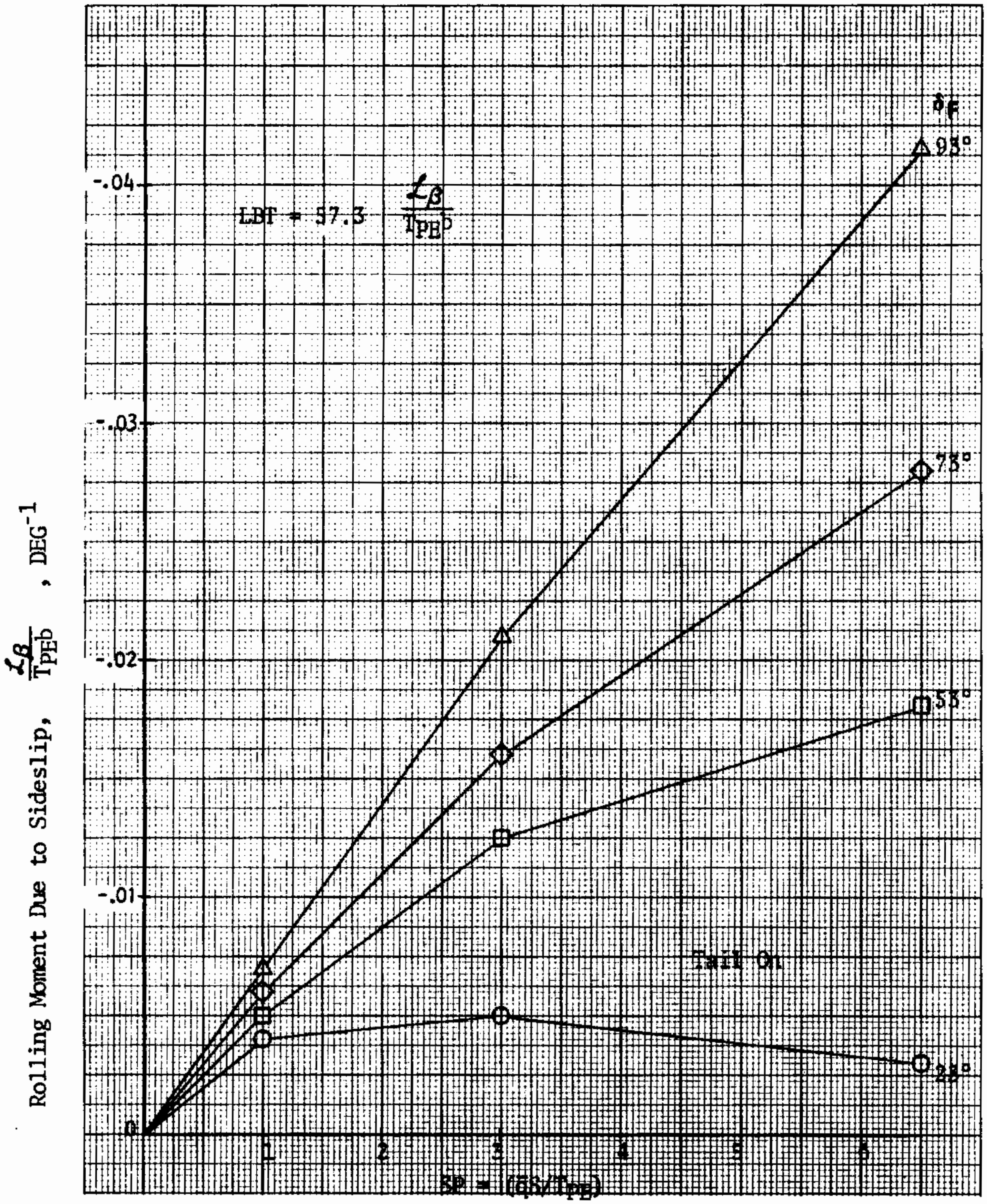


Figure 29. Rolling Moment Due to Sideslip Angle

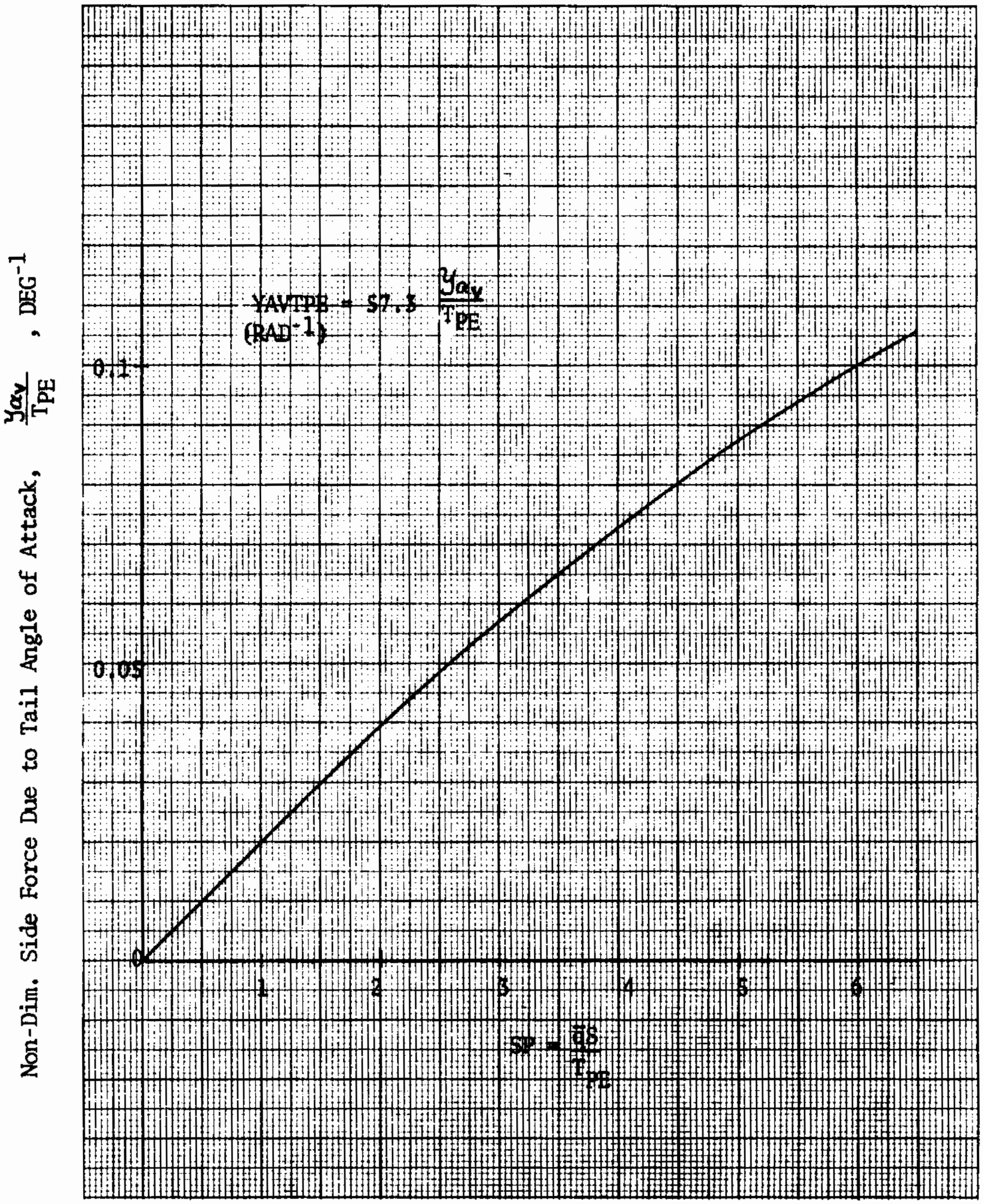


Figure 30. Side Force Derivative Versus Speed Parameter

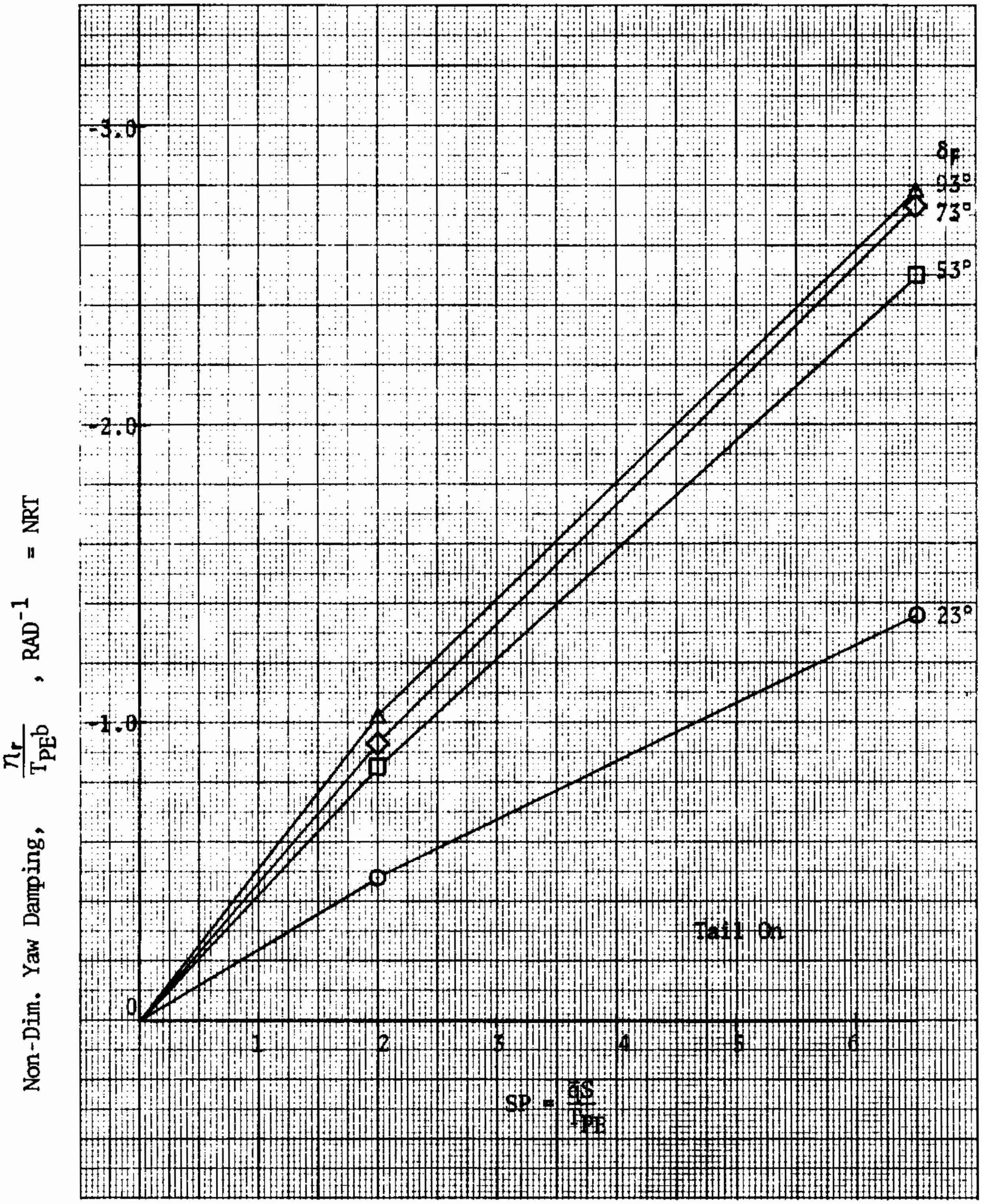


Figure 31. Yaw Damping Derivative Versus Speed

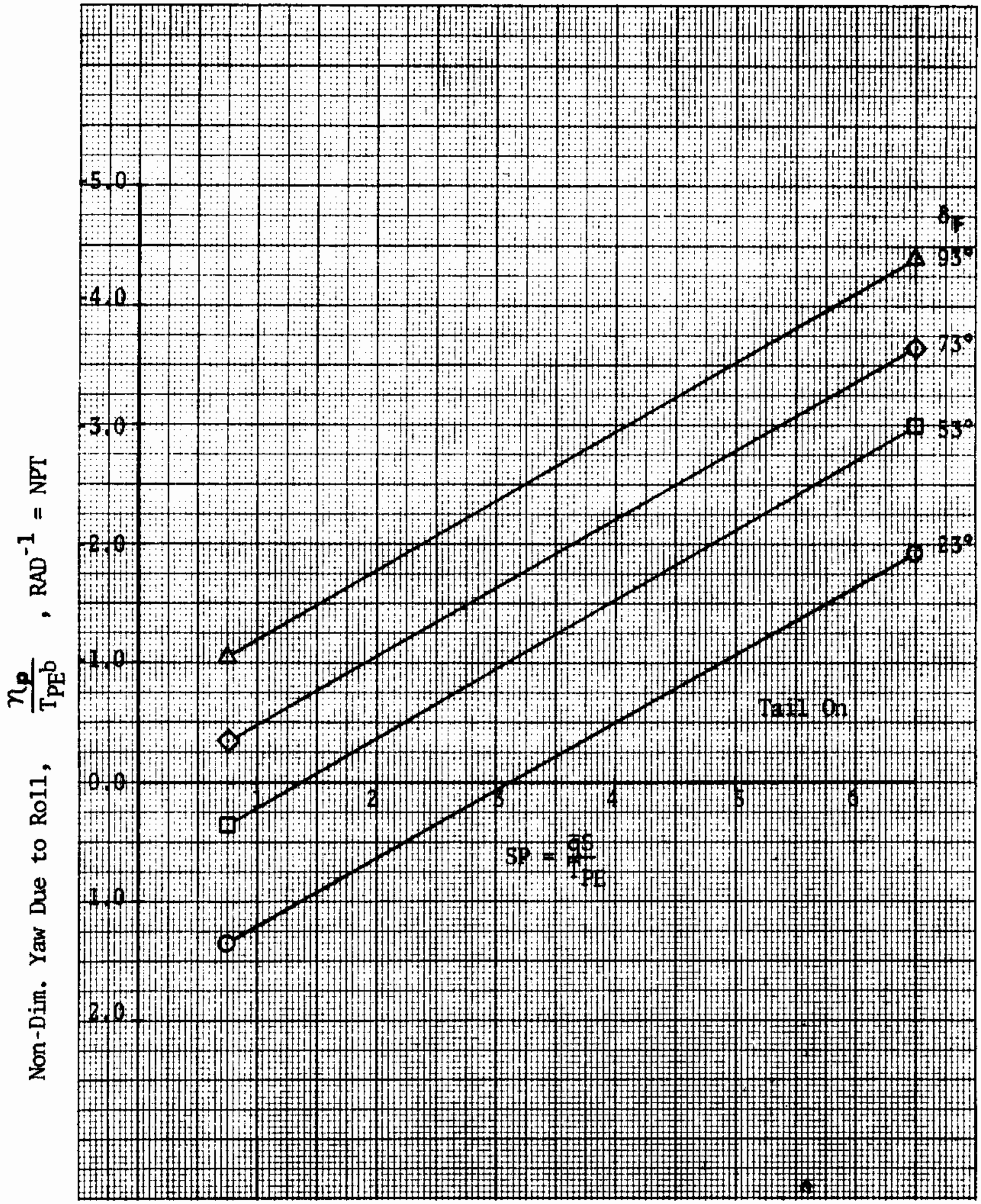


Figure 32. Yaw Due to Roll Versus Speed Parameter

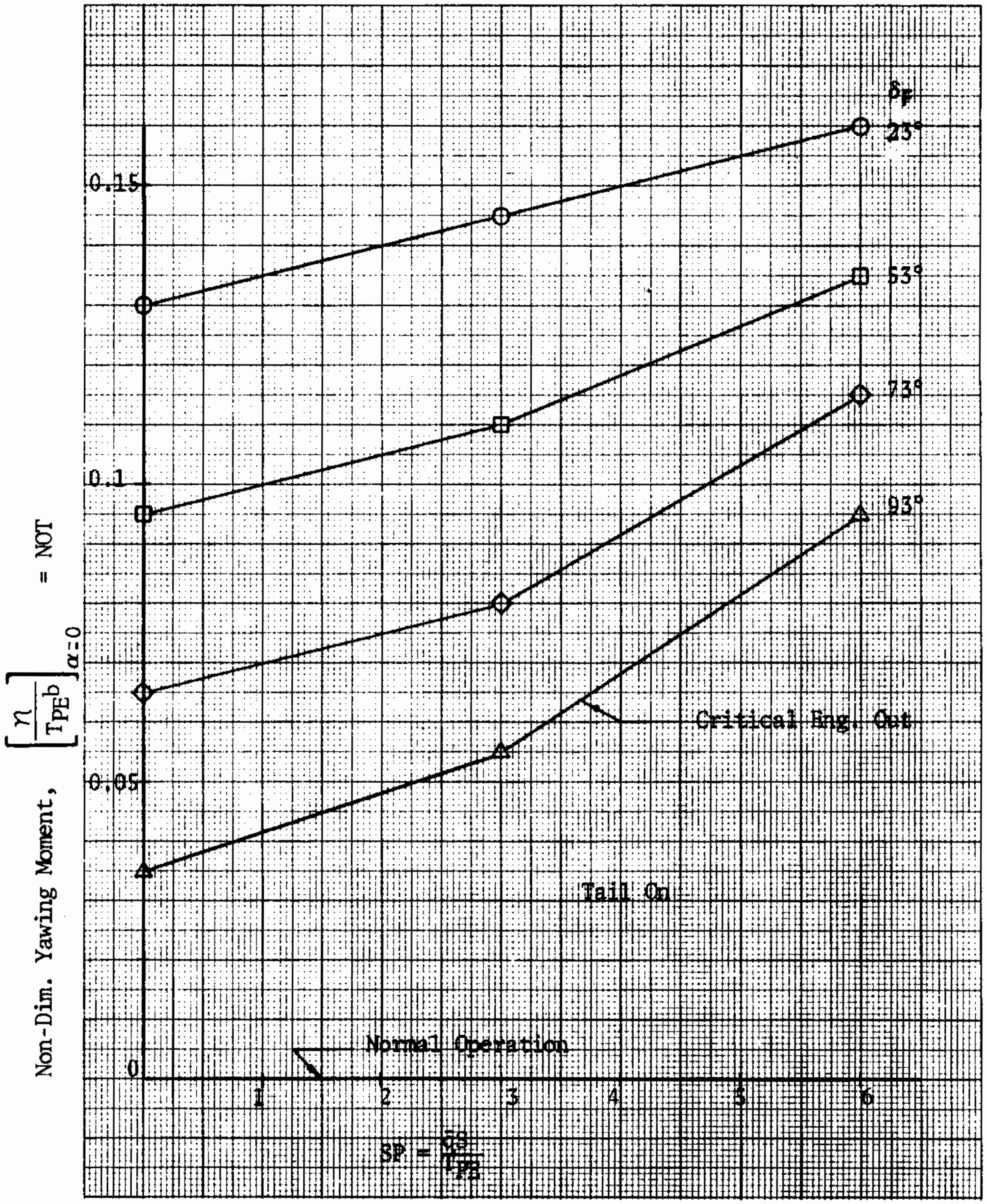


Figure 33. Yawing Moment Due to Right Outboard Engine Failure

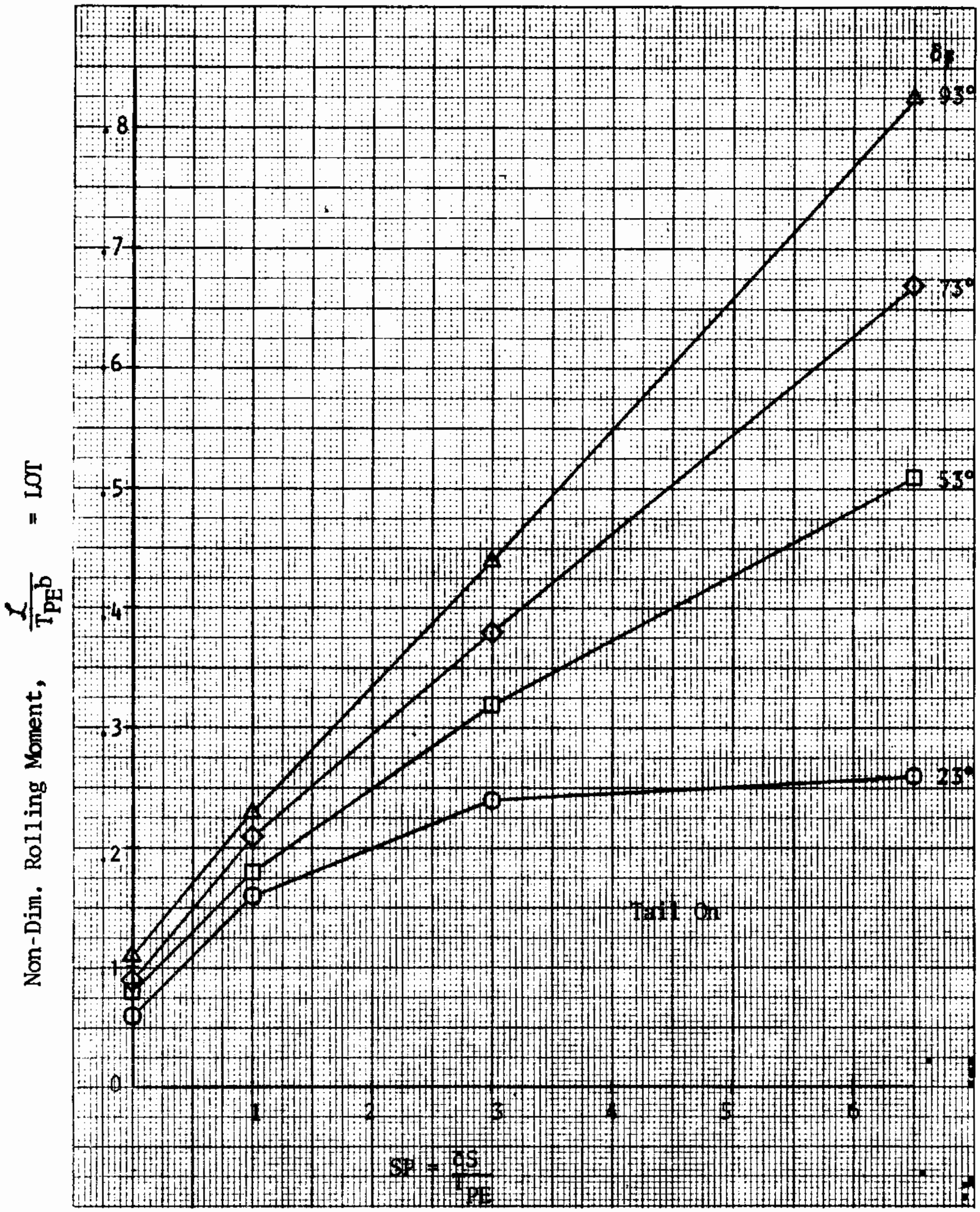


Figure 34. Roll Due to Right Outb'd Engine Failure versus Speed Parameter

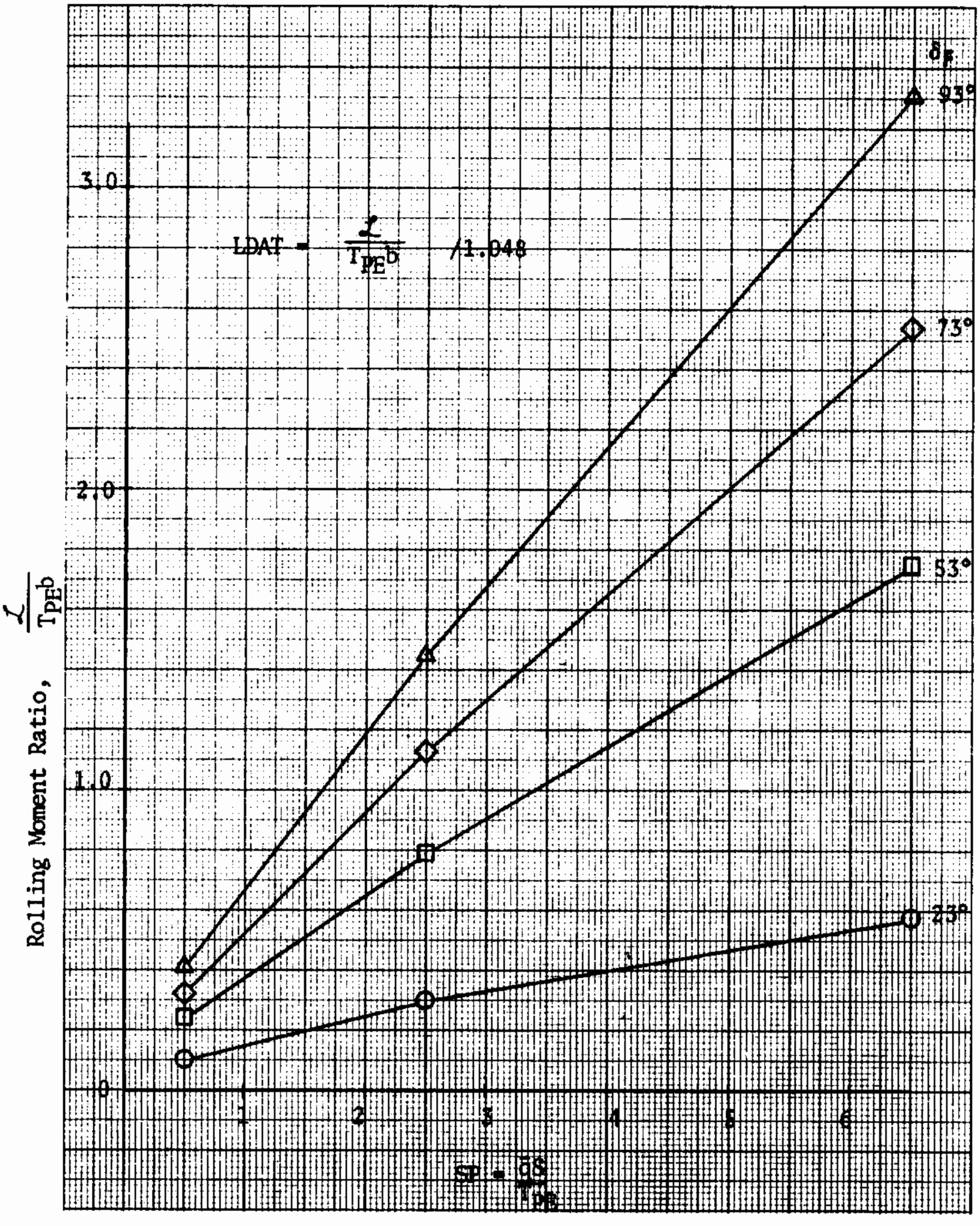


Figure 35. Maximum Roll Control Moment Versus Speed Parameter

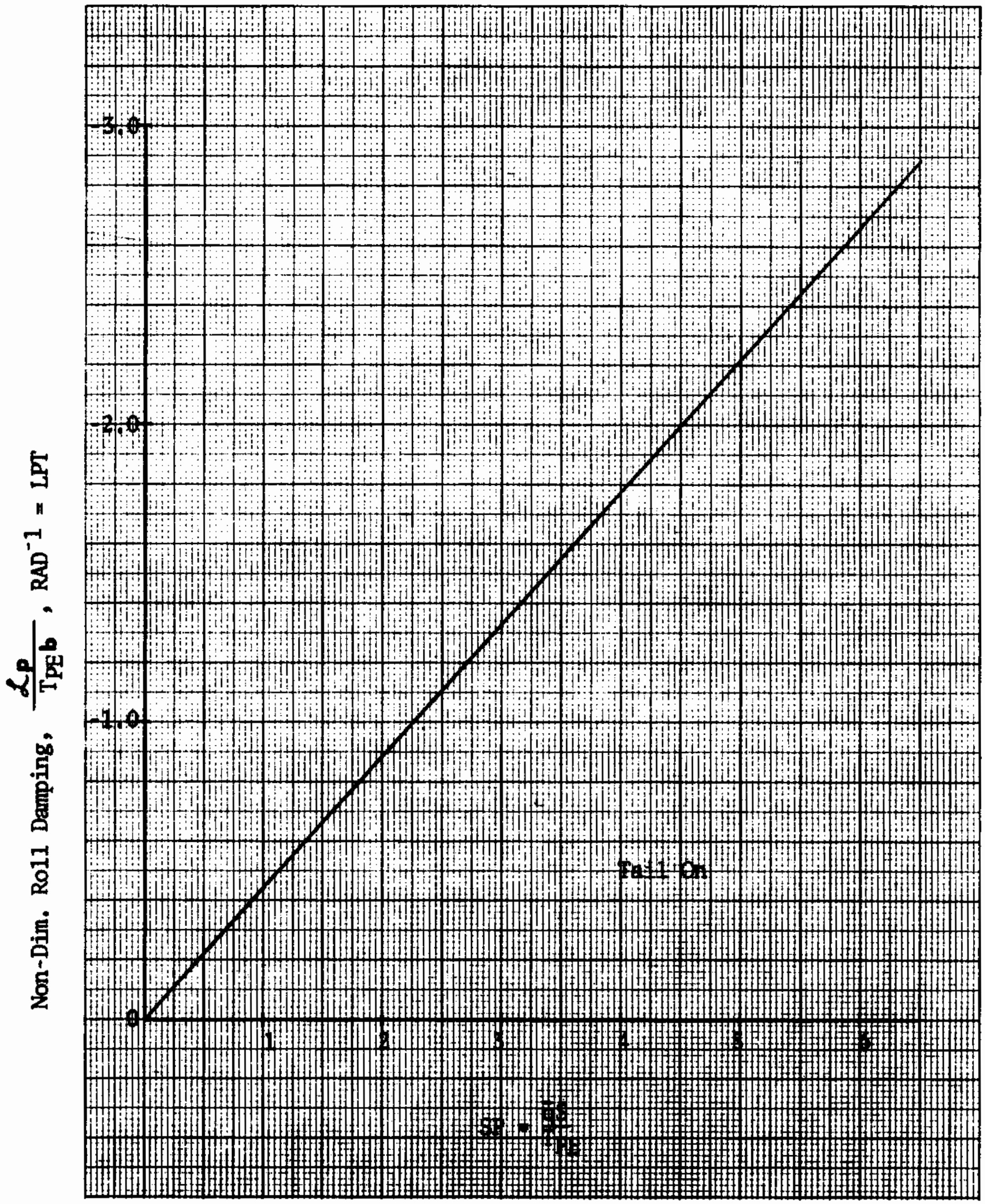


Figure 36. Roll Damping Derivative Versus Speed Parameter

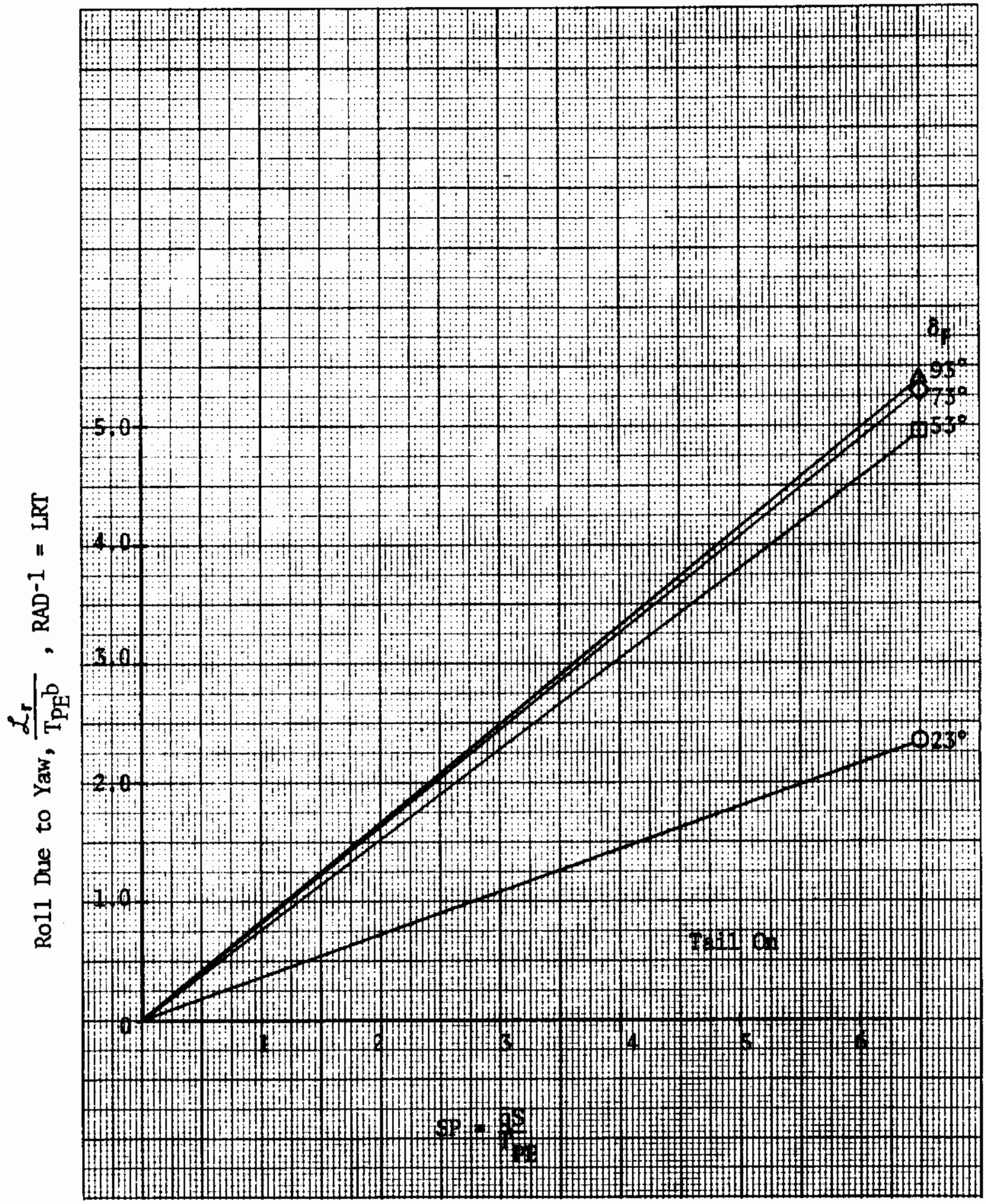


Figure 37. Roll-Due-to-Yaw Parameter

NORMAL FORCE COMPONENT

NZGND = GPFCTR*DCLGE*SP + NITPE*DEPSIG

AXIAL FORCE COMPONENT

DGND = GPFCTR*DCLGE*SP/(CLOGE-CLIFPO)
*[(DELCT/SP-CDO) + 0.8 *4.0/SP]

PITCHING MOMENT COMPONENT

MGND = (GPFCTR*DLCGE*MOT/NZOT) + NITPE
*(XHC-XCGC)*DEPSIG

WHERE:

GPFCTR = AFGEN(PRCTGP, HCBARB)*1

HCBARB = (H+HCBAR)/B

DCLGE = -AFGEN(TDCLGE,CLOGE)*2

DEPSIG = CLOGE/[3.1416*AR*(0.8+QUAD)]

QUAD = [(0.8*H+8.0*HCBAR=4HV)/B]^2

CLOGE = (NTPE + NATPE*ALP)/SP

*1 - See Figure 40

*2 - See Figure 39

Figure 38. Ground Effect Component Equations

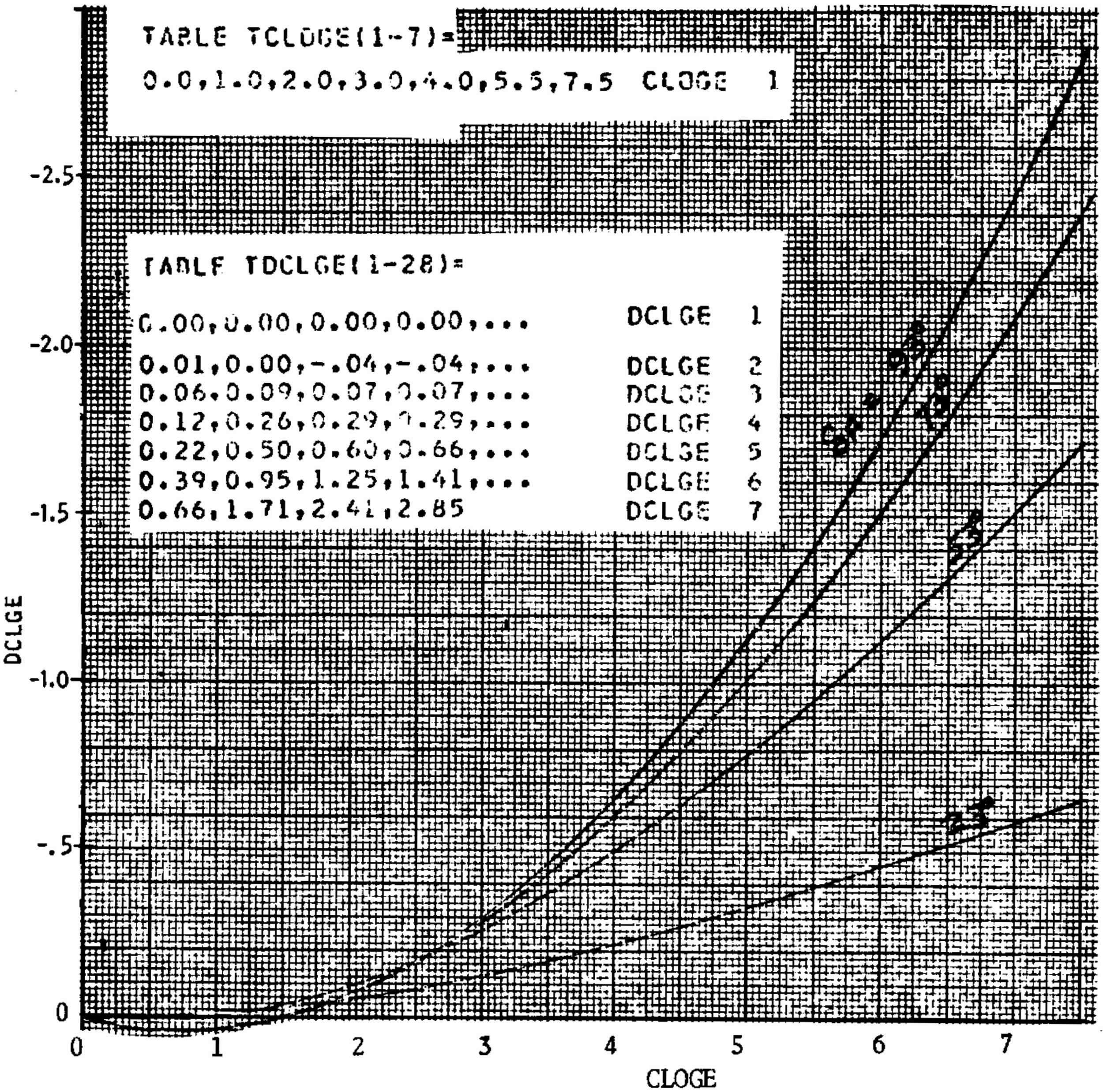


Figure 39. Incremental Change in Lift Due to Ground Effect

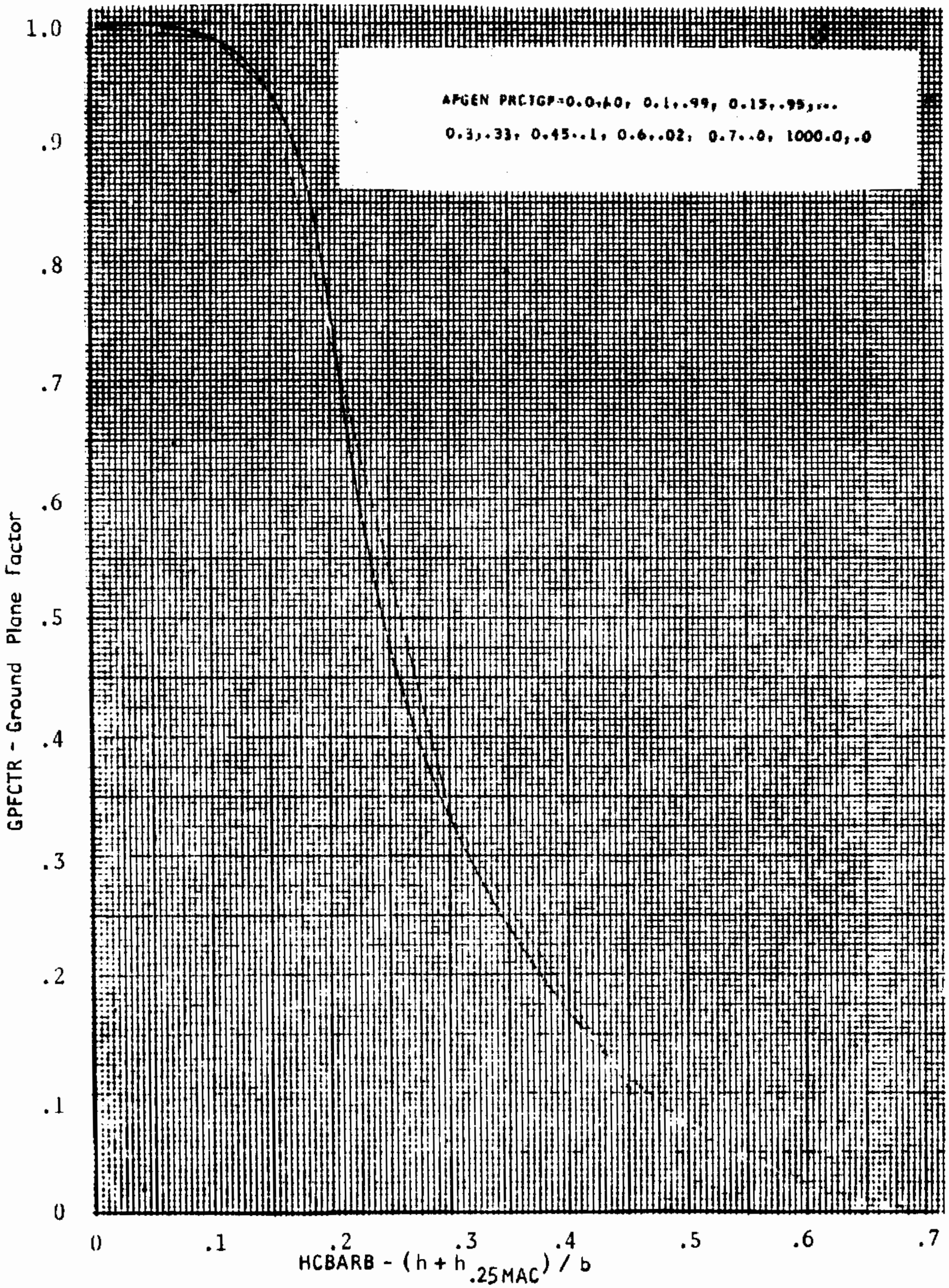


Figure 40. Ground Plane Factor

TABLE II

PROGRAMMED AERODYNAMIC COEFFICIENT VALUES AT $\bar{q}S/T_{PE}$ = 50

FIGURE NUMBER	COEFFICIENT	FLAP DEFLECTION (DEGREES) δ_F=23°	53°	73°	93°	ALL FLAPS
13	NTPE					
	NO	40	109	155	201	
	EO	19	94	144	194	
14	$(N_\alpha/T_{PE})_{\delta,\alpha=0}$	4.22	4.6	4.85	5.10	
15	$(N_i/T_{PE})\ \alpha=0$					
	NO					.97
	EO					.95
19	$(\Delta C/T_{PE})_{\delta a}$	-.345	-.48	-.57	-.66	
20	$(\Delta C/T_{PE})_{DLC}$	-.28	-.34	-.38	-.42	
23	XCPC	-.666	-.599	-.555	-.489	
24	XACC					
	NO	-.300	-.261	-.235	-.209	
	EO	-.307	-.279	-.251	-.223	
25	DEPSI					0.15
27	$\mathcal{Y}_\beta/T_{PE}$	-.65	-.87	-1.02	-1.17	
28	$\mathcal{N}_\beta/T_{PE}b$	+.151	+.161	+.155	+.158	
29	$\mathcal{L}_\beta/T_{PE}b$	-.025	-.105	-.189	-.274	
30	$(\mathcal{Y}_{\alpha_V}/T_{PE})$					0.68
31	NRT	-10.18	-18.77	-20.76	-21.44	
32	NPT	-27.23	-28.23	-28.97	-29.60	
33	NOT	+.195	+.192	+.154	+.191	
34	LOT	1.0	2.6	3.7	4.8	
35	$(\mathcal{L}/T_{PE}b)_{\delta a}$	4.2	11.4	17.3	23.2	
36	LPT					-21.68
37	LRT	18.40	38.15	40.81	41.52	

TABLE III

MODEL CONSTANTS AND INERTIAS

$K_{\ell} = -2.35$	$b = 118.78$ Ft.
$K_N = 0.05$	$\bar{c} = 17.917$ Ft. $L_H = 62.75$ Ft.
$K_S = -0.108$	$X_H = -67.4$ Ft.
$K_D = 0.75$	$\frac{\ell_V}{b} = 0.421$
$K_{\epsilon} = 0.0379$	
$(\frac{\partial \alpha}{\partial \delta})_H = 1.09$	$\frac{Z_V}{b} = -0.15$
$(\frac{\partial \alpha}{\partial \delta})_V = 0.909$	$S = 2{,}000$ Sq. Ft. $g = 32.174$ Ft./Sec.^{2}
$\epsilon_{0,0} = 0.026178$ Rad.	$\rho = 0.002377 \frac{\text{slugs}}{\text{cu. ft.}}$
HCBAR = 18.85 Ft.	$\ell_V = 49.84$ Ft.
AR = 7.0	HV = -9.24

WEIGHT (LBS)	$\frac{X_{cg}}{\bar{c}}$	I_X SLUG.FT^2	I_Y SLUG.FT^2	I_Z SLUG.FT^2	I_{XZ} SLUG.FT^2
160,000	-0.434	1,360,000	2,522,000	3,362,000	378,000
110,000	-0.487	1,291,000	2,084,000	2,956,000	373,000

TABLE IV

MAXIMUM VALUES FOR SCALE FACTORING

PARAMETER	LINEAR	MAX. VALUE	ANGULAR	MAX. VALUE
Accelerations	$\dot{V}, \dot{V}_X, \dot{V}_Z, \dot{V}_Y$ N_Z N_Y	50 Ft/Sec^2 +3,-1g $\pm$1g	$\dot{q}, \dot{p}$ $\dot{r}$	200 Deg/Sec^2 100 Deg/Sec^2
Velocities	V, V_X, V_{XE} V_Z, V_Y, V_{ZE} $V_{YE}, \dot{h}$	300 Ft/Sec 100 Ft/Sec 100 Ft/Sec	$p, \dot{\psi}$ $q, r, \dot{\beta}, \dot{\alpha}$	100 Deg/Sec 50 Deg/Sec
Displacements	X Y Z	30,000 Ft. $\pm$5,000 Ft. 800 Ft.	ϕ, θ, β ψ α	60 Deg. 450 Deg. +40,-10 Deg.
Moments	L M N	$\pm$1.10^6 Lb.·Ft. $\pm$1.10^5 Lb.·Ft. $\pm$5.10^5 Lb.·Ft.		
Flight Control Inputs Surfaces	X_c X_p	$\pm$5 Inches $\pm$3 Inches	X_W X_F, X_T $\delta_H, \delta_e, \delta_r$ $\delta_a, \delta_{sp}, \delta_F$	$\pm$60 Deg. 150 Deg. $\pm$50 Deg. $\pm$100 Deg.

Where flap deflections affect the value of a given coefficient, the curves for four flap deflections, 23, 53, 73, and 93 degrees, are incorporated into the model to compensate for non-linear effects between flap deflections. For flap deflections intermediate to the programmed values, the model uses linear interpolation to define the value of the appropriate aerodynamic coefficient.

The figures which identify coefficient changes resulting from an engine failure are programmed in a manner to permit introduction of a lag in the transition from the normal operation to the engine-out value. This lag represents the rate of thrust decay after losing an engine. The value of this lag is 0.1 second, and is considered to represent a severe case in which a rapid thrust decay occurs subsequent to engine failure. The initiation of transition from normal operation coefficient values to the engine out values are triggered by a switch on the computer control console.

The ground effect terms of Figure 6 are computed using the equations and data of Figures 38 through 40. These data incorporate incremental pitching moment, lift and drag forces into the model as a function of altitude, at altitudes below 50 feet. At altitudes above 50 feet these terms are zero.

DISTURBANCE EQUATIONS

All of the upset conditions available in the program are applied directly to the aerodynamic coefficients in conformance with the requirements (References 1 and 2). This section identifies the equations used to generate these disturbances.

ENGINE FAILURE

In the longitudinal axis, the effect of an engine failure on the aerodynamic coefficients is programmed as an incremental change to the baseline configuration aerodynamic coefficient. The coefficients affected by an engine failure in the longitudinal axis and the numerical values for these changes are defined in the previous section (Figures 13 through 24).

In the lateral-directional axis two terms are involved. These terms are added directly to the rolling and yawing moment equations as a contribution to the total normal operation moments. The rolling moment due to an engine failure is presented in Figure 34. The yawing moments due to an engine failure are defined in Figure 33 for the various flap deflections.

The simulation is mechanized such that a command switch on the computer console triggers the transition from the normal operation values to the failure values through a 0.1 second lag. This mechanization is schematically presented in Figure 10.

DISCRETE GUSTS

Both longitudinal and lateral-directional discrete gusts are available in the program. These are mechanized in accordance with the requirements of MIL-F-8785. The equations used to define these gusts are presented in Figure 41. These are of the 1-cos $\omega_g t$ form and represent linear and angular body axis velocity components. The gust magnitudes selected are based upon the MIL specification requirements for the Dryden scales and thunderstorm turbulence conditions. At typical STOL speeds of 135 feet/second these gust velocities range between 30 and 40 feet/second depending upon the gust frequency selected. Separate gust input commands for either longitudinal or lateral-directional gusts are provided on the computer console.

CROSSWIND LANDING

The crosswind equations are defined in Figure 41. These equations, expressed in terms of Euler angles, define incremental changes in body axis system linear velocities for a 90-degree 30-knot crosswind. The crosswind that is defined is perpendicular to the runway and parallel with the ground. This disturbance effect is applied as a constant input throughout the data run. It is triggered by a switch on the computer console. The equations used for this mechanization are discussed in Reference 7.

CONTINUOUS GUSTS

The program includes a continuous random turbulence gust model utilizing three orthogonal gust components. This model is in conformance with the requirements for the Dryden form of Reference 2. The turbulence model consists of three channels of filtered uncorrelated white noise on a 45-minute tape recording. A 45-minute tape recording permits sufficient variety in the gust data runs to avoid frequent repetition. During continuous gust data runs, the output of this tape is fed into the aerodynamic equations of motion as incremental velocity changes in the X, Y, and Z body axes. Rotational gusts are not simulated and gust shaping is not varied as a function of velocity since the study speed range, 120 through 160 feet/second, does not significantly influence turbulence model shaping.

Figure 42 shows the mechanization and basic transfer functions utilized to generate the clear air turbulence model. Consistent with the requirements of Reference 2, the average altitude used for the Category C

DISCRETE GUSTS

LONGITUDINAL

$$\Delta V_X = \frac{V_{MX}}{2}(1-\cos\omega_g t)$$

$$\Delta V_Z = \frac{V_{MZ}}{2}(1-\cos\omega_g t)$$

$$\Delta_q = \frac{V_{MZ}}{2}\frac{\omega_g}{V}\sin\omega_g t$$

LATERAL - DIRECTIONAL

$$\Delta V_Y = \frac{V_{MY}}{2}(1-\cos\omega_g t)$$

$$\Delta P = \frac{V_{MZ}}{2}\frac{\omega_g}{V}\sin\omega_g t$$

$$\Delta r = \frac{V_{MY}}{2}\frac{\omega_g}{V}\sin\omega_g t$$

90° F - 30-KNOT CROSSWIND EFFECT

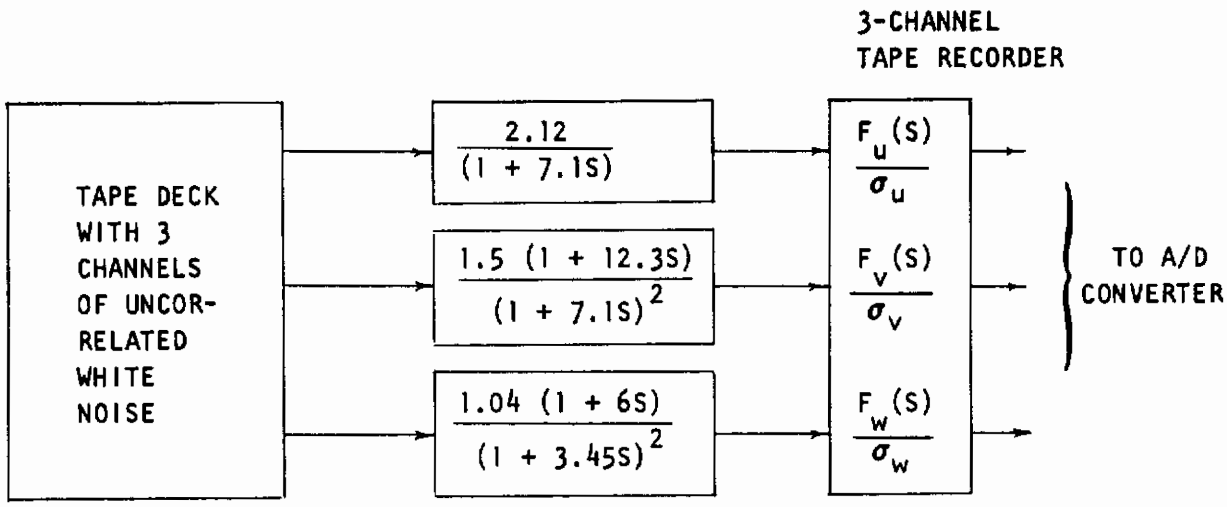
$$\Delta V_X = \Delta V_{YE}\cos\Theta\sin\psi$$

$$\Delta V_Y = \Delta V_{YE}(\sin\Phi\sin\Theta\sin\psi + \cos\Phi\cos\psi)$$

$$\Delta Y_Z = \Delta V_{YE}(\cos\Phi\sin\Theta\sin\psi - \sin\Phi\cos\psi)$$

$$\Delta V_{YE} = 50.5 \text{ FT/SEC}$$

Figure 41. Discrete Gust and Crosswind Disturbance Equations



$$\frac{F_u(S)}{\sigma_u} = \frac{\sqrt{\frac{2}{V_o}\frac{L_u}{\pi}}}{1 + \left(\frac{L_u}{V_u}\right) S}$$

$$\frac{F_v(S)}{\sigma_v} = \frac{\sqrt{\frac{L_v}{V_o \pi}}\left[1 + \left(\sqrt{3}\,\frac{L_v}{V_o}\right) S\right]}{\left(1 + \frac{L_v}{V_o} S\right)^2}$$

$$\frac{F_w(S)}{\sigma_w} = \frac{\sqrt{\frac{L_w}{V_o \pi}}\left[1 + \left(\sqrt{3}\,\frac{L_w}{V_o}\right) S\right]}{\left(1 + \frac{L_w}{V_o} S\right)^2}$$

Figure 42. Continuous Random Gust Model and Mechanization (Dryden Form)

flight phases was 500 feet. Other constants were:

$V_O = 145$ feet/second

$L_W = h = 500$ feet

$L_u = L_V = 145\ h^{1/3} = 1025$ feet

$$\frac{\sigma_u^2}{L_u} = \frac{\sigma_V^2}{L_V} = \frac{\sigma_W^2}{L_W}$$

Several levels of turbulence were simulated by assigning various values to σ_W, these were 7, 3.5 and 1.75 feet/second. These levels are varied by the computer operator.

Typical two-minute analog time histories of the uncorrelated turbulence are shown in Figure 43. These represent 1σ turbulence signals in the three axes as fed into digital computer program. The digital computer program multiplies these signals by the appropriate σ level and adds the resulting velocity increments to the body axis velocity equations. The model generates a constant turbulence level throughout the data run.

TRANSPORT SIMULATOR

The flight simulation study utilized a full six-degree-of-freedom model tied to a 2-axis moving base simulator with visual and instrument displays. Pilot controller and aircraft configuration commands feedback into the simulated model closing the aerodynamic loops. Evaluation pilot seating, controls and inputs to the model were configured in a transport flight station arrangement.

FLIGHT STATION

The evaluation pilot's flight station was mounted on a two-degree-of-freedom moving platform which responds to pitch and roll attitude and rate changes. In the pitch axis, the platform responds to attitude changes from +16 degrees to -8 degrees of pitch attitude at a maximum rate of 10 degrees per second. In the roll axis, the platform can be tilted to ±15 degrees at a maximum rate of 4 degrees per second. Driving signals from the computer mechanization are used to position the platform through a hydraulic servo actuated control system.

The flight station utilizes a side-by-side seating arrangement typical of transport aircraft. Pilot controls include a wheel, column and pedals with variable force feel characteristics. The left hand grip on the

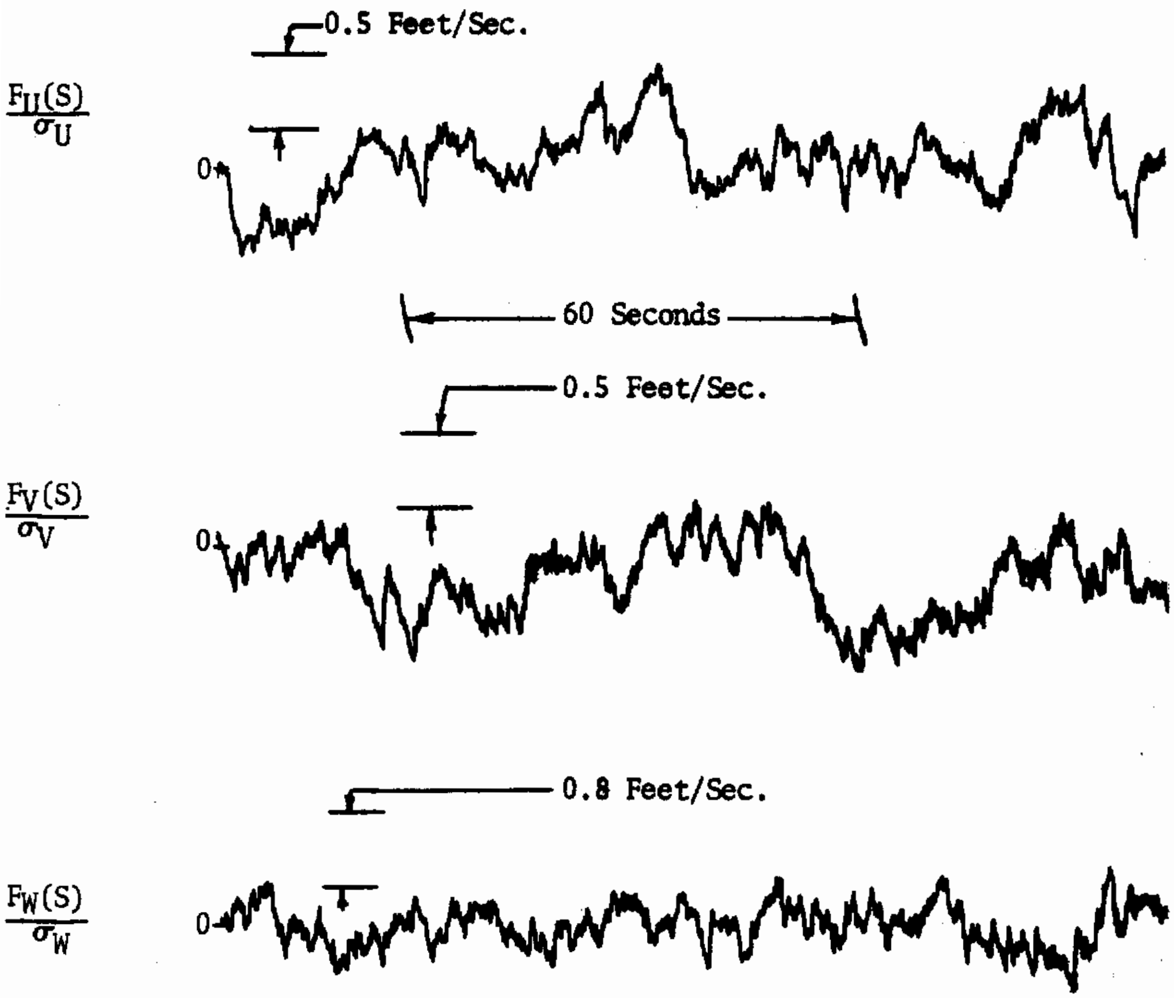


Figure 43. Time History of an Uncorrelated Random Gust

pilot's wheel contains primary pitch and roll trim switches which feed pilot trim commands to the computer simulated control systems. Positioned on the right hand grip under the pilot's thumb is the direct lift spoiler controller. This thumb wheel has approximately ±120 degrees throw and results in positioning the DLC spoilers ±30 degrees from the neutral bias position. Figure 44 shows these controls as viewed from the pilot's station. A landing gear control lever is located on the co-pilot's side of the center panel. The yaw trim control is located on the center console shown in Figure 45. This console also contains four throttles and a flap position lever. The center console also contains the DLC spoiler "lock and normal operation" two position switch. Directly in front of the center console is the throttle quadrant. The throttles are centrally located between the pilot and co-pilot. The flap position lever is located to the right of the throttles.

INSTRUMENT DISPLAYS

For the purposes of this study, only those displays and parameter ranges necessary for STOL-VFR operation have been considered. The evaluation pilot's display instruments include HSI, ADI, airspeed, altitude, altitude rate, bank and turn indicator, lateral velocity, normal acceleration, angle of attack, flap and control surface trim positions. These instruments are located in the pilot's direct cone of vision. Their location in the control panel and positions relative to each other are shown in Figure 46. It is noted, that through a mechanization error the "g" meter is incorrectly scaled. It is believed that this did not materially affect the study results however, since pilot comments indicated the instrument received little use during STOL mode operation.

The performance characteristics such as operational range, scale factor, display types and dynamic characteristics for the parameters associated with STOL-VFR operation are listed in Table V. The table also identifies the display associated with each parameter as well as other significant characteristics of each display. To avoid difficulty in reading the surface trim positions in roll and yaw due to oscillations caused by the augmentation servos, these instruments are connected to the trim position command inputs to the primary flight control system. This is comparable to monitoring the trim actuator output.

In addition to the parameters identified in Table III and the displays of Figure 46, the throttle positions as a percent of maximum throttle are displayed on the center panel. These instruments are shown in Figure 44. The display of throttle position as a percent of maximum throttle is comparable to displaying percent engine rpm. This display permits the pilot to visually determine whether additional thrust is available for maneuvering or engine failure recovery without removing his hand from the wheel.

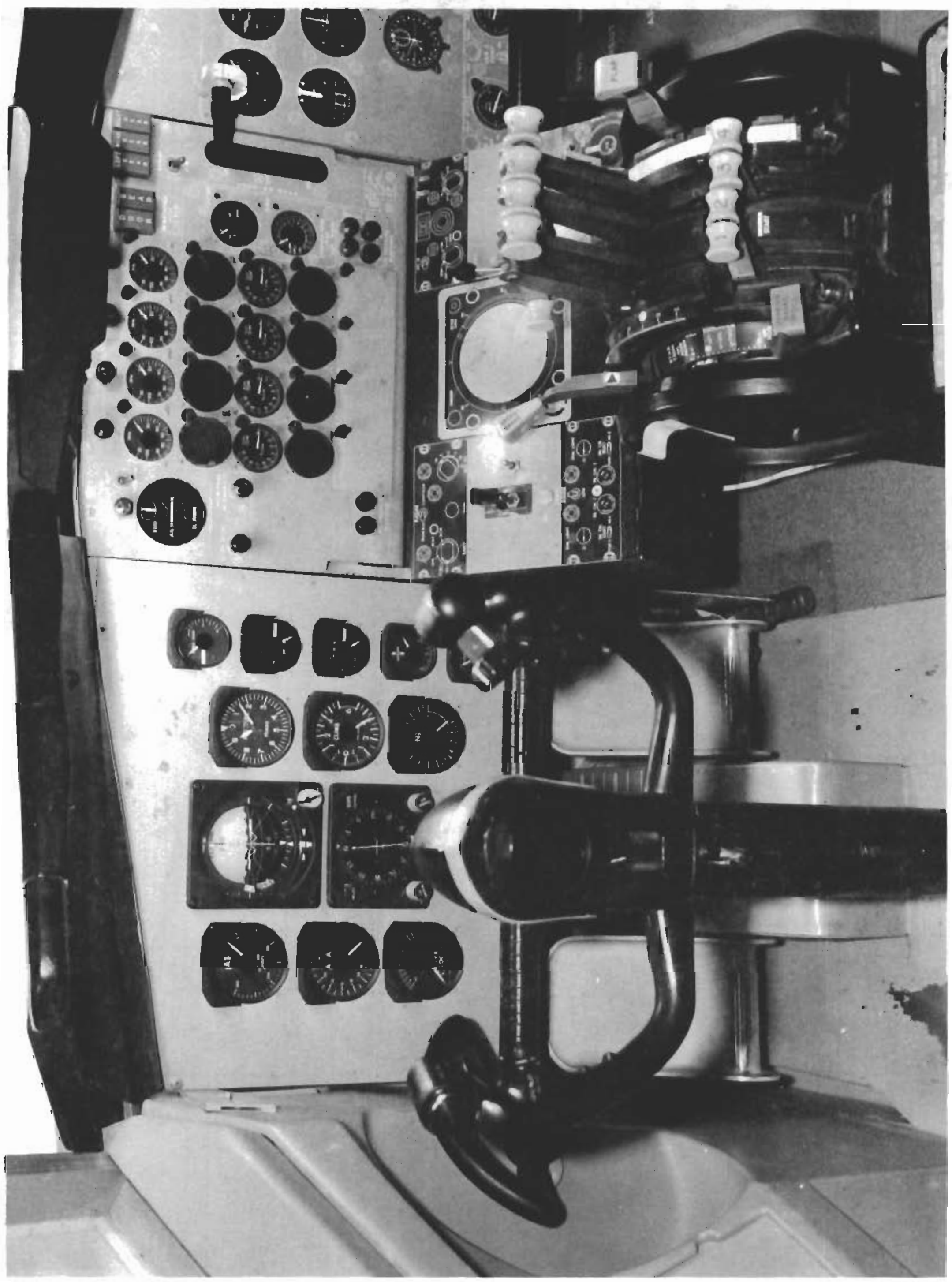


Figure 44. Pilot's Flight Station - MST Simulation

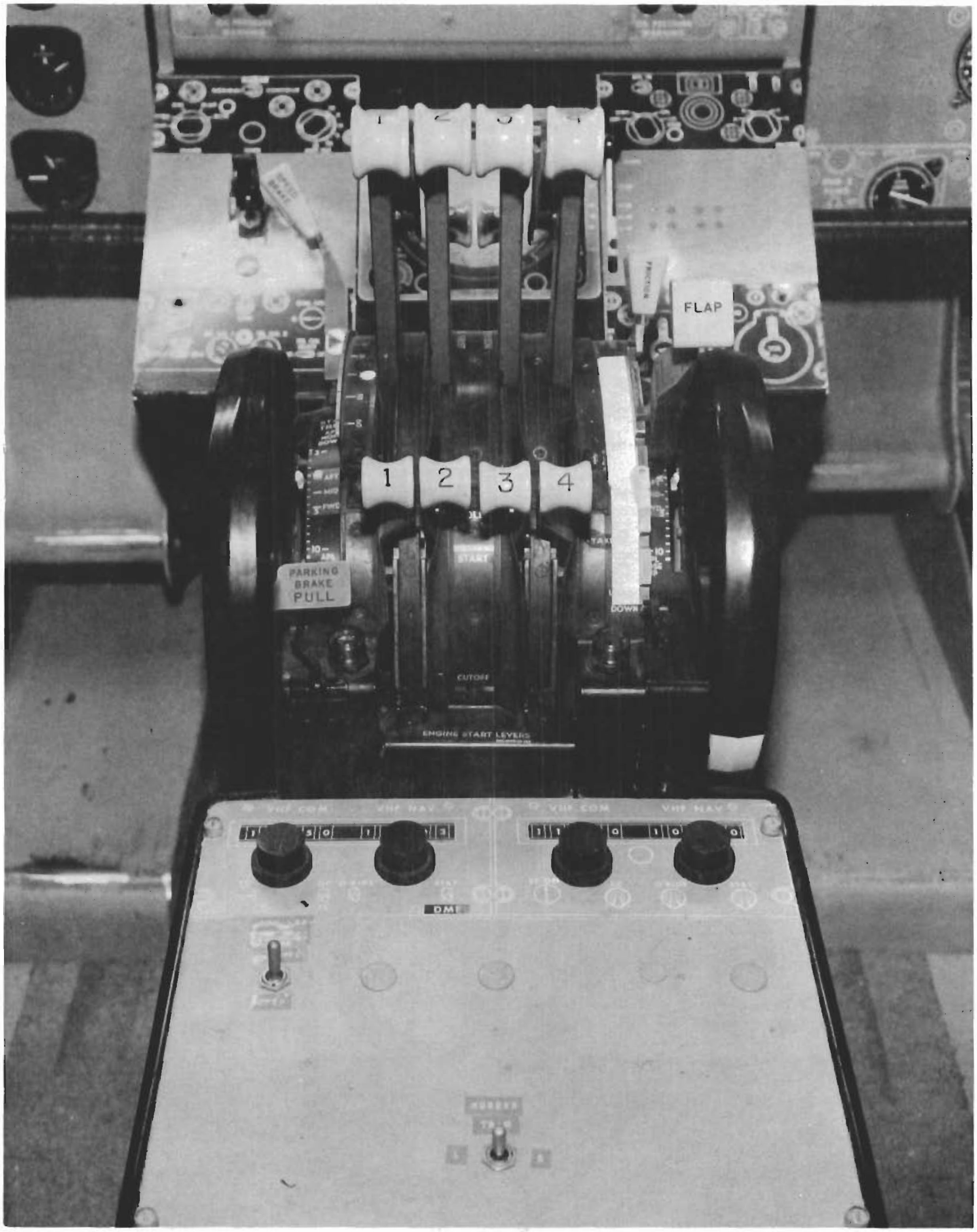


Figure 45. Center Console and Throttle Quadrant - MST Simulation

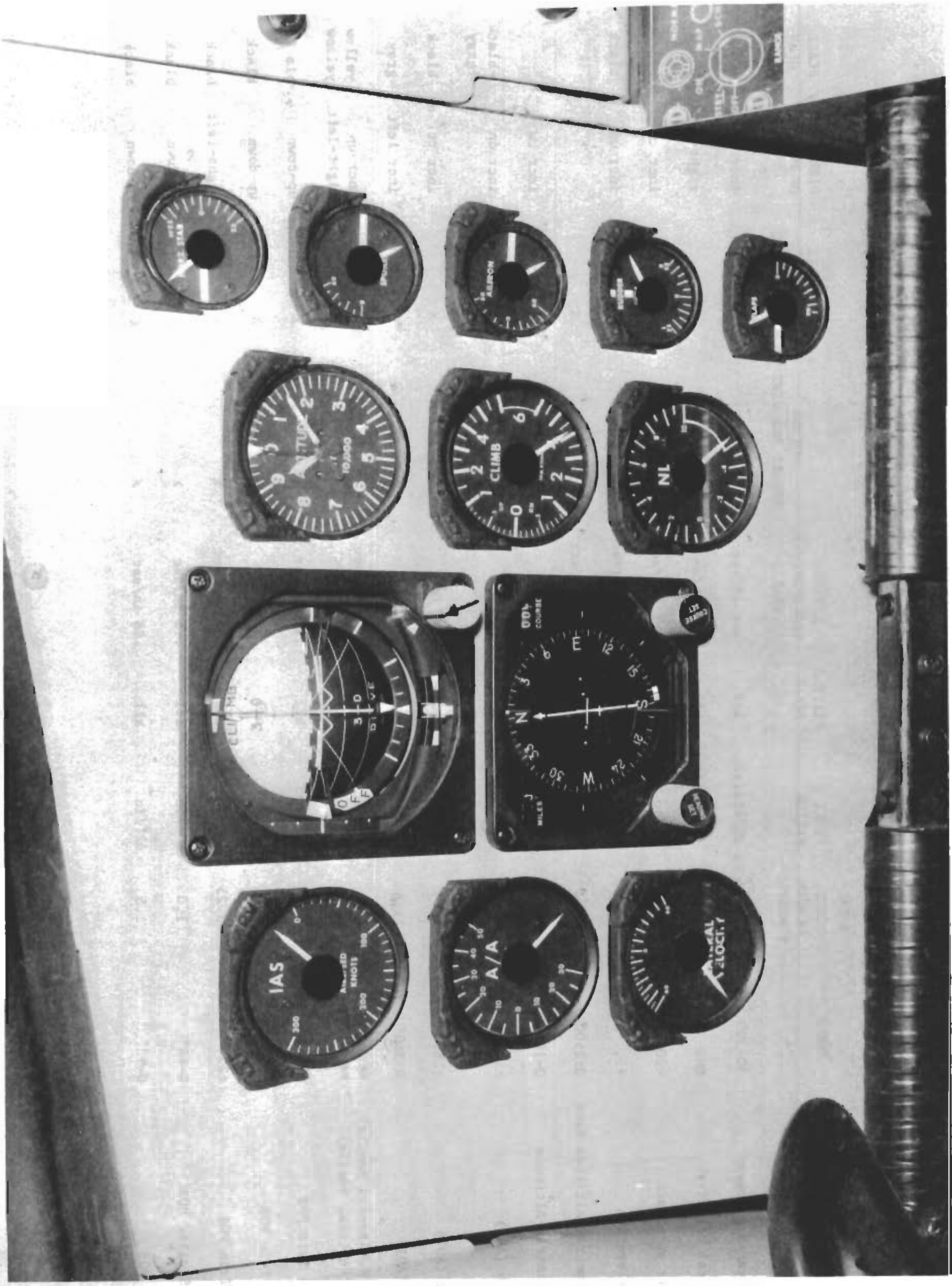


Figure 46. Pilot's Instrument Display - MST Simulation

TABLE V
FLIGHT DATA - DISPLAY SPECIFICATION CHART
MST TRANSPORT

FUNCTION	RANGE	TOTAL SCALE LENGTH (INCHES)	SCALE FACTOR	VISIBLE SCALE	DYNAMIC REQUIREMENTS (MAX.)	MOTION ROTARY	MOTION HOR	MOTION VERT	SCALE FIXED	SCALE MOVING	DIRECTION OF MOTION	SCALE COLOR	MARKING COLOR
Indicated Airspeed	30-300 kts	9.25	20 kts/in	all	rot 15°/sec	X			X		incr cw	black	white
Lateral Velocity	±60 ft/sec	2.5	48 kts/in	all	.35 in/sec	X			X		right-left	black	white
Angle of Attack	-10, +40	5.4	9°/in	all	rot 30°/sec	X			X		incr cw	black	white
Acceleration	+5, -2(g)	5.4	1.3 g's/in	all	rot 20°/sec	X			X		incr up	black	white
Barometric Altitude Rate	0±2500 fpm	5.4	1000 ft/sec	all	10.0 in/sec	X			X				
Barometric Altitude	0-100,000 ft	10.0	100 ft/in	all	360°/sec	X			X		incr cw		
Pitch (ADI)	±180°	5.8	31.0°/in	4.25 in	45°/sec	X				X	incr dn	-black +gray	white black
Roll (ADI)	±180°	11.6	31.0°/in	4.25 in	180°/sec	X			X		incr rt. cw	black	white
Yaw (ADI)	0-360°	11.6	31.0°/in	3.0 in	90°/sec		X			X	incr left	gray	black
ADI (Horizontal Needle)	**	1.5	-	-	0.75 in/sec			X		X	incr up	yellow	(none)
ADI (Vertical Needle)	**	1.5	-	-	1.5 in/sec		X			X	right-left	yellow	(none)
Pitch Trim POS	±20°	2.0	20°/in	all	.11 in/sec	X			X		up-down	black	white
Roll Trim POS	±60°	2.0	60°/in	all	.2 in/sec	X			X		up-down	black	white
Yaw Trim POS	±25°	1.25	40°/in	all	.375 in/sec	X			X		right-left	black	white
DLC Spoiler POS	0-60°	1.0	60°/in	all	.11 in/sec	X			X		up-down	black	white
Flap POS	0-93°	1.5	62°/in	all	.08 in/sec	X			X		up-down	black	white

** Flight Director Needles Mult-Mode

IFR instrumentation includes the display of glideslope command on the horizontal needle of the ADI and steering command on the vertical needle. The mechanizations for these display parameters are shown in Figure 47. These mechanizations are those which resulted from piloted evaluations of the MST model during preliminary validation testing. The initial mechanizations were adapted from Reference 8, these were modified during piloted evaluations and resulted in those shown in Figure 47.

Additional IFR instrumentation includes the presentation of a standard two-minute turn command on the turn rate indicator of the ADI. The turn rate command is varied as a function of aircraft velocity and lagged with a one second first order lag. The HSI presentation includes aircraft heading and course deviation error.

VISUAL DISPLAY

The visual display consists of a closed circuit television system in which a terrain model is projected in front of the flight station giving a through-the-windshield view to the evaluation pilot. Figure 48 typifies the pilot's view during a landing approach. The runway pictured in this figure is not that used during this study.

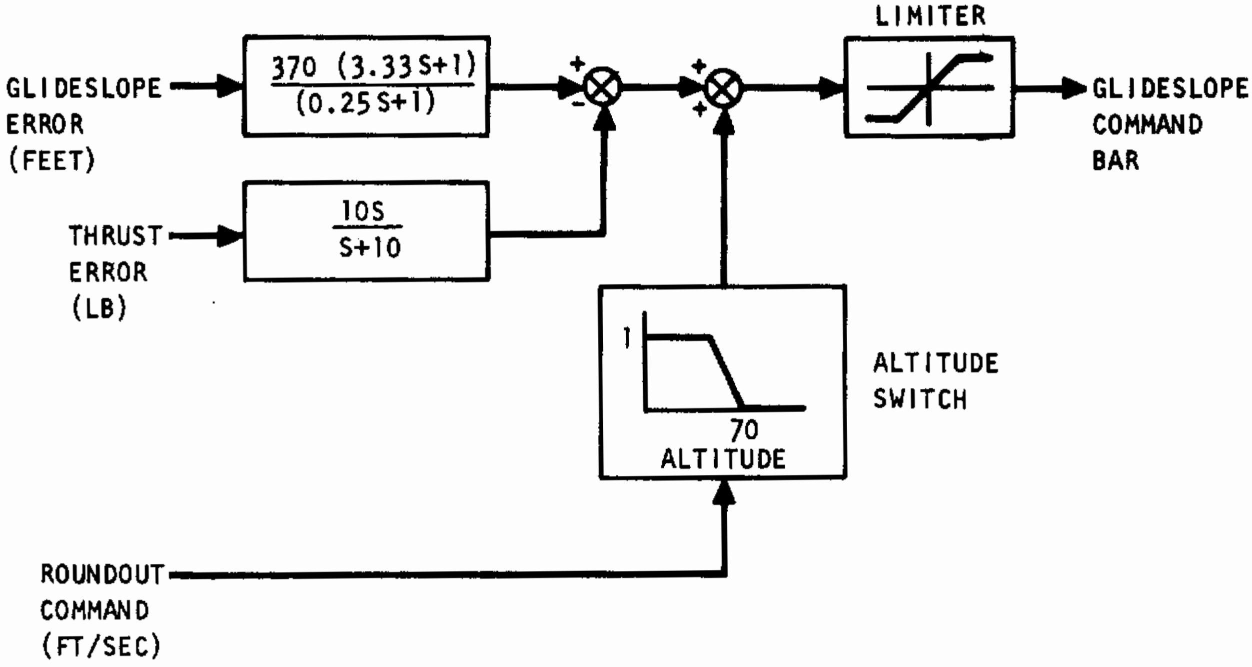
This system consists of a servo driven terrain belt map, optical probe, television camera and Schmidt projectors. The terrain model is constructed to a 1250 to 1 scale and consists of hilly terrain and an airport complex. The performance characteristics of this system are as follows:

Pitch	±25 degrees at 60 deg/sec
Roll	±90 degrees at 150 deg/sec
Yaw	±540 degrees at 120 deg/sec
Range	8.2 miles
Cross Range	±2.9 miles
Altitude	0 - 800 feet

MST RUNWAY DIMENSIONS

The landing strip consists of a 60 feet wide by 2100 feet long strip of asphalt centerally positioned between 50 feet high trees. The strip is unmarked except for a line indicating the desired touchdown point. The dimensions for this strip are shown in Figure 49 and are based upon the contractual MST mission requirements and those outlined in the Landing Zone Criteria of Reference 9.

FLIGHT DIRECTOR GLIDESLOPE



FLIGHT DIRECTOR STEERING

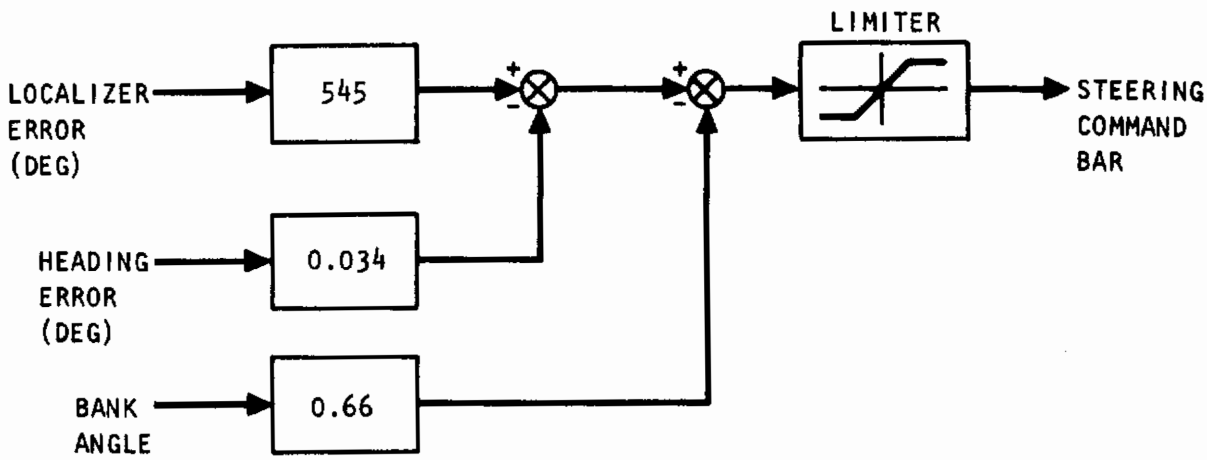


Figure 47. Flight Director Mechanization

Figure 48. Pilots Visual Display Perspective - MST Simulation

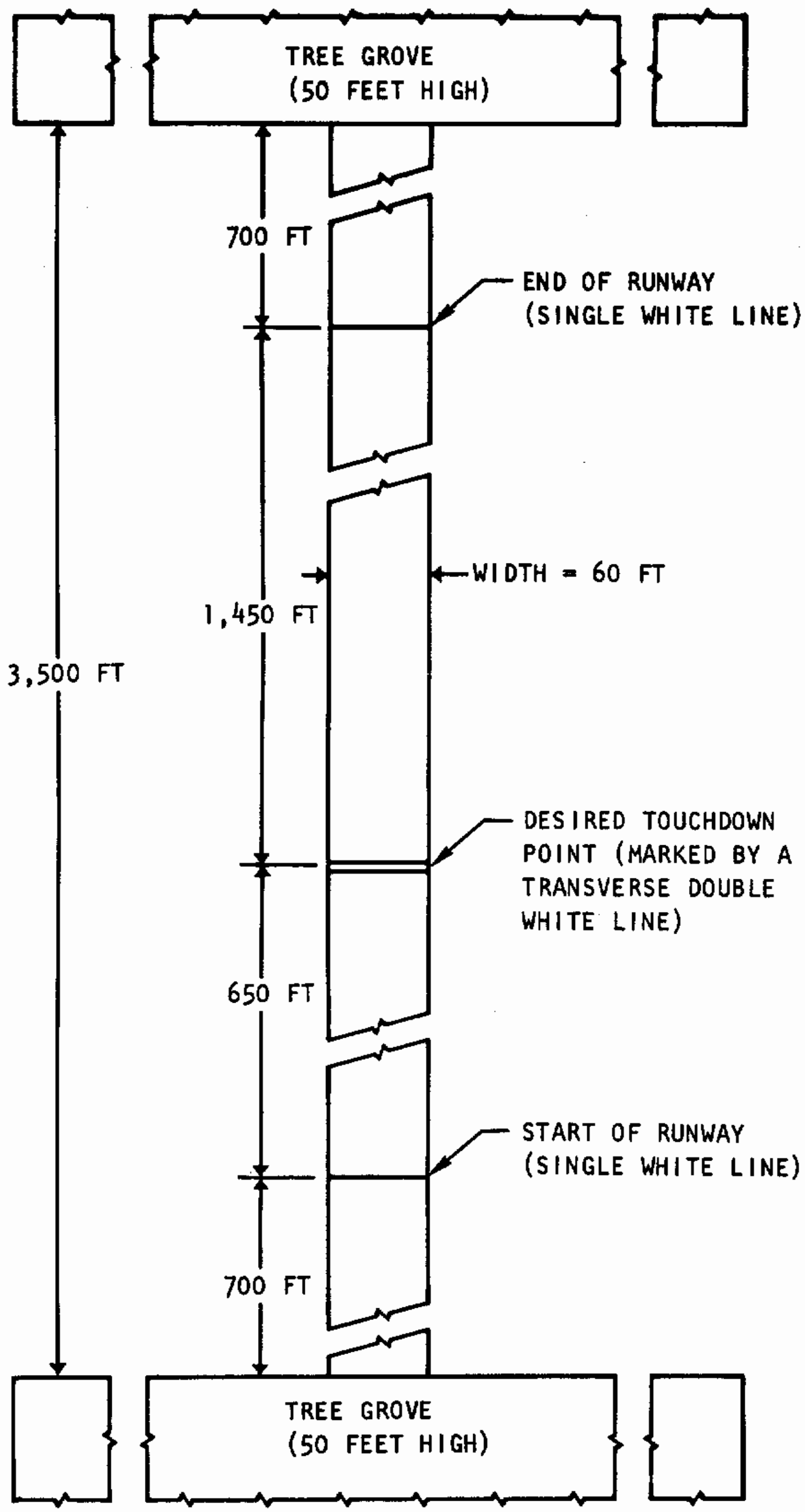


Figure 49. Remote STOL Strip Dimensions - MST Simulation

Section IV

STUDY RESULTS

STOL FLIGHT REGIME

The study results presented here are applicable to the STOL, i.e., flaps down, flight regime for the EBF MST. They cover the takeoff, landing and waveoff flight configurations. The specific trim conditions used during the investigations are identified in Figure 50. The broken line in this figure shows the maximum flight path angle that can be achieved, steady state, with three engines for the takeoff and landing configurations.

FLIGHT CONTROL SYSTEM DEVELOPMENT AND VALIDATION

Validation of the flight control system design consists of demonstration of the pilots' ability to use the control systems, in combination with the characteristics of the basic aircraft, to readily and effectively perform required maneuvers and tasks considering both normal operation and failure modes. A series of takeoff, landing, and waveoff flight simulation tests were run using the flight control systems, considering various failure conditions, during which pilot ratings and comments were obtained. These ratings and comments provide the basis for the system validation.

The pitch, roll and yaw flight control and augmentation systems were designed to satisfy the requirements of Reference (1). Satisfactory validation of the systems, along with correlation of ratings and handling qualities parameters, provides a degree of substantiation and validation of these design requirements. Also the pilot ratings and handling qualities obtained during failure mode tests provides a means for determining the minimum safe level of augmentation required and the corresponding amount of reliability needed in the system.

During the course of the initial simulation testing a certain degree of system development was required to cover areas not specifically defined by the requirements of Reference (1). These areas included the direct lift controls and the throttle systems. Also pilot comments on control sensitivities indicated a need for particular evaluation in these areas.

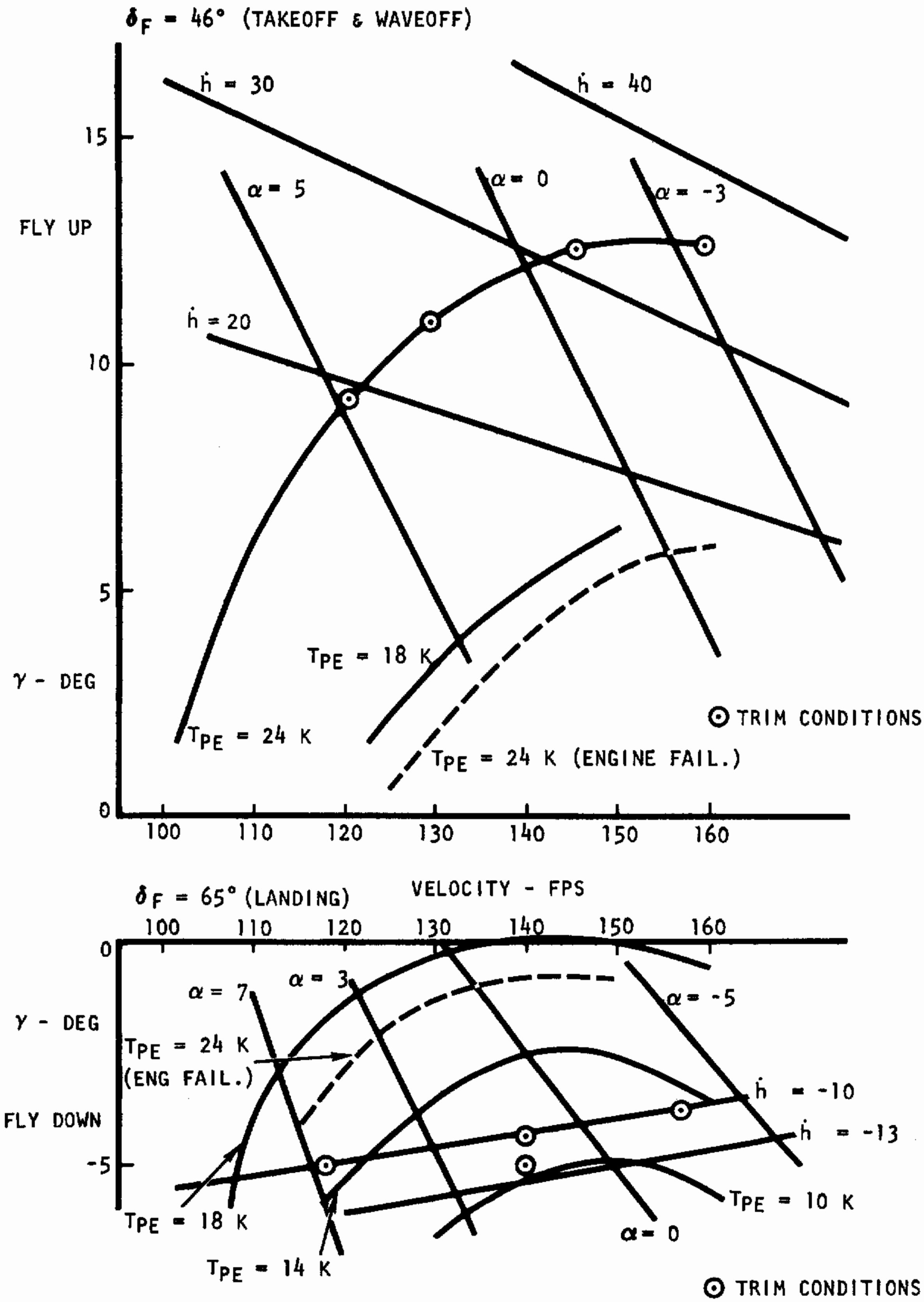


Figure 50. MST Simulation Trim Conditions

LONGITUDINAL CONTROL EVALUATION

During initial flight control system validation studies it became evident that a significant portion of the pilot control task in the presence of external disturbances or engine failures was in the lateral-directional axes. As a result, variations in the longitudinal control system were not easily identified in terms of their effect on pilot ratings. To more fully evaluate the effect of changes in the longitudinal control system the lateral-directional axes were locked out and the pilots evaluated a three-degree-of-freedom longitudinal mechanization. During this evaluation each pilot rated a series of control configuration changes which were outlined in a questionnaire. This questionnaire along with pilot ratings and comments are presented in Appendix I, Section I. The results of this analysis are summarized here and their effect on the longitudinal control system is identified.

Longitudinal Control Forces

One of the limitations in the simulation program was the fact that once the pitch column forces had been set up by installation of a force feel bungee, these could not be conveniently varied to suit individual pilot preferences. As indicated in Figure 7 the column force gradient was set at 6 pounds/inch consistent with the requirements of Reference 1. The level attitude breakout force was measured at two pounds with this force gradient. One of the program evaluation pilots particularily disliked these breakout and column gradient levels indicating that they were too high and as a result his pilot comments reflect these thoughts. The other two pilots were not particularily bothered by the level flight column forces however one felt that the augmented control system configuration of Figure 7 was overly sensitive.

Additionally all pilots were bothered somewhat by a column force imbalance with aircraft pitch attitude. This was particularly apparent during the takeoff maneuver which characteristically had simulation cockpit pitch attitudes of 10 to 12 degrees. This force imbalance resulted from the fact that the simulation cockpit column static balance could not practically be readjusted when the force gradient had been reduced from that for which the column had been designed. All pilot comments reflect a dislike for this characteristics which is to be expected. This characteristic would normally be designed out of an operational aircraft but was beyond the scope of this simulation study.

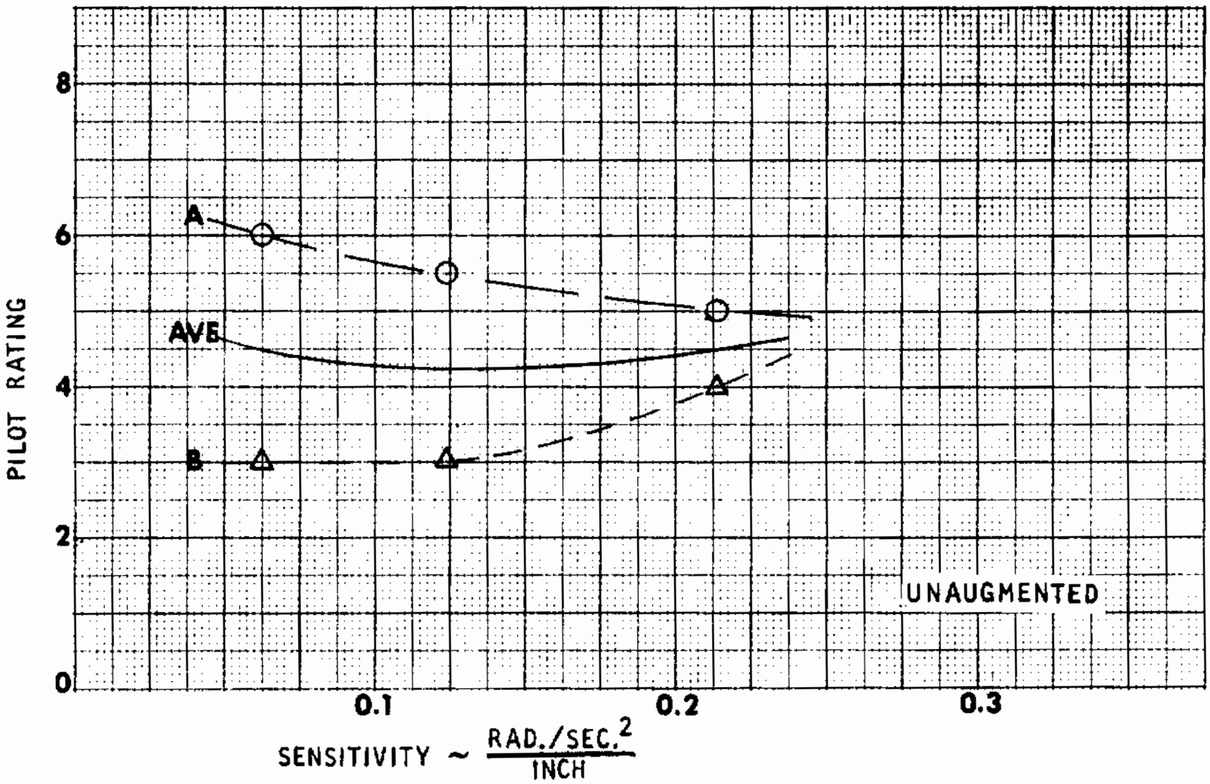
No action could be taken during this simulation with respect to comments pertaining to control gradient or breakout forces, however, with respect to comments pertaining to control sensitivities, it was decided to look at several reduced sensitivity levels from those designed into the system of Figure 7.

Longitudinal Control Sensitivity

The effect of longitudinal control sensitivity on pilot opinion was evaluated during the landing approach. Initial positioning of the aircraft was such that the pilot applied a nose-up column and throttle command at 800 feet altitude to level off and fly to the glideslope. Upon reaching the glideslope, a nose-down column and throttle command were applied to capture and trim on the glideslope while maintaining essentially constant speed. In addition, an engine failure was introduced at 700 feet altitude which also required longitudinal control inputs to maintain the glideslope.

Three control system sensitivity levels were evaluated using this maneuver with both the unaugmented and augmented vehicles. This parameter identifies the vehicle response in terms of its angular aerodynamic acceleration ($\dot{q}$) per unit controller displacement. It represents a closed aerodynamic loop response of the aircraft to a control surface displacement and is measured from time histories. The sensitivities evaluated ranged from 0.062 to 0.214 rad/sec^2/in. for the unaugmented configuration and 0.087 to 0.30 rad/sec^2/in. in the augmented case. The results of these tests are summarized in Figure 51. The individual pilot ratings for each of three pilots are shown as well as the average pilot ratings. The highest sensitivities shown in this figure are those which were designed into the configuration of Figure 7. The intermediate level represents that which is obtained when the horizontal stabilizer is disconnected from the column and is used for trim only. The lowest level of sensitivity in this figure represents one-half the baseline elevator effectiveness with the horizontal stabilizer disconnected.

These data reflect large differences in pilot preference with respect to sensitivity. In both the unaugmented and augmented configurations Pilot A preferred the higher sensitivities. Pilot B preferred the lower sensitivities for the unaugmented case and seemed to show no preference for the sensitivities evaluated with the augmented configuration. Pilot B's preference for lower sensitivity in the unaugmented case resulted from a tendency toward PIO during the pitch maneuvers at the higher sensitivity. As indicated by his comments, the lower sensitivities for the unaugmented configuration partially negated the effect of the breakout forces and column gradient of the system to which he objected. Pilot C did not evaluate the unaugmented configuration, however, for the augmented aircraft, his ratings indicated a preference toward lower sensitivities. As a result, the average sensitivities on these figures show that a sensitivity of 0.125 for the unaugmented aircraft and 0.170 for the augmented case are most acceptable for this configuration. These sensitivities are comparable to those which would be obtained if the connection between the column and the horizontal stabilizer were opened in Figure 7.



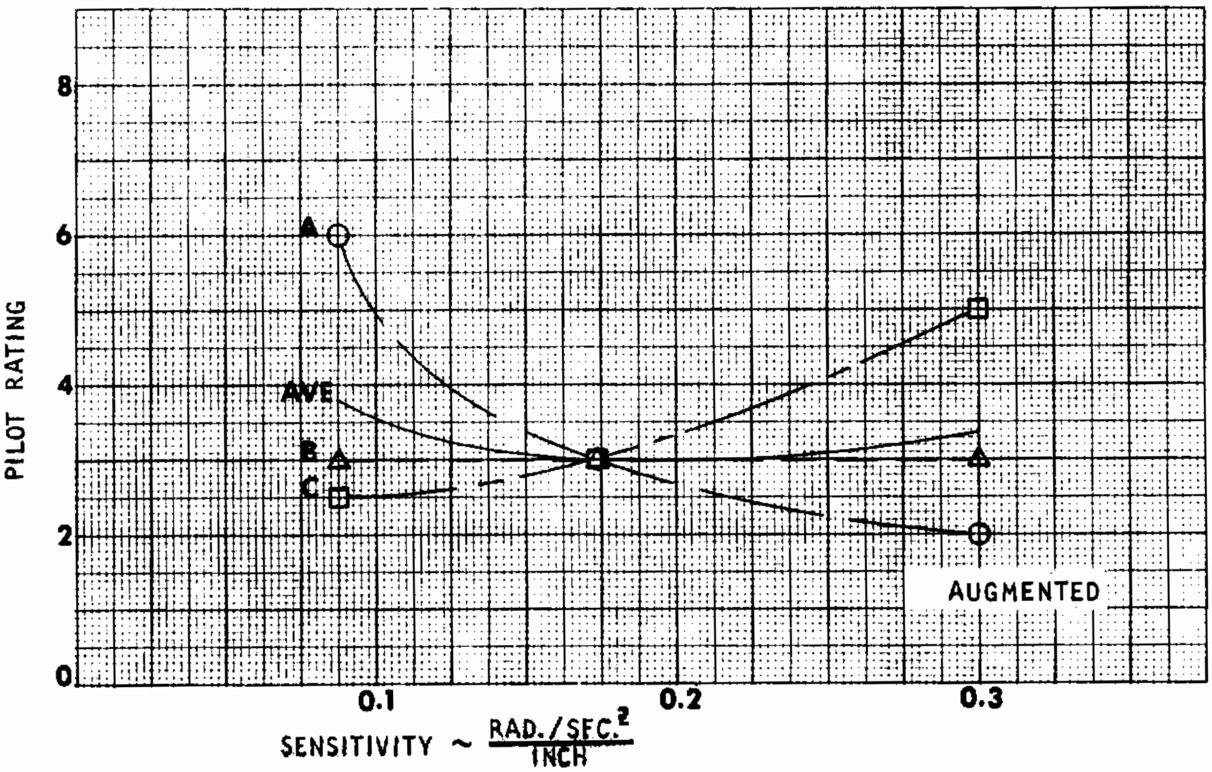


Figure 51. Effect of Column Control Sensitivity on Pilot Opinion

Direct Lift Control Mechanization

The baseline vehicle evaluated utilizes the inboard spoilers to provide a method for direct lift control. The purpose of the DLC is to facilitate small corrections about the glideslope and to provide a faster-responding more-direct means of rounding out, i.e,, controlling sink rate, in the ground effect.

Three control configurations for utilizing this device were evaluated: (1) A DLC position control knob on the right hand side of the pilot's wheel grip, (2) the DLC spoilers coupled to the column through a washout with a three-second lag, and (3) a combination of the above two configurations. These mechanizations are schematically shown in Figure 7. Pilots rated each configuration in two areas: (1) Controlling small deviations about the glideslope at altitudes above 100 feet and (2) use of the device for the round out operation at altitudes below 100 feet. Both normal and engine failure operation were examined in each case.

The results, based on pilot ratings, indicate that the column coupled method of control was preferred for both normal and engine failure operation, both above and below 100 feet. The third configuration, that of the column and DLC controller combination was rated only below 100 feet where the pilots used the DLC knob only to round out in the ground effect. Above the 100-foot level the DLC moved in response to column inputs through the 3-second washout and the pilot ratings would be the same as those for configuration two above 100 feet. These results are presented in Table VI and are summarized in Figure 52. Only one position of the DLC controller was evaluated, however pilots were asked to comment on their preference with respect to controller location. Two out of three pilots would have preferred the controller on the number 1 throttle under the pilot's thumb, the third pilot would have preferred it on the left wheel grip under the pilot's thumb. It is not known how different controller positions would have affected the outcome of these results, however, one pilot's comments indicate that his rating probably would not have been affected, but, he would have considered the throttle mounted controller a convenience factor.

To assess the influence of DLC effectiveness on pilot opinion, the DLC control effectiveness was increased by a factor of three for the system of Configuration 1. These results are indicated in Figure 53. They show, on the average, that increased effectiveness would be preferred by pilots. Insufficient data are available to define required effectiveness in terms of pilot opinion, however, the average ratings show that 2 to 3 times the baseline value would be preferred below 100 feet. No significant results above 100 feet can be observed for either normal or engine out operation.

TABLE VI

DLC CONTROL MECHANIZATION AND SENSITIVITY SUMMARY

CONFIGURATION		PILOT A				PILOT B				PILOT C			
		AUG ON		AUG OFF		AUG ON		AUG OFF		AUG ON		AUG OFF	
		NO	EO	NO	EO	NO	EO	NO	EO	NO	EO	NO	EO
Configuration 1 DLC coupled only to knob.													
Above 100'													
Baseline	Run No.	844	845			734	735			774 775	776		
	PR	2	2			3	3			7	7		
3 X Baseline	Run No.	856	857			738	739			777	778 777		
	PR	2	2			3	3			5	8		
Below 100'													
Baseline	Run No.	844	845			734	736			775	776		
	PR	5	5			3	3			4	9		
3 X Baseline	Run No.	856	857			738	740			777	778		
	PR	3	3			3	4			4	5		
Configuration 2 DLC coupled only to column.													
Above 100'													
Baseline	Run No.	858	857		859	741	742		753	779	780		
	PR	2	2		5	3	3		4	3	5		
Below 100'													
Baseline	Run No.	858	857			741	742			779	780		
	PR	2	3			3	3			3	3		
Configuration 3 DLC on column plus knob.													
Below 100'													
Baseline	Run No.	860	861			747	748			783	784		
	PR	3	4			3	3			6	7		

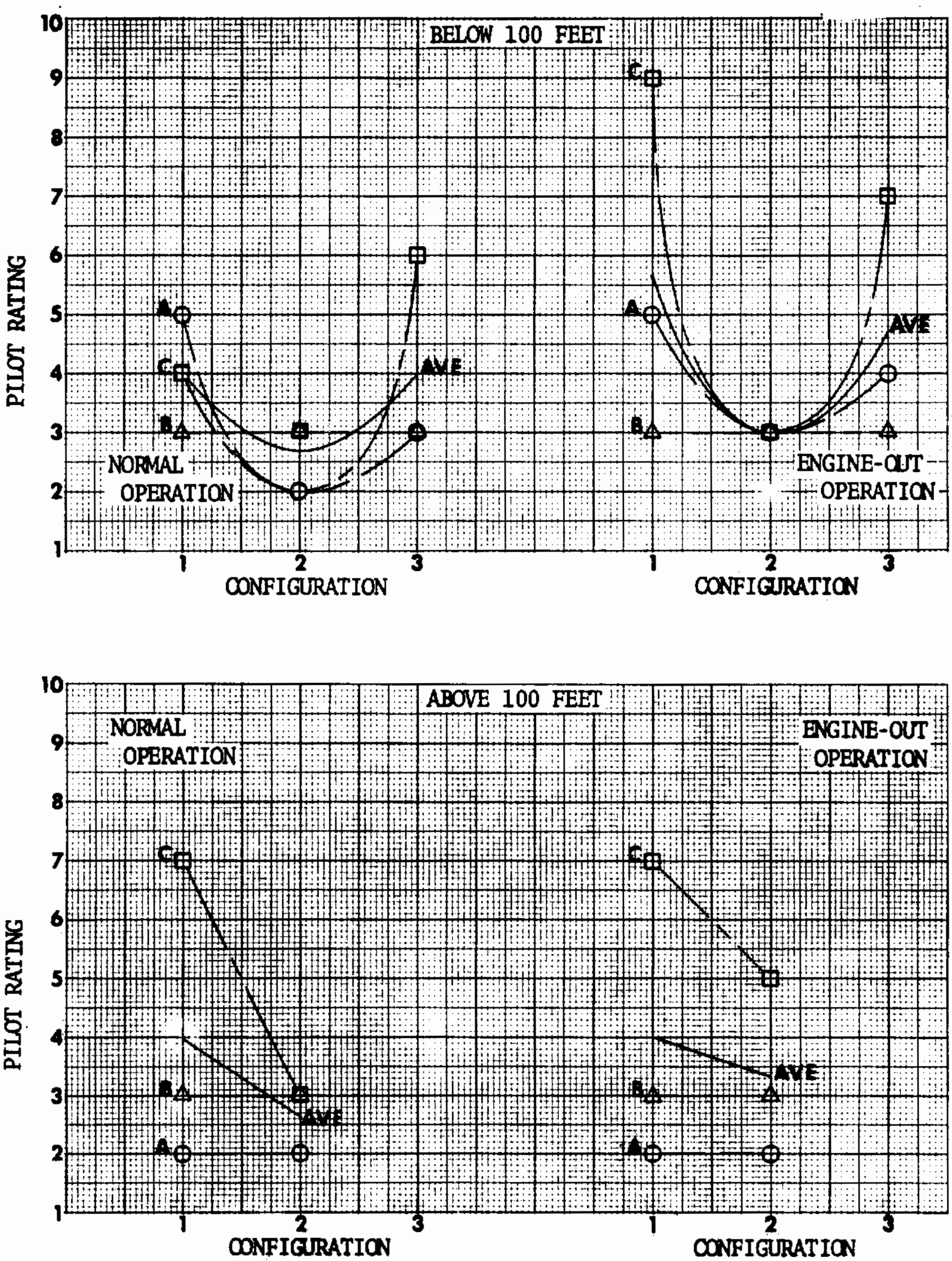


Figure 52. DLC Configuration Studies

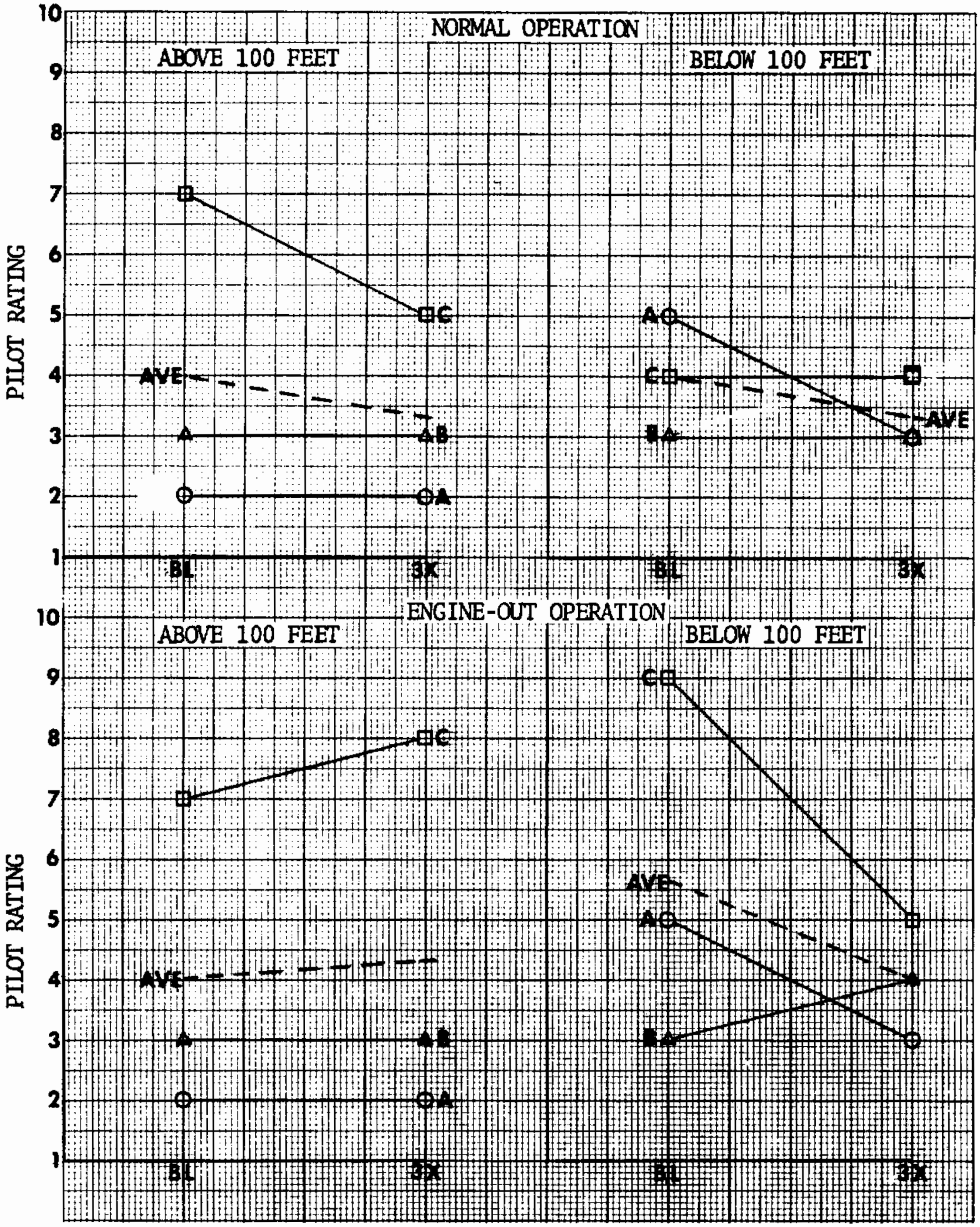


Figure 53. DLC Effectiveness Versus Pilot Opinion

Individual vs Collective Throttles

A brief evaluation of collective versus individual throttles was conducted. It consisted of evaluating the landing approach with an engine failure at 700 feet using the Number 1 throttle of Figure 45 as a collective throttle. These data were compared with comparable data runs in which the pilots used four throttles. The results are shown in Figure 54. Based on pilot ratings, both pilots B and C preferred the collective throttle arrangement over individual throttles, however their comments indicated that the collective throttle should be mounted to the pilot's left not on the right as evaluated. The pilot comments do not specifically identify why the collective throttle arrangement is preferred. Pilot A showed no preference in terms of the throttle arrangements evaluated.

While all other data presented in this study utilized the individual throttle arrangement of Figure 45, these data show that a slight improvement, approximately one-half Cooper-Harper rating on the average could be expected with the collective throttle arrangement evaluated. The study did not evaluate any other collective throttle positions.

SIX DOF VALIDATION STUDIES

The 6 DOF studies evaluated pilot controllability in all three axes, pitch, roll, and yaw, and, as previously stated, the pilots lateral-directional task workload was such that roll control system configuration changes were easily discernable in the resulting Cooper-Harper ratings. As a result, all of these studies were based upon a 6 DOF analysis. The pilot comments for many of these data runs are listed in Appendix I, Section II. The data runs in this appendix are listed in numerical sequence, they are not specifically correlated with the evaluations discussed in this section. The pilot ratings used for validating the flight control systems and discussed in this section were obtained at a safe speed margin and are listed in Tables I through III of Appendix II. These tables identify the data run number, trim condition, level of augmentation, engine failure and external disturbance data. They also include data obtained at all levels of augmentation to show the effect of control system failures on piloted handling qualities and assess the correlation of handling qualities requirements with the Cooper-Harper pilot opinion obtained. The takeoff data are presented in Table I. Tables II and III include the landing and waveoff data respectively.

Lateral Control Forces

Consistent with the requirements of Reference 1, a roll force gradient of 0.25 pounds/degree was used in the evaluation cockpit. The breakout force associated with this force gradient was measured at 0.5 pounds. The

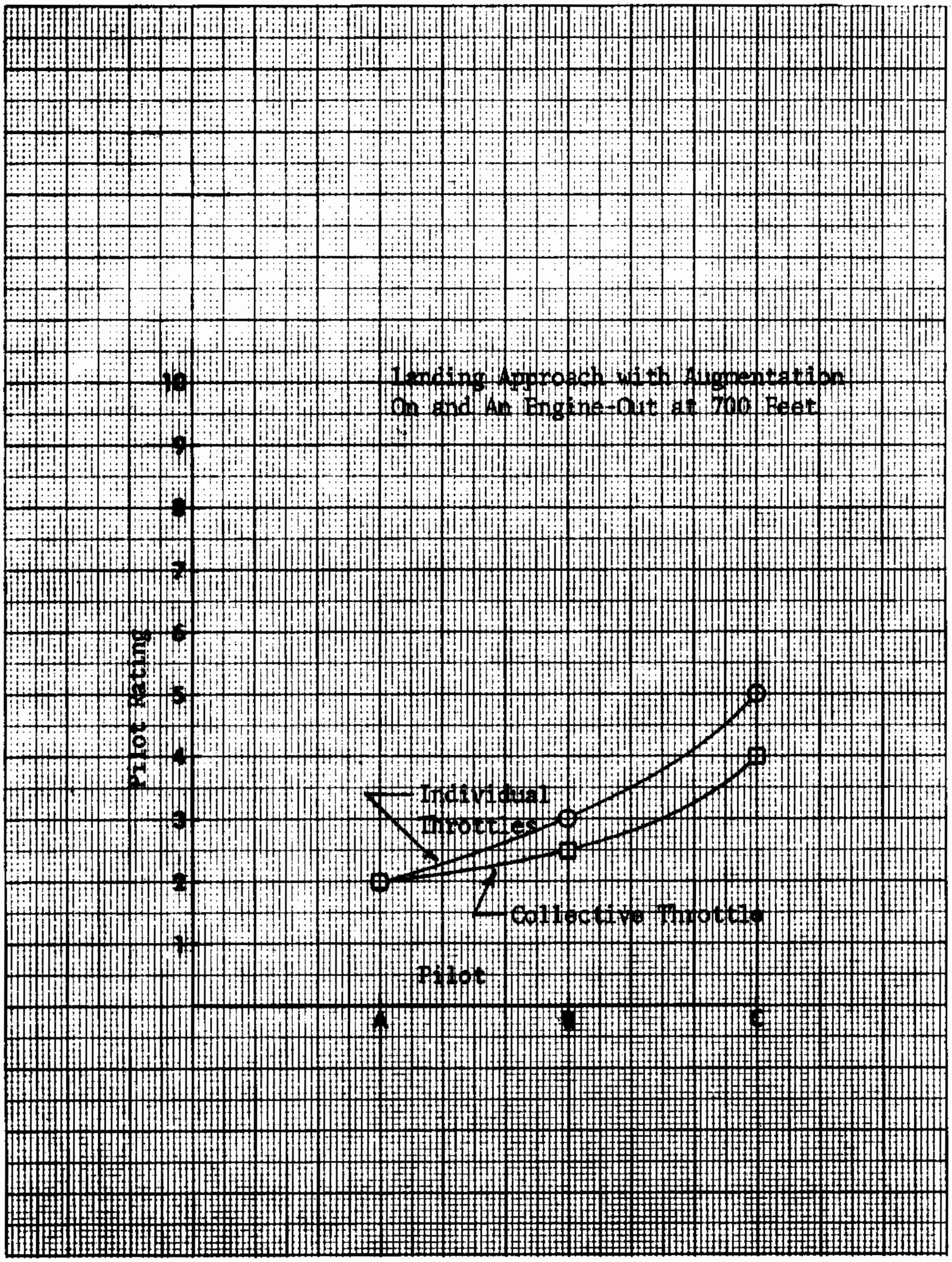


Figure 54. Pilot Opinion for Individual Versus Collective Throttles

forces were fixed throughout the simulation and were not varied. Only one pilot indicated mild annoyance by what he considered a high breakout force, the other pilot's comments did not indicate a dislike for these forces.

Directional Control Forces

A rudder pedal force gradient of 20 pounds/inch was used throughout the simulation. The breakout force associated with this gradient was 21 pounds. The pilot comments do not reflect any particular like or dislike for these forces.

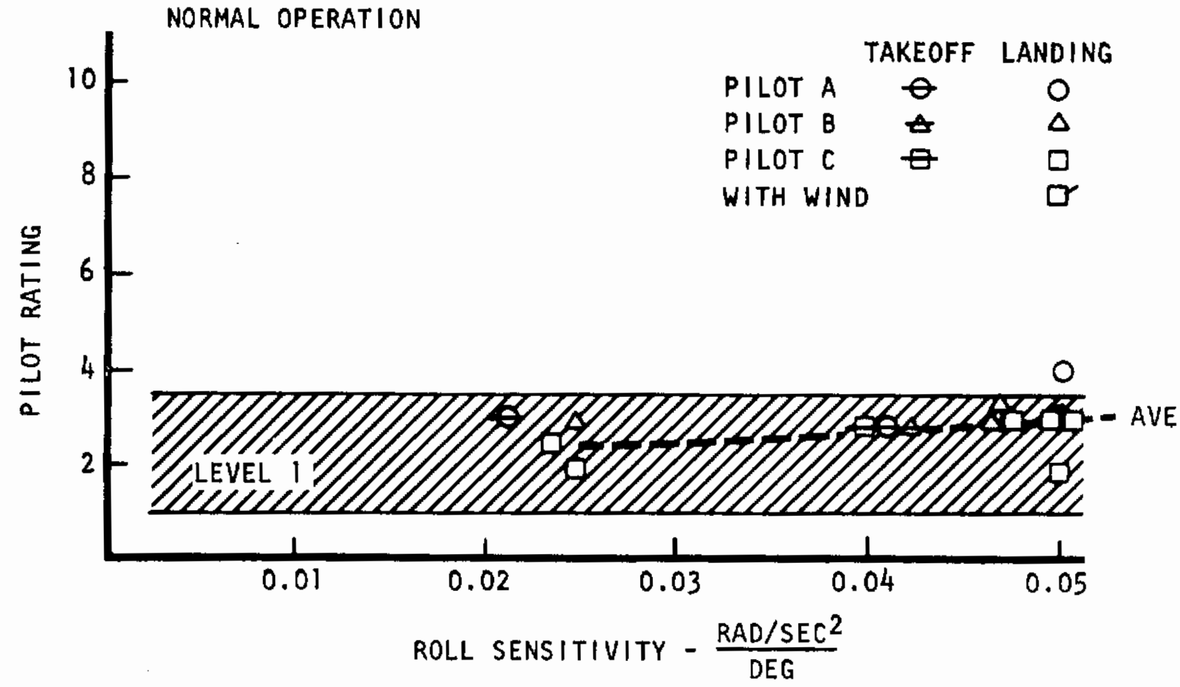
Roll Sensitivity

Variations in roll sensitivity influenced pilot ratings most significantly during engine failures. For normal operation pilots seemed to prefer the lower sensitivities in roll, however, during engine failure recovery a higher sensitivity was preferred as can be seen by an examination of Figure 55. This figure shows a limited number of data for variations in roll control sensitivity in both the takeoff and landing configurations. In each case, the pitch and yaw control sensitivities are constant. For the takeoff case, these were 0.15 rad/sec^2/inch and 0.113 rad/sec^2/inch in pitch and yaw respectively. For landing they were 0.30 in pitch and 0.13 in yaw.

Several linear sensitivity ranges were examined in both maneuvers. As a result of the incompatibility between the normal and failure operating mode requirements, in terms of pilot opinion, it was decided to use nonlinear roll gearing which would effectively provide two levels of sensitivity. The lower sensitivity for small displacements of the wheel about neutral and a higher sensitivity for wheel displacements greater than $\pm$15 degrees. The ratio of the higher to lower sensitivity is 1.5 or an increase of 50 percent for wheel displacements greater than $\pm$15 degrees. The gearing curve incorporating these sensitivities is shown in Figure 56. The effect of this nonlinear gearing on pilot opinion for both normal and failure mode operation is discussed in subsequent sections and presented in Figures 58 and 59.

Normal Operation Handling Qualities

The pilot ratings obtained for the unaugmented vehicle in each of the three maneuvers indicated correspond to those associated with Level three flying qualities. These results are shown in Figure 57 and are consistent with the expected flying qualities based on the guidelines of Reference (1). The baseline vehicle flying qualities are analyzed in Volume V-III and are shown to either meet or exceed the minimum levels required for the Level 3 terminal flight phase in all cases except the sideslip excursion parameter in the lateral-directional axes and short



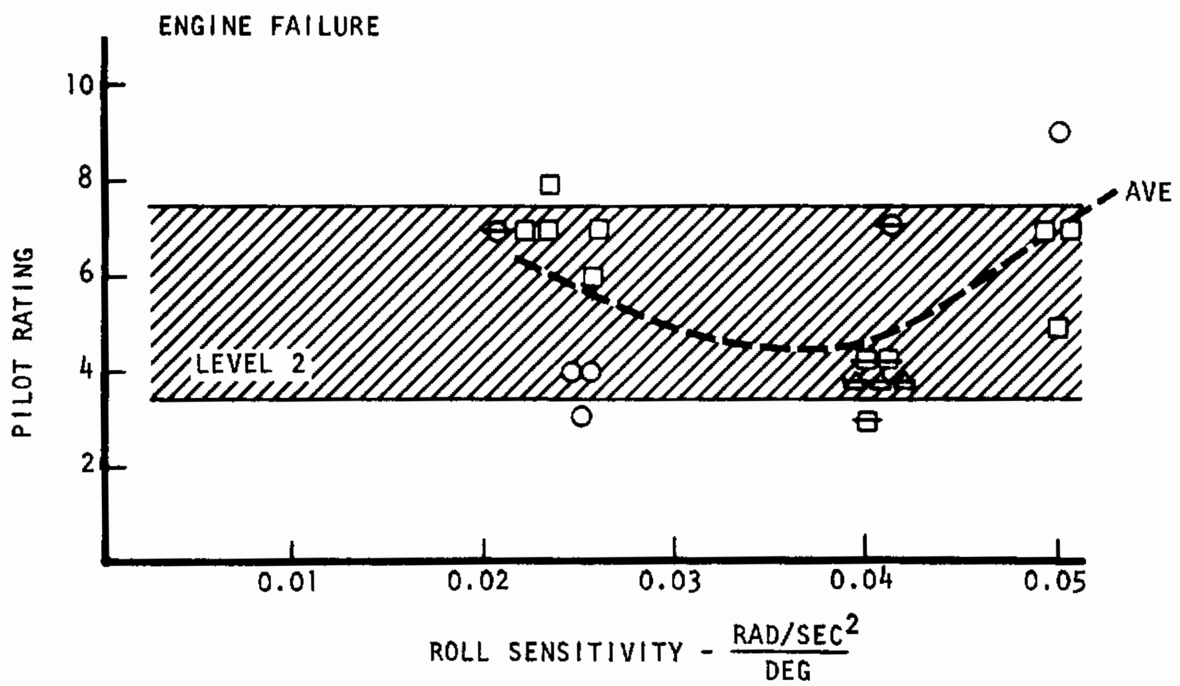


Figure 55. Pilot Rating Versus Roll Sensitivity - Takeoff and Landing

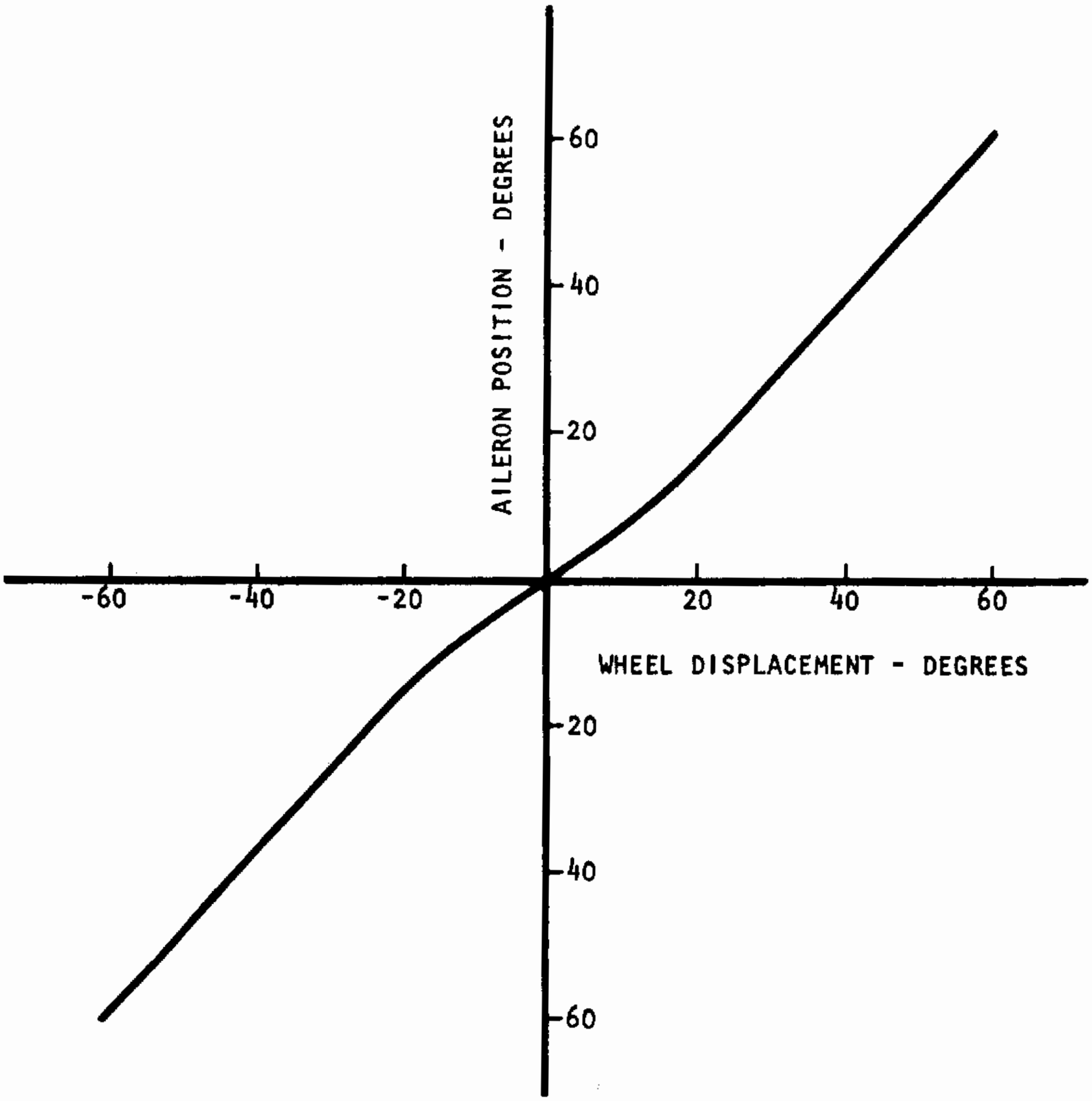


Figure 56. Roll Control to Aileron Gearing

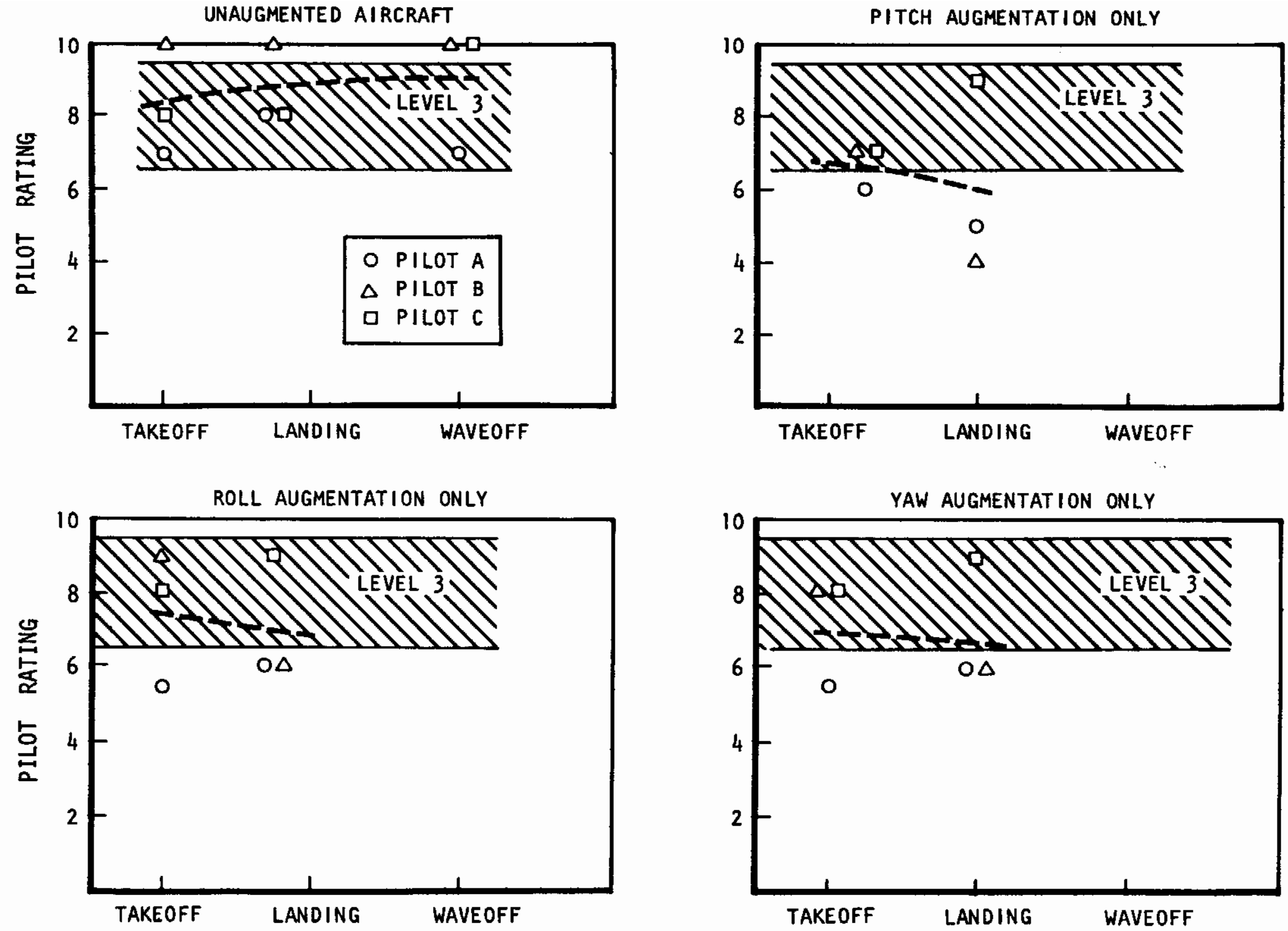


Figure 57. Effect of Augmentation Levels on Pilot Rating - Normal Operation

period frequencies in the longitudinal axis. They do not, however, meet the Level 1 requirements for this flight phase until pitch, roll and yaw augmentation are added. Pitch augmentation is required to increase the short period frequency and phugoid damping. Yaw augmentation is required to increase dutch roll frequency and damping and reduce the sideslip excursions. Roll augmentation provides a means of stabilizing the spiral mode roots. The pilot ratings for the unaugmented aircraft shown in Figure 57 range from 7 to 10 and the dotted line, which represents the average pilot ratings, coincides closely with the average rating associated with Level 3 performance. The Level 3 rating range is indicated by the shaded area. Also shown in this figure are the pilot ratings which were obtained when individual augmentation axes were added to the baseline vehicle for the takeoff and landing cases. These also indicate consistency with expected performance levels based upon the flying qualities requirements of Reference (1) when the aforementioned unaugmented baseline vehicle characteristics are taken into account. In terms of pilot opinion the most significant improvement occurs when pitch augmentation is added, bringing the average pilot ratings nearly into the Level 2 area. In all single axes augmentation cases, however, the average ratings are significantly improved over those for the unaugmented case.

As a result of incorporating the changes suggested by the 3 DOF longitudinal and roll sensitivity studies previously discussed, significant improvement in pilot ratings were obtained with three axes augmentation levels. These results are summarized in Figure 58 for the three maneuvers. This figure shows the pilot ratings obtained for normal operation with and without winds using a revised augmentation system. In the case of no wind operation the maximum and minimum pilot ratings ranged between 1-1/2 and 4, and are generally well within the pilot rating range corresponding to Level 1 which is represented by the shaded area. The takeoff maneuver is rated most severe by the evaluating pilots. It is believed the reason for this was the full power pitch maneuver required to level off at 500 feet while trying to maintain constant speed. This maneuver would be inconsistent with a normal takeoff in which speed would be allowed to increase after leveling off, however it served the purpose of the study for evaluation of gross pitch maneuvers.

When winds and turbulence are added to the control problem the average ratings are deteriorated into the Level 2 area. The two pilot ratings of 7 occurred during the landing approach with a 45 FPS crosswind. These are data runs 815 and 867 of Table II, Appendix II. No pilot comments are available for run 815, however the pilot comment for run 867 indicates that the combination of the high crosswind and the 60 foot runway for this configuration makes the task slightly more demanding than a Level 2 effort. This pilots comments also indicates that a wider runway would have made the

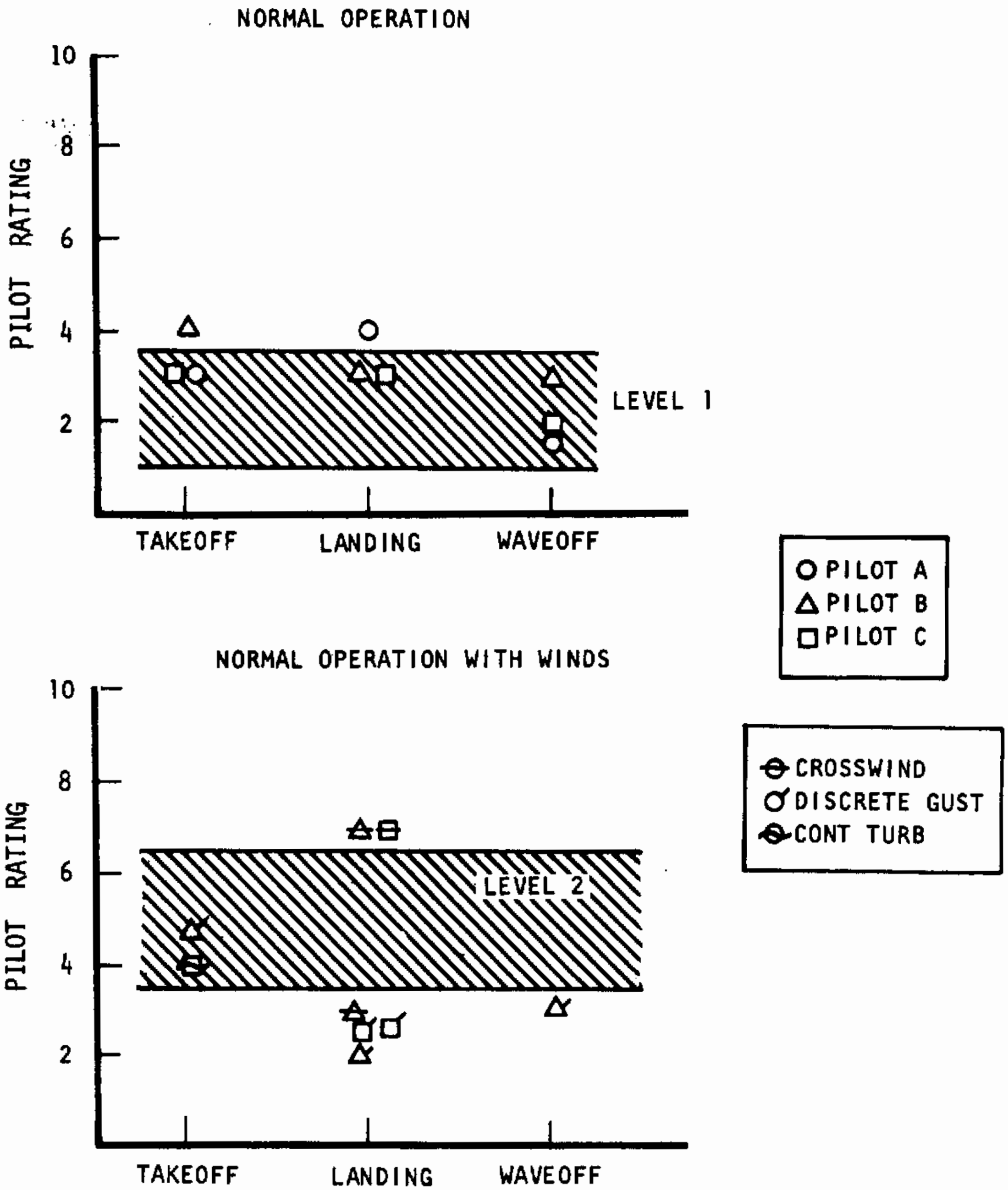


Figure 58. Normal Operation With and Without Winds Versus Pilot Ratings for Revised Augmentation System

problem less demanding with this configuration. This particular pilot used the decrabbed wing down approach technique and characteristically for this configuration seemed able to handle larger crosswinds than pilots using a crabbed approach.

This pilot comment also suggests, it would not be unreasonable to expect the pilot ratings to improve by a configuration improvement such as increased rudder effectiveness. As is shown later in the section on handling qualities criteria this is certainly the case. In this section increased rudder effectiveness was evaluated during crosswind landings by two pilots who used a crabbed approach technique.

The other ratings for the landing approach in the lower half of Figure 58 were obtained mostly for discrete longitudinal and lateral-directional gusts. These were runs 155, 157, 159, 215, 217, 229 and 231 of Table II-II. The run rated at 3 in this portion of the figure by pilot B was Run 816, a 45 FPS crosswind landing. This run was identical to 815 in terms of crosswind magnitude. Unfortunately no pilot comments are available for either or these runs, however examination of the time history data for these runs indicates that possibly the same situation existed as that for runs 725 and 726 in which this pilot's comments indicate that he decrabbed at a greater distance from the touchdown point on successive runs, and as a result, the difficulty of the landing task was reduced. This apparent spread in pilot ratings due to pilot crosswind control technique was apparent throughout the study and is an area in which more work is required. Also apparent in the data of this figure and in successive figures is the large rating spread with different types of external disturbances, such as differences in the rating spread between discrete gusts and crosswinds and/or continuous turbulence. In the case of random external disturbances and engine failures (not shown in this figure) the pilot rating spread was also influenced by the proximity of the aircraft to the touchdown point. Unfortunately this study was not sufficiently broad to investigate all of these areas in detail, however it did point out areas where further investigation is necessary. The influence of pilot technique on crosswind landings and engine failure control will be discussed again in the following section on Pilot Control Techniques.

Failure Operation Handling Qualities

The results obtained with the revised 3 axis augmentation systems under failure operating conditions are shown in Figure 59. They have been separated into ratings obtained for failures occurring above 160 feet and those obtained for failures occurring below 160 feet. The choice of 160 feet was based on the minimum waveoff altitude which is discussed more fully in a later section. Assuming, for the moment, that a waveoff will always be made at altitudes above 160 feet subsequent to experiencing an engine failure, then the top portion of this figure shows that the piloted handling qualities will always

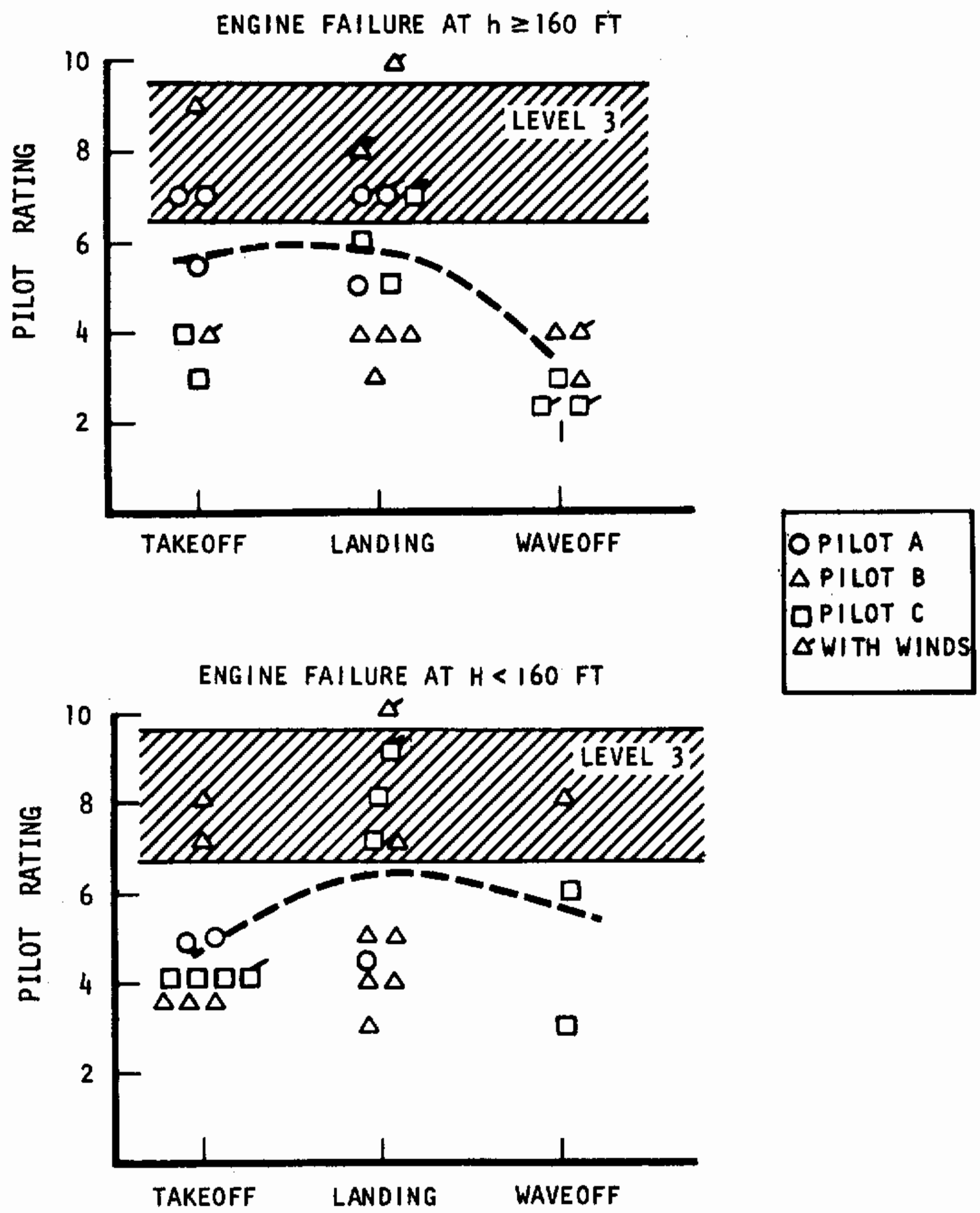


Figure 59. Effect of Engine Failures in the Presence of Winds on Pilot Ratings With Revised Three-Axis Augmentation

be in the lower Level 2 area for the waveoff, and, the pilot will have sufficient time during the go-around to trim the failure moments prior to making a new approach. Further, the data points for the landings in this figure can be ignored since these do not represent fully trimmed engine failure landing approaches but landing approaches in which the pilot is holding forces to maintain trim after the engine failure was experienced. No data were obtained during this study for trimmed engine failure landing approaches. Pilots generally tended to trim failure moments only after a full recovery had been made, thus, the majority of the data points presented represent only a partially trimmed aircraft depending upon the time available to the pilot. Examination of the takeoff engine failures shows that generally the pilot ratings are in the Level 2 area with and without external disturbances.

The lower portion of this figure shows the pilot ratings obtained for engine failures occurring below 160 feet. This figure shows that the majority of pilot ratings obtained are in the Level 2 handling qualities area for the takeoff and landing cases. As before, assuming that no waveoffs are attempted at altitudes below 160 feet the waveoff data points appearing here can be neglected. The pilot ratings of 9 and 10 occurred during tests involving 45 FPS crosswinds in addition to the engine failure. It is likely that additional rudder control power would have improved these pilot ratings.

The wide spread in pilot ratings of this figure is indicative of the results which were obtained throughout the study in the presence of engine failures and is most noticeable during the landing condition. These are attributable in part to variations in pilot technique and is discussed in the section on Pilot Control Techniques and later sections. The very fact that this spread exists however, indicates that there is something lacking in the pilot-vehicle combination. While the something which is lacking was not fully defined in terms of a system during this study it is clear from these results that some additional pilot assistance is needed in the form of either an automatic landing system or additional control augmentation. As a result an engine failure compensation system has been stipulated. An all automatic landing system would of course have to be justified for other reasons as well. Additional control augmentation in the form of roll and pitch control stick steering loops may also be the only additional requirement although this study, as well as, past experiences with similiar augmentation systems have shown that pilots tend to degrade system ratings with roll control stick steering because of the increased stiffness that results during normal operation maneuvers. During engine failures or external disturbances however, the pilot ratings are generally up rated with such a system. During the preliminary verification tests of this study, roll and pitch control stick steering loops were evaluated for this configuration with results similar to those just described. An engine failure compensation system could include any one or all of the above. In addition, the results of this study have shown that it must also include some form of sink rate control. Under normal operating conditions, when on final approach pilots can probably detect sink rate differences of ±2FPS. During conditions of extreme preoccupation such as is experienced under conditions of engine failure recovery this detection threshold would increase. In an aircraft such as the configuration of this study which is operating at two-thirds the maximum touchdown sink rate or more, control of this variable becomes important.

Minimum Safe Augmentation Level Requirements

In order to define the failure mode requirements of the augmentation systems, the takeoff and waveoff modes were rated by pilots with only two augmentation systems operational. Ratings were obtained with these configurations with and without engine failures. These results are shown in Figure 60 for pitch and yaw augmentation only and pitch and roll augmentation only, representing failure of the roll and yaw augmentation axis respectively. These data, while limited, show that with either pitch and yaw augmentation or pitch and roll augmentation and no engine failure, the handling qualities can be expected to be in the Level 2 area with a slight pilot preference, based on average ratings, for pitch and yaw. In the presence of engine failures, the data show that the handling qualities can be expected to fall in the Level 3 area. Augmentation configurations representing a pitch axis failure were also examined for the waveoff case. This configuration would involve roll and yaw augmentation only, and was generally considered unacceptable by pilots. The data are shown in Figure 61. It is probably safe to assume that the takeoff and landing cases would also be considered unacceptable. Figure 61 also summarizes the pitch and roll, and pitch and yaw data of Figure 60.

The data indicate a strong need for pitch augmentation, i.e., the aircraft is only marginally safe without it. The likely failure probability of a non-redundant pitch augmentation system is sufficiently great as to require redundancy and fail-operational capability, perhaps even two fail-operational capability. Reference to Figure 57 shows that pitch augmentation alone might be acceptable (Level 3) if operation in this configuration does not occur too frequently. Again, however, the likely failure probability of non-redundant augmentation is not sufficiently low to satisfy allowed probabilities of encountering Level 3 although it could satisfy Level 2 failure probability requirements. Based on these considerations and the data of Figure 60, fail-operational pitch and yaw augmentation combined with non-redundant roll augmentation appears to provide a satisfactory configuration.

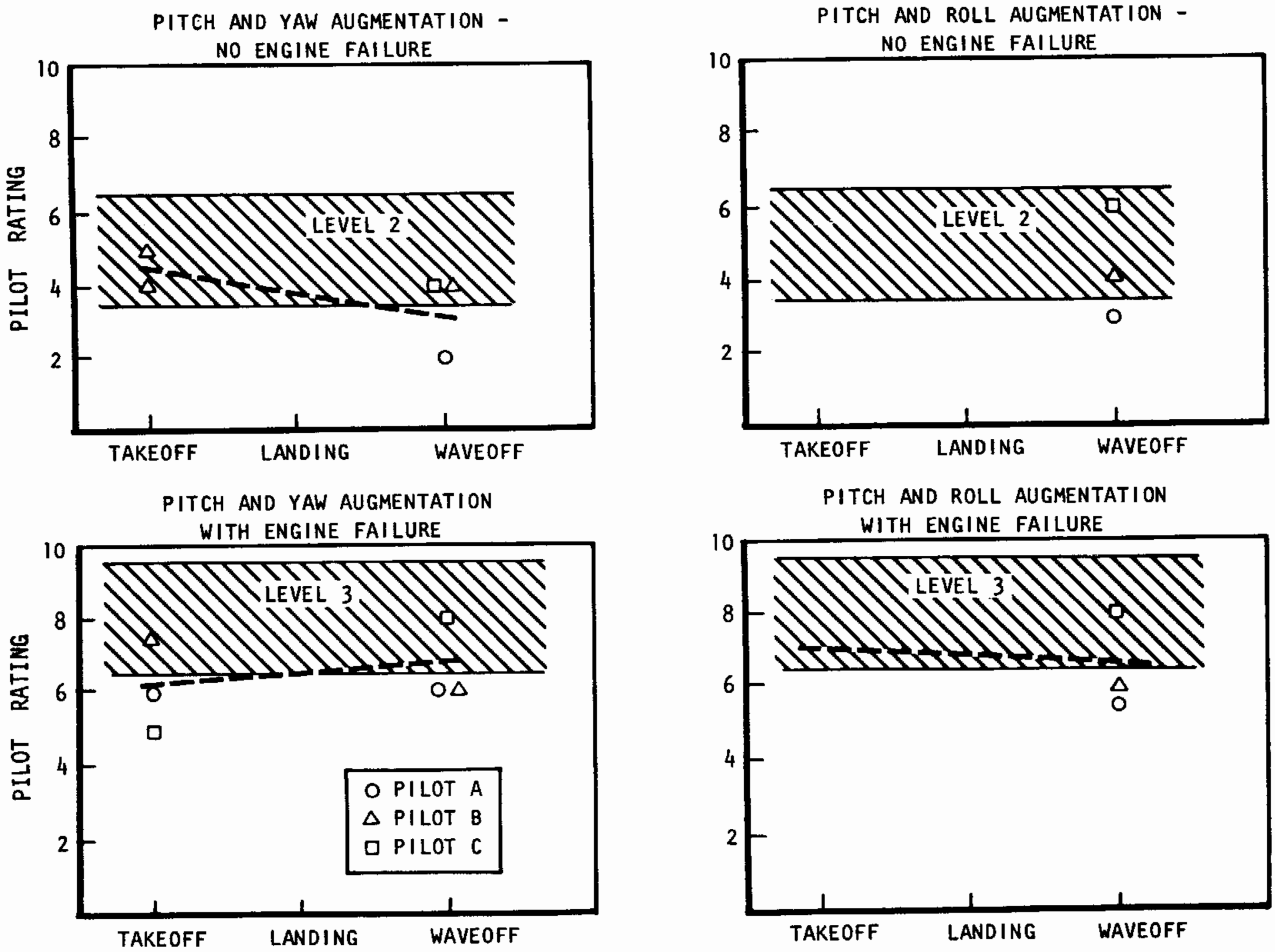


Figure 60. Effect of Augmentation Levels on Pilot Rating - Single-Axis Augmentation Failures

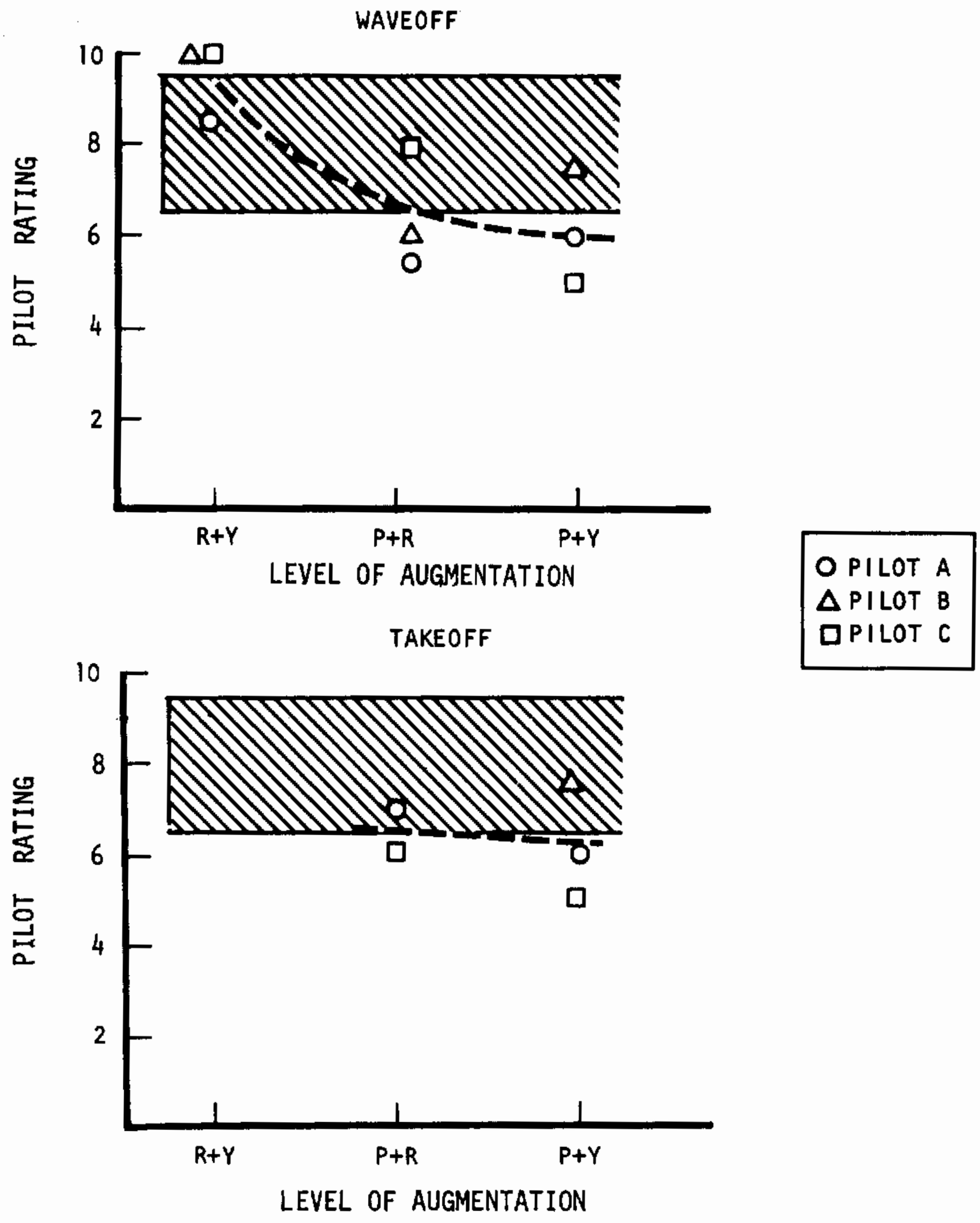


Figure 61. Pilot Ratings Versus Single-Axis Augmentation Failures in the Presence of Engine Failures

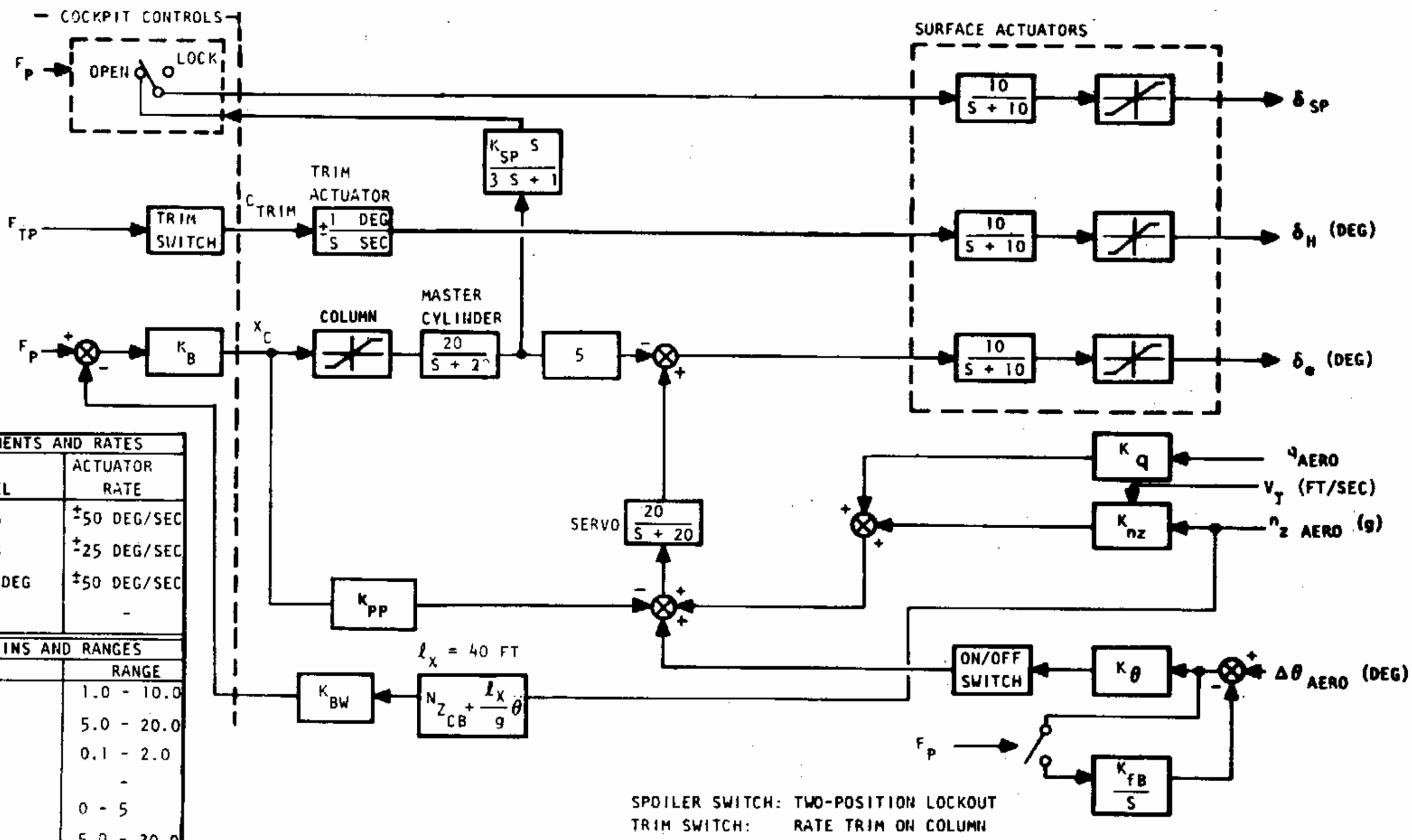
Revised Flight Control Systems

During the course of the simulation program a number of changes were incorporated in the control and augmentation systems as a result of piloted evaluations of the various maneuver handling qualities. The changes which were incorporated were the result of both normal and failure mode evaluations with and without external disturbances. These changes resulted in the revised control systems presented in Figures 62 through 64.

To achieve the preferred pitch control system sensitivity, the horizontal stabilizer has been decoupled from the column and responds only to trim actuator commands as shown on Figure 62. Also consistent with piloted evaluation study results, the DLC spoilers are coupled only to the column through a 3-second washout. The interlock between the thrust control system and the DLC has been deleted, but the pilots manual open-lock switch has been retained. The elevators are directly coupled to the column through a constant linear gearing curve. The pitch augmentation will be designed consistent with the failure probability requirements of Level 3 and will be constantly engaged. The study results also indicate that gain scheduling with speed would be required to satisfy Level 1 phugoid damping and short period frequency requirements. Although the study did not define gain scheduling requirements, a gain schedule speed input into the normal acceleration loop has been shown.

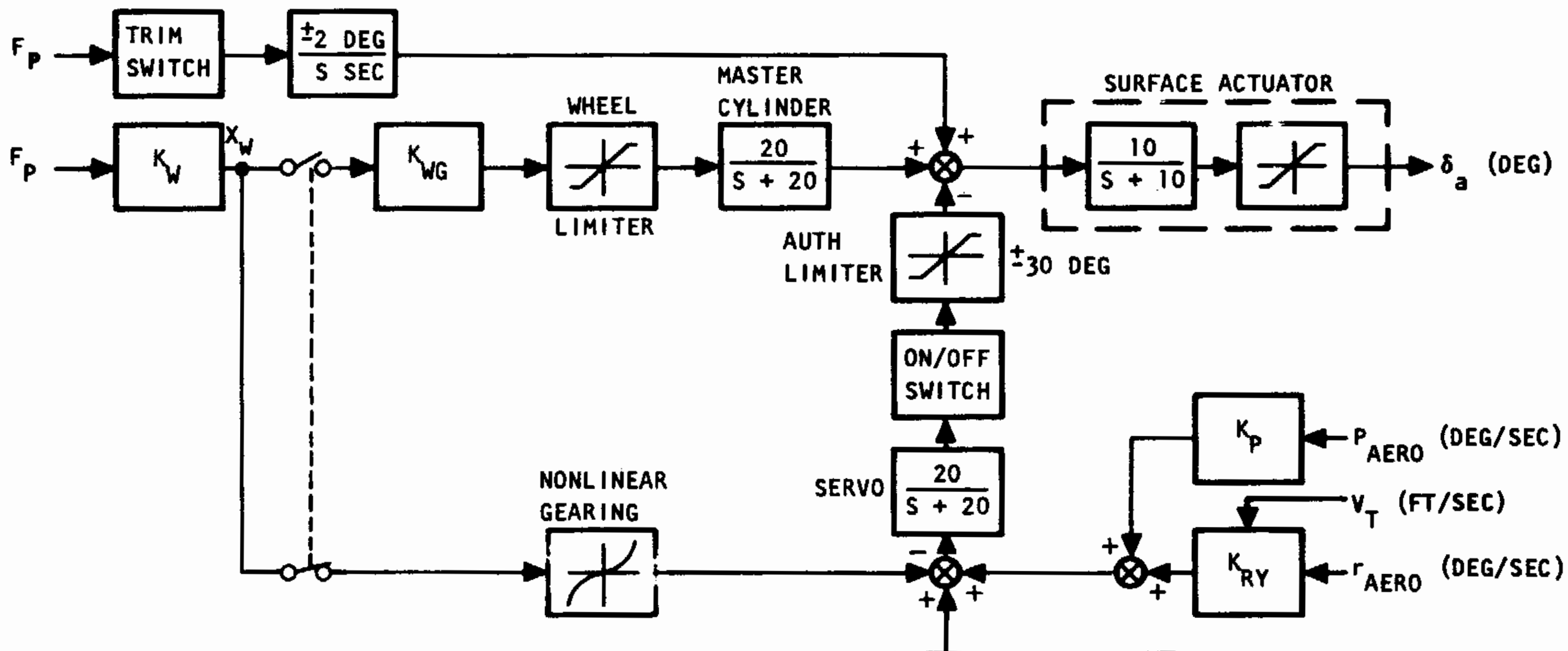
The roll augmentation system is shown in Figure 63. As in the case of pitch, only changes affecting control sensitivity resulted from pilot validation studies. The nonlinear gearing of Figure 56 would be used in the roll-augmentation on mode. Also gain scheduling of the yaw rate feedback into roll would be utilized to stabilize the spiral mode root for Level 1 requirements.

To satisfy the terminal phase sideslip excursion requirements and the piloted validation studies the yaw augmentation system will be designed to meet Level 3 failure probability requirements and the system will be left engaged at all times. Gain scheduling of the lateral acceleration feedback loop will also be incorporated to assure adequate dutch roll frequency and damping characteristics.



DISPLACEMENTS AND RATES		
	TRAVEL	ACTUATOR RATE
δ_e	±25 DEG	±50 DEG/SEC
δ_H	±20 DEG	±25 DEG/SEC
δ_{SP}	(0-60) DEG	±50 DEG/SEC
X_C	±5 IN.	-
NOMINAL GAINS AND RANGES		
	NOM	RANGE
K_q	1.66	1.0 - 10.0
K_{nz}	10.1	5.0 - 20.0
K_θ	0.5	0.1 - 2.0
K_{FB}	50 V/V	-
K_{PP}	2	0 - 5
K_{SP}	24	5.0 - 30.0
K_B	0.166 IN./LB	-
K_{BW}	10 LB/g	-

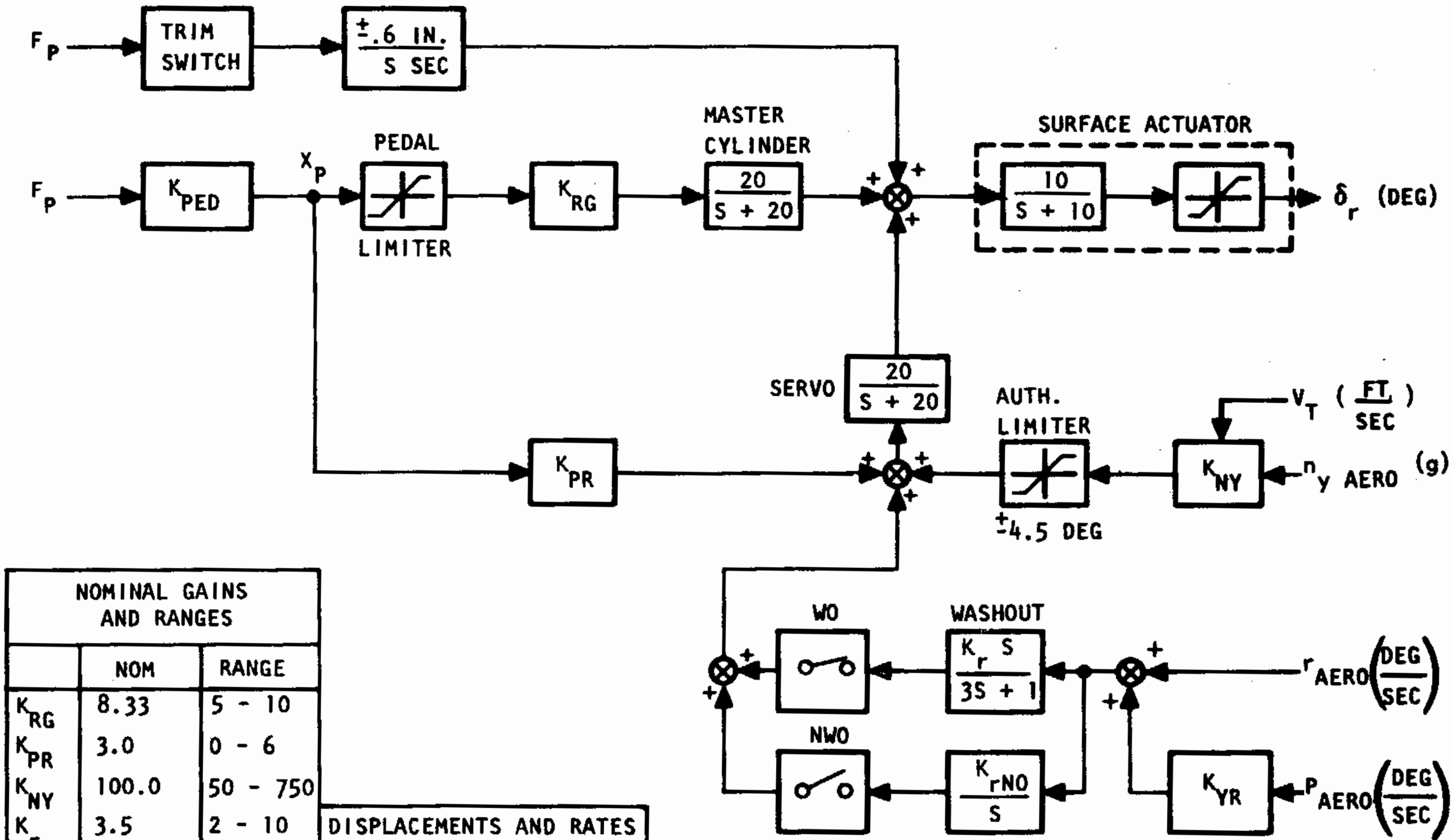
Figure 62. Revised STOL Mode Pitch Flight Control and Augmentation System



NOMINAL GAINS AND RANGES		
	NOM	RANGE
K_{WG}	1.0	0.75 - 1.8
K_P	0.85	0.5 - 1.5
K_{RY}	0.4	0 - 2.0
K_ϕ	0.5	0.25 - 2.0
$K_{f\phi}$	50.0 V/V	-
K_W	4 DEG/LB	±25 LB/DEG

DISPLACEMENTS AND RATES		
	TRAVEL	ACTUATOR RATE
	±60 DEG	±50 DEG/SEC
X_W	±60 DEG	-

Figure 63. Revised STOL Mode Roll Flight Control and Augmentation System



NOMINAL GAINS AND RANGES		
	NOM	RANGE
K_{RG}	8.33	5 - 10
K_{PR}	3.0	0 - 6
K_{NY}	100.0	50 - 750
K_r	3.5	2 - 10
K_{rNO}	1.75	1 - 5
K_{YR}	0.0	0 - 3
K_{PED}	0.05 $\frac{IN}{LB}$	-

DISPLACEMENTS AND RATES		
	TRAVEL	ACTUATOR RATE
δ_r	±25 DEG	±50 DEG/SEC
X_P	±3 IN.	-

Figure 64. Revised STOL Mode Yaw Flight Control and Augmentation System

PILOT CONTROL TECHNIQUES

During the course of the program, pilots were encouraged to discuss their control techniques both for the current simulation model and with respect to aircraft in general. Such discussion was requested both in questionaire format and also during the course of the simulation tests. The comments of Appendix I are profuse with such discussions. The objective of this investigation was not to rate the abilities of individual pilots but to identify areas where differences in pilot technique might influence study results. A number of such comments which were obtained are collected here. They are arranged in a question versus answer format and are used to show that pilot techniques do vary under certain circumstances, probably as a result of training, past experiences, or existing circumstances. Additional comments regarding pilot technique as observed in the test programs or from time history data are also included.

For a variety of reasons, the test data available in this area are limited and by themselves are not sufficient to justify any study conclusions. But, in some cases they do tend to support conclusions based on other data obtained during this study and in others they seem to point the way toward possible future study areas where results to some degree appear to be influenced by pilot technique.

GENERAL

The following are the self-described control techniques used by pilots during normal operation. In this area all pilots seemed to use similar techniques with only minor deviations.

1. Which pilot technique do you feel the aircraft responds to most favorably?

    a. Control pitch attitude with the column and speed with the throttles.

    b. Control speed with the column and flight path with the throttles.

    c. Other: (describe)

2. Do you feel that this configuration requires any special column or throttle control techniques?

Pilot A:

1. Answer b.

My basic control technique, is to fly airspeed (angle of attack) with longitudinal control inputs and glide-path (altitude control) with power.

This is very definitely the case when I fly a final precision instrument approach. I set my angle of attack, or airspeed (depending on type of aircraft and its associated instrumentation) with pitch inputs and trim out control forces. I then maintain the desired glidepath with smooth small adjustments in power. Throughout an instrument approach prior to the final glidepath I use the same technique adjusting altitude and trimming out forces as necessary for airspeed and configuration changes.

At altitude, when I desire to hold a constant mach or airspeed, I use the same technique, maintaining airspeed or attitude with pitch control and altitude with smooth gradual power changes. Once the aircraft is trimmed for the airspeed I desire, it will tend to continue to seek this trim condition regardless of power changes, as long as they are slow and smooth.

Of course there are exceptions to this technique, especially when abrupt or gross changes in flight conditions are required. In these cases, I modify rather than abandon or reverse my basic control technique as necessary to meet the situation. But I always strive towards this basic technique.

The only time I use the technique of controlling airspeed with power and altitude with the column is when the task requires it, such as a front side trim shot.

2. I do not feel that this configuration requires any special column or throttle control techniques.

Pilot B:

1. Answer c.

   My basic technique is the same one which I use on this aircraft. Essentially, you might say that my approach is to control speed with the column and rate of climb with the throttles. More specifically, I feel a coordinated movement of both pitch attitude (column) and power (throttle) is necessary.

2. I do not feel that this configuration requires any special column or throttle control techniques.

Pilot C:

1. Answer b.

   I control airspeed with the column and rate of descent with the throttle.

2. In my opinion, this configuration does not require any special column or throttle control techniques.

ENGINE FAILURE

Subsequent to loss of the right hand outboard engine during takeoff the uncontrolled aircraft typically develops a rolling acceleration of approximately 0.53 RAD/SEC^2, a yawing acceleration of 0.15 RAD/SEC^2, and a pitching acceleration of -0.13 RAD/SEC^2, and experiences a 25% loss in powered lift which results in a change in altitude rate. Because of the large roll acceleration encountered, the pilots gave their immediate attention to control of roll attitude. The next control problem pilots tended to cope with was in pitch. While this failure moment was actually smaller than that experienced in yaw, the uncontrolled deceleration which results from the engine failure is typically on the order of 2.5 FPS and, as a result, to avoid stalling, the pilot must pitch over to maintain speed. During the landing approach the uncontrolled speed also decreases initially and if the associated negative pitching moment is uncorrected the speed gradually builds up again. When the engine failure pitching moment in the landing approach is compensated for, the speed continues to decrease, as in the takeoff case, if no thrust compensation has been made. Subsequent to making corrections to regain control of bank angle and speed the pilot initiates the necessary heading correction with the wheel. It is then that he first has the opportunity to adjust throttles to compensate for the change in altitude rate due to the engine failure. Almost immediately he goes back to completion of the heading change correction before completing the throttle or power adjustment. During the landing approach, just short of touchdown, this procedure is sometimes reversed. The pilot realigns the aircraft with the runway and makes the necessary lateral displacement prior to concerning himself with speed or altitude rate corrections. Pilots tended to solve the control problem in one axis prior to going on to another and this technique seemed to minimize the engine failure. It usually takes from 2 - 4 seconds subsequent to engine failure for the pilot to be able to direct his efforts to the throttle control. When pilots attempted to put in simultaneous control inputs into more than one axis, the recovery times usually increased due to a tendency toward P.I.O. This P.I.O. tendency was in part due to the lack of certain motion cues received by the pilot, but it is believed, was also partially due to the workload the pilots were assuming in attempting simultaneous multiple axis control. Initially it was assumed that for engine failures during the landing approach pilots would almost automatically apply more throttle, as soon as an engine failure was recognized, without diverting their attention from the roll control problem. Pilots were instructed in this technique and it was attempted by pilots during the initial phases of the program but they soon reverted to their usual techniques. No further investigation was made as to why this occurred. As a result of this pilot technique, sink rate control during a landing approach appears to require some form of automatic compensation.

Examination of the time history data and pilot comments tends to support these observations made during actual data runs. The end result being that timing of pilot control inputs for engine failure recovery is quite critical, particularily on landing approach final. Minor differences in pilot technique under otherwise comparable conditions seemed to significantly influence pilot ratings between data runs and result in a broad spread of pilot ratings by the same pilot. Several pilot comments indicate that if the throttle were left alone subsequent to engine failure near the ground the problem of aligning with the runway is alleviated and as a result the pilot ratings were lower. This of course is the wrong solution, since merely controlling attitude subsequent to loosing an engine in the STOL mode does not solve the sink rate control problem, but in this pilots thinking it was the only solution, since it alleviated his immediate problem, that of getting on the runway. The data runs referred to are 830 and 898.

This study pointed up the fact that successful engine failure recovery is influenced by slight variations in piloting technique making up the difference between a successful recovery and an unsuccessful one. The specific differences in pilot technique that result in an unsuccessful recovery are somewhat immaterial since in an acutal aircraft this is a trade-off which cannot be tolerated. As a result, some form of automatic engine failure compensation is mandatory.

EXTERNAL DISTURBANCES

With respect to external disturbances, differences in pilot technique did not appear to significantly influence execution of desired maneuvers except in the crosswind landings. In this area a significant difference in technique appears to substantially reduce pilot workload just prior to touchdown. The program was fortunate in having evaluation pilots who compensated for crosswind effects in different ways during the landing approach. Two of the evaluation pilots used a conventional crosswind approach in that they came down the glideslope in a crabbed attitude and decrabbed at approximately 100 to 200 feet altitude just prior to touchdown. The third pilot came down the glideslope in a decrabbed attitude to the point of touchdown. This technique involved using bank angle to cancel the drift due to crosswind. The pilot using this last technique appeared to have more time available to align the aircraft with the runway and as a result no dynamics associated with decrabbing affected the problem. Leveling the wings occurs very near touchdown. While insufficient data are available to attempt to substantiate this, they are in part substantiated by the pilot comments to Runs 725 and 726 (Appendix I-2). This pilot used the more conventional technique of decrabbing just short of touchdown. These comments indicate that when the pilot decrabbed at a higher altitude (Run 726) he was able to do a better job with a higher crosswind (25 FPS) than by decrabbing at a lower altitude (Run 725) with a lower crosswind (10 FPS).

These data seem to show that in the area of crosswind landings, with a narrow runway and limited rudder power, pilot technique does influence the results and suggests that further study be conducted in this area.

TAKEOFF, WAVEOFF, AND LANDING CRITERIA

A series of landings, waveoffs, and takeoffs with three axes augmentation was made by three pilots for a wide range of glideslope angles, speeds, levels of crosswind, discrete gusts and turbulence, with and without engine failures. These are defined in Tables IV through VI of Appendix II along with pilot ratings and touchdown performance data. Table IV defines the results obtained during the landing approach and touchdown data runs. Table V defines results obtained during waveoffs and the takeoff data are presented in Table VI. Pilot comments for many of these data runs starting with Run 638 were taped and recorded and are listed in Appendix I-2.

To provide some consistency to these results certain ground rules were defined for each of the three maneuvers. These were followed by each participating pilot and, as a result, differences in pilot technique or personal preferences in areas covered by these ground rules did not influence the end results. The basic ground rule associated with the landing maneuver was that pilots were asked to continue the landing approach and touchdown regardless of where they found themselves with respect to the desired touchdown point as a result of external disturbances or engine failure. The ground rules associated with waveoffs were that pilots refrain from waveoff attempts until asked to do so and that during the engine failure waveoff speed could be increased but should not be allowed to bleed off significantly. During the engine failure takeoff, pilots were asked to maintain constant altitude while either regaining the initial trim speed or permitting a slight increase prior to trimming for a three-degree climb angle. During the no-engine failure modes of all three maneuvers, pilots were asked to make a reasonable attempt at holding the initial trim speed regardless of flight path angle desired.

APPROACH ANGLE EFFECTS

The altitude profiles that the pilots were commanded to fly during landings with different flight paths are indicated graphically on Figure 65. Flying on the 4.4° flight path at 140 FPS forward speed results in a nominal touchdown sink rate of 11 ft/second. Flying on the 5-degree glide slope at 140 FPS results in a nominal touchdown sink rate of 12.9 FPS. The two-segment flight path intersects the 4.4° flight path at 200 feet altitude. It was initiated on a 7° path and terminated on the 4.4° flight path if successfully negotiated. This flight profile was used to provide a form of roundout maneuver and prevent excessive touchdown sink rates. In all cases the pilot was asked to rate the handling qualities of the aircraft during the descent and touchdown phases of each approach for both normal and failure mode operation with and without external disturbances. In addition, for the 7° flight path approach the pilot was asked to evaluate his ability to pull up to and align on the 4.4 degree flight path.

The actual touchdown sink rates achieved during the various landings are summarized in Figure 65. The sink rate data are separated into two groups - those for normal landings with and without external disturbances and those for landings following an engine failure with and without external disturbances. The no failure data show a maximum sink rate of about 16 ft/second and there appears to be no trend or change in touchdown performance as a function of the two-segment approach angle. The fact that the pilots did not attempt to flare the aircraft prior to touchdown accounts for the large concentration of sink rates in the area of 11-12 ft/second.

The touchdown sink rates encountered in the presence of an engine failure vary over a wide range and are excessive in many cases. There appears to be no particular trend of the data as a function of flight path angle however. The high sink rates encountered resulted because the pilot must initially devote most of his attention, following the engine failure, to stabilizing the pitch, roll and yaw attitudes of the aircraft with the result that sink rate may be relatively unattended.

Pilot opinion data are also summarized as a function of sink rate and shown on Figure 66. These data, along with pilot verbal comments, indicate that the complexity of the landing task is not a function of the sink rate. These results agree closely with those of References 15 and 16 in which investigators found that there is very little influence on pilot opinion for various approach sink rates below 800 FPM. The studies of these references also show that if the 17.1 FPS approach had been continued to the normal flare altitude before pilots attempted to arrest the sink rate, the pilot ratings would have been affected. The two-segmented approach of this study with the transition initiated at an altitude of 200 feet is an adaptation of the recommendations made as a result of the study conducted in Reference 8.

It is interesting to note that the maximum pilot rating given is a function of task complexity. With no disturbance, pilot ratings compatible with Level 1 flying qualities would be expected. For extreme winds or turbulence, pilot work load is increased but the mission should not be impaired so that pilot ratings corresponding to Level 2 might be anticipated. For engine failures plus winds or turbulence, Level 3 pilot ratings are the minimum acceptable. Pilot ratings of 10 are, of course, not acceptable but the rating distribution patterns results in average ratings with failure that are much lower. Since all of the 10 ratings include winds, as well as engine failures it is believed that the 10 ratings would be eliminated with addition of engine failure compensation and some increase in yaw control power as subsequently discussed.

It will be noted that for the winds and turbulence cases the pilot ratings are spread from 2 to 7. This large spread results from the fact that these summary plots contain the results of discrete longitudinal and lateral-directional gust data, a range of crosswind amplitudes, and continuous

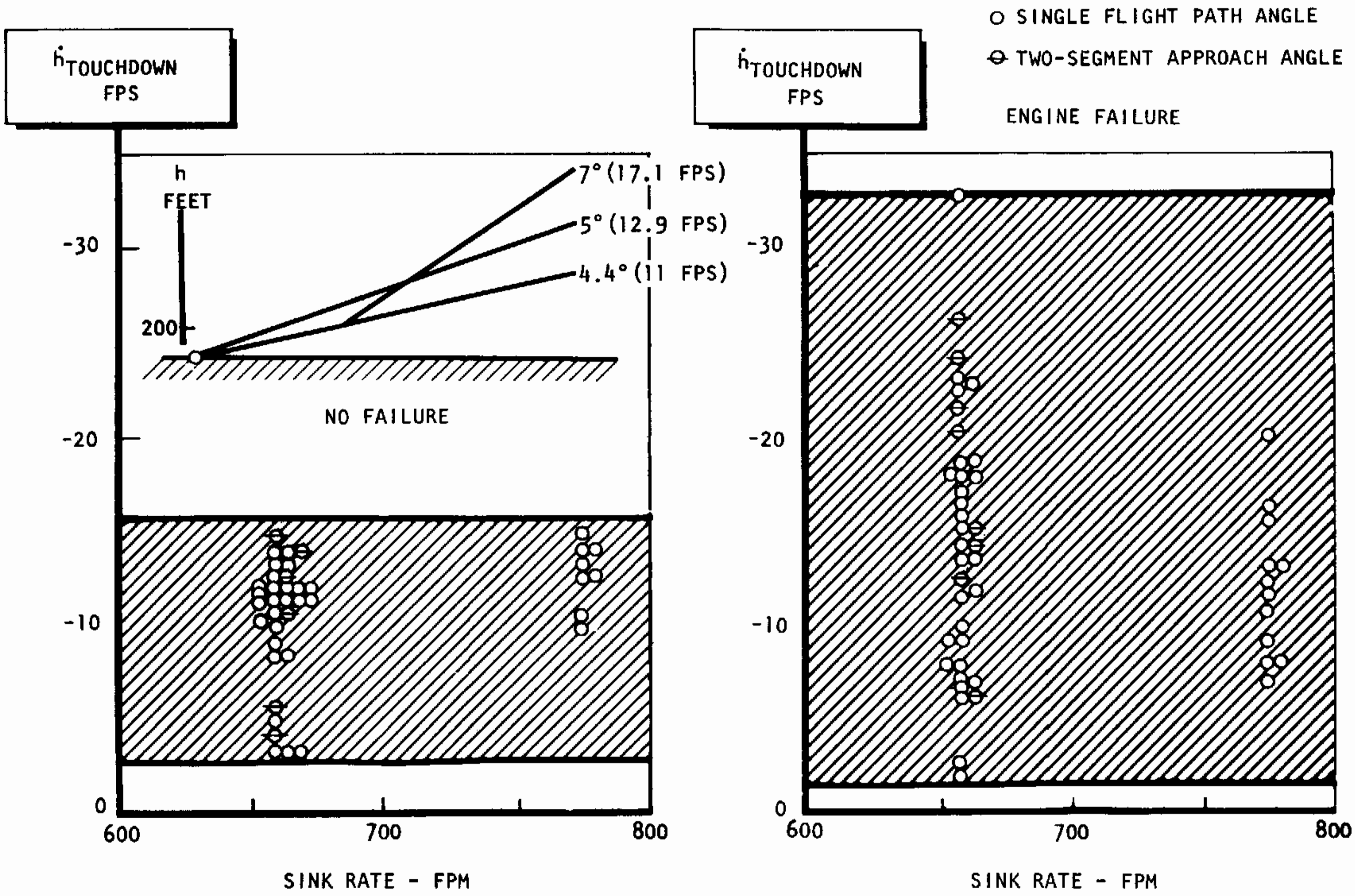


Figure 65. Effect of Glide Slope Variations on Touchdown Sink Rates

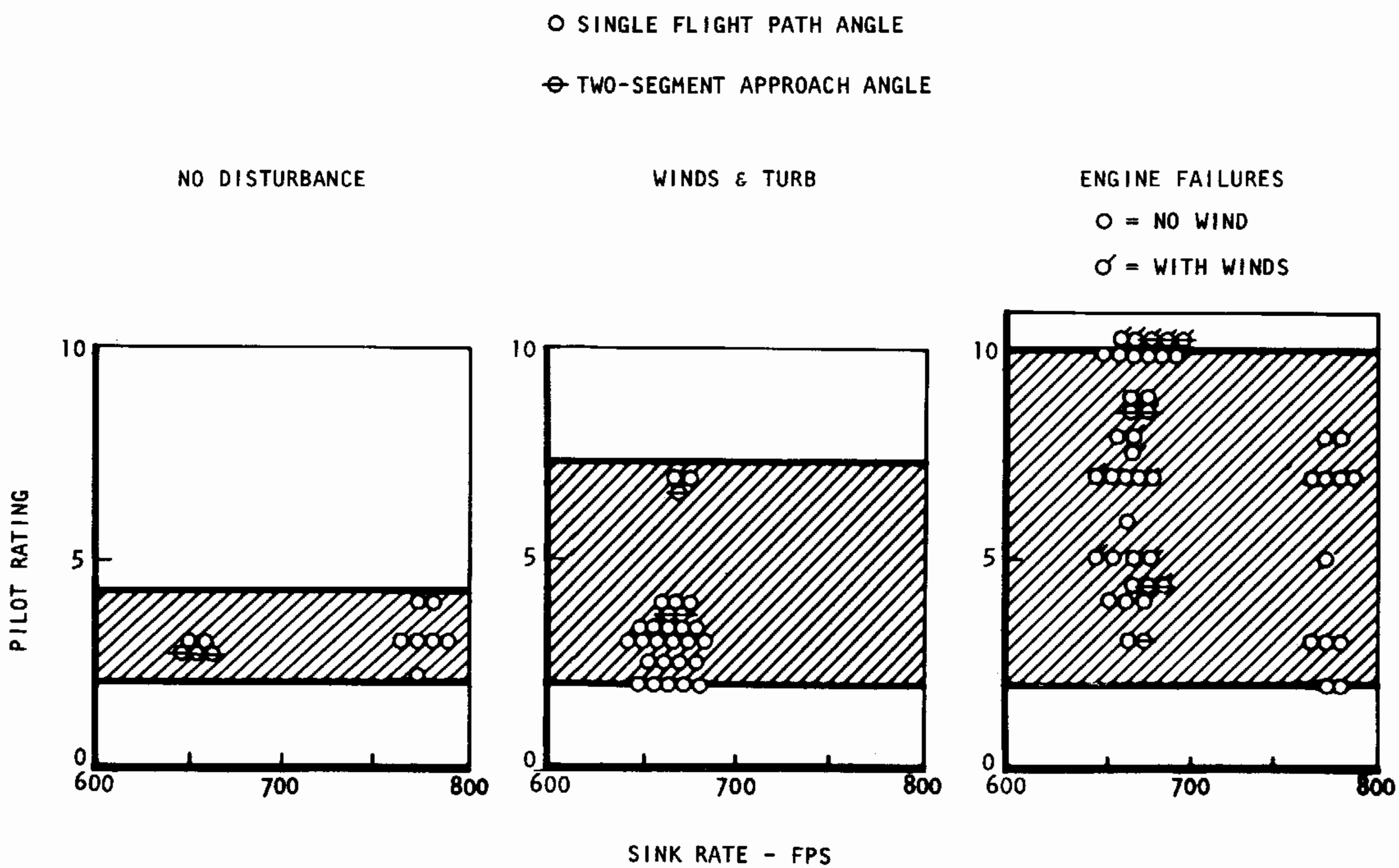


Figure 66. Effect of Glide Slope Variations on Pilot Opinion

turbulence data. The data runs plotted here are those of Table IV of Appendix II for the 140 FPS flight conditions. The breakdown of the individual wind and turbulence pilot ranges is as follows. The pilot ratings for the longitudinal and lateral-directional gusts ranged from 2 to 4. In most cases these are comparable to the no disturbance rating ranges. The continuous turbulence data plotted here ranged from σ_W values of 1.75 to 3.5 FPS. The range of pilot ratings obtained for this range of continuous turbulence levels was from 3 to 5. Crosswind magnitudes of 25 to 50 FPS are also plotted in this figure, the pilot ratings for this disturbance varied from 4 to 7.

For the reasons discussed previously in the section on Pilot Control Techniques, the spread in pilot ratings for single engine failures was quite broad as is seen from Figure 66. Interestingly, the pilot rating spread with only engine failures and no external disturbance seemed to increase as engine failure altitude decreased down to an altitude of 100-200 feet. At engine failure altitudes of 50 feet the pilot rating spread again decreased. Specifically the pilot rating spreads for the data of this figure with only an engine failure are as follows.

Engine Failure Altitude (feet)	PR Range	Number of Data Points
700	7-9	2
500	2-7	9
200	4-10	2
100	3-9	13
50	4-8	5

Also plotted in this portion of Figure 66 are data with continuous turbulence and crosswinds. A total of 16 data points are represented for engine failure altitudes of 100, 200, 500, and 700 feet. The pilot ratings for all of these data points ranged from 7-10.

LANDING SPEED MARGINS

One of the significant objectives of the simulation program is the determination of landing speed margins necessary for flight safety when considering handling qualities problems that may exist in the presence of external disturbances and engine failures. As previously indicated a large number of landings were made at various speeds with various levels of winds and turbulence, with and without engine failures. The results of these tests expressed in terms of pilot Cooper-Harper ratings are presented in Figure 67.

As seen from this figure there is a large spread on the pilot rating data for the winds and turbulence and engine failure cases. The reasons for these spreads, in both instances, and a breakdown of each for the 140 FPS trim speed case were identified in the previous and preceding sections. Similar comments can be made for the 118 and 157 FPS cases also shown in this figure. Because of the limited number of data points available for analysis of speed margins encompassing a broad scope of external disturbances and engine failure altitudes, it was determined that the best way to analyze the data was by use of an averaging technique. Statistical analysis techniques require a sufficiently large data sample at each sample point to be meaningful. Initially average pilot ratings were determined as functions of speed for the three conditions - no disturbance, winds and turbulence but no failures, and engine failures with and without winds and turbulence. For the no disturbance case, the trend of average pilot rating with speed is so flat that normal operation Level 1 handling qualities does not appear to be critical or pertinent in the determination of a landing speed margin. The other average curves show more significant trends with speed. In these two cases it was decided the most appropriate technique is to compare the average experimental pilot rating achieved with the average of the Cooper-Harper pilot rating corresponding to the appropriate level of flying qualities. Pilot ratings corresponding to Level 2 flying qualities are considered applicable to tests with winds and turbulence since pilot work loads are increased but no failures exist and mission completion is not affected. The average pilot rating corresponding to Level 2 is 5. Pilot ratings corresponding to Level 3 flying qualities are considered applicable with engine failures since pilot work loads are increased considerably and mission completion is affected. The average pilot rating corresponding to Level 3 is 8.0. Using these average pilot ratings indicates minimum safe trim speeds of 131 and 128 FPS based on the winds and turbulence and engine failure data respectively. These speeds correspond to speed margins of 1.16 V_{SL} and 1.13 V_{SL} where a V_{SL} of 113 FPS is the one engine-out reference speed. For the case of winds and turbulence, at the selected minimum safe speed, the maximum pilot rating of about 8.5 is not of too great concern since it does not represent a flight safety condition and would not be encountered very often. For the case of the engine failures, there are some pilot ratings of 10 that occurred at speeds above the speed established as the minimum safe speed and must be given special consideration. It is noted that the percentage of total pilot ratings at the 10 level is greatly reduced as speed is increased from 118 ft/second to 140 ft/second. Beyond 140 ft/second this percentage remains relatively low. The trend of this percentage with speed is similar to that of the average rating. As subsequently pointed out it

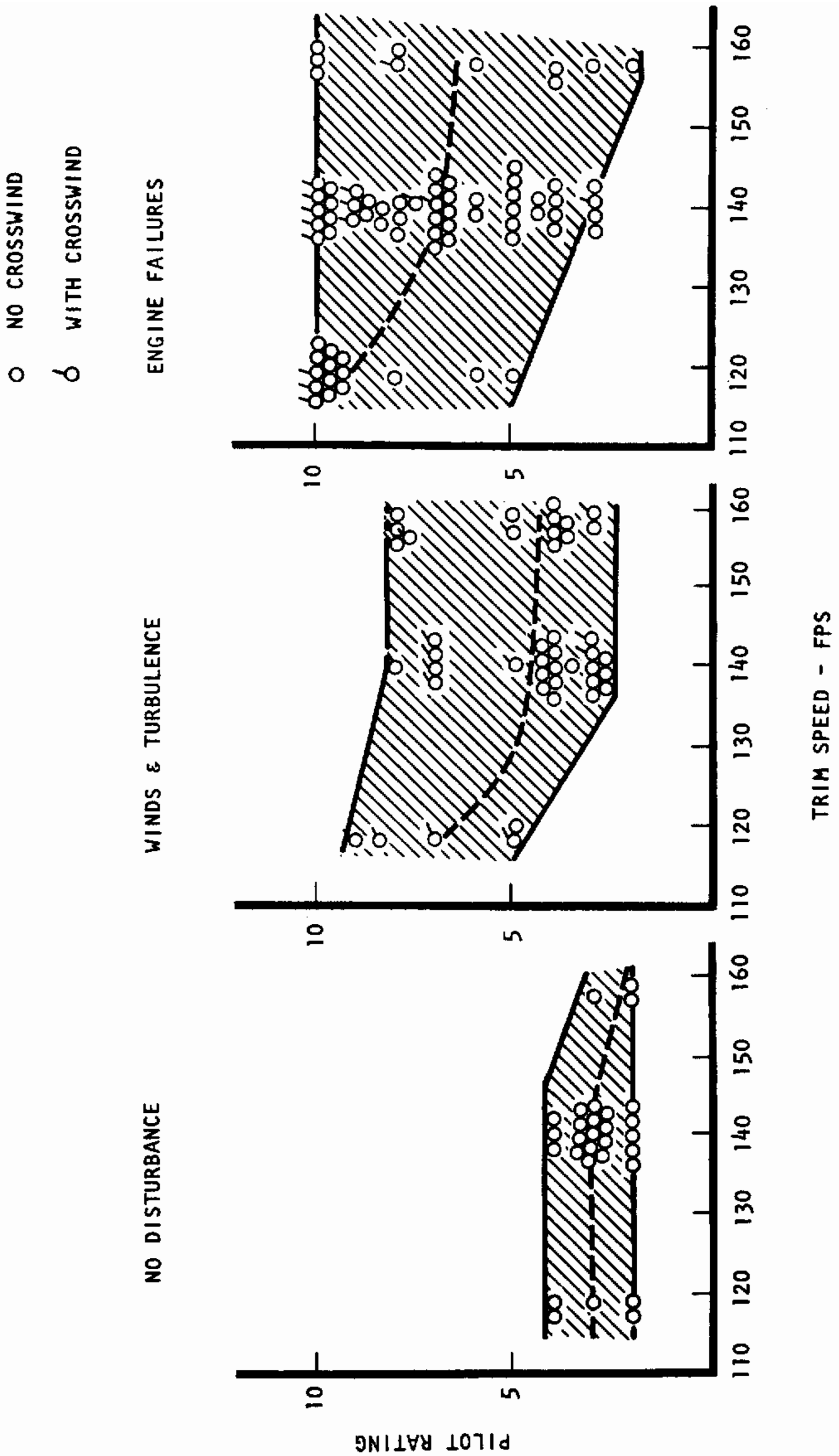


Figure 67. Effect of Landing Speed on Pilot Opinion

appears necessary to improve the pilots ability to control engine-out failures below some minimum waveoff altitude by use of some automatic failure compensation system. If such a system were incorporated it is believed that pilot ratings of 10 would be eliminated at the higher speeds like 140 and 157 FPS but that engine failures at 118 ft/second would still be critical since at this speed the pilots work load is considerably increased due to the necessity of monitoring speed closely. Addition of automatic engine failure compensation would have the effect of lowering the indicated speed margin slightly, or the stated speed margins might be considered slightly conservative.

WAVEOFF SPEED MARGINS

In addition to the landing tests during which the pilot was required to land even though he might have preferred to make a waveoff, another series of landing tests were made during which the pilot was required to waveoff. Landing approaches were made at various speeds with and without external disturbances, with and without engine failures at various altitudes. Insufficient speed variation data are available for the no failure cases to establish trends, however, no pilot ratings greater than 5 were observed for the cases with adequate speed margins.

Pilot opinions data for the engine failure cases are presented on Figure 68. Using the same technique for defining speed margin as previously discussed for engine failures, a minimum safe speed of 122 FPS is determined. This corresponds to a speed margin of 1.08 V_{SL} where V_S is again the one-engine-out reference speed. There are a number of pilot ratings of 10 that were recorded at a trim speed of 140 ft/second. These test points all occurred at engine failure altitudes less than the value established as the minimum waveoff altitude. These test points are an additional indication of the need for automatic engine failure compensation since they occur below what is to be established as the minimum safe waveoff altitude.

Pilot opinion of task complexity during waveoff at 140 FPS is shown as a function of engine failure altitude on Figure 68. These data are recorded at what is considered an adequate speed margin so that the pilots were concerned primarily with attitude and flight path control and not so much with speed control. The engine failure altitude at which the average test pilot rating equals the average Level 3 pilot rating is about 100 feet. The altitude at which the maximum test pilot rating equals the maximum Level 3 rating (9) is about 160 feet. Since the speed selected as the minimum safe landing speed is slightly less than 140 FPS, and the minimum safe altitude for waveoff increases with decreasing speed, the value of 160 feet is selected as the minimum waveoff altitude. The addition of an automatic engine failure compensation system would tend to reduce the minimum allowed waveoff altitude so that the value of 160 feet should be somewhat conservative.

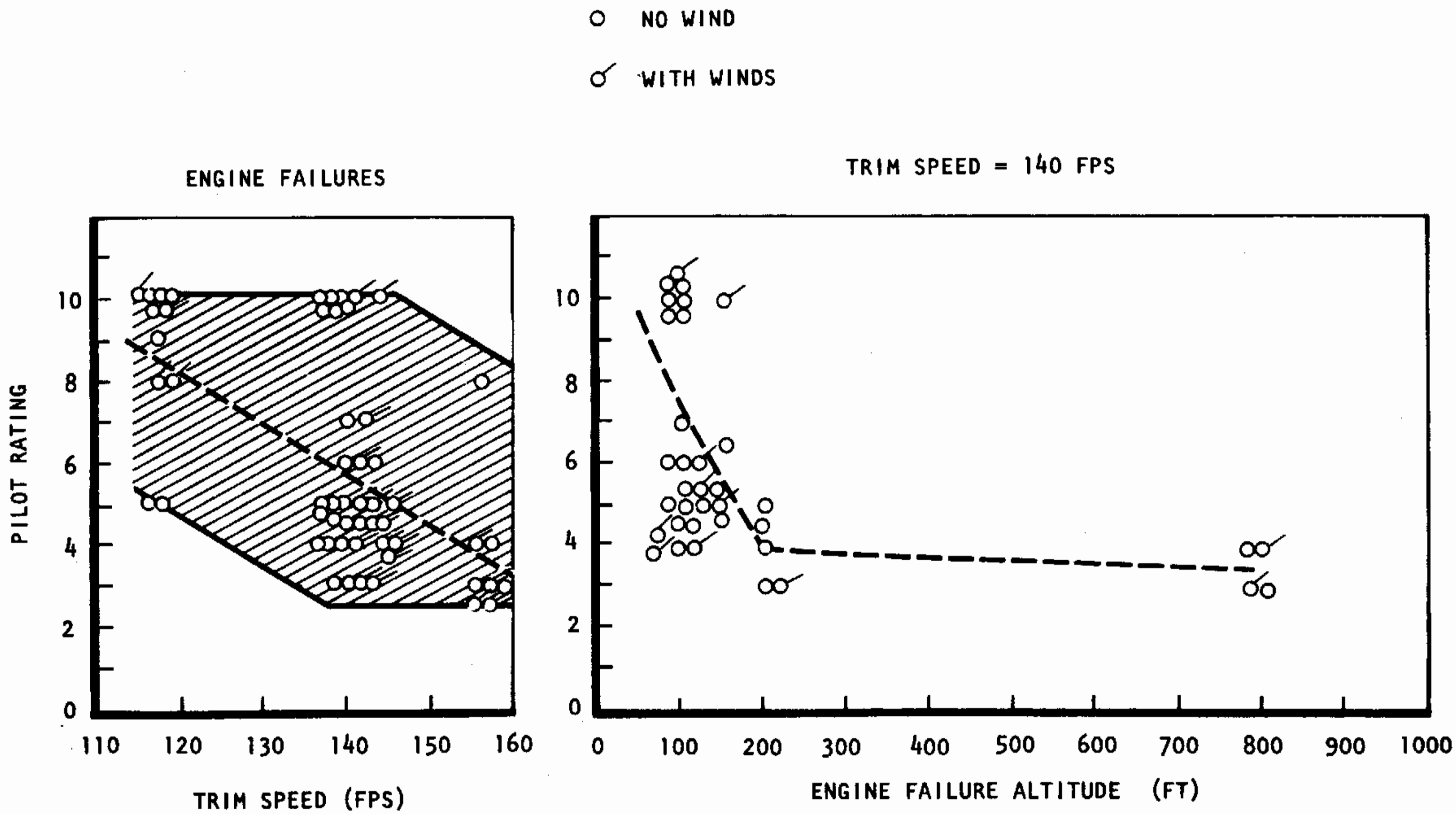


Figure 68. Effect of Waveoff Speed on Pilot Opinion

It is noted that even for the no wind cases a large spread in pilot ratings exists for engine failures occuring at altitudes below 150 feet at a trim speed of 140 FPS, and also, for all altitudes at trim speeds less than 140 FPS. These spreads are the result of several factors which point up the fact that the time avialable to the pilot for making the necessary corrections after an upset is significantly reduced from that found in conventional aircraft. The higher sink rates, the fact that 40 percent of the lift is obtained from thrust rather than the wing, the greater engine failure moments, all add up to a greater workload being imposed on the pilot if he is to complete the recovery cycle. As seen from the right hand data plot of Figure 68, the factor affecting the 140 FPS pilot rating spread in the engine failure case was the altitude at which the engine failure occurred, which of course means time available to affect a recovery. As engine failure altitude was decreased, the time available to the pilot for engine failure recovery and initiating a waveoff was reduced. With the result, that when failure altitudes decreased below 150 feet the ability to complete a waveoff became somewhat probabilistic and was significantly influenced by control input timing or the pilot technique used in a given data run. For instance when waveoffs were initiated at altitudes of 200 feet or above the pilot rating spread was from 3 to 5. When waveoffs were initiated at altitudes below 200 feet, the pilot ratings ranged from 4 to 10. Similar results were observed for trim speed cases below 140 FPS. In the 118 FPS trim speed case, the altitudes available for waveoff and the speed margin at which the aircraft was trimmed reduced the chances of successful waveoff in the event of an engine failure. As previously noted V_{SL} is 113 FPS. At an initial trim speed of 118 FPS, this leaves the pilot only a 5 FPS leeway to maintain level flight. These data show that in only a few cases did the pilots have sufficient time to regain the trim speed after recovering from an engine failure. In most cases successful waveoff was attained at this trim speed only when the engine failure occurred at 800 feet or above. Pilot ratings ranged from 5 to 8 when waveoffs were attempted subsequent to engine failure at altitudes between 800 and 1000 feet. For waveoffs attempted at altitudes of 500 feet or less, the pilot ratings ranged from 9-10. Only one out of seven waveoff attempts was successful at this trim speed and received a rating of 9. At the 157 FPS trim speed, waveoff attempts above 100 feet resulted in pilot ratings from 2-1/2 to 4. The waveoffs attempted at 100 feet had pilot ratings ranging from 3 to 8. These data are tabulated in Table II-V.

TAKEOFF SPEED MARGINS

Following the same general pattern of tests made for evaluation of landing and waveoff speed margins, another series of takeoff tests were run at several speeds, with and without gusts and turbulence, with and without engine failures at various altitudes. Again, insufficient speed variation data are available for the no failure cases to establish speed trends but no pilot ratings greater than 7 were observed for any of these cases.

Pilot opinion data for the engine failure cases are plotted versus speed on Figure 69 . This figure shows a significant trend of average pilot rating obtained as a function of trim speed. The speed at which the average rating obtained equals the average rating corresponding to Level 3 flying qualities is about 134 FPS which corresponds to a speed margin of 1.09 V_{STO} at an engine-out reference speed of 123 FPS. The minimum speed at which a maximum pilot rating of 9 is anticipated is just slightly above the 134 FPS speed. This speed is, of course, not necessarily the takeoff speed but should be another checkpoint in establishing the minimum normal takeoff speed.

During takeoff the altitude at which the engine failure occurs has very little to do with pilot opinion of the engine failure control task provided operation is at a safe speed margin. This is also illustrated in Figure 69.

LONGITUDINAL TOUCHDOWN DISPERSION

During the various landing tests that were run the pilots flew the airplane down the prescribed flight path until touchdown occurred. At this point the problem was terminated and various parameters such as lateral and longitudinal distance from the aim point, sink rate, attitudes, etc. were recorded. Touchdown dispersion distances for the cases of no disturbance, winds or turbulence, engine failure with and without external disturbances are presented in Figure 70 . During the initial phasing of the flight simulation program, the visual display was inoperative and landings were accomplished completely under IFR conditions by reference to glide slope and localizer command information. For these tests a runway width of 180 feet was used and it was not uncommon for a pilot to make a good landing near the edge of the runway and give the landing a low pilot rating. When the visual display was made operative the runway width was reduced to 60 feet. The test points that were obtained under these two conditions are differentiated on the figure as circles and triangles.

The longitudinal touchdown displacement data on this plot were analyzed for trends with respect to crosswind and turbulence magnitudes and engine failure altitude. No trends, under either VFR or IFR conditions, were observed. The data were also evaluated with respect to average touchdown position and maximum dispersion for no disturbance, with winds and turbulence and with engine failures including the no disturbance cases as well as those with winds and turbulence. The data were also segregated as to IFR and VFR operation. These results are indicated in Table VII.

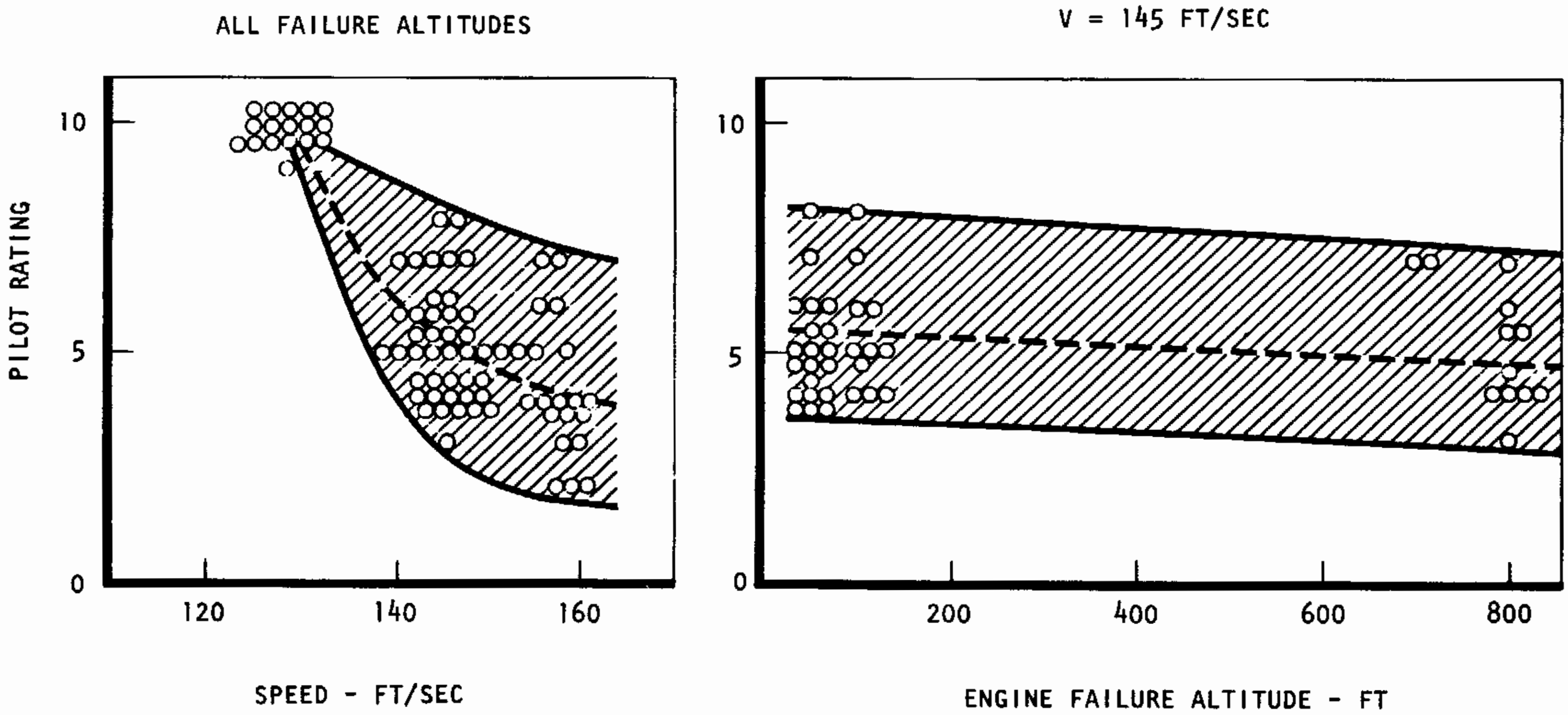


Figure 69. Effect of Takeoff Speed on Pilot Opinion

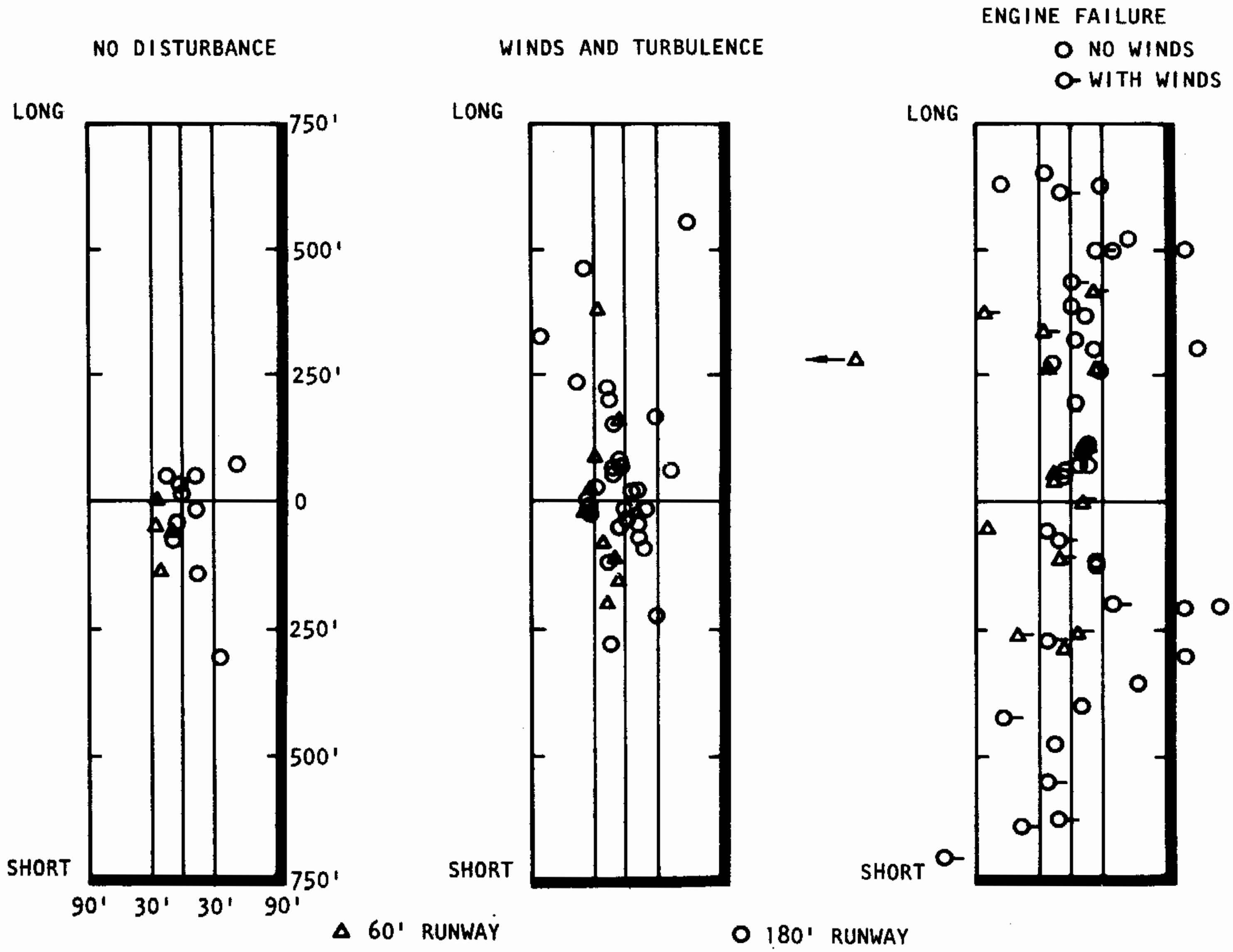


Figure 70. External Disturbance and Engine Failure Effects on Longitudinal Touchdown Dispersions

TABLE VII

LONGITUDINAL TOUCHDOWN DISPERSIONS
+ LANDING SHORT, -LANDING LONG

FLIGHT RULES	AVERAGE ΔX_{TD}, FT.			MAXIMUM ΔX_{TD}. FT.		
	NO DISTURBANCE	WINDS & TURBULENCE	ENGINE FAILURE	NO DISTURBANCE	WINDS & TURBULENCE	ENGINE FAILURE
IFR	23	-50	112	377	760	1200
VFR	38	15	-102	198	744	1110
Both	28	18	-1	377	834	1330

Observation of these data indicates no apparent trend with respect to average touchdown position. A maximum average touchdown position of 112 feet is observed for engine failure data under IFR conditions. When all data of all types are combined an average touchdown position of four feet is observed. When maximum dispersion data are compared there appear to be no significant differences for VFR and IFR conditions. As a result all data are evaluated together and these data are repeated below.

TABLE VIII

LONGITUDINAL TOUCHDOWN DISPERSION SUMMARY

	Maximum Dispersion, Ft.	Max Disp ÷ Max Disp. No Dist.	Max Disp Minus Max Disp. No Dist.
No Disturbance	377	1.0	0
Winds and Turbulence	834	2.2	467
Engine-Out	1330	3.5	963

As in other areas the increasing task complexity is seen to correspond to a decreasing performance capability. Although the no disturbance touchdown dispersion appears quite reasonable it is possible that differences between flight simulation and real life may exist. For this reason it is suggested that allowances be made for these differences by either (1) multiplying real life dispersions by 2.2 or 3.5 or, (2) adding increments of 500 or 1000 feet to real-life normal operating dispersions to account for turbulence and winds or engine failures. Based on a 1000-foot stopping distance, it would appear that a 2000-foot runway would be acceptable for landings without failures, but that 2500 feet might be required when allowing for engine failures. With an engine failure compensation system incorporated it is likely that some of the 500 feet added length could be eliminated, but not all of it.

RUNWAY WIDTH/LATERAL TOUCHDOWN DISPERSION

The same landing runs that were evaluated relative to longitudinal touchdown dispersions were also evaluated relative to lateral touchdown dispersion or runway width requirements. The general dispersion patterns can be seen by referring to Figure 70. It is important to note that in many cases, with excessively wide lateral dispersions, the pilot's preference would have been to attempt a waveoff had this option been open to him. These data were analyzed with respect to crosswind and turbulence magnitudes and engine failure altitude with the results shown in Figure 71. The pilot ratings for the data shown in this figure are tabulated in Table IV of Appendix II.

Initially consideration was given to whether or not any significance could be attached to the effect of IFR versus VFR operation on performance in winds, turbulence, or with failures. Although dispersion data for exactly comparable wind or failure conditions are not available, there appears to be no definite trend with respect to performance under IFR vs VFR conditions. Average lateral displacements, with no disturbance, are very nearly equal under the two conditions. With winds and turbulence, average lateral displacements are less for IFR operation. For engine failure conditions, average lateral displacements are less for VFR operation.

Similarly, based on average lateral displacements, there appears to be no trend with respect to performance when attempting to land on a 60-foot versus a 180-foot runway. No disturbance performances are similar. With winds and turbulence, lateral displacements during landings on the 60-foot runway are greater than on the 180-foot runway. However, for engine failures, displacements are greater for landings on the 180-foot runway.

As a result of the above considerations, all lateral displacements data are included on Figure 71 and are analyzed together. In evaluating the effect of crosswind magnitude there are several factors to keep in mind. The effect of workload on pilot technique during crosswind and engine failure landing approaches was discussed in detail in the section on Pilot Control Techniques. As noted earlier, pilot preference might have resulted in a waveoff with a possible improvement in performance. Also, the rudder maximum effectiveness in the aircraft simulated was somewhat low (about 30 percent) with respect to the requirement in MIL-F-83300. Further, different pilots used different control techniques in coping with the crosswind. Finally, the crosswind was maintained all the way to the ground and was not phased out or reduced in magnitude near the ground as has sometimes been done in previous evaluations. Even considering these factors there appears to be a need for some increase in runway width for landings in crosswinds. The maximum lateral touchdown displacement observed with no crosswind is 51 feet and is 114 feet for a 30-knot crosswind which is the maximum design crosswind required by MIL-F-83300.

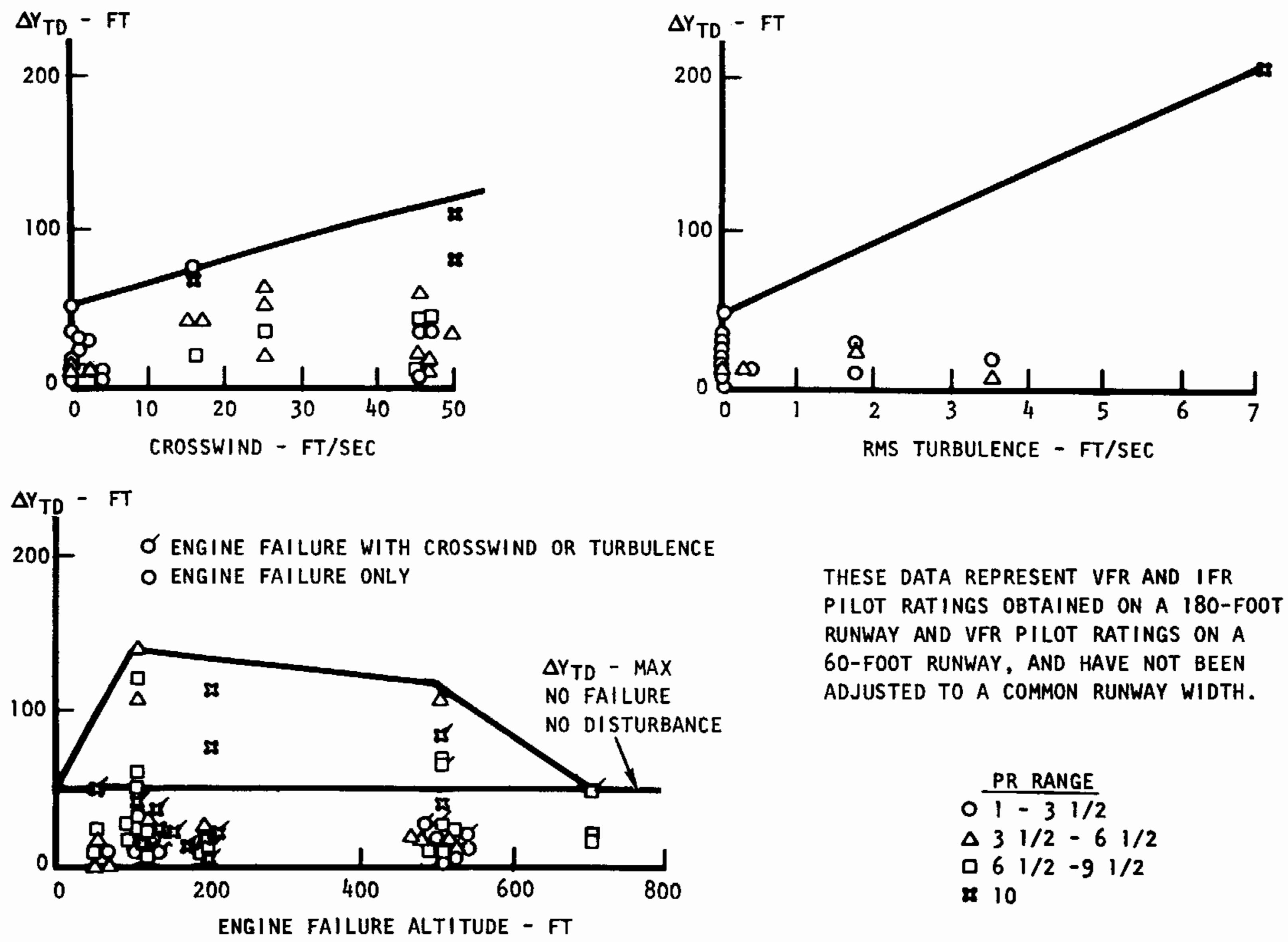


Figure 71. Effect of Touchdown Dispersion on Runway Width

Also the average lateral displacement observed (based on the 45 and 50-feet/second crosswind tests) is almost exactly twice that observed for no crosswind. Considering either averages or maximums it appears desirable to double the runway width to allow for severe crosswinds compared with runway widths considered suitable for landings with no crosswinds. As a further note, it should be kept in mind that no allowance is made in these data for the tread of the landing gear. This would impose a further width requirement - 20 feet for this particular STOL aircraft.

The effect of turbulence level on lateral displacement touchdown performance is not well defined. It would appear to be unwise to try to establish any runway width requirements based on the limited data shown on Figure 71, although it is reasonable to expect there would be a degradation in lateral touchdown displacement performance with increasing level of turbulence. Pilot comments have indicated that they consider the 7 ft/second RMS design turbulence level of MIL-F-8785 as being too severe to be compatible with landing on a 60-foot runway. It is evident that more testing and analysis is required in this area.

The effect of engine failure altitude on lateral displacements at touchdown is also shown on Figure 71 . The data presented here cover landings with and without winds and turbulence. There are a large number of landings that were accomplished with lateral displacements no greater than those observed with no disturbance or failure. There are, however, an additional number of landings that resulted in lateral displacements considerably above the no disturbance values. The worst case observed here is 140 feet compared with 51 feet maximum for no disturbance or a factor of 2.75. The average of all the engine failure lateral displacement data is 1.8 times the average for no disturbance. Although it would be expected that the use of automatic engine failure compensation would reduce the maximum and average values of lateral touchdown displacement, it again appears that some allowance must be made in runway width for the increased complexity of the piloting task in the presence of engine failures. Such an incremental allowance might be as much as 1.75 times the runway width considered suitable with no failures or disturbances.

As indicated in Table I other parameters were recorded at the point of touchdown, however, no attempt has been made to correlate these parameters with pilot ratings. Further these data have not been included in this report because of their large bulk. The reader should note carefully however that the spread in the engine failure pilot rating data as described previously in the section on Approach Angle Effects follows closely the spread in dispersion patterns with engine failure altitudes of Figure 71 and that for the touchdown sink rate distribution which will be described in a later section.

AUTOMATIC ENGINE FAILURE COMPENSATION

Throughout the foregoing discussions on speed margins, touchdown longitudinal and lateral dispersion and glide slope effects, the complexity of the pilot's control task and his performance in flying the aircraft following an engine failure have been pointed out. This is particularly true in the presence of external disturbances which add to the complexity of the problem. During the 5-10 seconds prior to touchdown on a narrow runway the pilot's vision and concentration are outside the aircraft and as a result failure detection and compensation is delayed by the aerodynamic lag involved. In many cases, when failures occur just short of the touchdown point under extreme environmental conditions, failure compensation is never made due to complexity of the external control problem. The end result being that either a short or hard touchdown is made off the runway or a combination of these. Pilot comments tend to show that below the 100' to 50' altitudes there is just not enough time left before touchdown to permit returning to instruments due to the complexity of the control task and the steepness of the glideslope. Pilot comments also indicate, as do the touchdown dispersion data for winds and turbulence, that performance is improved when steering and glideslope commands are available right to the point of touchdown. This is probably due to the fact that commands of this type are usually mechanized using rate signals and as a result provide lead time over the pilot's external visual reference. As a result of these, allusions have been made to the need for some sort of automatic engine failure compensation system to improve touchdown performance.

When making a landing approach at an adequate speed margin the pilots were readily able to accomplish a waveoff following an engine failure above a minimum altitude of about 160 feet. Following the waveoff, the pilots could trim out the unbalanced failure moments, increase power as required for steady state operation and go around for another landing approach. At engine failure altitudes below 160 feet, it was not found possible to consistently accomplish waveoffs even though many successful waveoffs were accomplished for engine failures at 100 feet or less. Lateral displacement touchdown data for engine failures have been presented on Figure 71 as a function of engine failure altitude. Sink rates at touchdown for engine failures are also presented on Figure 72 as a function of engine failure altitude. The lateral displacements of Figure 71 occurring for engine failures below 160 feet could, of course, be allowed for by use of wide runways but some of the sink rates encountered under similar conditions exceed the maximum design sink rate (15 feet/second) of the aircraft and must be compensated for.

Following the engine failure the pilot must initially stabilize the aircraft in roll and then increase throttles to compensate for the loss of lift and thrust accompanying the failure. This throttle response

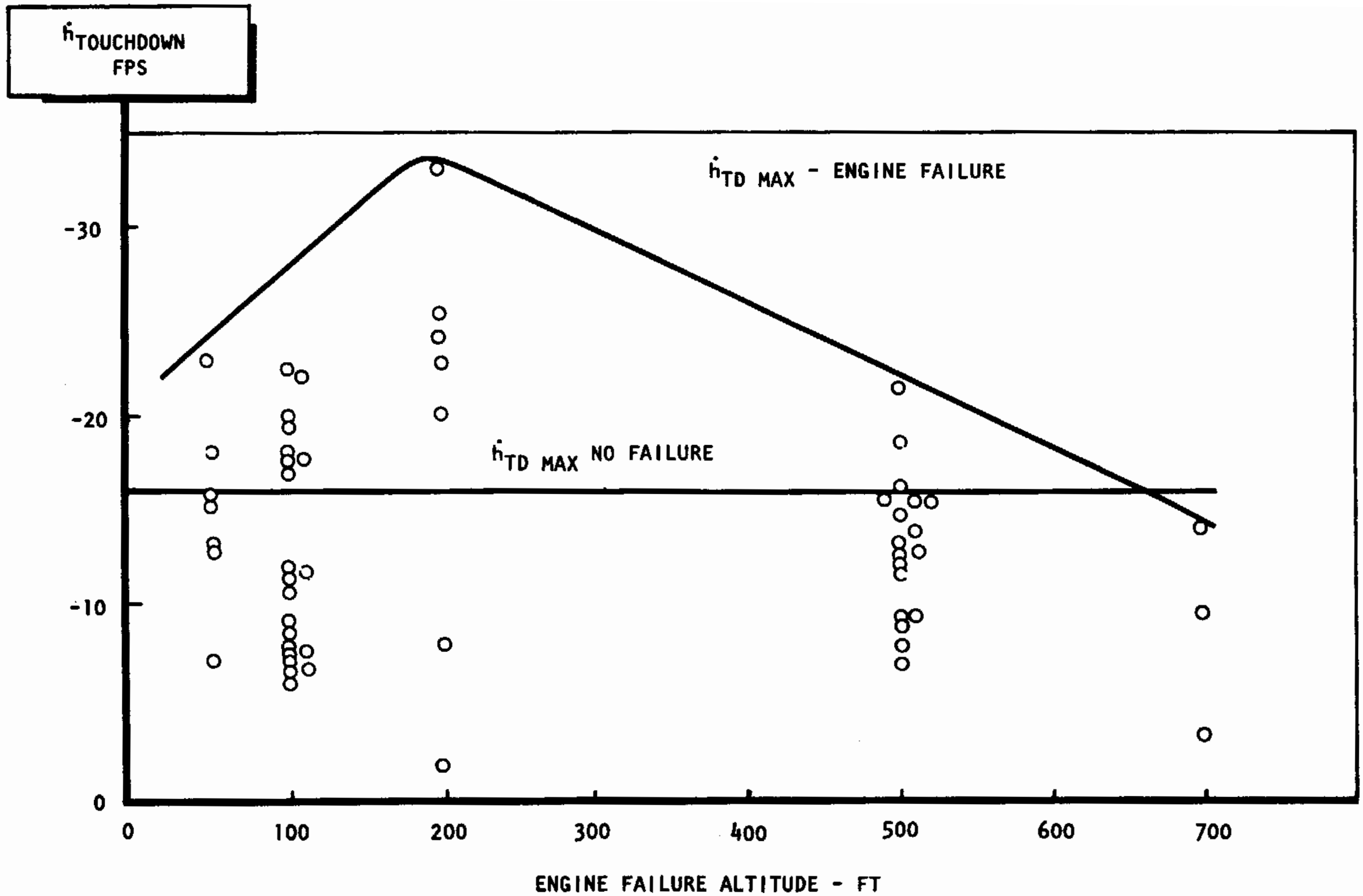


Figure 72. Effect of Engine Failure Altitude on Touchdown Sink Rate

generally followed the failure by about 2-3 seconds. This thrust response lag is very detrimental since it allows a rapid incremental buildup of rate of descent. No attempt has been made to design a failure compensation system but it appears that some degree of automatic compensation, acting through the throttle system, must be used to correct for altitude rate deviations from the desired value. The degree of automaticity involved might vary considerably. Different types of systems to be considered might include: (1) a fully automatic glideslope control or altitude profile follower in which errors are zeroed out by thrust change, (2) an automatic altitude rate mode that is selected when the aircraft has been trimmed up at the desired rate and forward speed, or perhaps (3) a mode in which a separate altitude rate lever is used either to command specific values of altitude rate proportional to lever displacement from neutral or to zero out errors between commanded and actual altitude as displayed to the pilot, (4) combine engine failure compensation commands with a "through the windshield" altitude and steering command display.

In addition to automatic thrust compensation, it is probable that pitch and roll control stick steering modes would also be sufficiently beneficial during engine failures to warrant this added control system complexity. These modes were evaluated to a degree during the simulation program and did reduce attitude transients and pilot workload following engine failures. However, mechanization problems resulted in inconsistent CSS operation and use of these modes was discontinued. The tests discussed in previous sections did not include CSS operation.

Even though the period of time during any flight during which an engine failure must occur to potentially affect flight safety is very small (15-20 seconds prior to touchdown) the consequences of such an occurrence are considered sufficiently important to warrant further study in this area. This study should consider all aspects of control following an engine failure but altitude rate at touchdown seems most critical.

HANDLING QUALITIES CRITERIA

In this segment of the study, pilots were asked to evaluate aircraft performance with respect to variations in aerodynamic coefficients. Two configurations were evaluated for each coefficient, the unaugmented vehicle and the vehicle with baseline augmentation. In areas where baseline augmentation did not meet Level 1 requirements, no attempt was made to initiate gain changes or revise the system configuration. The required changes are adequately defined in the analysis of Volume V-III which specifically identifies the amount of gains and/or system configuration change required in each case. Table II-VII identifies the coefficient variations for which pilot ratings were obtained by data run number, pilot rating, augmentation level, maneuver, and external disturbance.

In general, the results obtained with the pilot ratings of this study are in good agreement with those of Volume V-III and tend to point out the compatibility of the pilot rating system with the flying qualities requirements of Reference (1).

LATERAL-DIRECTIONAL AXIS

For evaluating the lateral-directional coefficient variations, either a gross maneuver consisting of a ± 90-degree heading change using ± 30-degree bank angles in the presence of continuous turbulence or a landing approach with crosswind or continuous turbulence was rated.

Figure 73 shows the lateral-directional coefficient variations evaluated and their respective pilot ratings. It is evident from this figure that the addition of baseline augmentation has a tendency to desensitize pilot ratings with respect to changes in the coefficients. In all cases except the $-3\ L_\beta$ case, pilot ratings for baseline augmentation are well within Levels 1 and 2 and confirm the results of Volume V-III which indicate that large excursions of these coefficients are required to significantly affect the handling qualities.

The $-3L_\beta$ case represents a large positive value of L_β which results in high spiral mode instability and undesirable roll time constant and ω_ϕ/ω_{nd} characteristics. Augmentation analysis of this large coefficient variation indicated the necessity of additional feedback to achieve satisfactory responses. A more detailed discussion of this coefficient can be found in Volume V-III.

The trends of pilot ratings with coefficient variations in both augmented and unaugmented cases appear to be in accord with the results using handling qualities levels that are presented in Volume V-III. Although

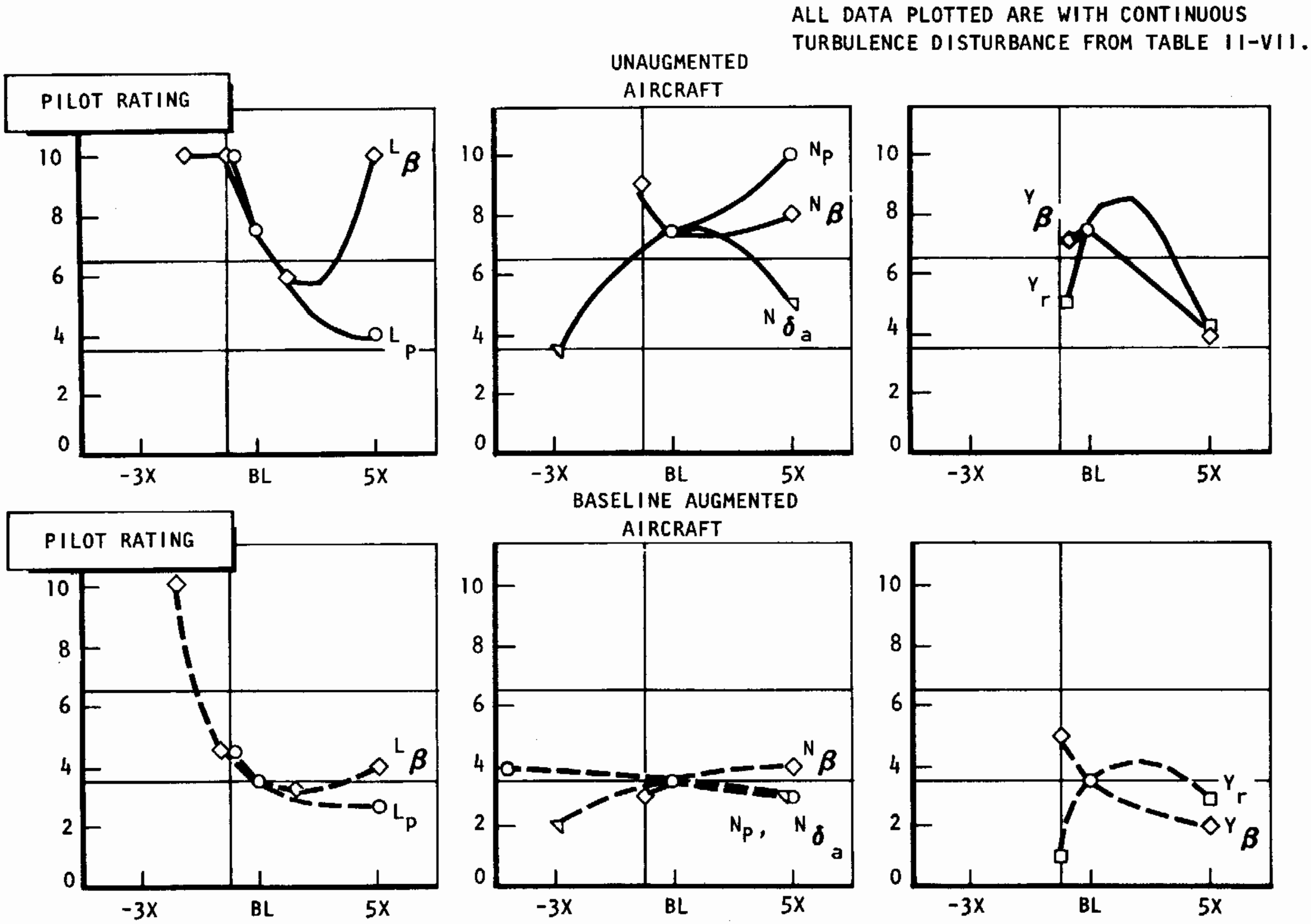


Figure 73. Pilot Ratings Versus Lateral - Directional Coefficient Variations

exact agreement between the pilot ratings and the Reference (1) handling qualities levels are not to be expected due to the small pilot sample available, additional investigation may be warranted to ascertain the cause of large pilot rating sensitivity to variations in the side force coefficients. This effect was not apparent in the results of Volume V-III.

LONGITUDINAL AXIS

For the longitudinal coefficient variations the aircraft was trimmed to level flight from an initial climb attitude and then retrimmed to climb at maximum rate, the continuous turbulence model was used as an external disturbance. This maneuver is described in Figure 1.

Figure 74 shows the longitudinal coefficient variations evaluated and their respective pilot ratings. The effect of baseline augmentation in desensitizing pilot ratings to coefficient changes is also evidenced in this figure. All coefficient variation cases evaluated are well within Level 1 and Level 2 requirements.

The trends exhibited in this figure are well explained from handling qualities considerations except for $M_{\dot{\alpha}}$ variation. These are also covered in detail in Volume V-III. The effect of $M_{\dot{\alpha}}$ variation on pilot ratings is not well understood at the present but similar variations were observed for both pilots giving ratings. Further investigation is required to correlate pilot ratings with changes in handling qualities parameters.

RUDDER EFFECTIVENESS

The effect of increased rudder power on pilot opinion was examined during crosswind landing approaches. A 15 FPS crosswind was evaluated at a trim speed of 118 FPS on a 60 foot runway under VFR conditions. The pilot comments and ratings generally indicated favorable response to increasing rudder effectiveness to a value slightly greater than that required by Reference 1. The results are shown in Figure 75. As noted earlier, the baseline value is approximately 30 percent less than the requirement of Reference 1. With this value the average pilot rating was 6 for the 15 FPS on a 60 ft runway. When this effectiveness was increased by 50 percent the average pilot rating dropped sharply to 3 1/2, indicating that adequate rudder power is very important for crosswind landing approaches on narrow runways. When considered with the rest of the corsswind landing data of this report, these data also suggest that the minimum requirement of Reference 1 is not adequate for the 50 FPS crosswind requirement on a runway width such as used in this study.

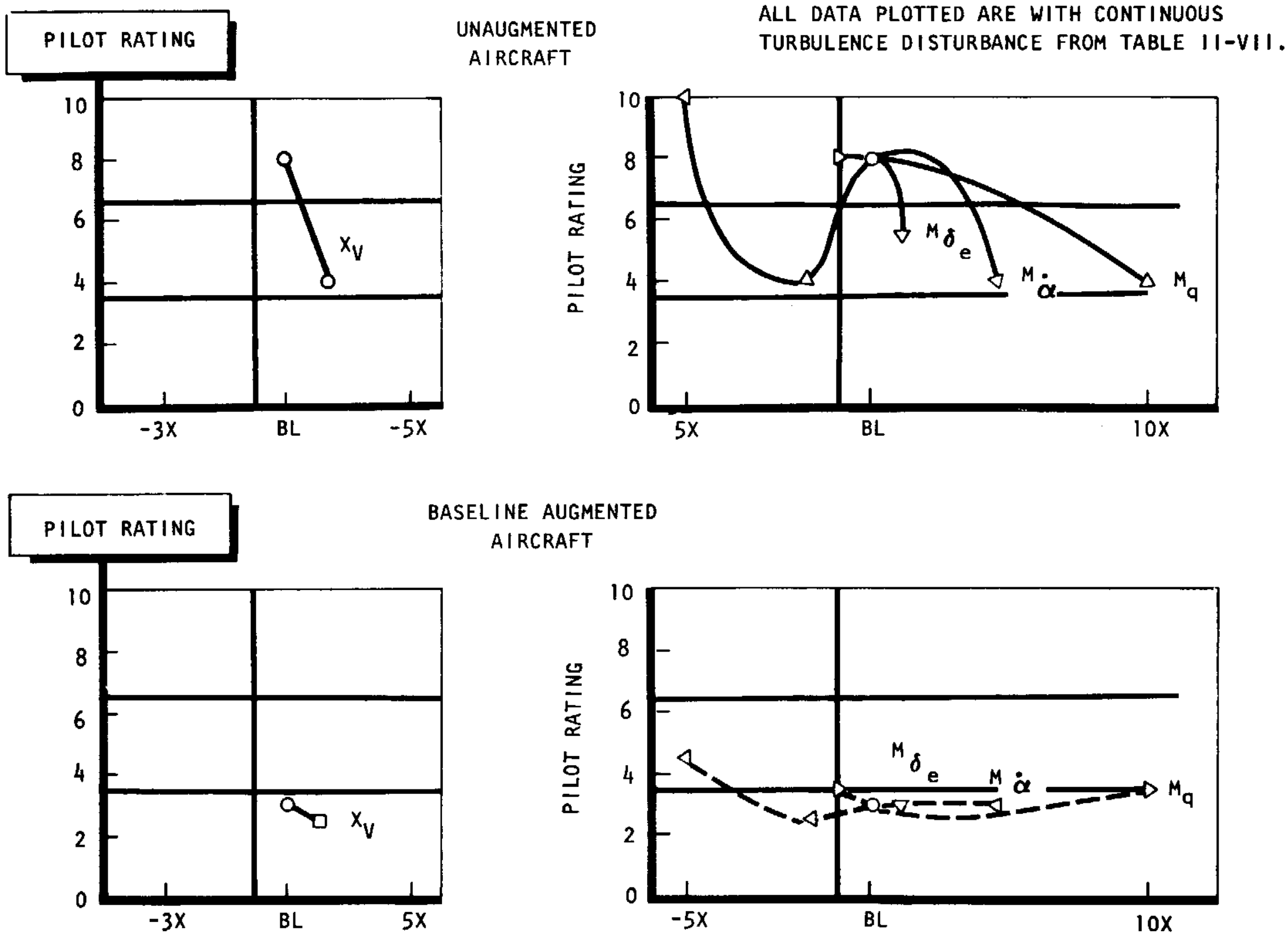


Figure 74. Pilot Ratings Versus Longitudinal Coefficient Variations

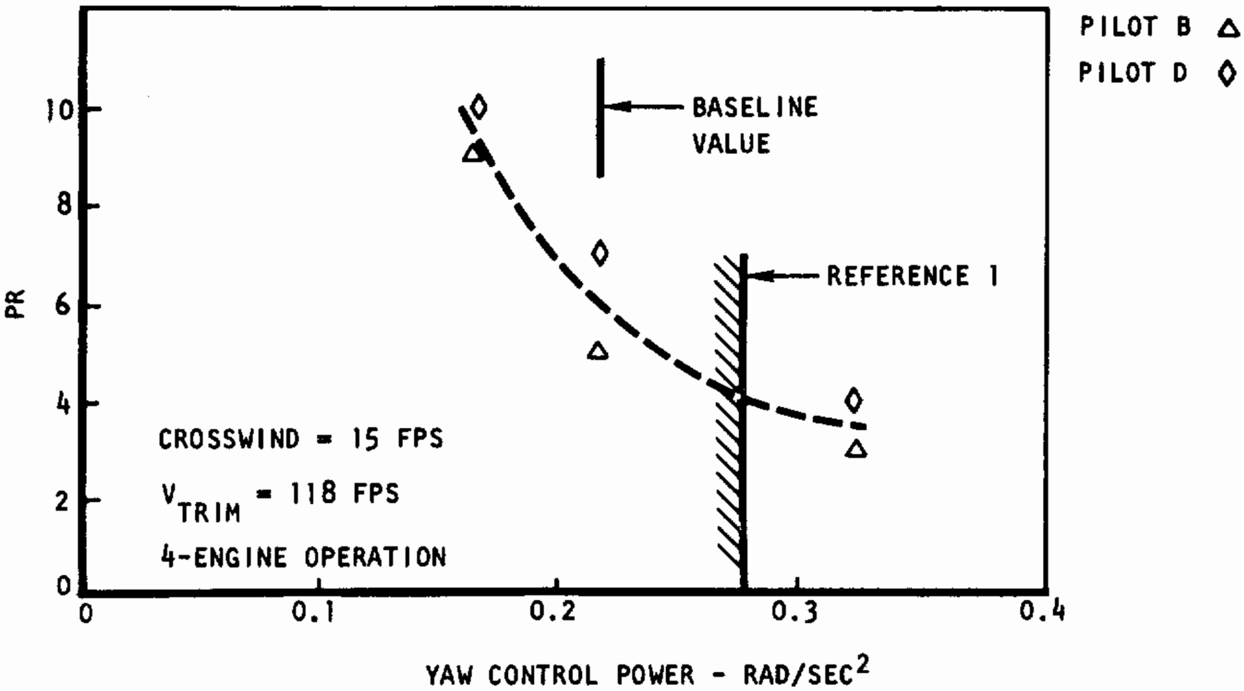


Figure 75. Normal Operation in the Presence of Crosswinds Versus Control Power

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SECTION V

CONCLUSIONS

A STOL flight simulation program has been completed that provides valuable data in a number of areas relating to flight control system design, aircraft operation with respect to its steady state limits, and runway requirements. In general, the study results verified the importance of taking into account the human pilot's capabilities and limitations when establishing safety margins. As might be expected, pilots' ratings and performance, on the average, are degraded with increasing task complexity. This means that severe and critical tasks and/or failures must be considered during flight simulation but it is also important to consider normal operation with no failures and no disturbances to provide a baseline for performance and ratings on the particular experimental setup being used.

FLIGHT CONTROL SYSTEM VALIDATION

1. Augmented flight control systems were developed that satisfied the requirements of Reference (1) with the exception that yaw control power is about 30 percent low. These systems are considered completely acceptable for normal operation and provide Level 1 flying qualities as determined by pilot opinion.

2. Full yaw control power, as required by Reference (1), is necessary and would result in pilot opinion ratings no less than those corresponding to Level 2 when flying in severe cross winds and turbulence.

3. Automatic engine failure compensation is required for engine failures during landings below 160 feet.

4. Pitch augmentation is more important than augmentation in the other axes. Loss of pitch augmentation followed by an engine failure during landing approach is only marginally safe. The need for pitch augmentation during all STOL landings and the general level of failure probability available in state-of-the-art non-redundant systems defines a fail-operational requirement for pitch augmentation.

5. The failure probability of non-redundant augmentation and the requirement on the probability of not encountering Level 3 flying qualities dictates the use of fail-operational yaw augmentation. (Pitch and roll augmentation alone result in Level 3 pilot ratings).

6. Fail-operational roll augmentation is not required (pitch and yaw augmentation alone result in Level 2 pilot ratings).

GLIDESLOPE EFFECTS

1. Landing approach glideslope angles between 3.8° and 7° had no effect on the range of touchdown sinkrates encountered and landing task difficulty as measured by pilot ratings. (It is noted that the "7°" glidesope flight profile included a transition from 7° to 4.4° at 200 feet altitude to avoid excessive touchdown sink rates).

LANDING SPEED MARGINS

1. Trim speed variations between 1.05 and 1.4V_{SL} had no effect on ability to achieve pilot opinions corresponding to Level 1 flying qualities during normal operation, no disturbance landings. Level 1 flying qualities is not significant in determining landing speed margin requirements since this level must exist at the speed margin defined by other considerations.

2. A speed of 1.16 V_{SL} is required to allow a satisfactory landing in the presence of crosswinds or turbulence as determined by the ability to achieve average pilot ratings corresponding to the average of the pilot rating range associated with Level 2 flying qualities.

3. A speed of 1.13 V_{SL} is required to allow a safe landing following an engine failure as determined by the ability to achieve average pilot ratings corresponding to the average of the pilot rating range associated with Level 3 flying qualities.

4. A speed of 1.08 V_{SL} is required to allow a safe waveoff following an engine failure occurring above the minimum waveoff altitude as determined by the ability to achieve average pilot ratings corresponding to the average of the pilot rating range associated with Level 3 flying qualities.

TAKEOFF SPEED MARGIN

1. A speed of 1.09 V_{STO} is required to allow a continued safe takeoff following an engine failure as determined by the ability to achieve average pilot ratings corresponding to the average of the pilot rating range associated with Level 3 flying qualities.

2. Engine failure altitude, for the range from 50 to 800 feet, does not affect average pilot opinion of the ability to achieve a safe takeoff assuming operation at a safe speed margin.

LONGITUDINAL TOUCHDOWN DISPERSION

1. Average and maximum incremental longitudinal touchdown displacements from the aimpoint (the maximum positive value minus the maximum negative value) are not functions of crosswind or turbulence magnitudes, engine failure altitude, or operation under IFR vs VFR conditions.

2. The average longitudinal touchdown displacement is not a function of task complexity. However, the maximum incremental displacement is a function of task complexity as seen from the increasing dispersion in the presence of winds and turbulence, and engine failures, compared with the no disturbance-no failure dispersion.

3. Increments of 500 and 1000 feet should be added to normally anticipated touchdown dispersion patterns to allow for effects of severe crosswinds and turbulence and effects of engine failures respectively.

RUNWAY WIDTH REQUIREMENTS

1. A 100-foot runway is required for normal operations with no disturbances or failures considering both IFR and VFR conditions. A 60-foot runway is acceptable for ideal VFR operations with no disturbances or failures.

2. An increase in runway width is required to permit safe operation in the presence of severe winds and turbulence. The amount of this increase is not well defined, especially relative to turbulence effects, when recalling that the yaw control power in the test aircraft was about 30 percent less than the MIL-F-83300 requirement. A 200 to 250-foot runway width requirement would appear reasonable for extreme conditions.

3. The 7 FPS RMS CAT turbulence level, defined in MIL-F-8785B as a design guide for conventional aircraft landings, is too extreme for consistent STOL operations to narrow (60 to 100 feet) runways.

4. An increase in runway width is still likely to be required to permit safe landings in the presence of an engine failure even if some automatic engine failure compensation is supplied. The amount of the increase might be similar to that required in extreme winds and turbulence.

AUTOMATIC ENGINE FAILURE COMPENSATION

1. Automatic engine failure compensation is required to reduce pilot workload, avoid excessive touchdown sink rates and touchdown dispersions for engine failures occurring at altitudes below a safe waveoff altitude.

WAVEOFF ALTITUDE

1. Consistently safe waveoffs from a normal landing approach can be accomplished following engine failures above 160 feet, assuming operation at a safe speed margin.

2. Safe waveoffs can readily be accomplished from a normal landing approach starting at 100 feet considering no failures.

COEFFICIENT VARIATIONS

1. Pilot opinion of augmented aircraft flying qualities is insensitive (essentially unaffected) by large aerodynamic coefficient variations from baseline values. (Augmented aircraft handling qualities parameters were also found to be insensitive to similar aerodynamic coefficient variations.)

2. Pilot opinion of unaugmented aircraft handling qualities is improved by coefficient variations resulting in improved phugoid damping and spiral stability tending to support specification requirements in these areas.

SECTION VI

RECOMMENDATIONS

1. The touchdown sink rate, dispersion patterns and analysis of pilot technique results obtained during this study show that there is a definite need for an automatic engine failure compensation system to alleviate pilot workload. A study should be conducted to define the parameter requirements and establish the required mechanization for this system.

2. The results of this study tend to indicate that IFR operation would not influence safe speed margins as determined by engine failures and external disturbances. However the study was not sufficiently exhaustive to determine the reasons which lead to these results. A more comprehensive study should be conducted to establish validity of these results.

3. Past experiences indicate that maximum simultaneous control power requirements appear to be inconsistent with those used in actual practice. Such requirements tend to produce systems which are overdesigned in terms of weight and cost effectiveness. In STOL these requirements affect primarily hydraulic systems sizing and in V/STOL they affect primarily reaction control system sizing. A study should be conducted which will define the maximum simultaneous control powers and surface rate requirements.

4. A study is required which will determine the influence of STOL ground effects on touchdown dispersions and control sizing for a variety of control system mechanization schemes including use of DLC devices.

5. The pilot comments and techniques used in this study tend to show that lower touchdown dispersions due to external disturbances might result with either a HUD for glideslope and steering commands or an automatic landing system. A study should be conducted to verify these results, establish the required display parameters, and parameter accuracy requirements for such a system.

6. A study should be conducted to assess safe speed margins for a trimmed engine out landing approach with and without external disturbances.

7. Additional data should be obtained in the area of crosswind landing approaches to define the influence of pilot technique on touchdown dispersions.

8. The results of this study indicate that the crosswind requirements of MIL-F-83300 and the CAT continuous turbulence model requirements of MIL-F-8785B below 100 feet altitude are inconsistent with a 60-foot runway width requirement. Studies should be conducted to more completely establish runway width requirements as a function of crosswind and continuous turbulence magnitudes and available roll and yaw control powers on the basis of allowable touchdown dispersions. The critical effect of turbulence and winds near the ground indicates a need to review the basis for specification requirements to make sure these are not overly stringent.

9. Flap rates significantly influence the minimum normal and one engine-out waveoff altitudes. They also influence pilot control during a normal V_{con} transition. Piloted simulation studies should be conducted in each of these areas to determine maximum safe flap rates.

10. Low speed flying qualities simulation studies conducted by various investigators have consistently shown that turn coordination is significantly improved when β or $\dot{\beta}$ feedback loops are employed in augmentations systems. The major obstacle in utilizing these parameters in actual hardware is lack of adequate and reliable sensors. Most current aircraft, particularly STOL/VSTOL have sufficient sensors for measurements of other, more easily sensed parameters such as attitude, rate and acceleration that computation of $\Delta\beta$ and/or $\Delta\alpha$ would require very little in the way of computing equipment. A literature survey and analytical study should be conducted which will define performance and accuracy requirements of the sensors and required mechanization and compare these results with state-of-the-art hardware availability.

11. Piloted evaluations of the coefficient variations were reasonably consistent and in line with expectations. However little data in the STOL flight regime are available which afford a direct comparison. To fully understand the implication of some of the results observed during this study additional comparable data should be made available from similar aircraft configurations.

12. Obtaining pilot comments with respect to control technique is difficult for a variety of reasons. To permit more adequate analyses in preliminary design, an analytical pilot model that can perform landings, takeoffs, waveoffs, in the presence of disturbances and engine failures should be developed based on analysis of piloted time history data.

13. The influence of failure forces and moments on pilot opinion is not well defined in terms of available control moments. A study should be conducted which determines allowable failure forces and moments based on pilot ratings of failure transients for a range of operational aircraft weights and inertias.

14. To facilitate control in the low speed end of the flight regime, additional study is required to determine suitable methods of applying and using specific STOL controls, including:

Direct Drag Control
Direct Lift Control
Thrust Vector Control

APPENDIX I

SIMULATION STUDY PILOT COMMENTS

This section contains evaluation pilot comments which were either transcribed from tape recordings taken during evaluation runs or obtained from pilot questionnaires designed to assess certain portions of the simulation study.

Section I-1 contains the pilot comments and ratings obtained during a 3 DOF longitudinal axis evaluation. This evaluation utilized an evaluation questionnaire which is duplicated in this section. The pilot comments and ratings have also been collated with each question. The analysis of these data are presented in the study results section of this report.

Pilot comments transcribed from tape during 6 DOF evaluations are presented in Section I-2. These comments are identified with each pilot and listed in numerical sequence. They are not arranged by type of evaluation and are presented only as background material. These comments were utilized for analysis of test evaluation data which are presented in Section IV of this report. They include pilot comments with reference to simulator validation, upset evaluations, runway dimensions, speed margins, glideslope variations, and aerodynamic coefficient variation study results.

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Section I-1

3 DOF LONGITUDINAL VEHICLE CONTROL EVALUATION PILOT QUESTIONNAIRE

This portion of the study is intended to evaluate MST longitudinal control characteristics. To permit an independent assessment of this control axis, the lateral-directional axes will be locked out during this portion of the study.

Basically six control configurations are available for evaluation. The first utilizes a direct lift control device located on the pilot's right hand wheel grip. This device operates direct lift control (DLC) spoilers which generate almost a pure lift because of their location with respect to the aircraft c.g. The device is intended for use in making small corrections on the glideslope and to counteract the ground effect at altitudes less than 50 feet. Two control-effectiveness values of this configuration will be available for comparison.

The second control configuration is that with the DLC spoilers coupled to the column through a 3-second washout. This configuration results in DLC response to column inputs. A third configuration will also be available for evaluation which consists of a combination of the above. For this evaluation, as in the first configuration, you are asked to fly the glideslope command bar at altitudes below 100 feet using the DLC control.

The fourth control configuration will examine the effect on the pilot control task using a collective throttle arrangement.

The fifth configuration will provide an evaluation of the vehicle handling qualities with the horizontal stabilizer decoupled from the column.

The sixth configuration will analyze the effect of reducing elevator sensitivity by 50 percent with the horizontal stabilizer decoupled from the column. Unless otherwise indicated all evaluations utilize full pitch axis augmentation.

BASELINE VEHICLE (PITCH AXIS AUGMENTATION)

1. Rate the longitudinal control task using the DLC controller to correct small deviations about the glideslope at altitudes above 100 feet.

		Run Number	Pilot Rating
PILOT A	Normal	844	2
	Eng. Out	845	2

Run 843. Cooper-Harper rating 6. DLC control on a glide path down to 100 feet was no problem until engine-out. When I got an engine-out I had to go back to power in order to get back on the glide path and by the time I got on the glide path I was below 100 feet and I changed the rating on the 843 to no rating.

Run 844. Without an engine-out, Cooper-Harper rating 5. Maintaining glide slope down to ground effect no problem at all; however, when getting into ground effect when the pitch bar starts to command a pull-up the system becomes overly sensitive causing overshoots in both directions in attempting to stay on glide path with the pitch command going up and down around center about 1/4 inch and it is objectionable since it makes the task more difficult. The glide slope problem above 100 feet is a Cooper-Harper rating of 2. The 5 applies to the problem below 100 feet in the ground effect.

Run 845. This run had an engine-out at 700 feet. Above 100 feet the Cooper-Harper rating is a 2. Losing the engine increased the problem of maintaining glide slope with direct lift control over that of the four-engine approach, however, the problem is the same once getting back on glide slope with power. Below 100 feet somewhat the same problem as in Run 844, however, being aware of it this time I was able to stay on top of it a little better - it became just an annoying deficiency. Was not able to break back on glide path but my vertical velocity was under control at touchdown.

		Run Number	Pilot Rating
PILOT B	Normal	734	3
	Eng. Out	735	3

Run 734. Question No. 1 - 85-knot approach to the runway. I would evaluate that pitch characteristics system as probably about a 3. Had very little trouble controlling the speed and pitch. The direct lift control works as advertised although whether or not it really helps your sink rate in the ground effect is something you will have to get off the data. It did not seem to but maybe it did.

Run 735. Evaluating the pitch axis. During this approach only a nominal amount of pitch control was required so it really does not get too much of an evaluation. I do not think we are getting near the evaluation we would say on a waveoff or a takeoff or a leveloff or something like that. We are just holding one constant pitch setting and driving right on down. I would rate that at a 3 and the direct lift control did seem to reduce sink rate at touchdown. I came in with full-up DLC at about 50 feet and the aircraft seemed to float. Perhaps land a little long.

		Run Number	Pilot Rating
PILOT C	Normal	774,775	7
	Eng. Out	776	7

Runs 774 and 775. To answer question 1, using the direct lift control to maintain glide slope providing power is set at a point whereby you are on the glide slope with the direct lift control at about the center of its authority, then it is useful in making small commands or corrections. But what you run into, is that, as you are going down final making these corrections they tend to buildup in one direction and all of a sudden you find that you have got full up or no spoilers so then you have got to go make a correction on the throttle and then you have to go immediately to make a correction on your spoilers again getting them back to some non-limit value again, so that overall, I do not like them in that configuration. I think the throttles are responsive enough where I can maintain a glide slope a lot better just using solely the throttles. I do not like them - I would rate it some place around 7.

Run 776. The comments for the previous runs still pertain. The only difference on this run,answering question no. 1,between this run and the other run was the fact that the throttles had to go up a little bit, that is all. When the engine went out I had to put up the throttles. I still had the same response. At about 400 feet or 300 feet I put the spoilers full up again and utilized the DLC to counteract the ground effect.

2. Rate the longitudinal control task using the DLC controller to follow the glideslope command bar at altitudes below 100 feet.

		Run Number	Pilot Rating
PILOT A	Normal	844	5
	Eng. Out	845	5

Runs 844 and 845. See comments to question 1 above.

		Run Number	Pilot Rating
PILOT B	Normal	734	3
	Eng. Out	736	3

Run 736. Evaluating the pitch axis and the ability to follow the glideslope command bar all the way to touch down after experiencing an engine failure at 700 feet. The direct lift control was used from about the last 100 feet on down almost exclusively to control sink rate. With one engine-out for most of the approach, I found the direct lift control to be very responsive,more so than the throttle. It is kind of an instantaneous type of response which does make it effective. I would rate that at probably a 3. The position of the direct lift control switch on the right side of the yoke though is awkward because you have to keep moving your hands from the throttle to the yoke and that is not the hand you fly with anyway so I would recommend that it be moved to the left side of the yoke where the left thumb can operate it. I would give the same rating (3) to the four-engine approach.

		Run Number	Pilot Rating
PILOT C	Normal	775	4
	Eng. Out	776	9

Runs 775 and 776. Answering question 2. On the second run I put the spoilers into a full up position and used the throttles to maintain glideslope, then at 100 feet I used only the direct lift control, so that I could follow the pitch command bar. I think with a little learning curve put into the study this could be a very good system. The only problem is your hand is on the wheel and I like my hand on the throttle. There was some question and answer comment about would you rather have it on the throttle or wheel - I would rather have it over on the throttle. However, I think that pilots could get used to this system so that when they came in and wanted to round out, it would be a matter of rounding out with their direct lift control. By rounding out I mean increasing the lift and thus counteracting the ground effects. I would rate this some place around 4. I think it needs some minor improvements in it such as moving it to the throttle, it also needs a detent to show where neutral is. Right now it just has two white lines on it at neutral. Summarizing, coming down final I do not like to use it; in the landing itself below 100 feet I think it could be beneficial.

Finishing my comments on that last run with an engine-out we get to the point where having the spoilers full open then trying to utilize them for the round-out as you are coming down final sometimes you may require a 100 percent power. At that time the spoilers close on you so - or fully close - what you would want is some kind of system where this feature would be cut out so that when you reach the 100 percent power - if that were not enough then you would slowly lower the spoilers in order to get the increase that you need.

3. Rate the longitudinal control tasks of 1 and 2 above using the increased DLC control effectiveness provided.

			Run Number	Pilot Rating
PILOT A	1	Normal	856	2
		Eng. Out	857	2
	2	Normal	856	3
		Eng. Out	857	3

Run 856. Cooper-Harper rating of 2 above 100 feet and 3 below 100 feet. I like this effectiveness much better than the previous value since it does not require as much concentration in getting the spoilers to the right position at 100 feet just before entering the ground effect. However, I think this level of effectiveness may be slightly higher than would normally be desired, but it certainly is an improvement over the first value.

Run 857. No change in comment from Run 856.

			Run Number	Pilot Rating
PILOT B	1	Normal	738	3
		Eng. Out	739	3
	2	Normal	738	3
		Eng. Out	740	4

Run was 738. Evaluating the longitudinal characteristics utilizing direct lift control from roughly 200 feet on down to touchdown. It seemed to work reasonably well - I came in with maximum nose-up DLC at about 20 feet in the air and it seemed to significantly decrease the rate of descent.

Run 739. Evaluating longitudinal characteristics with engine-out at 700 feet. The aircraft was quite controllable in pitch without any difficulty at all. The last 200 feet were flown using the direct lift control and it worked out quite nicely. The direct lift control is very responsive - in fact it might have a tendency to overcontrol it a little but I think that would decrease with a little practice. I would rate that a 3.

Run 740. Evaluating direct lift. The direct lift had so much authority that when I cranked it on to the flyer it actually stopped the rate of descent completely so that the aircraft touched down a little further down than I had intended. However, as far as the functioning piece of equipment goes it seems to work very well. I would evaluate it at about a 4, but that would only be because I tended to overcontrol it and with training I am sure that I could learn just about how much to put in.

			Run Number	Pilot Rating
PILOT C	1	Normal	777	5
		Eng. Out	778	8
	2	Normal	777	4
		Eng. Out	778	5

Run 777. This is concerning increasing the effectiveness of the DLC by a factor of 3. Above 100 feet I would rate it a 5. You have much better command ability once you get the throttle set - there is enough authority whereby you do not have to go back and readjust the throttles. It still needs to be moved at center the same as the last comment; however, it is much better than the previous run. Below 100 feet the main comment is that I would still rate it a 4; however, I liked it better than the previous run where I also rated it a 4. I don't want to rate it a 3, however, it is much easier to maintain the glide path below 100 feet. That was run 776.

Run 778. There are too many "goodies" thrown into this thing. You are in a point where you cannot put 100 percent power so your spoilers go down so you gotta up them to 100 percent and back off a little bit until you have got control of your spoilers. Too many variables thrown into this thing. The fact that the spoilers should go down at 100 percent should be taken out of the machine, its just like somebody flying with speed brakes - if they want to go around they advance the throttle and they pull in their speed brakes. In an airplane like this when you want the spoilers closed for a go-around you could do it manually with the DLC controller. In that way you can get rid of the interconnect. I think with that feature out this system will work a lot better than it will the way it is presently mechanized. Coming down final maintaining glide path with the engine-out I would rate it a - let's say an 8 mainly due to the mechanization of the system. Below 100 feet I would rate it a 5 due to the fact that below 100 feet by now you are back on the power and power is back in a normal range and you do have the authority. I would say increasing the effectiveness three times with your basic airplane is a little too much - I tend to go with increasing it just twice and see how that configuration works.

4. Would your longitudinal control have been improved if the DLC controller had been mounted in a different position? Say for instance on the #1 throttle under your thumb.

PILOT A

Concerning question no. 4 would my longitudinal control be improved had the DLC controller been mounted in a different position? I do not think it would change my Cooper-Harper ratings appreciably not even by a factor of one. However, it would make the pilot's job smoother operational-wise if he could keep his hands near the throttle and had his DLC in the same position. It would just be a pilot comfort factor more than anything else.

PILOT B

In reference to question no. 4 I would prefer to have the direct lift controller mounted on the left side of the pilot's yoke. (Also see comments to Run 736).

PILOT C

Answering question no. 4. The answer is yes. Move it over to the throttle. How about the left side of wheel? No, I would rather have it over on the throttle than under my left thumb. (See also comments to Runs 775 and 776).

5. Rate the longitudinal control tasks of 1 and 2 above with the DLC controller coupled directly to the column and utilizing the baseline value of control effectiveness.

			Aug. On		Aug. Off	
			Run Number	Pilot Rating	Run Number	Pilot Rating
PILOT A	1	Normal	858	2		
		Eng. Out	857	2	859	5
	2	Normal	858	2		
		Eng. Out	857	3		

Run 859. Cooper-Harper rating of 5. Too much sensitivity in pitch control, tended to wander off the desired attitude that I wanted, and at the bottom the aircraft tended to auto-rotate just before touchdown.

			Aug. On		Aug. Off	
			Run Number	Pilot Rating	Run Number	Pilot Rating
PILOT B	1	Normal	741	3		
		Eng. Out	742	3	753	4
	2	Normal	741	3		
		Eng. Out	742	3		

Run 741. Evaluating the direct lift control as it is connected to the column. The speed control and rate of descent seemed very good all the way down. Gives it a good flare characteristic at the bottom when I just eased back on the column a little bit. This configuration gives it a much better flare characteristic than it had before. I would rate that a 3. I think that would take a little more looking at. There certainly is nothing wrong with this but the previous configuration gives the pilot more control.

Run 742. We were evaluating the landing approach at 85 knots with the spoilers coupled both to the DLC knob and to the yoke. The control for the pilot is real nice. There is a great deal of control available to him and the only tendency you have to watch out for is overcontrolling it. There is a tendency, right at the flare, to come in with a little more up DLC than you should, as a result, you tend to float a little ways down and go beyond the intended touchdown point. I would rate it a 3. The reason that the ratings are not higher is due to excessive breakout forces in the longitudinal control column.

Run 753. Evaluating the landing approach with the baseline sensitivity unaugmented in pitch. At the baseline sensitivity the breakout forces are high enough so that they tend to mask the control forces and when you need a small application by the time you overcome the breakout forces you have more in than you want. So in this mode, this is a poor combination.

The obvious solution is to reduce the breakout forces but since we cannot do that we are probably stuck with the sensitivity problem. I would rate that a 4.

			Aug. On		Aug. Off	
			Run Number	Pilot Rating	Run Number	Pilot Rating
PILOT C	1	Normal	779	3		
		Eng. Out	780	5		
	2	Normal	779	3		
		Eng. Out	780	3		

Runs 779 and 780. I like this much better mainly due to the fact that you are not having to use the direct lift control and the position of which I did not like in the previous ones. I still do not like the fact that at 100 percent you dump the spoilers. However, I would rate it a 3 using the throttle to maintain the glide path under normal operation above 100 feet and using stick to maintain glide path I would rate it a 3 below 100 feet with the regular round out type. With the engine-out I rate it a 5 above 100 feet mainly due to the fact that your spoilers dump when you advance the throttles and when you lose an engine your first indication is to advance the throttles and the spoilers dump then it takes you a while to get back on and maintain glide path but once you are on it though and you got the throttles back above 100 feet I would rate it at a 3 and below 100 feet using the stick I would rate it at a 3 also for maintaining glide path for this system. The main objection for this system is the fact of the 100 percent spoiler stuff. This system is better in the fact that you are not using the direct lift control that is why the rating is a little bit higher.

6. Using the configuration as defined in 5 above and the DLC controller to maintain glideslope below 100 feet rate the longitudinal control task.

		Run Number	Pilot Rating
PILOT A	Normal	860	3
	Eng. Out	861	4

		Run Number	Pilot Rating
PILOT B	Normal	747	3
	Eng. Out	748	3

(Same comments as Runs 741 and 742 above)

		Run Number	Pilot Rating
PILOT C	Normal	783	6
	Eng. Out	784	7

Runs 783 and 784. With the engine running, for some reason there was no difference between it and the first set of runs; however, below 100 feet I could not round out. I do not know why because I used the same techniques as I used on the first runs we made. Above 100 feet you are hitting the same problem of the fact that you do not have enough effectiveness so therefore you hit a stop and you have got to adjust the throttle. You also run into the problem above 100 feet with the engine-out whereby you advance the throttle and spoilers close then you pull it back and it takes you time to get set up and finally find a happy medium. I would rate it a 6 for throttle control above 100 feet with no engine-out and rate it a 6 below 100 feet. With an engine-out I would rate it 7 above 100 feet. Using the combination of the stick and the spoilers to round out below 100 feet I would rate it 7 below 100 feet.

7. Using the control configuration as defined in 5 above and the number 1 throttle as a collective throttle lever, rate the longitudinal control task.

		Run Number	Pilot Rating
PILOT A	Normal		
	Eng. Out	862	2

		Run Number	Pilot Rating
PILOT B	Normal	743	2-1/2
	Eng. Out	744	2-1/2

Run 743. A collective throttle evaluation. The aircraft throttles are of course much easier to move and require less attention than they had previously and it made for a lighter workload on the pilot. The column breakout forces are still adverse and therefore cannot really improve the rating significantly, especially since I was not considering the big hand full of throttles when I was giving you the 3's. So, I would say we could rate it something less than a three but more than a two.

Run 744. One engine-out with the collective throttle. With a little practice now I find it very easy to control the touchdown point quite precisely with this direct lift and still not have it set up an excessive sink rate which makes for a rather advantageous characteristic for an aircraft of this type. I would rate that also at 2-1/2.

		Run Number	Pilot Rating
PILOT C	Normal		
	Eng. Out	785	4

Run 785. Concerning the use of one throttle versus four, I like it better, with the direct lift control bounded on the throttle I think would be the best configuration. I thought of one possible solution for this problem of advancing to 100 percent and then having the spoilers dump on you, would be to possibly have a little detent say at 99 percent where you could go to 99 percent and hit a stop and have the spoilers still stay open and you would have to give it a little extra effort to go over a detent into a 100 percent. Since we are concerned with the concept of just a single throttle I would rate that, the throttle only as a 4, because with a single throttle I would like it moved over to the left side. I do not like the positioning of the single throttle - I would rather have it on the left side. In this position I would fly the airplane with my right hand and use the throttle with my left then I would have the direct lift controller put on the throttle. That I would like much better, compared to the four throttles. I would rather have the single in that configuration. However, four throttles do not really bother me having them all out in the middle since you can get the co-pilot to run some of the throttles for you.

8. Using the DLC controller and column (with the horizontal stabilizer decoupled) rate the longitudinal control task.

		Aug. On		Aug. Off	
		Run Number	Pilot Rating	Run Number	Pilot Rating
PILOT A	Eng. Out	863	3	864	5-1/2

Run 864. I do not like the unaugmented vehicle response - it is difficult to control.

		Aug. On		Aug. Off	
		Run Number	Pilot Rating	Run Number	Pilot Rating
PILOT B	Eng. Out	745	3	751	3

Run 745. Evaluating the reduced control system sensitivity. There are so few pitch changes required that it was not a factor. The DLC is still your dominant control when it is hooked to the column like that and it worked out quite well. I would rate it at 3.

Run 751. Evaluation of the landing approach with no augmentation on slightly decreased sensitivity. The aircraft lost an engine at 700 feet. There was no particular problem controlling the aircraft in pitch. I would rate it a 3.

		Aug. On		Aug. Off	
		Run Number	Pilot Rating	Run Number	Pilot Rating
PILOT C	Eng. Out	787	3		

Run 787. Concerning question 8, I like that longitudinal configuration much better than the other ones. I would rate that one a 3 with the engine-out above 100 feet and 3 with the engine-out below 100 feet. Overall it was pretty good. As for reaching stall angle of attack, yes it was very easy to reach stall angle of attack. As far as the configuration itself goes it was not quite as sensitive. It was overall, a pretty good configuration. I rate that as a 2-1/2 - I like that better than the last configuration. No change in comments. No real problem with it. You can reach the stall from level flight. There is no problem with that. Just a little more control movement involved so that is why this got rated a little better.

I noticed from our Cooper ratings from this series of tests that most of the Cooper ratings were in the 3 and 4 area except this last one which was a 2-1/2. Does that indicate that your feelings regarding the pitch sensitivity is more to your liking in this area? Yes - I like this, this is getting more in the area of pitch sensitivity I like. To really pinpoint it you would have to sit around and try more configurations, then come up with a real good one but I think this coupled with that roll sensitivity would be half way decent.

9. With the configuration of question 8 and one-half the baseline δ_e sensitivity, rate the landing approach.

		Aug. On		Aug. Off	
		Run Number	Pilot Rating	Run Number	Pilot Rating
PILOT A	Eng. Out	865	6	866	6

Runs 865 and 866. This level of sensitivity is too low for this configuration. It requires excessively large column inputs to make minor corrections about the trim point and for the instantaneous engine failure correction it required almost full column.

		Aug. On		Aug. Off	
		Run Number	Pilot Rating	Run Number	Pilot Rating
PILOT B		749	3	750	3

Run 749. Landing approach evaluation. I used the direct lift control quite a bit in that run. Seemed like there was more pitch pumping than I had before but it was not - it did not degrade the quality - just more work for the pilot and still had about the - I would rate that a 3.

Run 750. Evaluating landing approach without pitch augmentation. The aircraft is basically stable in pitch with or without augmentation. It looked like it has about a half cycle to damp and as far as pitch control, lineup was no problem - it is not quite as good as it is augmented but as far the ability of the pilot to control the aircraft I would say it is essentially the same. Just slightly higher workload for the pilot. I would rate it a 3.

		Aug. On		Aug. Off	
		Run Number	Pilot Rating	Run Number	Pilot Rating
PILOT C	Eng. Out	788	2-1/2	789	

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SECTION I-2

PILOT COMMENTS - 6 DOF EVALUATION

PILOT A

Run 638. This run was a 10, because I could not get the aircraft to respond to my corrections to get it back to the runway. I had been flying down final with a 10- to 12-degree heading crab angle to correct for wind and during the attempt to take the crab out and flying with wing low tracking down the runway I was unable to get it to the runway or maintain its correction.

Run 650. Rating 10. I got the engine-out at 500 feet and got pretty good control of the aircraft. We seemed to have it lined up pretty well with the runway and once getting back on my glide path and CDI instruments, mainly on instruments, I went back to VFR and of course as I got in closer I begin to pick up our visual errors better and the closer we got the more they magnified and towards the end I was slightly left of the runway. I made a correction to drift back to the right, overshot to the right and was unable to bring the aircraft back to the left and back to the runway before touchdown. Touchdown occurred with a 45-degree bank aligned with the runway but 100 yards or so off to the side.

Run 651. The engine-out was 100 feet and at first I thought I had a lateral gust that I corrected for but as I was correcting for this I realized the airplane was dropping and I realized that I had an engine-out by this time I was so close to the runway I maintained visual just added power as necessary to round out and touch down. Satisfactory landing - rating 5 and the main reason for the rating is the lateral-directional problems throughout the whole approach of having to pay a lot of attention to the bank and lateral velocity in order to keep the aircraft where I wanted and to keep from getting unwanted changes in heading.

Run 653. Rating 10. The engine-out was at 50 feet and I was able to keep the aircraft aligned with the runway to get the proper bank angle to stop lateral drift; however, I was unable to get the power in soon enough or rotate soon enough to stop an excessive sink rate of 17 feet per second at touchdown and that is the reason for rating of 10.

Run 654. Rating at 10. This was with the 25-knot cross-wind. As we were tracking in on centerline with about 21-22 degrees crab. At just about 100 feet altitude as I was crossing the trees I started to kick out the crab and line up with the runway when I had engine failure and in picking up the low wing with opposite rudder and in combination with an engine-out I developed a sink rate that I could not control and hit the ground at about 18 feet per second.

Run 655. An engine failure at 200 feet with a subsequent waveoff. During the waveoff got the flaps up and while attempting to maintain air speed and rotate got into a lateral-directional problem where I started getting excessive bank angles up to 34 degrees back and forth and airspeed built to about 91 knots; however, we hit the ground before we could continue and finish the rotation to climb out. However, the roll problem never was solved before the contact with the ground.

Run 656. Landing approach with a 26-knot cross wind, engine-out at 200 feet and subsequent waveoff. While attempting the waveoff and maintaining airspeeds getting flaps up by trying to rotate again I got into a lateral-directional problem where I had excessive lateral velocities building up and got quite a bit of oscillation in roll trying to correct for it; however, unable to compensate for that and accomplish the rotation before ground contact.

Run 657. Rating 8. Engine failure at 800 feet with lateral gusts with subsequent waveoff. Waveoff was successful but again we developed quite large lateral velocities and problems with the roll control which took about 4 cycles, maybe 5, to correct for before we could get a steady climbout.

Run 687. Cooper Harper rating 10. The most difficult problem I had was bringing the roll problem under control and while doing that was not able to keep attention on the vertical velocity allowed it to go to zero - tried to recover it to 350 feet/per minute climb minimum and at the same time the speed kept decreasing until the simulator reset for going below speed margin. My most difficult problem was taking care of the lateral-directional problem.

Run 688. Pretty much the same comments. Looking at the problem a little more familiar this time. While I was working with the roll control again I was able to keep the vertical velocity under better control; however, as the speed bled off I was unable to maintain enough climb angle to keep the vertical velocity from going below zero. Again the simulator reset when the speed dropped too low.

Run 689. Rating 10. Engine failure occurred in a turn. Leveled out, regained control of the aircraft and tried to finish the turn and throughout the entire turn and during the level off the speed kept decreasing, vertical velocity wanted to enter descent and when I completed the turn the speed had decreased to the point where I no longer had authority - enough authority to roll out of the turn and the airplane spiraled into the ground.

Run 690. Rating 10. The same problems as on past runs. Quite a bit of difficulty in bringing the roll problem under control and then settling down the lateral velocity. Meanwhile the vertical velocity and airspeed are both decreasing until the simulator resets when we drop below the speed limit.

Run 691. Rating 10. Could not accomplish the task of minimizing altitude loss and getting an airspeed increase so as to resume the climb. Had difficulty in keeping the roll under control, but did get it under control; however could not stop airspeed decrease.

Run 693. Rating 10. Still having difficulties as mentioned before with roll control and engine failure occurred in a turn at 500 feet and even with picking up 4,000 feet per minute rate of descent was unable to stop the decrease in airspeed.

Run 694. On the first seven Cooper-Harper ratings throughout had a problem in the over-sensitivity of the roll control and I was unable to solve my lateral-directional problem especially in roll before I had gone through wings level at least three cycles. This of course gave me difficulty in following the other instruments and trying to meet our requirements keeping the climb angle at three degrees for the first runs or minimizing altitudes and airspeed loss for the latter runs. At these speeds and with this control sensitivity, overcontrol was the dominant reason in my not being able to recover, however, on these first seven data points I do not feel that I could have recovered from an engine-out situation with the climb speed of 79 knots or 76 knots as this was too close to the minimum three-engine - three-degree climb speed.

Run 695. Rating 6. Same comment.

Run 697. Rating 7. This configuration has high pitch sensitivity and is influenced by low column breakout forces due to the high pitch attitude of simulator. It requires constant attention to the longitudinal axis.

Run 698. Rating 7. On these past five runs at a higher speed margin, 93 knots, speed bleed off is not as critical as in the previous cases and as a result I can safely concentrate attention to the lateral control problem.

Run 849. Cooper-Harper rating of 7. The task is to maintain roll control and the desired heading and track at the same time. Lateral-directional excursions and lateral sensitivity worked against one another while I was trying to stay on the centerline and ended up overshooting the runway to the right. Nose gear and main gear in the dirt.

Run 850. Cooper-Harper rating of 4. Able to perform the task successfully, however, I do not like the control response in roll where it seems that I am always behind the aircraft. That is the best I can put my finger on it; it is that I just seem to be behind in my roll command and what my performance instruments show.

Run 853. Cooper-Harper rating of 3. However, I would still like to see the control de-sensitized somewhat about neutral.

PILOT B

These are Pilot B's comments regarding comparative ratings between IFR and VFR landing approaches with respect to the visual display presentation.

In discussing the comparative ratings between the visual display and the IFR type of approach, one of the reasons we had the higher ratings on the other one was we did not have a standard to try and make - in other words if I had that engine-out and if I had been on the IFR display I probably would have rated it at 4 or 5 because I would not have realized that I had gotten that far off the runway - see. I would have had nothing to compare it to. I would know I was not right on, but, I would not know whether I was way off or just a little bit off and the result is - now that we have this standard of being on that runway and ideally right in the middle of it, suddenly our standards are much higher and therefore the comparative ratings are going to be much lower in the IFR case - at least that is the way I see it.

Run 643. We are evaluating a 15-foot/second crosswind. The aircraft is uncontrollable laterally and therefore becomes extremely difficult to hit any particular spot on the ground such as a runway. The rating is 10.

Runs 722 and 723. Run 722 cross winds of 45 feet per second - 723 cross winds of 10 feet per second. I rated 722 a 10 due to inability to align with the runway. I rated 723 an 8 for the same reason.

Run 724. Was a 10 feet per second cross wind but assuming the cross wind landing gear. I was unable to hit the runway - I evaluated at 10 due to inability to control the aircraft laterally for fine corrections needed to get it on the runway.

Run 725. Evaluating a cross wind landing at 10 feet per second assuming cross wind gear. I would evaluate that at probably a 7. The problem being one of adequate lateral control to insure a wings level touchdown. Any lateral control inputs within the last 100 feet will just about guarantee some bank angle at touchdown. I just do not seem to be able to get it out.

Run 726. Twenty-five feet per second cross wind assuming a cross wind gear. I would probably rate that at somewhere around a 4 and my reason for rating that one higher is that, through the practice that I got, I was able to visualize the sight picture that I needed at some further distance out and I required no lateral inputs from about the last 200 feet of descent. With the complete absence of lateral inputs I had no trouble maintaining a stable aircraft.

Run 727. With a 45-foot per second cross wind assuming a cross wind gear. The run was reasonably good I probably would rate that at about an 8. The problem being once again tnat I was unable to make the fine lateral corrections in close that I needed to get on the runway and had to accept a little bit of off-center and would probably touchdown with our nose wheel on the left edge of the runway.

Run 728. Engine-out at 500 feet. Was unable to hit the runway due to inability to control the aircraft laterally for last minute corrections in close. I would have to rate that at 10.

Run 729. Engine failure at 100 feet. The engine failure occurred while I was applying left aileron and therefore I just did not notice it and the result was that the left aileron I was putting in just kept me from rolling it, did not give me the desired input and as a result I missed the runway again. I would have to rate that at 10.

Run 730. Waveoff and engine-out at 200 feet. No unusual characteristics during the approach. Well I got the engine-out and the waveoff almost simultaneously, we still had enough room to wave it off and of course there was no demands made on the lateral control so we did not have any problem. I would rate it probably about a 4.

Run 731. Engine-out at 200 feet and waveoff. The waveoff came at about 50 feet and we were able to make it. Had a lot of lateral oscillation with the engine-out the subsequent waveoff, and the raising of flaps, and that sort of thing and it was a very demanding on the pilot to damp out the lateral oscillation. I would rate it at probably an 8 because of the lateral oscillation. It was very uncomfortable and I am sure we lost performance due to that too. That lateral oscillation is kind of a pilot induced oscillation. The aircraft seems to get out of phase with the pilot.

Runs 827 and 828. Engine-out at 500 feet and 100 feet. I would rate the handling characteristics at 4. They were adequate all the way down. I had to work awfully hard to get my line up and never did get the nose pointed exactly in the direction I wanted. I feel that the rudder effectiveness is marginal in this condition and when you are holding in much aileron it, I think, loses rudder effectiveness and then you just cannot point the nose in the direction you want it.

Run 830. Engine-out at 100 feet. I rate it a 3. I did not add power on the engine failure rather I concentrated on maintaining runway heading and lineup and tried to decrease sink rate by adding full up direct lift control - this worked very well. We landed somewhat short of the touchdown area but on heading and on the runway and I do not think we exceeded our maximum sink rate. The addition of power naturally would have tended to aggravate the yaw which I think is one of the problems in keeping this thing where we want it.

Run 831. Cross wind and engine-out at 200 feet. I failed to recognize the engine-out in time which caused me to get dangerously low and trying to recover from the dangerously low situation we set up an unusual attitude. We landed on the runway but with an excessive sink rate and I would have to rate that a 10 as I was not able to control the sink rate.

Run 832. Engine-out at 50 feet - no cross wind. I would rate that probably a 4. I do not know what our sink rate was at touchdown but we were able to keep it on the runway and there was no addition of power. There really would not have been time for the engines to spool up I don't think even if we added power.

Run 833. With crosswind and engine-out at 100 feet. We seemed to be in pretty good shape until we got the engine-out and the sink rate got going. I came in with full power and landed on the runway but about 20 degrees off runway heading. If we had adequate rudder power I am sure I had time to get the nose around, because I had the rudder against the stop and it just was not responding. So, the problem was just inadequate rudder power. I would rate that probably - well I guess you have to rate it at 10 because it did not respond to the controls as necessary. What if you had crosswind gear? It would have to be an awfully smart crosswind gear to help there - you just cannot predict that kind of an angle. The only way you can use a crosswind gear is if you can predict the angle.

Run 834. Engine-out at 200 feet and waveoff decision three seconds later. OK, everything was under control. We had no problems with waveoff - probably lost about 100 feet in the waveoff, and I think with better technique that could have been held essentially to zero. I would rate it at 3.

Run 835. Crosswind approach with engine-out at 200 feet - waveoff decision three seconds later. I would rate it a 3. There were essentially no problems. Executed the waveoff without any loss of altitude.

Run 836. Engine-out at 100 feet - waveoff decision three seconds later. We executed the waveoff immediately, however, we were so close to the runway that our wheels touched down as we rotated. And we were on the runway and on heading, I am sure anybody in that position would not have waved off they would have gone ahead and landed. Was not a realistic test but I would rate it a 3;it behaved in every respect as I would have expected it to.

Run 841. Engine-out at 100 feet - trim speed 97 knots. At engine-out I went to full power to cushion the sink rate and we just did not have a chance to keep the aircraft over the runway at full power due to lack of rudder control. Just not enough rudder power in the aircraft. Could you have touched down on a wider runway? Yes, but if you cannot put the nose wheel where you want it - it is a 10. That is just like if you pave the whole world with concrete we will always hit it. But I couldn't judge.

Run 842. Engine-out at 50 feet - 97-knot trim speed. I was able to control the lateral-directional axes very well. But I do not think I ever got to full power - I was just coming up to full power when we hit. Once again if I had the direct lift control on the other side of the yoke I am sure we could have kept the sink rate within the ballpark. As it was I don't think it was excessive - you might have bent the gear a little bit but you would not have broken it. I would rate that at about a 4 and then the only problem was sink rate.

Run 884 with the engine-out and the crosswind I was just unable to control the aircraft laterally. I could not control both the heading and roll so we ought to take a look at that 2 or 3 more times. I would rate it a 10.

Run 885 which was crosswind and engine-out at 200 feet. I would rate it a 10 due to inability to maintain directional control due to lack of rudder authority. Was the lateral control adequate? I really don't think the aileron control has anything to do with it there. I think the aileron control is adequate.

Run 886 which was crosswind and engine-out at 200 feet. I rate it a 10 due to the same problem. Inadequate rudder authority.

Run 887. Thunderstorm turbulence. I would rate - it's unrealistic in that you just don't get that kind of turbulence that close to the ground. It is close to what you would get inside a thunderstorm at cruise speeds but we are at landing speeds which should say it is much less - in fact we were on the verge of stalling a few times. So I don't know what we are trying to show. The fact that I could hit the runway. You must say that we got a reasonable flight control system anyway. In that regard I would probably have to rate it about a 4 but the turbulence seems to be pretty vicious.

Run 889 was with .5 turbulence factor. I would rate the aircraft a 3. It rode out reasonably well. The turbulence seems to be too high in frequency and a little low on amplitudes since we cut it down from the previous run. It was more typical of the type of turbulence you would encounter in when what we call "light chop" or "light to moderate chop" which is a high speed type of turbulence very similar to riding a speed boat through choppy waves - just bouncing from one wave crest to another and that is not particularly typical of landing in an approach speed type turbulence.

Run 894. A 45-foot per second crosswind and engine-out at 500 feet with a steep glide slope. The transition on the glide slope was no problem. It reverted to the same old problem with the engine-out normal approach with adequate time to take corrective action and try to line the aircraft up and I was unable to control heading due to inadequate rudder control. I was able to hit the runway but it was mostly through aileron that I was able to achieve this. I had full rudder in from essentially 300 to 400 feet to touchdown. Could you have made it with crosswind gear? Yes, it would have been easier on the wheels - you would not have left as much rubber on the pavement. (But it has just got to be bordered on Unsat when you have to use full rudder all the way down. It just won't sell.)

Run 895. An engine-out at 200 feet, 7-degree glide slope. Glide slope really wasn't too much of a problem. Just unable to control the heading. Just absolutely no rudder control to do anything I needed done. I rate it a 10.

Run 896. Engine-out at 200 feet, waveoff 3 seconds later. It was executed satisfactorily. However, considerable problems with heading control during the waveoff, probably changed heading about 30 degrees. I rate it about a 5 because of the heading control problems.

Run 898 which was an engine-out at 200 feet. (Plus thunderstorm turbulence which did not amount to a hill of beans). I elected not to add full power to break the rate of descent instead I only added up to about 80 percent of power. Not too much trouble with directional control - we hit down on the edge of the runway. We were at an excessive sink rate and probably would have broken up the gear pretty badly but it sure beats killing yourself. I would rate it a 10 because I could not control sink rate.

Run 900 was a demonstration of stalling technique which is achieving 18 units angle of attack. I attempted to maintain level flight by using pitch attitude and reduce power. As the power was reduced and the altitude maintained the airspeed decreased and the angle of attack increased until such a point as I was clearly on the back side of the power curve and at which time I started adding power but not to any great amount back up to roughly 90 percent power. Added and continued to increase angle of attack and holding altitude until it stalled.

Run 921. The unaugmented vehicle with a crosswind and that is a 10. You just arm wrestle it all the way down and there was no chance of really getting a good shot at the runway. The lateral coupling into pitch is what finally makes you lose it.

Run 922. Same as 921 with augmentation. I was unable to get the aircraft on the runway. I have to rate it a 10. It was the same problem. Just being unable to line up properly and control it laterally. My comment would be that I don't know if more practice and technique could make it possible or not. Was the fact that you couldn't line it up on the runway because you didn't have enough rudder? No, I never had the rudder against the stops, I just couldn't control the lateral motion. It was the same problem we have seen previously and you really cannot control it.

Run 941. The pilot was holding in about 50 pounds of rudder at the point of touchdown and considered the aircraft still poor responding lateral-directionally.

Run 942. Unaugmented at 15 feet per second crosswind. The aircraft is uncontrollable any time an aileron input of more than 10 degrees is required. The directional heading is unstable - continually yawing throughout the approach.

Run 947. Rated it at 10 due to poor lateral control.

Run 948. Rated a 7. (In both 947 and 948 rolling moments due to yaw rate was increased and in the first case the increase was so large that it became uncontrollable lateral-directionally.)

Run 950. Rated a 10. Pilot was unable to control lateral velocity due to reduced roll control effectiveness.

Run 956. Evaluating increased rudder effectiveness. I rate it a 3. The rudder effectiveness is real good. You can control your heading right down to touchdown - it does not seem to be nearly as sensitive to lateral inputs and in fact I noticed at touchdown that my directional heading control was much superior to my lateral control. I rate it a 3.

Run 1007. The unaugmented baseline configuration at flight condition 32 was rated at 10 with three degrees of freedom lateral-directional. The pilot comments indicate that he cannot control heading.

Run 1020. This particular run of 4. A lateral velocity builds up very rapidly with aileron input but yet it seems quite stable when its on heading.

Runs 1021 through 1025. These runs exhibited superior heading and roll control characteristics and that is why they received the higher rating.

Run 1043. Rate this a 4 on the basis of pilot workload although the aircraft is very stable.

Run 1054. Rated it a 3 and it could be better if it were not so stiff.

PILOT C

These are Pilot C's comments regarding comparative ratings between IFR and VFR landing approaches for flight condition 28 with respect to the visual display and also the aircraft handling qualities.

Just taking the case of what we are presented right now, when you roll out on final centered on the azimuth in order to maintain it your visual display which is a couple of miles up ahead of you, is not accurate enough or does not give you enough visual clues it's only 2-dimensional and you can't really line up correctly so you have to use your azimuth indicator and your CDI. Using that, you have to put in a certain fixed amount of rudder which gives you approximately 40 units of lateral velocity. Then using bank which will be about 5 or 10 degrees of bank you have got to see if that will kill the drift on your CDI. If it does kill the drift then all you are doing is playing with 5 or 10 degrees of bank about your 10 degrees that you have in to kill the drift. Without the third dimension (in the visual display) what you enter in to is the fact that you have to rely on the instruments and even at that when you get down to the runway its still a matter of guessing - no not guessing but its still a matter of a little bit of luck entering into it whether you do get that final correction put in in order to put it down on the 60-foot runway. If you had a 3-dimensional display you would feel much more confident than you do with a 2-dimensional display. The other thing is that if I were actually up flying an airplane the learning curve would go up much faster than it does here because even here after say 10 runs I would not have the confidence of putting it down on this 2-dimensional display that I would have if I were VFR and actually flying. That is about it.

Run 713. Rated 10. After the engine-out, lost lateral control due to low airspeed. The previous run I did not lose it but this time I did. The secondary effect lost directional control.

Run 714. Rated 10. I appeared to have the crosswind killed, until about 100 feet when I lost the engine and in turn I lost - but I really didn't lose - lateral control it was just that it was excessive and landed off the side of the runway, for a 10. The aileron control was still quite sensitive but I think had I not lost the engine I could have gotten it on the ground, but, I don't know for sure.

Run 717. Engine-out at 200 feet and crosswind and waveoff. After the engine-out and a waveoff was given, flaps were retracted, however, the airspeed began bleeding off. The nose was lowered to gain airspeed, but I could never get enough to arrest the rate of descent. We might have had I leveled off a little bit higher - I don't know for sure.

Runs 790 and 791. The main difficulty in controlling the aircraft laterally, is due mainly to the sensitivity of the flight control system. It's far too sensitive. Had the runway been wider the Cooper rating might have gone up one point, however, it still would have been extremely difficult getting it on the ground safely. It is not an eask task to do.

Runs 792 through 794. On the past three or four runs the main comment was that the FCS is way too sensitive. The main reason for the 5 rating on the last one - mainly had to do with the 60-foot runway vs a 100- to 200-foot runway - had it been a 100 or 200-foot runway the rating would have been up in an acceptable category. With a 60-foot runway and any crosswind be it 5 knots or 10 knots however high it is, you are running into a problem of that final last 20 or 30 feet of altitude the lateral control getting in on the runway. Had the runway been 100 feet it would have been up in the acceptable category.

Run 795. Give it a 4 it was a little easier than the last one - I don't know why but we still make it a four. Same comments pertain. It would have been acceptable had the runway been wider. Due to the 60-foot limitation on the runway the pass was above what I would consider acceptable.

Run 796. I rate that a 7.

Run 797. I call that a 5 but I think it is mainly the 5 is due to the fact I was a little better set up and got a little closer to the centerline on the landing and not due to the fact that the K_β pot was set up to .375.

Run 800. Rated 10 because I landed short - I had engine-out at approximately 100 feet. The main reason for the rating of 10 is that I landed short. I had adequate lateral-directional control. I landed short due to the fact of keeping the 97 knots. Had I been allowed to bleed the airspeed off to make the runway I could have easily made it,there was no problem there. The only reason for the 10 is due to the maintaining the airspeed.

Run 802. Handling qualities wise I would rate a 3. The only problem was that I had too great a rate of descent at touchdown.

Run 804. That has to be rated a 10 due to the fact that I landed short of the runway; however, had I been able to make it up to the runway I would have rated that a 6 - the only difference in the ratings being the fact that the aircraft landed short.

Run 807. We will call that an 8 just mainly due to control of the aircraft. I got it on the runway, no problems there, but any time you have an engine-out coupled with crosswind like that you are really hard pressed to get it on a 60-foot runway. It made it on the runway; however, it was not completely under control. It was fairly well under control but not completely under control. I will rate that at a 7 mainly due to control of the aircraft on a 60-foot runway. If it had been wider that rating would have been up 5 or 6 due to the 60-foot runway it was down to a 7. There was no handling quality problems per se with the aircraft.

Run 812. Rated a 7 mainly due to the fact that the combination of engine-out and a 45-foot per second crosswind is going to give you a bad handling aircraft no matter what the handling qualities of the aircraft are. We did make it to the runway, however, these are not optimum conditions at all and I don't think you can get much above a 7 on that task anyway.

Run 813. Rate it a 9 mainly due to the fact that when I lost the engine, I added a little bit too much power, so I slowed it quite a bit longer than I wanted to - then when I took it off a wing came down slightly. Had I added the correct amount of power I think I could have gotten it up in the 7 category.

Run 858. Rate that at a 10. I did get it on the runway; however, with a combination of the crosswind and engine-out it was not really under control. The wing was up to about 20 to 30-degree bank. Wider runway? I don't know, I think the main problem there is the occurrence of the engine-out combined with the crosswind and even though I did get it on the runway I still would have gotten on a wider runway but I really wouldn't have been under control when it touched down. Concerning the turbulence model it is a good simulation of severe turbulence. However you would not land this airplane on that 60-foot runway in severe turbulence just due to the large excursions in airspeed and heading. Altitude is not too bad to control except that all of a sudden you lose a hundred feet or so. If the runway were wider you might attempt a landing, however, under the present tasking you would not attempt a landing except in an emergency on this runway with these flight conditions.

Run 867. I gave it a 7. The main problem still stems from the fact that it is a 60-foot runway and you do have a high crosswind and the combination of the two tend to make the task a little too demanding for the configuration you have. Had the runway been wider - say 100-150 feet - you wouldn't be under as much of a problem as there was here with the 60-foot runway.

Run 869. I would have to rate that a 10 just as I came over the trees and started to round out something just took me off to the side. Due to the 60-foot runway I think the runway would almost had to have been a 150-foot wide to get it on the ground. With these gust models as you come over the trees if you pick up any kind of a large excursion you just are not going to get it on the ground. It has got to stay a light turbulence - light - maybe almost moderate - but any large excursion that comes in there it's just going to be too much for the aircraft to handle.

Run 871. I rated it a 10 because I did not make it over the trees. I think it was just a combination of the engine loss and the continuous gusts that caused me to hit the trees.

PILOT D

Runs 927 through 940. The major difference between the runs with and without crosswind is the vertical needle on the ADI. Apparently, when I have the vertical needle available to compare with the center dot on a little airplane I have made consistent approaches down the middle of the runway and touched down in a fairly acceptable manner although maybe short of the line. When that is not available as is the case when any crosswind is in then the lateral control gets fairly wild and you can't predict whether or not I will be on the runway or not on the runway and that is the basis of the higher ratings on 927 through 940. So the problem as you see it is one of controlling heading? Its not heading, its keeping this thing on the centerline of the runway. I think with my current level of proficiency (at time of this statement approximately nine hours in the simulator) when I have the flight director needle available for lateral control I can probably hit the runway most of the time. Also with the needle, I will know when I can't hit it, which would tend to lower the Cooper-Harper ratings. In Run 939 in saying that it was a 4 I was just going by the letter of the Cooper rating and I would say it required moderate compensation and was not too easy.

Run 973. I was off to the left of the runway. I think the vehicle was controllable but I did not attain proper performance with maximum tolerable pilot compensation which is the words that are in the Cooper-Harper rating 7.

Run 974. The lateral axis seemed to be quite controllable. I did have a little difficulty with the pitch axis oscillating above and below the bar but looked out and the touchdown was unusually good compared to others. The question of adequate or desired performance on this gross heading change maneuver is an interesting question in regard to the Cooper-Harper rating. I am able to hold the bank angle probably within plus or minus 5 degrees and roll out on the heading within plus or minus 10. Altitude, I think with practice I could hold it plus or minus 100 feet but the rate of turn is very high.

Run 1001. If you can keep the bank angle below about 30 degrees or you can stay right side up but if it ever gets above that your altitude drops so fast that full aileron and rudder won't bring it right side up again. At least I have applied both full aileron and rudder and have not been able to erect it two or three times in a row now.

Run 1059. In my opinion the short period mode in the unaugmented pitch axis is very nearly the point where I am getting pilot induced oscillation and the component of frequency of that mode is so large in amplitude that it is hard to tell when a particularly large gust comes in. As a result, its surprising and nearly upsets the whole works. A surprise large gust could lead to loss of control although on that particular run it did not. I gave it an 8.

Run 1071. I had very little difficulty selecting the pitch attitude to any particular place and holding it within about plus or minus one degree; however, getting altitude stabilized seemed to be fairly difficult. I thought I had it there on 500 feet and attempted to nail it there and all of a sudden we were 150 feet below and getting it back up was quite an exercise on the throttles as well as pitch attitude again but just the pure task of selecting a pitch angle was not too difficult.

Run 1073. That run and all of the previous ones heretofore, actually the opportunity seems to be in coupling the power with speed, probably in an automatic manner to accomplish the same thing that is done by coupling the power control of a helicopter because a 3-knot difference in speed is about 5 percent difference in rpm on these instruments. Holding altitude and it gets to be quite an important factor and it could be cross coupled mechanically or electrically or however you wanted to do it.

Run 1077. This was an increase of .5 on the pitching moment with respect to velocity. This increase in MVT resulted in a dynamic instability of the pitch axis which was uncontrollable from the pilot's standpoint. Since this configuration with pitch-augmentation on is only slightly damped in the phugoid mode, with the pilot closing the loop it becomes dynamically unstable.

Run 1079. This run was a value for MVT switch of minus .5. Turning the computer on with this value in the equations of motion causes static instability with respect to the phugoid mode. The data point was rated at 10.

Run 1087. The unaugmented baseline configuration flight condition 32. Three-degree-of-freedom lateral directional gross maneuver. In this configuration I raised the question as to what adequate performance is and I could have picked the performance limits for instrument flight of what a transport pilot has to have for instrument flight but I did not. I was not able to hold those tolerances. Nominally the tolerance is three sigma of about 30 degrees of heading and I could nominally hold it with plus or minus 10 degrees of heading.

Run 1091. Was rated a 10. The lateral-directional mode unaugmented is dynamically instable and because of the lateral-directional control problem inherent in this aircraft the instability is uncontrollable by the pilot.

APPENDIX II

SIMULATION STUDY EVALUATION DATA

This appendix contains the tabular data obtained during the various phases of the simulation study. These phases included flight control system validation, takeoff, waveoff, and landing criteria and handling qualities criteria. In all cases the data are listed consecutively by run number and trim condition.

The takeoff, landing, and waveoff pilot opinion data for flight control system validation are listed in Tables I through III respectively. Those for the landing, waveoff, and takeoff criteria are presented in Tables IV through VI respectively. The parameter variation pilot opinion data are contained in Tables VII.

TABLE II-I

TAKEOFF PILOT OPINION DATA -
FLIGHT CONTROL SYSTEM VALIDATION

P = pitch aug.
R = roll aug.
Y = yaw aug.

LG = longitudinal gust
LDG = lateral-directional gust
CW - crosswind

CT = continuous turbulence

RUN	PILOT	PILOT RATING	TRIM SPEED (FPS)	FLIGHT PATH (DEG.)	EXTERNAL DISTURBANCE	FAILURE	FAILURE ALT.	AUG LEVEL
262	B	4	145	12.7	None	None		P-R-Y
264	B	10						None
266	B	7						P
268	B	9						R
270	B	8				None		Y
380	B	8				Engine	50	P-R-Y
382	B	9					500	P-R-Y
384	B	7					100	P-R-Y
394	C	8					100	P-R
396	C	8					500	P-R
398	C	7					50	P-R
400	B	8					100	P-Y
402	B	8					500	P-Y
404	B	7			None	Engine	50	P-Y
414	B	5			LG	None		P-R-Y
416	B	5						P-R-Y
418	B	4-1/2						P-R-Y
420	B	4-1/2			LG			P-R-Y
430	B	4			LDG		50	P-Y
432	B	5			LG		210	P-Y
434	B	5			LG		50	P-Y
520	C	3			None			P-R-Y
522	C	8						None
524	C	7						P
526	C	8						R
528	C	8						Y
551	A	3						P-R-Y
552	A	7						None
554	A	5-1/2						Y
555	A	5-1/2	145	12.7	None	None		R
556	A	6	145	12.7	None	None		P
568	A	5-1/2	145	12.7	None	Engine	500	P-R-Y
569	A	5	145	12.7	None	Engine	100	P-R-Y
570	A	5	145	12.7	None	Engine	50	P-R-Y
571	A	7	145	12.7	None	Engine	500	P-R

TABLE II-I - Concluded

TAKEOFF PILOT OPINION DATA -
FLIGHT CONTROL SYSTEM VALIDATION

RUN	PILOT	PILOT RATING	TRIM SPEED (FPS)	FLIGHT PATH (DEG.)	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALT.	AUG LEVEL
572	A	7	145	12.7	None	Engine	50	P-R
573	A	6					500	P-Y
574	A	6					50	P-Y
585	C	4					500	P-R-Y
586	C	4					50	P-R-Y
587	C	6					500	P-R
588	C	6					50	P-R
589	C	5					500	P-Y
590	C	5				Engine	50	P-Y
848	A	3				None		P-R-Y
849	A	7				Engine	700	P-R-Y
853	A	3			None	None		P-R-Y
854	A	7			CW=45	Engine	700	
874	C	4			None	Engine	50	
875	C	4			None	Engine	100	
876	C	4			CT=1.75	None		
877	C	4			CT=1.75	Engine	100	
878	C	3			None		500	
901	B	4			None		50	
902	B	4			None		100	
903	B	4			CT=1.75	Engine	500	P-R-Y
904	B	10			None	None		None
905	B	4	145	12.7	None	Engine	50	P-R-Y

TABLE II-II

LANDING PILOT OPINION DATA
FLIGHT CONTROL SYSTEM VALIDATION

P = pitch LG = longitudinal gust CT = continuous turbulence
R = roll LDG = lateral-directional gust
Y = yaw CW = crosswind

RUN	PILOT	PILOT RATING	TRIM SPEED (FPS)	FLIGHT PATH (DEG.)	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALT.	AUG LEVEL
1	A	8	140	-5.0	None	None		None
3	A	8	↑	↑	↑	↑		None
6	A	8						None
32	A	5						P
34	A	6						Y
36	A	6						R
55	B	6						R
57	B	4				↓		P
63	B	2				None		P-R-Y
65	B	3				Engine	500	↑
67	B	7				Engine	100	↓
69	B	5				Engine	50	P-R-Y
71	B	3				None		P-R-Y
83	B	6				None		Y
100	C	2-1/2	↓	↓	↓	Engine	500	P-R-Y
104	C	3	140	-5.0	None	None		P-R-Y
106	C	3	↑	↑	↑	None		P-R-Y
108	C	8				None		Y
110	C	9				↑		P
112	C	9	↓	↓	↓	↓		R
118	C	7	140	-5.0	None	Engine	500	P-R-Y
124	C	7	140	-5.0	None	Engine	100	P-R-Y
128	C	8	140	-5.0	None	Engine	50	P-R-Y
147	B	10	↑	-5.0	↑	None		None
151	B	2		-4.4	↓	↑		P-R-Y
153	B	2		-4.4	None			↑
155	B	2		-4.4	LDG			
157	B	2		-4.4	LDG			↓
159	B	2		-4.4	LDG			P-R-Y
211	C	3		-4.4	LDG			P-R-Y
213	C	8		-5.0	None			None
215	C	2-1/2		-4.4	LG			P-R-Y
217	C	2-1/2		-4.4	LG			
227	C	3		-4.4	LDG			P-R-Y
229	C	2-3/4	↓	-4.4	LDG	↓		P-R-Y

TABLE II-II - Concluded

LANDING PILOT OPINION DATA
FLIGHT CONTROL SYSTEM VALIDATION

RUN	PILOT	PILOT RATING	TRIM SPEED (FPS)	FLIGHT PATH (DEG.)	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALT.	AUG LEVEL
231	C	2-3/4	140	-4.4	LDG	None		P-R-Y
276	A	8	140	-4.4	None	None		None
300	A	5	140	-4.4	None	Engine	500	P-R-Y
302	A	4-1/2	140	-4.4	None	Engine	100	P-R-Y
489	B	5				Engine	100	
621	A	4				None		
626	A	9			None	Engine	100	
627	A	7			None		100	
628	A	7			None		100	
677	C	5			None	Engine	100	P-R-Y
809	C	2				None		
810	C	5				Engine	500	
811	C	7			None	Engine	100	
812	C	7			CW=45	Engine	200	
813	C	9				Engine	100	
815	B	7				None		
816	B	3			CW=45	None		
827	B	4			None	Engine	500	
828	B	4			None		500	
830	B	3			None		100	
831	B	10			CW=45		200	
832	B	4			None		50	
833	B	10			CW=45		100	
849	A	7			None		700	
854	A	7			CW=45	Engine	700	
855	C	3			None	None		
856	C	6			None	Engine	500	
857	C	8			None	Engine	100	
867	C	7			CW=45	None		
881	B	4			None	Engine	500	
882	B	3			None	None		
883	B	4	140	-4.4	None	Engine	100	P-R-Y

TABLE II-III

WAVEOFF PILOT OPINION DATA
FLIGHT CONTROL SYSTEM VALIDATION

P = pitch aug. LG = longitudinal gust CT = continuous turbulence
R = roll aug. LDG = lateral-directional gust
Y = yaw aug. CW = crosswind

RUN	PILOT	PILOT RATING	TRIM SPEED (FPS)	FLIGHT PATH (DEG.)	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALT.	AUG. LEVEL
236	B	3	140	-4.4	None	None		P-R-Y
238	B	4			None			P-R
240	B	4			None			P-Y
246	B	3			LG			P-R-Y
274	A	2			None	None		P-R-Y
312	B	6			None	Engine	100	P-R
314	B	6				Engine	100	P-Y
320	B	10				Engine	100	R-Y
452	A	1-1/2				None		P-R-Y
454	A	1-1/2		-4.4		None		P-R-Y
456	A	7		-5.0				None
458	A	3		-4.4				P-R
460	A	3						P-R
462	A	2				None		P-Y
482	A	5-1/2				Engine	100	P-R
484	A	6				Engine	100	P-Y
486	A	8-1/2				Engine	100	R-Y
487	C	2		-4.4		None		P-R-Y
488	C	6		-5.0		Engine	80	P-R-Y
502	C	10		-5.0		None		None
504	C	6		-4.4		None		P-R
506	C	8				Engine	100	P-R
508	C	8				Engine	100	P-Y
510	C	10				Engine	100	R-Y
512	C	4		-4.4		None		P-Y
661	B	10		-5.0	None	None		None
730	B	4			CW=45	Engine	200	P-R-Y
731	B	4			None		200	
732	B	8			None		200	
733	B	3			LDG		800	
805	C	3			None		200	
806	C	2-1/2			CW=45		200	
808	C	3			None		100	
809	C	2-1/2	140	-5.0	LDG	Engine	800	P-R-Y

TABLE II-IV

LANDING-PILOT OPINION AND TOUCHDOWN DATA, THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALT. FT.	$\dot{h}_{TD}$ FPS	ΔX_{TD} FT.	ΔY_{TD} FT.
63	B	2	140	-5.	IFR	None	None		-9.5	-40.	-3.
65		3			180'		Engine	500	-8.9	-77.	16.2
67		7			Rnwy			100	-10.4	-267.	120.
69		5					Engine	50	-12.7	-104.	14.
71		3					None		-10.9	-49.	-16.
73		2					Engine	500.	-11.6	-391.	1.
75		3						100	-12.0	-62.	-7.
77								50.	-6.8	-53.	-11.
79	B	3					Engine	100.	-7.8	-497.	108.
97	C	4					None		-12.8	306.	36.
98		4							-13.3	16.	14.
100		2 1/2							-13.8	-19.	1.
102		3							-12.8	-50.	10.
104		3							-14.0	76.	-9.
106		3					None		-10.2	-71	51.
118		7					Engine	500.	-15.4	-621.	-65.
124		7						100	-7.8	49	-24.
126		7						100	-19.9	350.	63.
128		8						50	-15.9	120.	23.
130	C	8		-5.0		None	Engine	50	-12.8	-72.	9.
137	B			-4.4		LG	None		-10.3		
139		3							-10.7	13.	-2.
141		3							-8.0	-155.	-12.
151	B	3	140	-4.4	180' Rnwy	LG	None		-13.0	-84.	-6.

TABLE II-IV - Continued

LANDING-PILOT OPINION AND TOUCHDOWN DATA, THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALT. FT.	$\dot{h}_{TD}$ FPS	ΔX_{TD} FT.	ΔY_{TD} FT.
153	B	2	140	-4.4	180' Rnwy	None	None		-9.9	-95.	14.
155		2				LDG			-10.0	-84.	-6.
157		2							-12.6	-59.	-13.
159	B	2	140	-4.4	180' Rnwy	LDG	None		-13.0	-29.	-29.
207	C	3	140	-4.4	IFR 180' Runwy	LG	None		-10.8	-64.	42.
209		3							-11.2	12.	17.
211		3							-13.4	-222.	-18.
215		2-1/2							-11.0	16.	-33.
217		2-1/2							-11.4	-71	-13.
219		2							-11.3	-167.	29
221	C	2	140	-4.4	IFR 180' Rnwy	LDG	None		-10.0	45	12
223		2-1/2							-11.3	52	8
225		3							-11.6	-23	4
227		3							-10.4	41	1
229		2-1/2							-11.2	-22	10
231	C	3							-11.5	22.	-36

TABLE II-IV - Continued

LANDING-PILOT OPINION AND TOUCHDOWN DATA, THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALT. FT.	$\dot{h}_{TD}$ FPS	ΔX_{TD} FT.	ΔY_{TD} FT.
300	A	5	140	-4.4	IFR	None	Engine	500	-9.1	206.	110
302	A	4-1/2			180'			100	-6.4	201.	140
489	B	5			Rnwy		Engine	100	-13.0	300	110
621	A	4				None	None		-8.7	142	10
623		4				CW=45			-3.0	68	10
626		9				None	Engine	100	-17.5	-265	27
627		7						100	-7.0	526	54
628		7						100	-7.5	432	9
630		10				CW=45		100	-17.0	198	39
631		10						500	-18.5	700	-118
632		8			IFR			500	-16.0	550	-26
633	A	7-1/2	140	-4.4	180'	CW=45	Engine	500	-15.0	423	-64
637	A	10	140.	-4.4	Rnwy	CW=50	None		-11.5	-324.	-82
639	A	5				CW=25			-14.2	-554	+62
643	B	10				CW=15	None		-13.7	-54.	-69.
650	A	10				None	Engine	500	-13.2	-501.	39.
651		5				None		100	-17.9	+646	-26.
653		10				CW=45		50	-18.1	+640	-48.
654	A	10			IFR	CW=45		100	-17.8	630.	-12.
677	C	5			VFR	None	Engine	500	-9.3	480	-15.
809		2			180'		None		-8.0	+40.	-5.
810		5			Rnwy		Engine	500	-7.9	118	26.
811		7				None		100	-5.9	-321	7
812		7				CW=45		200	-1.4	78	-14
813	C	9					Engine	100	-22.5	272	-23.

TABLE II-IV - Continued

LANDING-PILOT OPINION AND TOUCHDOWN DATA, THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALT. FT.	$\dot{h}_{TD}$ FPS	ΔX_{TD} FT.	ΔY_{TD} FT.
815	B	7	140	-4.4	VFR	CW=45	None		-11.3	15	-39
816		3	140		180'	None			-13.4	-24	-33
827		4	140		Rnwy		Engine	500	-15.7	-301	20
828		4						500	-13.6	-84	14
830		3				None		100	-22.2	-369	16
831		10			VFR	CW=45		200	-33.1	-432	2
832		4			180'	None		50	-22.7	-195	4
833		10	140	-4.4	Rnwy	CW=45		100	-11.1	-503	23
849	A	7	140	-4.4	VFR	None	Engine	700	-13.9	-104	21
852		9			60'		Engine	700	-9.4	-36	-17
853		3			Rnwy	None	None		-5.9	42	-23
854		7				CW=45	Engine	700	-2.8	260	-51
855	C	3				None	None		-3.1	58	-11
856		6					Engine	500	-6.9	284	-6
857		8						100	-11.7	-258	-25
858	C	10				CW=45		200	-22.8	90	-10
859	C	10				CT=7	None		-6.8	-282	+217
864	C	3				CT=1.75			-7.9	-163	-9
865	C	4				CT=3.5			-2.5	244	-9
866	C	3		-7°to							
				4.4°		None			-4.6	-56	-8
867		7		-4.4°		CW=45			-3.0	110	-13
868		7		-7°to							
				4.4°		CW=45			-5.0	-25	-34

TABLE II-IV - Continued

LANDING-PILOT OPINION AND TOUCHDOWN DATA, THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALT. FT.	$\dot{h}_{TD}$ FPS	ΔX_{TD} FT.	ΔY_{TD} FT.
870	C	9	↑	-7° to -4.4°	↑	CW=45	Engine	500	-12.5	-337	-28
871	C	10		↑		CT=1.75	↓	200	-6.6	7	11
881	B	4				None		500	-15.4	-56	-18
882	↑	3				↓	None		-11.7	-1	-26
883		4					Engine	200	-25.4	-262	23
884		10		↓		CW=50	None		22.0		-114
886		10		-7° to -4.4°		CW=45	Engine	200	-21.6	-372	-85
887		4		-4.4		CW=50	None				-29
889		3		-4.4		CT=3.5	↓		-16.6	201	-17
890		3		-4.4		CT=1.75			-11.1	-88	-30
891		3		7°to		None			-12.6	47	-27
892		4		-4.4°		CW=45			-12.7	27	-44
893		4		7°to		↕	↓		-14.6	19	9
894		9		-4.4°		CW=45	Engine	500	-12.9	256	7
895		10		↕	↓	None	↓	200	-24.0	51	-78
897	↓	4	↓		VFR	CT=1.75	None		-13.5	82	-21
898	B	10	140	-7°to -4.4°	60' Rnwy	CT=1.75 ↓	Engine	200	-20.0	408	20
657	B	9	118	-5°	VFR	None	Engine	100			
658	↓	10	↓	↓	180'	CW=45	↓	100			
678	C	10			Rnwy	None		100			
679	↓	↓			↓	↓		500			
680								500			
681	↓							50			

TABLE II-IV - Continued

LANDING-PILOT OPINION AND TOUCHDOWN DATA, THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALT. FT.	$\dot{h}_{TD}$ FPS	ΔX_{TD} FT.	ΔY_{TD} FT.
699	A		118	-5°			Engine	500			
700		10						500			
701		10						100			
702		6				None		50			
703		10				CW=45		100			
710	C	10				None		500			
712		5						100			
713		10						50			
714						CW=50		100			
715						CW=45		100			
716					180'	CW=45		200			
928	D	9			VFR	CW=15	None				
929		8			60'						
930		8			Rnwy						
724	B	3	157	-3.8°	VFR		None		-16.0	-199	-78
725		4			180'	CW=15			-10.5	-464	-41
726		4			Rnwy	CW=25			-11.5	-238	-49
791	C	8				CW=45			-11.1	-33	4
792		8				CW=25			-4.0	-229	28
793		8				CW=15			-10.6	94	15
794		5				CW=15			-5.7	-1	-39
795		4				CW=25			-4.7	280	-17
797		5				CW=45	None		-2.6	126	-19
800		10				None	Engine	100	-19.6	-630	28

TABLE II-IV - Concluded

LANDING-PILOT OPINION AND TOUCHDOWN DATA, THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALT. FT.	$\dot{h}_{TD}$ FPS	ΔX_{TD} FT.	ΔY_{TD} FT.
802	C	3	157	-3.8°	VFR	None	Engine	500	-15.6	-286	-19
803	↓	4	↕	↓	180'	None	Engine	50	-15.0		0
804	↓	6	↕	↓	Rnwy	↓	↕	100	-8.4	-618	-11
807	↓	8	157	-3.8°	VFR	CW=45	Engine	200	-8		10

TABLE II-V

WAVEOFF PILOT OPINION DATA
THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALTI., FT.
230	B	2	140	-4.4°	IFR	None	None	
232		2						
234		2						
236		3				None		
242		2				LG		
244		1						
246		3				LG	None	
296		7				None	Engine	150
298		4						200
300		4						100
302		5				None		100
304		5				LDG		100
306		7				LG		100
310		5				None	None	
324	A	4		-5°			Engine	800
326		4-1/2						200
328		10						100
332		5						100
334		10						90
336	A	5						90
350	C	3					Engine	800
352		5						200
354		10						100
356		3				LDG		800
358		10				LDG		100
360		10				LG		150
362		5				LG		
364		5				LDG		
366		2				None	None	
368		2						
370		2						
440	A	2						
442								
444								
446	A	2	140	-4.4°	IFR	None	None	
448	A	2	140	-5°	IFR	None	None	
450	A	2	140	-5°	IFR	None	None	
464	A	10	140	-4.4°	IFR	None	Engine	80

TABLE II-V - Continued

WAVEOFF PILOT OPINION DATA
THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALTI., FT.
466	A	10	140	-4.4°	IFR	None	Engine	80
468	↓	5	↓	↓	↓	↓	↓	150
470	↓	4	↓	↓	↓	LG	↓	800
472	↓	4	↓	↓	↓	LDG	↓	80
474	↓	4	↓	-4.4°	↓	LDG	↓	80
476	↓	4-1/2	↓	-5°	↓	None	↓	100
478	↓	4-1/2	↓	↓	↓	LG	↓	↓
480	A	4	↓	↓	↓	LDG	↓	100
488	C	6	↓	↓	↓	None	Engine	80
490	C	2-1/2	↓	↓	↓	None	None	
492	C	6	↓	↓	↓	None	Engine	100
494	↓	6	↓	↓	↓	LDG	↓	
496	↓	10	↓	↓	↓	LG	↓	
498	C	5	↓	↓	↓	LG	↓	
452	A	1	↓	↓	↓	None	None	
454	A	2	↓	↓	↓	↓	↓	
487	C	2	↓	↓	↓	↓	↓	
488	C	6	140	↓	↓	↓	Engine	80
606	B	10	118	↓	↓	↓	↓	500
607	↓	10	118	↓	↓	↓	↓	500
608	↓	9	↓	↓	↓	↓	↓	100
645	↓	10	↓	↓	↓	↓	↓	500
647	↓	8	↓	↓	IFR	↓	↓	1000
659	↓	10	↓	↓	VFR	None	↓	200
660	↓	10	↓	↓	↓	VCW=45	↓	200
662	B	8	↓	↓	↓	LDG	↓	800
717	C	10	↓	↓	↓	VCW=45	↓	200
718	↓	10	↓	↓	↓	None	↓	100
719	↓	5	↓	↓	↓	None	Engine	800
720	C	10	118	-5°	VFR	VCW=45	None	
730	B	4	157	-3.8°	↓	VCW=45	Engine	200
731	↓	4	↓	↓	↓	None	↓	200
732	↓	8	↓	↓	↓	None	↓	100
733	B	3	157	-3.8°	VFR	LDG	Engine	800
805	C	3	157	-3.8°	VFR	None	Engine	200
806	C	2-1/2	157	-3.8°	VFR	CW=45	Engine	200
808	C	3	157	-3.8°	VFR	None	Engine	100
809	C	2-1/2	157	-3.8°	VFR	LDG	Engine	800

TABLE II-V - Concluded

WAVEOFF PILOT OPINION DATA
THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALTI., FT.
834	B	3	140	-4.4°	VFR	None	Engine	200
835	B	3	140	-4.4°	VFR	CW=45	Engine	200
836	B	10	140	-4.4°	VFR	None	Engine	100

TABLE II-VI

TAKEOFF PILOT OPINION DATA
THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALTI., FT.
248	B	7	145	12.7°	IFR	None	None	
258		7						
260		6					↓	
262		4					None	
372		8					Engine	100
374		7				↓		500
376		6				LG		50
378		7				LDG		50
380		8				None		50
384		7						100
386		6						500
388		6				↓	↓	100
390		5				None	Engine	50
406		5				LG	None	
408		5				LG		
410		5				LDG		
412		6						
414		5				↓		
416		5				LDG		
418		4				LG		
420		5						
422		4				↓		
424		5				LG		
426	↓	4				LDG		
428	B	4				LDG		
512	C	5				None		
516		5						
520	↓	3						
529	C	4						
538	A	4						
541		↓						
543	↓	4	↓	↓	↓	↓	↓	
551	A	3	145	12.7°	IFR	None	None	
559	A	6	145	12.6°	IFR	None	Engine	50
560		6						50
561		6				↓		100
562	↓	5-1/2	↓	↓	↓	None	↓	500
563	A	5-1/2	145	12.6°	IFR	LG	Engine	50

TABLE II-VI - Continued

TAKEOFF PILOT OPINION DATA
THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALTI., FT.
564	A	5-1/2	145	12.6°	IFR	LDG	Engine	50
565	↓	4-1/2	↓	↓	↓	LDG	↓	50
566	↓	4-1/2	↓	↓	↓	None	↓	500
567	↓	5	↓	↓	↓	↓	↓	100
568	↓	5-1/2	↓	↓	↓	↓	↓	500
569	↓	5	↓	↓	↓	↓	↓	100
570	A	5	↓	↓	↓	↓	↓	50
576	C	5	↓	↓	↓	↓	↓	50
577	↓	5	↓	↓	↓	↓	↓	100
578	↓	4	↓	↓	↓	None	↓	500
579	↓	5	↓	↓	↓	LG	↓	50
580	↓	5	↓	↓	↓	LDG	↓	50
581	↓	5	↓	↓	↓	None	↓	50
583	↓	4	↓	↓	↓	↓	↓	500
584	↓	5	↓	↓	↓	↓	↓	100
585	↓	4	↓	↓	↓	↓	↓	500
586	C	4	145	12.6°	↓	↓	↓	50
595	B	10	129	11.6°	↓	↓	↓	50
596	↓	10	↓	↓	↓	↓	↓	50
597	↓	10	↓	↓	↓	↓	↓	100
598	↓	9	↓	↓	↓	None	↓	500
599	↓	10	↓	↓	↓	LG	↓	50
600	↓	10	129	11.6°	↓	LDG	↓	50
601	↓	3	159	12.6°	↓	None	↓	50
602	↓	3	↓	↓	↓	↓	↓	100
603	↓	2	↓	↓	↓	None	↓	500
604	↓	2	↓	↓	↓	LG	↓	50
605	B	2	159	12.6°	IFR	LDG	Engine	50
610	C	10	129	11.6°	IFR	None	Engine	50
611	↓	↓	↓	↓	↓	↓	↓	50
612	↓	↓	↓	↓	↓	↓	↓	100
613	↓	↓	↓	↓	↓	None	↓	500
614	↓	10	129	11.6°	↓	LG	↓	50
616	↓	4	159	12.6°	↓	None	↓	50
617	↓	↓	↓	↓	↓	↓	↓	100
618	↓	↓	↓	↓	↓	None	↓	500
619	↓	↓	↓	↓	↓	LG	↓	50
620	C	4	159	12.6°	IFR	LDG	Engine	50

TABLE II-VI - Concluded

TAKEOFF PILOT OPINION DATA
THREE AXIS STABILITY AUGMENTATION

RUN NO.	PILOT	PILOT RATING	SPEED FPS	FLT. PATH DEG.	FLT. RULES	EXTERNAL DISTURB-ANCE	FAILURE	FAILURE ALTI., FT.
621	C	4	145	12.6°	IFR	None	Engine	50
622	C	4	145	12.6°	↓	↓	↓	50
687	A	10	129	11.6°	↓	↓	↓	↓
688	↓	↓	↓	↓	↓	↓	↓	100
689	↓	↓	↓	↓	↓	None	↓	500
690	↓	↓	↓	↓	↓	LG	↓	50
691	↓	↓	↓	↓	↓	None	↓	50
692	↓	↓	↓	↓	↓	↓	↓	100
693	↓	10	129	11.6°	IFR	↓	↓	500
694	↓	6	159	12.6°	VFR	↓	↓	50
695	↓	6	↓	↓	↓	↓	↓	100
696	↓	5	↓	↓	↓	↓	↓	500
697	↓	7	↓	↓	↓	↓	↓	50
698	↓	7	159	↓	↓	↓	Engine	50
848	↓	3	145	↓	↓	↓	None	
849	↓	7	↓	↓	↓	↓	Engine	700
853	↓	3	↓	↓	↓	None	None	
854	A	7	↓	↓	↓	CW=45	Engine	700
874	C	4	↓	↓	↓	None	↓	50
875	↓	4	↓	↓	↓	None	Engine	100
876	↓	4	↓	↓	↓	CT=1.75	None	
877	↓	4	↓	↓	↓	CT=1.75	Engine	100
878	C	3	↓	↓	↓	None	↓	500
901	B	4	↓	↓	↓	None	↓	50
902	↓	4	↓	↓	↓	↓	↓	100
903	↓	↓	↓	↓	↓	CT=1.75	↓	500
905	↓	4	145	12.6°	↓	None	Engine	50
1034	↓	2	120	9.4°	↓	None	None	
1056	↓	3	120	↓	↓	None	None	
1057	B	4	120	9.4°	VFR	CT=1.75	None	

TABLE II-VII

PARAMETER VARIATION PILOT OPINION DATA

CT = continuous turbulence PM = pitch maneuver
GM = gross maneuver CW = cross wind

RUN NO.	COEFF VARIED	MAG OF VARIA.	DOF	AUG LEVEL	EXT. DIST.	MANEUVER	PILOT B RATING	PILOT D RATING
914	Baseline		6	PRY	None	GM	5	
915	Baseline		6	PRY	None	GM	3	
916	Baseline		6	None	None	GM	9	
921	Baseline		6	None	CW	Landing	10	
941	Baseline		6	PRY	CW	Landing	5	
956	$N_{\delta r}$	1.5X	6	PRY	CW	Landing	3	
957	$N_{\delta r}$	1.5X	6	None	CW	Landing	10	
966	$N_{\delta r}$	0.75X	6	PRY	CW	Landing	9	
973	Baseline		6	PRY	CW	Landing		7
978	Baseline		6	None	CW	Landing		10
993	$N_{\delta r}$	1.5X	6	None	CW	Landing		10
994	$N_{\delta r}$	1.5X	6	None	CW	Landing		10
995	$N_{\delta r}$	1.5X	6	PRY	CW	Landing		4
996	$N_{\delta r}$	0.75X	6	PRY	CW	Landing		10
997	Baseline		6	PRY	None	GM		5
998	Baseline		6	PRY	CT	GM		5
999	L_β	Zero	6	PRY	CT	GM		6
1001	L_β	-3X	6	PRY	CT	GM		10
1006	Baseline		3	PRY	None	GM	3	
1007	Baseline		3	None	None	GM	10	
1008	Baseline		3	None	CT	GM	10	
1009	Baseline		3	PRY	CT	GM	3	
1010	L_β	Zero	3	PRY	CT	GM	3	
1011	L_β	Zero	3	None	CT	GM	10	
1012	L_β	-2X	3	None	CT	GM	10	
1013	L_β	-2X	3	PRY	CT	GM	10	
1014a	L_β	2X	3	PRY	CT	GM	3	
1014b	L_β	2X	3	None	CT	GM	6	
1015	L_β	5X	3	None	CT	GM	10	
1017	L_β	5X	3	PRY	CT	GM	4	
1018a	L_p	0.2X	3	PRY	CT	GM	4	
1018b	L_p	0.2X	3	None	CT	GM	10	
1019a	L_p	5X	3	None	CT	GM	5	
1019b	L_p	5X	3	PRY	CT	GM	3	
1020a	Y_β	0.2X	3	PRY	CT	GM	4	
1020b	Y_β	0.2X	3	None	CT	GM	8	
1021a	Y_β	5X	3	None	CT	GM	4	
1021b	Y_β	5X	3	PRY	CT	GM	2	

TABLE II-VII - Continued

PARAMETER VARIATION PILOT OPINION DATA

RUN NO.	COEFF VARIED	MAG OF VARIA.	DOF	AUG LEVEL	EXT. DIST.	MANEUVER	PILOT B RATING	PILOT D RATING
1022a	Y_β	7X	3	PRY	CT	GM	1	
1022b	Y_β	7X	3	None	CT	GM	3	
1023a	Y_r	5X	3	None	CT	GM	4	
1023b	Y_r	5X	3	PRY	CT	GM	3	
1025a	Y_r	0.2X	3	PRY	CT	GM	1	
1025b	Y_r	0.2X	3	None	CT	GM	5	
1026a	N_β	5X	3	None	CT	GM	8	
1026b	N_β	5X	3	PRY	CT	GM	4	
1027a	N_β	Zero	3	PRY	CT	GM	3	
1027b	N_β	Zero	3	None	CT	GM	9	
1028a	N_p	5X	3	None	CT	GM	10	
1028b	N_p	5X	3	PRY	CT	GM	3	
1029	N_p	-5X	3	PRY	CT	GM	4	
1030a	$N_{\delta a}$	5X	3	PRY	CT	GM	3	
1030b	$N_{\delta a}$	5X	3	None	CT	GM	5	
1031a	$N_{\delta a}$	-3X	3	None	CT	GM	3	
1031b	$N_{\delta a}$	-3X	3	PRY	CT	GM	2	
1032	Baseline		3	None	CT	GM	9	
1034	Baseline		6	PRY	None	PM	2	
1035	Baseline		6	None	None	PM	6	
1036	Baseline		6	None	CT	PM	8	
1037	Baseline		6	PRY	CT	PM	2	
1038	$M_{\dot\alpha}$	5X	6	PRY	CT	PM	2	
1039	$M_{\dot\alpha}$	5X	6	None	CT	PM	3	
1040	$M_{\dot\alpha}$	-5X	6	None	CT	PM	10	
1041	$M_{\dot\alpha}$	-5X	6	PRY	CT	PM	4	
1042	$M_{\dot\alpha}$	-1X	6	PRY	CT	PM	2	
1043	$M_{\dot\alpha}$	-1X	6	None	CT	PM	4	
1044	M_q	10X	6	None	CT	PM	4	
1045	M_q	10X	6	PRY	CT	PM	4	
1046	M_q	Zero	6	PRY	CT	PM	3	
1047	M_q	Zero	6	None	CT	PM	6	
1048	$M_{\delta e}$	2X	6	None	CT	PM	5	
1049	$M_{\delta e}$	2X	6	PRY	CT	PM	3	
1053	X_v	2X	6	None	CT	PM	5	
1054	X_v	2X	6	PRY	CT	PM	3	
1055	Baseline		6	None	None	PM		7
1056	Baseline		6	PRY	None	PM		3
1057	Baseline		6	PRY	CT	PM		4
1059	Baseline		6	None	CT	PM		8

TABLE II-VII - Concluded

PARAMETER VARIATION PILOT OPINION DATA

RUN NO.	COEFF VARIED	MAG OF VARIA.	DOF	AUG LEVEL	EXT. DIST.	MANEUVER	PILOT B RATING	PILOT D RATING
1061	$M_{\dot{\alpha}}$	5X	6	None	CT	PM		5
1062	$M_{\dot{\alpha}}$	5X	6	PRY	CT	PM		4
1063	$M_{\dot{\alpha}}$	-1X	6	PRY	CT	PM		3
1064	$M_{\dot{\alpha}}$	-1X	6	None	CT	PM		4
1065	$M_{\dot{\alpha}}$	-5X	6	None	CT	PM		10
1069	$M_{\dot{\alpha}}$	-5X	6	PRY	CT	PM		5
1070	M_q	10X	6	PRY	CT	PM		3
1071	M_q	10X	6	None	CT	PM		4
1072	M_q	Zero	6	None	CT	PM		10
1073	M_q	Zero	6	PRY	CT	PM		4
1074	$M_{\delta e}$	2X	6	PRY	CT	PM		3
1075	$M_{\delta e}$	2X	6	None	CT	PM		6
1080	X_v	2.2X	6	PRY	CT	PM		2
1081	X_v	2.2X	6	None	CT	PM		3
1086	Baseline		3	PRY	CT	GM		4
1087	Baseline		3	None	CT	GM		6
1088	L_p	5X	3	None	CT	GM		3
1089	L_p	5X	3	PRY	CT	GM		2-1/2
1090	L_p	0.2X	3	PRY	CT	GM		5
1091	L_p	0.2X	3	None	CT	GM		10
1093	Y_β	7X	3	None	CT	GM		5
1094	Y_β	7X	3	PRY	CT	GM		4
1095	Y_β	0.2X	3	PRY	CT	GM		6
1096	Y_β	0.2X	3	None	CT	GM		6-1/2

APPENDIX III

MST STOL EVALUATION - PILOT EXPERIENCE

Following are the background experiences of the test pilots for the MST evaluation. It is believed that the experience level of these pilots is a representative cross section of typical pilot experience backgrounds which might be found in any STOL flight test program.

R. L. GORHAM - NORTH AMERICAN ROCKWELL ENGINEERING TEST PILOT

Mr. Gorham was trained in small Bell Helicopters in 1966 and has flown small helicopters continuously since that time. He has performed several test programs with experimental configurations in the Bell Jet Ranger (206A) in 1969 and 1970.

He has maintained proficiency for the last two and one-half years by flying the North American Helicopter executive passenger routes in relief of regularly assigned pilots.

His total helicopter time is approximately 575 hours and his total time as a pilot in all aircraft is 8,592 hours.

W. J. GEIGER - NORTH AMERICAN ROCKWELL ENGINEERING TEST PILOT

Mr. Geiger was a graduate of the U. S. Naval Test Pilot School in 1960. He was the F-4 A/B Project Officer at the Naval Air Test Center from the years 1960 to 1963. His experience in the F-4, which has blown leading and trailing edge flaps, include carrier landings and takeoffs (catapult).

OtherV/STOL aircraft experience which he possesses include the OV-10A (1969 to 1970), the CH-46 (1971), and the AH-1G (1971-1972).

MAJOR MIKE CLARKE - UNITED STATES AIR FORCE

Major Clarke is a graduate of the U. S. Air Force R&D Test Pilot School. He is presently a member of the STOL, V/STOL Evaluation Test Pilot's Program at Edwards Air Force Base.

His related STOL flight experience includes the UC-123 (transport), the DH-58 and UH-1B. D, H (helicopters), and the AV-238 (Pilatus Porter Utility STOL).

His total helicopter time is 703 hours and his total time as a pilot in all aircraft consists of 3,800 hours.

MAJOR RICHARD VOEHL - UNITED STATES AIR FORCE

Major Voehl is a graduate of the U. S. Air Force R&D Test Pilot School at Edwards Air Force Base. He is presently a member of the STOL, V/STOL Evaluation Test Pilot's Program at Edwards Air Force Base.

He has served as a test pilot at Eglin AFB, Florida, Tyndall AFB, Florida. He has a total of 8 years in testing experience.

He has also served as a helicopter pilot instructor at the Aerospace Research Pilot School and has 50 hours of flight experience in U2 aircraft.

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13. ABSTRACT

The basic objective of the work reported herein was to provide a broader technology base to support the development of a medium STOL Transport (MST) airplane. This work was limited to the application of the externally blown flap (EBF) powered lift concept.

The technology of EBF STOL aircraft has been investigated through analytical studies, wind tunnel testing, flight simulator testing, and design trade studies. The results obtained include development of methods,for the estimation of the aerodynamic characteristics of an EBF configuration, STOL performance estimation methods, safety margins for takeoff and landing, wind tunnel investigation of the effects of varying EBF system geometry parameters, configuration definition to meet MST requirements, trade data on performance and configuration requirement variations, flight control system mechanization trade data, handling qualities characteristics; piloting procedures, and effects of applying an air cushion landing system to the MST.

From an overall assessment of study results, it is concluded that the EBF concept provides a practical means of obtaining STOL performance for an MST with relatively low risk.

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