DIRECT SIDE FORCE CONTROL (DSFC) FOR STOL CROSSWIND LANDINGS

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FOREWORD

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ABSTRACT

The application of Direct Side Force Control (DSFC) during crosswind landings of an airplane having the characteristics of a Class II STOL was investigated in the USAF Total In-Flight Simulator (TIFS) airplane. The primary purpose was to evaluate the usefulness of DSFC during the crosswind landing. Other objectives were to investigate the type of cockpit controller or mechanization scheme for use with DSFC, and to define parameters which affect pilot workload during crosswind landings with DSFC. Landing approaches to simulated touchdown were flown both without and with DSFC. The approach speed was 130 knots. Two modes of DSFC control were investigated, an independent manual control of DSFC through a cockpit mounted thumbwheel proportional controller, and an automatic scheme which tracked the ILS localizer signal. Evaluations were performed for three values of the bank angle per unit crosswind, ϕ / v_{cw}, required for conventional sideslipping, crosswind landings, and for two values of each of the derivatives L_β and N_β.

Fifty-four evaluations were accomplished; twenty-one with no DSFC, twenty with manual DSFC, and thirteen with automatic DSFC. With the exception of three cases there was always an improvement in pilot rating with manual DSFC as opposed to no DSFC. The automatic DSFC resulted in a pilot rating improvement in nine of the thirteen cases evaluated. The greatest improvement in pilot rating occurred for those configurations which had the least desirable handling qualities when evaluated without DSFC. The pilots' main objections when performing crosswind landings without DSFC centered around large control forces. The objections were alleviated with DSFC. The capability to land, wings level, in a 15 knot crosswind was demonstrated. The ability to make a crosswind correction with DSFC and land the airplane with a small or zero bank angle was considered a significant improvement over having to hold a steady bank angle and sideslip with aileron and rudder. The automatic DSFC system relieved the pilot of all lateral-directional control tasks, but was found somewhat objectionable because of DSFC induced lateral accelerations while tracking the VHF ILS localizer and frequently unsatisfactory runway alignment error at touchdown. In view of its potential, further development of the automatic DSFC would seem warranted. It was concluded that DSFC significantly improved the pilot's ability to perform the crosswind landing.

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b	Reference span of wing, ft
$\bar{c}$	Mean aerodynamic chord, ft
C_D	Drag coefficient, $= D/\bar{q}S$
C_{D_0}	Drag coefficient at zero lift
C_ℓ	Rolling moment coefficient, $= L/\bar{q}Sb$
C_{ℓ_p}	$= \partial C_\ell / \partial\left(\frac{pb}{2V}\right)$, rad^{-1}
C_{ℓ_r}	$= \partial C_\ell / \partial\left(\frac{rb}{2V}\right)$, rad^{-1}
C_{ℓ_β}	$= \partial C_\ell / \partial\beta$, rad^{-1}
$C_{\ell_{\delta_a}}$	$= \partial C_\ell / \partial\delta_a$, rad^{-1}
$C_{\ell_{\delta_y}}$	$= \partial C_\ell / \partial\delta_y$, rad^{-1}
$C_{\ell_{\delta_r}}$	$= \partial C_\ell / \partial\delta_r$, rad^{-1}
C_L	Lift coefficient, $= L/\bar{q}S$
$C_L\rvert_{\alpha=0}$	Lift coefficient at zero angle of attack
C_{L_q}	$= \partial C_L / \partial\left(\frac{q\bar{c}}{2V}\right)$, rad^{-1}
C_{L_α}	$= \partial C_L / \partial\alpha$, rad^{-1}
$C_{L_{\dot\alpha}}$	$= \partial C_L / \partial\left(\frac{\dot\alpha\bar{c}}{2V}\right)$, rad^{-1}
$C_{L_{\delta_e}}$	$= \partial C_L / \partial\delta_e$, rad^{-1}
C_m	Pitching moment coefficient, $= M/\bar{q}S\bar{c}$
$C_m\rvert_{\alpha=0}$	Pitching moment coefficient at zero angle of attack
C_{m_q}	$= \partial C_m / \left(\frac{q\bar{c}}{2V}\right)$, rad^{-1}
C_{m_α}	$= \partial C_m / \partial\alpha$, rad^{-1}
$C_{m_{\dot\alpha}}$	$= \partial C_m / \partial\left(\frac{\dot\alpha\bar{c}}{2V}\right)$, rad^{-1}
$C_{m_{\delta_e}}$	$= \partial C_m / \partial\delta_e$, rad^{-1}

C_n Yawing moment coefficient, $= N/\bar{q}Sb$

C_{n_p} $= \partial C_n / \partial\left(\frac{pb}{2V}\right)$, rad^{-1}

C_{n_r} $= \partial C_n / \partial\left(\frac{rb}{2V}\right)$, rad^{-1}

C_{n_β} $= \partial C_n / \partial \beta$, rad^{-1}

$C_{n_{\delta_a}}$ $= \partial C_n / \partial \delta_a$, rad^{-1}

$C_{n_{\delta_r}}$ $= \partial C_n / \partial \delta_r$, rad^{-1}

$C_{n_{\delta_y}}$ $= \partial C_n / \partial \delta_y$, rad^{-1}

C_y = Lateral force coefficient, $= Y/\bar{q}S$

C_{y_β} $= \partial C_y / \partial \beta$, rad^{-1}

$C_{y_{\delta_a}}$ $= \partial C_y / \partial \delta_a$, rad^{-1}

$C_{y_{\delta_y}}$ $= \partial C_y / \partial \delta_y$, rad^{-1}

$C_{y_{\delta_r}}$ $= \partial C_y / \partial \delta_r$, rad^{-1}

C_z z - force coefficient, $= Z/\bar{q}S$

D Drag, positive along negative x wind axis, lb

F Force , lb

F_{AW} Aileron wheel force, lb

F_{EW} Elevator wheel force, lb

F_{RP} Rudder pedal force, lb

g Gravitational constant, 32.17, ft/sec^2

h_e Model wheel height , ft

h Absolute altitude, ft

i_T Thrust incidence angle, rad or deg

I_{xx}, I_{yy}, I_{zz} Moments of inertia about x, y, z body axes, respectively, slug-ft^2

I_{xz} Product of inertia about x, z body axes, slug-ft^2

l_x Distance from the c.g. to a point on the x body axis, positive along positive x axis, ft

l_z Distance from the c.g. to a point on the z body axis, positive along positive z axis, ft

L Lift, positive along negative z wind axis, lb

L Rolling moment about x body axis, ft

$L_\beta = \frac{1}{I_{xx}} \frac{\partial L}{\partial \beta}$, sec^{-2} rad^{-1}

$L_{\delta_a} = \frac{1}{I_{xx}} \frac{\partial L}{\partial \delta_a}$, sec^{-2} rad^{-1}

$L_{\delta_y} = \frac{1}{I_{xx}} \frac{\partial L}{\partial \delta_y}$, sec^{-2} rad^{-1}

$L_p = \frac{1}{I_{xx}} \frac{\partial L}{\partial p}$, sec^{-1} rad^{-1}

$L_r = \frac{1}{I_{xx}} \frac{\partial L}{\partial r}$, sec^{-1} rad^{-1}

m Mass of aircraft, slugs

M Pitching moment about y body axis, ft-lb

n_x Longitudinal acceleration, g units

n_y Lateral acceleration, g units

n_z Normal acceleration, g units

N Yawing moment about z body axis, ft-lb

$N_\beta = \frac{1}{I_{zz}} \frac{\partial N}{\partial \beta}$, sec^{-2} rad^{-1}

$N_{\delta_a} = \frac{1}{I_{zz}} \frac{\partial N}{\partial \delta_a}$, sec^{-2} rad^{-1}

$N_{\delta_y} = \frac{1}{I_{zz}} \frac{\partial N}{\partial \delta_y}$, sec^{-2} rad^{-1}

$N_{\delta_r} = \frac{1}{I_{zz}} \frac{\partial N}{\partial \delta_r}$, sec^{-2} rad^{-1}

$N_p = \frac{1}{I_{33}} \frac{\partial N}{\partial p}$, sec^{-1} rad^{-1}

$N_r = \frac{1}{I_{33}} \frac{\partial N}{\partial r}$, sec^{-1} rad^{-1}

p Roll rate, rad/sec or deg/sec

$\dot{p}$ Roll acceleration, rad/sec^2 or deg/sec^2

q Pitch rate, rad/sec or deg/sec

$\bar{q}$ Dynamic pressure, $= 1/2 \rho V^2$, lb/ft^2

r Yaw rate, rad/sec or deg/sec

S Reference area of wing, ft^2

t Time, seconds

T Total thrust of aircraft, lb

u True airspeed component along the x body axis, ft/sec

u_g Gust airspeed component along the x body axis, ft/sec

u_I Inertial velocity component along the x body axis, ft/sec

v True airspeed component along the y body axis, ft/sec

v_g Gust airspeed component along the y body axis, ft/sec

v_I Inertial velocity component along the y body axis, ft/sec

v_{cw} Crosswind component, knots or ft/sec

V True airspeed of the c.g. of the aircraft, ft/sec

V_I Inertial velocity component along the body axis, ft/sec

W Aircraft weight, lb

w True airspeed component along the z body axis, ft/sec

w_g Gust airspeed component along the z body axis, ft/sec

w_I Inertial velocity component along the z body axis, ft/sec

x, y, z Body axes, x-z plane is in the plane of symmetry of the airplane with x directed forward parallel to the fuselage reference line, z directed downward, and y directed out the right wing.

X, Y, Z Component of aerodynamic forces along the x, y and z body axes, respectively, lb

$Y_\beta = \frac{1}{mV} \frac{\partial Y}{\partial \beta}$, sec^{-1} rad^{-1}

$Y_{\delta_a} = \frac{1}{mV} \frac{\partial Y}{\partial \delta_a}$, sec^{-1} rad^{-1}

$Y_{\delta_r} = \frac{1}{mV} \frac{\partial Y}{\partial \delta_r}$, sec^{-1} rad^{-1}

$Y_{\delta_y} = \frac{1}{mV} \frac{\partial Y}{\partial \delta_y}$, sec^{-1} rad^{-1}

$Y_p = \frac{1}{mV} \frac{\partial Y}{\partial p}$, rad^{-1}

$Y_r = \frac{1}{mV} \frac{\partial Y}{\partial r}$, rad^{-1}

z_T Thrust pitching moment arm component (positive along $+z$ body axis measured relative to the c.g.), ft

α Total angle of attack, with respect to true airspeed, rad or deg

α_I Inertial angle of attack referenced to inertial velocity vector, rad or deg

β Total angle of sideslip with respect to true airspeed, rad or deg

$\dot{\beta}$ Sideslip rate, rad/sec or deg/sec

β_I Inertial angle of sideslip, referenced to inertial velocity vector, rad or deg

γ Flight path angle, rad or deg

δ_a Total aileron deflection, positive right T.E. down, rad or deg

δ_{AW} Aileron wheel deflection, positive wheel clockwise, in

δ_e Elevator deflection, positive T.E. down, rad or deg

δ_{EW} Elevator wheel deflection, positive wheel aft, rad or deg

δ_r Rudder deflection, positive T.E. left, deg

δ_{RP} Rudder pedal deflection, positive right rudder pedal down, in

δ_y Side force generator deflection, positive when positive sideslip produced, rad or deg

δ_T Throttle displacement in cockpit, positive forward, rad or deg

Δ Incremental value

ε Error

ζ_d Damping ratio of the Dutch roll mode

ζ_{FS} Damping ratio of the feel system

ζ_{ph} Damping ratio of the phugoid mode

ζ_{sp} Damping ratio of the longitudinal short period mode

θ Pitch angle, rad or deg

ρ Air density, slugs/ft^3

σ Root-mean square value

τ_R Roll mode time constant, sec

τ_S Spiral mode time constant, sec

ϕ Bank angle, rad or deg

ϕ/v_{cw} Bank angle per unit crosswind component, deg/ft/sec

$|\phi/\beta|_d$ At any instant, the ratio of amplitudes of the bank-angle and sideslip-angle envelopes in the Dutch roll mode

ψ Yaw angle, rad or deg

ω_d Undamped natural frequency of the Dutch roll mode, rad/sec

ω_{ph} Undamped natural frequency of the phugoid mode, rad/sec

ω_{sp} Undamped natural frequency of the short period mode, rad/sec

ω_{FS} Undamped natural frequency of the feel system, rad/sec

Subscripts

A,aero - Aerodynamic

B - Body axis

c - Command

c.g.	-	Center of gravity
cw	-	Crosswind
d	-	Dutch roll
g	-	Gust
I	-	Inertial
m	-	Model
NT	-	Not trimmed
P	-	Pilot's location
ph	-	Phugoid
S	-	Stability axis
SP	-	Short period
t	-	Trim
T	-	Thrust
TCG	-	At the TIFS center of gravity
unt	-	Untrimmed

Abbreviations

deg	-	Degrees
ft	-	Feet
IAS	-	Indicated Airspeed
ILS	-	Instrument Landing System
kts	-	Knots
lb	-	Pounds
PR	-	Pilot rating
rad	-	Radians
sec	-	Seconds

TR	-	Turbulence Effect Rating
VFR	-	Visual Flight Rules
VHF	-	Very High Frequency

Superscripts

L	-	Left
R	-	Right

Section I

INTRODUCTION

Direct Side Force Control (DSFC), used as an additional maneuvering control, or as a trim control, may have the potential of reducing pilot workload and improving task performance. One potential application for DSFC is the crosswind landing task.

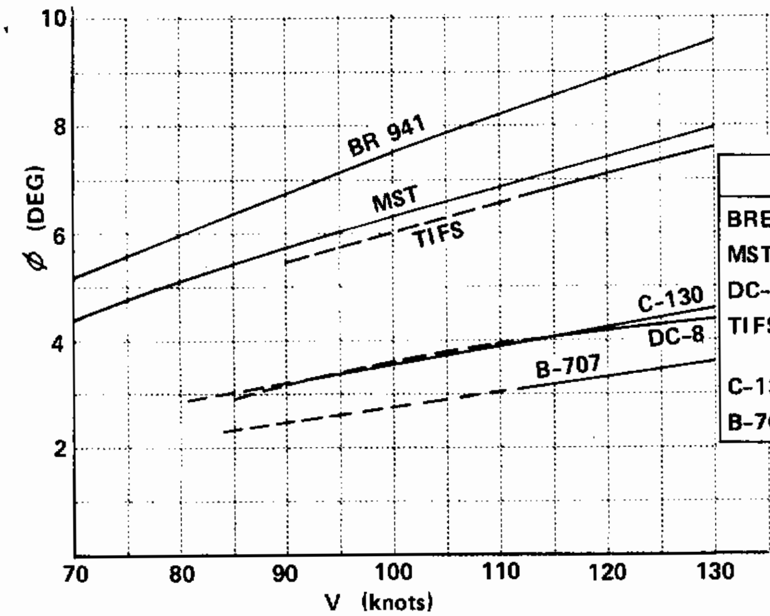
In flight a pilot must adjust the heading of the airplane to arrive over a specified point on the surface of the earth. While in the air, a crab angle, which is defined as the angular difference between the airplane's heading and its track over the ground, does not cause any problems so long as it is recognized. The crab angle is necessary in order for a component of the airplane's velocity to balance the effects of a wind component normal to the ground track. After the airplane touches down on the runway, however, the pilot must make the heading coincide with a ground track along the runway for the airplane to roll to a stop within the confinement of the runway. Hence, during the landing and landing roll the crab angle must be eliminated unless the airplane is equipped with a pivoting crosswind landing gear. Therefore, for the landing flare and touchdown the pilot must precisely control the ground track and heading while overcoming the lateral velocity or drift due to the crosswind. This lateral-directional task must be performed while the pilot is also concerned with precise height, airspeed and pitch attitude control during the flare maneuver. A turbulence environment further complicates the problem since it may prevent the airplane from reaching a desired steady state condition just prior to, and at touchdown.

Generally, the pilot has two methods available for coping with a crosswind: 1) the crabbed approach and 2) the sideslipping approach. During the crabbed approach, the airplane is headed toward the upwind side of the runway with no sideslip and with the wings level. Using this method the crab angle must be removed just prior to touchdown. If the crab angle is removed too early the airplane will drift, with the crosswind, across the runway. If the crab angle is not removed before touchdown, the landing gear will be subjected to side loading. In the sideslipping approach, the airplane heading is parallel to the runway direction and the airplane is landed with enough sideslip to balance the sidewise drift that would result from the crosswind. The side force required to produce the necessary sideslip is developed through a steady bank angle. Hence, the airplane is landed with a wing down. The objective of both methods is to maintain the ground track of the airplane coincident with the runway and to touch down with a zero lateral velocity relative to the runway. Pilots of conventional airplanes have adopted a combination of the two techniques. A crabbed approach is used until the aircraft is on a short final approach, at which time the nose is rotated to align the aircraft with the runway and the aircraft is landed wing down with a steady sideslip into the wind.

It is, of course, preferable to remove all the crab angle and land with pure sideslip, but a combination of crab angle and sideslip requiring some "decrab" before touchdown may also be used. This type of crosswind landing approach has worked well for conventional aircraft since landing approach speeds are high relative to crosswind component speeds and a choice of runway may be available so that the crosswind component can be minimized. In the operation of STOL aircraft the landing approach speeds are low relative to wind speeds. Hence, for a given crosswind component the STOL may have to develop nearly twice the sideslip that a CTOL would require in making a crosswind landing. The sideslip required is $\beta = \sin^{-1} v_{cw} / V_0$: where v_{cw} is the crosswind component and V_0 is the final approach airspeed.

The magnitude of bank angle required during a crosswind landing may become an important factor to the pilot both from the standpoint of precision of aircraft control and because of ground clearance. To maintain a steady sideslip and bank angle the pilot must hold steady, and perhaps large, aileron and rudder forces during the crosswind flare and touchdown. For a given value of the side force coefficient, C_{y_β}, the bank angle required to develop one degree of sideslip for STOL airplanes is generally smaller than that required for conventional airplanes at higher approach speeds. This can be seen from the simplified expression: $\phi = -C_{y_\beta} \beta \frac{\bar{q}}{W/S}$ where $\bar{q}$ is the dynamic pressure $= 1/2 \rho V_0^2$. However, STOL aircraft typically have larger values of C_{y_β} than conventional airplanes and, as shown above, must land with higher sideslip angles than conventional airplanes. For a given crosswind, therefore, the bank angle necessary for a sideslipping crosswind landing in a STOL may be approximately the same as the bank angle required for conventional airplanes.

Furthermore, since the pilot of a STOL aircraft may not have a choice of runway so as to minimize the crosswind component, bank angles higher than those normally experienced in conventional airplane crosswind landings may be encountered. Figure 1 shows a comparison of the approximate bank angles required for various aircraft to land in a 15 knot crosswind.



BASED ON: $-C_{y_\beta} \beta \frac{q}{W/S} = \phi$

	W/S	C_{y_β} /deg
BREQUET 941	60	-.026
MST (TYPICAL)	80	-.03
DC-8	73	-.015
TIFS (SIDE FORCE SURFACE FIXED)	56	-.02
C-130	63	-.014
B-707	80	-.0139

Figure 1 COMPARISON OF BANK ANGLE REQUIRED FOR LANDING IN A 15 KNOT CROSSWIND FOR VARIOUS AIRPLANES

For the aircraft to have zero lateral velocity relative to the runway in a crosswind, some side force must be generated to overcome the side force due to crosswind. In a sideslipping approach the side force is largely developed through bank angle. However, if the pilot had direct control of side force, he may have the capability of handling light crosswinds with the wings level. For more severe crosswinds, DSFC may enable the pilot to reduce the magnitude of the bank angle required to balance the side force.

To investigate application of DSFC during the crosswind landing task, a flight test program was conducted in the USAF Total In-Flight Simulator (TIFS). Primary objectives of the program were to evaluate the usefulness of DSFC during crosswind landings, and to define parameters associated with the use of DSFC which would increase pilot performance or decrease pilot workload.

The TIFS was a practical flight test vehicle for this investigation since it incorporated side force control as part of its six-degree-of-freedom in-flight simulation capability. For this program, the characteristics of a "typical" Class II STOL airplane with DSFC were programmed on the TIFS model following computer. Two modes of side force control were provided: 1) Manual thumbwheel controllers mounted on the evaluation pilot's power lever and aileron wheel, and 2) an automatic side force control system activated by a switch mounted on the evaluation pilot's power lever. Vehicle parameters varied during the evaluations were L_β , N_β , and the bank angle per unit crosswind component ϕ / v_{cw} required for a conventional sideslipping crosswind landing.

The investigation was accomplished by having the evaluation pilots perform actual crosswind landings, first without and then with the aid of side force control. Turbulence inputs to the model following system were included on all evaluations. At the completion of each evaluation, pilot comments and an overall pilot rating were recorded. A separate turbulence effect rating was also obtained at the end of each evaluation.

This report describes the concept of side force control for crosswind landings, the experimental procedure used for evaluation, the flight tests and the results of the investigation.

Section II
TECHNICAL DISCUSSION

2.1 PURPOSE

The purpose of this program was to investigate through in-flight simulation the use of Direct Side Force Control (DSFC) during crosswind landings. This required that evaluations be made during landing approach, flare, and simulated touchdown with and without the aid of DSFC. Comparisons could then be made to determine the usefulness of DSFC during the crosswind landing task. The objective was to define vehicle characteristics and parameters associated with the use of DSFC which would increase pilot performance or decrease pilot workload during the crosswind landing task.

The above objective included:

(a) Definition of parameters which affect pilot workload during crosswind landings with DSFC.

(b) The effects of DSFC on roll control power required.

(c) Investigation of the type of cockpit controller or mechanization scheme for use with DSFC.

(d) The effect of vehicle characteristics on the usefulness of DSFC.

2.2 SCOPE OF THE INVESTIGATION

Potentially, there are numerous possibilities for the application of DSFC, including:

(a) Trimming to counter steady state side forces which are generated during a crosswind landing.

(b) Use of DSFC as an active device for maneuvering.

(c) Use of DSFC with feedback to augment the characteristics of the aircraft.

(d) Use of DSFC as a gust alleviation device by generating the required forces and moments to counteract gust induced forces and moments acting on the aircraft.

There was a very limited amount of data available on which to base the design of an experiment on the application of side force control. It was desirable to limit this investigation to a single task and a single application. The most straightforward use of DSFC was to use it to counter the side force due to a crosswind during landing approach. Even with this limitation of scope, the number of parameters which could be investigated in a single program also had to be limited. Thus, it was necessary to choose for investigation those parameters which were considered most important, and would have the greatest influence on the application of DSFC during the crosswind landing task. The following paragraphs discuss the relative import of certain parameters and present some rationale for the selection of parameters investigated in this program.

2.2.1 The Generation of Side Force

For the pilot to have direct control of side force, some mechanization for the side force generation must be incorporated in the airframe or engine design. Deflected thrust probably offers the most efficient means for generating side force. The side force generated would then be a function of the thrust and exhaust deflection angle.

Regardless of the side force generating mechanism, control derivatives and deflections for studies of DSFC can be defined. The symbol δ_y has been adopted as side force generator deflection. The sign of δ_y is the same as the accepted sign convention for rudder deflection, i.e., positive δ_y produces positive sideslip. The side force, rolling moment and yawing moment due to side force generator deflection are Y_{δ_y}, L_{δ_y} and N_{δ_y} respectively, or in nondimensional terms, $C_{y_{\delta_y}}$, $C_{\ell_{\delta_y}}$ and $C_{n_{\delta_y}}$.

2.2.2 Parameters Which Affect Side Force Generation During Crosswind Landings

The lateral-directional equations of motion referred to body axes and using the small angle assumption may be written as follows

$$\dot{\beta} + r - \alpha_o p - \frac{g}{V_0}\phi = Y_r r + Y_\beta \beta + Y_p p + Y_{\delta_a}\delta_a + Y_{\delta_r}\delta_r$$

$$\dot{p} - \dot{r}\frac{I_{xz}}{I_{xx}} = L_r r + L_\beta \beta + L_p p + L_{\delta_a}\delta_a + L_{\delta_r}\delta_r \qquad (1)$$

$$\dot{r} - \dot{p}\frac{I_{xz}}{I_{zz}} = N_\beta \beta + N_r r + N_p p + N_{\delta_r}\delta_r + N_{\delta_a}\delta_a$$

Since for crosswind landings, steady state sideslip and bank angle are of prime interest, and also for landing it is desirable to have $p = \dot{p} = r = \dot{r} = 0$ the equations may be reduced to the following steady state form

$$
\begin{aligned}
Y_{\delta_r}\delta_r + Y_{\delta_a}\delta_a + \frac{g}{V_0}\phi &= -Y_\beta\beta \\
L_{\delta_r}\delta_r + L_{\delta_a}\delta_a &= -L_\beta\beta \\
N_{\delta_r}\delta_r + N_{\delta_a}\delta_a &= -N_\beta\beta
\end{aligned}
\qquad (2)
$$

Assuming $Y_{\delta_a} = 0$ and solving for bank angle, ϕ , there results

$$
\phi = \beta\left[\frac{-Y_\beta\left(L_{\delta_r}N_{\delta_a} - N_{\delta_r}L_{\delta_a}\right) + Y_{\delta_r}\left(N_{\delta_a}L_\beta - L_{\delta_a}N_\beta\right)}{\frac{g}{V_0}\left(L_{\delta_r}N_{\delta_a} - N_{\delta_r}L_{\delta_a}\right)}\right] \qquad (3)
$$

For simplicity, if it is assumed that $N_{\delta_a} = 0$, then

$$
\phi = \beta\left[\frac{-Y_\beta + Y_{\delta_r}\frac{N_\beta}{N_{\delta_r}}}{\frac{g}{V_0}}\right] \qquad (4)
$$

Equation (4) shows that the bank angle necessary for a given sideslip, as in a crosswind landing, is primarily determined by the side force derivatives Y_β and Y_{δ_r} with the contribution of Y_{δ_r} being weighted by the ratio of the yawing moment due to sideslip derivative N_β and the rudder control derivative, N_{δ_r} . If N_β / N_{δ_r} is large, large rudder deflection will be required to prevent weathercocking. Since Y_β and N_{δ_r} are negative, less bank angle is required for a given value of β than would be the case for small values of N_β / N_{δ_r} . Large values of Y_{δ_r} also reduce the bank angle required. However, Y_{δ_r} , N_{δ_r} and N_β (tail contribution) are interrelated by airframe geometry, particularly vertical tail area, rudder area, and tail length. Vertical tail area is also a large contributing factor to Y_β . For small bank angles in crosswind landings, however, it would be desirable to have small Y_β and N_{δ_r} and large Y_{δ_r} and N_β . Unfortunately this combination of relative values of the above derivatives is not generally compatible. Of course, the speed V_0 is also a powerful factor in determining the steady state bank angle.

Equation (4) may be written in terms of a crosswind component v_{cw} through use of the expression $\beta = \frac{v_{cw}}{V_0}$ for small values of β. Then

$$\phi = \frac{v_{cw}}{g}\left[-Y_\beta + Y_{\delta_r}\frac{N_\beta}{N_{\delta_r}} \right] \qquad (5)$$

which directly relates bank angle and crosswind component, v_{cw}, or bank angle and side force.

To investigate how wing loading, $\frac{W}{S}$, affects the crosswind landing, it is useful to write Equation (3) using nondimensional derivatives

$$\phi = \beta \left[\frac{-C_{y_\beta}\left(C_{l_{\delta_r}} C_{n_{\delta_a}} - C_{n_{\delta_r}} C_{l_{\delta_a}}\right) + C_{y_{\delta_r}}\left(C_{n_a} C_{l_\beta} - C_{l_{\delta_a}} C_{n_\beta}\right)}{\left(\frac{1}{g}\right)\left(\frac{W}{S}\right)\left(C_{l_{\delta_r}} C_{n_{\delta_a}} - C_{n_{\delta_r}} C_{l_{\delta_a}}\right)} \right]$$

and in terms of crosswind component V_{cw}, this may be written

$$\phi = \frac{v_{cw}}{W/S}\left[\frac{-C_{y_\beta}\left(C_{l_{\delta_r}} C_{n_{\delta_a}} - C_{n_{\delta_r}} C_{l_{\delta_a}}\right) + C_{y_{\delta_r}}\left(C_{n_{\delta_a}} C_{l_\beta} - C_{l_{\delta_a}} C_{n_\beta}\right)}{\frac{V_0}{g}\left(C_{l_{\delta_r}} C_{n_{\delta_a}} - C_{n_{\delta_r}} C_{l_{\delta_a}}\right)} \right] \qquad (6)$$

It can be seen from Equation (6) that wing loading and bank angle are inversely proportional, hence high wing loading results in a reduced bank angle requirement for landing in a given crosswind. Equation (6) also shows that C_{l_β} affects the bank angle to some extent if the yawing moment due to aileron is non-zero.

Briefly summarizing the above, the parameters that determine the bank angle, and hence, the side force required to make a sideslipping crosswind approach are Y_β, Y_{δ_r}, N_β , N_{δ_r}, V_0 , and wing loading, W/S.

If a direct side force generating mechanism is used on the airplane, then several options are available for reducing the bank angle in a crosswind landing. The addition of side force as a function of bank angle, Y_ϕ, would have the same effect on bank angle required during a sideslip, as would increased wing loading. However, to maintain $\phi = 0$, it is necessary to provide independent direct side force of a magnitude which is equal to the bracketed numerator of Equation (6). If side force were introduced as a function of bank angle then Equation (6) would become

$$\phi = \left[\frac{v_{cw}}{C_{y_\phi} + \frac{W}{\bar{q}S}}\right] \left[\frac{-C_{y_\beta}\left(C_{l_{\delta_r}} C_{n_{\delta_a}} - C_{n_{\delta_r}} C_{l_{\delta_a}}\right) + C_{y_{\delta_r}}\left(C_{n_{\delta_a}} C_{l_\beta} - C_{l_{\delta_a}} C_{n_\beta}\right)}{V_0\left(C_{l_{\delta_r}} C_{n_{\delta_a}} - C_{n_{\delta_r}} C_{l_{\delta_a}}\right)}\right] \quad (7)$$

This arrangement obviously would not allow a crosswind landing to be made with zero bank angle. Therefore it appears that it would be desirable to have a direct and independent control of side force. Since it is desired to have $\phi = 0$, Equation (2) can be written with the introduction of a third controller for side force as follows

$$\begin{aligned} Y_{\delta_r}\delta_r + Y_{\delta_a}\delta_a + Y_{\delta_y}\delta_y &= -Y_\beta\beta \\ L_{\delta_r}\delta_r + L_{\delta_a}\delta_a + L_{\delta_y}\delta_y &= -L_\beta\beta \\ N_{\delta_r}\delta_r + N_{\delta_a}\delta_a + N_{\delta_y}\delta_y &= -N_\beta\beta \end{aligned} \quad (8)$$

If it is assumed that $Y_{\delta_a} = 0$ and for simplicity that $L_{\delta_y} = N_{\delta_y} = 0$, then, from Equation (8), the side force required to produce a wings level sideslip is

$$Y_{\delta_y}\delta_y = \beta\left[\frac{-Y_\beta\left(L_{\delta_r} N_{\delta_a} - N_{\delta_r} L_{\delta_a}\right) + Y_{\delta_r}\left(N_{\delta_a} L_\beta - L_{\delta_a} N_\beta\right)}{L_{\delta_r} N_{\delta_a} - N_{\delta_r} L_{\delta_a}}\right] \quad (9)$$

Again if, $N_{\delta_a} = 0$ then

$$Y_{\delta_y}\delta_y = \beta\left[-Y_\beta + Y_{\delta_r}\frac{N_\beta}{N_{\delta_r}}\right] \quad (10)$$

The right side of Equation (10) is identical to the numerator of the right side of Equation(4), therefore, the side force control power ($Y_{\delta_y} \delta_y$) necessary for a wings level crosswind landing with $Y_{\delta_a} = L_{\delta_a} = N_{\delta_y} = 0$ is simply

$$Y_{\delta_y} \delta_y = \frac{g}{V_0} \phi \tag{11}$$

where ϕ is the bank angle that would be necessary in a conventional, sideslipping crosswind landing. Hence, the parameters which determine the necessary side force using independent side force control are Y_β , Y_{δ_r}, N_β and N_{δ_r} .

Equation (11) defines the side force necessary for a wings level crosswind landing. However, since N_β and L_β are not zero, yawing and rolling moments will be introduced when sideslip occurs. If pure independent side force is generated, then the pilot must counter the resulting rolling and yawing moments using aileron and rudder respectively, just as he would have to in a conventional crosswind landing.

Equation (10) implies that part of the side force is obtained by rudder deflection, but the contribution due to rudder deflection is the same for conventional wing down sideslipping approaches or wings level crosswind approaches with independent side force control, as can be seen by comparing Equations (4) and (10).

2.2.3 Lateral-Directional Dynamics and Crosswind Landings

Reference 1 has shown that the lateral-directional dynamics of the airplane significantly influence the pilot's ability to handle a crosswind landing approach. The parameters which had the major influence on the crosswind landing were the Dutch roll damping ratio, ζ_d, the magnitude of the roll-to-sideslip ratio, $\left|\frac{\phi}{\beta}\right|_d$, and the roll mode time constant, τ_R . Low Dutch roll damping ratio ($\zeta_d \approx 0.03$) did not present a serious problem at a Dutch-roll frequency of $\omega_d \approx 2.0$ rad/sec but became a major problem at $\omega_d \approx 1.0$ rad/sec. The continuous nose oscillations resulting from the low damping ratio coupled with the slow directional response caused a tendency to overcontrol directionally in a sideslipping crosswind landing approach or to set up directional oscillations during a decrab maneuver. High roll-to-sideslip ratio ($\left|\frac{\phi}{\beta}\right| \approx 3.0$) led to high aileron forces in the wing-down approach and a reluctance on the part of the pilot to decrab after flying a crabbed final approach because of rapid and large roll response to rudder inputs. Roll mode time constants as long as one second did not adversely affect the pilot's control in a crosswind.

Hence, in a study of crosswind landings, the effects of lateral-directional dynamics must be considered. Further, the effects of DSFC on the airplane's lateral-directional handling qualities in the landing approach should be investigated.

2.2.4 The Pilot's Workload With DSFC

Since one of the objectives of DSFC is to reduce the pilot's workload, some provision must be made to relieve the pilot of the aileron and rudder usage workload that he normally copes with on a conventional crosswind landing. In conventional crosswind landings, the pilot develops side force through bank angle and from the force resulting from the rudder deflection required to maintain proper aircraft heading. Because of the steady-state sideslip and positive effective dihedral (L_β negative), he must maintain steady-state aileron forces to prevent the airplane from rolling out of the wing-low attitude. Steady rudder forces are, of course, required to prevent the airplane, with positive directional stability, from weathercocking into the resultant relative wind. Side force at the vertical tail is a by-product of maintaining the proper heading with the rudder. Superimposed on the steady aileron and rudder forces the pilot must make continuous transient aileron and rudder inputs, especially near the ground, to counter turbulence upsets and wind shear which excite the lateral-directional dynamic modes of motion. If the pilot has a separate controller for pure independent side force control, then he must still counter the rolling and yawing due to sideslip in a conventional way by holding steady aileron and rudder forces. Hence, rather than reduce workload, this approach to side force control may simply introduce the pilot to an additional control from which he may derive little benefit and it may, as a result, even increase his workload. The aileron and rudder deflection for a steady state sideslip without and with pure independent sideforce control can be determined from Equations (2) and (9), respectively. Both these sets of equations yield upon solution for δ_a ,

$$\delta_a = \frac{v_{cw}}{V_0}\left[\frac{N_{\delta_r} L_\beta - L_{\delta_r} N_\beta}{L_{\delta_r} N_{\delta_a} - N_{\delta_r} L_{\delta_a}}\right] \tag{12}$$

and likewise for δ_r,

$$\delta_r = \frac{v_{cw}}{V_0}\left[\frac{L_{\delta_a} N_\beta - L_\beta N_{\delta_a}}{L_{\delta_r} N_{\delta_a} - L_{\delta_a} N_{\delta_r}}\right] \tag{13}$$

When Equations (12) and (13) are multiplied through by the respective control derivatives, L_{δ_a} and N_{δ_r}, they are a measure of the steady state control powers required to perform the steady sideslip either with bank angle or with side force control.

To relieve the pilot's workload it would seem reasonable to interconnect the aileron and the rudder with the DSFC so that when side force inputs are made the airplane has zero steady-state bank angle and no tendency to weathercock or roll after the steady-state sideslip is established. The interconnects, $\frac{\delta_a}{\delta_y}$ and $\frac{\delta_r}{\delta_y}$, may be determined from Equation (8). With aileron to side force and rudder to side force interconnects the pilot would have to contend with transients (the nature of which depend on lateral-directional dynamics) due to turbulence, wind shear, and control inputs; but would not have to maintain steady-state aileron and rudder forces during a crosswind landing. Therefore, his workload should be reduced which should improve pilot performance during the demanding crosswind landing task. Proper compensation for the aileron and rudder signals which result from the interconnects with DSFC commands may be necessary to minimize excitation of the lateral-directional modes of motion when the pilot makes DSFC inputs.

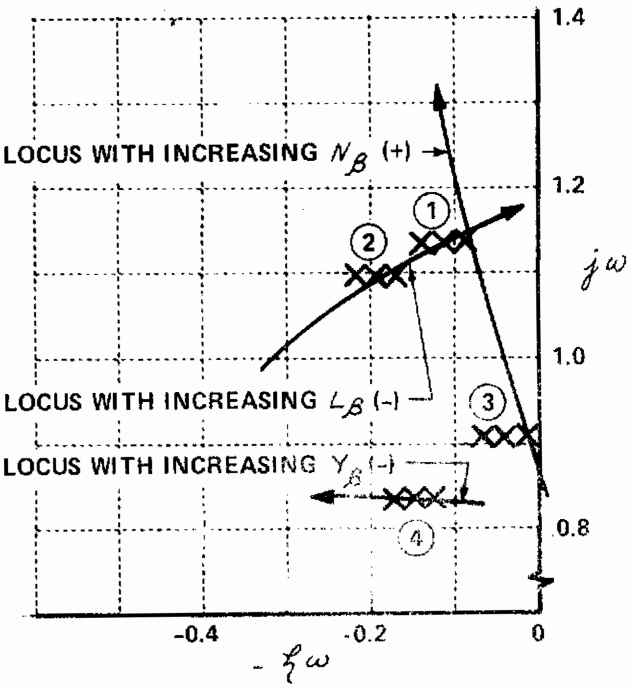
2.2.5 Parameters Chosen For Investigation

It has been shown above that the stability derivatives of concern in steady-state sideslipping conditions, as in a crosswind landing are Y_β, N_β, and L_β. The rudder control derivatives Y_{δ_r} and N_{δ_r} are also quite significant in the determination of side force control power. The lateral-directional dynamic parameters which influence the pilots ability to execute a crosswind landing were shown in Reference 1 to be the Dutch roll damping ratio, ζ_d, especially at Dutch-roll frequencies near $\omega_d = 1.0$ rad/sec, the roll-to-sideslip ratio in the Dutch roll, $\left|\frac{\phi}{\beta}\right|_d$, and the roll mode time constant, τ_R.

Previous studies of lateral-directional dynamics, including Reference 2, have shown that ζ_d is a function of Y_β, N_β, and L_β, as well as N_r and other lateral-directional derivatives. The Dutch-roll frequency ω_d is also a function of Y_β, N_β, and L_β plus other lateral-directional derivatives. The roll-to-sideslip ratio is also a function of these derivatives and has been shown to vary as a rough approximation of the ratio $|L_\beta / N_\beta|$. Hence, the dynamic modal parameters of interest in crosswind landings are strongly related to the stability derivatives of concern in steady-state sideslipping conditions. It is these same stability derivatives which determine the side force, roll, and directional control power necessary to perform a crosswind landing, as shown by Equations (10), (12), and (13).

Figure 2 shows a locus of the Dutch-roll pole location in the s plane with variations in L_β, N_β, and Y_β. It can be seen that variations in any one of these three derivatives, while holding all other lateral-directional derivatives constant, has a pronounced effect on the Dutch roll pole locations in the s plane. Therefore, L_β and N_β were chosen as two of the parameters for investigation in this experiment. The third variable chosen for investigation was the ratio of bank angle to unit crosswind component, ϕ/v_{cw} directly, rather than Y_β . As previously discussed, the bank angle is important as a visually apparent parameter to the pilot. Also, the side force required for a wings level crosswind landing is directly proportional to the bank angle required in a conventional crosswind landing. From Equation (6), it is apparent that ϕ/v_{cw} is a function of Y_β, L_β and N_β. As a result, Y_β was allowed to vary as necessary to attain the desired values of ϕ/v_{cw}, L_β and N_β for investigation. The roll mode time constant, τ_R , was maintained in this experiment at values found to be characteristic of STOL aircraft in the landing approach ($\tau_R < 1.0$ sec), but varied somewhat due to variations in L_β.

L_{δ_y} and N_{δ_y} , although certainly significant parameters when side force control is used, were maintained at zero throughout this experiment. The influence of these parameters should, however, be the subject of further investigation.



NOTES:

ENCIRCLED NUMBERS IDENTIFY THE EVALUATION DUTCH ROLL POLE LOCATIONS FOR THE CONFIGURATIONS LISTED IN TABLES III AND IV. READING FROM LEFT TO RIGHT:

(1) CORRESPONDS TO CONFIGURATIONS 10, 6 AND 2.

(2) CORRESPONDS TO CONFIGURATIONS 9, 5 AND 1.

(3) CORRESPONDS TO CONFIGURATIONS 12, 8 AND 4.

(4) CORRESPONDS TO CONFIGURATIONS 11, 7 AND 3.

Figure 2 LOCUS OF DUTCH ROLL POLE WITH CHANGES IN A SINGLE STABILITY DERIVATIVE

2.2.6 Side Force Mechanizations

Several options are available for the mechanization of DSFC. A major consideration is whether the pilot should have direct control through an additional independent DSFC controller or whether side force control should be mechanized as a function of some aircraft response or conventional control input. There is also the attractive option of a completely automatic side force control system where the airplane would fly the final approach with the wings level and with the heading aligned with the runway. The automatic side force control would be used to maintain a side velocity to counter any crosswind. In effect, this would amount to an automatic ILS localizer coupler, through an autopilot, with heading hold, bank angle stabilization, and effective elimination of crosswind through side force generation. The pilots' workload would then be reduced to only longitudinal control of the aircraft in manually performing the landing flare and touchdown.

Potential side force control mechanizations then include:

1) Side force as a function of bank angle.

2) Side force as a function of aileron controller deflection.

3) Side force as a function of rudder pedal deflection.

4) Manual side force control with an independent proportional or rate controller.

5) Completely automatic side force control with the pilot having only to manually perform longitudinal control.

All the above options for the mechanization could not be investigated in one experiment. For this program, it was decided to evaluate two mechanizations of side force control, one of which was manual control of side force with an independent cockpit side force controller, and the other, some form of automatic control.

Rather than choose an automatic mechanization scheme beforehand, it seemed desirable to briefly investigate, in flight, the relative merits of more than one system. During the flight checkout phase, side force as a function of bank angle, Y_ϕ , side force as a function of aileron wheel deflection, $Y_{\delta_{AW}}$, and a fully automatic side force control system were mechanized. After flying each of these mechanizations, it was decided to pursue the fully automatic system since this system potentially offered the greatest reduction in the pilot's workload.

2.2.7 Cockpit Side Force Controllers

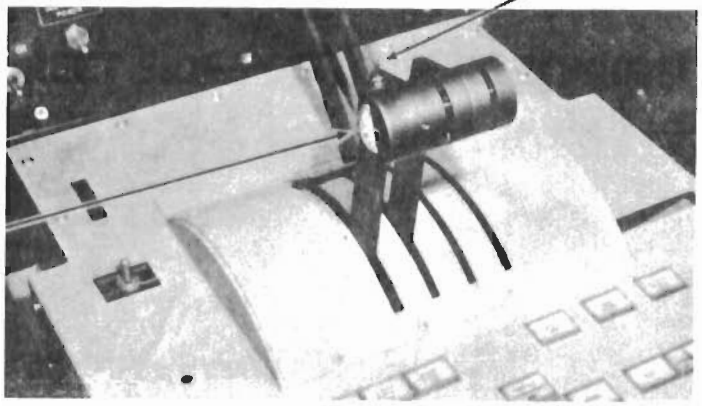
The type of cockpit controller and its location in the cockpit may be important to the usefulness of DSFC. Because there was no previous experience or data on the cockpit location or on desirable types of DSFC cockpit controllers, two were installed for this program. One controller was located integral to the number one power lever knob, and the other was located to the left side of the pilot's aileron control wheel. Figure 3 shows the controllers. In this way, the pilot could use the controller of his choice, the one that in his opinion was most efficient and most convenient for the task. Further, the most desirable of the two locations could then be determined during the course of the program evaluations.

The only control the evaluation pilot had for the automatic system was an engage-disengage switch. The switch, a toggle type, was located on the number one power lever and is shown on Figure 3b.

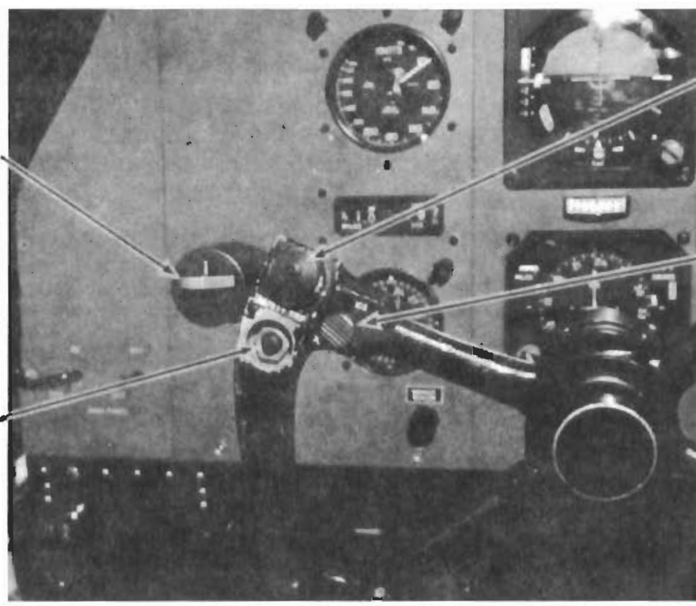
2.2.8 Control Power

Equation (10) shows that side force control power required, $Y_{\delta_y} \delta_y$, is primarily a function of the stability derivatives Y_β and N_β and the control derivatives Y_{δ_r} and N_{δ_r}. Also, Equation (11) relates the side force control power for a wings level crosswind landing to the bank angle required for a conventional sideslipping crosswind landing. However, it may not be necessary to have enough side force for a wings level landing, but merely enough to reduce the bank angle to a magnitude that is comfortable for the pilot. The question of side force control authority requires investigation of its effects on the airplane dynamics, crew and passenger acceptance of lateral accelerations, and on the roll and directional control power.

In contrast to side force control power, roll control power must be adequate to cope with a combination of normal landing approach maneuvers while the pilot is simultaneously dealing with the effects of crosswinds and turbulence or gust upsets. A lateral offset from the runway may make further demands on the available roll control power. During sideslipping maneuvers, whether in a conventional manner or with DSFC, sufficient roll control power must be available to balance the roll due to sideslip and rudder deflection. Without adequate roll control power it would be impossible to maintain the wings level while generating sufficient sideslip to counter a crosswind. Hence, roll control power limitations can reduce the crosswind landing capability of the airplane or limit the side force control power that could be introduced to counter crosswinds. Rolling moments due to side force would also affect the roll control needed. This effect, however, could be adverse or favorable. If side force generation produces rolling moments which complement the dihedral effect (L_{δ_y} negative), then the requirements for roll control power would be increased, however positive L_{δ_y} would help offset rolling moments due to positive effective dihedral and would tend to reduce the necessary roll control power.



(a) SIDE FORCE CONTROLLER ON POWER LEVER



(b) SIDE FORCE CONTROLLER ON CONTROL WHEEL

Figure 3 SIDE FORCE CONTROLLER

Roll control power requirements are also related to the gust response of the airplane, a factor which is of prime importance during the landing flare and touchdown. If the airplane is susceptible to large rolling response due to side gusts, as with large dihedral effect, then roll control power requirements may be greater than for airplanes with low dihedral effect.

Directional control power requirements or rudder power also are of prime importance during crosswind landings. Directional control power must be adequate to maintain runway alignment and to cope with any yaw excursions of the airplane caused by turbulence or other control inputs. High directional stiffness, large N_β, requires large directional control power to maintain runway heading during sideslipping crosswind landings. As directional stability, and hence Dutch roll frequency, is reduced, then directional control power requirements are reduced. If yawing moments are produced as a result of side force inputs, N_{δ_y}, then more demands could be placed on directional control power.

To obtain a measure of the control power required during a crosswind landing, the pilot's roll and directional control usage were measured during each evaluation. When DSFC was used, the roll and directional control deflections, as a result of interconnects with side force control, were also measured, since these must be considered in addition to the pilot's direct roll and directional control usage to determine the total control power used.

2.2.9 Turbulence and Crosswinds

In the landing approach, consideration must be given to the importance of atmospheric turbulence. Characteristics acceptable in smooth air may be quite undesirable in turbulence. A turbulence field can be resolved into side gust, vertical gust, and fore and aft gust components. Each of these components produces aerodynamic loads on the airplane resulting in forces and moments that excite the airplane dynamics. The airplane response to the gust component is related to the corresponding stability derivatives.

There are two general approaches to the turbulence and crosswind problem. The first would be to always fly on calm days when the air is smooth and to simulate the turbulence and wind disturbances. This approach severely constrains flight operations. The second approach would be to fly routinely from day to day, documenting the environment during each evaluation. This approach would have the disadvantage of introducing an uncontrolled variable into the experiment. To account for the important effects of the uncontrolled environment, it would be necessary to document the environment during each evaluation and to increase the number of evaluations or the sample size of the experiment. For this investigation, these two approaches were combined. To obtain the proper response for the turbulence environment, the natural turbulence was derived from the TIFS sensors and fed to the proper inputs of the model in the TIFS model following system. If the natural turbulence was below a predetermined level, then it was augmented with a taped turbulence input. Because of some difficulty with the turbulence system, and because of high natural turbulence during some of the evaluations, it was not possible to maintain a constant turbulence level. The turbulence fed to the model was, however, documented by recording the level of v_g , u_g and w_g during each evaluation. Reference 3 describes the mechanization used in this experiment and the method of measuring the turbulence components fed to the model.

During each evaluation, the natural crosswind component was augmented with a simulated crosswind in an effort to produce a constant crosswind for all evaluations. The natural wind was obtained from the Air Traffic Control Facility, and a crosswind component was determined. The TIFS side force capability was then used to produce enough simulated crosswind to have a total of 15 knots. Of course natural wind variations may have caused some variation in the actual total crosswind from landing to landing. Every effort was made to maintain the constant 15 knot crosswind by getting a final reading on the natural wind when approximately two miles from touchdown and at that point making a final adjustment on the simulated wind.

Section III

DESCRIPTION OF EXPERIMENT

3.1 EQUIPMENT

The flight evaluation program was conducted in the Air Force Total In-Flight Simulator (TIFS) shown in Figure 4. TIFS development, design, and fabrication are described in Reference 4. This unique aircraft provides the following major features inherent in its design.

1) Independent control of all aerodynamic forces and moments. This is achieved by use of elevator, aileron, rudder, throttle, direct lift flaps and side force surfaces.

2) Longitudinal and lateral-directional model-following systems which allow the motions at the evaluation cockpit in TIFS to match (follow) the cockpit motions of simulated aircraft. The specific model equations of motion used in this investigation are presented in Appendix I.

3) Separate evaluation cockpit with wheel controller and rudder pedals. The evaluation cockpit has a standard IFR instrument display including an Attitude Director Indicator (ADI) and a Horizontal Situation Indicator (HSI). A sideslip (β) meter is also included in the instrument display. For this program, separate DSFC controllers were also installed.

4) Digital magnetic tape recording system capable of simultaneously recording 58 selected parameters.

Since the TIFS airplane incorporates side force control as part of its six-degree-of-freedom in-flight simulation capability, it was uniquely suited for the DSFC evaluation. Previous use of the TIFS airplane has used the side force capability only to achieve the desired model following. During the previous TIFS programs the side force surfaces were controlled solely by the model computer to produce the proper aerodynamic side forces which, when combined with the other independent forces and moments, resulted in the desired motions at the evaluation cockpit. For this program, the TIFS side force surfaces were mechanized so that they could be independently controlled by both the evaluation pilot, through the model following system, and by the model computer. The evaluation pilot could control the model side force using a thumb wheel controller, and the model computer controlled the TIFS side force surfaces to obtain model following about the pilot's commanded side force input.

Figure 4 USAF/CALSPAN TIFS AIRPLANE IN FLIGHT

3.2 DEVELOPMENT OF THE SIMULATED VEHICLE MODEL

The objective for this initial evaluation of DSFC was to provide a model in the landing approach configuration that was typical of a Class II STOL as defined by MIL-F-83300. Dimensional derivatives, both longitudinal and lateral-directional, were collected from available data of proposed and existing Class II STOL airplanes (References 5 to 12). These data were analyzed to obtain a set of composite dimensional derivatives to define the basic STOL vehicle to be simulated.

Table I gives resulting lateral-directional dimensional derivatives for the basic STOL model. Configuration 5 of this investigation was defined to be the baseline case. All the derivatives in Table I are referred to a standard day at 2000 ft MSL.

Though not obtained from any of the above references, the side force control derivative, Y_{δ_y} , is also presented in Table I. The value of Y_{δ_y} was based on the capability of the TIFS airplane to counter a 15 knot crosswind and simultaneously maintain proper model following.

Although the simulated vehicle characteristics were based on the above described composite set of dimensional derivatives, the TIFS model computer is designed to be programmed using nondimensional coefficients. The nondimensional coefficients are internally multiplied in the model computer by the proper physical data to obtain the equations of motion of the simulated vehicle (model). Appendix I presents the complete model equations as mechanized. Since the velocity of the model was that of TIFS, care was taken to assure that the nondimensionalizing velocity was 130 knots rather than a typical STOL velocity of 70 knots. As a result, the nondimensional coefficients presented in Table II may not be typical of a Class II STOL aircraft. However, when dimensional derivatives were computed from these nondimensional coefficients using the TIFS velocity, the equations of motion and modal parameters for the typical Class II STOL aircraft operating at STOL speed were obtained. The evaluation pilot was therefore flying with the dynamic characteristics that a Class II STOL would exhibit in a speed range of 70 to 90 knots even though the TIFS was flying at 130 knots.

The parameters varied in this investigation and the reason for their selection were discussed in paragraph 2.2.5. The two values of L_β , two values of N_β , and three values of ϕ/v_{cw} resulted in twelve configurations with differing lateral-dimensional dynamic characteristics. It should be mentioned that the original intent was to evaluate three values of the incremental steady-state bank angle per incremental steady-state sideslip, $\Delta\phi/\Delta\beta$. However, because of the confusion in terminology between $\Delta\phi/\Delta\beta$ and the roll-to-sideslip ratio in the Dutch roll, $\left|\frac{\phi}{\beta}\right|_d$, the parameter $\Delta\phi/\Delta\beta$ was abandoned in favor of the parameter ϕ/v_{cw}, bank angle per unit crosswind component. Values of $\Delta\phi/\Delta\beta$ were chosen to be 0.8, 1.2 and 1.6; these became ϕ/v_{cw} values of 0.208, 0.311 and 0.415 deg/ft/sec. For a 15 knot crosswind component, the above values of ϕ/v_{cw} required bank angles of

Table I

DIMENSIONAL LATERAL-DIRECTIONAL DERIVATIVES
BASELINE – CONFIGURATION 5

(BASED ON STANDARD DAY, 2000 ft)

(SEE TEXT PAGE 20)

L_p	=	-1.052	$sec^{-1} rad^{-1}$
L_r	=	1.140	$sec^{-1} rad^{-1}$
L_β	=	-1.573	$sec^{-2} rad^{-1}$
L_{δ_r}	=	0.295	$sec^{-2} rad^{-1}$
L_{δ_a}	=	-1.081	$sec^{-2} rad^{-1}$
N_p	=	-0.0986	$sec^{-1} rad^{-1}$
N_r	=	-0.350	$sec^{-1} rad^{-1}$
N_β	=	+0.939	$sec^{-2} rad^{-1}$
N_{δ_r}	=	-0.442	$sec^{-2} rad^{-1}$
N_{δ_a}	=	-0.0736	$sec^{-2} rad^{-1}$
Y_p	=	0.00605	rad^{-1}
Y_r	=	0.00136	rad^{-1}
Y_β	=	-0.207	$sec^{-1} rad^{-1}$
Y_{δ_r}	=	0.0173	$sec^{-1} rad^{-1}$
Y_{δ_a}	=	0.00	$sec^{-1} rad^{-1}$
Y_{δ_y}	=	0.0585	$sec^{-1} rad^{-1}$

Table II
LATERAL-DIRECTIONAL MODEL DEFINITION USED IN TIFS BASELINE – CONFIGURATION 5

(SEE TEXT PAGE 20)

V_0	=	130 kts
S	=	1650.0 ft^2
b	=	115.0 ft
I_{xx}	=	1.23×10^6 slug-ft^2
I_{zz}	=	2.56×10^6 slug-ft^2
I_{xz}	=	1.40×10^5 slug-ft^2
W	=	130,000 lb
C_{ℓ_p}	=	-0.474
C_{ℓ_r}	=	0.514
C_{ℓ_β}	=	-0.180
$C_{\ell_{\delta_r}}$	=	0.0338
$C_{\ell_{\delta_a}}$	=	-0.124
C_{n_p}	=	-0.0925
C_{n_r}	=	-0.338
C_{n_β}	=	0.224
$C_{n_{\delta_r}}$	=	-0.106
$C_{n_{\delta_a}}$	=	-0.0176
C_{y_p}	=	0.233
C_{y_r}	=	0.0524
C_{y_β}	=	-2.027
$C_{y_{\delta_r}}$	=	0.170
$C_{y_{\delta_a}}$	=	0.0
$C_{y_{\delta_y}}$	=	0.573

approximately 5 degrees, 7.5 degrees, and 10 degrees. The L_β and N_β values were chosen to obtain a reasonable variation in the Dutch roll damping and frequency. The resulting Dutch-roll pole locations have been shown on Figure 2. Once L_β and N_β were determined, Y_β was adjusted to obtain the desired values of ϕ/v_{cw}. In this way a total of 12 configurations were obtained. The values of the parameters which varied for the 12 configurations are shown in Table III and the lateral-directional modal parameters are presented in Table IV. With the exception of Y_β , L_β and N_β , all stability and control derivatives were held constant at the values given in Tables I and VI.

Each of the twelve dynamic configurations described above was evaluated to determine the influence of the usefulness of DSFC on the overall handling qualities. First an evaluation was conducted with no DSFC, then the same configuration was evaluated with the pilot having manual control of side force, and finally an evaluation was conducted with an automatic mode of DSFC. The most basic change in the simulated vehicle as presented to the evaluation pilot was, therefore, the availability or lack of DSFC.

As mentioned in paragraph 2.2.4, to reduce the pilot's workload, it was desirable to provide an aileron per side force input interconnent, δ_a/δ_y , and a rudder per side force input interconnect, δ_r/δ_y. Static values of δ_a/δ_y and δ_r/δ_y were determined from Equation (8), and are listed in Table V. Computer time histories showed that these aileron interconnect values for Configurations 1, 5 and 9, which had an unstable spiral mode, to be low by approximately 3 percent. The corrected aileron interconnects for these configurations are shown in parenthesis in Table V.

Rudder and aileron interconnects from the side force generator were designed to produce the necessary aileron and rudder deflections, or trim, required for zero yawing and rolling moments in steady-state sideslip. Appendix III shows digital responses with and without these interconnects.

To limit the lateral acceleration and excitation of the Dutch roll with DSFC inputs, filtering was provided in the manual DSFC mechanization as shown by the block diagram presented on Figure 5. The filter corner frequency of 0.5 rad/sec was experimentally determined during the ground and flight checkout phase of the TIFS mechanization. A value was chosen which reduced transient excitation during DSFC inputs with no attempt to determine an optimum value for the corner frequency of the δ_a/δ_y and δ_r/δ_y filter. For the baseline configuration, Figure 6 shows the model responses to a DSFC input with and without the filter.

The longitudinal model was developed in much the same way as the lateral-directional model. A search of references of both present and proposed STOL airplanes provided a range of typical Class II STOL modal parameters. Since the evaluation program was primarily a lateral-directional

Table III

PARAMETER VARIATIONS WITH CONFIGURATION CHANGES

CONFIGURATION NO.	ϕ/v_{cw} $\left(\frac{deg}{ft/sec}\right)$	C_{Y_β} (rad^{-1})	Y_β $\left(\frac{1}{rad\text{-}sec}\right)$	C_{n_β} (rad^{-1})	N_β $\left(\frac{1}{sec^2\text{-}rad}\right)$	C_{ℓ_β} (rad^{-1})	L_β $\left(\frac{1}{sec^2\text{-}rad}\right)$
1	0.208	-1.480	-0.151	0.224	0.939	-0.180	-1.573
2	0.208	-1.514	-0.155	0.224	0.939	-0.338	-2.946
3	0.208	-1.289	-0.132	0.100	0.419	-0.180	-1.573
4	0.208	-1.323	-0.135	0.100	0.419	-0.338	-2.946
5 (BASELINE)	0.311	-2.027	-0.207	0.224	0.939	-0.180	-1.573
6	0.311	-2.062	-0.211	0.224	0.939	-0.338	-2.946
7	0.311	-1.836	-0.188	0.100	0.419	-0.180	-1.573
8	0.311	-1.871	-0.191	0.100	0.419	-0.338	-2.946
9	0.415	-2.576	-0.263	0.224	0.939	-0.180	-1.573
10	0.415	-2.609	-0.266	0.224	0.939	-0.338	-2.946
11	0.415	-2.384	-0.243	0.100	0.419	-0.180	-1.573
12	0.415	-2.418	-0.247	0.100	0.419	-0.338	-2.946

Table IV

MODAL PARAMETERS FOR DSFC EVALUATION CONFIGURATIONS

CONFIGURATION NO.	ω_d (rad/sec)	ζ_d	$\left\|\frac{\phi}{\beta}\right\|_d$	τ_R (sec)	τ_S (sec)
1	1.11	0.155	1.11	0.82	-20.7
2	1.14	0.071	1.74	0.73	-807.0
3	0.836	0.146	1.53	0.80	70.2
4	0.909	0.015	2.34	0.71	14.0
5 (BASELINE)	1.12	0.175	1.13	0.81	-21.1
6	1.14	0.091	1.76	0.73	-820.0
7	0.846	0.172	1.56	0.80	72.4
8	0.914	0.040	2.37	0.71	14.3
9	1.12	0.195	1.15	0.81	-21.5
10	1.15	0.115	1.80	0.72	-832.0
11	0.855	0.197	1.58	0.79	74.6
12	0.919	0.065	2.40	0.70	14.5

Table V

AILERON AND RUDDER INTERCONNECTS WITH SIDE FORCE COMMAND

CONFIGURATION NO.	δ_a / δ_Y	δ_r / δ_Y
1	-0.4387 (-0.4540)*	1.184
2	-1.075	1.290
3	-0.5993	0.5955
4	-1.235	0.7015
5 (BASELINE)	-0.2925 (-0.3025)*	0.7897
6	-0.7165	0.8604
7	-0.3995	0.3970
8	-0.8235	0.4676
9	-0.2194 (-0.2263)*	0.5922
10	-0.5373	0.6452
11	-0.2997	0.2977
12	-0.6160	0.3507

*VALUES IN PARENTHESES WERE THE ACTUAL VALUES NECESSARY TO PRODUCE A ZERO STEADY STATE BANK ANGLE AND WERE EMPIRICALLY DETERMINED.

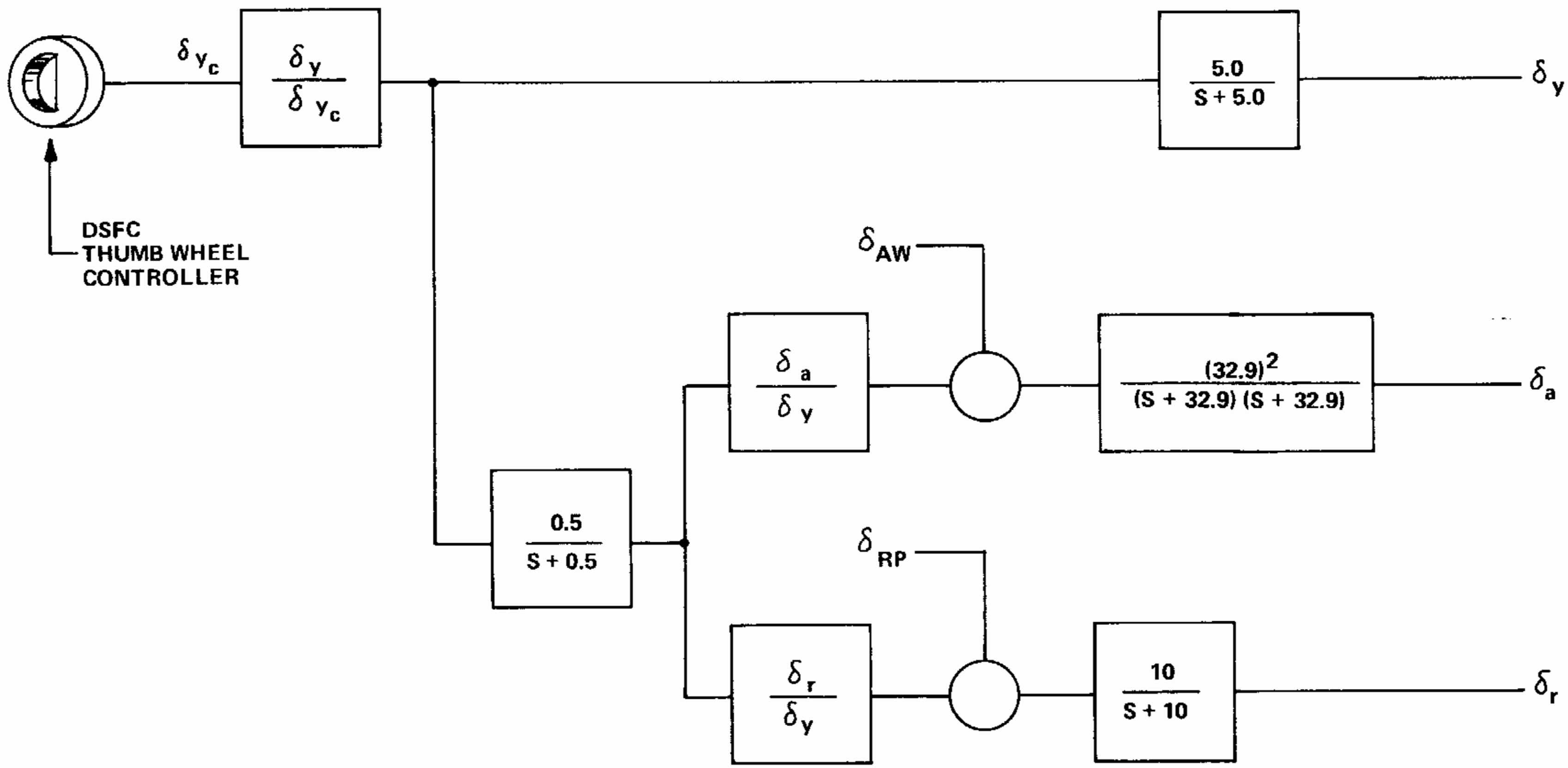
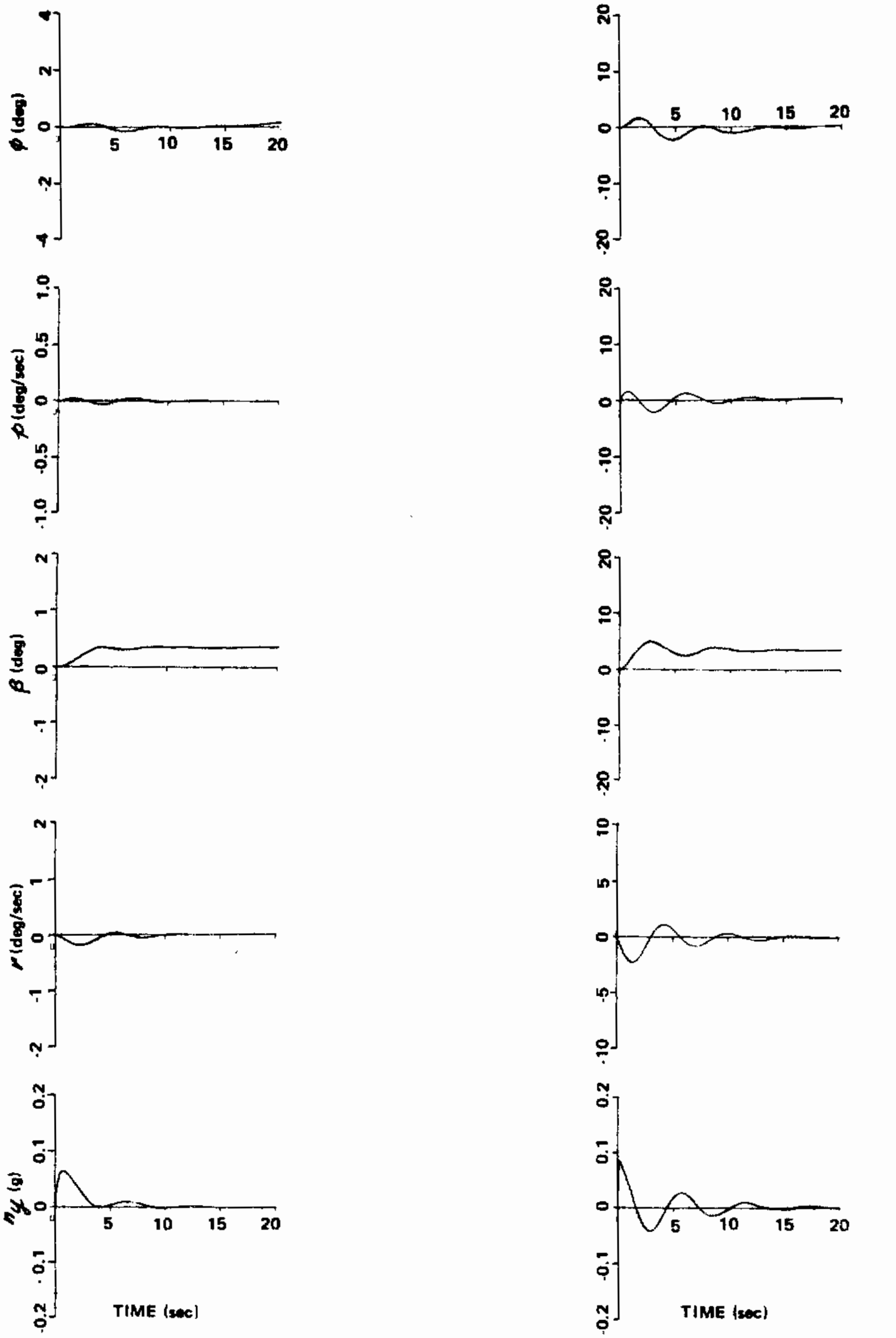


Figure 5 MANUAL DSFC MECHANIZATION



a) WITH δ_a/δ_y AND δ_r/δ_y FILTER

b) WITHOUT δ_a/δ_y AND δ_r/δ_y FILTER

Figure 6 MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH INTERCONNECTS TO THE AILERON AND RUDDER BASELINE CONFIGURATION 5 experiment, it was desirable to have good longitudinal handling qualities which would not adversely affect pilot rating. The longitudinal characteristics remained constant throughout the experiment.

Nondimensional longitudinal derivatives were selected at values which, when dimensionalized using TIFS airspeed of 130 knots, produced the equivalent dynamics of a Class II STOL flying at 80 knots. Therefore, the nondimensional coefficients presented in Table VI may not be illustrative STOL values. The resulting modal parameters, typical of a Class II STOL, are also listed in Table VI. Appendix I presents the detailed model equations and mechanization.

Due to the low airspeeds of the TIFS during final approach and flare, and in the interest of flight safety, the direct lift flaps were operated in a small range of ±10 degrees about a nominal 25 degrees down deflection. As a result, L_α , and therefore n_z/α , could not be decreased to the typically low values of STOL airplanes. The complete evaluation program was flown with $n_z/\alpha \approx 6.25$, while typical STOL values would be $n_z/\alpha \approx 2.0$. The mismatch of n_z/α was not considered detrimental to the investigation of DSFC. The limitation of direct lift flap motion also precluded any possibility of simulating any thrust inclination angle, $Z_{\delta_T}/X_{\delta_T}$, other than the inherent angle of TIFS itself. Again this was not considered detrimental to the evaluation program.

TIFS was able to simulate the typical STOL glidepath ($\gamma = -6°$). However, TIFS final approach speed was 130 knots. The vertical and horizontal runway closure rates were approximately twice as fast as a STOL landing at 70-80 knots. The effects of this closure rate were not known and could possibly have been a source of degradation in the pilot rating. Each pilot was asked specifically to comment on the closure rate after each evaluation to assess the effects of the runway closure rate.

3.2.1 Model Validation Procedures

When using a model-following type of variable stability airplane for research, the verification that a particular dynamic configuration is being flown consists of checking two basic items:

1) Ascertaining that the correct model has been set up on the analog computer (i.e., the pots defining stability derivatives were set correctly, and that the analog was producing the correct time histories for selected control inputs).

2) Ascertaining that the TIFS responses in flight were in fact following the analog generated responses for pilot control inputs.

Table VI
LONGITUDINAL MODEL DEFINITION USED IN TIFS

S = 1650.0 ft^2

b = 115.0 ft

$\bar{c}$ = 16.0 ft

W = 130,000 lb

m = 4037.3 slugs

I_{yy} = 1.43 x 10^6 slug-ft^2

V_0 = 130 kias

C_{L_0} = 1.32 (UNTRIMMED VALUE)

C_{L_α} = 7.16 (UNTRIMMED VALUE)

$C_{L_{\delta_e}}$ = 0.517

C_{D_0} = 0.120 (UNTRIMMED VALUE)

$C_{D_{\delta_e}}$ = 0.064

K = 0.026 $\qquad C_{D\,unt} = C_{D_0\,unt} + KC_{L\,unt}^2$

C_{m_0} = 0.067

C_{m_α} = -0.531

$C_{m_{\dot{\alpha}}}$ = -9.739

C_{m_q} = -25.44

$C_{m_{\delta_e}}$ = -1.418

MODAL PARAMETERS

ω_{sp} rad/sec	ζ_{sp}	ω_{ph} rad/sec	ζ_{ph}
1.09	0.910	0.137	0.138

Item 1 was accomplished in the following ways:

1) A static voltage check was performed on the analog setup to verify proper mechanization of equations of motion.

2) Three-degree-of-freedom digital computer time histories of model responses to model control inputs were compared with those generated for identical control inputs by the VSS model analog computer. This comparison was simplified by producing time history overlays from the digital computer responses which were then used to compare with the time histories generated by the VSS model analog and recorded on the on-board strip chart recorder.

   While using only the model computer on board, model computer responses on the strip chart were compared with digital computer time history overlays. The β, p, and r responses for both δ_a and δ_r step inputs were compared as were the α, θ and V responses for δ_e step inputs. This step was performed before each configuration was evaluated.

Item 2 was achieved by the following procedures in flight:

1) TIFS airplane responses were compared on-line on the strip chart with the model computer responses generated for specific control inputs to the model.

2) After satisfactory performance was verified in Step 1, TIFS model-following responses to pilot control inputs were similarly compared.

3) Continuous monitoring of model following was performed during the evaluation flying.

3.3 SIMULATION COCKPIT AND CONTROLS

The TIFS evaluation cockpit is a two-seat side-by-side arrangement with control wheel and rudder pedals. The evaluation pilot occupies the left seat during the evaluation flights. Four power levers are located between the two seats on a center console. For this flight program only the two left power levers were used, which commanded the total thrust of the model. The two right power levers were disconnected electrically and moved forward to eliminate any possible interference.

Two center detent thumb wheels were mounted in the simulation cockpit. One was mounted on the left side of the aileron wheel near the intercom button and trim switch, while the other thumb wheel was integral to the number one power lever knob so that the pilot could control the thumb wheel while his right hand was on the power lever during the approach. Also mounted on the number one power lever was a toggle switch that activated the automatic DSFC system. The switch could be activated easily when the pilot had his right hand on the throttles during the approach.

The evaluation pilot had direct independent control side force using either of the two thumb wheels provided. Both controllers were connected in parallel allowing the pilot to independently use either controller. The direct side force controllers were proportional controllers, that is, $\delta_y = K\delta_c$.

3.3.1 Automatic DSFC

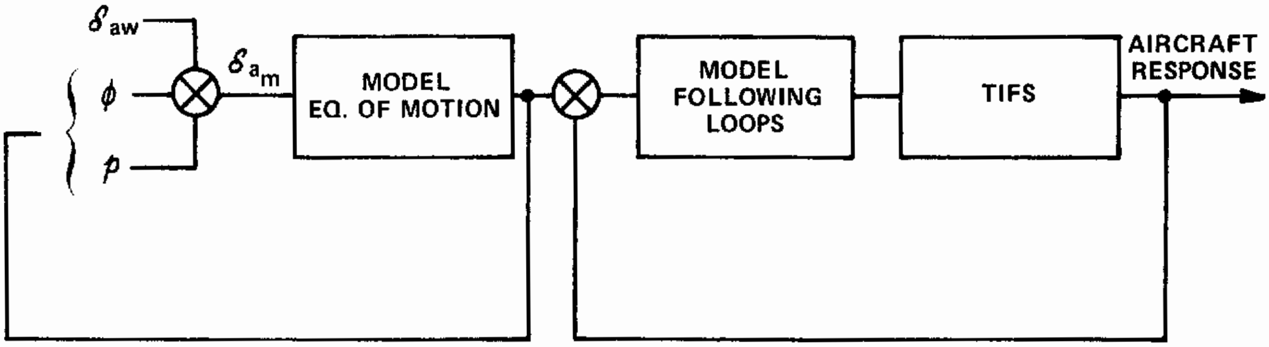
The automatic DSFC system mechanized for this program was an auto-pilot approach coupler which used the DSFC capability. The unique feature of this system was its capability to maintain the airplane on ILS localizer course with the wings level and without crab angle in a crosswind.

The automatic DSFC system was designed to be activated after the pilot performed the normal visual maneuvering to place the airplane on the extended runway centerline with the airplane heading approximately aligned with the runway and in a position to commence a descent. After engaging the automatic system, the pilot's task was reduced to the longitudinal control of the airplane.

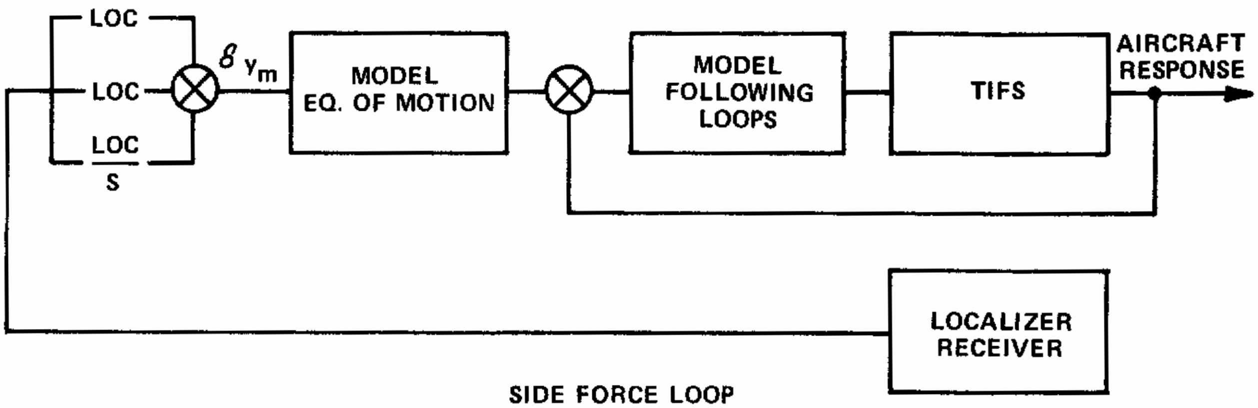
Figure 7 shows a block diagram of the system mechanization. Since the TIFS is used in the model following mode, the responses of the model and the TIFS are essentially the same. Therefore, the transfer function of the model following loops and the TIFS can be considered to be unity. Bank angle, roll rate, localizer error, and heading error signals were used as input commands. The bank angle stabilization loop maintained a wings level attitude throughout the approach. Damping in the roll axis was achieved through roll rate feedback. Provision was made for the pilot to superimpose a bank angle command through the bank angle stabilization loop.

The localizer error signal was used to drive the side force generators to maintain the airplane on an extended runway centerline. The integral of the localizer error signal was included to eliminate steady state localizer errors. Damping of the side force loop was achieved through a localizer rate signal.

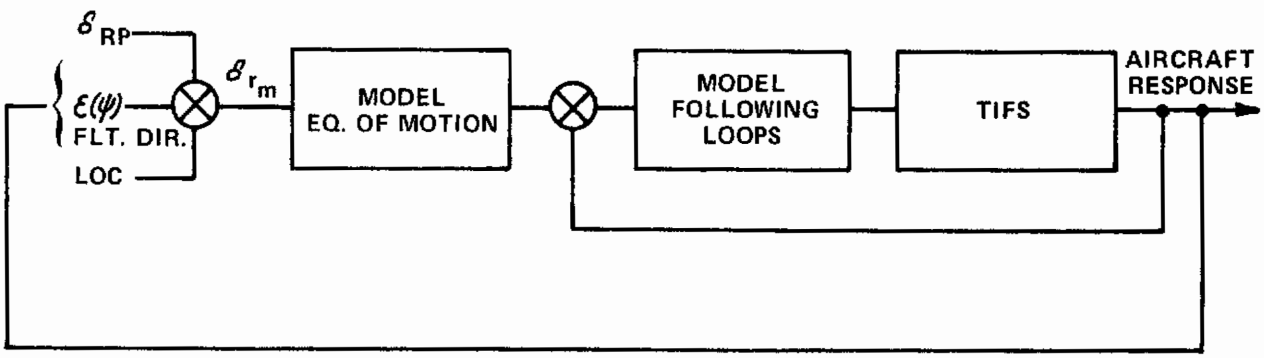
The heading angle stabilization loop maintained the airplane heading coincident with runway direction. The TIFS flight director was used to provide an error signal which was the difference between the airplane heading and the landing runway direction, $\varepsilon(\psi)$. In this control loop, a small amount of localizer error signal was used to rotate the airplane heading towards the centerline when a localizer error existed. For example, if the airplane was to the right of centerline, the heading was automatically corrected to the left a maximum of 2.5 degrees. Using rudder pedal inputs, the pilot could superimpose a change in airplane heading through the heading stabilization loop.



BANK ANGLE STABILIZATION LOOP



SIDE FORCE LOOP



HEADING ANGLE STABILIZATION LOOP

Figure 7 BLOCK DIAGRAM OF AUTOMATIC DSFC MECHANIZATION

Track and hold circuits, limiters and filters were provided in the automatic DSFC control loops to prevent engage and disengage transients and rapid control surface motions.

3.3.2 Feel System

Control feel to the wheel and rudder pedals was provided by electrically controlled hydraulic feel servos which provide forces proportional to the control wheel and rudder pedal deflection. The feel system dynamics for the elevator, aileron, and rudder were all held constant at the following values

$$\omega_{FS} = 15 \text{ rad/sec} \qquad \zeta_{FS} = .85$$

Elevator and aileron control surface actuator dynamics were mechanized as second order systems with the dynamics listed below. The rudder and side force actuators were mechanized as first order systems as listed below.

Control Actuator	Freq-rad/sec	Damping Ratio
Elevator	32.9	$\zeta = 1.0$
Aileron	32.9	$\zeta = 1.0$
Rudder	10.0	
Side force	5.0	
Aileron interconnect (δ_a/δ_y)	0.5	
Rudder interconnect (δ_r/δ_y)	0.5	

Force gradients, and breakout forces for elevator, aileron and rudder were initially set at the maximum values recommended in Reference 13. These values are presented below. Control hysteresis was maintained at zero throughout the program.

During the initial checkout and pre-evaluation flights, the pilot noticed a tendency to PIO longitudinally during the landing flare and touchdown. The elevator force gradient was therefore increased to 10 lb/in before the first evaluation flight.

	Force Gradient (lb/in*)	Breakout (lb)
Elevator	5	2
Aileron	3	2
Rudder	35	7

*Control displacement is in terms of the pilots' hand movement at the rim of the control wheel.

Pilot A felt the aileron force gradient of 3 lb/in to be unacceptably heavy during the flare when ailerons had to be controlled using one hand while the other hand was on the power levers. Before the first approach on evaluation flight number 8, he reduced the aileron force gradient to 2.25 lb/in, and continued using this gradient for the rest of his evaluations. To maintain a constant basis for comparison of pilot rating, Pilot B was asked to use the same control forces and gradients used by Pilot A. Below is a table of the forces and gradients used during the evaluation program.

Flights	Force Gradient		
	Elevator (lb/in)	Aileron (lb/in)	Rudder (lb/in)
Pre-evaluation flights	5	3	35
Evaluation flights 1-7	10	3	35
Evaluation flights 8-22	10	2.25	35

The control motion gradients used during the entire program were as follows:

$$\delta_e/\delta_{EW} = 2.0 \text{ deg/in}$$

$$\delta_a/\delta_{AW}{}^* = 2.8 \text{ deg/in}$$

$$\delta_r/\delta_{RP} = 10.0 \text{ deg/in}$$

3.4 EVALUATIONS

3.4.1 Task Description

The evaluation tasks consisted of a VFR approach, the flare maneuver, and simulated touchdown. The airplane was flown briefly by the evaluation pilot in up-and-away flight for familiarization with the configuration. At the completion of this phase of maneuvering, the landing traffic pattern was entered and three successive VFR landing approaches were accomplished following the pattern shown in Figure 8.

As shown on Figure 8, the evaluation pilot was given control on the downwind leg, completed the downwind leg and performed the base turn to final approach heading so as to intercept the extended runway centerline at approximately 2 n.mi. and 1100 ft above the ground. The simulated crosswind was input during the latter portion of the base turn. The first approach was flown without "canned" turbulence or natural turbulence inputs to the model.

*Control displacements are in terms of pilot's hand movement at rim of the control wheel.

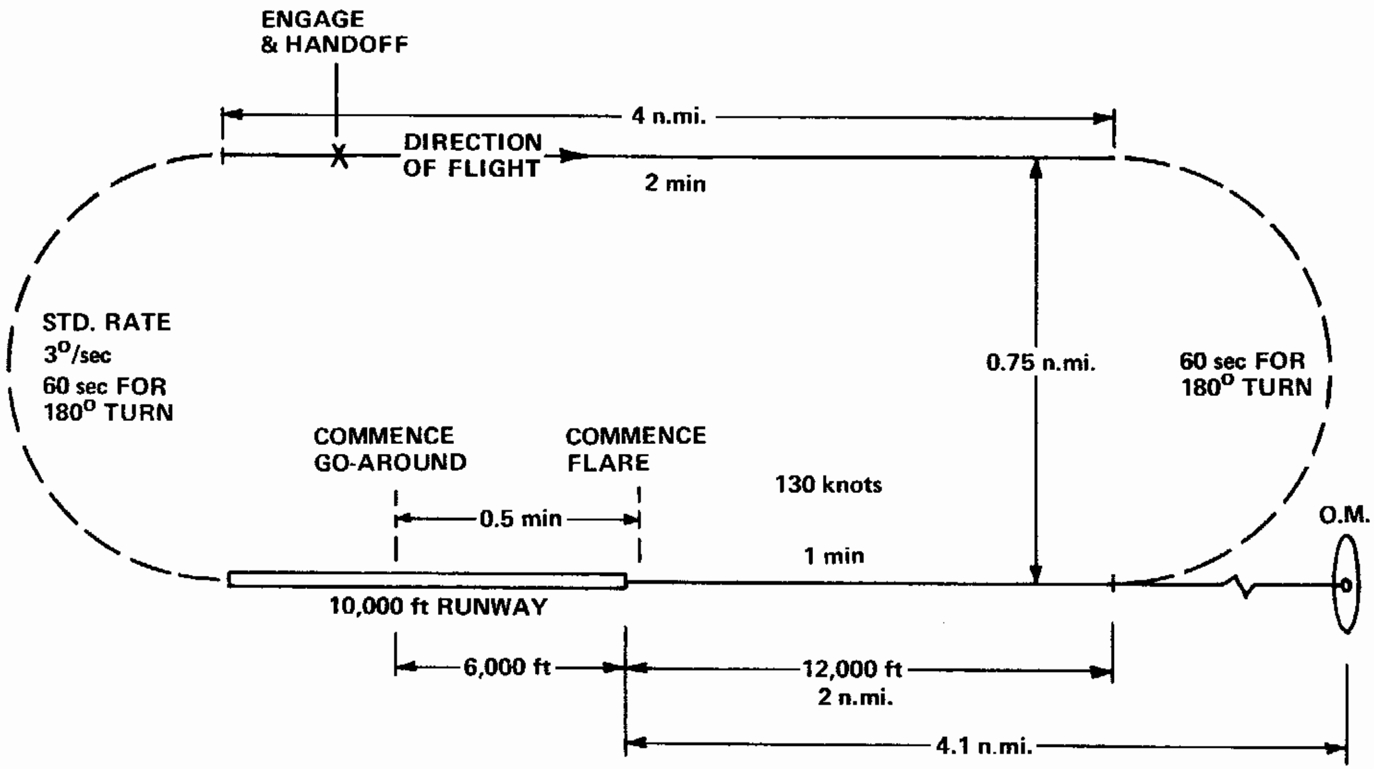


Figure 8 LANDING TRAFFIC PATTERN SHOWING TIME REQUIRED FOR EACH LEG

During the second and third approaches, turbulence was input to the model which was a combination of natural turbulence and taped turbulence signals. Each approach was carried to a simulated touchdown altitude at which the evaluation pilot received a visual and an aural touchdown signal. The entire landing traffic pattern was flown at 130 KIAS with the exception of the flare and post-flare where the minimum speed was 115 KIAS.

After the third landing approach and flare was completed, the safety pilots assumed control and flew the airplane away from the airport traffic pattern. During this time, the evaluation pilot tape recorded his evaluation comments and pilot rating while the next configuration was prepared for evaluation.

Three evaluations were scheduled for a given flight, all with the same dynamic airplane characteristics. The first evaluation, consisting of three approaches, was flown without any form of DSFC. The second evaluation was flown with the manual thumb control for DSFC, and the third evaluation was flown with the automatic mode of DSFC. The evaluation pilot was informed of the unchanging dynamic characteristics and also the kind or form of DSFC he was expected to exercise and evaluate. This procedure resulted in a direct evaluation of the DSFC itself after the particular "goodness" of the dynamic characteristics had been determined.

Each evaluation pilot was given a familiarization flight during which he attempted to complete at least one evaluation. This pre-evaluation flight served as practice for the evaluation pilot in using the pilot comment card and rating scale. At the same time the pilot became familiar with the evaluation procedures and maneuvers.

3.4.2 Crosswind Simulation During Evaluations

All approaches were made with the effect of a 15 knot crosswind from either the left or the right. The crosswind was achieved in one of three ways.

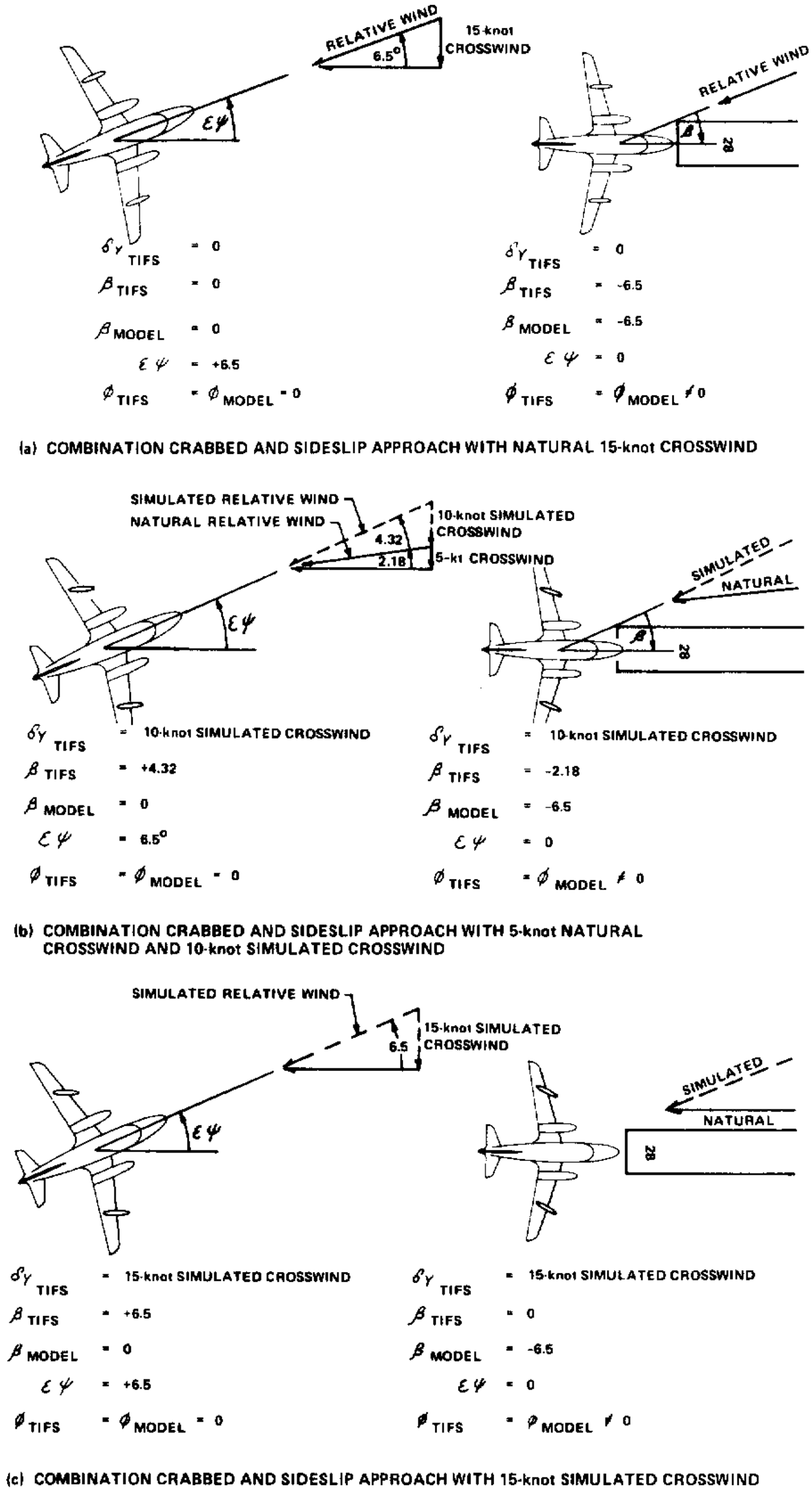
1) 15 knots of natural crosswind.

2) Natural crosswind supplemented by the direct side force capabilities of TIFS to produce the wings level crab angle which would result from a total 15 knot crosswind.

3) No natural crosswind. The direct side force capabilities of TIFS produced the total simulated 15 knot crosswind.

Figure 9 shows the three methods of achieving the 15 knot crosswind.

The total 15 knot crosswind combined with the 130 knot approach speeds produces approximately 6.5 degrees of crab angle during a crabbed approach or approximately 6.5 degrees of sideslip during a sideslipping approach with zero crab angle.



(a) COMBINATION CRABBED AND SIDESLIP APPROACH WITH NATURAL 15-knot CROSSWIND

(b) COMBINATION CRABBED AND SIDESLIP APPROACH WITH 5-knot NATURAL CROSSWIND AND 10-knot SIMULATED CROSSWIND

(c) COMBINATION CRABBED AND SIDESLIP APPROACH WITH 15-knot SIMULATED CROSSWIND

Figure 9 CROSSWIND SIMULATION

3.4.3 Evaluation Pilots

Two evaluation pilots participated in the program. A summary of their experience is presented below.

Pilot A

A Calspan research pilot with over 5000 hours of flight time, including 300 hours of helicopter time and 65 hours in variable stability STOL aircraft. He is a graduate of the U.S. Air Force Experimental Test Pilot School and has been an evaluation pilot in numerous handling qualities programs using variable stability aircraft for both lateral-directional and longitudinal investigations. He also has considerable experience in evaluating handling qualities, using ground simulators, for conventional and STOL aircraft.

Pilot B

USAF pilot with over 2300 hours including 1100 hours in rotary wing aircraft. He is a graduate of U.S. Navy Test Pilot School and has four year's experience in flight test. He has performed STOL flight evaluations on the Buffalo, Twin Otter, and XC-1 (Japan). He has also performed STOL ground simulator studies for the Air Force Flight Dynamics Laboratory (AFFDL).

3.4.4 Pilot Comment and Rating Data

Pilot comments and ratings were the primary data source. The pilot rating can only be properly interpreted and objections properly assessed if good comments are obtained. Pilot comments were encouraged at any time that the pilot felt it appropriate during the evaluation. For data consistency, it was required that the pilot comment on the items listed in Table VII either during or at the completion of each evaluation. An overall pilot rating was assigned by the evaluation pilot to each configuration in accordance with the Cooper-Harper rating scale established and described in Reference 14 and shown in Figure 10. The pilot rating assigned by the evaluation pilot to each configuration included the effects that turbulence and disturbance inputs may have had on the overall handling qualities.

In addition, an alphabetical turbulence effect rating was assigned which was solely an assessment of the effects on the handling qualities of turbulence disturbances. These ratings were established in accordance with the turbulence effect rating scale, Figure 11.

3.4.5 Data Acquisition

The TIFS airplane is equipped with the following data acquisition equipment:

1) Four-channel Brush strip chart recorder.
2) Fifty-eight channel Ampex digital magnetic tape recorder.
3) Norelco cassette tape voice recorder.

Table VII

PILOT COMMENT CARD

A. COMMENT ON INITIAL IMPRESSIONS OF THE CONFIGURATION AND THE LATERAL-DIRECTIONAL AND LONGITUDINAL HANDLING QUALITIES IN GENERAL.

B. COMMENT ON FOLLOWING SPECIFIC ITEMS:

1. ABILITY TO TRIM
   a. LATERAL-DIRECTIONAL
   b. LONGITUDINAL

2. FEEL CHARACTERISTICS
   a. FORCES
   b. DISPLACEMENTS
   c. HARMONY

3. SELECTION OF CONTROL SENSITIVITIES *
   a. EXPLAIN SELECTIONS
   b. DISCUSS COMPROMISES

4. RESPONSE TO INPUTS REQUIRED TO PERFORM TASK
   a. ROLL CONTROL
      – INITIAL RESPONSE, PREDICTABILITY (PRECISION) OF FINAL RESPONSE
      – DESCRIBE PILOT INPUT REQUIRED
   b. DIRECTIONAL CONTROL
      – COMPLAINTS?
   c. TURN COORDINATION REQUIREMENTS IN THE CONTEXT OF THE TASK
   d. PITCH ATTITUDE CONTROL
      – INITIAL RESPONSE, PREDICTABILITY OF FINAL RESPONSE, ANY COMPLAINTS?

5. CROSSWIND ON TURNING FINAL
   a. DID IT CAUSE ANY DIFFICULTIES, IF SO EXPLAIN.

6. LANDING APPROACH METHOD
   a. CRAB, WHY
   b. SIDESLIP, WHY
   c. COMBINATION OF CRAB AND SIDESLIP, EXPLAIN.

7. RUNWAY ALIGNMENT
   a. DESCRIBE TECHNIQUE
   b. ANY DIFFICULTIES
   c. PERFORMANCE

*APPLIED ONLY TO PILOT A.

Table VII (Cont.)

PILOT COMMENT CARD

8. CONTROL TECHNIQUES
   a. AILERON, RUDDER AND DSFC USAGE
   b. COORDINATION, IF ANY
9. CONTROL OF SIDESLIP WITH DSFC
   a. ADEQUATE
   b. WAS SOME BANK ANGLE NEEDED?
10. DOES DSFC INTERFERE WITH LATERAL-DIRECTIONAL CONTROL? EXPLAIN.
11. DOES AUTOMATIC DSFC INTERFERE WITH ANY OTHER ASPECTS OF CONTROL. EXPLAIN.
12. CONTROL OF GLIDE PATH
   a. DOES DSFC INTERFERE WITH THROTTLE OR ELEVATOR CONTROL? EXPLAIN.
13. DO LATERAL-DIRECTIONAL CONTROL INPUTS AFFECT LONGITUDINAL MOTIONS?
14. DO LONGITUDINAL CONTROL INPUTS AFFECT LATERAL-DIRECTIONAL MOTIONS?

C. SUMMARY

1. GOOD FEATURES
2. OBJECTIONABLE FEATURES
3. SPECIAL PILOTING TECHNIQUE
4. PILOT RATING AND PRIMARY REASON
5. TURBULENCE RATING

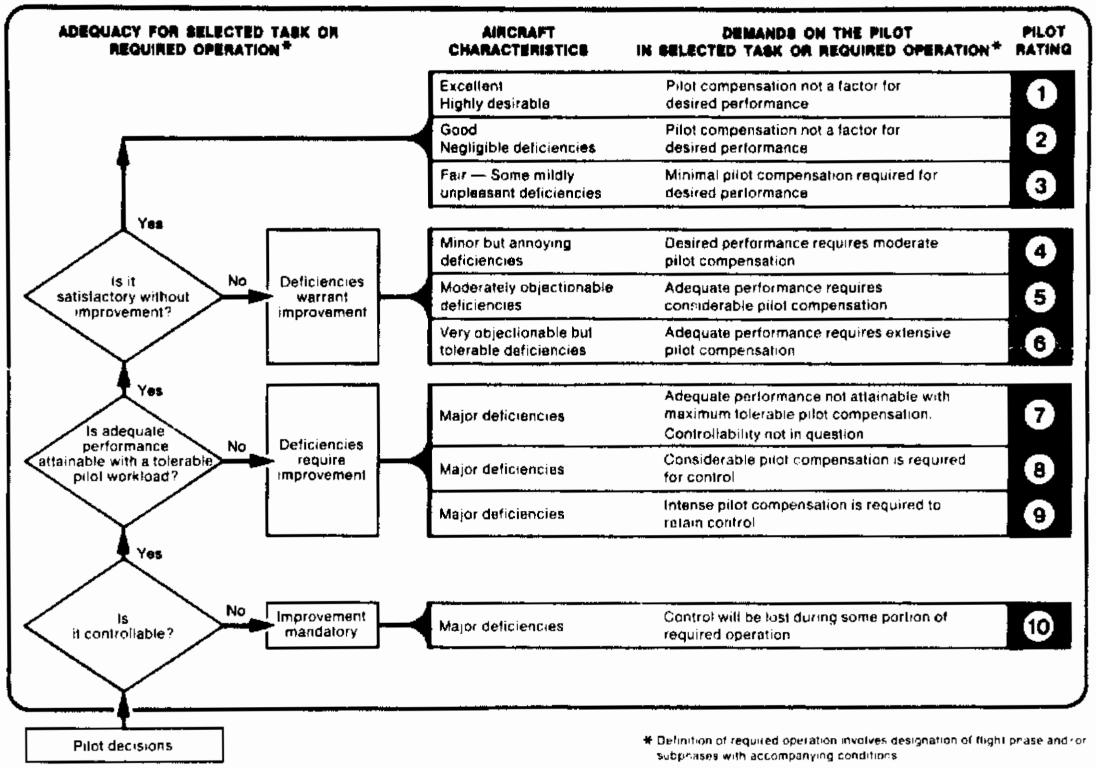


Figure 10 COOPER-HARPER HANDLING QUALITIES RATING SCALE

INCREASE OF PILOT EFFORT WITH TURBULENCE	DETERIORATION OF TASK PERFORMANCE WITH TURBULENCE	RATING
NO SIGNIFICANT INCREASE	NO SIGNIFICANT DETERIORATION	A
MORE EFFORT REQUIRED	NO SIGNIFICANT DETERIORATION	B
	MINOR	C
	MODERATE	D
BEST EFFORTS REQUIRED	MODERATE	E
	MAJOR (BUT EVALUATION TASKS CAN STILL BE ACCOMPLISHED)	F
	LARGE (SOME TASKS CANNOT BE PERFORMED)	G
UNABLE TO PERFORM TASKS		H

Figure 11 TURBULENCE EFFECT RATING SCALE

The strip chart recorder, which incorporates the ability to select ten different combinations of four output channels, was used continuously during flight to monitor model-following performance. The digital magnetic tape recorder was used to acquire specific documentation records of responses to classic inputs and records of the evaluation approaches for more detailed analysis after the flight. Specific data recorded on the magnetic tape recorder is listed in Appendix II. The voice recorder was used to record evaluation pilot comments and ratings.

Section IV

DISCUSSION OF RESULTS

4.1 PARAMETERS INVESTIGATED AND EVALUATIONS ACCOMPLISHED

The parameters varied in this program and the reason for their selection has been discussed in Sections II and III of this report. The parameter ϕ/v_{cw}, the bank angle per unit crosswind for a sideslipping wing low crosswind landing, was chosen to adequately cover the expected crosswind landing bank angle requirements of STOL aircraft. In this experiment, the bank angles for a conventional type wing low crosswind landing ranged between approximately 5 and 10 degrees.

It was shown in Section II that the derivatives L_β and N_β may be expected to have a significant influence on the pilot's ability to execute a crosswind landing by conventional techniques. Therefore, these derivatives were chosen as parameters for investigation in this program. L_β was chosen at values which represent the approximate higher and lower extremes determined from a review of available data on existing and proposed STOL aircraft. The two values of N_β chosen bracket the values found to be representative from the literature search. The lower value of N_β and the higher value of were limited from considerations of lateral-directional modal parameters. The s plane plot, Figure 2, showed that the higher L_β and lower N_β result, in one case (Configuration 4) in a Dutch roll damping ratio that is only slightly positive.

A total of twelve configurations was evaluated. The configurations were defined by their values of ϕ/v_{cw}, N_β and L_β. Variations in ϕ/v_{cw} required variations in Y_β. All other lateral-directional derivatives were held constant for all configurations. The lateral-directional modal parameters, of course, changed with changes in the above mentioned variables. However, the modal parameter changes were small among configurations having in common their values of N_β and L_β. The most noticeable modal parameter change with ϕ/v_{cw} variations and constant N_β and L_β was the Dutch roll damping ratio, ζ_d, as shown in Table IV.

With one exception, each configuration was evaluated at least three times, usually on the same evaluation flight. First an evaluation was conducted without any side force control, then the same configuration was evaluated with the pilot having manual control of side force and, finally, the configuration was evaluated with automatic control of side force. The exception was configuration 11 which was not evaluated with the automatic system because of deteriorating weather conditions.

Overall, 54 evaluations were accomplished; 21 with no DSFC, 20 with manual DSFC, and 13 with automatic DSFC. Of the 21 evaluations with no DSFC, 8 received a pilot rating of PR = 4 or better. With manual DSFC, 17 of the 20 evaluations resulted in PR of 4 or better and with the automatic system 11 of the 13 evaluations resulted in a pilot rating of PR = 4 or better.

The complete equations programmed on the TIFS model computer are presented in Appendix I. Pilot comments and time histories of crosswind landing approaches are presented in Appendix III, along with significant quantitative data extracted from digitally recorded tapes. Three approaches were flown for each configuration, however, quantitative data shown was taken from only one approach. The approach from which the data is quoted was selected during data analysis. If the pilot comments indicated that the pilot's rating was strongly influenced by a given approach, then the quantitative data for that approach is shown. Otherwise, the approach for which data is quoted was chosen according to the judgment of the analyst.

The RMS gust intensities presented in Appendix III vary considerably from one evaluation to another. This occurred for the following reasons:

1) The natural turbulence level varied from nil to RMS gust intensities of more than 3 ft/sec during the course of the evaluations.

2) The major reason for the differences in gust intensities from one evaluation to another is the length of time over which the RMS values were calculated. In reviewing the pilot comments, it became apparent that although the pilot was evaluating the overall task, he based most of his opinion on the flare and simulated touchdown where he had to maneuver into and maintain the airplane in the proper position and heading relative to the runway, and maintain the proper attitude for touchdown. To represent the actual conditions with which the pilot was confronted during this critical phase, it was necessary to limit the time period for data extraction usually to 10-20 seconds prior to touchdown. It was during this short time period that the pilot was attempting to establish a steady-state sideslip when not using DSFC for the crosswind landing and only during this time period was it necessary for him to hold large steady control forces.

All data extracted from digital records including pilot control inputs and airplane state parameters was taken from the 10-20 seconds prior to touchdown. The mean sideslip attained by the pilot during this time was used as an indication of performance. To counter a 15 knot crosswind with a 130 knot approach speed required 6.5 degrees of sideslip.

It is important to point out that refinements in the development of the automatic side force control system continued during the evaluations and it is reasonable to expect that changes made in the system affected pilot opinion as the evaluations progressed. Where appropriate, these changes will be pointed out during the discussions of the results for the automatic system.

4.2 THE MANUAL SIDE FORCE CONTROLLER

Two manual side force thumbwheel controllers were provided in the evaluation cockpit. One thumbwheel was mounted on the pilot's control wheel as was shown on Figure 3a. The second thumbwheel was mounted in the knob of the number one power lever as shown on Figure 3b. Since there was no a priori knowledge of the best location for the controller, both were installed in parallel and remained in the airplane throughout the evaluation program so that the pilot could use the controller location of his choice. The intent of providing the evaluation pilot with the above option was to minimize possible adverse opinions of DSFC because of an inconvenient controller location.

During the experimental design stage of this program, consideration was given to whether the direct side force controller should be a proportional type, i.e., $\delta_Y = K\delta_{control}$, or a rate controller, $\dot{\delta}_Y = K \cdot$(Switch On). The decision was made to install the proportional type and evaluate it briefly during the checkout and pre-evaluation flight phase. The proportional controller proved to be satisfactory, however, there is still the open question as to whether a rate controller would be more suitable.

The proportional side force controllers were provided with a center detent so that the pilot could ascertain the zero side force position. Total authority of the controllers was determined so as to provide enough sideslip to counter a fifteen knot direct crosswind for the configurations with the highest values of the side force derivative Y_β, and the directional stiffness N_β. Hence, total authority was not required for the configurations with the lower values of Y_β.

4.2.1 Sense of the Side Force Controller

Originally the side force controller sense was direct in that a pilot thumb movement to the right, or clockwise on the power lever mounted controller, provided positive sideslip or drift to the right. In this way, if the pilot sensed drift to the left, the drift could be arrested with application of direct side force to the right. It was soon realized, however, that on the final approach, where the pilot is concerned with assessing the effects of crosswind, his primary cue is crab angle, relative to the runway, not side velocity or drift. It is quite difficult for the pilot to sense side velocity until the airplane is quite close to the runway, i.e., just prior to commencing the flare. As a result, the proper direction for application of DSFC for a crosswind landing was confusing at a time when the pilot was the busiest. The pilot, in seeing a crab angle to the left (nose left of runway centerline) would have to apply side force to the left when he wanted the nose of the airplane to move right for proper runway alignment. This often led to applying side force in the wrong direction since the pilot wanted the nose to move right his reaction was to deflect the side force controller to the right. Therefore, after the first evaluation flight, the sense of the side force controllers was changed so that right deflection of the controller produced left sideslip or negative side force, thus making the controllers non-directional. This controller sense was maintained through the remainder of the evaluation program, and proved to be satisfactory without introducing any further confusion to the pilot about which way to deflect the side force controller.

4.2.2 The Preferred Side Force Controller

During the early evaluation flights, Pilot A found that he most naturally used the side force controller mounted on the power lever. During the landing approach and landing the pilot normally flies with one hand on the power lever anyway, and to perform the additional task of side force control with the "power lever hand" was not difficult. Evaluation Pilot B also preferred the power lever mounted thumbwheel controller. On his last evaluation flight, Pilot B stated "I tried to use both side force controllers...to get a little more feel for the one on the control column, but---I'm more comfortable using the one on the throttle. It does feel more comfortable to rest the right hand on the throttle as I work the side force control wheel."

The pilots' objection to the control wheel mounted side force controller was the additional control task for an already "busy" left thumb. The controller was placed adjacent to the aileron-elevator trim switch so that the side force controller, aileron-elevator trim control and interphone-radio transmit switch were all within the arc of the thumb when the pilot gripped the control wheel with his left hand (Figure 3a). On several occasions the evaluation pilot inadvertently made a side force input when intending to make an aileron trim correction or he attempted to make side force inputs with the trim control. The three closely located controls proved to burden the pilot in that he had to make a conscientious effort to reach for the proper controller when his attention was directed at the precise tasks of landing approach, flare and touchdown.

4.2.3 Precision of Side Force Control

Both pilots experienced some difficulty in establishing the required amount of side force control to use, especially when flying in turbulence. This was partly due to the variations in the natural wind as altitude was reduced on final approach. Also precise final adjustment of the side force control required that any crab angle or side velocity be sensed precisely which, again was a problem with turbulence induced oscillations of the airplane present. Side velocity is easily sensed in the flare but both pilots preferred, at that point, to stop the side velocity by conventional aileron and rudder techniques rather than try to take into account the effects of an additional controller during the critical flare and touchdown task. It was, on occasion, noticed from the safety cockpit that there was some overcontrol of side force resulting in the pilot having to cope with an effective crosswind from the direction opposite to that for which he had corrected. Therefore, as mechanized in this investigation, manual DSFC was used to establish the airplane in a trimmed, wings level, steady state sideslip condition. Normal aileron and rudder control techniques were then used to make small corrections about the established steady state condition.

4.3 COMPARISON OF RESULTS WITHOUT DSFC TO RESULTS WITH DSFC

The following subsections present the results obtained for the cross-wind landing task without DSFC and then with DSFC. For purposes of this discussion, the twelve configurations are divided into four groups of three configurations. The configurations within each group have in common their values of L_β and N_β. The variable among the configurations of each group is ϕ/v_{cw} and, therefore, Y_β. The relationship between ϕ/v_{cw} and Y_β is shown in paragraph 2.2.2. A complete description of all configurations is presented in Section III.

4.3.1 Configurations with N_β = 0.94 and L_β = -1.57 (Configurations 1, 5 and 9)

Figure 12 shows the experimental results for these configurations as a function of ϕ/v_{cw}. With most of the evaluations of these configurations there was an improvement of about one incremental pilot rating when the pilot had the aid of DSFC as compared to when he had no DSFC. However, with this set of configurations, there were two instances of manual DSFC being rated worse than the airplane with no DSFC. One of these cases was pilot B's first evaluation and the other case was a repeat rating in which Pilot A assigned a pilot rating (PR) = 2 to a configuration which he had previously rated a PR = 8. Both of these cases will be discussed in detail in the paragraphs to follow. The configurations with automatic DSFC were rated better than, or equal to, the airplane with no DSFC in every case. From Figure 12, it can be seen that the pilot rating was essentially insensitive to the parameter ϕ/v_{cw}. All the configurations of this set met the Level 1 requirements of MIL-F-83300 except for spiral mode time to double amplitude for which all three configurations were Level 2.

4.3.1.1 Configuration 1, ϕ/v_{cw} = 0.21

This configuration was evaluated three times without DSFC and three times with manual DSFC. Four of the evaluations were performed by pilot B, two of which were on his first evaluation flight of the program. Pilot A performed the only evaluation of this configuration using the automatic DSFC system.

Without DSFC, pilot A found the only objectionable feature was that the airplane was fairly responsive to turbulence which caused a considerable increase in pilot effort. Though his turbulence effect rating of D reflects a moderate increase in workload in turbulence, the overall pilot rating of 4 was based largely on the airplane's response to turbulence. The pilot's crosswind landing technique was to use a crabbed approach until just before flare and to then convert to a sideslipping wing low attitude. The pilot found his aileron and rudder control adequate to perform the crosswind landing task. The tabulated data in Appendix III show that the RMS value of bank angle was quite small during the flare (ϕ = -0.8 deg) where the pilot stated

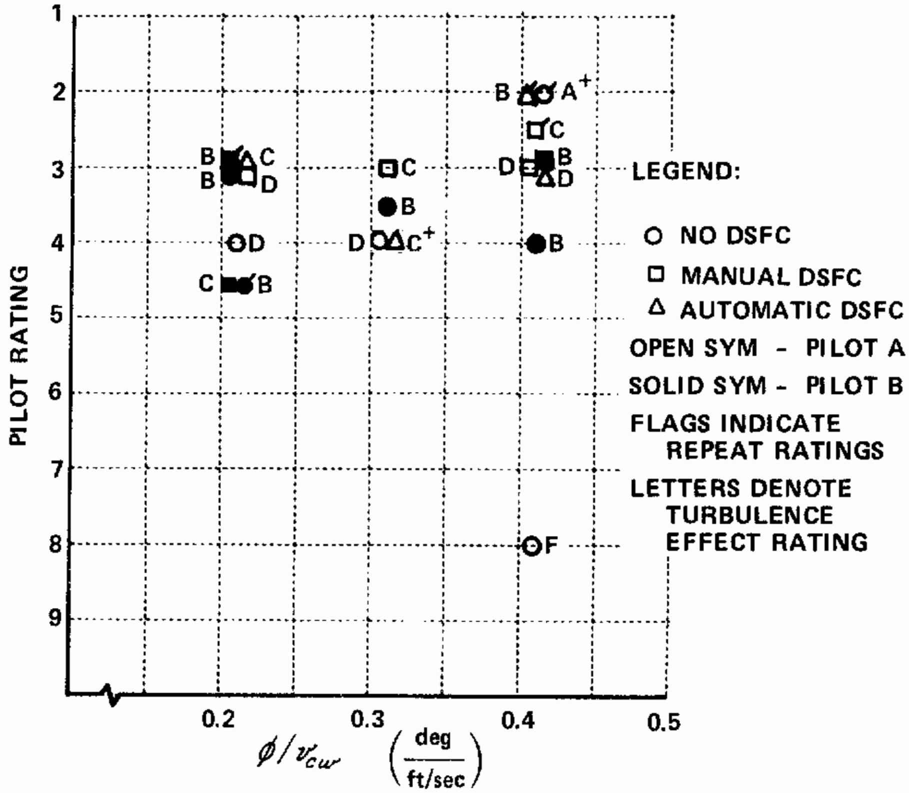


Figure 12 EFFECT OF DSFC ON CONFIGURATIONS 1, 5 AND 9 WITH N_β = 0.94 AND L_β = -1.57

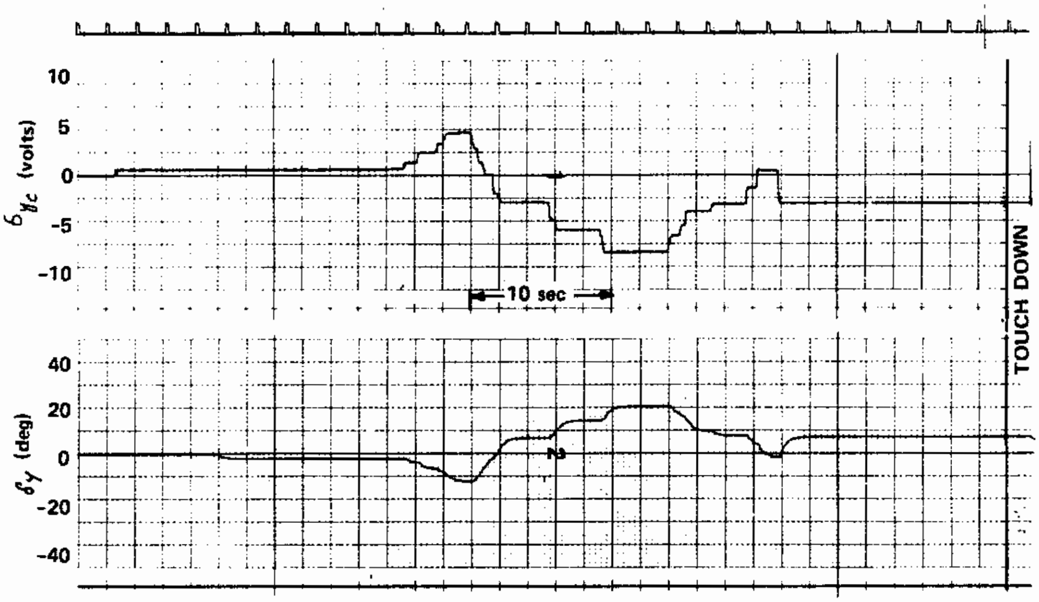
that he encountered a gust just before touchdown; however, the discrete value of bank angle at touchdown was ϕ = -4.0 deg. Evidently the pilot encountered difficulty in establishing the proper wing down landing attitude which supports his pilot rating of PR = 4. Pilot B on his first evaluation of this configuration, and his first evaluation in this program, had only minor objections to the airplane's handling qualities. These included a slow aileron trim rate, small yawing oscillations when aileron inputs were made, and the requirement to hold small aileron forces opposite to the direction of a steady state turn. He also noticed a tendency to PIO longitudinally during the landing flare. As a result he rated the airplane a PR = 3. On his repeat evaluation, near the end of the flight program, pilot B lowered his rating to PR = 4.5. His main objections during this evaluation were the large control forces , deflections required in flare, and the slow aileron trim rate. He stated that there was no significant difficulty in accomplishing the crosswind landing task other than the large rudder pedal forces and displacements required to maintain runway heading and alignment. During this evaluation the pilots' mean rudder pedal force was 67 lb and mean aileron forces were 7.2 lb during the landing flare. The mean sideslip during the landing flare was 7.8 degrees which indicates that the natural wind was larger than that quoted by the control tower or that the pilot overcorrected. In contrast, on his first evaluation of this configuration (PR = 3), pilot B's mean rudder and aileron forces were 34 lb and 4.2 lb, respectively. His mean sideslip was 4.5 degrees. Based on the above force comparison and the pilots' interpretation of the heavy forces as "considerable pilot compensation," the workload increase on pilot B's second evaluation with no DSFC as compared to his first accounts for the pilot rating of 4.5 versus PR = 3 for the first evaluation. It is noteworthy that the mean forces applied by pilot A were 34 lb and 3.4 lb on the rudder and aileron respectively, and his mean sideslip during the landing flare was 3.5 degrees. These force levels are nearly the same as those listed above for the PR = 3, pilot B case. Pilot A, however, downrated the airplane to a 4 because of its turbulence response while pilot B noted no significant deterioration in task performance with turbulence and assigned a turbulence effect rating of B on both of his evaluations.

With manual control of side force, pilot A found the airplane somewhat easier to land in a crosswind because he could eliminate the heading alignment problem. That is, he could land wings level with the airplane heading aligned with the runway heading. His objections centered, again, around the airplane's response to turbulence which made it difficult to determine how much side force input was necessary. He found that he used the sideslipping technique of dropping a wing to stop drift rather than using just DSFC, i.e., as the requirement for DSFC changed during the progression of the approach the DSFC was essentially left at a pre-selected setting while small drift variations were counteracted with bank angle changes. No adverse effects of DSFC on other aspects of aircraft control were noted.

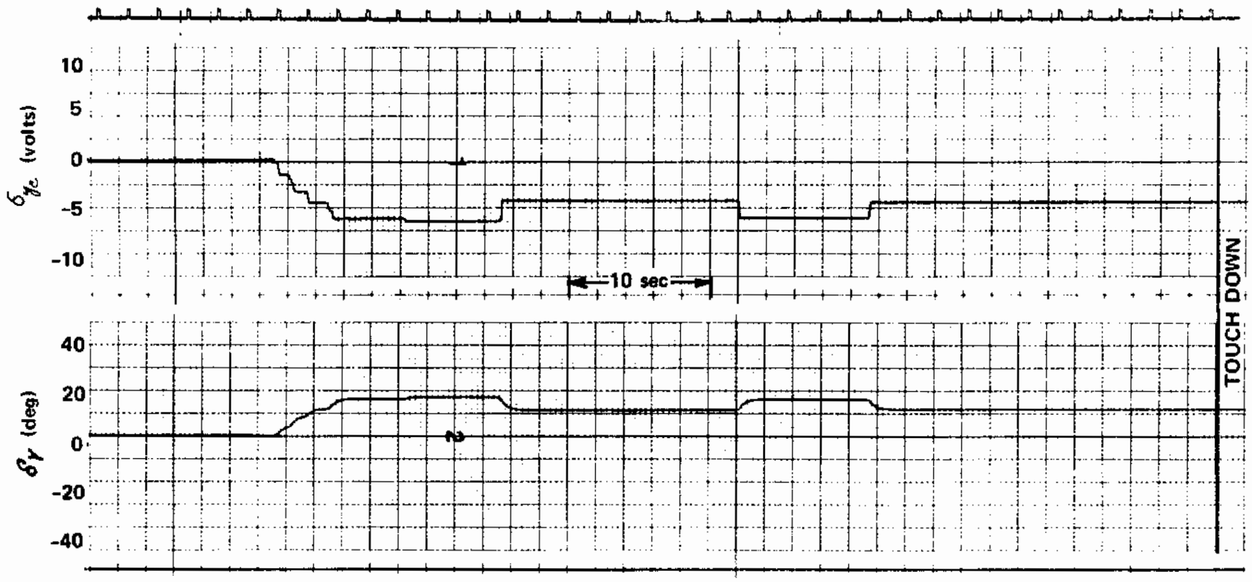
Pilot B, on his first evaluation with manual DSFC, had more difficulty in performing the crosswind landing than he did without DSFC. On this evaluation the pilot had a few minor complaints about normal aircraft control such as large aileron wheel displacements, slow roll response and a slight

Dutch roll oscillation accompanying aileron or rudder inputs. He had trouble, however, maintaining runway alignment using the DSFC controller. In the pilot's own words, "I was able to align easily with the runway initially and then seemed to have...some problems in maintaining runway alignment. I tended to overshoot the amount of side force control required and this deteriorated overall azimuth control. Although it was comfortable coming down final wings level in the crosswind, I did feel that I was not aligning with the runway to the point where I could make a precise touchdown as far as lateral displacements are concerned." Pilot B didn't feel he could properly coordinate aileron, rudder and DSFC inputs. An input of any of the three controls excited the Dutch roll oscillation. His primary objection to the configuration and the primary reason for his pilot rating of 4.5 was the inability to predict the necessary DSFC input. On his second evaluation of this configuration with manual DSFC, near the end of the evaluation program, pilot B stated that "The side force controller made the task much easier than when I performed the approach without the side force controller." He further commented that the airplane seemed well damped and none of the oscillations he had seen when flying without DSFC were present. Time histories of pilot B's side force controller usage are shown on Figure 13. On his first evaluation flight, PR = 4.5, with DSFC the controller was used almost continuously to a point and then left at a final setting. The side force was initially applied the wrong way and then there was over-control in the opposite, and correct, direction. This complicated the pilot's requirements for aileron and rudder inputs to maintain the required flight path. On the repeat evaluation, the pilot applied side force control initially in small steps and in the proper direction. As the landing approach progressed he made only three additional discrete corrections with the DSFC controller. He stated in his comments "I used the side force controller the way it was intended to be used...for aligning the aircraft with the runway heading." His method during the landing approach was to establish the airplane on runway lineup with a crab angle and then remove the crab angle using DSFC. As mentioned, pilot B assigned a PR = 3 using DSFC on this flight. His first DSFC pilot rating of 4.5 points out the need for allowance for a learning period, especially in this case where there was a new mode of aircraft control. In this experiment, therefore, during the early evaluations the technique of "how to use DSFC" evolved as well as an evaluation of the usefulness of DSFC.

Aileron and rudder mean force inputs when not using DSFC have been mentioned above. Rudder pedal forces as high as 67 lb and aileron wheel forces as high as 7.2 lb were used. With the aid of DSFC, neither pilot exceeded a mean rudder pedal force of 20 lb nor mean aileron wheel force of 3 lb. Mean sideslip angles during the flare with DSFC were larger than they were without DSFC. Hence, the pilots were able to develop the necessary sideslip to counteract the crosswind with the wings essentially level and with relatively light control forces. Therefore, the same task was accomplished with less work, holding smaller steady forces. If one considers the sideslip generated as an indicator of performance, then the task was accomplished better using DSFC.



(a) CONFIGURATION 1 EVALUATION FLIGHT NO. 14



(b) CONFIGURATION 1 EVALUATION FLIGHT NO. 21

Figure 13 EXAMPLE OF PILOT DSFC INPUT

The automatic mode of DSFC was evaluated only once with this configuration. The pilot listed the good feature as the fact that the pilot is relieved of the responsibility of alignment and has to be concerned only with control of power, the glide slope and the flare. The pilot objected to the lateral accelerations developed as the airplane tracked the ILS localizer with wings level using side force to maintain localizer and counter side gusts. Lateral accelerations of $n_y = \pm 0.1$ g experienced on the automatic approaches were largely a result of irregularities in the localizer signal which are common to many VHF ILS installations. Filtering of the ILS error signal eliminated small high frequency variations in the signal, however, the large, sharp irregularities could not be removed with filtering alone.

The system tracked to the left side of the runway centerline, a factor to which the pilot also objected. However, the automatic DSFC system did counteract the crosswind, maintain runway heading and position the airplane over the runway with the wings level relieving the pilot of this lateral-directional task. But, because of the pilot objections stated above, the pilot felt he could rate the airplane with automatic DSFC no better than PR = 3.

4.3.1.2 Configuration 5, $\phi / v_{cw} = 0.31$

Configuration 5 was evaluated by pilot A once for each mode of side force control, that is, without DSFC, with manual DSFC and with automatic DSFC. He found the crosswind landing task to be easier with manual DSFC, but he stated that the airplane with automatic DSFC was no better than it was without DSFC. With the automatic system, however, his problems were of a different nature from those he encountered with no DSFC. Pilot B rated this configuration with no DSFC on his practice evaluation. His pilot rating and comments are included in the results, but no quantitative data was extracted from the practice evaluation.

Without DSFC the pilot used the conventional crosswind landing technique of crab angle on final approach converting to a sideslipping wing low attitude prior to flare. He also tried a combination of sideslipping and crab on final approach so that the conversion to pure sideslip would be a maneuver of less magnitude. He stated that runway alignment was no problem until just before touchdown. At that point he felt that he "de-crabbed" without actually increasing the sideslip and therefore drifted across the runway. To complicate the decrab problem, the pilot noticed a "fairly substantial" rolling oscillation near the ground which he attributed to the effects of turbulence. As a result he felt his precision of control suffered during the flare where it was most important. Because of the poor precision of control just prior to touchdown, he assigned a pilot rating of 4, and because he attributed part of his difficulties to the airplane's response to turbulence, a turbulence effect rating of D was assigned.

Pilot B, on his practice evaluation, objected to the airplane's tendency to continue to roll in the direction of the turn which caused him to have to hold aileron force away from the turn. This feature was a result of the unstable spiral mode which had a time to double amplitude of 14.5 seconds. He also noted some yaw oscillations and a tendency for PIO longitudinally when trying to establish landing attitude. These deficiencies, of course, made the crosswind landing somewhat more difficult and resulted in a PR = 3.5.

With manual control of side force, pilot A noted that it was easier to establish the landing attitude in a crosswind, but he had difficulty in establishing the precise amount of side force to use. The pilot technique in this case was to make an initial side force input to align the aircraft properly and then make small iterations from the initial setting. There was sufficient side force available to counter the crosswind and no noticeable interference with other aspects of lateral-directional control. The pilot did encounter some difficulty with airspeed control which he attributed to turbulence, but he stated that the side force controller did not interfere with the throttle or elevator control. As a good feature, the pilot noted the ability to counter the crosswind drift and align the airplane with the runway using the side force control. The most objectionable feature was the airplane's response to turbulence disturbances. The pilot rating of 3 was assigned on the basis that the pilot thought his performance was not much better than it was without DSFC, but he felt that he got equivalent performance with less effort. The rudder pedal and aileron wheel force inputs during the cases without and with DSFC confirm that less pilot effort was required with the aid of DSFC. Using the conventional crosswind landing technique, the pilots' mean rudder pedal and aileron wheel forces were 35 lb and 4.8 lb, respectively, to generate 4.2 degrees of sideslip. With the aid of DSFC the mean forces were 8.6 lb and 0.8 lb on the rudder and aileron controllers, respectively. In this case, 3.8 degrees of sideslip was generated. It is interesting to note that the mean aileron wheel force with DSFC was less than the aileron wheel breakout force of 2.0 lb.

The automatic system was not considered by the pilot to be as good as the manual DSFC system. This system, as on previous evaluations, tracked the airplane on the left side of the runway and oscillated from side to side when tracking the ILS localizer. The oscillations were largely a result of the irregularities of the localizer signal. The pilot commented that, at times, the corrections to centerline seemed to be much larger than were warranted by his instrument indications. As a result of his dissatisfaction with the automatic system performance, the pilot attempted to superimpose his own inputs. He found it very difficult to override the system and also noted that it was difficult to ascertain whether his inputs were effecting a correction or the automatic DSFC was correcting the same way as his inputs. The only good feature the pilot could list was that localizer tracking was automatic and all he really had to be concerned about was longitudinal control. Because of the difficulties with automatic DSFC the pilot stated it was no better, in this case, than no DSFC at all, and assigned a pilot rating of 4. In turbulence there was quite a bit more activity of the airplane about the localizer with the automatic system engaged than there was out of turbulence.

4.3.1.3 Configuration 9, $\phi/v_{cw} = 0.42$

This configuration was evaluated three times with no DSFC, twice by pilot A and once by pilot B. With manual DSFC three evaluations were also performed, two by pilot A and one by pilot B. Two evaluations were performed using the automatic DSFC system, both by pilot A. The experimental results are presented on Figure 10, which shows a wide variation in pilot rating for this configuration without DSFC. With DSFC, manual and automatic, the pilot ratings are all in the PR = 2 to PR = 3 range. During the evaluations of this configuration by pilot B, the digital recorder in the TIFS airplane malfunctioned and it was impossible to extract any data on pilot control inputs or airplane state.

This configuration was evaluated by pilot A on the first evaluation flight of the program. Without DSFC a pilot rating of 8 with a turbulence effect rating of F was assigned. On a later repeat evaluation, evaluation flight number 10, pilot A assigned a pilot rating of 2 with a turbulence effect rating of A+, the "plus" indicating more than A but not as much as B. This anomaly in pilot rating was caused by several factors which affected the evaluations, not the least of which was turbulence. The first evaluation of this configuration was conducted with natural winds of twenty knots gusting to thirty knots varying in direction from thirty degrees left of runway heading to runway heading. That is, runway 28 was being used and the wind direction was 230 degrees variable to 280 degrees. The natural turbulence level was also high. As shown in Appendix III, σ_{v_g} was nearly five feet per second. The second evaluation flight for the day was cancelled because of the wind conditions.

On this first evaluation, without DSFC the pilot had some difficulty trimming the airplane. He stated that because of the responses of the airplane to turbulence that it was difficult to determine trim attitude. Longitudinal trim was affected by rapid changes in airspeed of ten to fifteen knots. He found the aileron forces were somewhat larger than he would like; his control sensitivity selection having been based on his previous practice flight. The pilot described his landing approach and runway alignment problems as follows:

> "The big problem I think is in trying to line up with the runway. I found that a fair amount of crab angle is required. I certainly wouldn't try to maintain the centerline by sideslipping the aircraft. The turbulence is fairly high and so it's pretty hard to tell what's going on with the sideslip. My aim here was to try to keep the flight path along the ground parallel or lined up with the centerline by crabbing the airplane. Closer to the runway I started to sideslip the airplane, dropping a wing and hopefully pointing the airplane down the centerline. I was not really able to do this.

I had a very difficult time controlling the drift and staying along the centerline to begin with, and in each case, I didn't want to drop the wing any more than I had which meant, of course, that I also had to crab a little bit and this gave me a pretty uncomfortable feeling. I think I made the comment on the second attempted landing, that I didn't think I could land it. Or I wouldn't try to land it. I had a combination of things going that time. The nose was way over on one side, crabbed in other words, and the wing down quite a bit and I think I did have a little bit of longitudinal problems there in attempting to find the ground. Also I let the airspeed get down quite a bit. It takes quite a bit of power by the way to keep the airspeed up and then the fact that we're in heavy turbulence makes it very difficult. One time I'd see 130 knots, the next time I'd see 145 knots and very quickly. I could control the sideslip okay with the rudder but, as I said, I just didn't dare drop the wing any more. Therefore, I limited my sideslip input."

The mean bank angle for this evaluation was 7.7 degrees with RMS bank angle about the mean approximately 1.0 degree. The large aileron force required to maintain this bank angle was cited as a possible contribution to longitudinal PIO tendencies. It was difficult for the pilot to make precise longitudinal inputs while holding large aileron forces. As a result of the difficulties described above, the pilot felt that, for the crosswind landing task, considerable compensation was required for aircraft control even though he described the airplane as "a pretty good airplane, well damped and reasonably responsive." Because of the turbulence level, the pilot noted that the evaluation could be accomplished but his best efforts were required, therefore, he assigned a turbulence effect rating of F.

The above evaluation without DSFC was followed immediately by an evaluation with manual control of side force. The natural wind conditions were the same as those described above. The recorded turbulence level during the flare and touchdown was σ_{v_g} = 3.6 ft/sec and σ_{u_g} = 5.3 ft/sec. On this evaluation, the pilot stated "I certainly would put this in the acceptable category with minimal pilot compensation." He had no complaints about trim or feel characteristics, however, the pilot explained that the feel characteristics were fine in up and away flight on the previous evaluation (without DSFC) but forces were high when trying to establish a steady state sideslip for landing. On this evaluation, during which he did not have to establish a large wing low sideslipping attitude for landing, the control forces were not burdensome to the pilot. The technique used with manual DSFC was to establish a crab angle on final approach with the airplane on extended runway centerline and then eliminate the crab angle with DSFC. Full authority of the DSFC was required; therefore, the pilot just set the side force controller at full deflection, left it there, and continued to fly the airplane normally. (The authority of the DSFC controller was increased prior to evaluation flight number 4.) Adequate side force authority was not available and a small amount of bank angle was required during the flare and touchdown. There was no interference of DSFC with other aspects of aircraft control. The pilot stated that good features of the configuration were the fact that he had a lot of help in countering the crosswind and that the airplane itself was a fairly comfortable airplane. His only objection was that he didn't have quite enough side force control authority. As a result, the airplane was rated a PR = 3. Turbulence still caused an increase in pilot effort and a turbulence effect rating of D was assigned.

On the repeat evaluation of this configuration, evaluation flight number 10, pilot A encountered none of the difficulties that he had on the first evaluation of configuration 9. He stated no objectionable features and said that everything about the airplane was "pretty good, even in the turbulence." The natural wind during this evaluation was variable at 70 degrees to 30 degrees to the left of runway direction at speeds of 10 knots or less. Of course, the natural wind was supplemented, as usual, with simulated crosswind to obtain a total fifteen knot crosswind, based on the wind reported by the air traffic control facility. However, the variable condition may have resulted in a crosswind component of less than fifteen knots at times during the evaluation. The recorded turbulence level, the combination of natural and taped, was quite low during the time of the landing, flare and touchdown with RMS values of approximately one foot per second. The only difference in the airplane configuration or feel system was that the aileron wheel force gradient had been reduced to 2.25 lb per inch prior to this flight in lieu of the 3.0 lb per inch used on his first evaluation of this configuration. Since the pilot listed no objectionable features and said everything about the airplane was "pretty good" with negligible deficiencies, a pilot rating of 2 was assigned. No significant deterioration with turbulence was noted.

With manual control of side force, the pilot lowered his rating to 2.5. He noted that there was a tendency to overcontrol with the side force controller and stated that perhaps the sensitivity of the side force controller should be decreased. Adequate side force control was available, however. The manual side force controller was indeed more sensitive than on the first evaluation of this configuration since total side force authority was increased, but maximum controller deflection was not changed. The difficulty of precision of side force control was essentially the pilot's only objection to the configuration. He also noted, however, an apparent increased response of the aircraft to turbulence over that experienced on the previous evaluation without DSFC, which caused some deterioration in his performance. As shown in Appendix III, the σ_{v_g} was approximately double that of the previous evaluation without DSFC.

Pilot B also evaluated this configuration. Without DSFC, his objections centered around high aileron wheel forces with excessive aileron trim required and a slow aileron trim rate, large rudder pedal forces and apparent lags in the aileron and rudder control systems. He felt that it took too long for the airplane to respond after making a rudder input. He also noted that the initial roll response was slow and it was difficult for him to predict the final roll response. As a result, runway alignment was difficult and the pilot stated that he didn't think he ever stopped the yaw rate because of the rudder pedal forces. Because of these difficulties, he assigned a pilot rating of 4 noting that there was no significant deterioration in task performance with turbulence. With manual DSFC, pilot B had the same general comments about control forces and feel system, though to a lesser degree, as he did on the evaluation without DSFC. He still objected to the large rudder forces, but since he was able to align the airplane for landing with DSFC, he had no difficulty with runway alignment when countering the crosswind. Therefore, he rated the airplane a PR = 3, again noting no significant deterioration in performance because of turbulence.

In view of pilot A's comments on his first evaluation of this configuration, "considerable compensation required for aircraft control" and on the second evaluation, "negligible deficiencies" it is worth delving somewhat deeper into the pilot effort involved in the two evaluations. On the first evaluation, PR = 8, the airplane was landed with 4.6 degrees of sideslip. The mean rudder pedal force for the flare and landing was 40 lb and the mean aileron wheel force was 5.9 lb. RMS force inputs about the above mean were 16 lb and 3.5 lb for the rudder and aileron respectively. On the repeat evaluation, PR = 2, the mean rudder pedal and aileron wheel forces were 35 lb and 5 lb, respectively, with 4.0 degrees of sideslip being generated during the flare and landing. The RMS force inputs about the above means were only 4.2 lb and 1.2 lb for the rudder and aileron forces, respectively. The mean forces for the PR = 2 case were somewhat lower than for the PR = 8 case, but it is probably more important to note that the RMS value about the mean for the PR = 8 case were approximately three times those recorded for the PR = 2 case. It appears that the pilot objected much less to holding the steady force if he did not have to make large inputs about the steady force level. Of course, if the airplane was continually being upset by turbulence when the pilot was attempting to maintain a steady sideslipping condition near the ground, then rapid, and evidently large, transient control inputs were required to be superimposed on an already large steady force. This obviously presented the pilot with a quite difficult task. It can also be noted from Appendix III that the pilot's RMS about the mean aileron and rudder force inputs were generally larger when he had the aid of DSFC as compared to the cases without DSFC. However, the high RMS force inputs with DSFC were about a lower mean force level. For the first evaluation of this configuration, with DSFC, the mean rudder pedal and aileron wheel forces were 10 lb and 1.8 lb, respectively. On the repeat evaluation with DSFC, they were very low, at 0.7 lb and 0.3 lb, respectively. Except for the 10 lb rudder pedal force, the above force levels, with DSFC, were below the breakout force.

Other investigators, Reference 15, have found that poor pilot ratings were usually accompanied by a lot of control activity at the higher frequencies. It has been shown above, in the case of configuration 9, that large RMS values of control force inputs were accompanied by a poor pilot rating, but the RMS value provides no information on frequency content. Figures 12 through 15 show Power Spectral Density (PSD) plots of pilot A's aileron and rudder force inputs for his evaluations of Configuration 9 with and without DSFC. The power spectra on each figure have been multiplied by frequency and plotted on a linear scale versus frequency on a log scale. In this way, the area under the plotted curve between two frequency values is proportional to the mean square controller force in that frequency band. Figure 14 compares the power spectra of aileron wheel force for the two evaluations by pilot A of Configuration 9 with no DSFC. The PR = 8 case shows considerably more control activity, and hence, more pilot effort than the PR = 2 case. There is also a higher frequency peak in control activity in the PR = 8 case around 0.7 Hz, which agrees with the findings of Reference 15 that poor pilot ratings are usually accompanied by control activity at the higher frequencies. Figure 15 shows the power spectra of the pilot's aileron wheel force inputs when he was using manual DSFC. These power spectra show considerably more control activity than the case without DSFC. Even though the control activity is greater on the PSD plot when the pilot had DSFC, the pilot rating was PR = 3 versus PR = 8 without DSFC. In the case with DSFC, however, it must be remembered that the pilot was making the inputs about a much lower mean aileron wheel force level since he did not have to "hold the wing down" as he would in a sideslipping conventional crosswind landing. Therefore, it is probable that the pilot was able to devote his attention to suppressing transient motions of the airplane due to gust upsets and wind shear rather than maintaining a sideslip using aileron and rudder. As a result he was able to attain better performance, in his own estimation, which is reflected in the pilot rating. Figures 16 and 17 show the power spectra of the pilot's rudder pedal force inputs. In the case without DSFC, PR = 8, the pilot's rudder control activity was considerably greater than it was for the case with DSFC, PR = 3. For the repeat evaluation, more activity is noticed in the case with DSFC, PR = 2.5, than for the case without DSFC, PR = 2. The rudder control force activity somewhat contradicts, in terms of pilot effort, the above statements about aileron force activity and so it is difficult to determine on which controller the pilot places emphasis in evaluating his effort. In this case, it was noted, however, that pilot A complained more about aileron forces and stated "I'm not worried much about the rudder, but the aileron forces are somewhat high." Pilot B, on the other hand, had rather strong objections about rudder forces as well as aileron forces. The data listed in Appendix III for all configurations that he evaluated shows that pilot B's rudder force levels were usually higher in the no DSFC cases than those of pilot A, and the sideslip angles he attained were greater. Unfortunately, it was impossible to obtain PSD plots for the evaluation of configuration 9 by pilot B because of digital recorder problems.

Configuration 9 was evaluated twice by pilot A with automatic DSFC and was rated PR = 3 with a repeat rating of PR = 2. On the first evaluation,

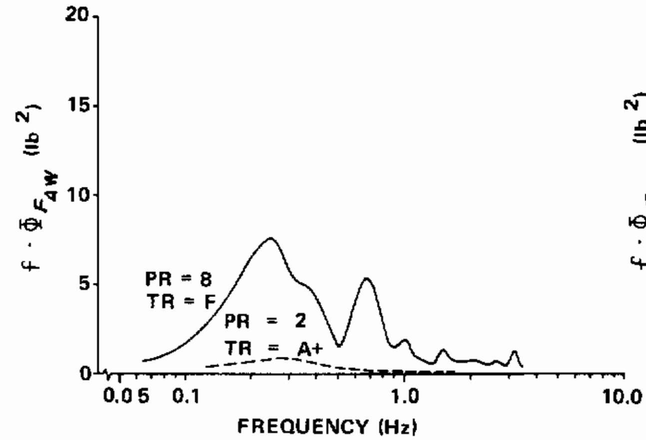


Figure 14 POWER SPECTRUM OF AILERON WHEEL FORCE INPUTS WITHOUT DSFC, CONFIGURATION 9

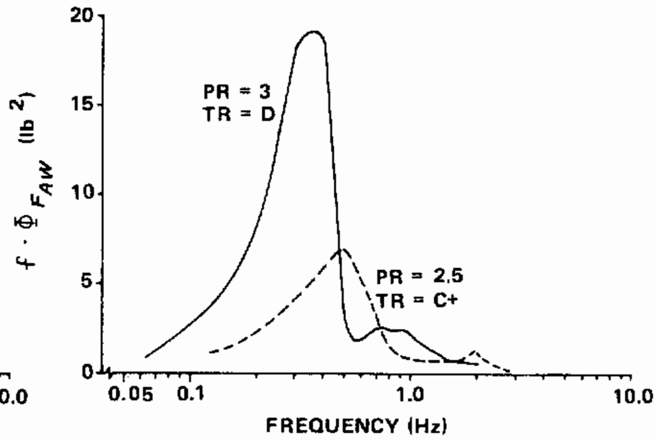


Figure 15 POWER SPECTRUM OF AILERON WHEEL FORCE INPUTS WITH MANUAL DSFC, CONFIGURATION 9

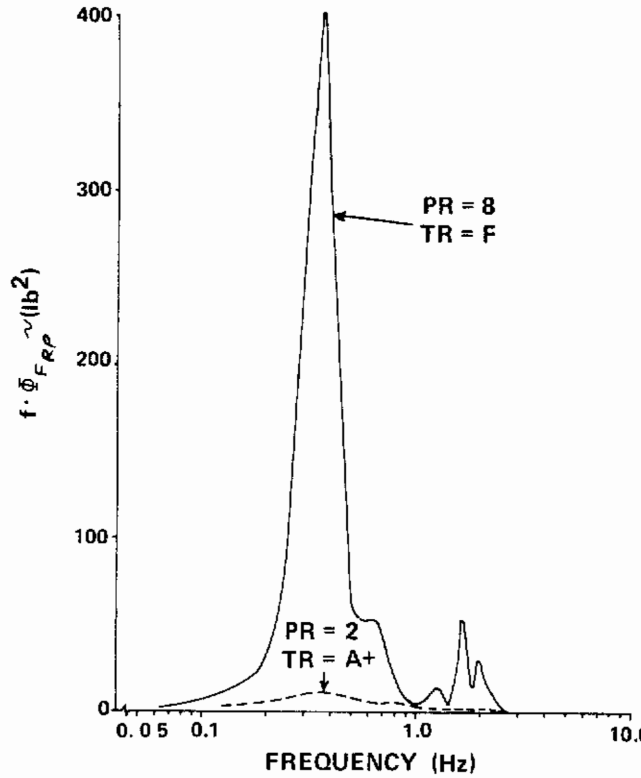


Figure 16 POWER SPECTRUM OF RUDDER PEDAL FORCE INPUTS WITHOUT MANUAL DSFC, CONFIGURATION 9

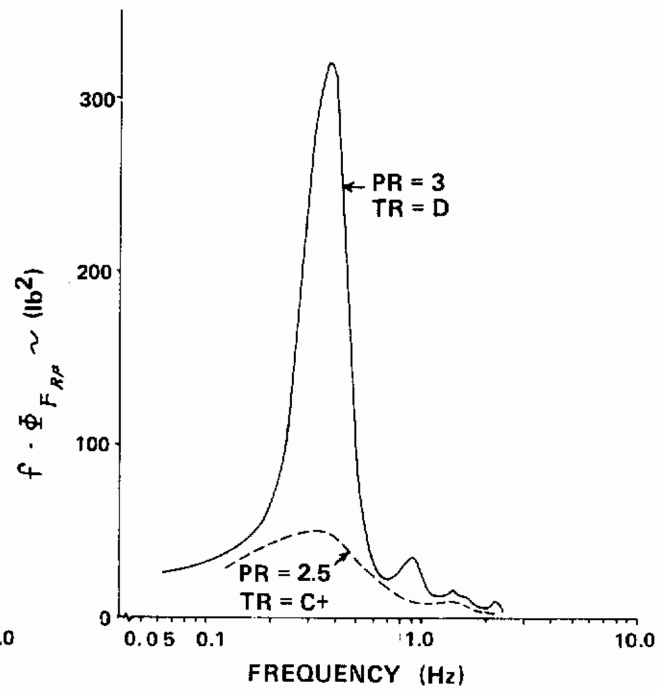


Figure 17 POWER SPECTRUM OF RUDDER PEDAL FORCE INPUTS WITH MANUAL DSFC, CONFIGURATION 9

performed in the high wind conditions previously described, the pilot stated that the automatic system maintained the airplane on runway centerline but there was some crab angle during the flare. He superimposed his inputs on the automatic system inputs to attempt to correct the heading error. The airplane was in an acceptable attitude for landing. The pilot, for the most part, merely flew the airplane longitudinally and let the automatic DSFC system do the rest. The good feature was the fact that there was no requirement for the pilot to be concerned with runway alignment. The only objection was the heading angle error. On the repeat evaluation, the only objection the pilot stated was that there was more lateral activity than he thought there should be. The good feature was, again, the fact that runway alignment was taken care of for the pilot and he could devote more of his attention to the glide path, flare and touchdown.

4.3.2 Configurations with N_β = 0.94 and L_β = -2.95 (Configurations 2, 6 and 10)

Figure 18 shows the experimental results for these configurations as a function of ϕ/v_{cw}. Comparing the cases with no DSFC to manual DSFC, there is an incremental pilot rating, Δ PR, improvement of Δ PR = 1 to Δ PR = 1.5 when using manual DSFC. The automatic DSFC system resulted in an improvement of Δ PR = 1.5 to Δ PR = 2 except in one case for which no improvement in pilot rating was attained. The above rating improvements were in several cases across a major division of the pilot rating scale improving the airplane from "deficiencies warrant improvement" to "satisfactory without improvement." The amount of bank angle required to complete the crosswind landing, without DSFC, does not appear to affect the pilot rating significantly. It is rare in the pilot comments that either pilot objected to the amount of bank angle required.

Configuration 10 met the Level 1 requirements of MIL-F-83300. Configurations 2 and 6 did not meet the Level 1 sideslip excursion requirements and Configuration 2 also failed to meet the Dutch roll damping ratio requirement of MIL-F-83300.

4.3.2.1 Configuration 2, ϕ/v_{cw} = 0.21

Configuration 2 had the lowest value of ϕ/v_{cw} and, therefore, the lowest value of Y_β , for this group. Without DSFC, the pilot's primary objection was the low Dutch roll damping ratio. This configuration had a Dutch roll damping ratio, ζ_d = 0.071. He commented that he had to "stay right on top of the airplane to position it properly, especially in bank." He also found that having to pay such extensive attention to the lateral-directional control affected the longitudinal control. In turbulence the airplane was in a constant lateral-directional oscillation, which affected the pilot's ability to precisely control attitude; this was especially true when the pilot attempted to maintain a steady bank angle and sideslip for the crosswind landing. Directional control was also a problem in that the rudder control seemed oversensitive for damping the Dutch roll oscillation, yet, the rudder felt about right for maneuvering the aircraft. Because of

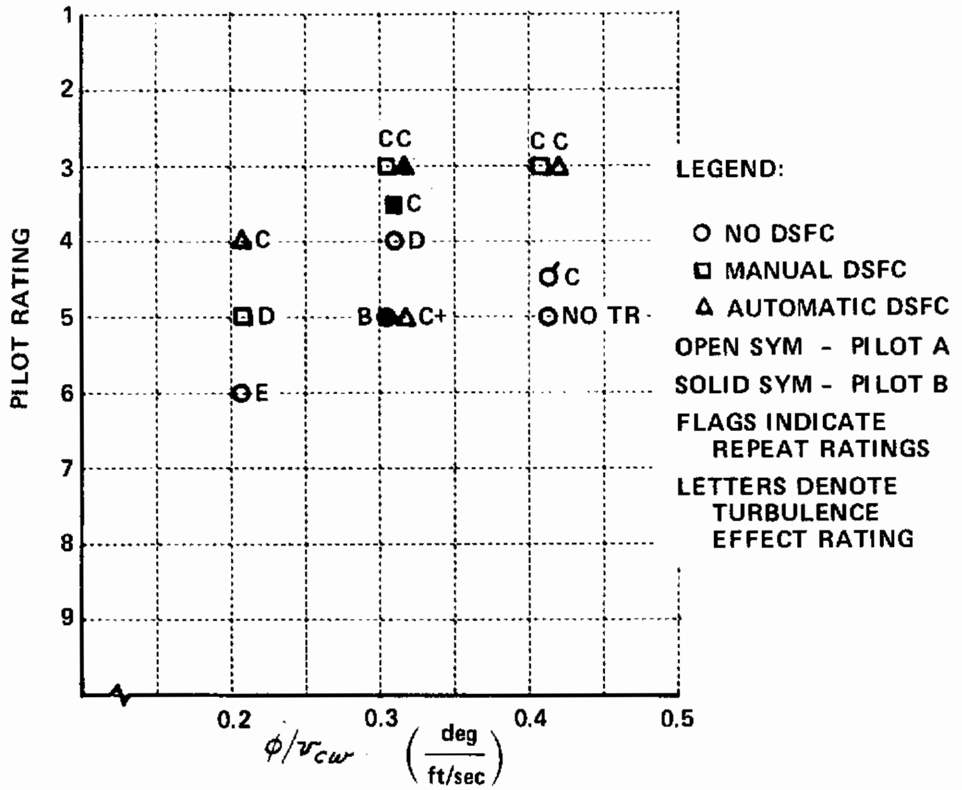


Figure 18 EFFECT OF DSFC ON CONFIGURATIONS 2, 6 AND 10 WITH N_β = 0.94 AND L_β = -2.95

the lack of precision of bank angle control and the constant oscillations the airplane was rated PR = 6. The constant excitation of the Dutch roll by disturbance inputs resulted in a turbulence effect rating of "E". For this configuration, the airplane was adjudged to have a good level of control forces and sufficient control power to control attitude within the expectations of the pilot.

With manual DSFC the pilot stated as an initial impression "there is no question that the pilot effort has decreased. " He found that there was still a fair amount of effort with the airplane in turbulence but he could align the airplane with the runway, keep the wings level, and devote more of his attention to damping the turbulence induced disturbances of the airplane. To align the airplane with the runway, the technique was to establish a crab angle and then make corrections with the DSFC controller to establish the proper heading with no drift. The pilot did, however, have difficulty in determining the precise amount of side force to use, a factor which he contributed to the continuous Dutch roll oscillation. The use of DSFC did not, in the pilot's opinion, interfere with any other aspects of aircraft control. So the advantage of DSFC was the ability to align the airplane with the runway with reduced pilot effort from that required for the no DSFC case. The pilot's major objection to this configuration was again the low Dutch roll damping ratio and the difficulties in maintaining a constant bank angle. There was still a moderate deterioration of performance in turbulence, but because the pilot could devote more attention to damping the airplane when using DSFC, both the pilot rating of 5 and turbulence effect rating of D were better than for the case with no DSFC.

With automatic DSFC there was a further improvement in pilot rating, PR = 4, but the pilot qualified the rating by stating he would have to ignore the lateral oscillation about the ILS localizer. The airplane continuously "hunted" from side to side while tracking the localizer, which was a primary problem with the automatic DSFC system. The piloting task, however, was reduced to a longitudinal control problem, which relieved the pilot of the lateral-directional control and runway alignment task. Since the pilot had only to contend with longitudinal disturbances, the turbulence effect rating was improved to "C".

The tabulated data in Appendix III show that with no DSFC the mean sideslip during the flare was approximately 5.5 degrees and with the manual DSFC it was 6.3 degrees. Slightly more sideslip was developed using the DSFC which may be considered as slightly better performance. Pilot workload may be assessed by comparing the aileron and rudder force inputs.

The mean value of the aileron wheel forces during the landing flare was 9.5 lb without DSFC as opposed to 3.9 lb with DSFC; however, the RMS inputs about the mean were 1.6 lb with no DSFC and 3.2 lb with DSFC. The rudder pedal forces were also quite different. Without DSFC the mean rudder pedal force was 53 lb and with manual DSFC the mean rudder pedal force was 15 lb. The RMS rudder pedal force about the mean was about 7 lb in both cases. If the necessity for the pilot to maintain steady aileron wheel and rudder pedal force is interpreted as workload, then certainly the pilot was substantially relieved of this workload during the crosswind landing with the aid of DSFC. The higher RMS about the mean of aileron wheel force when using DSFC confirms that the pilot was able to devote more of his attention to suppressing disturbance induced motions and, hence, attaining better performance with DSFC.

With the automatic system, the pilot workload was obviously reduced because the pilot task was reduced to single axis control. The pilots objections to the automatic system are directed more toward the system performance than toward pilot workload.

4.3.2.2 Configuration 6, $\phi / v_{cw} = 0.31$

As shown in Figure 18, this configuration was evaluated by both evaluation pilots. Without DSFC pilot ratings of 4 and 5 were assigned by pilots A and B, respectively. Pilot A had no strong objections to the configuration except that his performance in turbulence was not as good as he would have liked. He found the roll control adequate, but directionally the airplane felt a "little loose." The pilot mentioned that the airplane was a bit sluggish longitudinally. The control feel characteristics were satisfactory. The reason for the pilot rating was that the pilot was not satisfied with the performance he achieved. He mentioned this specifically for the last landing he made. The mean sideslip during this landing was approximately 2 degrees when 6.5 degrees was required to completely counter the crosswind. The largest sideslip that pilot A achieved for this configuration was 2.2 degrees. Pilot B achieved better performance in terms of sideslip, a mean value of 6.0 degrees, but objected to excessive aileron wheel displacements, large directional control displacements and heavy rudder pedal forces while establishing the flare and during runway alignment. Pilot B had no other strong objections to the configuration but did mention some difficulty with minor roll oscillations. The primary reason for his rating was stated as "the lack of ability to really establish good landing attitude and runway alignment." Pilot B's mean aileron wheel and rudder pedal forces were 12.6 lb and 66 lb, respectively, while pilot A used mean values of aileron wheel and rudder pedal forces of 6.1 lb and 24 lb, respectively; therefore, to achieve the greater sideslip in his crosswind landing, Pilot B expended considerably more effort than Pilot A and this is reflected in his rating.

With manual control of direct side force, pilot A raised his rating to PR = 3 and pilot B to PR = 3.5. The only objection pilot A had to the airplane was again "its loose directional characteristics." He used the DSFC to eliminate his crab angle by stopping the side velocity and aligning the airplane heading with the runway heading. He had some difficulty in establishing where to put the side force controller because the turbulence induced motions of the airplane made it difficult to precisely determine the crab angle. Pilot A stated "there was certainly a definite and very noticeable improvement when I was able to eliminate the crosswind with the side force control." Pilot B also used the side force controller to align the airplane with the runway from a pre-established crab angle. He stated that "runway alignment was no problem when using DSFC and it eliminated the need for relatively large directional and lateral control inputs." Neither pilot noticed any interference of DSFC with any other aspects of aircraft control. Pilot A did mention, however, that his lateral-directional control inputs slightly affected his longitudinal control.

The pilots' control force levels with and without DSFC and the mean sideslip developed during the crosswind landing are tabulated in Appendix III. Pilot A's mean rudder pedal forces reduced from 24 lb without using DSFC to 12 lb when using DSFC. His aileron wheel mean force level was reduced from 6 to 3 lb. Pilot B, however, reduced his mean rudder forces from 66 lb without DSFC to 18 lb with DSFC and his aileron forces from 12.5 to 3.06 lb. Again, interpreting the steady forces as a measure of pilot workload, both pilots were relieved of workload when using the DSFC.

With the automatic DSFC system, pilot A assigned a PR = 5 and pilot B assigned a PR = 3. As mentioned earlier, the automatic system underwent refinement during the evaluation program. This configuration was evaluated by pilot A on evaluation flight number 3 and by pilot B on evaluation flight number 22. Hence, the two pilots' rating of the automatic system varied considerably. On evaluation flight number 3, the automatic DSFC system successfully maintained the proper heading and eliminated side velocity due to crosswind but it aligned the airplane with the left edge of the runway. The pilot considered this aspect of the system as a definite hazard. Because of this hazard, the pilot attempted to superimpose his own inputs on the autopilot inputs to properly align the airplane. He found that the control forces were quite high and that it was very difficult to displace the airplane. He stated that under these circumstances he would have preferred not to have a DSFC at all and to just land the airplane using conventional techniques. Further he objected to the continuous lateral accelerations, n_y , to which he was exposed as the airplane hunted back and forth across the extended runway centerline while following the localizer. These n_y excursions were a maximum of ±0.1 g during this evaluation. Pilot B stated that "although this is my first series of automatic approaches that I have evaluated, I am perfectly well satisfied with the system." He further stated, "there is no doubt that the task is easier with side force control, automatic or manual, than without it." On this evaluation, the airplane was still left of runway centerline at touchdown but it was safely over the runway.

4.3.2.3 Configuration 10, ϕ / v_{cw} = 0.42

On the first evaluation of this configuration, without DSFC, no turbulence effect rating was assigned because of an in-flight difficulty in the random disturbance system. The difficulty was corrected in flight before the configuration was evaluated with DSFC. On his first evaluacion of this configuration, without DSFC, the pilot complained about the large aileron wheel forces required to establish the proper attitude for a sideslipping crosswind landing. He commented that the control sensitivity and feel characteristics were good in up and away flight, but close to the ground, during the flare, both hands were required on the aileron wheel. The pilot had no objections to the aircraft responses to control inputs. Roll control was judged as "reasonable," directional control and coordination were "no problem." Pitch response was somewhat sluggish. Because of the large aileron forces required, the pilot felt that his longitudinal control was affected. He found it difficult to make small precise elevator inputs while maintaining large aileron forces. As a result of the aileron forces and the associated pilot effort, the configuration was rated PR = 5. On his repeat evaluation near the end of the evaluation program, the aileron force gradient had been changed to 2.25 lb per inch. Control forces were judged as good in up and away flight. During the landing, however, aileron forces were still too large. Again, the pilot had no significant objections to the configuration except the aileron force required and the associated difficulty in establishing the proper crosswind landing attitude. The pilot also noticed on this evaluation that his aileron control caused imprecision in his elevator control or vice versa because of large steady forces. Hence, he rated the configuration PR = 4.5 for the same reasons that he had previously assigned a PR = 5.

With manual DSFC, the pilot stated "it sure is a much better way to make the approach, you don't have to worry about aileron forces at all." Thus, his main objection to the configuration without DSFC was removed. Otherwise his difficulties were concerned with determining the precise amount of DSFC to use. For this configuration, there is evidence that the pilot overcontrolled the DSFC and by doing so created an apparent crosswind from the right when his actual crosswind was from the left. This is evidenced by the mean value of sideslip of -8 degrees during the landing flare and a small positive bank angle, ϕ = 1 degree, with which he was attempting to overcome the apparent right crosswind. DSFC was not found to effect the normal lateral-directional control. There was still some tendency to PIO longitudinally during the flare but the pilot was reluctant to make any changes in the longitudinal control feel or sensitivity. He stated that the longitudinal control feel was good for the longitudinal response of the airplane and was in harmony with the aileron control system.

With automatic DSFC, the pilot liked the reduced effort in maintaining runway alignment and heading, but objected to the large side accelerations that were generated as the airplane followed the VHF localizer signal with its inherent irregularities or "sharp bends." Side accelerations of $n_y = \pm 0.15$ g were experienced during this evaluation. There was also the tendency for the airplane to be off runway centerline at flare and touchdown on one of the landings, but on the first landing of this evaluation the airplane was lined up very well and on centerline. The pilot felt that he had better control of glide path and airspeed when using the automatic system, but stated that overall he would prefer the manual DSFC because of the large n_y experienced with the automatic system.

Reference to the tabulated data in Appendix III shows that the pilot was able to generate larger mean sideslip during the crosswind landing with DSFC than he was without DSFC. Based on the requirement of β = 6.5 degrees to counter a 15 knot crosswind, better performance was attained when using the manual DSFC. The pilot actually overcontrolled (i.e., crabbed) when using the manual DSFC and was able to obtain 8 degrees of sideslip, as opposed to 2.3 and 4.2 degrees when using conventional crosswind landing techniques. The pilots' mean aileron wheel and rudder pedals forces when using manual DSFC were less than half the values used without the aid of DSFC.

In all of the evaluations of this configuration, except the case without DSFC where no turbulence effect rating was assigned, some increase in workload was attributed to the effects of turbulence disturbances of the airplane. In each case this was adjudged as a minor increase in effort and turbulence ratings of C were assigned.

4.3.3 Configurations With N_β = 0.42 L_β = -1.57 (Configurations 3, 7, and 11)

Only pilot A evaluated these configurations, with a repeat evaluation of the middle ϕ / v_{cw} configuration. Figure 19 presents the results as a function of required bank angle per unit crosswind velocity ϕ / v_{cw}. Included in Figure 19 is the turbulence effect ratings and the type of evaluation (no DSFC, manual DSFC or automatic DSFC). As shown, most of the pilot ratings improved at least one pilot rating with DSFC as compared to no DSFC. The one exception will be discussed in the following subsections. None of these configurations met the Level 1 sideslip excursion requirements of MIL-F-83300. Configuration 3 also failed to meet the Level 1 bank angle oscillation requirements of MIL-F-83300.

4.3.3.1 Configuration 3, ϕ / v_{cw} = 0.21

During each of the approaches without DSFC, pilot A indicated difficulty in establishing the proper aileron and rudder inputs to obtain the necessary bank angle to align the airplane with the runway. He tended to overcontrol with rudder and decrab more than he should, thus drifting across the runway. Aileron and rudder forces were large enough to become bothersome and the pilot noted that there seemed to be coupling between them. He stated that maybe his problems were associated with the roll to sideslip ratio, $\left|\frac{\phi}{\beta}\right|_d$, rather than just the control forces. For this configuration, $\left|\frac{\phi}{\beta}\right|_d \approx 1.5$.

The pilot also complained about the "rolly" characteristics of the airplane. The most bothersome feature, however, was the responsiveness to turbulence. He stated that he had "to work fairly hard to overcome just the [Dutch roll] disturbance from the turbulence" and this factor was the main reason for the PR = 5 and a turbulence effect rating of D+.

Pilot comments were similar with manual DSFC to the comments without DSFC. The major objections to the airplane were the roll oscillations and the excessive response to turbulence. Due to the rolling characteristics, runway alignment was difficult which in turn produced a hunting tendency to find the

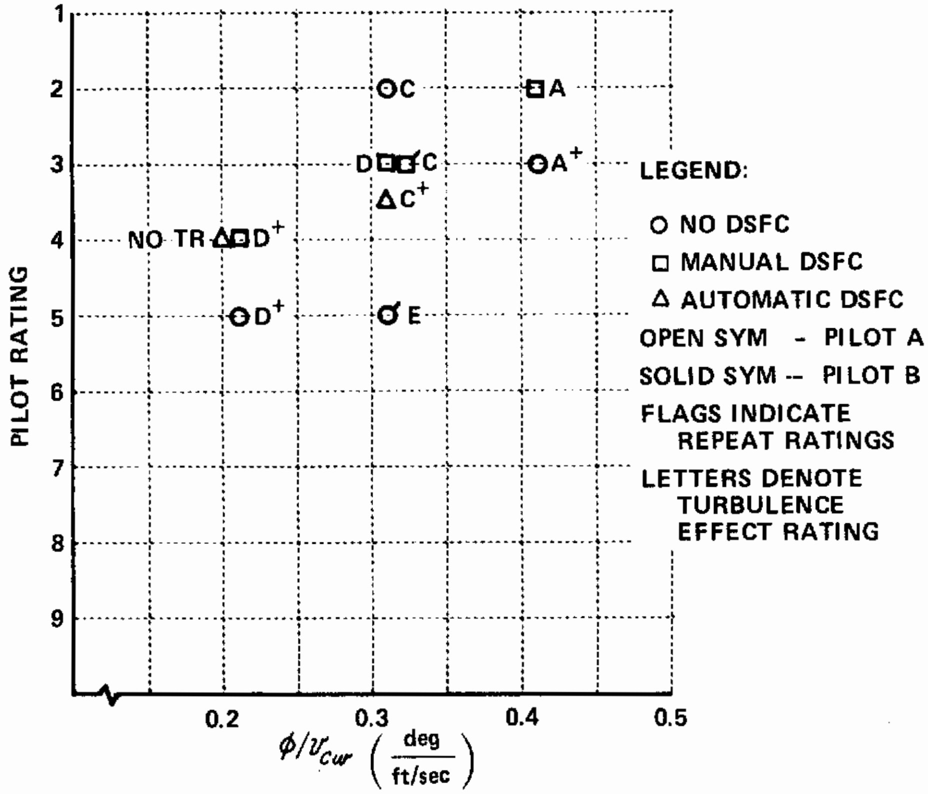


Figure 19 EFFECT OF DSFC ON CONFIGURATIONS 3, 7 AND 11 WITH N_β = 0.42 AND L_β = -1.57

proper DSFC position. Despite these difficulties he felt he had "better performance with a little more precision -- [and] had things under better control with the manual DSFC." As a result he upgraded the aircraft one pilot rating to a 4, while the turbulence effect rating remained the same, D+.

Only one approach using automatic DSFC was flown due to poor visibility. A pilot rating of PR = 4 was assigned based on this approach. The pilot's major complaint was the hunting on both sides of centerline caused by the automatic system. No turbulence rating was given since the configuration was not flown in turbulence.

The performance obtained during the no DSFC approaches was not as good as it should have been since the pilot mentioned he drifted to the right during the landing. He was not sure if this was due to excessive decrabbing or not enough bank angle. The bank angle required to counter a 15 knot crosswind with the lower ϕ/v_{cw} was approximately five degrees, but the pilot obtained only 2.3 degrees of mean bank angle and a mean sideslip of 4.5 degrees indicating not enough bank angle. The aileron and rudder forces were 4.5 lb and 24 lb, respectively, which he said was high enough to be bothersome. The pilot's difficulty in suppressing the effects of turbulence can be seen from the RMS values of aileron and rudder forces. These values (2.8 lb and 7.6 lb) are reasonably high with respect to the mean values. The pilot based his pilot rating (PR = 5) primarily on the difficulties he had in countering the turbulence induced roll oscillations of the airplane.

With manual DSFC the pilot was able to obtain 4.3 degrees of mean sideslip with nearly zero bank angle. The sideslip is nearly the same as the approach without DSFC, however, his mean aileron and rudder forces were drastically reduced. Aileron forces decreased from 4.51 lb to .53 lb, while rudder forces decreased from 24 lb to only 5.1 lb. The pilot was able to perform the same task with much less effort. The major complaint for the manual DSFC approaches was again the airplane response to turbulence. The difficulty the pilot had damping out turbulence induced roll oscillations is reflected in the RMS values of aileron and rudder forces. These values were 3.7 lb and 11.5 lb, respectively. Due to these large RMS values, the pilot upgraded the airplane only one pilot rating from the no DSFC case.

Digital data for the automatic DSFC case is presented in Appendix III. Since only one automatic DSFC approach was flown, no discussion on these numerical values will be presented.

4.3.3.2 Configuration 7, ϕ/v_{cw} = 0.31

On his first evaluation of this configuration without DSFC, the pilot complained only of "a little bit of rolling oscillation." The turbulence effect and wheel forces were minor enough that "pilot compensation was not a factor for the desired performance." As a result he rated the configuration a 2. Turbulence caused only minor deterioration of performance which appeared as very small bank angle oscillations and, therefore, the turbulence effect rating he assigned to this configuration was C.

With manual DSFC, the pilot based his opinion largely on the last approach. The pilot stated that he was either hit with a heavy gust near the end of the approach or that he was overcontrolling with rudder. In either case, he had difficulty with lateral-directional oscillations of the airplane. He noticed that throughout the manual DSFC approaches, there was a higher level of turbulence than there was for the evaluation without DSFC. The RMS gust intensities shown in Appendix III confirmed that, indeed, there was more turbulence during the evaluation with DSFC. The lateral-directional oscillation due to turbulence was the only degrading remark the pilot made about this configuration. As a result, his overall pilot rating with DSFC, PR = 3, was worse than the PR for the no DSFC case. Turbulence effect rating was also increased from C to a D.

Pilot A's comments for the evaluation of the automatic system was similar to the manual DSFC evaluation. He felt the gust to be higher, especially during the last part of the approach. At the same time, the automatic system would try to correct for the disturbance and align the airplane causing a fair amount of side acceleration which was disconcerting to the pilot. "The deficiency with the automatic system is that it's difficult to superimpose precise corrections over the autopilot." The pilot stated that he liked the automatic DSFC less than the manual DSFC because of his inability to make necessary control inputs. His pilot rating of 3.5 reflects the minor difficulties encountered with automatic DSFC.

On his repeat evaluation of this configuration without DSFC, pilot A stated that he thought the Dutch roll damping ratio was a bit low (ζ_d = 0.17). Dutch roll oscillations were particularly noticeable in turbulence. He also complained about low directional stiffness and oversensitive rudder control. Rudder inputs also appeared to the pilot to induce large rolling moments which the pilot recognized as a tendency for "the rudder....to overpower the aileron." The oversensitive rudder control can be attributed to the low value of N_β of this configuration with the same value of N_{δ_r} that was used for the higher N_β configurations. Because of the above deficiencies, particularly the response to turbulence, the pilot assigned a PR = 5 and a TR = E stating that the turbulence response was the major degrading factor.

The comments during the repeat evaluation with manual DSFC were similar to the comment of the repeated evaluation without DSFC. The pilot complained of the Dutch roll oscillations particularly in turbulence. He felt that the Dutch roll damping was a bit lower than he would have liked. Again, he mentioned a tendency to overcontrol when using rudder which aggravated the oscillations. Despite these complaints, he stated that it "is a much better airplane than --- without side force" citing the fact that the coordination problem disappeared because he didn't have to use bank angle and he could suppress the disturbances due to turbulence using just the aileron control. The pilot noted that the amount he worked to land the airplane with DSFC was much reduced from the no DSFC case and, as a result, he assigned a PR = 3.

On the first evaluations of this configuration without DSFC, with manual DSFC and with automatic DSFC, each successive pilot rating became worse. The pilot comments were similar with the exception of turbulence levels. During the evaluation with no DSFC the pilot stated that he thought the disturbance due to turbulence was pretty mild. He mentioned the turbulence level had increased throughout the flight to a point where it caused some Dutch roll disturbances. Appendix III presents the RMS gust components which in general increased by a factor of 2 for DSFC evaluations compared to the evaluation with no DSFC. The mean sideslip values show that the pilot obtained only 2.7 degrees of sideslip without DSFC while obtaining 7.2 degrees using manual DSFC. The RMS values of sideslip also show this same trend respectively. Assuming the sideslip RMS value indicates the degree of difficulty the pilot had in maintaining these mean sideslips, it can be seen that the pilot had much less trouble with the no DSFC evaluation than with the use of DSFC. The mean sideslip he obtained without DSFC, however, was not near the desired 6.5 degrees.

Pilot A was given a repeat evaluation of this configuration in which the pilot rating for no DSFC decreased from PR = 2 to PR = 5 while the pilot rating of a manual DSFC remained at PR = 3. Shown in Appendix III, σ_{v_g} for the approach without DSFC was quite high at 4.35 ft/sec. The mean sideslip he was able to obtain was only 2.0 degrees. This is similar to the mean sideslip he obtained during the first evaluation without DSFC, indicating similar performance. Also the mean aileron and rudder forces are similar. Aileron forces during his first evaluation were 3.7 lb as compared to 2.7 lb for the repeat evaluation. Rudder forces during the first evaluation were 14.5 lb and for the repeat 18.9 lb. The similarity of these values indicates the relatively same performance and steady forces for the two evaluations. However, comparing the RMS values of sideslip (.6 compared to 1.1) shows the increased difficulty in maintaining the mean sideslip. RMS values of aileron and rudder forces may be an indication of the pilot workload during the approach. Comparing RMS values of aileron forces between the first no DSFC evaluation and the repeat evaluation (3.4 lb compared to 5.5 lb), indicates that the pilot workload increased. RMS rudder forces can also be compared in the same way (5.5 lb compared to 8.1 lb) indicating the same increased workload.

The pilot rating of 5 is based on the rather high pilot workload the pilot had in order to perform the task. However, his performance was not acceptable either. The turbulence effect rating of E also indicates the amount of increased workload that contributed to turbulence.

The power spectral density data presented in Figure 20 and Figure 21 for aileron and rudder force substantiate the increased pilot workload. From these figures it can be seen that the pilot needed considerably greater aileron and rudder activity during his repeat evaluation without DSFC than he did during the first evaluation without DSFC.

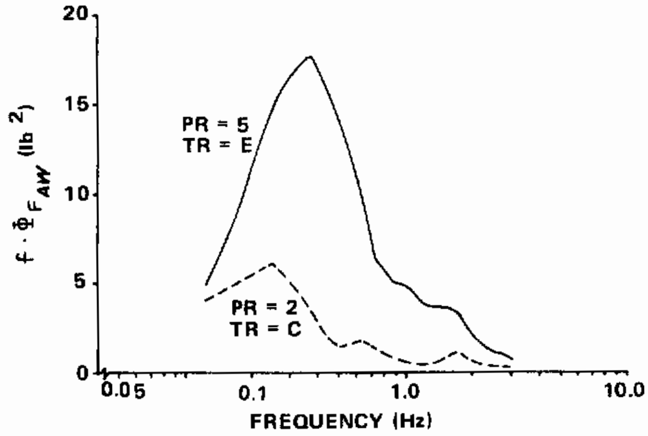


Figure 20 POWER SPECTRUM OF AILERON WHEEL FORCE INPUTS WITHOUT DSFC, CONFIGURATION 7

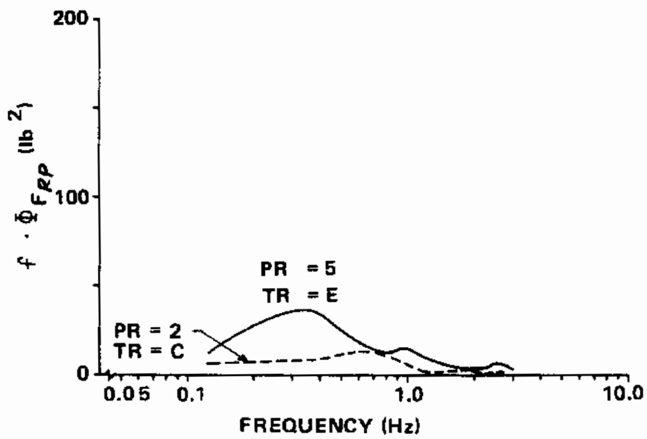


Figure 21 POWER SPECTRUM OF RUDDER PEDAL FORCE INPUTS WITHOUT DSFC, CONFIGURATION 7

4.3.3.3 Configuration 11, $\phi / v_{cw} = 0.42$

This configuration was rated without DSFC and with manual DSFC. The automatic DSFC mode was not evaluated because of deteriorating weather conditions which caused the flight to be terminated early. Without DSFC the pilot stated that he noticed no really objectionable features. He had some minor complaints about aileron wheel forces during the sideslipping, wing down crosswind landing. His technique was to use a crabbed approach until just prior to the flare and then convert to a wing low attitude. The response of the airplane to turbulence was considered minimal, however, as shown by the tabulation in Appendix III the RMS gust intensities that the pilot encountered during the flare and touchdown were only on the order of one foot per second. With DSFC the pilot again stated that this configuration was "A pretty good airplane." The ability to counter the crosswind with DSFC eliminated the high aileron forces about which the pilot mildly complained when evaluating the configuration with no DSFC. Again, the response to turbulence was hardly noticeable, but the RMS gust intensities were quite small, about one foot per second.

As a result this configuration received a PR = 3 for the no DSFC case and a PR = 2 for the case with manual DSFC. Turbulence effect ratings were TR = A+ and TR = A respectively.

A mean sideslip of 3.9 degrees was established for the no DSFC approach which required the pilot to hold average aileron and rudder forces of 7.0 lb and 22 lb respectively.

The use of manual DSFC allowed the pilot to obtain a mean sideslip of 4.9 degrees, but some bank angle was still needed ($\phi \approx 1.0$ deg) to nullify the crosswind, which resulted in mean aileron and rudder force of 4.2 lb and 17 lb respectively. These forces were considerably less than those required for the no DSFC evaluation which may be interpreted as a decrease in pilot effort for the case with manual DSFC as compared to the case without DSFC.

4.3.4 Configuration with $N_\beta = 0.42$ and $L_\beta = -2.95$ (Configurations 4, 8 and 12)

The experimental results for these configurations as a function of ϕ / v_{cw} are shown in Figure 22. Without DSFC, all these configurations received pilot ratings of PR = 6 or poorer. Configurations 8 and 12 with the medium and higher values of ϕ / v_{cw} were both rated worse than configuration 4 with the lower ϕ / v_{cw} showing some pilot rating sensitivity with increasing ϕ / v_{cw}. With DSFC the pilot rating was comparatively insensitive to ϕ / v_{cw} with all three configurations being rated PR = 5 or better. Configuration 8 was improved from PR = 7 or worse without DSFC to PR = 3 with DSFC. All of these configurations failed to meet the Level 1 bank angle oscillation, sideslip excursion, and Dutch roll damping ratio requirements of MIL-F-83300. They did, however, meet the Level 2 requirements for bank angle oscillation and Dutch roll damping ratio.

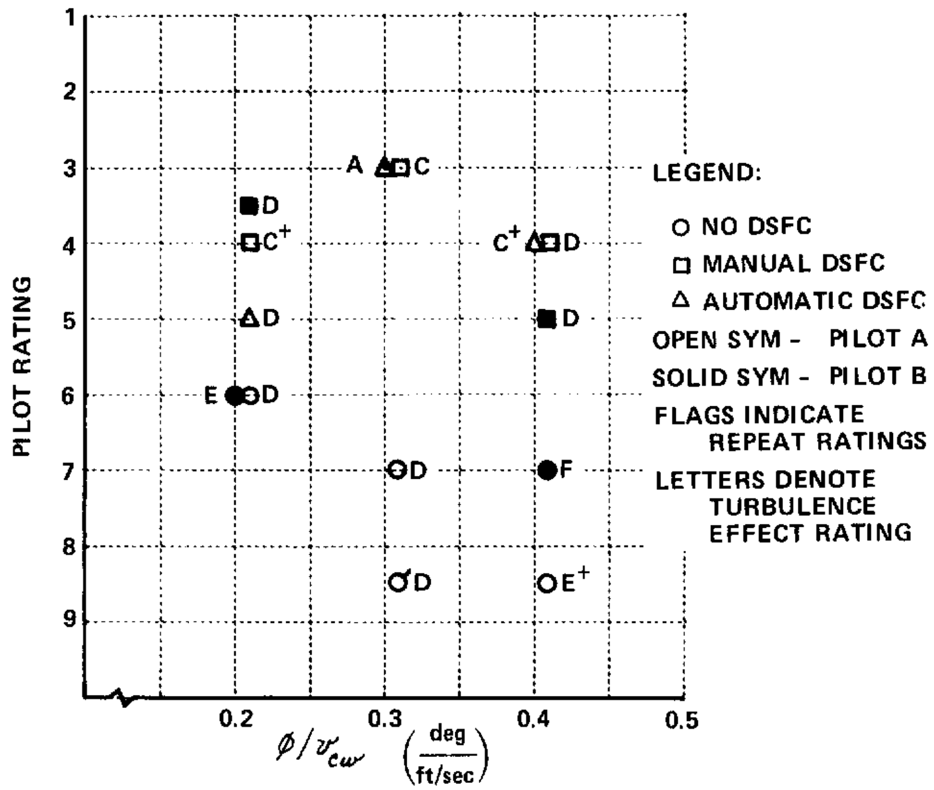


Figure 22 EFFECT OF DSFC ON CONFIGURATIONS 4, 8 AND 12 WITH $\mathcal{N}_\beta$ = 0.42 AND $\mathcal{L}_\beta$ = -2.95

4.3.4.1 Configuration 4, ϕ / v_{cw} = 0.21

This configuration was evaluated by both evaluation pilots with no DSFC and with manual DSFC. The automatic DSFC mode was evaluated only by pilot A.

Without DSFC, pilot A complained of the poor lateral-directional characteristics, in particular, low Dutch roll damping ratio (ζ_d = .015) and high roll to sideslip ratio ($|\phi/\beta|_d$ = 2.34). His approach technique was to align the airplane into the wind (crabbed approach) until he was close to the runway, at which time he tried to establish a wing down, sideslipping condition. The first approach without turbulence was satisfactory, however, the second and third approaches with turbulence were not satisfactory. During the latter approaches he felt he was late in decrabbing the airplane and as a result never established zero drift with the wing down. Appendix III shows he obtained only 2.6 degree of sideslip and 1.8 degrees of bank angle. In addition he had a tendency to "balloon" and his efforts to damp the longitudinal motions added to his problems of establishing a sideslip and zero crab angle. The pilot noted that the final roll response was not very predictable and, therefore, had difficulty establishing a desired bank angle. The airplane would oscillate about the desired bank angle preventing the pilot from maintaining a steady crosswind landing attitude.

Pilot B commented that the lateral-directional handling qualities were degraded, while the longitudinal were adequate. He contributed some of his difficulties to the control system. He felt that the aileron wheel required quite a bit of displacement to feel the force gradient. He stated there was a lot of "free play" about center wheel position which destroyed the overall control harmony. Although he stated that the longitudinal control system was average, he noticed a slight tendency to PIO when establishing a flare and making precise pitch attitude corrections. He stated that the Dutch roll did not seem to be very well damped and turbulence caused some problems because it excited the Dutch roll resulting in roll and yaw oscillations. As a result, he found that precise runway alignment was difficult due to these continuous oscillations. The combination of the poor lateral dynamics and the lateral control system caused the pilot to encounter a PIO laterally, complicating the wing down sideslip landing.

Due to an on-board digital recorder system malfunction the numerical data could not be analyzed.

With manual DSFC, pilot A again complained of the poor lateral-directional characteristics and stated that he had overly sensitive rudder control which aggravated the Dutch roll oscillations. He tried to control these oscillations mostly with aileron and very little with rudder inputs, in an effort not to aggravate the Dutch roll oscillations. The oscillations were never damped out completely, making steady state runway alignment difficult and causing overcontrol when using the DSFC. The pilot stated, using the manual DSFC, that he could "wipe out the crosswind very nicely and stay pretty well down the centerline with a little bit of effort" although he was not very happy with steady state runway alignment.

As shown in Appendix III the pilot was able to obtain more steady sideslip using the manual DSFC than without DSFC. The steady bank angle was not zero, using manual DSFC, indicating difficulty in finding the proper DSFC position as stated in the pilot comments.

Manual DSFC was also evaluated by pilot B. His comments about the basic airplane characteristics were similar to his evaluation without DSFC. He complained of the large aileron wheel displacements required to obtain the desired bank angles and roll rates, and the yaw oscillations.

Turbulence effects were felt to be significant and added to the difficulties the pilot was having in trying to suppress the yaw and roll oscillations which were excited with every control input. Runway alignment using the manual DSFC was fairly easy for the pilot, although the oscillations in yaw and roll made it difficult to maintain constant runway alignment. He stated he did not have any tendency to overcontrol using DSFC and made only very minor corrections on final approach. The pilot noted that "control of sideslip was easy with the side force controller" and bank angle was not required. Numerical data for the evaluation by pilot B is not available due to malfunction of the on-board digital tape recorder.

Only pilot A evaluated this configuration using the automatic mode of DSFC and only two evaluation approaches were performed. The PR = 5 is based on these two approaches. The basic airplane received the same complaints as in the previous evaluation, poor lateral-directional characteristics, easy to induce the Dutch roll and turbulence aggravating the oscillatory tendencies. The pilot liked the automatic system because it relieved him of the responsibility of aligning the airplane but criticized it for hunting on either side of the localizer with fairly large amplitude excursions. He found the lateral excursions and the associated lateral accelerations quite distracting. The pilot rating of PR = 5 for the automatic mode, was based mainly on the lateral hunting of the airplane and the resulting lateral accelerations.

4.3.4.2 Configuration 8, Medium $\phi / v_{cw} = 0.31$

Four evaluations by pilot A were completed for configuration 8, two without DSFC, one using the manual DSFC mode and one using the automatic DSFC mode.

For both evaluations without DSFC, the pilot complained of the low Dutch roll damping ratios ($\zeta_d = .04$) saying it seemed close to zero. He also stated "the airplane was loose directionally." The initial roll response was very good but he mentioned he had to make a conscious effort to damp out roll oscillations. As a result, it was very difficult to establish a good steady bank angle during the sideslip approach. The pilot also stated that the aileron forces required to hold the steady bank angle for the crosswind landing were quite high, and he felt there was cross coupling between the lateral and longitudinal controls due to these very high aileron forces. The pilot's primary objection was the difficulty he encountered in trying to place the airplane in the proper wing down attitude with the correct heading for a crosswind landing. He stated, "this is a very difficult task and I think it's primarily a function of rudder effectiveness and Dutch roll damping." He stated further, "it seems that I'm overcontrolling with the rudder...the force on the ailerons required to generate a bank angle for alignment purposes gets much too high, and yet, in up and away flight the aileron forces are fine." "If you happen to land the airplane you wonder whether it was a matter of luck or whether you actually were the cause of it." As mentioned earlier the Dutch roll damping ratio of this configuration was $\zeta_d \approx 0.04$. The roll-to-sideslip ratio was $|\phi/\beta|_d \approx 2.4$. Because of the lower N_β the airplane was quite sensitive directionally to rudder inputs and, because of the low value of ζ_d, once the airplane was excited with the rudder input it would continue to oscillate in the Dutch roll mode. With the roll to sideslip ratio of $|\phi/\beta|_d \approx 2.4$ when the pilot attempted to sideslip and maintain a wing low, there was a strong tendency for the airplane to roll out of the wing low attitude. Hence, the large aileron forces were required for the pilot to try to hold the wing down. The pilot also noted that he wasn't having much trouble with the airplane until he attempted to decrab and convert to the sideslipping wing low crosswind landing attitude, at which point he felt that his precision of aircraft control deteriorated to the point that he could not repeat his performance. This comment clarifies the statement about the landing performance being somewhat a matter of luck. Turbulence added to the pilot's problems by exciting the Dutch roll which was difficult to damp out due to overly sensitive rudder control and the low Dutch roll damping. As a result of his difficulties, the pilot assigned a PR = 7 for the initial evaluation and PR = 8.5 for the repeat evaluation.

The manual DSFC rating showed a significant improvemement to a PR of 3. The pilot stated the main reason was "practically all the problems I had without the crosswind controller --- disappeared essentially completely." Large aileron forces were not required during landing thus eliminating the coupling into pitch and the ballooning tendencies. Aileron and rudder inputs were required only to suppress the effects of turbulence which, of course, decreased pilot workload. The pilot mentioned he had some difficulty in finding the proper DSFC position and had a slight tendency to overcontrol, however, it was a much simplified task.

The automatic system resulted in good runway alignment and with the pilot effort reduced to essentially controlling the airplane longitudinally. The pilot complained of the airplane mildly hunting from side to side of the localizer but noted that the side accelerations were not as noticeable as they had been on some previous flights. By ignoring the side accelerations, the pilot stated that the automatic DSFC was just as good as the manual DSFC. The fact that the pilot only had to control the airplane longitudinally was mentioned as a good feature and the pilot stated that his workload was certainly reduced. Therefore a PR = 3 was assigned for this configuration with automatic DSFC.

Pilot A's first evaluation with no DSFC was flown with about half the gust intensity as his repeat evaluation flight. During his first evaluation he was able to obtain a mean sideslip of 3.5 degrees with aileron wheel forces of 11.5 lb and a mean rudder pedal force of 23 lb. The RMS force values about the above mean were approximately 4.0 lb and 6.0 lb for the aileron and rudder respectively. These relatively large RMS values may be indicative of the pilot's difficulty in maintaining the wing low crosswind landing attitude.

His performance on the repeat evaluation decreased since he obtained a mean sideslip of only 2.2 degrees during the landing. His mean control forces were 5.6 lb and 19 lb for the aileron and rudder respectively. The RMS values of aileron and rudder force were substantially higher than the initial evaluation, 5.1 lb and 13.7 lb, respectively. These higher values indicate a higher effort than was used on the first evaluation even though less sideslip was obtained during the landing. More effort during the repeat evaluation was the result of a higher turbulence level and is reflected in the PR = 8.5 as opposed to the initial PR = 7.

Nearly all the problems the pilot had disappeared with manual DSFC, as shown by the data presented in Appendix III. He was able to obtain a much larger sideslip (5.0 degree) which indicates better performance. However, he mentioned it was difficult to find the proper position of DSFC to nullify the crosswind, which is shown by the 1.0 degree of bank angle he needed during landing. The data also shows the tremendous difference in mean aileron wheel forces. The pilot needed only 1.9 lb of force, less than breakout level, using DSFC instead of 5.6 lb without DSFC. Rudder forces were similarly decreased from 19.0 lb to 4.0 lb which was less than the rudder pedal breakout force of 7 lb. The RMS values of aileron and rudder were reduced by nearly a factor of two from the approaches without DSFC. The RMS values of aileron forces decreased from 5.1 lb to 2.6 lb while rudder force decreased from 13.7 lb to 6.4 lb. The gust level for these approaches was similar. The small RMS control forces would indicate, therefore, that the pilot had less difficulty in suppressing the effects of turbulence when he had the aid of DSFC. Both the lower mean force levels and the lower RMS control forces can be interpreted as reduced pilot workload when using DSFC. Of course, the pilot rating itself, PR = 3, reflects less effort and better performance in the pilot's own opinion.

4.3.4.3 Configuration 12, $\phi/v_{cw}' = 0.42$

This configuration was evaluated by both pilots, however, only pilot A evaluated the configuration with the automatic DSFC mode.

Without DSFC, pilot A found it very difficult to perform a satisfactory crosswind landing. The only good feature he mentioned was that the longitudinal characteristics were reasonable. The major difficulty was maintaining the airplane in the proper wing low attitude after converting from a crabbed final approach. The control forces were good for normal maneuvering of the airplane, however, the pilot found that the aileron forces were "overpowering" in attempting the crosswind landing. The pilot also stated that he had trouble "displacing the airplane sideways." Since this configuration had the higher ϕ/v_{cw}, large bank angle was required in order to perform a sideslip. Approximately 10 degrees of bank angle were required to counter a 15 knot crosswind by sideslipping. The roll-to-sideslip ratio in the Dutch roll mode was also high, $\left|\frac{\phi}{\beta}\right|_d = 2.4$, for this configuration. Therefore when the pilot attempted to sideslip, the large dihedral effect, high $\left|\frac{\phi}{\beta}\right|_d$, tended to roll the airplane away from the direction of sideslip. To maintain the sideslipping condition therefore required a large rolling moment from aileron to counteract the rolling moment due to dihedral. The pilot found the aileron forces were high enough to require both hands on the aileron wheel, a condition which he found unacceptable for landing. The low Dutch roll damping ratio, $\zeta_d \approx 0.06$, was another source of the difficulties encountered by the pilot. He stated that "the lateral-directional characteristics are so poor that the pilot is always working trying just to hopefully smooth out the Dutch roll, it's not a big problem in smooth air, but in turbulence, it certainly shows up." Further, because of the low directional stiffness, lower N_β, the Dutch roll was easily excited, especially with rudder inputs. Because of the combination of the above difficulties, the pilot could not, with the conventional cross-control aileron and rudder technique, set up a steady sideslip just before touchdown. He found he could land the airplane by neglecting power control and using both hands for aileron control to "manhandle" the airplane down to the runway centerline. As a result of his difficulties he assigned a pilot rating of 8.5 with a turbulence effect rating of E+.

With manual control of DSFC the pilot stated "there's just no question that this is a much better task for the pilot," however, the aid of DSFC did not cure all the pilot's problems. His landing approach method with DSFC was to eliminate the crab angle on final approach by the application of side force. Small iterations on the side force input were then made as the airplane approached the runway. Some difficulties were encountered in determining the precise amount of side force input required and the pilot found that he had to continue making side force corrections. He would overcontrol slightly, and after making a correction, find himself drifting in the direction opposite to that for which a correction had been made. The DSFC authority was adequate and it did not interfere with any other aspects of aircraft control. The major objection with DSFC was the continuous excitation of the Dutch roll mode in turbulence. The pilot remarked that the only reason he rated the airplane poorer than "satisfactory without improvement" was the oscillatory characteristics in turbulence. The resulting pilot rating was PR = 4 with a turbulence effect rating of D.

Pilot B, on his evaluation without DSFC found the airplane adequate longitudinally, but encountered difficulties with lateral-directional control. He had no serious complaints about trim or control sensitivities. He noted, however, that the initial roll control was quite slow and the roll response seemed to lag the control input considerably. The final roll response was unpredictable causing him to overshoot a desired bank angle of 10 degrees by as much as 5 degrees. He stated that during the crosswind landing flare the aileron wheel forces were large but not excessive for the amount of aileron wheel deflection required. His use of the rudder excited roll oscillations which aggravated his bank angle control difficulties. Because of the bank angle oscillations and his difficulty in controlling them, pilot B stated "I didn't feel that I had the aircraft under control at an acceptable level to make a touchdown adequately," as a result he assigned a PR = 7. Pilot B's turbulence effect rating of F was a result of the continuous oscillations of the airplane in turbulence. The difficulties encountered by pilot B were due to the low Dutch roll damping ratio and relatively large $\left|\frac{\phi}{\beta}\right|_d$ of this configuration. Once excited by turbulence or control inputs the low ζ_d allowed the airplane to continue oscillating in the Dutch roll mode. His bank angle control difficulties are related to the relatively high $\left|\frac{\phi}{\beta}\right|_d$. Small rudder inputs, which the pilot stated he used for vernier heading control, or small sideslips generated in attempts to coordinate the rudder with aileron inputs would generate relatively large rolling moments. If the pilot applied too much rudder into the turn for coordination then the rolling moment due to sideslip would cause the airplane to overbank resulting in the pilot's bank angle overshoot problem.

With DSFC, pilot B found the airplane somewhat improved over the case without DSFC but he still objected to the "roll rate excited by yaw rate." He encountered many of the same difficulties that he did without DSFC but stated that the task was "easier using the side force" controller because it gave him the ability to align with the runway using "a minimum amount of crab." He had some difficulty determining the precise amount of side force to use and noted that he thought the side force input did excite some roll response. His main reasons for the PR = 5 were the slow response to aileron inputs, the excitation of roll rate by yaw rate and the response of the airplane to turbulence. His turbulence effect rating for the configuration with DSFC was TR = D.

The automatic DSFC performance was adjudged by pilot A to be not much different from the manual DSFC. His only objection to the automatic mode was the lateral accelerations generated as the airplane tracked the ILS localizer using DSFC to maintain track. As a result he assigned the same pilot rating, PR = 4, as he did for the manual DSFC case. He commented that turbulence caused him to work a little harder and assigned a TR = C+.

In view of the pilots' comments about the difficulty of maintaining a steady sideslip and the large control forces required, it is interesting to compare the sideslip and control forces actually attained without and with DSFC. Without DSFC pilot A achieved a mean sideslip of 3.6 degrees during the landing flare using mean aileron and rudder forces of 11.9 lb and 26 lb respectively. His RMS force inputs about the above mean were approximately 8.0 lb and 10 lb for the aileron and rudder respectively. The relative large RMS value of aileron wheel force above the mean value of almost 12 lb may be a measure of the difficulty he had in suppressing the Dutch roll oscillations of the airplane. With DSFC, pilot A achieved 6.2 degrees of mean sideslip using mean aileron and rudder forces of 1.0 lb and 2.4 lb respectively. Both these mean force values are below the breakout force level. His RMS aileron and rudder force levels about the mean were 4.6 lb and 7.9 lb for the aileron and rudder respectively. These lower RMS values for the case with DSFC may indicate that the Dutch roll was less excited when the pilot had DSFC and hence less effort was necessary to suppress the Dutch roll oscillations. It should be noted, however, that σ_{v_g} = 1.9 ft/sec was recorded for the DSFC case as opposed to σ_{v_g} = 3.0 ft/sec for the case without DSFC. Other gust components were also higher for the case with DSFC as shown in Appendix III.

The important point is that with DSFC pilot A achieved considerably more sideslip during the crosswind landing than he did without DSFC and he was able to achieve the larger mean sideslip with much smaller control forces. Thus, better performance was attained with less pilot effort. Numerical data is not available for pilot B's evaluation without DSFC, however, with the use of DSFC he attained a mean sideslip of 9.2 degrees using mean aileron wheel and rudder pedal forces of 6.8 lb and 16 lb respectively. He also landed with a mean bank angle of ϕ = 2.0° indicating that he probably overcorrected for the crosswind and was drifting into the wind or that the natural wind increased, resulting in a total crosswind component of greater than 15 knots. In either event, to have achieved 9 degrees of sideslip without DSFC would have required approximately 15 degrees of bank angle for this configuration. In view of the complaints above about aileron wheel forces this would have been quite a difficult task.

4.4 EFFECTS OF N_β AND L_β

The effects on pilot rating of N_β can be seen by comparing Figures 12 and 19 for configurations with the lower value of L_β and Figures 18 and 22 for configurations with the higher L_β.

For configurations with the lower L_β there is little difference in pilot rating for the variation in N_β. Without DSFC, the two configurations with the lower and medium values of ϕ/v_{cw} and lower N_β were rated slightly worse than the configurations with higher N_β, i.e. an incremental pilot rating of $\Delta PR \leq 1$. With DSFC, only the configurations with $\phi/v_{cw} = 0.21$ show any significant difference in pilot rating, with N_β, a PR = 4 for lower N_β versus PR = 3 for the higher N_β. For Configuration 3, lower ϕ/v_{cw} and lower N_β, the pilot made no mention of directional stiffness. He did comment that the airplane was "rolly" and that the roll to sideslip ratio seemed to be high. He also noted that the response of the airplane to turbulence was "substantial" and fairly low frequency." The pilot stated that the most objectionable feature was the turbulence response and that his PR = 5 was more a function of the turbulence response than anything else. Configuration 1, lower ϕ/v_{cw} and higher N_β, was evaluated three times. Pilot A again complained about the turbulence response and pilot B complained about high rudder forces. Of course, for a given rudder control sensitivity, increasing N_β will result in increased rudder force to accomplish the same task. Both these configurations received better pilot ratings when the pilot had the aid of DSFC. Configuration 3 was improved from a PR = 5 to PR = 4, but the pilot still complained about the turbulence response of the airplane and the "rolly" character. Configuration 1 also was improved with DSFC with the exception of the first evaluation flight by pilot B which was discussed in paragraph 4.3.1.1. Pilot A again objected to the turbulence response and pilot B had no significant objections for the evaluation on which he assigned a PR = 3. With the higher ϕ/v_{cw}, Configuration 9 was once rated PR = 8 and TR = F without DSFC, but as explained previously, this rating resulted largely from turbulence considerations and was the one evaluation where the pilot strongly objected to the amount of bank angle required. Conversely, the configuration with lower N_β and higher ϕ/v_{cw} received a turbulence effect rating of A and the pilot stated that there were really no objectionable features.

With the exception of the one comment by pilot B about high rudder pedal forces, there is no discernible effect of N_β on pilot rating for configurations with the lower L_β.

Comparing Figures 18 and 22, for configurations with the higher L_β, there is no significant effect of N_β on configurations with the lower value of ϕ/v_{cw}. There is, however, an apparent effect of N_β on pilot rating at the two higher values of ϕ/v_{cw} for evaluations without DSFC.

Configuration 8, medium ϕ/v_{cw} and lower N_β, was rated a 7D and 8.5D. On both of these evaluations the pilot complained about the low Dutch roll damping ratio, ζ_d = 0.04, heavy aileron wheel forces required to establish the necessary bank angle for a sideslipping approach, the low directional stiffness, and possible overcontrol with the rudder. The pilot felt that he was overpowering the roll control with the rudder because of the rolling moment due to sideslip. The roll-to-sideslip ratio in the Dutch roll for this configuration was $|\phi/\beta|_d = 2.37$. Because of the low N_β and relatively high $|\phi/\beta|_d$ it was easy for the pilot to develop yawing moments with the rudder when trying to establish a steady sideslip, but the sideslip would also excite large rolling moments resulting in roll oscillations and heavy aileron forces to suppress the roll oscillations. Hence, as the pilot stated, it was a very difficult task to place the airplane in a wing down attitude with the nose pointed down the runway.

The pilot comments for Configuration 12, higher ϕ/v_{cw} and lower N_β, were quite similar to those for Configuration 8 above. Pilot A again stated "The objectionable feature basically is the Dutch roll damping." When the pilot had the aid of DSFC the pilot ratings for both Configurations 8 and 12 improved considerably, Configuration 8 was rated PR = 3 and Configuration 12 was rated PR = 4 by pilot A and PR = 5 by pilot B. For Configuration 8, the pilot stated that "practically all of the problems that [he] had without DSFC disappeared essentially completely." For Configuration 12 pilot A still objected to the excitation of the Dutch roll in turbulence and pilot B objected to the roll rate excited by yaw rate.

Neither Configuration 6 nor Configuration 10, both with higher N_β and higher L_β, were ever rated worse than a PR = 5. For Configuration 6 pilot A objected mainly to the turbulence response of the airplane. Pilot B objected to heavy rudder and aileron forces and excessive aileron wheel displacements. A more nearly optimum selection of control sensitivities may have eliminated the control force and displacement objections voiced by pilot B. However, both pilots generally reported control sensitivity and feel characteristics to be all right in up and away flight but unsatisfactorily heavy in the landing flare. Therefore, some compromise between over-sensitivity in up and away flight and heavy forces in the flare would have to be made to arrive at an overall satisfactory control sensitivity.

Again, few of the pilots' problems appear to be directly related to the effects of N_β, per se, except for the rudder control force sensitivity when trying to establish a sideslip. This could probably be improved, however, by tailoring the rudder control sensitivity to the directional characteristics of the airplane. The pilots' complaints can be related to the modal parameters $|\phi/\beta|_d$ and ζ_d, but these parameters are a function of all three of the variables in this program.

The effects of L_β on pilot rating can be seen by comparing Figures 19 and 22 for configurations with lower N_β and Figures 12 and 18 for configurations with the higher N_β .

For configurations with the lower N_β, there was a significant change in pilot rating with L_β . Without DSFC, Configurations 4, 8 and 12 with high L_β were rated in the $6 \leq PR \leq 8.5$ range while Configurations 3, 7 and 11 were all rated $PR \leq 5$. The primary pilot objections to all these configurations have been discussed above when comparing the effects of N_β . It will be recalled that primary objections voiced by the pilots for Configurations 4, 8 and 12 were low Dutch roll damping ratio, manifested to the pilot by continuous lateral-directional oscillations, and the response of the airplane to turbulence. There were also objections about the roll response to rudder inputs and heavy aileron forces during sideslips. This condition usually results from high dihedral effect i.e., relatively large $|\phi/\beta|_d$ which is associated with large L_β and small N_β . The objections to the lower L_β , Configurations 3, 7 and 11, were mostly concerned with rudder control sensitivity and airplane turbulence response. With DSFC, many of the pilots' problems were eliminated or, at least, reduced in magnitude. There were still complaints, however, about the "rolliness" of the airplanes and the excitation of the Dutch roll.

For configurations with the higher N_β, the effect on pilot rating of L_β was not as significant as in the low N_β case. Comparing Figures 12 and 18 the configurations with the higher L_β were rated PR = 5 for the medium and higher values of ϕ/v_{cw} (Configuration 6 and 10) and PR = 6 for the lower value of ϕ/v_{cw} (Configuration 4). The configurations with lower L_β were all rated $PR < 4.5$ except the one PR = 8 for Configuration 9. Again the primary reasons for poorer ratings for the higher L_β configurations were Dutch roll oscillations, response to turbulence and large aileron forces when trying to sideslip. With DSFC there were no significant differences in pilot rating for the two values of L_β

In view of the many pilot comments about low Dutch roll damping and the response of the various configurations to turbulence, it appeared desirable to plot pilot rating both with and without DSFC as a function of Dutch roll damping, Figures 23, 24 and 25. It must be remembered, however, that because of the way derivatives were varied in this program, each change in L_β or N_β caused changes in all the lateral-directional modal parameters. Also changes in ϕ/v_{cw} through the derivative Y_β caused changes in Dutch roll damping. For example, an increase in L_β primarily causes $|\phi/\beta|_d$ to increase and ζ_d to decrease. A decrease in N_β primarily causes ω_d to decrease and $|\phi/\beta|_d$ to increase. Therefore, in interpreting Figures 23 through 25 it should be noted that as $\zeta_d \, \omega_d$ decreased, $|\phi/\beta|_d$ increased. The $|\phi/\beta|_d$ values for each configuration are shown in Table IV , paragraph 3.2.

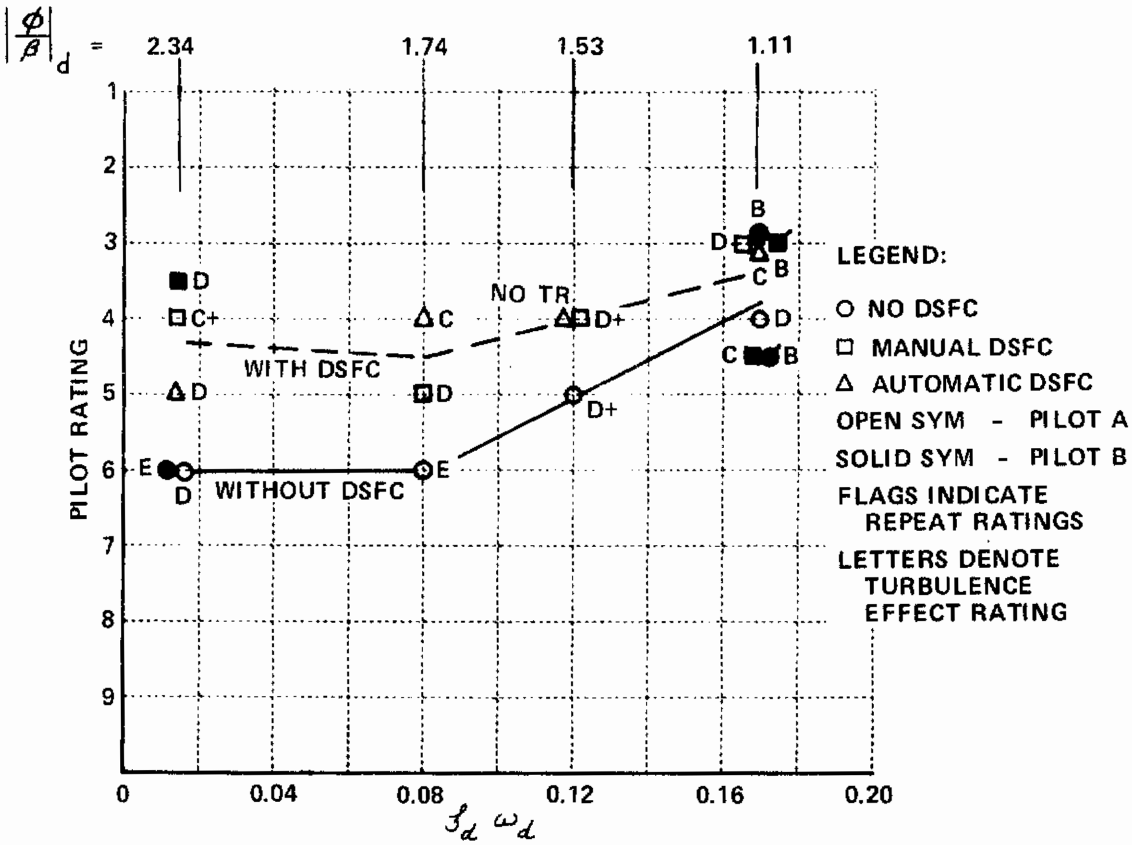


Figure 23 PILOT RATING VS TOTAL DUTCH ROLL DAMPING FOR CONFIGURATIONS WITH ϕ / v_{cw} = 0.21

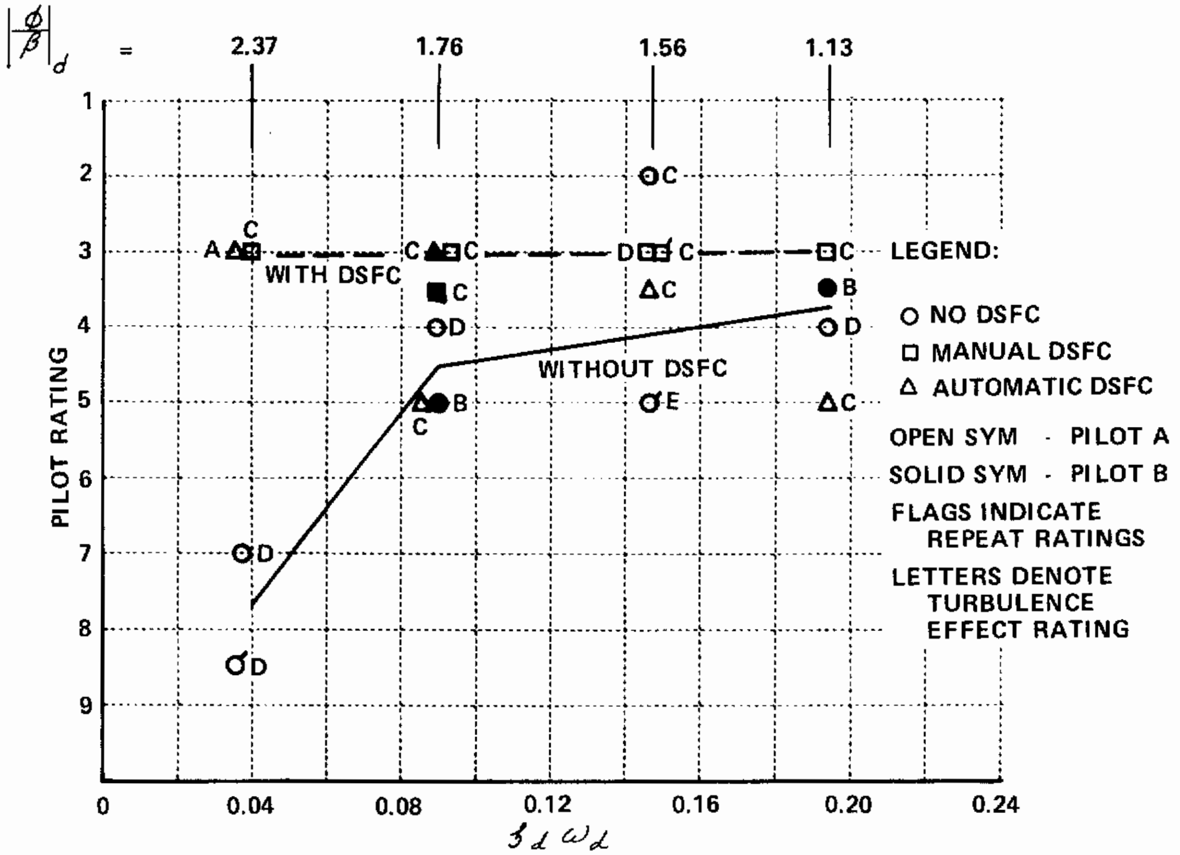


Figure 24 PILOT RATING VS TOTAL DUTCH ROLL DAMPING FOR CONFIGURATIONS WITH ϕ/v_{cw} = 0.31

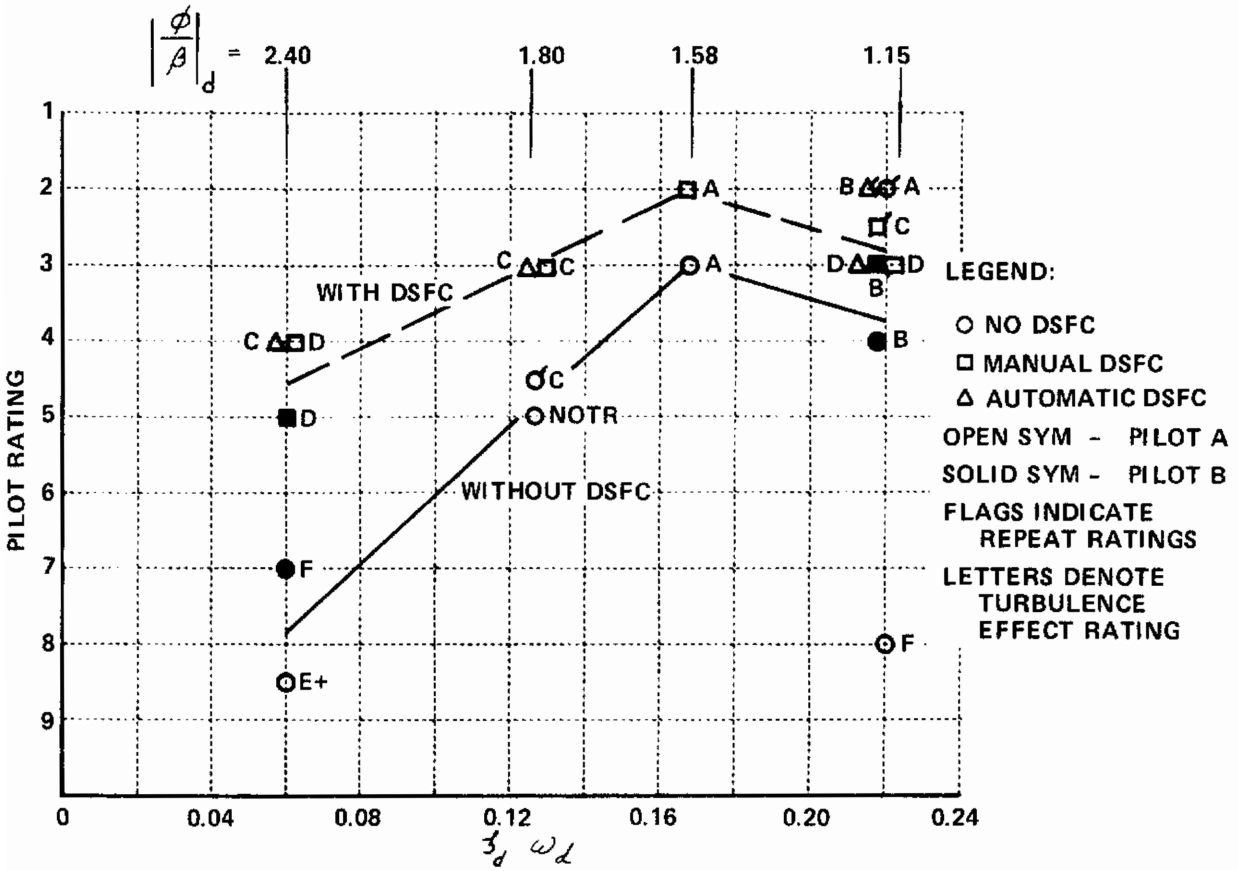


Figure 25 PILOT RATING VS TOTAL DUTCH ROLL DAMPING FOR CONFIGURATIONS WITH ϕ / v_{cw} = 0.42

Figures 23 through 25 show the pilot ratings obtained in this investigation as a function of the total Dutch roll damping, $\zeta_d \omega_d$. Lines connecting points on the plots are to serve as an eye guide to the reader and should not be interpreted as a functional relationship between PR and $\zeta_d \omega_d$. All three plots, for the three values of ϕ / v_{cw} investigated in this experiment, show a tendency for pilot rating for evaluations without DSFC to become worse with decreasing $\zeta_d \omega_d$. This, of course, is not an unexpected result. In all cases, however, pilot rating for evaluations with DSFC decreased much less with $\zeta_d \omega_d$. For the medium ϕ / v_{cw} cases the pilot rating for evaluations with DSFC was essentially invariant with decreasing $\zeta_d \omega_d$. These plots point out that the greatest benefits from DSFC in the crosswind landing task were obtained for configurations with the least desirable lateral-directional handling qualities. That is, configurations which received the poorest pilot ratings without DSFC showed the greatest improvement in terms of an incremental improvement in the numerical pilot rating when the pilot had the aid of DSFC. Configurations which were reasonably good without DSFC were improved by about one incremental pilot rating, when the pilot had the aid of DSFC. Though numerically small in terms of incremental pilot rating, this improvement is considered important since on several occasions the use of DSFC raised the airplane from the "deficiencies warrant improvement" category to the "satisfactory without improvement" category.

4.5 CONTROL POWER AND PILOT CONTROL FORCES USED

In order to determine the roll control power, yaw control power and side force control power actually used by the pilot, the model aileron, rudder and side force generator deflections were recorded during the crosswind approaches and landings performed in this investigation. Of course, the side force generator, aileron, and rudder deflections required for the steady state sideslipping crosswind landing condition could easily be determined from Equations (9), (12) and (13) of Section II of this report. Control power values determined from these expressions would not, however, account for the magnitude of control power that the pilot actually needed and used to cope with the turbulence and wind environment in which the evaluations were conducted. Tables VIII through XI show the values of control power used by the pilot during the evaluations. The pilots' maximum aileron wheel and rudder pedal force inputs used during the evaluations are also shown on the tables so that the forces can be compared for the cases with and without DSFC. The pilots' control forces cannot be directly converted to surface deflections through multiplication by δ_a / F_{AW} or δ_r / F_{RP} because the forces shown include breakout. Also, when the pilot used DSFC, the δ_a / δ_y and δ_r / δ_y interconnects provided sufficient aileron and rudder deflection to counter steady state rolling and yawing moments.

The control deflections used to determine control power were essentially the maximum value used by the pilot in performing the crosswind landing task, including the aileron and rudder deflections resulting from the δ_a / δ_y and δ_r / δ_y interconnects.

Table VIII

CONTROL POWER USED BY THE PILOT IN EVALUATION OF CONFIGURATIONS WITH N_β = 0.94 AND L_β = -1.57 (CONFIGURATIONS 1, 5 AND 9)

CONFIGURATION NO. N - NO DSFC M - MAN. DSFC	PILOT/PR/TR	F_{AW} (lb)	ROLL CONTROL POWER USED $L_{\delta_a}\delta_a$ (deg/sec^2)	F_{RP} (lb)	YAW CONTROL POWER USED $N_{\delta_r}\delta_r$ (deg/sec^2)	SIDEFORCE CONTROL POWER $Y_{\delta_y}\delta_y$ (1/sec)	SIDESLIP ATTAINED β (deg)
1 N	A/4/D	6.8	6.6	43.0	4.2	0	3.5
1 M	A/3/D	7.5	14.6	28.0	10.3	0.0153	8.4
1 N	B/4½/B	12.5	12.8	78.0	8.9	0	7.8
1 M	B/3/B	7.0	10.3	40.0	8.4	0.0082	8.8
5 N	A/4/D	10.0	10.6	54.0	5.2	0	4.2
5 M	A/3/C	7.5	9.9	18.0	5.0	0.0102	3.8
9 N	A/8/F	11.0	8.4	62.6	6.7	0	4.6
9 M	A/3/D	9.5	13.2	40.0	10.7	0.0265	7.5
9 N	A/2/A+	7.0	7.8	44.0	9.8	0	4.0
9M	A/2½/C	5.5	9.5	18.0	5.8	0.018	5.7
9 N	B/4/B	DIGITAL RECORDER MALFUNCTION					
9 M	B/3/B						

Table IX

CONTROL POWER USED BY THE PILOT IN EVALUATION OF CONFIGURATIONS WITH N_β = 0.94 AND L_β = -2.95 (CONFIGURATIONS 2, 6 AND 10)

CONFIGURATION NO. N - NO DSFC M - MAN. DSFC	PILOT/PR/TR	F_{AW} (lb)	ROLL CONTROL CONTROL USED $L_{\delta_a}\delta_a$ (deg/sec^2)	F_{RP} (lb)	YAW CONTROL POWER USED $N_{\delta_r}\delta_r$ (deg/sec^2)	SIDEFORCE CONTROL POWER $Y_{\delta_y}\delta_y$ (1/sec)	SIDESLIP ATTAINED β (deg)
2 N	A/6/E	12.0	13.8	66.0	7.1	0	5.4
2 M	A/5/D	9.0	16.0	26.0	6.9	0.0061	6.3
6 N	A/4/D	12.0	9.2	38.0	3.9	0	1.9
6 M	A/3/C	9.5	20.0	14.0	7.1	0.0163	5.7
6 N	B/5/B	15.0	16.2	76.0	8.0	0	6.0
6 M	B/3½/C	8.0	17.3	29.0	7.9	0.0122	7.2
10 N	A/5/–	14.0	14.1	52.0	5.5	0	2.3
10 M	A/3/C	8.5	24.6	20.0	10.5	0.0316	8.0
10 N	A/4½/C	14.0	16.2	52.0	5.7	0	4.2

Table X

CONTROL POWER USED BY THE PILOT IN EVALUATION OF CONFIGURATIONS WITH N_β = 0.42 AND L_β = -1.57 (CONFIGURATIONS 3, 7 AND 11)

CONFIGURATION NO. N - NO DSFC M - MAN. DSFC	PILOT/PR/TR	F_{AW} (lb)	ROLL CONTROL POWER USED $L_{\delta_a}\delta_a$ (deg/sec^2)	F_{RP} (lb)	YAW CONTROL POWER USED $N_{\delta_r}\delta_r$ (deg/sec^2)	SIDEFORCE CONTROL POWER $Y_{\delta_y}\delta_y$ (1/sec)	SIDESLIP ATTAINED β (deg)
3 N	A/5/D	8.5	9.5	42.0	4.1	0	4.5
3 M	A/4/D	6.8	10.9	15.0	3.3	0.0082	4.3
7 N	A/2/C	9.0	9.5	28.0	2.0	0	2.7
7 M	A/3/D	9.0	15.3	24.0	4.3	0.0133	7.2
7 N	A/5/E	11.5	12.4	36.0	3.2	0	2.0
7 M	A/3/C	8.0	15.1	18.0	4.9	0.0173	6.8
11 N	A/3/A+	9.0	9.4	34.0	3.2	0	3.8
11 M	A/2/A	8.5	9.9	22.0	3.0	0.0102	4.9

Table XI

CONTROL POWER USED BY THE PILOT IN EVALUATION OF CONFIGURATIONS WITH N_β = 0.42 AND L_β = -2.95 (CONFIGURATIONS 4, 8 AND 12)

CONFIGURATION NO. N - NO. DSFC M - MAN. DSFC	PILOT/PR/TR	F_{AW} (lb)	ROLL CONTROL POWER USED $L_{\delta_a}\delta_a$ (deg/sec^2)	F_{RP} (lb)	YAW CONTROL POWER USED $N_{\delta_r}\delta_r$ (deg/sec^2)	SIDEFORCE CONTROL POWER $Y_{\delta_y}\delta_y$ (1/sec)	SIDESLIP ATTAINED β (deg)
4 N	A/6/D	15.0	12.4	42.0	4.1	0	2.6
4 M	A/4/C	9.5	14.1	26.0	3.9	0.0051	3.6
8 N*	A/7/D	15.0	13.0	37.0	3.5	0	3.5
8 N*	A/8½/D	11.5	13.5	39.0	3.8	0	2.2
8 M	A/3/C	6.5	15.7	16.0	3.0	0.0082	5.0
12 N	A/8½/E	17.9	16.0	44.0	4.3	0	3.6
12 M	A/4/D	7.7	16.2	14.0	4.6	0.0204	6.2
12 N	B/7/F	DIGITAL RECORDER MALFUNCTION					
12 M	B/5/D	16.0	23.8	38.0	7.1	0.0153	9.2

*AILERON WHEEL FORCE GRADIENT WAS CHANGED BETWEEN THESE TWO EVALUATIONS OF CONFIGURATION 8

These "maximum" values of aileron and rudder deflection were taken from probability density distributions. The actual values used to compute the control power were model control surface deflections for which the probability of exceeding was 0.02. The pilots' force inputs were also obtained from probability density distributions using values which the probability of exceeding was 0.02. Side force generator deflections were taken from analog records of the in-flight digitally recorded data.

The sideslip attained during the landing flare maneuver and touchdown is also shown on Tables VIII through XI. Equations (9), (12) and (13) in Section II show that the control surface deflections required and therefore the control power are a function of sideslip, β . If the pilot, in performing the crosswind landing, exactly counters the existing crosswind with a zero crab angle then $\beta = v_{cw}/V_o$ within the limits of the small angle approximation. Therefore sideslip can be considered as an approximate measure of how well the pilot performed the crosswind landing in this experiment since an effort was made to always have the same crosswind component of 15 knots. When comparing and assessing the control power values shown, therefore, the sideslip attained must be considered.

It can be seen from Tables VIII through XI that with the aid of DSFC the pilot generally attained a larger sideslip during the flare and landing than was attained without DSFC. Not only were larger sideslips achieved, but because of the aileron and rudder interconnects with side force control, smaller maximum aileron wheel and rudder pedal forces were used. If the crosswind component were always exactly 15 knots and the turbulence always the same and if the pilot had always landed with a zero crab angle relative to the runway, then a direct comparison of control power could be made for the cases with and without DSFC. The sideslip values listed, and the pilot comments, indicate that zero crab angle was not always achieved. Also, because the natural wind was often variable, the crosswind during the flare and touchdown may have been different from 15 knots. However, comparison of configurations in which similar values of sideslip were attained with and without DSFC indicate that the use of side force does not result in any reduction of roll or yaw control power for the crosswind landing task. Actually, if sideslip is considered indicative of pilot performance, then better performance was generally achieved when the pilot had the aid of DSFC. This better performance was achieved with smaller pilot control force inputs, but also resulted in more control power being used. The fact that the pilot was able to achieve better performance (larger sideslip in the crosswind) with less effort (smaller control forces) resulted in better pilot ratings generally when the pilot was able to use DSFC.

To put the side force control power required into perspective, the side force required to develop 6.5 degrees of sideslip for the configurations evaluated in this investigation was calculated from Equation (9). The rudder deflection was determined from Equation (13). From the $Y_{\delta_y}\,\delta_y$ and $Y_{\delta_r}\,\delta_r$ values so obtained the total side force in pounds was determined and ratioed to the weight of the 130,000 lb model used in this investigation. The values obtained are listed in Table XII. The tabulated values show that depending on the basic side force characteristics of the airplane, principally Y_β , magnitudes of generated side force necessary to center a 15 knot crosswind with a final approach speed of 130 knots vary from approximately 10 to 20 percent of the airplanes lift in 1 g flight.

4.6 EFFECTS OF RUNWAY CLOSURE RATE

TIFS airspeed during the approach and flare was between 120 and 130 knots. This is about twice as fast as a typical STOL landing approach speed. Since TIFS was able to simulate the glide slope of a STOL (γ = -5 to -6 degrees) both the vertical and horizontal approach speeds were doubled compared to a typical STOL. The effects of these high closure rates on the task accomplishment was not known. Each pilot was asked specifically to comment on this closure rate after each evaluation.

Pilot A initially commented that the closure rates were fairly fast which was a mental hazard because of the attitude of the airplane close to the ground. His comments were more specific in later flights, mentioning, "rate of sink is pretty high so vertical closure rates are certainly noticeable, however, the fact that you are doing 130 knots doesn't shake me very much at all." Throughout the program he periodically commented that the vertical closure rate, or sink rate, caused him to hurry a little bit adding to the difficulty of the task, especially when he was late in flaring and needing a rather rapid flare. The rapid flare at times produced longitudinal PIO and ballooning. However, when he was not hurried in making the flare the pilot said, "The closure rates are no particular difficulty."

Pilot B's comments initally were, "The runway closure rate did affect the task accomplishment as far as I'm concerned. I could not divorce myself from the fact that I was approaching much faster than I would be performing the actual task at STOL approach speeds. Runway closure rate does affect task accomplishment, but I think it's a matter of getting used to it. It's obvious that it's not a STOL low speed approach."

As the evaluations progressed, Pilot B completely changed his comment on closure rate stating, "Runway closure rate doesn't seem to affect the task accomplishments, I guess I've just compensated for it." On his final evaluation flight, Pilot B commented, "Runway closure rate didn't affect the task accomplishment at all. I could compensate for that in my own mind."

The main complaint of the high closure rates was the rapid flare required to arrest the relatively high rate of sink. The horizontal closure rate proved to be no problem. Therefore, the possibility exists that some of the earlier evaluations were affected by the high runway closure rates, particularly the vertical closure rate, however, the amount of degradation in pilot rating that closure rate may have caused cannot be determined. Both pilots attempted to compensate for closure rate when assigning pilot ratings but often longitudinal PIO problems were cited as an objectionable feature of the airplanes

Table XII

SIDE FORCE REQUIRED FOR LANDING IN A 15 KNOT CROSSWIND WITH ZERO BANK ANGLE FOR CONFIGURATIONS EVALUATED IN THIS INVESTIGATION

CONFIGURATION NO.	$Y_{\delta_y}\ \delta_y$ (1/sec)	$Y_{\delta_r}\ \delta_r$ (1/sec)	Y/W
1	0.0124	0.0044	0.122
2	0.0124	0.0048	0.125
3	0.0124	0.0022	0.107
4	0.0124	0.0026	0.109
5	0.0187	0.0044	0.169
6	0.0187	0.0048	0.172
7	0.0187	0.0022	0.152
8	0.0187	0.0026	0.155
9	0.0248	0.0044	0.213
10	0.0248	0.0048	0.216
11	0.0248	0.0022	0.197
12	0.0248	0.0026	0.200

during the flare maneuver. At the approach speed used, 130 KIAS, a flight path angle of $\gamma = -6°$ required an abrupt flare. If the pilot overcontrolled when commencing the flare then the longitudinal PIO sometimes resulted. The abrupt flare may have caused less trouble if the parameter n_z/α had been more nearly a typical STOL value, however as already discussed, n_z/α could not be reduced unless a faster final approach speed were used in the TIFS airplane. Probably the elimination of the large vertical closure rate and therefore the abrupt flare requirement is more important to good evaluations than is the simulation of the steep, $\gamma = -6°$, STOL flight path angle. It is reasonable, therefore, that future DSFC studies minimize vertical closure rates by using normal flight path angles, $\gamma \approx -3°$, for 130 knot approach speeds.

Section V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

An investigation of two methods of implementation and benefits that could accrue from providing the pilot with direct side force control (DSFC) during the crosswind landing of STOL and conventional airplanes was conducted in the USAF Total In-Flight Simulator (TIFS). A summary of the results obtained and the conclusions drawn are included in the following paragraphs:

1. The controller provided to the pilot for manual control of side force was a proportional type $\delta_y = K\delta_c$ center detent, controller. The following conclusions were reached concerning the manual DSFC controller:

   (a) The proportional type controller was generally satisfactory to the pilot for the application of DSFC during the crosswind landing approach.

   (b) Two identical manual controllers were installed in the evaluation cockpit for all evaluations. One was mounted on the aileron wheel adjacent to the aileron-elevator trim controller and the other was mounted integral to the number one power lever knob. Both evaluation pilots preferred to use the manual DSFC controller on the power lever, commenting that it felt more natural and that it did not interfere with any other aspects of aircraft control. The DSFC controller mounted on the aileron wheel was sometimes used inadvertently when the pilot was trimming the aileron.

   (c) It was determined early in the evaluation program that the sense of the DSFC controller should be such that the direction of the controller deflection was opposite to the applied direction of side force. In this way, after the pilot had established a crab angle on final approach, he could eliminate the crab angle by rotating the thumbwheel controller in the direction he wanted to rotate the nose of the airplane. Hence, if the airplane was crabbed with the nose to the left, side force controller deflection to the right, or clockwise on the power lever mounted controller, was the sense desired by the pilot.

   (d) The use of the manual DSFC controller was usually limited by the pilot to making an initial input followed by several small iterations prior to the pilot commencing the landing flare. During the flare, any additional corrections to combat the crosswind were usually made with conventional aileron and rudder control techniques. Both pilots, especially pilot B, found that attempts to use DSFC during the flare were not always successful and could make the crosswind landing more difficult, however, making a nominal correction for the crosswind with DSFC prior to the flare so that the airplane was in a trimmed, wings level, steady state sideslip, and then using conventional control techniques for small corrections made the crosswind landing easier for the pilot.

(e) Both pilots encountered some difficulty in determining the precise amount of DSFC to use, especially in turbulence. Further investigation is necessary to determine whether the imprecise control was a result of the DSFC controller sensitivity or was a result of the basic design of the controller itself.

2. The capability to land wings level in a 15 knot crosswind with 130 knot approach speed was demonstrated.

3. The availability of manual DSFC to the pilot was found to improve the pilot rating obtained in the crosswind landing task. The degree of improvement was found to be largely determined by the basic airplane lateral-directional dynamics. Airplanes which received the best pilot rating without DSFC showed the smallest improvement in terms of incremental pilot rating when the pilot had the aid of DSFC. However, the use of DSFC during the crosswind landing task often resulted in an airplane which was considered as "satisfactory without improvement" after having been evaluated as being in the "deficiencies warrant improvement" category without DSFC. Airplanes which received the poorest pilot rating without DSFC showed the greatest improvement in terms of incremental pilot rating when evaluated with DSFC.

4. The aileron wheel forces required to maintain the steady banked sideslipping attitude was a frequent objection for all configurations evaluated, even though the control forces and sensitivities were satisfactory for normal maneuvering in up-and-away flight. The aileron wheel forces were a major objection during the crosswind landing for configurations with the higher L_β and lower N_β.

5. For configurations with the higher N_β pilots objected to the large rudder pedal forces required, mean values up to 65 lb, to maintain the conventional steady sideslipping crosswind landing attitude.

6. The use of DSFC, with interconnects to the aileron and rudder which counteracted the steady state yawing and rolling moments, essentially eliminated the pilots' complaints about control forces since it eliminated the requirement for the pilot to maintain steady state control forces. Therefore, DSFC, as mechanized in this investigation, provided the pilot with the ability to align the airplane with the runway with reduced effort from that required without DSFC.

7. The RMS value of control force about the mean value was often larger when the pilot used DSFC than it was without DSFC. This can be interpreted to indicate that it was easier for the pilot to make continuous transient control inputs about a low mean force level than it was for him to make continuous transient inputs about a high mean control force level as was required without DSFC. Therefore, the pilot found it less difficult to suppress the responses of the airplane to turbulence when he had the aid of DSFC.

8. During the crosswind landings of this investigation, larger mean values of sideslip were generated with manual DSFC than without any DSFC. This indicates that the pilot was able to achieve better crosswind landing performance with DSFC.

9. Automatic localizer tracking with the wings level and with the airplane heading aligned with the runway heading in a crosswind was demonstrated. The automatic DSFC system successfully relieved the pilot of the lateral-directional control task during the crosswind landing, however, the pilot objected to lateral accelerations of $n_y = \pm 0.10$ g induced by the automatic DSFC system as it tracked the ILS localizer signal. In order for automatic DSFC to be completely successful the bothersome lateral accelerations must be reduced or eliminated. Further system refinement is also required to obtain reliable, repeatable approaches with the airplane positioned on runway centerline with no heading error. When it appeared to the pilot that the automatic system was going to place the aircraft off centerline and with a heading error when over the touchdown point, the pilot became apprehensive and attempted to superimpose control inputs on the automatic mode. This resulted in large control forces with little airplane response. Therefore, completely successful automatic side force control for crosswind landings may depend on the availability of a better localizer signal and/or on the use of inertial signals to the automatic pilot system to smooth the transient motions of the airplane. From the evaluations of this investigation it can be concluded that automatic DSFC appreciably reduces pilot effort since the pilot need only be concerned with longitudinal control of the airplane.

10. The combination of the lower N_β, higher L_β and the medium or higher value of ϕ/v_{cw} resulted in the poorest pilot ratings for the crosswind landing task. It was for this same combination of parameters that the greatest improvement in pilot rating was achieved when the pilot used DSFC as opposed to the evaluations with no DSFC.

11. The lower N_β higher L_β combinations evaluated had a low Dutch roll damping ratio, $0.015 \doteq \zeta_d \doteq 0.065$, and high roll-to-sideslip ratio, $|\phi/\beta|_d \approx 2.4$. The pilot directly objected to the low Dutch roll damping ratio, the low directional stiffness and to sideslip or yaw induced roll responses. With DSFC, as mechanized in this investigation, the sensitivity of pilot rating to these parameters was reduced. As indicated by the improvement in pilot rating, DSFC considerably reduced pilot objections about low ζ_d and high $|\phi/\beta|_d$ and made crosswind landings much easier for the pilot to perform.

12. Pilot effort resulting from the effects of turbulence was reduced when the pilot had the aid of DSFC. This reduction in sensitivity to turbulence is indicated by the turbulence effect rating for configurations which received the poorest pilot ratings without DSFC.

13. No reduction in roll or directional control power was realized with the use of DSFC in the crosswind landing task. Generally more roll control power was used with DSFC because the pilot was able to achieve larger mean values of sideslip during crosswind landings with DSFC.

14. Both pilots stated that they were able to compensate for the effects of runway closure rate when evaluating the configurations of this investigation. It is thought that the 130 knot final approach speed did not adversely affect the evaluations of this program.

Based on the results of this investigation the following are recommended for future studies of the application of direct side force control during the crosswind landing task:

1. Further studies to determine the best type of cockpit controller and optimum controller sensitivity should be undertaken. In this investigation only a proportional, $(\delta_y = K\delta_c)$ controller was used, however, a side force rate controller, $(\dot{\delta}_y$ = K·SWITCH ON), warrants investigation.

2. The automatic DSFC mode was satisfactorily demonstrated and numerous approaches were flown to simulated touchdown. There were occasions, however, when irregularities in the localizer signal required large, fast displacements of the side force generators to keep the airplane on the localizer course. In a system designed specifically for automatic mode operation, consideration should be given to further development to compensate for momentary irregularities in the localizer signal which are not uncommon at many ILS installations. The use of inertial type signals should be investigated, Reference 20, as a means to eliminate the effect of these sharp bends in the VHF localizer signal.

3. The effects of rolling moment due to side force generator deflection, L_{δ_y}, and yawing moment due to side force generator deflection, N_{δ_y}, may have a significant effect on the utility of DSFC. For example, if the design of the side force generator provides L_{δ_y} of the proper sign to oppose L_β then some reduction in required roll control power may be realized when using DSFC. These parameters should be the subject of some further DSFC investigation.

4. Because of the way stability derivatives were varied in this investigation, any change in Dutch roll damping ratio, ζ_d, was accompanied by a change in the roll-to-sideslip ratio $|\phi/\beta|_d$ such that smaller values of ζ_d were accompanied by larger values of $|\phi/\beta|_d$. Therefore, it is difficult to assess the source of the pilots' difficulties. Some investigation of the independent effects of ζ_d and $|\phi/\beta|_d$ on the usefulness of DSFC should be undertaken.

5. In this investigation the sideslip attained during the crosswind landing was used as a measure of the pilots' performance, and on this basis the pilot was able to either achieve better performance with DSFC or achieve equivalent performance with reduced pilot effort. To obtain a better measure of pilot performance during the crosswind landing it would be desirable to accurately measure the difference between the aircraft and runway heading, and probably more important, the lateral velocity of the airplane relative to the runway. Then pilot performance during the crosswind landing could be accurately assessed since heading error and lateral velocity relative to the runway should be zero at touchdown. A measure of these parameters would require additional instrumentation in the TIFS including a very sensitive heading indication and an inertial velocity sensing device.

6. It is recommended that future studies of DSFC performed in the TIFS airplane use conventional flight path angles of $\gamma \approx -3°$ to help eliminate longitudinal control problems the pilot may encounter when commencing the flare maneuver.

7. An investigation of DSFC during crosswind landings with larger crosswind components and higher turbulence levels than those used in this investigation should be undertaken. This investigation has shown DSFC to be beneficial in a 15 knot crosswind, but it is important to determine if greater benefits could be realized in more severe crosswind and turbulence conditions. Further, it would be beneficial to determine whether a pilot rating improvement results only from landing wings level in a crosswind or whether merely reducing the required bank angle would be sufficient.

Since the results of this investigation show positive benefits from the application of DSFC to the crosswind landing task, other applications of DSFC should be investigated. One such application would include DSFC as a maneuvering control especially for performing the "side step" maneuver which the pilot must perform at the completion of an instrument approach when he finds he is laterally offset from the runway. The use of DSFC as a device to reduce the bank angle required in performing the side step maneuver may require a method of mechanization different from that used in this investigation.

Appendix I

DEVELOPMENT OF THE EQUATIONS OF MOTION USED FOR THE TIFS SIMULATION OF STOL AIRPLANES IN CROSSWIND LANDING APPROACH

The purpose of this appendix is to develop the equations of motion that were programmed on the TIFS airplane analog computer for the evaluation of direct side force control (DSFC). The contents of this section are divided into the following order: (1) development of the generalized equations of motion of the model at the model center of gravity, (2) approximations used for simplification of the equations, and (3) transformation of output states to the center of gravity of the TIFS aircraft. The equations shown are a modification of those presented in Reference 3.

Development of Model Equations at Model C.G.

Reference 21 presents the exact nonlinear equations of motion in body axes and also illustrates that the model following system is based on the V_I α_I, β_I states of the airplane and their respective time derivatives rather than on the components of the velocity vector. The reference also introduces a non-orthogonal axis system to simplify the computation of V_I and $\dot{V}_I$ from the drag equation and introduces approximations into the other force equations to obtain an approximate nonlinear representative of the x and y force equations to obtain the desired outputs, angle of attack and angle of sideslip. The treatment in this section will be first to recast the equations of motion into a form which produces the desired output states prior to the introduction of simplifying assumptions.

The force equations in body axes at the model c.g. may be written as (Reference 22)

$$\dot{u}_I + w_I q_I - v_I r_I = \frac{F_{x_B}}{m} - g \sin\theta \qquad (14)$$

$$\dot{v}_I - w_I p_I + u_I r_I = \frac{F_{y_B}}{m} + g \cos\theta \sin\phi \qquad (15)$$

$$\dot{w}_I - u_I q_I + v_I p_I = \frac{F_{z_B}}{m} + g \cos\theta \cos\phi \qquad (16)$$

while the relationships between the velocity components and angle of attack and sideslip are as follows

$$u_I = V_I \cos\alpha_I \cos\beta_I \qquad (17)$$

$$v_I = V_I \sin\beta_I \tag{18}$$

$$w_I = V_I \sin\alpha_I \cos\beta_I \tag{19}$$

Substitution of Equations (17), (18), (19) into Equations (14), (15), and (16) yields the following nonlinear form of the force equations of motion

$$\dot{V}_I = \frac{1}{m}\left\{F_{x_B}\cos\alpha_I\cos\beta_I + F_{z_B}\sin\alpha_I\cos\beta_I + F_{y_B}\sin\beta_I\right\} - g\sin\gamma \tag{20}$$

$$\dot{\alpha}_I = \frac{1}{mV_I\cos\beta_I}\left\{F_{z_B}\cos\alpha_I - F_{x_B}\sin\alpha_I\right\} + \frac{g}{V_I\cos\beta_I}\left\{\cos\theta\cos\phi\cos\alpha_I + \sin\theta\sin\alpha_I\right\} + q_I - \left[p_I\cos\alpha_I + r_I\sin\alpha_I\right]\tan\beta_I \tag{21}$$

$$\beta_I = \frac{1}{mV_I}\left\{F_{y_B}\cos\beta_I - F_{x_B}\cos\alpha_I\sin\beta_I - F_{z_B}\sin\alpha_I\sin\beta_I\right\} + \frac{g}{V_I}\quad \cos\theta\cos\beta_I\sin\phi - (\cos\theta\cos\phi\sin\alpha_I - \sin\theta\cos\alpha_I)\sin\beta_I\,] + p_I\sin\alpha_I - r_I\cos\alpha_I \tag{22}$$

where

$$\sin\gamma = \sin\theta\cos\alpha_I\cos\beta_I - \sin\beta_I\cos\theta\sin\phi - \sin\alpha_I\cos\beta_I\cos\theta\cos\phi$$

Separating the force terms into aerodynamic and engine contributions, there results:

$$T_{x_B} = T\cos i_T$$

$$T_{z_B} = -T\sin i_T$$

$$T_{y_B} = 0$$

$$F_{x_B} = F_{x_{AB}} + T_{x_B}$$

$$F_{y_B} = F_{y_{AB}} + T_{y_B}$$

$$F_{z_B} = F_{z_{AB}} + T_{z_B}$$

Substitution of the relationships between the aerodynamic forces in wind, stability and body axis systems yields the following equations.

$$\dot{V}_I = \frac{1}{m}\left[T\cos(\alpha_I + i_T)\cos\beta_I - D\right] - g\sin\gamma \tag{23}$$

$$\dot{\alpha}_I = -\frac{\left[L + T\sin(\alpha_I + i_T)\right]}{mV_I\cos\beta_I} + \frac{g}{V_I\cos\beta_I}\left\{\cos\theta\cos\phi\cos\alpha_I + \sin\theta\sin\alpha_I\right\}$$
$$+ q_I - \left[p_I\cos\alpha_I + r_I\sin\alpha_I\right]\tan\beta_I \tag{24}$$

$$\dot{\beta}_I = \frac{\left[Y_W - T\sin\beta_I\cos(\alpha_I + i_T)\right]}{mV_I} - \left[r_I\cos\alpha_I - p_I\sin\alpha_I\right]$$
$$+ \frac{g}{V_I}\left\{\cos\theta\cos\beta_I\sin\phi - \sin\beta_I\left(\cos\theta\cos\phi\sin\alpha_I - \sin\theta\cos\alpha_I\right)\right\} \tag{25}$$

where

$$D = -\left[F_{y_{AB}}\sin\beta_I + \cos\beta_I\left(F_{x_{AB}}\cos\alpha_I + F_{z_{AB}}\sin\alpha_I\right)\right]$$
$$= -\left[F_{y_{AB}}\sin\beta_I + \cos\beta_I F_{x_{AS}}\right] \tag{26}$$

$$L = -\left[F_{z_{AB}}\cos\alpha_I - F_{x_{AB}}\sin\alpha_I\right] = -F_{z_{AS}} \tag{27}$$

$$Y_W = \left[F_{y_{AB}} \cos\beta_I - (F_{x_{AB}} \cos\alpha_I + F_{z_{AB}} \sin\alpha_I) \sin\beta_I \right]$$

$$= \left[F_{y_{AB}} \cos\beta_I - F_{x_{AS}} \sin\beta_I \right] \qquad (28)$$

The preceding force equations are exact; no simplifications have been introduced. The force equations as written in this section require information concerning Euler angles and rotational rates in body axis. Thus, the exact moment equations are written in body axes with the effects of thrust offset introduced.

Pitching moment

$$\dot{q}_I = \frac{1}{I_{yy}} \left[M_A + M_T \right] - \frac{1}{I_{yy}} \left[(I_{xx} - I_{zz}) p_I r_I + I_{xz} (p_I^2 - r_I^2) \right] \qquad (29)$$

Rolling moment

$$\dot{p}_I - \frac{I_{xz}}{I_{xx}} \dot{r}_I = \frac{1}{I_{xx}} \left[L_A + L_T \right] - \frac{1}{I_{xx}} \left[r_I (I_{zz} - I_{yy}) - I_{xz} p_I \right] q_I \qquad (30)$$

Yawing moment

$$\dot{r}_I - \frac{I_{xz}}{I_{zz}} \dot{p}_I = \frac{1}{I_{zz}} \left[N_A + N_T \right] - \frac{1}{I_{zz}} \left[p_I (I_{yy} - I_{xx}) + I_{xz} r_I \right] q_I \qquad (31)$$

Where M_T, L_T and N_T are dependent upon the location and incidence of the engines with respect to the body axis reference system and center of gravity location. The Euler angle equations may be written as:

$$\dot{\theta} = q_I \cos\phi - r_I \sin\phi \qquad (32)$$

$$\dot{\phi} = p_I + \dot{\psi}_I \sin\theta \tag{33}$$

$$\dot{\psi} = \frac{q_I \sin\phi + r_I \cos\phi}{\cos\theta} \tag{34}$$

Approximate Nonlinear Equations of Motion

The approximate equations of motion are determined from the exact nonlinear equations by the introduction of simplifying assumptions. For the DSFC program the simplifying assumptions in the force equations were small angle assumptions on α_I, β_I and θ and assuming the thrust incidence angle to be zero. Neglecting higher order cross-coupling terms were the simplifying assumptions in the moment equations. Thus the force equations may be written as follows:

$$\dot{V}_I = \frac{1}{m}\left[T + F_{x_{AS}} + \beta_I F_{x_{AB}}\right] - g \sin\gamma \tag{35}$$

where

$$\sin\gamma = \theta - \alpha_I \cos\phi - \beta_I \sin\phi \tag{36}$$

$$\dot{\alpha}_I = -\frac{1}{mV_I}\left[L - T\alpha_I\right] + \frac{g\cos\phi}{V_I} + q_I - \beta_I p_I \tag{37}$$

$$\dot{\beta}_I = \frac{F_{y_{AB}}}{mV_I} - \frac{\beta_I}{mV_I}\left[F_{x_{AS}} + T\right] - r_I + \alpha_I p_I + \frac{g}{V_I}\left[\sin\phi - \beta_I(\alpha_I\cos\phi - \theta)\right] \tag{38}$$

Substitution of Equations (35) and (36) into Equation (38) and neglecting higher order terms, yields:

$$\dot{\beta}_I = -\frac{\beta_I V_I}{V_I} + \frac{g}{V_I}\sin\phi - r_I \alpha_I + p_I \alpha_I + \frac{F_{y_{AB}}}{m V_I} \quad (39)$$

The moment equations become

$$\dot{q}_I = \frac{1}{I_{yy}}\left[M_A + M_T\right] - \frac{1}{I_{xy}}\left[\left(I_{xx} - I_{zz}\right) p_I r_I\right] \quad (40)$$

$$\dot{p}_I - \frac{I_{xz}}{I_{xx}}\dot{r}_I = \frac{1}{I_{xx}}\left[L_A + L_T\right] \quad (41)$$

$$\dot{r}_I - \frac{I_{xz}}{I_{zz}} p_I = \frac{1}{I_{zz}}\left[N_A + N_T\right] \quad (42)$$

The following auxiliary equations were also programmed.

$$\dot{h}_m = V_{I_m}\sin\gamma_m \quad (43)$$

$$n_{y_{B_m}} = \frac{1}{mg} F_{y_{AB}} \quad (44)$$

$$n_{z_{B_m}} = \frac{1}{mg}\left[F_{z_{AS}} + F_{x_{AS}}\,\alpha_{I_m}\right] \quad (45)$$

To obtain the greatest flexibility for airplane derivatives and airspeeds, the model computer was programmed using nondimensional derivatives. They were multiplied internally by the appropriate dynamic pressures, velocity and wing area to obtain the proper forces and moments used in the equations of motion. These equations are:

$$F_{X_{AS}} = \bar{q} S C_{D_S} = \bar{q} S \left(C_{D_o} + K\, C_{L_{NT}}^{2} + C_{D_{\delta_e}} \delta_e \right) \tag{46}$$

where

$$C_{L_{NT}} = C_{L_o} + C_{L_\alpha} \alpha_T + \frac{\bar{c}}{2V_T} C_{L_{DYN}} \tag{47}$$

$$C_{L_{DYN}} = C_{L_q} q_T + C_{L_{\dot{\alpha}}} \dot{\alpha}_T \tag{48}$$

$$L = \bar{q} S C_L = \bar{q} S \left(C_{L_{NT}} + C_{L_{\delta_e}} \delta_e \right) \tag{49}$$

$$F_{Y_{AB}} = \bar{q} S C_Y = \bar{q} S \Big(C_{Y_\beta} \beta_T + C_{Y_{\delta_r}} \delta_r + C_{Y_{\delta_a}} \delta_a + C_{Y_{\delta_y}} \delta_y + \frac{b}{2V_T} C_{Y_{DYN}} \Big) \tag{50}$$

where

$$C_{Y_{DYN}} = C_{Y_r} r_T + C_{Y_p} p_T + C_{Y_{\dot{\beta}}} \dot{\beta}_T \tag{51}$$

$$M_A = \bar{q} S \ell C_m = \bar{q} S \ell \left(C_{m_o} + C_{m_\alpha} \alpha_T + C_{m_{\delta_e}} \delta_e + \frac{\bar{c}}{2V_T} C_{m_{DYN}} \right) \tag{52}$$

where

$$C_{m_{DYN}} = C_{m_{\dot{\alpha}}} \dot{\alpha}_T + C_{m_q} q_T \tag{53}$$

$$M_T = z_T T \tag{54}$$

$$L_A = \bar{q} S b C_l = \bar{q} S b \left(C_{l_\beta} \beta_T + C_{l_{\delta_r}} \delta_r + C_{l_{\delta_a}} \delta_a + \frac{b}{2VT} C_{l_{DYN}} \right) \tag{55}$$

where

$$C_{l_{DYN}} = C_{l_p} p_T + C_{l_r} r_T \tag{56}$$

$$L_T = 0 \tag{57}$$

$$N_A = \bar{q} S b C_n = \bar{q} S b \left(C_{n_\beta} \beta_T + C_{n_{\delta_r}} \delta_r + C_{n_{\delta_a}} \delta_a + \frac{b}{2VT} C_{n_{DYN}} \right) \tag{58}$$

where

$$C_{n_{DYN}} = C_{n_{\dot{\beta}}} \dot{\beta}_T + C_{n_r} r_T + C_{n_p} p_T \tag{59}$$

$$N_T = 0 \tag{60}$$

Some of the above derivatives were zero in this investigation, however, in the interest of flexibility and completeness all were programmed and are shown.

Transformation of Model States from Model c.g. to TIFS c.g. and the Evaluation Cockpit

Response variables of the model were computed in flight at the model c.g. These parameters had to be transformed to the TIFS c.g. since model following was about the TIFS center of gravity. The body axes of the model and TIFS were assumed to be parallel enabling only a linear (ℓ_x, ℓ_z) transformation to be used. The transformation distances were determined as follows: first the evaluation cockpit of TIFS and the model cockpit were assumed to be the same point in space, then from the distances between the evaluation cockpit and the TIFS c.g. and the distance between the model cockpit and the model c.g. the transformation distances were determined. Transforming model data to the TIFS c.g. from the model c.g. is necessary because the sensor data is determined at the TIFS c.g. From the dynamics of rigid bodies, if the motions of the TIFS c.g. are the same as those of a point in the model with the same geometric relationship to the model c.g., then following is achieved at the evaluation cockpit. The transformations used, neglecting high order terms, are:

$$\dot{\alpha}_{IMTCG} = \dot{\alpha}_{IM} - \frac{\dot{q}_{IM}}{V_{IM}} \left(\ell_{x_{MTCG}}\right) \quad (61)$$

$$\alpha_{IMTCG} = \alpha_{IMT} - \frac{q_{IM}}{V_{IM}} \left(\ell_{x_{MTCG}}\right) \quad (62)$$

$$\dot{\beta}_{IMTCG} = \dot{\beta}_{IM} + \frac{1}{V_I} \left[\dot{r}_{IM} \ell_{x_{MTCG}} - \dot{p}_{IM} \ell_{z_{MTCG}} \right] \quad (63)$$

$$\beta_{IMTCG} = \beta_{IM} + \frac{1}{V_I} \left[r_{IMT} \ell_{x_{MTCG}} - p_{IMT} \ell_{z_{MTCG}} \right] \quad (64)$$

$$\dot{V}_{IMTCG} = \dot{V}_{IM} + \frac{\dot{q}_{IM}}{57.3} \left(\ell_{z_{MTCG}}\right) \quad (65)$$

$$\left(n_{y_B}\right)_{MTCG} = \left(n_{y_B}\right)_M + \frac{1}{(57.3)(32.2)}\left[\dot{r}_{IM}\ell_{x_{MTCG}} - \dot{p}_{IM}\ell_{z_{MTCG}}\right] \tag{66}$$

$$\left(n_{y_B}\right)_P = \left(n_{y_B}\right)_M + \frac{1}{(57.3)(32.2)}\left[\dot{r}_{IM}\ell_{x_{MP}} - \dot{p}_{IM}\ell_{z_{MP}}\right] \tag{67}$$

$$\left(n_{z_B}\right)_{MTCG} = \left(n_{z_B}\right)_M - \frac{\dot{q}_{IM}}{(57.3)(32.2)}\left(\ell_{x_{MTCG}}\right) \tag{68}$$

$$\left(n_{z_B}\right)_P = \left(n_{z_B}\right)_M - \frac{\dot{q}_{IM}}{(57.3)(32.2)}\left(\ell_{x_{MP}}\right) \tag{69}$$

where

$$\ell_{x_{MTCG}} = \ell_{x_{MP}} - \ell_{x_{TP}} = \ell_{x_{MP}} - 35.0 \tag{70}$$

$$\ell_{z_{MTCG}} = \ell_{z_{MP}} - \ell_{z_{TP}} = \ell_{z_{MP}} - 2.75 \tag{71}$$

A complete development of the above transformation is presented in Reference 23.

Appendix II

DATA RECORDING

A 60 channel digital recording system was used for the acquisition of quantitative data. Two channels were used for "bookkeeping," such as record numbers and calibrations. The remaining 58 channels recorded model parameters, aircraft attitude data, control data and cockpit instrument data.

Model parameters recorded were:

$\Delta\theta_m$, $\Delta\alpha_{I_{m_{TCG}}}$, $\Delta V_{I_{m_{TCG}}}$, $\Delta n_{z_{p_m}}$, $\Delta\delta_{e_m}$, $\Delta\delta_{a_m}$, $\Delta\delta_{r_m}$, θ_m — incremental values from time of engage.

q_{I_m}

$\dot{\alpha}_{I_{m_{TCG}}}$

$\dot{V}_{I_{m_{TCG}}}$

ϕ_m

p_{I_m}

r_{I_m}

$\beta_{I_{m_{TCG}}}$

$\dot{\beta}_{I_{m_{TCG}}}$

$n_{y_{p_m}}$

T_m

$\sin\gamma_m$

h_e

$\dot{h}_m$

δ_c wheel position

δ_{Y_m}

p_{T_m}, V_{T_m}, α_{T_m} — Total model values, include gust terms.

The following airplane (TIFS) data, incremental and total were recorded. Details of TIFS sensor signals are presented in Reference 4.

$\Delta \theta$
$\Delta \alpha_I$
ΔV
Δn_{z_p}
} incremental values from time of engage.

$\sin \epsilon \psi$ (ϵ = error)
q_I
$\dot{\alpha}_I$
V_I
$\dot{V}_I$
ϕ
p_I
r_I
β_I
$\dot{\beta}_I$
n_{y_p}
$\sin \gamma$
$\dot{h}$

$\alpha_{g_{TOTAL}}$
$\beta_{g_{TOTAL}}$
$V_{g_{TOTAL}}$
} gust terms

p_g

The following (TIFS) control data were also recorded.

δ_a
δ_r
δ_e

δ_x^R

δ_y^R

δ_z^L

δ_F

F_{AW} F_{EW} F_{RP}	Force inputs by evaluation pilot

Instrument data recorded were

$y(TD_{ind})$	DME with touchdown indication
ILS	Localizer

Additionally, pilot comments and ratings were tape recorded immediately after each evaluation was completed. Pilot ratings were also hand recorded on a in-flight data record for backup in case of voice recorder failure.

Appendix III

COMPUTER GENERATED RESPONSES WITH AND WITHOUT $\frac{\delta_a}{\delta_y}$ AND $\frac{\delta_r}{\delta_y}$ INTERCONNECTS FLIGHT DATA TABULATION

IN-FLIGHT RESPONSES DURING FLARE AND TOUCHDOWN PILOT COMMENTS

This appendix is arranged in four sections in accordance with the four combinations of N_β and L_β.

Appendix III.1 CONFIGURATIONS WITH N_β = 0.94 AND L_β = -1.57 (Configurations 1,5 and 9)

Appendix III.2 CONFIGURATIONS WITH N_β = 0.94 AND L_β = -2.95 (Configurations 2,6 and 10)

Appendix III.3 CONFIGURATIONS WITH N_β = 0.42 AND L_β = -1.57 (Configurations 3,7 and 11)

Appendix III.4 CONFIGURATIONS WITH N_β = 0.42 AND L_β = -2.95 (Configurations 4,8 and 12)

Presented in each section are digital computer responses of ϕ, p, β, r and n_y to a 10 degree side force generator input with and without interconnects to the aileron and rudder. The control inputs used to produce the time histories did not include the interconnect filters and control system dynamics. Therefore, for the case with aileron and rudder to side force interconnects, all three controls were input simultaneously.

Each section of this appendix also contains a tabulation of selected flight data, along with turbulence data, for each of the configurations and modes (no DSFC, manual DSFC, automatic DSFC) evaluated. The majority of pilot difficulties occurred during the final portion of the approach just prior to touchdown. As a result, only the final 10 to 20 seconds of the approach data were analyzed and presented. The Root Mean Square (RMS) values presented were computed about the mean value of each variable. Therefore, they represent a measure of activity around the average value of the variable. These data were recorded by means of the onboard Ampex digital tape recorder during each landing approach. A malfunction of the Ampex recorder precluded any possibility of obtaining quantitative data on three flights, which are noted where appropriate.

Selected flight responses (ϕ, p, β, r and n_y) and pilot inputs F_{AW}, F_{RP} and δ_y during approach, flare and touchdown are presented for each configuration and evaluation mode. Pilot comments, which have been edited for clarity, follow each set of flight responses.

Appendix III.1

CONFIGURATIONS WITH N_{β} = 0.94 AND L_{β} =-1.57

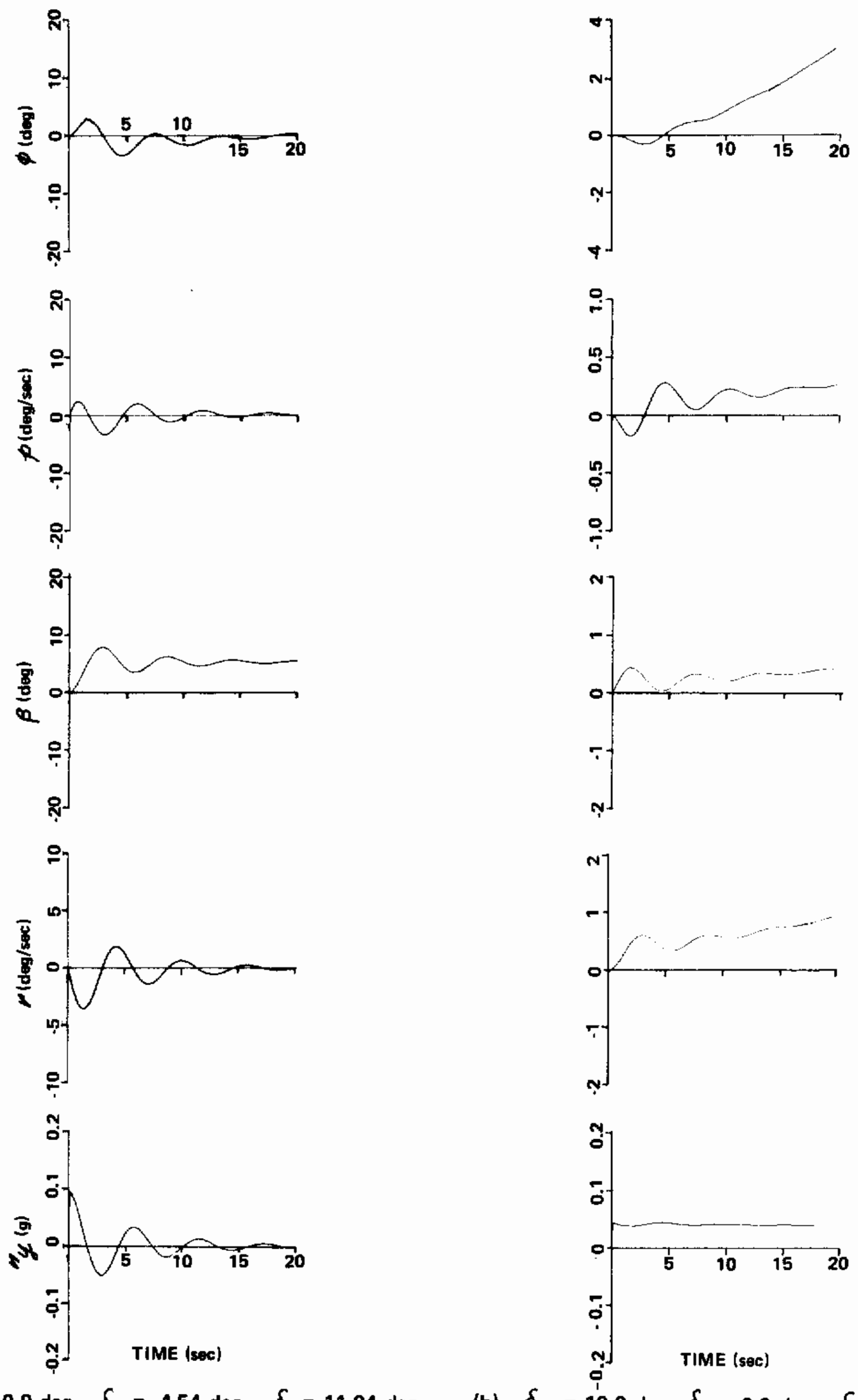
(CONFIGURATIONS 1,5 and 9)

DIGITAL RESPONSES WITH AND WITHOUT INTERCONNECTS

FLIGHT DATA TABULATION

IN-FLIGHT RESPONSES DURING LANDING

PILOT COMMENTS



(a) δ_y = 10.0 deg, δ_a = -4.54 deg, δ_r = 11.84 deg (b) δ_y = 10.0 deg, δ_a = 0.0 deg, δ_r = 0.0 deg

MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO AILERON AND RUDDER (CONFIGURATION 1)

CONFIGURATION 1 FLIGHT TEST DATA TABULATION

(EVALUATION FLIGHT NO. 8 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	-0.79	1.84	-3.52	0.67	-3.38	2.10	34.2	4.26	0	4	D
MANUAL	1.35	1.32	-8.36	0.59	-0.96	3.38	19.5	4.77	-15	3	D
AUTOMATIC	-0.18	0.36	5.40	0.53	-1.10	0.53	4.0	2.68	+10	3	6

CONFIGURATION 1 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	070	15	1.91	1.46	2.44	100
MANUAL	070	15	2.57	1.36	3.69	100
AUTOMATIC	080	11	1.02	1.05	1.00	100

CONFIGURATION 1 FLIGHT TEST DATA TABULATION
(EVALUATION FLIGHT NO. 14 PILOT B)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	2.02	1.11	4.54	1.06	4.18	3.47	-34.1	4.65	0	3	B
MANUAL	-1.08	1.76	4.91	0.60	1.53	1.52	- 4.26	3.43	8	4.5	C

CONFIGURATION 1 WIND AND GUST DATA

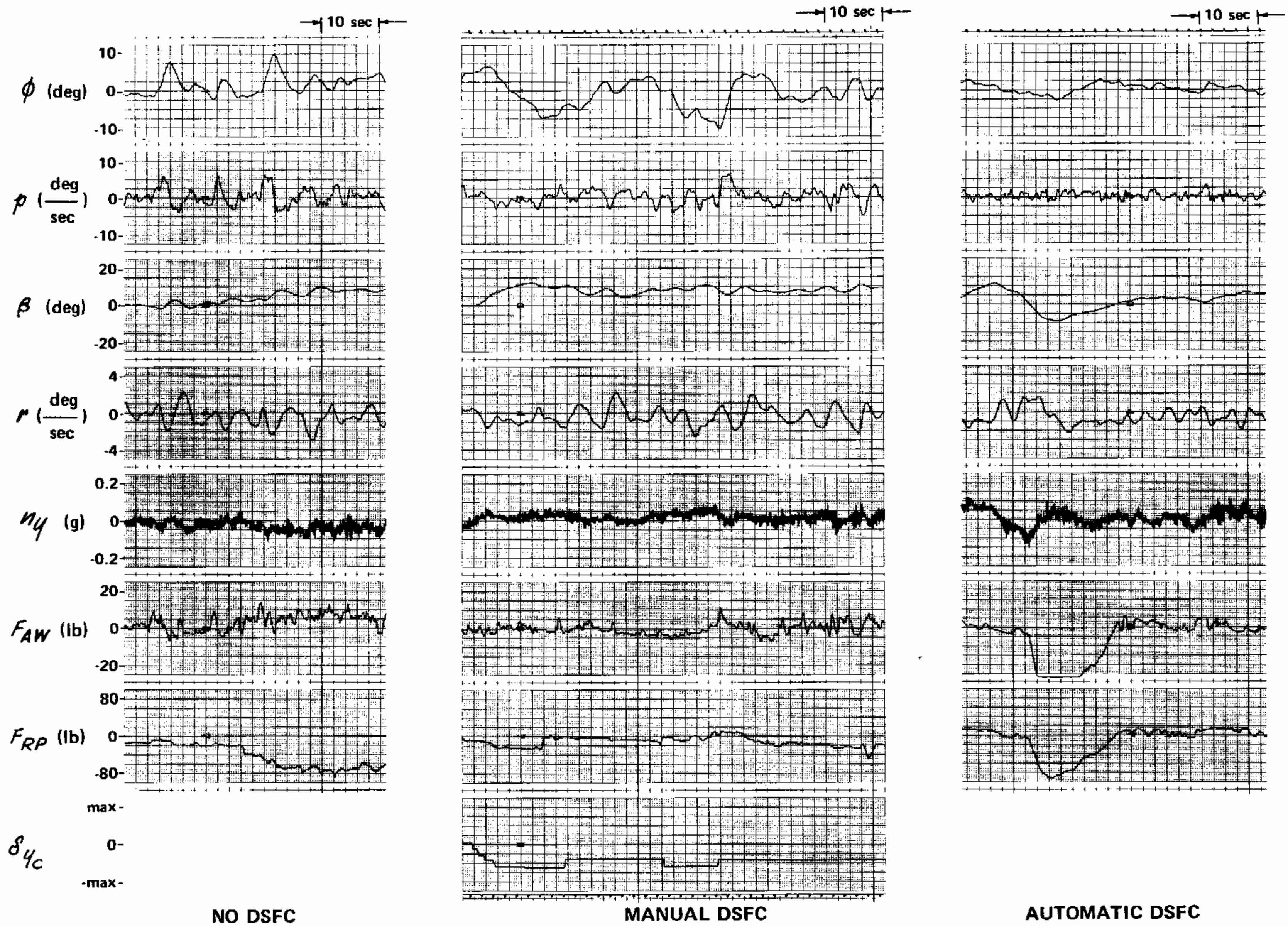
	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	090	10	1.83	1.77	2.64	100
MANUAL	090	10	1.40	1.42	1.93	100

CONFIGURATION 1 FLIGHT TEST DATA TABULATION
(EVALUATION FLIGHT NO. 21 PILOT B)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	2.32	1.14	7.8	1.02	7.16	2.06	-66.8	5.75	0	4.5	B
MANUAL	0.0	0.98	8.8	0.80	2.10	2.03	-20.0	6.70	8	3.0	B

CONFIGURATION 1 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	330	10.0	1.97	1.70	2.05	280
MANUAL	340	0.8	1.87	1.92	1.70	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN
CONFIGURATION 1

CONFIGURATION 1 NO DSFC | PILOT A | PR 4 | TR D | EVAL. FLT. NO. 8

INITIAL IMPRESSION AND GENERAL COMMENTS

The practice and this second approach appeared to be quite reasonable, I didn't have any big problems. So far it looks like a pretty good configuration. Lightening the aileron forces some helped on that. We apparently have a low roll to sideslip ratio. I don't know whether we have a high side force model or not, but it looks like it doesn't take a lot of bank angle to kill the crosswind. Without the turbulence in, we have some natural turbulence which I think I would call light. Feeding the natural turbulence into the model amplifies the turbulence effect. The aircraft response is significantly larger with the canned or the introduction of the natural turbulence into the model. The first two landings I thought were okay and I was going to probably rate this acceptable without any compensation for deficiencies but the last one, I didn't like the landing, especially since I got hit with a gust just before landing.

ABILITY TO TRIM

Ability to trim is no problem.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

I choose a lighter aileron force, 75 percent of what I've been flying with. There's some slight mismatch in the harmony but it's acceptable.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll control seems to be okay, seemed to have a little bit of proverse yaw. Turn coordination requirements are minor. Pitch control is okay.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind turning final was no problem.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

I used the crab although I think in couple of those approaches I was actually angling in a little bit because I was not making good ground track lineup with the centerline. In decrabbing and establishing a bank angle and a sideslip for touchdown, the first one, with no turbulence, I thought, was a pretty good landing. The first one with turbulence I also thought was a pretty good landing and there was a moderate amount of effort required. The last one took a little more effort, I think mainly because just before and during the flare, I was a little late in the flare, I hit a fairly good gust. The airplane feels somewhat lose directionally, although it's hard for me to really say that with 100 percent assurance. I do work the rudders quite a bit, so I don't know, maybe I'm just generating some of this and it's apparently a flat Dutch roll, so that also would give you the impression that the airplane is slushing around directionally.

CONTROL TECHNIQUE

Control technique is nothing special.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I don't think that the lateral control was affected by longitudinal motions to any great extent, if any. Longitudinal control inputs did not affect the lateral as far as I could tell.

EFFECT OF RUNWAY CLOSURE RATE

The vertical closure rates on the last one seemed to be somewhat high, mainly as I said because I was a little late flaring and I added power and maybe I didn't add enough power or something, but the rate of sink seemed to be sort of high and I touched down okay with attitude, aircraft attitude seemed to be reasonable, where I thought it would have been a fairly hard landing, not as good as I would have liked.

GOOD FEATURES

The good features I think is they have fairly good damping in Dutch roll, good in longitudinal. You do seem to have sufficient aileron control to kill the crab and hold a bank angle properly and make a decent touchdown on one wheel.

OBJECTIONABLE FEATURES

The objectional features I guess is that the airplane seems to be fairly responsive to turbulence and that increases the workload of the pilot a pretty fair amount.

PILOT RATING AND PRIMARY REASON

I rated this a 4, I'm leaning toward a 3. The only reason I rated it a 4 is that I wasn't happy with the second landing in the turbulence and maybe this is one of those insidious ones where you might run into trouble with some heavy turbulence, on the other hand it might have just been poor pilot technqiue on my part. So the main reason I'm rating it a 4 is because I didn't feel as comfortable as I should have on the last landing. But, not a bad airplane, I think I could have landed every time, pretty well.

TURBULENCE EFFECT RATING

The turbulence rating - I rate it a D. I'd say that there is a moderate increase in workload in turbulence.

CONFIGURATION 1 MAN DSFC	PILOT A	PR 3	TR D	EVAL. FLT. NO. 8

INITIAL IMPRESSION AND GENERAL COMMENTS

I worked quite a bit with the side force [on the first approach]. I ended up with about half, I guess, the side force surface, I really didn't have a lock-on on the heading but I guess basically it was a fairly simple one. I think I touched down a little sooner than I wanted to, and I ballooned sligthly. Flying around here a little bit in the pattern it seems that the ailerons feel a little soft and the displacements may be a little high, so that maybe I should have reduced the gearing some. On that one [the second approach] there I was sort of feeling for the runway. I thought I had it pretty well the first time I rounded out but I guess I was just barely off the runway, the touchdown point and in attempting to get it down there I did get into a very slight Dutch roll oscillation, but I think it probably would have been a good enough touchdown. This is with the manual controller. Generally, the first, without the turbulence, I thought was pretty good; with the turbulence I was hunting for the proper side force position to align me with the centerline. It always seemed that I was overcontrolling with it. I ended up just making an arbitrary input to get the nose around where it looked okay and then I found myself drifting to the left, opposite to where the crosswind was coming from. So then I would make a correction for that and I'd find myself doing a little drifting back the other way and just without really thinking too much about the side force. I was also introducing some bank angle trying to kill some small drift angles or drift rates and maybe that complicated my control. So, in other words, I think you can probably eliminate most of the crosswind without trouble of the precision of setting the side force controller, especially in the turbulence as I said, it was not the greatest. However, I usually ended up in a reasonable landing I guess.

ABILITY TO TRIM

The ability to trim was no problem.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The feel characteristics are the same, I didn't go through any selection process.

AIRPLANE RESPONSE TO PILOT INPUTS

Responses seemed to be adequate for the task, both in roll and in pitch, and yaw control is certainly adequate. Coordination, you don't really look for the coordination and the crosswind anyway, so that's not a problem. Pitch attitude control I guess I can make the same comments everytime, it somewhat feels like a big airplane I guess, slow responding, not exceptionally slow but certainly not anyway near a fighter.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind turning on final; I've been making these approaches on final fairly close and so I don't really have much time in aligning myself and maybe that's one of the problems that I have in trying to find the proper side force position for the particular crosswind, maybe if I started a little farther out it would be a little better.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

Landing approach method, as I said, was just to take out the crab angle with the side force surface. Alignment was a little bit of a problem due to the turbulence inputs and so I think I was sort of hunting around for it. I didn't think the performance was the greatest but it was good enough to bring the airplane in without any particular effort.

CONTROL TECHNIQUE

The control technique, it's fairly normal aileron rudder, it's really not necessary if you can set the side force surface exact.

CONTROL OF SIDESLIP WITH DSFC

In the turbulence the pilot has a tendency to try to fly the airplane when he sees some drifting, dropping a wing rather than just using the side forces. In other words, there is a built-in correction in the pilot and if you don't remember that you have something to kill the drift for you, with the side force surface, you may end up not really doing yourself as much good as you could.

CONTROL OF GLIDE SLOPE

I don't think that the side force interferes with the throttle or elevator control. On the flares, I don't know what these angles are coming out, but it does seem like I'm sinking pretty good when I start my flare. I don't want to start it too soon, to flatten out the approach too much and on the other hand if you start a little late then you get to rushing yourself a little bit to try to get the attitude right.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I don't think that the lateral inputs really affected the longitudinal, although it surprised me. On both of these approaches with the turbulence in I think I ballooned a little bit. I had a tendency to round-out a little high - maybe I'm just sitting too low on this seat, I don't know. So I think that the cross coupling between longitudinal and lateral is fairly minor.

EFFECT OF RUNWAY CLOSURE RATE

The closure rates, not the horizontal closure rates; in other words, V; the W is the thing that can be troublesome. I didn't really feel pushed on the sink rates but this kind of an angle does make you work some to kill the rate of sink.

GOOD FEATURES

Certainly the fact that you can eliminate the heading alignment problem; in other words, the nose of the airplane can be pointed down the runway without having to drop a wind to any great extent is certainly a very good feature.

OBJECTIONABLE FEATURES

The responsiveness of the airplane in turbulence. In smooth air it seemed to be a fairly easy task. In turbulence, it's a little more of a task only because the pilot had trouble judging when he had sufficient side force surface in. I think really that it relieves the pilot quite a bit when he has control of the sideslip with the side force. I guess that when you come right down to it, the only objection I have is the responsiveness of the thing in turbulence, but I think I was able to make reasonable landings each time. I suspect that with a few more of these approaches with the side force control you could probably determine a little better what's required for making a good approach. Also, I think if you started your approach where you normally would, a little farther out, and you could pick up the drift and establish the drift angle sooner and have a little more time to play with the side force control, I think that would all probably turn out to give you a pretty good approach, a pretty good landing.

PILOT RATING AND PRIMARY REASON

I think that the responsiveness in turbulence is a mildly unpleasant deficiency. The pilot compensation is maybe less than moderate. Call it a 3 because I still think that the pilot has to work in the turbulence, so that really, we are downgrading it some because of the responsiveness of the airplane in turbulence, which makes the pilot work a little harder. I really can't think of any reason why I shouldn't even rate it a 2 for that matter. You would expect that you have to work a little harder in turbulence anyway in any airplane. Maybe this particular airplane is just too much of a disturbance. So, I will rate it a 3 only because the pilot effort, pilot compensation for turbulence, is enough of a task.

TURBULENCE EFFECT RATING

The turbulence rating I think we are still talking about moderate, minor to moderate - I'd say probably more like moderate. I think part of the problem I created myself as I said before, the fact that I was overcontrolling with the side force maybe actually made inputs. We'll call it a Delta although maybe it's a little less than that.

CONFIGURATION 1 AUTO DSFC PILOT A PR 3 TR C EVAL. FLT. NO. 8

INITIAL IMPRESSION AND GENERAL COMMENTS

I'm not really sure that I can be fair about the rating here since I really didn't see the second approach with the turbulence. However, I think the first one with no turbulence didn't seem to be any difficulty, took me down the left side. Second one with turbulence worked okay and it took me down the left side, but there we had a little conflict with some landing or traffic, or traffic in front of us on the runway and I didn't round-out properly and I ended up a little high and I ballooned a little bit, so we went way down the runway. So it wouldn't have been what I consider a very good approach but part of the trouble there I think was that I had more power than I needed, that's why I ballooned because I sort of half-way between wanting to go around and completing the approach. Again the most noticeable deficiency is this hunting back and forth on the centerline on the localizer and the side forces that you feel are annoying and not too pleasant.

ABILITY TO TRIM

I think that the ability to trim was not a problem.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

I didn't really try to help it at all except, with the turbulence in, I was playing around a little bit with the ailerons, but really not very much, so there's not much that you can say about that. I hardly used any controls. I just let the thing fly itself automatically.

AIRPLANE RESPONSE TO PILOT INPUTS

As far as the pilot making inputs, superimposed on the auto-pilot, I really didn't notice any particular problems because I wasn't making any inputs to speak of, small just reflex kind of things.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The actual alignment, I thought was good, all the way down, but again the thing was wings level and back and forth along the centerline, a little bit, not enough to ever take you outside the runway. The landing as far as I could see was really okay, if you can ignore the fact that you're getting these side forces, that you are being subjected to these lateral accelerations, there is really no problem, you just let the thing fly itself down. It's a good ILS coupler except that you do have to work on the attitude and the elevator and that didn't seem to be a big problem.

GOOD FEATURES

I guess the good feature is that the pilot is relieved of the responsibility of alignment and all he has to do is worry about the power and glide slope and flare.

OBJECTIONABLE FEATURES

The objectionable features, as far as I could see is this lateral acceleration and I don't know what to say about that, it's just presumably something that you can develop and design properly so that you don't get this lateral acceleration problem.

PILOT RATING AND PRIMARY REASON

Pilot compensation not a factor for desired performance? Maybe that's close to it, but I don't know, there are enough of these little things like not being aligned with the centerline, being slightly off centerline, but as far as killing the crosswind I've got to say that it's okay. Except that it's hunting. I don't think I should rate this any better than the manual, although I thought that without the turbulence, and the first approach with the turbulence the airplane really wasn't that bad. In other words, my effort was on a fairly low level because all I had to worry about was the flare. But I think I'll rate it a 3 anyway. It's acceptable I guess, I'm sorry I didn't see at least another one with turbulence there to see if I did really have any problem with the longitudinal control.

TURBULENCE EFFECT RATING

Turbulence rating, I guess there is some additional effort, minor though. There is a tendency for the pilot to try to correct for some lateral oscillation, that is rolling the wings level, which is caused by the turbulence. This is fairly minor, so I would say that I don't really think that I was working much harder in turbulence than I was without the turbulence as far as making the landing was concerned. I would call it minor and call it a Charlie for the turbulence.

CONFIGURATION 1 NO DSFC PILOT B PR 3 TR B EVAL. FLT. NO. 14

INITIAL IMPRESSION AND GENERAL COMMENTS

In general, I was well satisfied with the both lateral-directional and longitudinal handling qualities except for some minor things I'd like to bring up. I'll enumerate those as I go down the comment sheet.

ABILITY TO TRIM

Ability to trim longitudinally was fine. I though the rate was good and there was no significant lag. I didn't note any tendency to use it excessively. I was required to use trim however when I established a bank. I was required to use some aft trim. Lateral-directionally, I used more aileron trim than I would like to and the rate seemed to be a little slow and I wasn't able to coordinate that with longitudinal trim. I didn't use a directional trim at all during this evaluation approach.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Longitudinally, I felt it was adequate. Really don't feel the breakout force such that was noticeable. The same goes for lateral. The force gradient felt comfortable. Displacements were not excessive except slightly on the lateral axis, just a 90° turn to final; using a 20° angle of bank I probably used 25° of wheel throw laterally to initiate the turn. Control force harmony felt comfortable. Nothing significant there. The sensitivity on the lateral axis was, I felt, slightly low. Longitudinally it was fine and directionally it was okay.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll control, it seemed like I put in 10 to 15° of wheel throw before I got any noticeable response and, however, once the response was initiated it was entirely predictable and didn't have a tendency to overcontrol and I was able to establish my desired bank angle quite readily so that it was predictable. Directionally I just noticed slight, very slight oscillation in yaw and a hangup when I put in the lateral control. The ball went slightly to the outside before coordinating in a turn. Nose didn't swing to the outside though. Turn coordination was fine. I was even able to make minor corrections using solely aileron control, or rudder control. The pitch attitude control down final was excellent until I established a flare. What I did was come into 1700 feet and anticipated the proper amount of thrust pulloff and dipped the nose over and established an attitude to maintain the flight path angle and didn't use longitudinal control significantly after that until establishing the flare at which time I did notice the tendency towards PIO.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

A crosswind on turning final didn't affect anything.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

My approach method in a crosswind was to maintain a crab down final to about 100 to 200 feet and then kick it out. When I kicked out the crab I noticed some slight yaw oscillation but it was damped and wouldn't deteriorate aligning with the runway, or the ability to align with the runway. I just feel more comfortable with holding a crab down final and bringing it out as long as I don't get any large excursions in yaw or roll and am able to line up with the runway.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I didn't realize any significant coupling between axes except that in the turns with some roll input I was required to pull back on the control stick but that's a normal requirement with the increased g.

EFFECT OF RUNWAY CLOSURE RATE

Runway closure rate does affect task accomplishment but I think it's a matter of getting used to it. I think it eventually will not affect the rating as I become more familiar with it. But it's obvious that it's not a STOL lowspeed approach.

GOOD FEATURES

I felt quite comfortable in the aircraft as soon as I got on the controls and was able to perform tracking task fairly well with just a slight yaw oscillation.

OBJECTIONABLE FEATURES

Nothing very objectionable. Just minor deficiencies which I saw, the slightly slow aileron trim rate, the yaw oscillations, kicking out the crab during final and the PIO tendency longitudinally. I did require a slight amount of force opposite to the direction of the turn once I established the bank angle but nothing uncomfortable and it felt to me that it was, spirally, it was neutrally stable.

SPECIAL PITLOTING TECHNIQUES

No special piloting technique.

PILOT RATING AND PRIMARY REASON

I've already discussed the method I used on my approach in a crosswind. Overall rating of 3.

TURBULENCE EFFECT RATING

Turbulence rating of "B".

CONFIGURATION 1 MAN DSFC PILOT B PR 4.5 TR C EVAL. FLT. NO. 14

INITIAL IMPRESSION AND GENERAL COMMENTS

In general, lateral-directional handling qualities were a little less than desired because the little sloppiness I felt more noticeable on this run. I'll go down the comment card and expand on any comments I have to make.

ABILITY TO TRIM

I did notice I was using a little more longitudinal trim than I'd like although everything was fine as far as rate authority and no lag evident. Laterally I also used quite a bit of aileron trim. None directionally in the normal flight.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics, harmony was all right although I still have to hold a slight force once I get the bank angle established and laterally against the turn but the force gradient feels all right. Displacements fine except laterally, slightly excessive lateral displacement required for the desired bank angle. Control sensitivities were okay.

AIRPLANE RESPONSE TO PILOT INPUTS

I have the bank possibly half way in, 15° of bank for a 30° desired angle of bank before I get any roll response although it is predictable and there is not any great tendency to overshoot in a desired bank angle. Directionally I had no complaint although yaw oscillations were slightly easy to excite. During coordination of turns there's slight oscillations both in yaw and roll with any lateral or directional input. They're slight but noticeable. Nothing significant on pitch attitude control. I felt initial response was adequate and predictability of the final response was evident.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final didn't cause any difficulties whatsoever.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

On this I used the DSFC and didn't use a crab then. I was able to align easily with the runway initially and then seemed to have trouble, some problems in maintaining runway alignment and I tended to overshoot the amount of side force control required and this deteriorated overall azimuth control. Although it was comfortable coming down final wings level in the crosswind, I did feel that I was not aligning with the runway to the point where I could make a precise touchdown as far as lateral displacements are concerned.

CONTROL TECHNIQUE

My control technique down final with the DSFC, I did use a little bit of aileron and rudder but I think I probably used them because of an inability to predict exactly how much side force control I needed to maintain runway alignment. Again, each time I did make any lateral correction regardless by what control I did have oscillations on the nose and these were ±2, 3°, and it seems that the lower I got, closer to the runway, the frequency of inputs increased.

CONTROL OF SIDESLIP WITH DSFC

Control of sideslips with the side force controller was adequate. I didn't note any bank angle required.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

As far as the side force control interfering with lateral-directional control, I did note that, that I wasn't able to coordinate the rudders, ailerons and the side force controller the way that I felt that I should have. I wasn't able to attain the precision that I felt was required.

CONTROL OF GLIDE SLOPE

I didn't note that the side force controller interfered with throttle or longitudinal control.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

The lateral-directional control inputs do affect longitudinal motion to the point where putting in a bank for a turn, a large amount of aft longitudinal control force is required to maintain level flight and of course an advance in the throttles. I did note that longitudinal trim, I said that I used it more than I like, trim rate might have been a little slow compared to what are the requirements when I put in a bank angle. I'd be clicking that Cooly hat aft four or five times before getting what I wanted. Did not notice any longitudinal control inputs affecting lateral-directional motions.

EFFECT OF RUNWAY CLOSURE RATE

Runway closure rate does affect the task accomplishment slightly. I think it's a matter of divorcing yourself from the fact that you're approaching at a higher speed.

GOOD FEATURES

I've already touched on any significant good features.

OBJECTIONABLE FEATURES

The objectionable features were the oscillations in yaw and roll. Although I didn't feel any great control sensitivity on the two axes, I did have oscillations, felt when the turbulence model was initiated and there were significant 2 or 3° of motion each side of center and I felt this was one of the primary reasons for any deterioration of performance in heading control, and an inability to predict exactly how much side force control it required was also a deficiency although the rate of application was satisfactory. I think the primary deficiency is the inability to predict how much side force control you use.

SPECIAL PILOTING TECHNIQUES

Special piloting technique was to line up with the runway and align the aircraft heading with the runway with DSFC and I try to minimize any bank or rudder inputs although I was required to make some because of overshooting the amount of DSFC I used.

PILOT RATING AND PRIMARY REASON

I'll give the overall system a 4.5 primarily because of the direct side force controland what it should give me and what it did give me. If anything, I'd lean towards a pilot rating of 4 but I felt that I was moderately tasked to align with the runway so I'll leave it at a 4.5.

TURBULENCE EFFECT RATING

I did notice a significant increase in workload with turbulence such that I'll rate it a "C". I did notice yaw and roll oscillations in turbulence which increased my workload to a minor degree.

CONFIGURATION 1 NO DSFC PILOT B PR 4.5 TR B EVAL. FLT. NO. 21

INITIAL IMPRESSION AND GENERAL COMMENTS

My initial impressions of the handling qualities of the aircraft were good but there were some minor discrepancies I noted later on. I will comment on them.

ABILITY TO TRIM

The ability to trim longitudinally, directionally, was good. Laterally it was somewhat slow and I really didn't get a feel for how much aileron trim is required to eliminate the forces or to establish bank angle without holding forces.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics, longitudinally, laterally, were all right but somewhat light laterally and somewhat heavy directionally. I didn't note this until later on when I was compensating, holding the wing low in the flare in trying to align myself with the runway. Control sensitivities on all axes were okay.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll control was adequate. Initial response, was a slight delay but it was predictable at final response. There was some slight lag, but nothing significant such that the roll response was good. Directional control as I just noted was such that my displacement and force required in the flare to align the aircraft with the runway were excessive enough to increase my other workload significantly, but I would have been able to accomplish a touchdown adequately. The aircraft coordinated very well. In fact I was able to put the aircraft exactly where I wanted but there were some slight residual oscillations plus or minus a degree or two in trying to acquire a certain heading. Pitch attitude control was okay. No comments, no complaints.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final didn't cause any difficulties. Turbulence effects were minimal. Some slight effects on final when I used lateral-directional axis a little more but they were minimal. There seemed like there was good damping on lateral-directional axis.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

My approach method was to establish the crab and hold it down final until about 200 ft. above the surface and then kick it out and hold wing low. As I stated, the required directional force was excessive and also displacement of approximately three inches. There was no significant difficulty other than that in accomplishing the task.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Lateral control inputs didn't affect longitudinal motions, and vice versa, at least that I noted.

EFFECT OF RUNWAY CLOSURE RATE

Runway closure did not affect the task accomplishment.

GOOD FEATURES

I felt that there was good force harmony in the system until I realized the need for the large directional displacement which required a particularly large control force directionally. So, what appeared to be a good feature of the system became an objectionable feature down in the flare, at least directionally. The aircraft did coordinate good and I felt comfortable putting the aircraft where I wanted it as far as heading control, the tracking maneuver. But I did have some residual oscillation and I noted some slight oscillation in a steady state bank just a degree or two.

OBJECTIONABLE FEATURES

The objectionable feature was the high control force and displacement required in the flare and in aileron the trim rate is slow.

SPECIAL PILOTING TECHNIQUE

No special piloting technique used.

PILOT RATING AND PRIMARY REASON

Based on the directional control force gradient and the displacement required to get the desired response in yaw during the flare, I'll give it a 4.5. I felt that there was some moderate to considerable pilot compensation required to perform the task precisely.

TURBULENCE EFFECT RATING

Turbulence, no significant deterioration. With turbulence that I felt, no tendency to PIO and the aircraft seemed comfortable enough, everything seemed well damped. So I will call it a Bravo - B.

CONFIGURATION 1 MAN DSFC   PILOT B   PR 3   TR B   EVAL. FLT. NO. 21

INITIAL IMPRESSION AND GENERAL COMMENTS

My initial impressions of the handling qualities were good, however there was some minor discrepancy in the directional system which I will discuss later. However, the aircraft did feel good initially.

ABILITY TO TRIM

The ability to trim laterally, the trim rate was slow so that I did not have a good feel for the trim system. Directionally I thought I used more trim than I would have liked to. Just some minor difficulty in getting the aircraft trimmed lateral-directionally. Longitudinally it was fine.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics longitudinally, okay. Laterally, somewhat light on the controls but acceptable. However, directionally there was a distinct difference in direction of turn with force gradient seemed to be steeper in a right turn about half as heavy to the left. [This can occur if rudder pedal force is being applied during the VSS engagement, even though the rudder pedals are centered.] Control sensitivity was okay; however, it was a little low in the directional axis and required that I put in an unusually large directional control displacements to coordinate a turn.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll control was okay. I did have slight oscillations in steady state banked turns but I could predict my final bank angle desired within a degree or two although there was some residual oscillations. Directional control, I already mentioned the fact that there was a definite control force, nonlinearity and appeared to change with direction of turn which deteriorated turn coordination a little. However, to the left it coordinated fairly well; to the right it took quite a bit of force and a little more displacement. Pitch attitude control, no problem. You still have a little tendency to PIO at the bottom. I feel that the less I'm on that control column lateral-directionally the less requirement for longitudinal control inputs. However, I don't think there is any coupling between the axes. It's a matter of trying to obtain some level of precision and workload. Maybe a little working. Nothing too significant though.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Nothing on my crosswind turning final. Turbulence effects were almost negligible. I just felt the turbulence and I didn't feel anything in the control system.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

My method during the landing approach was to establish crab line up with the runway and use the side force controller on the follow through. Align the aircraft heading with the runway heading and then about half way down checking and making sure that no further corrections were required.

CONTROL TECHNIQUE

I used the side force controller the way it was intended to be used on flying the aircraft with the runway heading and then I made some minor corrections.

CONTROL OF SIDESLIP WITH DSFC

I still don't have a real good feel for how much to use and this was the only minor deficiency in the system. I have a fairly good feel for rate, I think, in the real world we wouldn't know exactly how much was required based on the crosswind. It could be difficult to get a real good precise amount of side force in to counteract the crosswind. So, all it means, is that it takes a little more use of the side force controller, I think, on final approach than will eventually be required. Again I used the throttle side force controller switch; it just feels more comfortable using the one on the throttle even though it is an up and down rotary switch.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

No apparent interference with throttle or elevator control with the side force controller.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Lateral directional control inputs did not affect longitudinal motions and vice versa.

EFFECT OF RUNWAY CLOSURE RATE

Runway closure rate does not affect task accomplishment.

GOOD FEATURES

Good features were the overall handling qualities. Initially I felt good with the aircraft. The fact that I noticed something in the directional feel system was resolved with a definite investigation of it. I don't think it would have been that apparent had I not really looked into it.

OBJECTIONABLE FEATURES

The only deficiency that I see is the fact that there is some nonlinearity, possibly discontinunity [in the rudder feel] but these were in higher bank angle turns up to 30°, 20 - 30°. That is really the only significant objectionable feature.

SPECIAL PILOTING TECHNIQUES

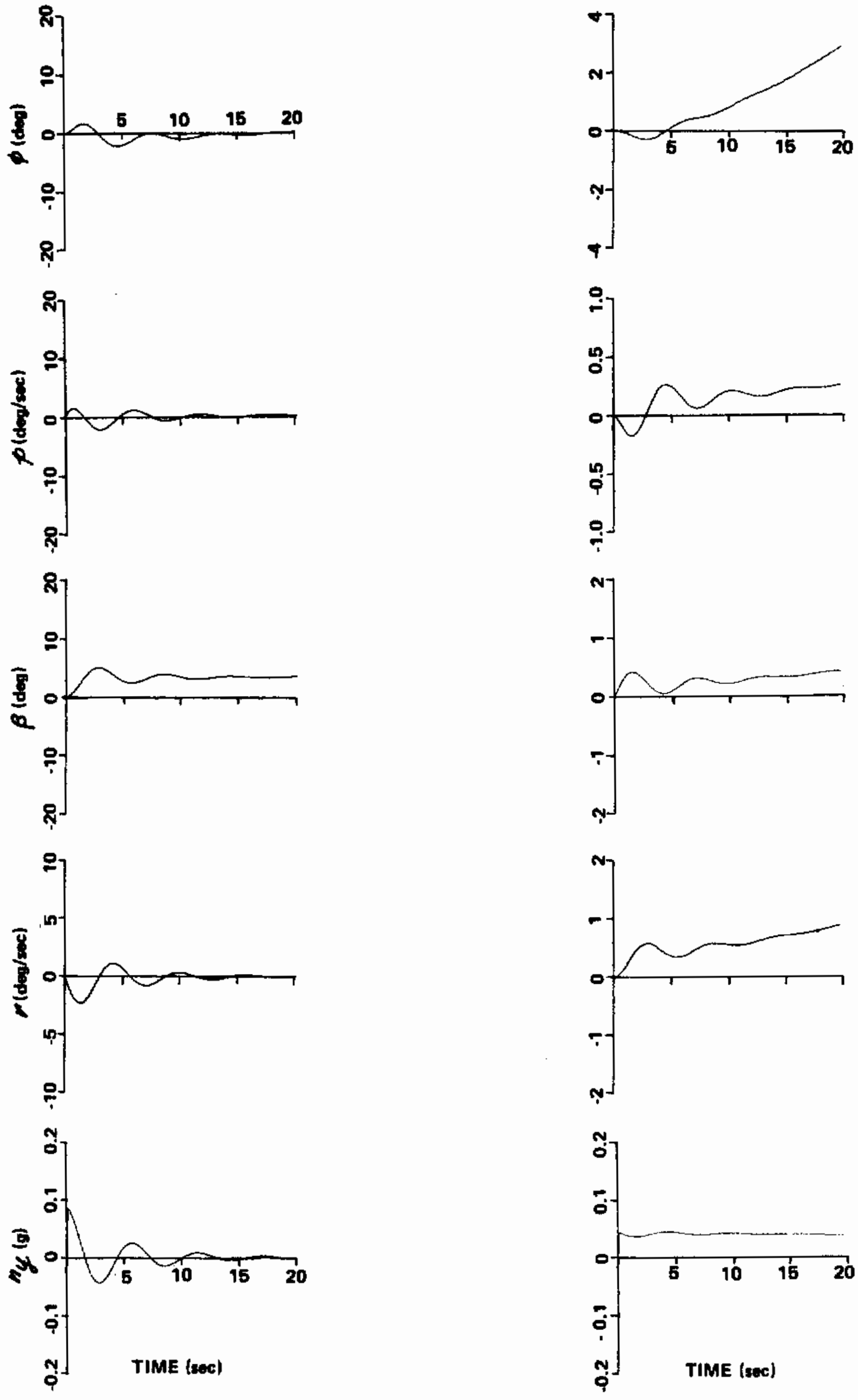
The side force controller made the task much easier than when I performed the approach without the side force controller. The fact that all axes seemed well damped. I didn't get any of the oscillations that I induced myself on the previous approaches not using this side force controller.

PILOT RATING AND PRIMARY REASON

There wasn't really anything deficient using the side force controller, because I didn't get into the lateral-directional axis significantly. Overall 3 rating for this side force controller approaches.

TURBULENCE EFFECT RATING

No significant deterioration of task performance with turbulence. Bravo rating.



(a) δ_y = 10.0 deg, δ_a = -3.02 deg, δ_r = 7.90 deg (b) δ_y = 10.0 deg, δ_a = 0.0 deg, δ_r = 0.0 deg

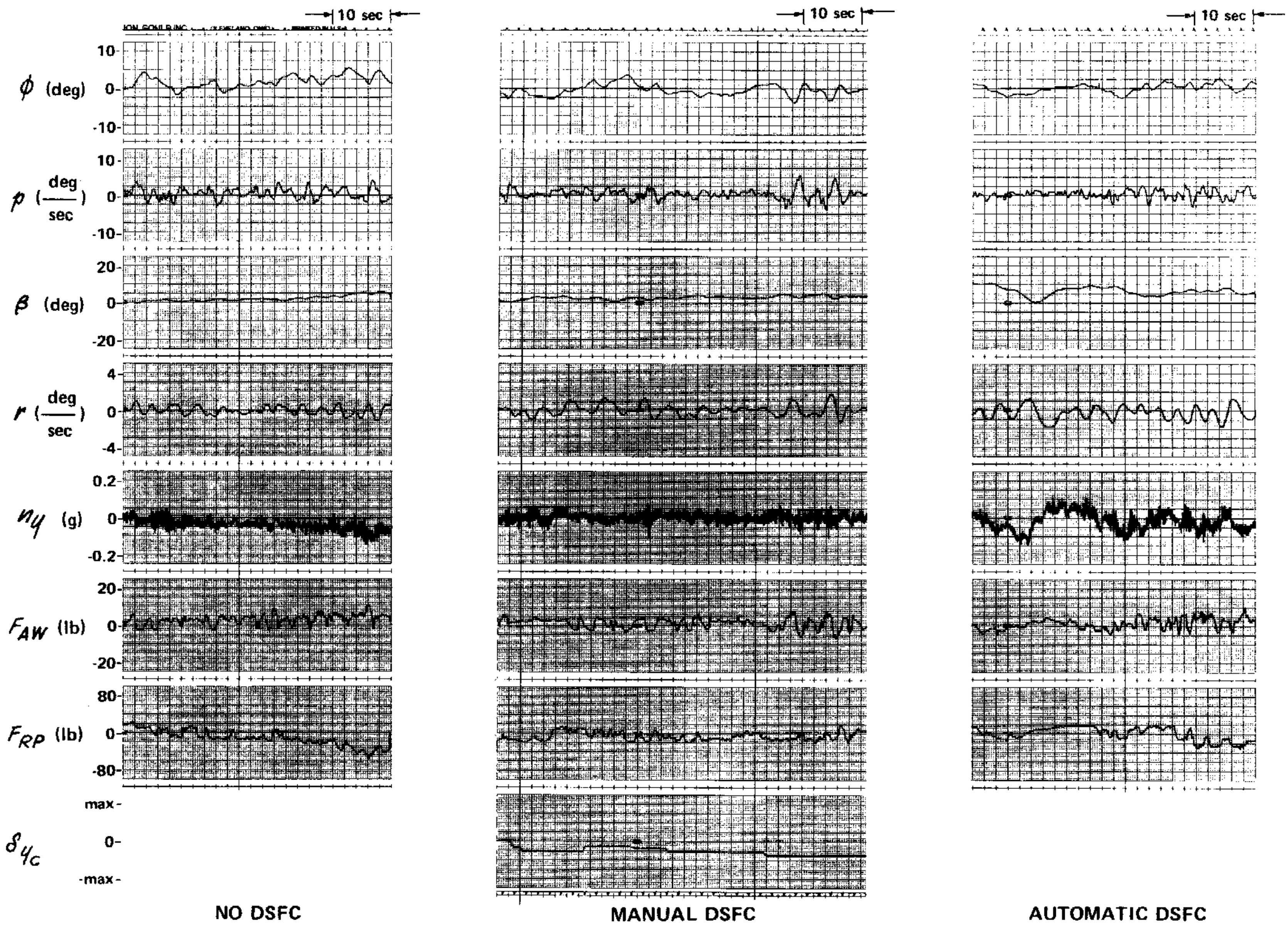
MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO AILERON AND RUDDER (CONFIGURATION 5)

CONFIGURATION 5 FLIGHT TEST DATA TABULATION
(EVALUATION FLIGHT NO. 12 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	3.91	1.18	4.18	0.87	4.85	2.16	-34.9	8.58	0	4	D
MANUAL	-0.94	1.53	3.83	0.88	0.81	4.17	- 8.58	5.87	10	3	C+
AUTOMATIC	1.32	0.74	6.02	1.05	2.08	3.21	- 7.28	15.3	10	4	C+

CONFIGURATION 5 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	310	12	1.95	1.26	4.48	280
MANUAL	320	15	1.34	1.77	2.72	280
AUTOMATIC	310	15	1.70	1.40	2.84	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN
CONFIGURATION 5

CONFIGURATION 5 NO DSFC PILOT A PR 4 TR D EVAL. FLT. NO. 12

INITIAL IMPRESSION AND GENERAL COMMENTS

It's a little bit different than flying it with a crosswind from the left and I find it's always a little bit more difficult for me at least to establish the landing attitude when I have to hold right aileron. I would say that it was not very difficult, but it wasn't too easy. The performance was not the greatest. On the last approach, I ended up on the left side of centerline. I crabbed a little bit into the wind on the first landing with no turbulence. I also ended up hunting around for the proper heading and bank angle. It wasn't too bad I guess at touchdown. The middle one was probably the better of the approaches at touchdown.

ABILITY TO TRIM

Ability to trim, lateral, directionally, longitudinally there was no difficulty.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Forces are slightly high on the aileron but not really too bad. The criteria, is to see if I could establish a heading with a 10° bank angle and one hand on the ailerons and I was able to do that.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll control initial response I would say is probably moderate and the input required as far as this deflection is concerned is a little bit on the high side. The impression I get is that the Dutch roll damping is moderate, somewhere between 0.1 and 0.2. Longitudinally, the airplane is a little slow in responding and the gearing seems a little low. In other words, the deflections are a little bit high, but I needed this kind of a lag in the response in pitch to reduce the tendency to PIO when I'm close to the ground, and to reduce the coupling between lateral and longitudinal. Directional control didn't seem to be any difficulty. Coordination is really not difficult.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

The crosswind turning final was of no particular difficulty.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

On the first three approaches, I merely set up a crab angle which happened to be about 8° and the last one I did a little bit of sideslipping in addition to crabbing a little bit. I thought it might relieve the task close to the ground if I didn't have quite so much decrabbing to do. I think what I ended up doing actually was to decrab without increasing the sideslip or I relaxed on the sideslip and decrabbed at the same time so I ended up drifting to the left a little bit. Also with the disturbance caused by the turbulence inputs - it seems that you do get fairly substantial rolling oscillation close to the ground. I don't know whether that's just a shear problem but we always seem to hit a pretty good gust, maybe 100 ft. or so off the ground. Runway alignment going down from the 2 miles out was no problem. The only problem was very close in just before touchdown.

CONTROL TECHNIQUE

Control technique is normal.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

The lateral control inputs are affecting the longitudinal motion. I think there is a slight amount of cross coupling. I'm leveled off, it seems, higher than I have in the past and then I have to sort of dip in a little bit to get down to touchdown and when I do this of course I begin to worry a little bit about the airspeed because I don't want it to get too slow and I'm a little bit distracted maybe from the task of maintaining zero drift and zero crab angle.

GOOD FEATURES

The forces I'm experiencing on the ailerons are not exceptionally high.

OBJECTIONABLE FEATURES

The objectionable feature I guess is only the fact that I seem to be working fairly hard right close to the ground and whether this is partly due to the fact that this is a relatively new experience here in trying to land the airplane with the crosswind from the right so that I'm not highly proficient. I guess I was getting fairly good at doing things with the crosswind from the left since I made so darn many approaches that way. So this is probably one of the factors in what appears to be somewhat sloppy control. It's good enough to put the airplane on the ground but it's not good enough that I feel I've got real high precision of control, because of the little rolling oscillations.

SPECIAL PILOTING TECHNIQUES

I don't think there is any special piloting technique.

PILOT RATING AND PRIMARY REASON

I've been thinking here in terms of a 3 or a 4. Moderate pilot compensation before touchdown. Certainly you have that so I would think that a 4, based on the performance, would be pretty good number for this configuration so I'll go along with the 4 although I have a feeling that maybe I'm downgrading the configuration some, that maybe it should have been a 3, but I'll say a 4 and the primary reason is I think the fact that my precision of control just before touchdown seems to leave something to be desired.

TURBULENCE EFFECT RATING

I think there's more effort required. The task performance is deteriorated. I wasn't much better as far as the actual touchdown is concerned without the turbulence. A little better, I felt more comfortable. So I think we'll call it halfway between minor and moderate although it's probably moderate; we'll call it a D.

CONFIGURATION 5 MAN DSFC PILOT A PR 3 TR C+ EVAL. FLT. NO. 12

INITIAL IMPRESSION AND GENERAL COMMENTS

It's a little easier for the pilot to set up for a touchdown with the side force introduced into it. The first approach had quite a bit of hunting to find out where I should put the side force controller and when I completed the landing I noticed that I had something less than half of the side force available introduced into it. In the landing itself I did have a little bit of drift to the left to kill. The next couple of approaches were done with turbulence and the second one was a little better but I had a little problem in the rate of descent. It wasn't really well established by the time I got close in and I ended up making a fairly rapid flare which I think would have resulted in substantial amount of vertical velocity when I hit the ground. I don't think it was quite that bad but it was certainly not zero descent rate on that one. The last one was much better I thought. I think I had the side force surface in about right. However, there is quite a bit of hunting and pecking on that thing, I think basically because the winds change as we get closer to the runway and also the wind here today is quite variable. And I think that's the problem. Of course, that's a fairly realistic situation. This is real life and that's what you get. On that last approach just before touchdown and just about the time I had landing attitude, I made a small sideforce input which seemed to help establish a pretty good heading and I was fairly well in the centerline of the runway. I think that the effort involved is certainly reduced with the side force but it isn't all gravy because you do have to, not continuously, but quite often you have to make a correction with the side force surface. If you had poor visibility, you'd have to be aware of the drift and heading changes required and then go ahead and do it. The sensitivity of the side force controller would probably enter into this.

ABILITY TO TRIM

The ability to trim is no problem.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The feel characteristics are okay.

AIRPLANE RESPONSE TO PLOT INPUTS

The initial responses of the airplane both in roll, directional and pitch attitude are adequate and turn coordination was not a problem.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

The crosswind on turning final was not really noticeable.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

See initial impressions and general comments.

CONTROL TECHNIQUE

You set up approximately what you think you need for a right crosswind and when it looks reasonable that your drift is about zero, then go ahead and made a side force input and then just watch it for a while to see what happens. I then iterated from there.

CONTROL OF SIDESLIP WITH DSFC

There is sufficient side force surface available to kill the crosswind.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

I don't think there's any interference between this lateral-directional control and the side force surface.

CONTROL OF GLIDE SLOPE

There's no interference with the throttle or elevator control. In this turbulence today I'm having some difficulty in establishing reasonably stable airspeed and rate of descent on approach. The airplane is quite responsive to the turbulence that we're putting into the model. And the natural turbulence is high enough that the airplane is certainly disturbed by the turbulence because of the fact that the airspeed control is not good. I can see airspeed changing 5 knots very rapidly just due to gust inputs. And you have a tendency to sort of chase, I think, the airspeed a little bit. It's a little difficult really to establish what power to set. And so the rate of descent is quite a bit of a variable. When you get close in if your descent angle is fairly high, that is, your rate of descent is above say 12 to 1400 feet a minute, and your're a little late in starting your flare. Then things sort of all bunch up at the end. I guess the actual performance on the touchdown is a function of history.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I would say no cross coupling between longitudinal and lateral.

EFFECT OF RUNWAY CLOSURE RATE

Closure rate on the runway did not affect the task.

GOOD FEATURES

I think the best feature of that approach is the fact that I don't have to bank the airplane to kill the drift and I can align the airplane with the centerline pretty well with the side force surface, at least good enough to make a decent landing.

OBJECTIONABLE FEATURES

The most objectionable feature would probably be the disturbance due to the gust which makes the pilot work somewhat hard. Now whether increasing the Dutch roll damping would make an improvement on this I don't really know. Probably will help some.

PILOT RATING AND PRIMARY REASON

I have to rate this I think better than the manual landings. I'm not so sure that the landings themselves were much better but I got equivalent performance with less effort so it's better. Minimal compensation maybe would answer that. I'll rate this one a 3. I still am not overjoyed by the performance but it's reasonable.

TURBULENCE EFFECT RATING

There is certainly more effort required in turbulence than in smooth air. The actual performance in smooth air was not much better as far as touchdown was concerned than the turbulence one. But the effort was less. We do have moderate additional compensation required by the pilot, so the rating on the turbulence is C+.

CONFIGURATION 5 AUTO DSFC   PILOT A   PR 4   TR C+   EVAL. FLT. NO. 12

INITIAL IMPRESSION AND GENERAL COMMENTS

On that last approach I tried to superimpose my input to the automatic system and I was just moderately successful. I think I ended up closer to the centerline but the autopilot was tending to keep it to the right. I think I had made proper correction on the heading with the side controller here. When we're on automatic, the aide controller is a heading changer. So I don't have to reach up and change the course-heading manually. Okay, the other problem on that approach however was that because I was flying the airplane more than I would normally do, in other words, trying to overpower the automatic control, I let the airspeed get down a little bit and that got the safety pilots a little nervous but the actual touchdown would have probably been all right but airspeed was a little on the low side. I wasn't too impressed I guess with the automatic system as compared to the manual system. I mean, this problem of having to try to overpower the automatic system to get the airplane to go down the centerline. I would have preferred to have the manual because of the tendency for the automatic system to take me down the left side, the oscillation about the localizer and the fact that when I do try to superimpose my inputs onto the automatic system, the forces are fairly high and it's very difficult to effect the end result to any great degree. You can't really tell what you're doing, when you make an input. Sometimes the system takes over and starts going in the same direction so you've overcontrolled and it's a little difficult. You don't have a sense of having precise control through the automatic system.

ABILITY TO TRIM

Trimming the airplane is no problem until you get on automatic system and then the only trimming you can really do is longitudinally and I was having some difficulty again in trying to establish a steady state rate of descent because of the turbulence. And also some of these excursions laterally, I suppose, do affect the apparent airspeed that I read here. That's in addition to the gusts, the sideslip that is generated I think is changing the airspeed on me enough that it's very, very difficult to maintain airspeed say within 5 to 10 knots.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

There is no alignment problem. It does seem that the airplane pretty much is pointed down the runway but the centerline tracking is not very good, which I think is strictly a limitation of the system.

CONTROL TECHNIQUE

Control technique, the first one I just accepted whatever the system gave me and the last two approaches, I was trying to compensate for the deficiencies of the automatic system but I wasn't too successful, modified it some, but not really enough.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

Obviously there is interference with lateral control and that's rudder and aileron but if the system was working properly where it would keep you down the centerline that wouldn't be any problem at all then.

CONTROL OF GLIDE SLOPE

I guess there's not really any interference with elevator except as it affects the indication of airspeeds so that I had a tendency to manipulate the power more than I really should on the approach. Once you establish a power setting you should sort of apply the mean attitude then. It's not what I was doing actually because the airspeeds seemed to change quite radically.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I don't really think there was any. I just accepted whatever the system gave plus whatever I tried to correct.

GOOD FEATURES

The actual touchdowns I suppose were not bad. But I still think that the manual control was better. If you want to call it a good feature is the fact that the localizer tracking is more or less out of your hands and all you really should have to worry about is pitch control.

OBJECTIONABLE FEATURES

I don't think the system is working good enough although there were periods of time on that localizer where it seemed to be quite stable and then for no apparent reason at all the darn thing would start making a correction which seemed much larger than what the instruments would indicate would be required and also the visual appearance looking down the runway. You'd suddenly see yourself feeling the lateral acceleration and you wondered why because you weren't really that far off the centerline.

SPECIAL PILOTING TECHNIQUES

The only special piloting technique is in trying to overpower the automatic system to some extent and I wouldn't call that special. You do what you normally would do under the circumstances; if you're rolling right, you try to stop the roll and bring the wings level so that's not special.

PILOT RATING AND PRIMARY REASON

As far as the actual touchdown was concerned, again I have to say that all these ratings on the automatic system are tainted by how much weight I put on the performance as I'm coming down the centerline and whether I get that last fairly large transient just before I get to the point where I should be more or less concentrating on altitude and attitude control for touchdown. So, I can't rate this as good as the manual because of all these reasons so I'm going to rate it as bad I think, if you want to call it bad, as I did with no side force controller available. I think I'll downgrade it to a 4 only because there are too many things I don't like and they're sort of coupled in with my overall impression of the configuration.

TURBULENCE EFFECT RATING

I got a lot more activity in turbulence than I did in smooth air. I was really surprised that we had as little activity in so-called smooth air which means that we were just in the presence of natural turbulence but I didn't like it as well on the last two approaches as I did on the first approach. There seemed to be quite a bit more activity with the turbulence in so I guess we'll have to say there was a minor to moderate deterioration in the performance so I'll stick with a C+.

CONFIGURATION 5 NO DSFC   PILOT B   PR 3.5   TR C   EVAL. FLT. NO. 13

INITIAL IMPRESSION AND GENERAL COMMENTS

I will comment on the use of manual DSFC but I will not rate it. I'll rate the basic aircraft. My impressions of the lateral and longitudinal handling qualities are that they are adequate.

ABILITY TO TRIM

Ability to trim longitudinally is adequate. The rate seemed good and comfortable. I didn't note any lag but laterally felt that the trim rate was slightly slow in that I was not able to trim predictably in lateral axis. Directionally I used a little more trim than would be desired and the location of the trim switch normally would indicate that rudder trim is the least used. However, in normal flight here I was required to use quite a bit of rudder trim.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Force feel characteristics were such that the overall control force harmony was destroyed by the relatively high aileron force gradient. I noted what appeared to be a good amount of friction in the longitudinal control system, and I didn't really feel a significant breakout force. What I felt primarily was the friction force and this caused or induced a tendency to PIO longitudinally. Directionally I didn't notice anything significant. It seemed adequate. It was a gradient that allowed some predictability. Displacements were good. However, I used a little more rudder than I would like. Control sensitivities on all axes were good. If anything, they were a little excessive longitudinally but not to be detrimental to the overall control system.

AIRPLANE RESPONSE TO PILOT INPUTS

The initial roll response was such that I tended to overshoot my desired bank angle so that precision of rolling into a bank was deteriorated and on an approximately 20°/sec roll input I would overshoot my desired bank angle of 20° by 2 to 3 degrees. So, I was not able to predict my final response. The input was, I would suppose, about 5 to 10° of wheel throw. Directionally, I am able to control heading on a tracking maneuver fairly precisely. When I want to correct 3° I maybe get a 1° overshoot but the sensitivity felt okay. It does coordinate fairly well using both lateral and directional control surfaces. In pitch, it tended to overshoot just a little bit and sensitivity was such that I did have a tendency to PIO, especially preparing for the flare and moving into the flare and establishing a landing attitude. I had some difficulty with airspeed control and attitude control and determining what exactly was required. This may come as I move up on the learning curve but I tended to overcontrol longitudinally and also with the power lever and this in turn induced some PIO getting down into ground effect.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

The crosswind on turning final didn't appear to cause any difficulties.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

My technique of establishing my approach to a landing was to use a crab during the initial portion of my descent and this was, of course, without side force control, and at about 100 to 200 feet above the landing surface, I brought the crab out and held the wing low. This caused some wallowing, some wavering in heading control and there was some yaw oscillations as I tried to align myself with the runway and I think this is a combination of the lateral control sensitivity and the directional control system. I think that the pilot would be somewhat tasked to make a precise landing and to really hit a spot with the level of ability I have in this aircraft now. I tend to overshoot my landing spot although it is not difficult to align with the runway. I do encounter the oscillation so that I do seem to have some yaw oscillation, some excursion going after I establish myself in alignment with the runway heading.

CONTROL TECHNIQUE

One thing I did note about the lateral control, I rolled into a bank, I had to hold force opposite to my direction of turn. It felt like it was going to continue rolling over and if anything it exhibited neutral spiral stability at best and this made me uncomfortable. However, it did coordinate well and I did note that I had to use a lot of aileron trim when I trimmed into a turn. I had to trim opposite to rid myself of that force that seemed to be wanting to turn me further or roll me further.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I did not notice any coupling between lateral-directional and longitudinal motions, nothing significant.

EFFECT OF RUNWAY CLOSURE RATE

The runway closure rate did affect the task accomplishment as far as I'm concerned. I could not divorce myself from the fact that I was approaching must faster than I would be performing the actual task in real life situation.

GOOD GEATURES

I felt comfortable immediately taking control of the aircraft. I felt force gradients were sufficiently good. I felt the displacements were also, but as I got the feel of the aircraft. I noted some objectionable characteristics

OBJECTIONABLE FEATURES

Primarily the aileron control tending to bank me further than desired: the unpredictability of lateral control response and also the yaw oscillations about a desired heading and the PIO tendency longitudinally when I was trying to establish my flare.

SPECIAL PILOTING TECHNIQUES

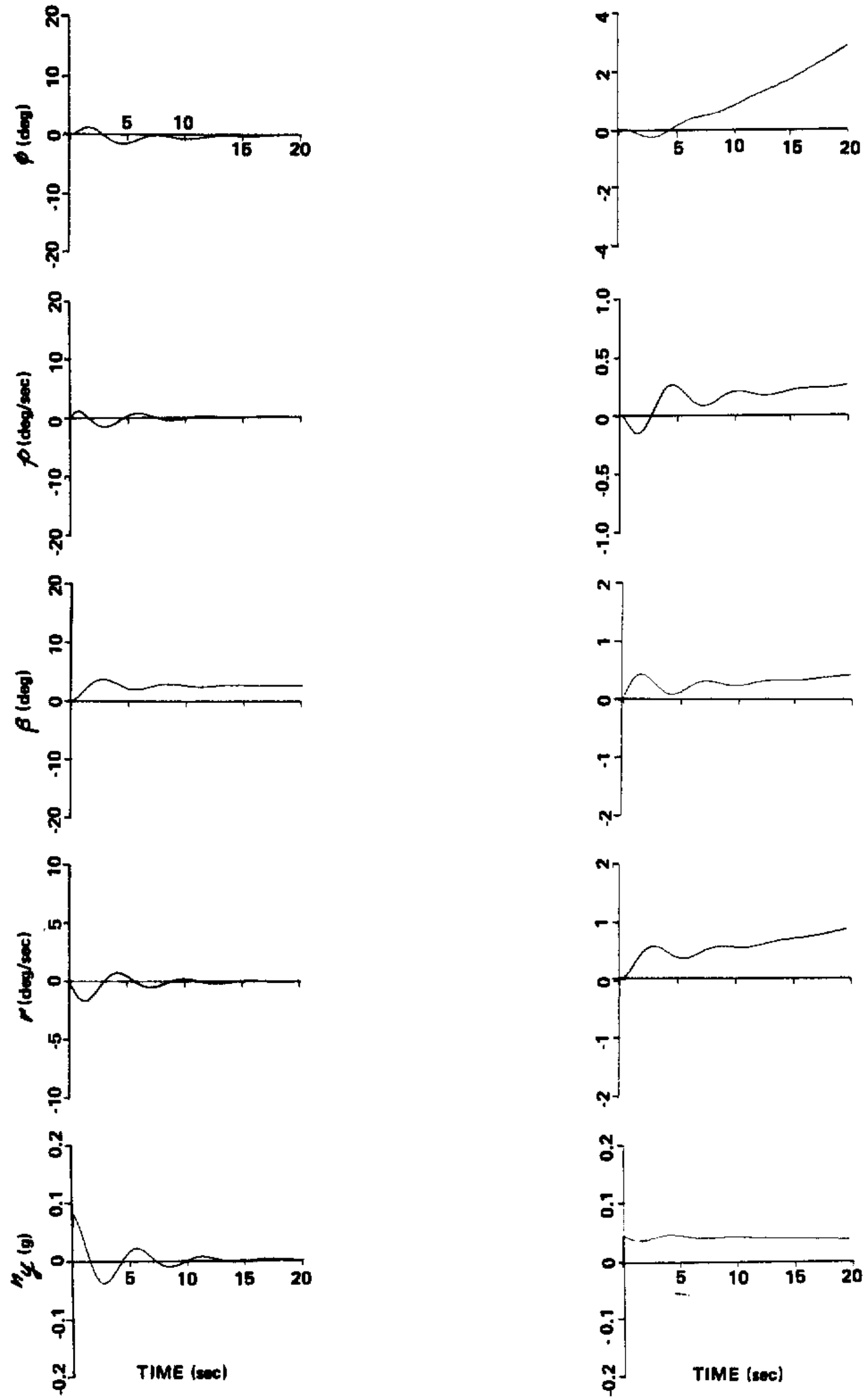
No special piloting technique used.

PILOT RATING AND PRIMARY REASON

I would rate the overall aircraft 3.5 because of the compensation that was required to acquire my desired performance. I've already enumerated longitudinally the PIO tendency, the aileron force that I held away from the direction of bank and yaw oscillations. I say 3.5 because all these combined to deteriorate precision. Not that the task could not be performed with minimal compensation on the part of the pilot but to accomplish the task with the desired performance level, I think, there was some moderate pilot compensation required.

TURBULENCE EFFECT RATING

I would rate the deterioration of task performance with turbulence a "B" .



(a) δ_y = 10.0 deg, δ_a = -2.26 deg, δ_r = 5.92 deg

(b) δ_y = 10.0 deg, δ_a = 0.0 deg, δ_r = 0.0 deg

MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO THE AILERON AND RUDDER (CONFIGURATION 9)

CONFIGURATION 9 FLIGHT TEST DATA TABULATION

(EVALUATION FLIGHT NO. 1 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	-7.73	0.92	-4.65	0.77	-5.91	3.49	40.1	15.6	0	8	F
MANUAL	-0.83	1.14	-7.48	0.74	-1.80	4.52	9.79	17.29	-26	3	D
AUTOMATIC	-0.01	0.93	-3.07	0.50	-1.41	2.54	2.55	4.61	-12	3	D

CONFIGURATION 9 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	260	20	4.95	2.22	3.97	280
MANUAL	250	20	3.56	2.93	5.32	280
AUTOMATIC	250	20	3.20	2.03	4.75	280

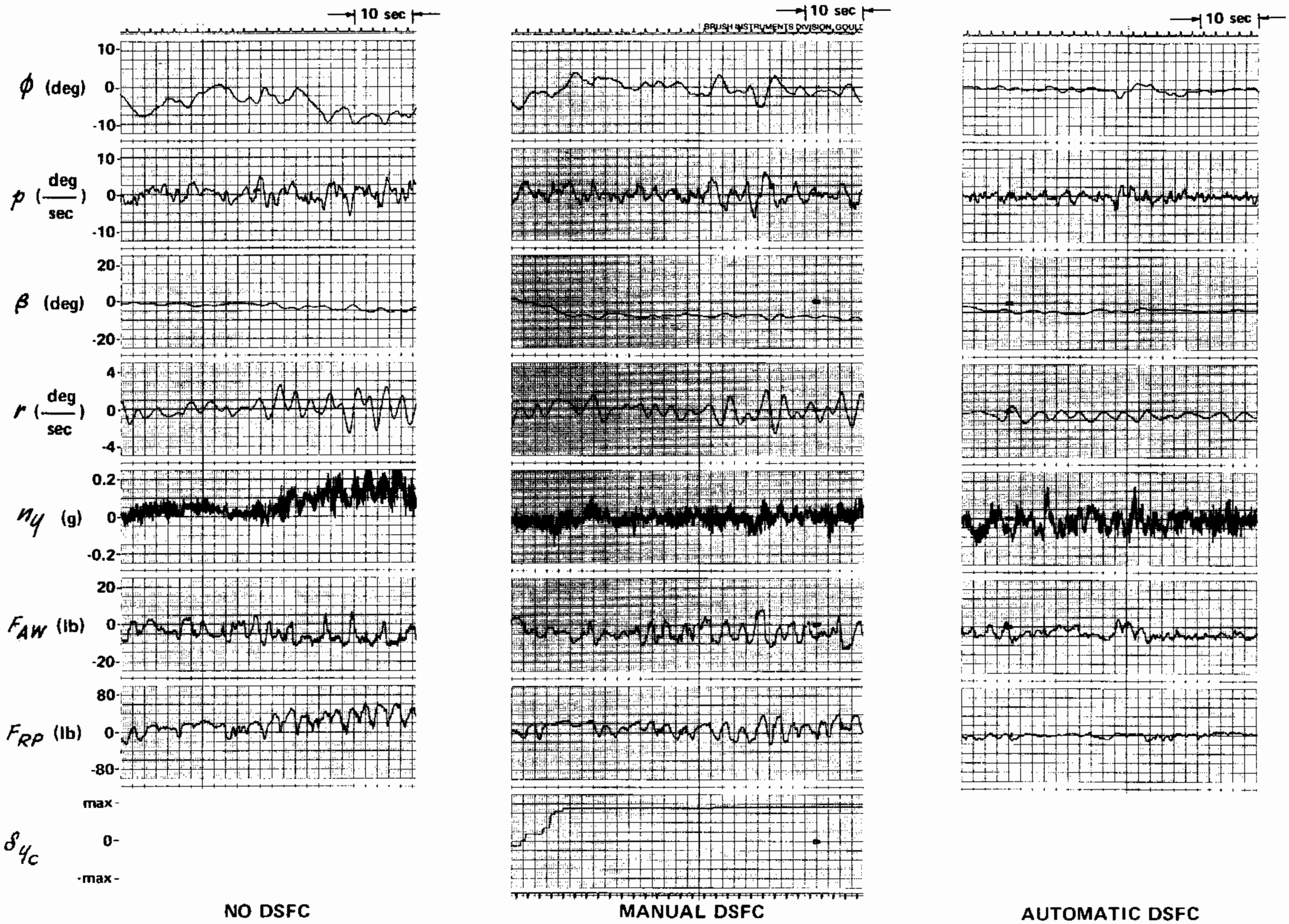
CONFIGURATION 9 FLIGHT TEST DATA TABULATION

(EVALUATION FLIGHT NO. 10 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	-4.21	0.39	-4.03	0.39	-5.02	1.21	34.6	4.23	0	2	A+
MANUAL	0.81	1.49	-5.71	0.87	0.38	3.11	0.71	10.47	-18	2.5	C+
AUTOMATIC	-1.02	0.80	-4.93	1.00	-2.59	1.32	9.89	7.83	-16	2	B+

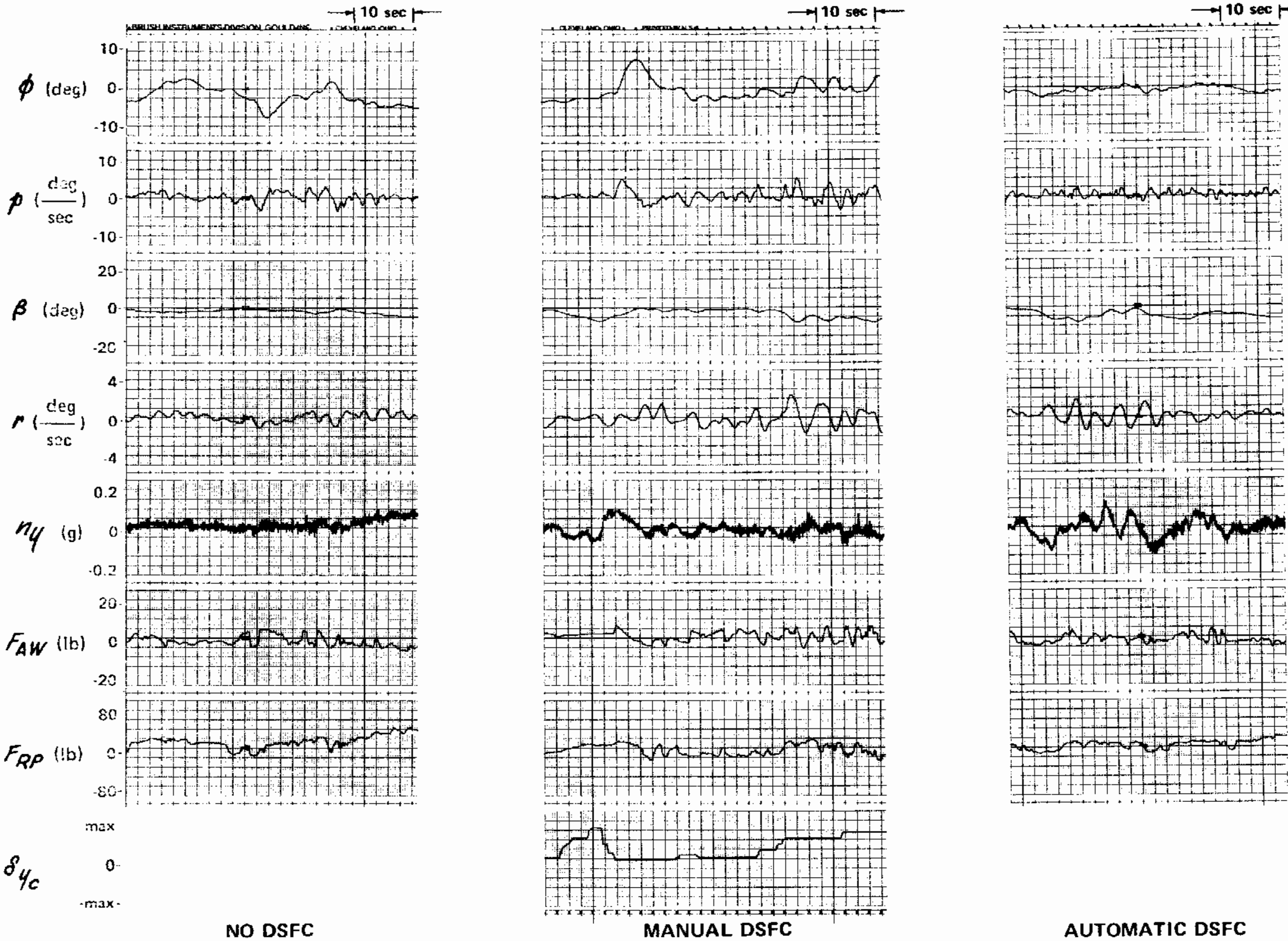
CONFIGURATION 9 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	250	06	0.92	0.81	1.00	280
MANUAL	240	10	1.84	1.65	1.24	280
AUTOMATIC	270	06	1.02	0.55	1.03	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN

CONFIGURATION 9 (FIRST EVALUATION PILOT A)



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN
CONFIGURATION 9 (REPEAT EVALUATION PILOT A)

CONFIGURATION 9 NO DSFC PILOT A PR 8 TR F EVAL. FLT. NO. 1

INITIAL IMPRESSION AND GENERAL COMMENTS

This was an evaluation with no side force control to the pilot. This was just a crosswind with the pilot attempting to land the aircraft or at least lining up for a landing.

ABILITY TO TRIM

I think it was fair. I didn't really think it was too good. I think we're in so much turbulence actually today that it's difficult to tell where the trim point is. The gusts are, on occasion, as much as 10 knots and airspeed control is very poor. The longitudinal trim in other words is not very good. Lateral-directional wasn't too bad but I get the impression because of these high crosswind components that I should be doing some trimming but I had done some, but it usually still ends up with fairly high forces.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Forces and displacements are quite large on the aileron and the rudder. The harmony seems to be good. The forces may be a little bit on the high side but I think for this class airplane at least, if I consider this as a fairly large airplane, it's probably not bad. I think that I might choose the aileron forces a little bit lighter. I'm not worried too much about the rudder but the aileron forces are somewhat high. In the longitudinal case, I found myself doing some trimming so maybe the forces there are a little bit high too. I chose control sensitivities on the basis that the last flight, on the practice flight, I was getting into PIO in the longitudinal case and therefore I chose a heavier force. This might not be the best selection but it wasn't a big factor.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll, initial response, it was pretty good. I can't say there's any particular problems with the roll or the directional. Turn coordination, well, it's a little bit difficult. You have to hold a little bit of bottom rudder to begin with but in this turbulence, coordination goes out the window anyway. The ball is bouncing around quite a bit so I can't really judge that too well. I would say that you do try to coordinate and there is a certain amount of effort expended but it isn't anything extraordinary. The pitch control, I thought, was good enough and the inital response is adequate. The final predictability of the pilot response is okay.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind turning on final didn't seem to give me any problems.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The big problem I think is in the trying to line up with the runway. I found that a fair amount of crab angle is required. I certainly wouldn't try to maintain the centerline by sideslipping the aircraft, although, as I say, the turbulence is fairly high and so it's pretty darn hard to tell what's going on with the sideslip. But my aim here was to try to keep the flight path along the ground parallel or lined up with the centerline by crabbing the airplane. Now, closer to the runway I started to sideslip the airplane, dropping a wing and hopefully pointing the airplane down the centerline. I was not really able to do this. I had a very difficult time controlling the drift and staying along the centerline to begin with and in each case I didn't want to drop the wing any more than I had which meant of course that I also had to crab a little bit and this gave me a pretty uncomfortable feeling. I think I made the comment on the second go-around, second attempted landing, that I didn't think I could land it. Or I wouldn't try to land it. Now I had a combination of things going that time. The nose was way over on one side, crabbed in other words, and the wing was down quite a bit and I think I did have a little bit of longitudinal problems there in that attempting to find the ground. And also I let the airspeed get down quite a bit. It takes quite a bit of power by the way to keep the airspeed up and then the fact that we're in heavy turbulence makes it very difficult. One time I'd see 130, the next time I'd see 145 on that thing and very quickly. I'm sure it's the gusty conditions that's giving me this.

CONTROL TECHNIQUE

I could control the sideslip okay with the rudder but, as I said, I just didn't dare drop the wing any more. Therefore, I limited my sideslip input.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Lateral control inputs, yeah, these large bank angles and large sideslip angles. I think I was adversely affected longitudinally also although I don't know whether my big problem was because of the gearing and forces or whether it was a combination of the large aileron and rudder inputs required which gave me a tendency to PIO in pitch a little bit.

EFFECT OF RUNWAY CLOSURE RATE

Closure rates on the runway are fairly fast but it's, I think, the biggest mental hazard is in the attitude of the aircraft so close to the ground. I'm pretty sure we never got any touchdown, never got down to 20 feet, mainly I think because I chickened out. I just didn't feel that I should put the airplane that close to the ground with these large attitudes so maybe I shouldn't worry about that and let the safety pilot worry about it.

GOOD FEATURES

As far as the crosswind feature, this airplane had very good features. I think the lateral and longitudinal condition was pretty good. I think I had a pretty good airplane, well damped and reasonably responsive.

OBJECTIONALBE FEATURES

In the crosswind, I found that, I think I made the comment that the forces seemed a little bit high. The aircraft attitudes required to kill the drift due to crosswind I think were too high.

SPECIAL PILOTING TECHNIQUES

I don't think there's anything special about this. This is the way you normally would try to land the airplane.

PILOT RATING AND PRIMARY REASON

The pilot rating I think would have to be that from the crosswind landing, in the crosswind is it controllable? Yeah, it's controllable. Do we get adequate performance with tolerable pilot workload. I don't really think so. I would say that it's a very marginal airplane at the best as far as landing it is concerned but I don't really think that I'd want to be faced with this situation routinely on a landing. I'm debating here whether to put this in the 6 category or down in the major deficiencies, considerable pilot compensation required for control in the crosswind so obviously I think I'm talking myself into saying it has major deficiencies, does require some improvement and the only problem or the only question is considerable compensation or intense. Well, I think I'm still on the learning curve. I don't think it was really intense although I got that feeling at times, but I think that part of the problem is that I wasn't flying the airplane as well as I could if I had seen a few more approaches. In other words, I probably should have asked for another approach on this at least to get squared away, so I'm going to compromise and I'm going to call it an 8 with the feeling that maybe I should have been calling it a 9. I'm just hedging there because I think that I'm on the learning curve.

TURBULENCE EFFECT RATING

The turbulence level, I think we would have to call this level moderate to heavy. I don't know really how to rate this using this scale because the natural turbulence is always there and when you say increase of pilot effort with turbulence, we always had turbulence. I never had a smooth situation so this is a relative thing about the rating. It's hard to do that. But I would say best efforts required and major, but evaluation can still be accomplished. Well, here is a problem because the problems I had probably were not directly associated with the turbulence, although it had some effect, but it was primarily the crosswind rather than the turbulence so I don't really know how to rate this but I'm going to call it major anyway, moderate to major, so we're calling it an "E" or an "F". Let's call it an "F".

CONFIGURATION 9 MAN DSFC PILOT A PR 3 TR D EVAL. FLT. NO. 1

INITIAL IMPRESSION AND GENERAL COMMENTS

This time it was the same configuration as the previous one except that we now had manual control of the side force surfaces.

ABILITY TO TRIM

Ability to trim was pretty good. I think generally it was okay all the way around.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The feel characteristics that time felt pretty good to me. Basically, the reason for it is that we did have some side force control to help us. I might make the general comment that the feel characteristics feel fine and dandy in up and away flight and on the first configuration, or the first evaluation point that I made the comment that the forces were somewhat high. I'm sure they are associated with the fact that I had to put in manual controls, that's aileron and rudder, to control the sideslip and make the approaches. That's where they began to feel high. But in up and away flight I chose these to be in good harmony and reasonable displacement so I don't think we should belabor that point. In explaining the selections, it's merely I think to get a good pleasant harmonious feel characteristic and I think I have that for what I would consider to be a moderate size airplane.

AIRPLANE RESPONSE TO PILOT INPUTS

The roll control, the initial response is good. I think we have a good lateral and longitudinal characteristics here. There are no complaints either in directional control. Now the turn coordination requirements, there's some objection to the fact that you have to hold the rudder in a little bit but we are in some turbulence and it's a little difficult to really coordinate very precisely. Anyway, pitch attitude control was okay.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final, that particular evaluation didn't seem to be very noticeable. As a matter of fact, I think on one of those, it almost seemed like we didn't have a crosswind in but there is a variable here, when you start out at 1700 or 1800 or 1900 ft. which is the altitude I'm starting from, turning inbound. The wind at altitude of course could be different than it is down lower and so I may get different opinions or different perspective when I'm up and away than when I'm closer to the ground. Also, it's obvious that when you get close to the ground you have to kill that crosswind right now or you're not going to be able to land, so obviously you have to close the loop much tighter, but no difficulties in turning final that I could see.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

I started out by setting up a crab angle to line it up and then wiping out as much of that as I could with the side force surface and this worked pretty good. After I got closer to the ground it seemed to me I didn't have sufficient side force control to wipe out the drift completely and therefore I had to use left aileron, right rudder to keep alignment and no drift. That is the description of the runway alignment.

CONTROL TECHNIQUE

The additional requirements by the pilot for aileron and rudder inputs to keep the alignment I think, on one of those approaches, was moderate. On one of the approaches it was, I think it was the first one, very nearly zero. On the second one, I got into a little bit of a Dutch roll oscillation I think close to the ground. On the third approach I ended up establishing a fairly good steady state but it seemed to me that the aileron/rudder requirements were moderate at that time. However, the performance was okay. So that is the control technique.

CONTROL OF SIDESLIP WITH DSFC

All I did was try to wipe out the crab angle and it always ended up that I needed full throw on the control that I have, and I use by the way, the control on the throttles, and then I just went ahead from there. I didn't have to manipulate that any further because I just had to leave it there. So we didn't have adequate control of the sideslip with the side force and some bank angle was needed.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

There doesn't seem to be any interference with lateral-directional control with the side force input that I could see.

CONTROL OF GLIDE SLOPE

I'm still trying to establish exactly what my rate of descent should be and where I should start the descent visually so I am hunting a little bit on the glide path control but also the fact that I have some trouble establishing a steady state airspeed because of the turbulence complicates the problem some.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Do lateral-directional controls affect longitudinal motions? Yes, to some extent in the ground effect. I think that is true in the ground effect but not in the up and away. It's not noticeable or at least not objectionable, whatever does happen there. It's something that I think is minor.

EFFECT OF RUNWAY CLOSURE RATE

Closure rates, well, certainly I'm aware of the closure rates. They're fairly substantial but at that time when I had the airplane under control, that is, sideslip was killed pretty well and I didn't have to use too much of a cross control technique, that is, wing down and rudder, the closure rates were less noticeable. In other words, I think you feel comfortable. You know you're doing everything with some pretty good precision and you don't have to worry about the fact that you're closing on the runway fairly fast. I think my rates of descent have been varying some, but they're somewhat around 1000 to maybe 1500 feet on the average, something like that.

GOOD FEATURES

The good features of this one obviously was the fact that I had a lot of help in killing the crosswind. The airplane itself is a fairly comfortable airplane.

OBJECTIONABLE FEATURES

Objectionable features, minor I think, is the fact that I didn't have sufficient side force control to kill the sideslip completely, that is the drift completely.

SPECIAL PILOTING TECHNIQUES

There's no special piloting technique except that I did have to superimpose on the side force controller, some aileron and rudder inputs.

PILOT RATING AND PRIMARY REASON

Is it satisfactory without improvement? I would think so. If I had an airplane that was this easy, you might say, to land in a crosswind, I don't think I'd squawk about it. So I certainly would put this in the acceptable category with minimal pilot compensation. I think the fact that we do have some inputs required, the fact that I do couple a little bit with the longitudinal in ground effect is a mildly unpleasant deficiency. So I'm going to rate that a 3.

TURBULENCE EFFECT RATING

In up and away flight the turbulence actually seems reasonable. I'd say at most it's something like moderate. The airplane response at least gives me that impression. I don't know whether they put in the turbulence on one of those approaches or not but on the second approach I got the impression because of this PIO that I got into, this actually disturbed the Dutch roll, I was actually fighting some turbulence and there's no question that there's some deterioration in the precision of the approach or the landing task. So more effort was required in turbulence. Not knowing exactly what was given to me, the fact that my second approach at least seemed to be more wobbly, I don't know what you'd want to call it, some oscillatory tendency by the pilot so it's a C to a D. I'll call it a D.

CONFIGURATION 9 AUTO DSFC   PILOT A   PR 3   TR D   EVAL. FLT. NO. 1

INITIAL IMPRESSION AND GENERAL COMMENTS

The lateral and longitudinal handling qualities were reasonable I think. And I don't think we should comment any more than that. And that one was now using the automatic side force control system.

ABILITY TO TRIM

Trimmability was okay in all three axes.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics were all right. I got the impression, I think, again on some occasions that the longitudinal might have been a little bit on the heavy side. The selection of the control sensitivities; I didn't go through any of that, just accepted what I had on the previous evaluations.

AIRPLANE RESPONSE TO PILOT INPUTS

Response to inputs I think are reasonable. I don't really have anything to add to the responses. This is the same configuration, I assume, as the other two. That's my understanding that you start with one basic configuration and then you go through the evaluation with the three different controllers.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final was no particular problem.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

All I did there was, on the first approach I attempted to just merely fly the longitudinal and let the automatic system kill the drift. I think it did that quite well. We were lined up pretty well with the centerline. On the flare and touchdown, I got into a little bit of a PIO. I noticed as I started my flare generally if I hold 130 knots, I need a little nose down trim once I get into ground effect and it seems a little bit odd really but I do add some power so I think this is probably tied in with the fact that I'm adding some power at the same time because I don't want the airspeed to get too low and there is a difference between the evaluation pilot and the safety cockpit instruments. When I read 120, apparently they're reading 115 so I'm very conscious of the fact that I don't want the airspeed to get low so I'm manipulating the power some. The runway alignment was okay and I thought that the thing was doing pretty good.

CONTROL TECHNIQUE

Getting close to the runway, it seemed like we were crabbed over on the first one, where I did try to correct the heading by superimposing my inputs on the automatic system. It was an acceptable attitude for landing. I did make some input to the system on that last landing and there does seem to be some increase in forces, when you're trying to superimpose your inputs to the automatic system and that particular time the input requirement was fairly small and therefore I didn't really think it was a big deal.

CONTROL OF SIDESLIP WITH DSFC

I think that the sideslip control was adequate that time.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

I don't really think there was any significant interference there as far as I could see except that there is a noticeable difference in the forces; the input requirements when you try to superimpose yourself on the automatic side force control system.

CONTROL OF GLIDE SLOPE

I'm still having some learning I think in the ground effect but it's very noticeable that my PIO tendency with this elevator force that I picked is certainly much reduced from what I remember on the practice flight. On the other hand, I also get the feeling at times that the force is a little bit high so this may not be optimum. There may be some other number as far as stick force is concerned that might give us a little better compromise. I didn't explore that because of time considerations.

EFFECT OF RUNWAY CLOSURE RATE

The runway closure rate, that was not a problem; you sort of get used to it. The airplane is under pretty good control. You don't worry too much about that as a feature. As a matter of fact it's just a routine landing type of thing.

GOOD FEATURES

Number one I think is the fact that there was no requirement for the pilot to attempt to keep himself lined up with the runway. That's pretty darn nice.

OBJECTIONABLE FEATURES

Down close [to the runway] there is some, requirement there, not the alignment, but rather the heading crab angle that you still have to work with.

SPECIAL PILOTING TECHNIQUES

There was no special piloting technique that I could see there.

PILOT RATING AND PRIMARY REASON

The pilot rating and the primary reason for it is that I thought the performance was pretty good with a fairly low pilot effort so I'd say that certainly it's in the acceptable category and the only objection or the only minor deficiency was the fact that on the automatic system I still had to do a little bit of correction or correcting on the heading, the crab angle in other words, but that was fairly minor input. Alignment with the runway seemed to be pretty good. It does seem to take maybe more effort than you might expect for the small amount of error to make a correction to kill the crab angle so, in other words, I think the automatic system maybe is fighting the pilot a little bit. But all in all it's a pretty minor thing. For the desired performance, minimal pilot compensation might answer that question so I certainly would rate that a 3. Possibly it's even a little better than that.

TURBULENCE EFFECT RATING

The turbulence rating, it's a comparative thing. We didn't have smooth air and therefore we were always in some kind of turbulence so I'm pretty sure though that there is going to be some deterioration here. In other words, this might have been rated a 2 or even better or let's say if there was no turbulence. Although, as I said, in the automatic feature and in manual sideforce control too, there were some differences from approach to approach and I think I would relate that to differences in wind turbulence, wind shear, we definitely had wind shear. So I guess, I'm only guessing, that we would have to say that there is more effort required and therefore there's some deterioration. Minor to moderate, I suppose so I think I'll stick to the D.

CONFIGURATION 9 NO DSFC   PILOT A   PR 2   TR A+   EVAL. FLT. NO. 10

INITIAL IMPRESSION AND GENERAL COMMENTS

General impression is that in smooth and in turbulence, basically it was not that difficult a job. It was a pretty good airplane I guess, as far as I could see. I didn't have any particular difficulty. The last approach had a little more crosswind and that ended up that I had significantly more bank angle but I still had the alignment pretty well and we were more or less on the centerline.

ABILITY TO TRIM

Ability to trim, lateral and longitudinal, no problem.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics, somehow the gearings don't seem to be as sloppy this afternoon as they were this morning. This morning the airplane just felt looser. I'm sure that's associated with the change in configuration. The L_β maybe was a little lower. N_β might have been lower. Whatever it was, it does feel a bit more solid this afternoon for the same gearings that I had this morning. I was able to fly the airplane with one hand on the aileron so I don't see any particular problems with the selection that I have here which is essentially what I've been going with all along.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll control, the initial response is reasonable and you can fly bank angle quite well. Directional control, I don't have any particular problems either and no coordination problems except that on each turn I do have to hold a little bit of bank angle or I should say a little bit of bottom rudder to hold the bank angle, nothing too extraordinary though. Pitch attitude control was okay. I had a slight tendency actually to balloon the airplane in close to the ground but I'm more convinced that that's associated with the power which I add just before setting up the landing attitude. I add a little power because I know that the airspeed is going to drop off otherwise and I don't bother to retrim the airplane at this point so I think that the pitchup due to power probably is causing some of this tendency to balloon the airplane.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind turning final, not significantly difficult thing to establish crab angle. I did notice on the last one that I did drift off and I had the same crab angle correction as the previous one so I suspect that one or two things: either they cranked in more crosswind than they had on the previous ones or the natural crosswind was actually higher and anyway that was no particular problem although I did have a tendency to angle in to the centerline rather than hold the crab angle.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The runway alignment was not a big problem and, as I said, I did use the crab technique.

CONTROL TECHNIQUE

The usage of aileron, rudder and elevator were all pretty normal.

CONTROL OF SIDESLIP WITH DSFC

No side force that time so no comments on that.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Lateral-directional inputs, I didn't really think there was any cross coupling with the longitudinal to speak of and vice versa. I really didn't have much tendency to cross couple in any of the axes so that it felt pretty normal and pretty much like I had the airplane under control.

GOOD FEATURES

I guess everything about it is pretty darn good Even in the turbulence, I didn't have any particular difficulty so I would say that it's a pretty good airplane.

OBJECTIONABLE FEATURES

I can't think of any really objectionable features to it.

SPECIAL PILOTING TECHNIQUES

There was no special piloting technique involved.

PILOT RATING AND PRIMARY REASON

I felt pretty comfortable and it was a pretty solid airplane and everything looked quite normal with just a slight amount of pilot effort involved, so I think I'm going to have to rate this a pretty good airplane, maybe I'm just getting better at these crosswind landings. Negligible deficiencies, I'd say. I'm going to rate it a 2.

TURBULENCE EFFECT RATING

I don't really feel that turbulence was a really significant factor on this one so I'm going to rate that as no significant deterioration. There's a slight increase in effort. I'm debating between and A and a B. And there's just a slight amount of increase so we'll call it an "A+", that's between an "A" and a "B".

CONFIGURATION 9 MAN DSFC   PILOT A   PR 2.5   TR C+   EVAL. FLT. NO. 10

INITIAL IMPRESSION AND GENERAL COMMENTS

The impression that I had that time actually was that for some reason I was working a little bit harder having control of the side force than I did without it. I think it was basically my overcontrolling with it and I don't know whether that's because of wind shear, that is, that the wind is stronger at higher altitude than it is down close to the ground. With the second approach in turbulence I wasn't too happy. The last one was okay although I was still cocked a little bit nose left, but at least I had things pretty well stabilized. The landing was okay. I guess the rate of sink was pretty low. I really wasn't in any particular difficulty with smooth air. I was right down the centerline. In turbulence I definitely had an increase in effort, pilot inputs. For some reason, what appeared to be small side force corrections, gave me some fairly large changes in drift and this might be a problem which is associated with sensitivity. Maybe for this particular airplane, the sensitivity of the side force controller should be lower so that you have a little better precision of control. But anyway, it's not really a bad airplane.

ABILITY TO TRIM

Ability to trim was okay.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics were okay. I didn't have any problems.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll control was okay, directional control was okay, coordination was all right, pitch attitude control was okay.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

I didn't have any difficulties. The last approach I started a little farther out. This gave me a little more time to figure out what to do. And this worked better. I was able to stay on centerline better I thought although I did have some excursions from it and this is basically my overcontrolling with the side force surface.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

I was trying to establish zero crab angle with the steady state sideslip, with the side force, and as I said I had some difficulty.

CONTROL OF SIDESLIP WITH DSFC

The precision of control wasn't as good as I would have liked. Okay, so I think I've explained the side force usage already and it seems to me that I was overcontrolling. Maybe this is associated with, as I said before, sensitivity of the side controller itself. There was certainly an adequate amount of side force available. I think I only used something like a half, possibly a little more, a little less.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

There was no interference lateral-directional that I could tell.

CONTROL OF GLIDE SLOPE

Pitch attitude control was not a problem.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

The lateral-directional cross coupling with the longitudinal didn't seem to be a problem at all.

EFFECT OF RUNWAY CLOSURE RATE

Closure rates on the runway were pretty good actually. I think I started my flare soon enough and I added power soon enough. So that everything looked okay. It's a well behaved airplane. The control forces are adequate. They're not difficult to overcome in any respect.

OBJECTIONABLE FEATURES

The only objection I had I think on that one was the fact that I just could not precisely find the direct side force control position that would give me zero drift and runway heading and maintain the runway alignment that I wanted. I think that the turbulence level that time, I don't know whether it was just more natural turbulence or what, but it gave me a reasonably increased level of effort to keep the wings level.

PILOT RATING AND PRIMARY REASON

I think that there were some mildly unpleasant deficiencies here which I think are more associated with the controller than they were with the actual performance. There is a minor amount of pilot compensation. I think I would accept this airplane but I think I would downgrade it because I didn't think the performance was as precise and as good as I would have liked, especially in turbulence. I just didn't feel as comfortable with this as I did just making the final correction myself on the end and just dropping a wing so we're splitting hairs maybe, but it's pretty good airplane. I wasn't, as I said, too happy about one of those approaches, the second one, so to differentiate, I'll make it a 2.5.

TURBULENCE EFFECT RATING

I think that there is more effort required in turbulence and there is deterioration in the performance, whether that's all turbulence or just a combination of turbulence and side force overcontrol I don't know but I would say it's minor to moderate anyway. So we're going to call that one a "C+".

CONFIGURATION 9 AUTO DSFC PILOT A PR 2 TR B+ EVAL. FLT. NO. 10

INITIAL IMPRESSION AND GENERAL COMMENTS

The general impression is that this automatic thing is working certainly much better since we made these changes on the rudder command and the time delay. I was actually able to keep the airplane down the centerline with just a modest amount of effort, not really as much as I would have expected to overpower the automatic feature so it's pretty good. I liked it.

ABILITY TO TRIM

There's no problem in trimming.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Forces were okay and in the selection of sensitivities there's no changes.

AIRPLANE RESPONSE TO PILOT INPUTS

Responses are okay. As far as directional, lateral, I really didn't try to do very much except occasionally try to help it laterally. Pitch attitude control was no problem.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

The crosswind was no problem.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The landing approach was to just let the system do it and there are always a couple of glitches, fairly large ones while we're on the final and that's a combination I'm sure of our system or the raw localizer signal which probably has some bends in it. The runway alignment, two of those approaches were on the left side. The last one I forced it to the centerline and it turned out to be pretty darn good.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

I don't really think there's any interference between the side force and any of the other controls.

CONTROL OF GLIDE SLOPE

On all of my approaches, the glide path starts out at 1200 ft/min and increases and then decreases back down again. So there's sort of like a little bend in the glide path everytime. I never am really able to establish exactly what the power should be because I think I start the power probably off a little bit and it doesn't really take much because we're starting these approaches from only a couple of miles out and if I don't push over properly, the airspeed drops off and so maybe I take too much power off and if I push over fast, the airspeed picks up so I pull the power off so there's a certain amount of raggedness in the glide slope but it's perfectly legitimate I think for VFR. You just make the corrections necessary to set you up for a good touchdown at the threshold on the numbers type of thing. I didn't have any trouble with the closure rates because I was able to start my flare each time at a pretty good spot. In other words, one of the problems with this business of where do you start the flare very often is a function of how well I establish the glide path and if I'm a little bit long, I maintain the rate of sink a little high a little longer and that means I'm delaying my flare. The purpose of that being so that I don't land too far down the runway so that's really probably the biggest factor.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I don't think there was much in the way of cross coupling at all, longitudinal and lateral.

EFFECT OF RUNWAY CLOSURE RATE

The runway closure rates that time were pretty good and we set up very well on that one so there's no problem.

GOOD FEATURES

The good feature obviously is the fact that your runway alignment is taken care of and you can spend a lot more time on setting up glide paths.

OBJECTIONABLE FEATURES

I still feel there is a deficiency in the localizer attainment by the system, or maintaining the centerline. There is a little more activity laterally than I think you should have. This is more noticeable in turbulence.

PILOT RATING AND PRIMARY REASON

In smooth air it was pretty darn good so I think it was a pretty good airplane all the way around and I'm going to rate it I think on the basis of the performance in smooth air and in rough air except for that middle one [the second approach]. I would still rate that about a 2. So I'm going to rate it a 2.

TURBULENCE EFFECT RATING

I think that the turbulence really was a minor effect this time. The last landing was probably the best one of the bunch so maybe there was no significant deterioration although, as I say, this business of being down the left side is a mental hazard so we'll call it a B+ for the turbulence.

CONFIGURATION 9 NO DSFC   PILOT B   PR 4   TR B   EVAL. FLT. NO. 19

INITIAL IMPRESSION AND GENERAL COMMENTS

My initial impression of the handling qualities of the aircraft were good. I will enumerate any deficiencies that I saw lateral-directionally as I go through the comment card. Longitudinally it is all right.

ABILITY TO TRIM

As far as trim goes longitudinally it felt good, good trim rate, no significant lag. Didn't feel like I had to use it very much. I used it mostly controlling attitude and rate of descent during final approach. I did use it more than I like to when I made steep bank angle turns because this required a lot of nose up trim. Lateral trim rate is excessively slow and I didn't really feel the effects although I used it quite a bit. Directionally trim felt good and I did use it quite often on downwind and its effect was good.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics, longitudinally were all right. I felt the force gradient gave me good cues for establishing desired attitude. Displacements were not too high. But laterally I didn't feel a real good gradient. There was a lot of slop around center and this destroyed the overall control force harmony. Sensitivity laterally was not excessively high. Directionally the control force gradient was a little high, uncomfortably so, at least noticeably so. It also contributed to destroying overall harmony. Sensitivity in yaw was not good either.

AIRPLANE RESPONSE TO PILOT INPUTS

I felt a distinct lag in yaw response with rudder deflection. In roll, the initial response was a lag and then this degraded the ability to make, to predict final response and lateral control. It led to slight overshoot but this was only a minor objection. Again, directionally I have some complaints in the lag and excess of force. I was required to use rudders on final approach. Turn coordination was good, once I've adapted to the yaw and roll control inputs required. Pitch attitude as I said was okay. Initial response, just a slight lag but I was able to get final response fairly well with no excessive overshoots. Turbulence did not affect the performance of the task significantly. I didn't feel any great disturbances or oscillations caused by disturbances on any axis. It seemed like they were damped out adequately.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The method I used on final approach was to establish a crab and then approximately 200 ft. above touchdown point to kick it out and align the aircraft heading with the runway. Runway alignment was somewhat difficult at the bottom in the flare. When I have to kick out the crab I felt the rather excessive directional force required and I don't think I ever got rid of the yaw rate. I think I would have some yaw rate going on touchdown and wasn't able to adapt very well.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I did not note any coupling between lateral-directional and longitudinal motions other than the nose up trim required in the 20 to 30° bank angle turn which is natural.

GOOD FEATURES

I felt damping was good on all axes and the dynamic responses were good except for the lags in directional and lateral axes. There was a little tendency to over control. It's a matter of working a little harder to get the desired deflection.

OBJECTIONABLE FEATURES

The primary objectionable features were the excessive aileron trim required or the lag and the slow aileron trim rate, the rather high rudder force gradient that I felt, and the lag in the directional control system, and the lag in the aileron control.

PILOT RATING AND PRIMARY REASON

I rated it overall a 4. Primarily for the directional control force and lag in rudder response.

TURBULENCE EFFECT RATING

Deterioration of the task performance with turbulence I rate a B. I did not note any significant deterioration.

CONFIGURATION 9 MAN DSFC PILOT B PR 3 TR B EVAL. FLT. NO. 19

INITIAL IMPRESSION AND GENERAL COMMENTS

The handling qualities are adequate longitudinally. There were some minor deficiencies lateral-directionally.

ABILITY TO TRIM

In trim the longitudinal system was all right, the rate was fine, I did not notice any lag to speak of. Laterally, I don't get the kind of response that I am looking for when comparing the two; I don't know if it is the lag or slow rate I think it is the rate. Directionally trim rate is good and authority is good.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Longitudinally there is a good force gradient, feels very comfortable. Laterally the gradient is okay. There doesn't seem to be a significant or noticeable force gradient laterally. Directionally it's slightly high, uncomfortably high, and therefore destroys the overall control force harmony. Sensitivity is good on each axis, except the directional axis. I felt there was some slop, laterally, however, it was minor.

AIRPLANE RESPONSE TO PILOT INPUTS

There was fairly good response in roll. There is a slight lag initially with a slight overshoot, but you can pretty well put the bank angle where you want it. Directionally it is another question. It was well damped, the force gradient ran a little high and some lag in the initial response made it difficult to make precise heading changes. I felt like I pumped just a little bit on the rudders coming down final. The aircraft coordinates very well using rudder-aileron. No problem there. In pitch I was able to establish attitude fairly well but I did note a tendency, just a little tendency to PIO in pitch in the flare.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

No real difficulty caused by the crosswind during final. Effects of turbulence were almost negligible although they were apparent and I did see some slight oscillations. I felt the heave a little more this time for some reason but it was noticeable. But I did not see any yaw-roll oscillations, it was damped such that I did not see the Dutch roll excited. It was excited but damped out well.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The landing approach method used was to establish the crab out on final just after aligning with the runway.

CONTROL TECHNIQUE

The use of the direct side force came into play to align the aircraft heading fairly well to the runway heading. I thought I ran out of authority one time but I may not have. I may have overcontrolled just a little on one of the approaches. Runway alignment was no problem whatsoever once I did establish the crab.

CONTROL OF SIDESLIP WITH DSFC

I just rolled in the side force and didn't tend to overcontrol at all. There's no lag at all and the aircraft comes right around and aligns itself. It had good cues, not excessive, but good side force cue in seat of the pants. The one time when I didn't think I had the control authority. I did use a little bank and crab coming down final approach.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

It did not interfere at all with the lateral-directional system nor did it excite any modes of response that I could see. I used the side force controller on the throttle. It seems more comfortable there. Again, the detent is not that apparent and you have to look to see when you are in the detent and there really could be some indicator gradations on the controller on the wheel itself to indicate how much side force surface deflection is being used. The approach, the task, the entire task and the performance; it was quite a bit easier and a decreased workload as a result of the use of direct side force control.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Didn't notice any coupling between the axes of the motion. Again, I just note the rather noticeable nose-up trim required in a comparatively large bank angle turn, say 20 to 30 degrees, although easily trimmed out. Possibly the learning curve enters in because I am anticipating the amount of trim required and not loosing altitude or gaining airspeed as I have been.

EFFECT OF RUNWAY CLOSURE RATE

Runway closure rate had no effects on the test accomplishment in my estimation.

GOOD FEATURES

Good features were the basically good damping on all axes with adequate control response except directionally. I would say the low directional control response is the major discrepancy that I saw.

OBJECTIONABLE FEATURES

There is a slightly excessive directional control force gradient and inability, because of the lag directionally, to establish precise yaw control especially down at the bottom when you are trying to align with the runway heading for a touchdown.

PILOT RATING AND PRIMARY REASON

I'll give it an overall rating of 3 and I rate it at 3 because of the directional control difficulties that I had. On the other hand it did have good damping characteristics and dynamic responses.

TURBULENCE EFFECT RATING

Turbulence rating of Bravo. I did not note any significant deterioration for that task performance with turbulence. Although there was slight motions which were readily damped out so that the turbulence did not affect task performance significantly.

Appendix III.2

CONFIGURATIONS WITH N_{β} = 0.94 AND L_{β} = -2.95

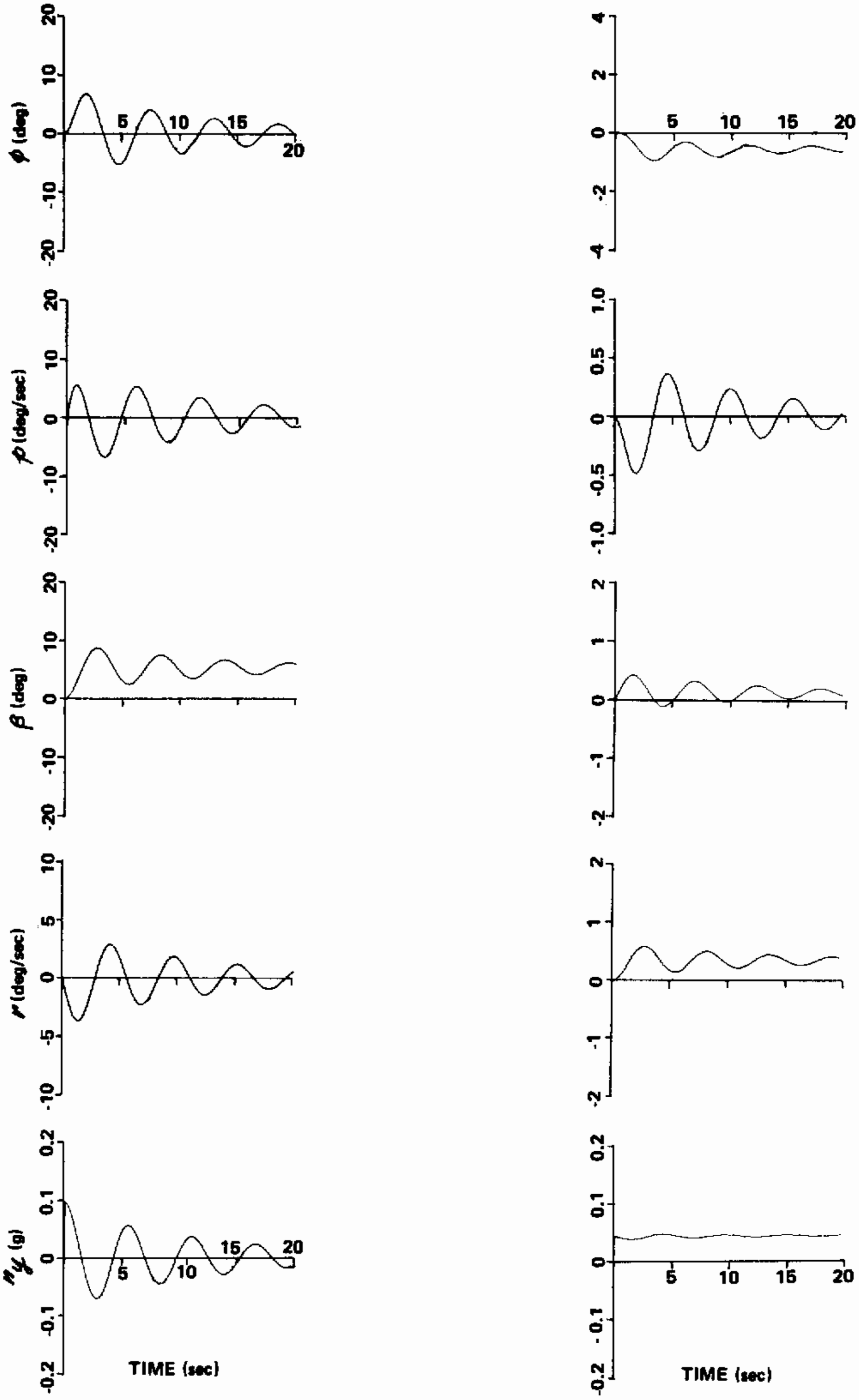
(CONFIGURATIONS 2,6 and 10)

DIGITAL RESPONSES WITH AND WITHOUT INTERCONNECTS

FLIGHT DATA TABULATION

IN-FLIGHT RESPONSES DURING LANDING

PILOT COMMENTS



(a) δ_y = 10.0 deg, δ_a = -10.75 deg, δ_r = 12.9 deg (b) δ_y = 10.0 deg, δ_a = 0.0 deg, δ_r = 0.0 deg

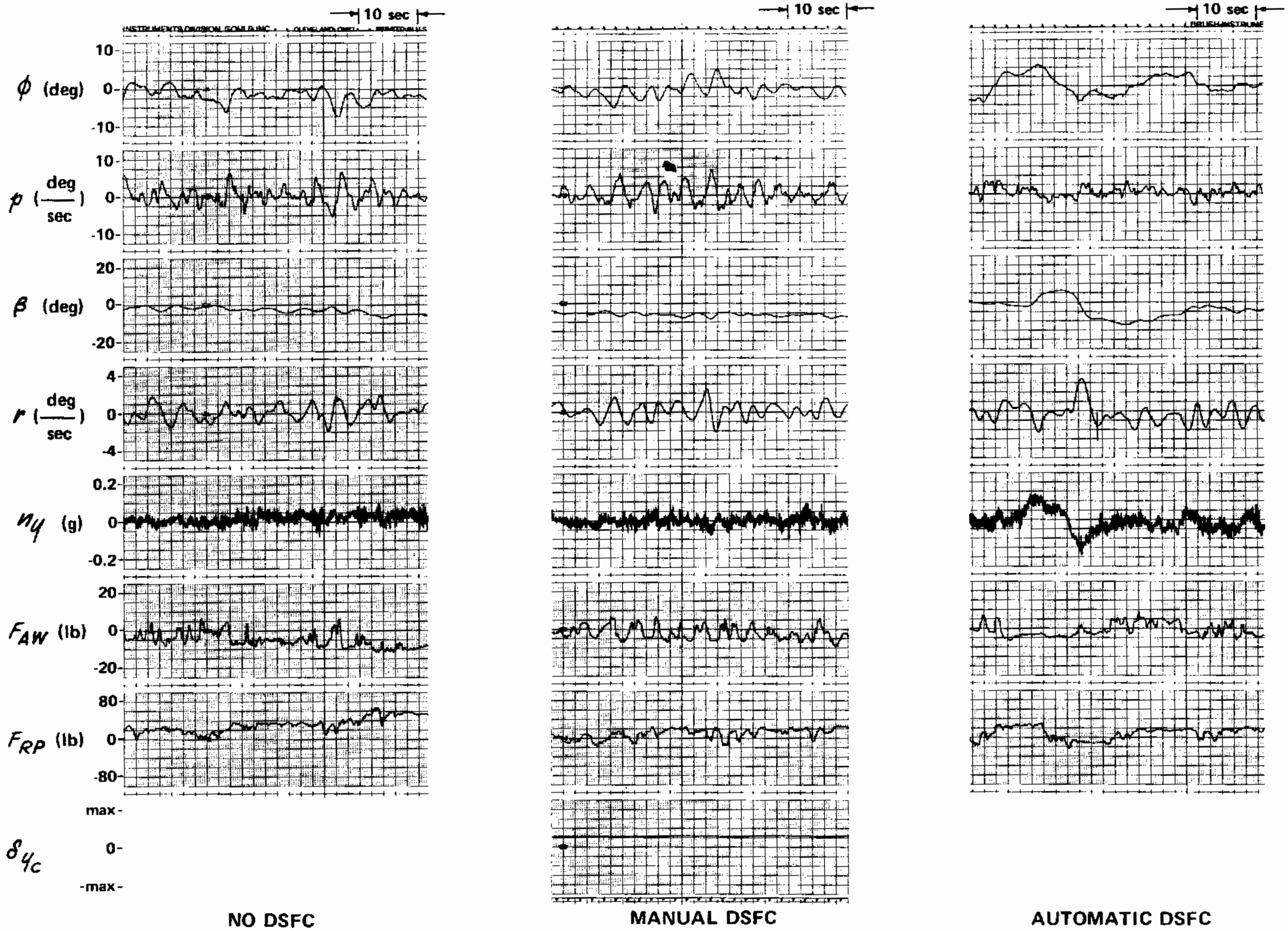
MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO THE AILERON AND RUDDER (CONFIGURATION 2)

CONFIGURATION 2 FLIGHT TEST DATA TABULATION
(EVALUATION FLIGHT NO. 15 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	-1.66	1.34	-5.44	0.74	-9.51	1.61	52.7	6.92	0	6	E
MANUAL	-0.61	1.27	-6.29	0.69	-3.92	3.25	15.1	7.26	-6	5	D
AUTOMATIC	-0.68	0.73	-3.58	1.31	-1.43	2.89	10.5	7.43	-8	4	C

CONFIGURATION 2 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	200	15	2.49	2.24	2.40	280
MANUAL	210	12	2.11	1.51	2.81	280
AUTOMATIC	220	13	1.92	2.32	2.28	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN
CONFIGURATION 2

CONFIGURATION 2 NO DSFC | PILOT A | PR 6 | TR E | EVAL. FLT. NO. 15

INITIAL IMPRESSION AND GENERAL COMMENTS

I had sufficient control and the forces were not excessive. Without the turbulence we have some small amount of natural turbulence, it really wasn't that bad. I didn't succeed in getting the airplane down on the first approach without turbulence, I think primarily because I estimated the height of touchdown a little bit too high and I got into a little bit of a PIO and I was hunting for the runway. But generally I felt that it should not have been too big of a problem. However, when we got the turbulence in there, it was obviously a pretty lousy airplane. I would estimate the damping ratio to be slightly positive and but it's very lightly damped and the airplane wallows around quite a bit.

ABILITY TO TRIM

I was hunting around quite a bit for the trim point there but I think it was primarily caused by this constant oscillation agitated by the turbulence that was being fed into the model. So lateral-directional, I really didn't worry too much about trying to keep the sideslip zero as long as it stayed plus or minus one or two degrees. Longitudinally I was playing around quite a bit just trying to get the airspeed back up.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The feel characteristics, I think that the forces and displacements were adequate. The forces go up a little bit, maybe a little bit higher than I would like when I try to establish the landing attitude. This is primarily in the aileron. However, I think part of the problem is trying to damp out this lateral directional oscillation with the rudder and I think at times, I actually disturb the airplane rather than damp it. The harmony seems reasonable. I would think that the sensitivities are probably adequate at least for the actual control of the aircraft, even if it's not proper for the damping function. In other words, for small inputs you probably would like to have less sensitive controls but on the other hand, for the maneuvering of the aircraft the sensitivies feel about right.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll control was okay. This business of trying to establish a bank angle is very difficult because of the low damping of the Dutch roll. You sort of set a gross bank angle and then hope that you're close enough to where you want to be. Directional control, again you get this feeling that you're just wallowing around and on occasion it does feel like the pilot is actually disturbing the airplane. So I don't know what to do about it. I guess the only thing you have to do is increase the Dutch roll damping and you might be okay. Turn coordination, it's difficult as I said to try to keep the sideslip zero because of the constant oscillation. Pitch attitude control is acequate. It's sort of sluggish but for this particular task it's okay.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind turning on final caused no problems that I could see.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The landing approach was a crab until I started my flare and then I tried to set up bank angle and sideslip to maintain the center of the runway. This, was a little bit of a problem. And the biggest problem I think is this overcrontrolling with the rudder on occasion and also this tendency to PIO the airplane and partly I think it's a little bit of rustiness on my part to find the proper height above the runway for touchdown.

CONTROL TECHNIQUE

There is no particular control technique.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I did seem to have some coupling between longitudinal and lateral directional because of this oscillatory motion of the aircraft. When I put longitudinal inputs, I didn't really feel I was putting in anything laterally but I think it's all sort of subtle and it's a little difficult to separate the oscillation just due to the low damping and oscillation due to the pilot input. If you try to chase it, I think you'd have more of a chance of getting back into a larger amplitude oscillation rather than damping it and this is sort of sporadic. At times it looks pretty good like I'm able to dampen it, other times it's not.

GOOD FEATURES

The good features are the fairly good level of forces and having sufficient control to make the airplane move around in attitude the way I want.

OBJECTIONABLE FEATURES

The biggest problem of course is precision of attitude control. This is caused by this constant oscillation. This is particularly noticeable in turbulence. I didn't feel too bad about it in the normal turbulence that we had on the first approach, but on the two other approaches I didn't particularly like it.

SPECIAL PILOTING TECHNIQUES

There is no particular special piloting technique unless you consider staying off the controls, the rudder in particular, so that you don't actually agitate, disturb the airplane.

PILOT RATING AND PRIMARY REASON

Is it controllable? I guess it is. Is adequate performance attainable with a tolerable pilot workload? Well, the first and the third approach I was happy with as far as being able to land it but it did take quite a bit of concentration. So, I think we're going to be talking here about deficiencies warrant improvement. I'm debating between a 5 and a 6 I'm going to call it adequate performance requires extensive pilot compensation and the primary reason for that rating is the low damping of the Dutch roll and the fact that I have to stay right on top of the airplane to position it properly, especially in bank and, of course, that also affects the longitudinal. So I'm going to call it a 6.

TURBULENCE EFFECT RATING

There is certainly a definite effect of turbulence and I'm rating this the difference between the small amount of natural turbulence and the input to the model. Best efforts required. It's close to the moderate so we're talking between a "D" and an "E". I think I'm going to call that an "E".

CONFIGURATION 2 MAN DSFC PILOT A PR 5 TR D EVAL. FLT. NO. 15

INITIAL IMPRESSION AND GENERAL COMMENTS

There is no question that the pilot task is improved. That is, the pilot effort is decreased, having control over the sideslip and the side force surface. We are experiencing some fairly healthy turbulence here and it's still a fair amount of effort involved but you certainly can line the airplane up with the runway, keep the wings level and still do a pretty good job so generally with the side force control, the task is definitely improved.

ABILITY TO TRIM

Ability to trim is difficult airspeedwise. The airspeed in the turbulence is bouncing around quite a bit and so it's quite difficult really to trim out airspeed. Lateral-directional, I don't even bother with it really because the airplane is oscillating all the time and as long as I don't feel I'm having to hold either rudder or aileron in any direction, I just let it go. It's probably fairly well, or fairly close to trim anyway. I notice we developed a cloud layer here at about 3500 to 4000 and I think this is part of the problem, the heating here is giving us quite a bit more turbulence, as the flight progresses.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics are okay.

AIRPLANE RESPONSE TO PILOT INPUTS

The big problem is to try to maintain any given bank angle. The initial response certainly is adequate. Directional control, the airplane feels loose directionally and it does seem easy to disturb the Dutch roll with the rudder. Turn coordination, I don't think that you can coordinate with any degree of precision. All you do is try to keep the ball somewhere in the middle. Pitch attitude control was okay. I still think I'm getting some cross coupling in pitch attitude control when I try to get the airplane in landing attitude.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

The crosswind, turning final did not cause any noticeable difficulty.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The approach method was to establish a crab angle which is a little difficult to do because of this continuous agitation due to the turbulence I had to make at least two or three corrections on the side force surface to establish zero drift with the nose of the airplane pointed down the runway. You never really feel that you've got a real positive lock on that either because of this continuous Dutch roll oscillation. It's quite difficult to be precise with it. The runway alignment however seemed to be pretty good with the side force controller.

CONTROL TECHNIQUE

The control techniques are really not much different with the side force surface, than they are without the side force surface.

CONTROL OF SIDESLIP WITH DSFC

Control of sideslip is certainly adequate. I think I used something like a little less than a half of the side force surface.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

I don't think it interferes with the lateral control.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I do feel that there is some cross coupling and I think primarily because I try to damp out this Dutch roll especially with the turbulence input to the model, it takes some farily large amplitude inputs and I did feel closer to the runway, that I had some cross coupling between the pitch and the lateral.

EFFECT OF RUNWAY CLOSURE RATE

There was no particular closure rate problem that time although on the one prior to that one, the nose suddenly went down. We were descending pretty good. It was uncomfortable obviously. But I don't think it affected the task as far as aligning the airplane and trying to establish a zero drift.

GOOD FEATURES

The good features is that by being able to align yourself with the side force controller, it reduces the amount of effort that the pilot has to expend in flying the airplane.

OBJECTIONABLE FEATURES

This lateral-directional looseness and low damping and especially the roll feature of this thing. I didn't look at the thing long enough to have too much feel for what the phi to beta is but the results might indicate that the phi to beta is high, but I think it's primarily just the damping. I don't really think the phi to beta is that high but it is maybe a little higher than normal.

SPECIAL PILOTING TECHNIQUES

There is no special piloting technique except on attempting to damp the airplane. I used mostly rudder.

PILOT RATING AND PRIMARY REASON

I'm going to have to certainly rate this better than the 6 without the side force surface because the effort is lower but it still requires a pretty fair amount of pilot compensation. I can't upgrade the airplane very much, maybe a 5 and maybe a 4-1/2, I think it takes more than moderate pilot compensation to get the airplane in turbulence to a landing so I think I'm going to rate this a 5. It doesn't make it a completely acceptable airplane and I think the primary reason for that is the Dutch roll damping. You just have to work at it no matter what you do with the drift correction. You will have to work hard enough that it downgrades the airplane.

TURBULENCE EFFECT RATING

With the turbulence into the model, there is certainly a more effort required to fly the airplane although the normal turbulence level right now is fairly high and, well, I'd call it moderate. So that with the turbulence into the model, the airplane is definitely more squirrelly, I guess you might say so that there is more effort required. There is definitely a moderate deterioration in the performance of the task. So I'm going to call it a "D". I think the deterioration is not as severe as it was without the side force controller because then I could spend more time in damping the airplane.

CONFIGURATION 2 AUTO DSFC   PILOT A   PR 4   TR C   EVAL. FLT. NO. 15

INITIAL IMPRESSION AND GENERAL COMMENTS

We made two approaches with the automatic system, one without the turbulence into the model and one with turbulence. I think there's too much hunting back and forth on the localizer. That's the primary problem. If I can ignore the oscillation about the localizer, in other words, the hunting back and forth from either side of the localizer, it does reduce the task to a two-dimensional thing, power and longitudinal control inputs and really the first one without the turbulence, I guess the touchdown wasn't really very bad. We were cocked a little bit left but possibly that's just an error in the heading. But the second one was much more noticeable, at least I thought it was much more noticeable heading discrepancy. It could have been that the airplane was actually trying to correct back. The airplane is being brought down on left of centerline but not as much as I remember. It's just 15 to 20 feet off the centerline, which isn't really too bad.

GOOD FEATURES

The good feature I guess is the fact that the automatic system relieves the pilot of quite a bit of the lateral-directional problem and alignment problem.

OBJECTIONABLE FEATURES

The objectionable features I think are primarily limits on the system.

SPECIAL PILOTING TECHNIQUES

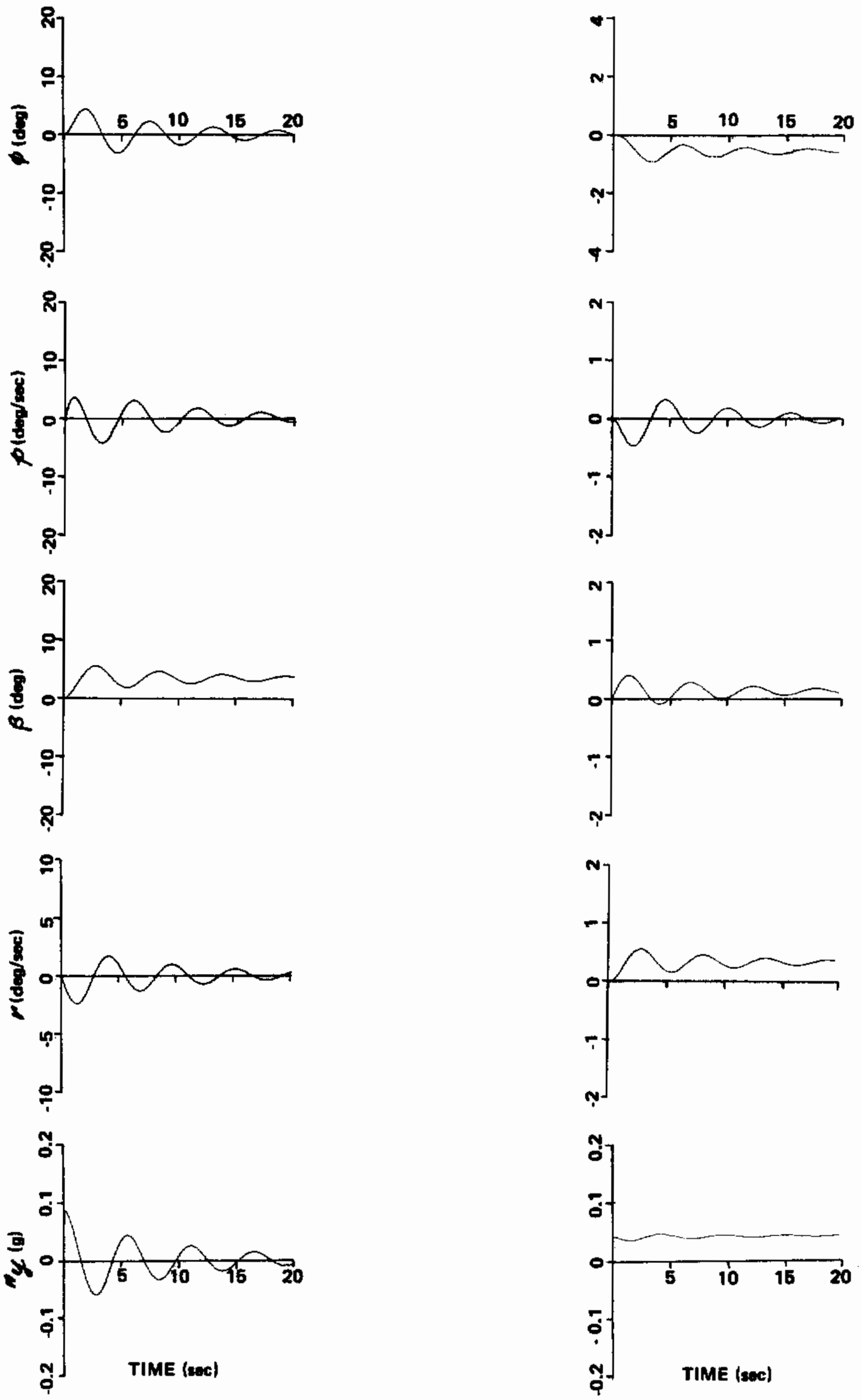
The only special piloting technique is that I flew the airplane just longitudinally and, that is throttle and pitch attitude.

PILOT RATING AND PRIMARY REASON

I think that the airplane certainly is better than the airplane without side force control and the only question is, is it better with the manual. I don't really think its better only because I don't like this oscillation about the centerline but I certainly think it's probably as good. The effort is less on the pilot's part, if he can ignore this oscillation about the localizer. I don't know, I certainly thought it was a much better airplane than it was without the side force so I'm sort of torn between rating it a 4 or a 5. I think I'm in the same boat as I was before. The effort was certainly less. I've got to admit that the pilot effort was less to get to the touchdown so I'm going to rate this better than the manual with the understanding that I only do this if I can ignore the fact that the airplane is hunting about the localizer so I'm going to rate it a 4.

TURBULENCE EFFECT RATING

With or without turbulence, there's definitely deterioration I think in performance as far as I can see. The excursions were larger but as far as the pilot effort is concerned, it's just a slight minor increase of effort in turbulence because all you have to worry about is the longitudinal so I'll call the turbulence as minor and that will be a "C".



(a) δ_y = 10.0 deg, δ_a = -7.16 deg, δ_r = 8.60 deg (b) δ_y = 10.0 deg, δ_a = 0.0 deg, δ_r = 0.0 deg

MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO THE AILERON AND RUDDER (CONFIGURATION 6)

CONFIGURATION 6 FLIGHT TEST DATA TABULATION

(EVALUATION FLIGHT NO. 3 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	2.50	0.84	1.90	0.47	6.10	2.61	-24.4	3.80	0	4	D
MANUAL	0.11	0.90	5.71	0.56	3.00	2.77	- 4.02	5.33	16	3	C+
AUTOMATIC	3.00	0.53	3.60	0.53	4.20	2.50	8.00	3.46	6	5	C+

CONFIGURATION 6 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	310	12	2.31	0.77	3.00	280
MANUAL	310	12	3.34	1.54	2.18	280
AUTOMATIC	320	10	2.04	1.18	2.31	280

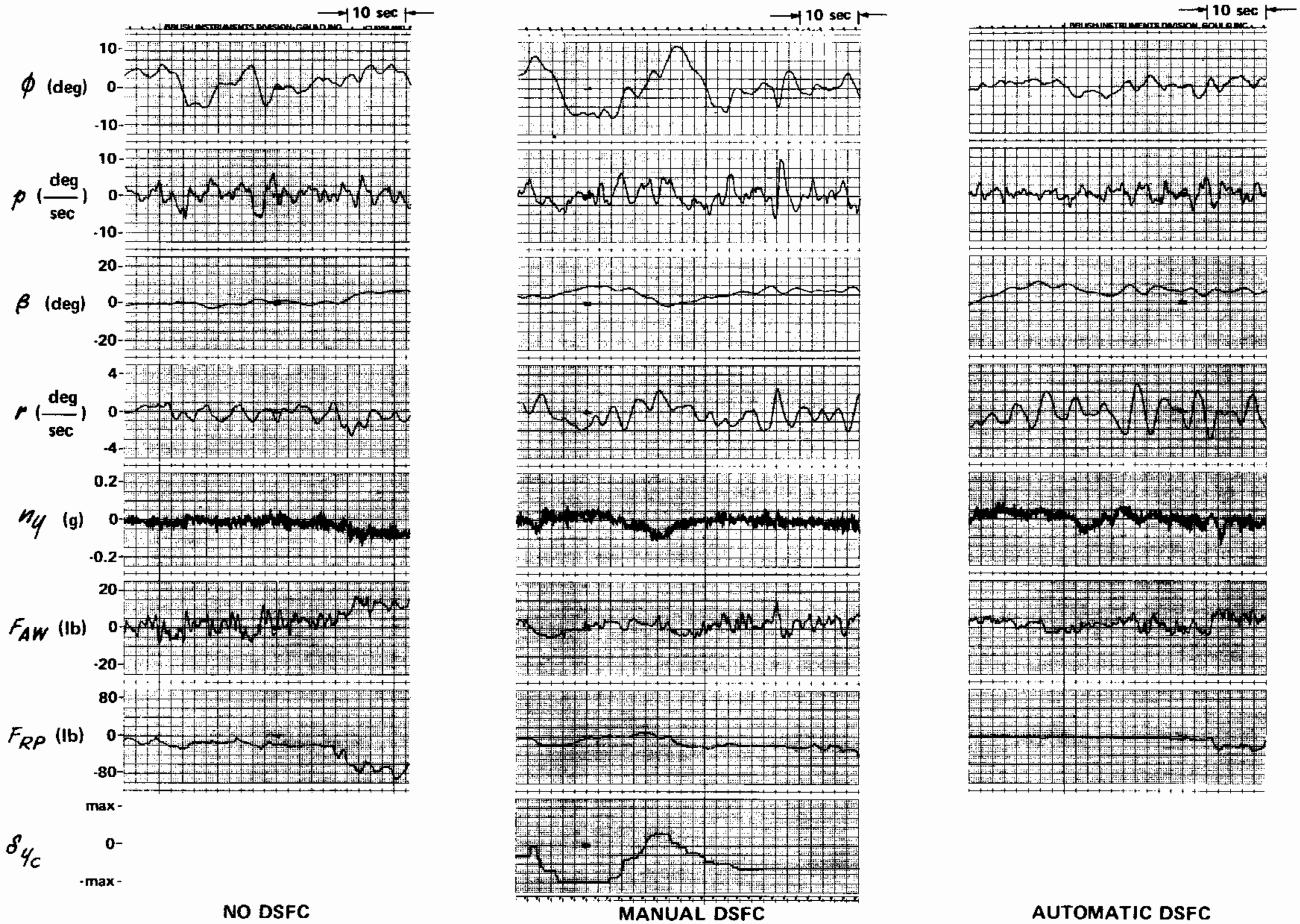
CONFIGURATION 6 FLIGHT TEST DATA TABULATION

(EVALUATION FLIGHT NO. 22 PILOT B)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	4.49	1.31	5.96	0.52	12.63	2.11	-65.6	7.97	0	5	B
MANUAL	0.61	1.82	7.24	0.63	3.06	3.07	-17.9	2.78	12	3.5	C
AUTOMATIC	0.90	1.31	6.10	0.90	5.16	3.91	-14.3	7.62	10	3	C

CONFIGURATION 6 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	360	10	1.88	1.66	2.51	280
MANUAL	340	10	1.45	1.81	1.87	280
AUTOMATIC	360	10	2.37	1.33	1.86	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN

CONFIGURATION 6

CONFIGURATION 6 NO DSFC PILOT A PR 4 TR D EVAL. FLT. NO. 3

INITIAL IMPRESSION AND GENERAL COMMENTS

I made the first approach supposedly in smooth air .. in other words, with no turbulence into the model and I thought that was pretty simple. I made a second one with turbulence and I had to do a little bit of control for a touchdown but I probably didn't touchdown heading directly down the runway but it was a nice easy touchdown. The last one I made was also with turbulence. Now with this one I had a lot more trouble. I had plenty of time to set up but I wasn't too happy with that last one. We may have had more crosswind than we did on the previous one. It wasn't nearly as nice and I was really oscillating back and forth both in yaw and in roll. So, I'm a little bit in a quandry somewhat here to decide how good or bad this was.

ABILITY TO TRIM

I didn't particularly have any difficulty in trimming.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

I thought the airplane feel characteristics were okay and during the practice approach I didn't change anything. I just decided to go ahead with it, but on the practice approach, I didn't really have to do very much of anything. So, I thought I had a pretty docile airplane and the next two approaches didn't dispell that -- the last one sort of seemed significantly worse as far as performance was concerned and I don't really know exactly why except maybe to blame it on the heavier turbulence and the higher crosswind. The wind is quite variable today.

AIRPLANE RESPONSE TO PILOT INPUTS

The roll control is adequate. I think that this airplane has sort of a moderate roll to sideslip ratio and Dutch roll damping as I would say moderate, the pitch supposedly is always the same, but it looks a little bit sluggish and almost deadbeat. As far as damping is concerned, directionally it may feel a little bit loose, but not really what I would call bad. Coordination requirements -- didn't really have any difficulty. I think it was a pretty good airplane.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final certainly didn't cause any particular problems.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

I'm always using the same technique; I'm crabbing as I'm coming in on final, and I'm trying to kick out crab and establish a sideslip and bank angle for the landing. There is no requirement for any combination of crab and sideslip, you have plenty of rudder control and aileron control.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Not really too bad that time, but on that last landing there was some coupling between the longitudinal and the lateral. I really wasn't too successful in the sense of getting well established, I had some drift to the left and I was trying to establish a bank angle, but because of gusts or turbulence or something, I was oscillating a little bit and this made me actually feel for the runway with the slight ballooning tendency.

EFFECT OF RUNWAY CLOSURE RATE

Closure rate doesn't really affect the task. I think the rates of descent at touchdown are fairly low.

GOOD FEATURES

It's a fairly well damped airplane and the coordination requirements aren't too severe. I did, for the first time, specifically check the yawing moment due to aileron input, the initial impression is that there is essentially none. In other words, it's zero. I suspect that it's probably somewhat proverse, a little bit maybe.

OBJECTIONABLE FEATURES

Objectionable features, ...I didn't really see anything very highly objectionable with it on the first two approaches. On the last one I thought that the performance in the turbulence was not nearly as good as I would have liked it. As a matter of fact, I think it would have been a pretty sloppy landing, if I had landed. I was down the runway quite a bit too, for that matter.

SPECIAL PILOTING TECHNIQUES

I don't think there is anything special here, it's just the way you land the airplane with wing down and hopefully zero drift.

PILOT RATING AND PRIMARY REASON

Is it controllable? yes. Is adequate performance attainable with a tolerable workload? yes. Is it satisfactory without improvement? Well, I suspect that it is, I don't think that I really worked very hard at all on the first two approaches, one of which had the turbulence in and one that didn't. I was very surprised how easy it was really to line up. The only hooker was that last one - I don't know if we had higher turbulence, higher crosswind or what, but that last one I probably would have rated it not satisfactory without improvement and this would put it back down to about a 4 maybe. So, as I say, I'm a little bit in a quandry here. I'm really on the fence with this one. The reason I'm on the fence is because it was such a dramatic difference between the last approach and the previous approaches -- so I'm going to rate it a 4.

TURBULENCE EFFECT RATING

More effort required in turbulence? There certainly is. Are best efforts required? I don't think so. I don't think I was pushed that far. It's more than minor, maybe, between a C and a D again...so I think we will rate it a D.

CONFIGURATION 6 MAN DSFC   PILOT A   PR 3   TR C+   EVAL. FLT. NO. 3

INITIAL IMPRESSION AND GENERAL COMMENTS

Generally there is no question that this is quite a help to the pilot. The first approach, without the turbulence, I thought was beautiful, right down the centerline. I didn't have any problems and I established the zero drift quite a ways out. When they put the turbulence in however, it wasn't quite as neat. On the second approach I probably should have had two hands on the wheel just before touchdown. Anyway, it wasn't nearly as good. The last approach I think was even worse than the second one from the standpoint of turbulence. I don't really know why it seemed to get progressively worse, just the same as the first series I don't know whether they are increasing my turbulence level or what, but it definitely seemed that the performance at least on the last one was worse than it was on the previous one which also had turbulence in it.

ABILITY TO TRIM

I think that was no problem.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The feel characteristics were okay, and the sensitivities I think were okay.

AIRPLANE RESPONSE TO PILOT INPUTS

The responses are not bad. I think the coordination is okay. The airplane feels, as I said before, somewhat lose directionally so, I don't know what the N_β is but maybe that's one of the problems in the turbulence. I don't think that the roll to sideslip ratio is especially high.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

The crosswind on final is no problem.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The approach was made to establish centerline roughly with a crab angle and then wiping out the crab angle with the side force surface and, as I said, I had difficulty establishing where to put the side force surface to kill the sideslip or align the nose of the airplane with the centerline and still maintain zero lateral velocities. I think that was primarily caused by the fact that the turbulence makes it more difficult to really establish where the heck the nose is pointed when the ball is in the center. There was definitely a deterioration in the performance caused by turbulence. The runway alignment, again, everthing I just said shows that without the turbulence in I had no trouble. With the turbulence in, I was working somewhat harder.

CONTROL TECHNIQUE

The control technique is merely, to kill the drift or point the nose down the runway, with no drift, with the side force and then from there you just really worry about alignment with the centerline.

CONTROL OF SIDESLIP WITH DSFC

There was adequate control with the side force to kill the sideslip, or kill the drift and also have alignment with the centerline.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

There doesn't seem to be any interference of the side force with lateral-directional control that I can tell.

CONTROL OF GLIDE SLOPE

Control of glide path - I don't think it interfered with that.

LATERAL - DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Did lateral-directional control affect the longitudinal motions? I think yes, close in - just a slight amount. On the last approach, as I said I didn't quite have the crosswind eliminated with the side force surface and so I actually ended up by making a controlled input, small, but some, to try to get the touckdown. The touchdown was not nearly as good as the first one - it was better than the second one I would think, but definitely not what you might call a grease job.

EFFECT OF RUNWAY CLOSURE RATE

Closure rates, ... I'm getting used to this sort of thing now, I don't think it's such a big problem. In making these approaches, some are a little steeper than others. One of these I think was pretty steep, I had the power way back, airspeed was up slightly initially and so I actually started my rate of descent late, so it was a little steeper approach. The round out was fairly abrupt. The next one was a little better because I anticipated a little more. So, if you are talking about vertical closure rates, close to the ground, the rate of sink is pretty high, so vertical closure rates are certainly noticeable, however, the fact that you are doing 130 knots doesn't shake me very much at all.

GOOD FEATURES

Good features I think are apparently the fact that it's a well behaved airplane, reasonably well behaved with pretty good damping.

OBJECTIONABLE FEATURES

Objectionable features are some feel of looseness directionally, some Dutch roll disturbance in other words in turbulence where the pilot has to fight it some, and that's probably about all. There could be some improvement in the dynamics of the lateral modes but they are not overpowering.

SPECIAL PILOTING TECHNIQUES

There is no particular special piloting technique.

PILOT RATING AND PRIMARY REASON

It's controllable. Adequate performance, satisfactory without improvement? That always is the key question, whether you stay in that category or whether you go down to "the deficiencies needing improvement." I don't know, generally I was pretty happy. I think everyone of those probably would have been a successful landing. There was certainly a definite, very noticeable improvement when I was able to eliminate the crosswind with the side force. Some mildly unpleasant deficiencies. I would say the overall rating, I'd have to give it a 3 because I have to assume that you are always going to run into turbulence. The improvement is very noticeable but I still think I would like a little bit of improvement on top of that. Now, that probably means you've got to do something to the dynamics (I think that's what it means), but I don't know how much or what, so I will call it a 3.

TURBULENCE EFFECT RATING

In the turbulence there certainly is a significant requirement for pilot effort to do a good job so it's not the best efforts. It's more effort, it's probably between the minor or moderate so I will call it a C+.

CONFIGURATION 6 AUTO DSFC PILOT A PR 5 TR C+ EVAL. FLT. NO. 3

INITIAL IMPRESSION AND GENERAL COMMENTS

I've made the three approaches with the automatic system and I made the comment that I have reservations about rating this because the fact that the airplane doesn't go down the centerline. Going down the edge of the runway is a mental hazard and you can't really concentrate on trying to flare and make a good touchdown. I think what I'll be rating here is the fact that we have a deficiency in the system. It's automatic all right, it kills the crab angle, kills the drift, but it doesn't bring it down to centerline. The fact it's not down the centerline is a mental hazard so that you downgrade the airplane even though you don't want to.

ABILITY TO TRIM

Ability to trim is okay.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The feel characteristics and sensitivities are okay.

AIRPLANE RESPONSE TO PILOT INPUTS

The response of the airplane is okay. The roll control, when you are on automatic is obviously not as good as it is when you are not - it's not as sensitive, it's not as responsive. To make turns you do have to overpower or ---superimpose yourself on this automatic system and the forces are pretty darn high and to try to displace the airplane against the automatic system is not easy to do at all. So, I made one approach...without turbulence and as I remember that one again took us down to the left side but the touchdown was reasonable I thought, but along the left edge of the runway. The second one I decided to go ahead and take off the automatic feature which supposedly stops the side force surfaces wherever they happen to be when I throw the switch and that went all right without any transients. But then I tried to fly the airplane back towards the centerline and it almost seemed as if I had just as much trouble as if I had the automatic feature on, so the next one I said okay, I'm going to fly it all the way down and try to stay on the centerline by superimposing my inputs upon the automatic control. I was able to do this fairly well, up and away I was happy with it but the closer I got to the ground, the more I required input to keep the airplane from going along the left edge of the runway. I finally ended up with a little bit of a ballooning maneuver there but I was left of centerline, one wing down a little bit and using rudder to try to hold the heading. The forces were quite high and it was just about as much effort I think to try to make a decent touchdown with this system as there was if I didn't have any automatic system. As a matter of fact, I would have preferred not to have it at all. In other words, what I'm saying is that I would have rather probably tried to land the airplane normally. I think what I'm really saying is that this offset from centerline is enough of a factor that no matter what you try to do, it doesn't ease the pilot problem, which it's supposed to.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

The side force does interfere with the lateral and directional control as I explained in trying to align the thing with the centerline. I think I've covered that well enough.

CONTROL OF GLIDE SLOPE

Glide path control is no particular trouble, if you don't try to overpower the automatic system. When you start putting in aileron and rudder to get to the centerline, you are holding quite a bit of force therefore, there is some tendency to overcontrol in pitch. When you want to make some small corrections in pitch - it's hard to do. So the longitudinal control inputs are affected by this automatic feature. [If the pilot attempts to override the automatic system.]

EFFECT OF RUNWAY CLOSURE RATE

The closure rates are not excessive but they do affect you because you are not lined up. The fact that you are close to the ground at a fairly good rate and you still haven't established the centerline of the runway is somewhat of a hazard, so in that respect the closure rate does affect the task accomplishment. Makes you hurry a little bit.

GOOD FEATURES

I suppose if you were making a normal ILS from way out - the fact that you don't have to worry about staying on the localizer is a good feature, but that's somewhat reduced in effectiveness because of this side force that is continuously disturbing you.

OBJECTIONABLE FEATURES

I must say that with the automatic feature, this hunting about both sides of the localizer, even if it isn't actually displacing the airplane very much, there is a continuous lateral acceleration on the pilot, and the aircraft of course, and this is very annoying. It's not the way airplanes should feel. And, so this, again, is another factor that would tend to degrade to down-grade the configuration.

SPECIAL PILOTING TECHNIQUES

Special piloting techniques I've mentioned those in trying to improve the automatic feature.

PILOT RATING AND PRIMARY REASON

I'm going to have to say that it is not satisfactory without improvement and I think basically the improvement probably has to be in the system itself, that is, eliminate some of these things that Iv'e been talking about. So, I'm going to have to rate it down. Desired performance requires moderate pilot compensation? No, I think it takes considerable - if you want to land it, on the centerline, so that really [the deficiencies] are moderately objectionable maybe even very objectionable. So, I am debating between a 5 and a 6. I think if I had to land it with this situation, I'd probably have to say that adequate performance requires extensive pilot compensation at the touchdown, prior to that or even moderate compensation would answer that question. So, I think it's just at the flare and touchdown, where really everything pays off and it would have to be downgraded quite a bit, I'm going to call it a 5. I'll be a little kind to it because on that last one even though I was working hard because of the forces I thought that the touchdown would have been pretty successful.

TURBULENCE EFFECT RATING

The turbulence apparently does degrade it, more effort is required, I would say moderate. We will call that minor to moderate I suppose, so we will call it a C+ again.

CONFIGURATION 6 NO DSFC PILOT B PR 5 TR B EVAL. FLT. NO. 22

INITIAL IMPRESSION AND GENERAL COMMENTS

My initial impressions of the handling qualities of the aircraft are good. There were some minor discrepancies which I will note later on. I will expand on that as I go down the comment card.

ABILITY TO TRIM

Trim systems were all right. Longitudinally and directionally. However, the rate of the aileron trim system was slow and hard to adapt to, hard to get the feel for.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics of the overall control system were good and I didn't notice any lack of control force harmony until in the flare and I will discuss that later. Control sensitivities were good on all axes. Nothing significant there.

AIRPLANE RESPONSE TO PILOT INPUTS

It seemed fairly well damped and roll control was slightly slow, the rate was slightly slow and there was a little lag, a noticeable lag so that the final response for the roll input was not entirely predictable. I tended to overshoot just a little and there was some residual oscillation in roll. Turn coordination was good in this configuration. No complaints there. Pitch attitude and control was pretty standard. Good longitudinal control response. No significant lags. The rate of attitude change was good. Final response was entirely predictable with no significant overshoots.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final didn't cause any difficulties. Turbulence effect was very minor. It was felt a little more noticeably along the longitudinal axis. Airspeed control was difficult to attain with any precision, within 2 knots of desired airspeed. At times during my final approach airspeed was 5 knots off and I had to really pay attention to airspeed control. I don't think it was lack of attention to power or attitude longitudinally, I think it was effects of gust and I had to stay on top of it to maintain a precise airspeed.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The method I used in establishing my approach attitude was to set up a crab into the wind and maintain it throughout my rate of descent until about 200 ft. above the runway surface at which time I kicked out the crab to a wing low attitude. I found that the directional force gradient was fairly steep and it required an excessive amount of directional control, displacement, as well as, an excessive amount of lateral control, to align my self with the runway. Runway alignment was difficult and I felt that the two combined served to increase pilot workload significantly.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I didn't see any noticeable coupling between the lateral-directional and longitudinal axes.

EFFECT OF RUNWAY CLOSURE RATE

Runway closure rate didn't affect the task accomplishment at all. I could compensate for that in my own mind.

GOOD FEATURES

I felt the aircraft handled well, up and away. I felt entirely comfortable and easily adapted to controlling the aircraft. It was easy to perform tracking maneuvers, not precisely, however because I did have some minor oscillations, primarily in roll. These were somewhat excited by yaw rates, I believe it was yaw rates.

OBJECTIONABLE FEATURES

The only objectionable features were the excessive aileron displacements, large directional control displacements and heavy forces felt in the directional axis during the flare and in establishing the runway alignment.

PILOT RATING AND PRIMARY REASON

I rate the overall system 5, because of the lack of ability to really establish good landing attitude and azimuth control in runway alignment.

TURBULENCE EFFECT RATING

I didn't notice anything significant as far as the turbulence effects other than the airspeed control. I didn't feel anything in the lateral-directional axis. I felt any gust disturbances were fairly well damped out. I will rate that a Bravo.

CONFIGURATION 6 MAN DSFC   PILOT B   PR 3.5   TR C   EVAL. FLT. NO. 22

INITIAL IMPRESSION AND GENERAL COMMENTS

My initial impressions of the handling qualities of the aircraft were good.

ABILITY TO TRIM

Trim rates seemed all right except for the aileron trim which was somewhat slow.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics along all axes were all right until I noticed high direction force gradients especially in the flare. Seems to be a nonlinearity in the directional control force gradient. Displacements were slightly excessive in the lateral system and not as much in the directional system but noticeable, a little bit more than I would like. Control sensitivities felt okay, no problem there.

AIRPLANE RESPONSE TO PILOT INPUTS

I did note some oscillations in the roll axis due to the gust disturbances. If anything, it affected roll axis more than the others. Not really a whallowing, just kind of oscillation on the roll with no directional heading changes. Turn coordination is okay. Directional control felt all right until the flare where I did use it a little bit more. On this last approach I was using more rudder and aileron because I was trying to use both of the side force switches. Therefore, I was using rudders a little more. Nothing significant in the longitudinal axis. Pitch attitude control was adequate. Entirely predictable. Maybe because I was working a little harder in the lateral-directional axis during the flare I had a tendency towards PIOing in the longitudinal axis.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final was no problem. Turbulence effects again were seen in an erratic airspeed control and primarily in the roll axis where I had some oscillations about center. They were damped and didn't seem to be excessive, however, they were obviously there.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

My method for establishing a landing approach was to set up the crab and work it out with the side force controller and then to go on and make the landing. Runway alignment was no problem.

CONTROL TECHNIQUE

I tried to use both side force controllers and tried to get a little more feel on the one on the control wheel column but I feel that I'm more comfortable using the one on the throttle. I am adapting more to how much side force surface deflection is required, but I think it would take some time to adapt to just exactly how much is required although the rate of deflection is good to get the proper cues in the seat of the pants to feel the side force. But for precise type corrections it leaves just a little bit to be desired.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

It didn't appear to interfere at all with lateral-directional control although on this last approach, as I said, I was using both controllers, trying to work them both in. Trying to fly the aircraft as I have been with one hand, and one hand on the throttle so it does feel more comfortable to rest that right hand on the throttle as I work the side force control wheel on throttle rather than the one on the control column.

CONTROL OF GLIDE SLOPE

Control of the glide path was no problem. I thought at one time I did note some coupling with thrust but I looked at it in more detail and I didn't notice anything significant.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

No coupling was noticed between the lateral-directional and longitudinal axis.

EFFECT OF RUNWAY CLOSURE RATE

Runway closure rate does not affect task accomplishment, although it is still in the back of my mind that it's a steeper glide path and the closure rate is still high for simulating a STOL aircraft but it doesn't deteriorate the evaluation of the task.

GOOD FEATURES

Good features were the initial feel for the aircraft, handling qualities were good and I didn't really notice any big objections until I realized the directional force control gradient.

OBJECTIONABLE FEATURES

An objectionable feature was the slight roll oscillations which were obviously produced by gust disturbances. They were well damped. There were some slight oscillations a couple degrees either side.

SPECIAL PILOTING TECHNIQUES

No special piloting technique used.

PILOT RATING AND PRIMARY REASON

A pilot rating of 3.5 primarily because of the roll oscillations that were so apparent and increased the workload. They were apparently excited by gusts. Runway alignment, there was no problem with the side force controllers so it eliminated the need for the relatively large directional control input and same for lateral control input. So I rated it a 3.5.

TURBULENCE EFFECT RATING

Turbulence effects were minor and were felt as I said on the lateral axis and somewhat deteriorated the airspeed controllability. So I will call it Charlie.

CONFIGURATION 6 AUTO DSFC	PILOT B	PR 3	TR C	EVAL. FLT. NO. 22

INITIAL IMPRESSION AND GENERAL COMMENTS

General handling qualities here felt good.

ABILITY TO TRIM

The only objection was to the slow aileron trim rate.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics were adequate and all over control force harmony was good. I was required to use what I felt was excessive lateral displacements. The force gradient on the directional control system was slightly high. Sensitivities were good on all axes, although lateral control sensitivity was a little low. In the directional control system, I felt the force gradient was slightly high, when I did need a large input. However, right around center it wasn't bad at all.

AIRPLANE RESPONSE TO PILOT INPUTS

Response to roll inputs was a slight delay, but the predictability of the final response was not affected significantly. I tended to overshoot a couple of degrees and I noted that anytime I put in the yaw or roll input I did get some residual oscillation about the steady state bank angle turn. It coordinated well. I was able to keep the ball in the center during the turns using both the aileron and rudder coordination. However there was that oscillation about center and some slop in the lateral control system and the rocking back and forth of the control wheel. It contributed slightly to a PIO tendency. Since this was with the automatic side force controller I did tend to by emphasizing longitudinal control overwork myself. But there was a tendency to PIO and I probably would have been better off just making the gross corrections and let the minor vernier corrections take care of themselves. I probably induced as much attitude change deviations as I did corrections.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final, had no effect, I had no difficulties at all. Turbulence effects were felt mostly on the roll axis and slightly in airspeed control, although I was able to keep within a knot or so of my desired airspeed

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

With the automatic system I established the crab and brought the aircraft over an alignment with the runway heading and on localizer and engaged the automatic system and there is this slight side force felt when the system was initiated, it is slightly uncomfortable, but it is a cue and that's felt all the way down final with a slight oscillation in the localizer signal. And there was a resultant oscillation in side forces.

CONTROL TECHNIQUE

My control technique was to use some aileron and rudder to make very small changes along azimuth and in azimuth control. I just used longitudinal control primarily for the glide path control.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

I didn't note any interference with the system with the lateral-directional control. It held localizer azimuth control all the way down final. So I did not notice any interference of the automatic system with any other aspects of control. There is no doubt that the task is easier with side force control, automatic or manual, than without it. Although this is my first series of automatic approaches that I have evaluated I am perfectly well satisfied with the system. To be able to make small corrections with your aileron and rudder and side force control in the automatic system maintains your aircraft right on the localizer. Each time we came down we were slightly to the left but over concrete.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

No coupling noticed in the longitudinal axis with lateral-directional inputs and none vice versa.

EFFECT OF RUNWAY CLOSURE RATE

Closure rate did not affect task accomplishment.

GOOD FEATURES

Good features were the good performance of the automatic side force control system and primarily the basic good handling qualities of the aircraft.

OBJECTIONABLE FEATURES

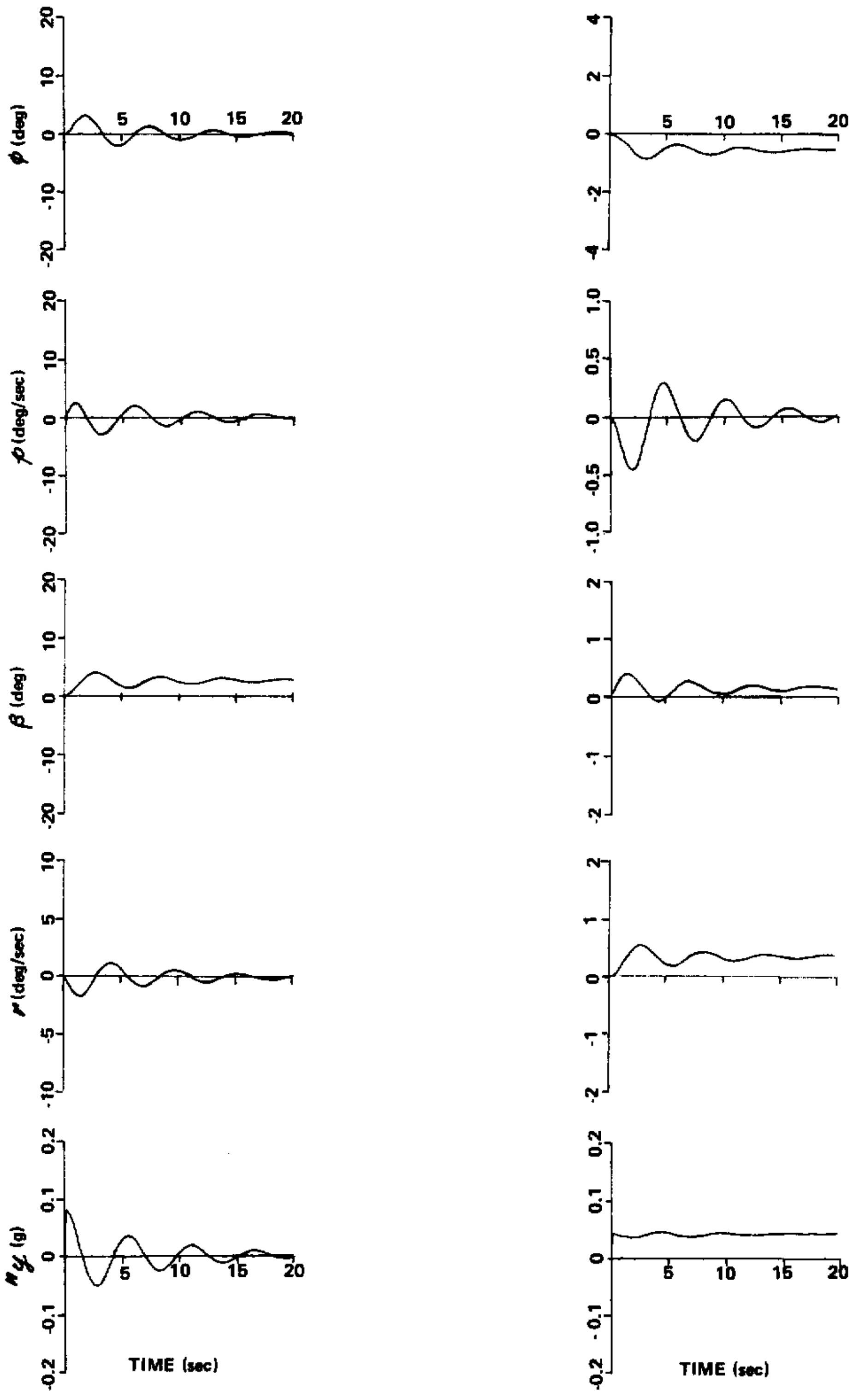
Objectionable features being the high, relatively high directional force gradient and the slop in the aileron system just about center and the easily induced roll oscillations.

PILOT RATING AND PRIMARY REASON

A pilot rating of 3 for those latter two comments.

TURBULENCE EFFECT RATING

Turbulence did upset the aircraft in roll axis enough to cause a slight increase of workload, so I will give it a C Charlie.



(a) δ_y = 10.0 deg, δ_a = -5.37 deg, δ_r = 6.45 deg (b) δ_y = 10.0, δ_a = 0.0 deg, δ_r = 0.0 deg

MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO AILERON AND RUDDER (CONFIGURATION 10)

CONFIGURATION 10 FLIGHT TEST DATA TABULATION
(EVALUATION FLIGHT NO. 5 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	-3.22	0.94	-2.30	1.21	-6.87	5.33	29.8	10.76	0	5	–
MANUAL	1.00	1.30	-8.0	0.21	-2.50	2.60	8.00	6.7	-31	3	C
AUTOMATIC	0.05	0.45	-3.29	0.39	0.39	1.72	10.5	2.03	-14	3	C

CONFIGURATION 10 WIND AND GUST DATA

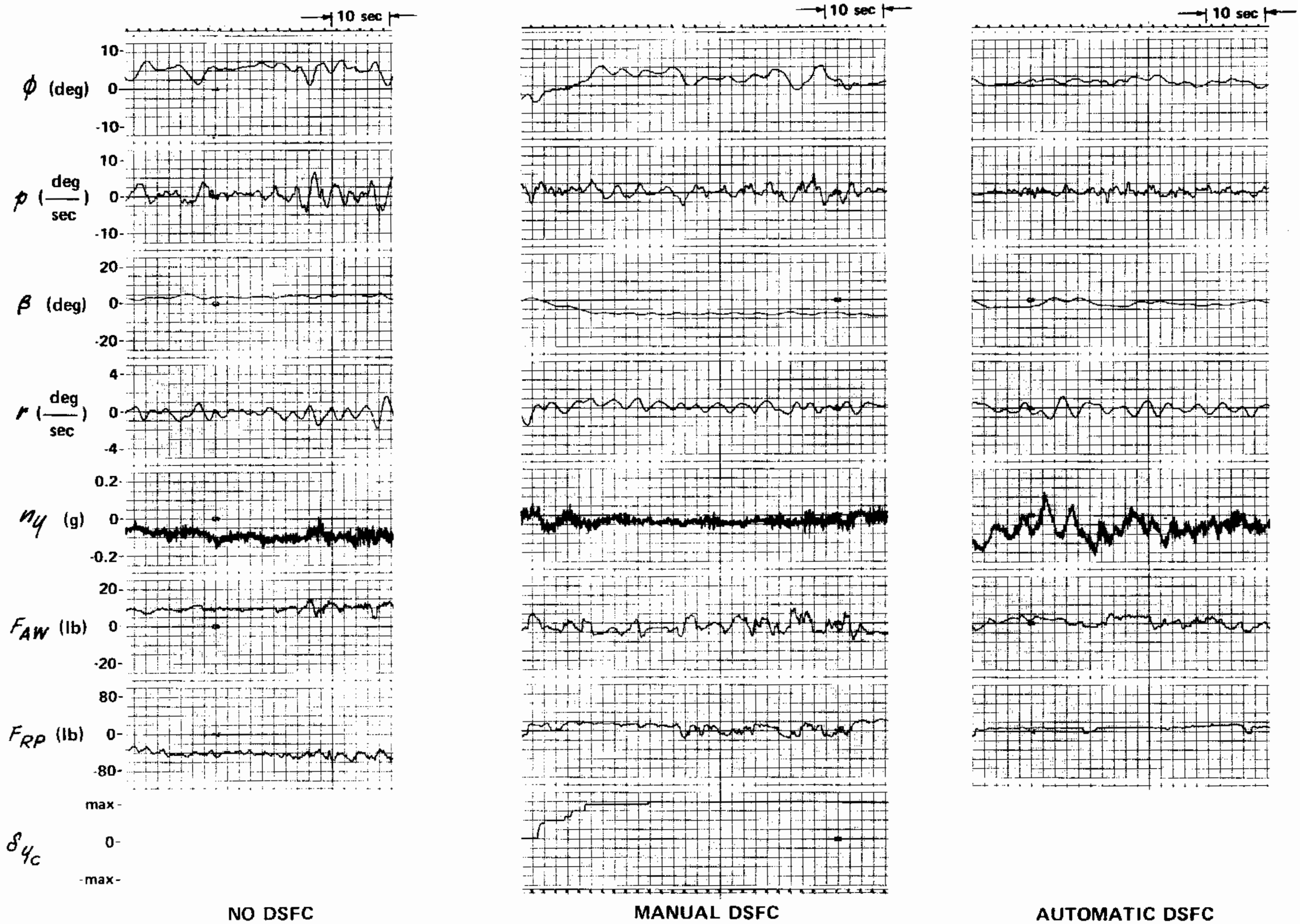
	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	230	08	2.22	1.01	2.15	280
MANUAL	240	05	1.11	0.83	1.69	280
AUTOMATIC	180	10	0.73	1.62	2.55	280

CONFIGURATION 10 FLIGHT TEST DATA TABULATION
(EVALUATION FLIGHT NO. 17 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	5.31	1.74	4.18	0.56	10.1	1.90	-44.8	6.33	0	4.5	C

CONFIGURATION 10 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	340	12	1.22	1.80	2.31	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN
CONFIGURATION 10

CONFIGURATION 10 NO DSFC | PILOT A | PR 5 | TR - NOT GIVEN | EVAL. FLT. NO. 5

INITIAL IMPRESSION AND GENERAL COMMENTS

We made an approach on the configuration with no help from the side force surface and it went fairly well although I was having one hell of a time with one hand on the wheel and trying to establish the proper attitude to kill the drift and touch down so I had made up my mind that on the next time around I was going to, if necessary, use two hands to land the airplane. We made two more approaches after that. The next one was with the turbulence in and we dumped [VSS disengaged] reasonably far out. [The VSS was re-engaged and] we dumped again and so we had to make a go-round. We attempted another approach and it dumped again and so we continued with just the normal turbulence, that is, the natural turbulence but not fed into the model. Obviously, it's an easier airplane, I think, but anyway I don't know what it would be like with the turbulence in there so I made an approach and this time we stayed on the system. I did, in fact, use two hands on the wheel and I think I had the drift fairly well killed and I was pretty much down the centerline so I guess you can do it but I don't think you could do it with one hand on the ailerons. That's the biggest problem.

ABILITY TO TRIM

Ability to trim was okay.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Lateral and longitudinal feel characteristics, the displacements and control harmony is good in up and away flight. The ailerons get exceptionally heavy, what I mean is very heavy close to the ground when you're trying to set up a sideslip. The rudder is not the problem. It's the aileron. Okay, so I didn't do anything about changing the gearings or the sensitivities. When we get the time, if we have the time on one of these where I start complaining about these aileron forces, it might be worth while to cut down the forces maybe by a factor of 2 or something and see how that feels in up and away flight and then , make an approach with it that way assuming it feels okay in up and away flight. Maybe that's what you'd have to compromise on to be able to land with one hand in the crosswind.

AIRPLANE RESPONSE TO PILOT INPUTS

The roll control initial response seems reasonable. I don't see any difficulty there. The damping of the Dutch roll seems to be pretty fair. I think it's pretty good as most airplanes go. Could be better but it's all right. The directional control doesn't seem to be any problem. The coordination is not any problem. I think we have a slight amount of proverse yaw due to aileron, it's either zero or slightly proverse. Pitch attitude control, initial response is sluggish---it's a somewhat sluggish airplane, I think in pitch. Now one thing I did notice is that in putting in the rudder, there's a pretty fair delay before you actually get a roll rate so I suspect that the phi per beta on this thing is a little bit on the low side. Nothing that bothers me but I would say it's on the low side.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind turning final no problem.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

In the approach I used the crab technique. It was a pretty fair amount of crab angle but I wouldn't say that it's as much as I've seen in a lot of airplanes. In other words, it's certainly the kind of a crab angle that you can expect to get many times, a large percentage of the time in a crosswind. Okay, the sideslip combination didn't appeal to me too much mainly because it takes quite a bit of aileron to maintain the sideslip. So the runway alignment wasn't too much of a problem until you got close where you have to start cross controlling aileron and rudder and at that time it gets to be quite a handful if you try to do this flying, the elevator and ailerons with the left hand, right hand on the throttles.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I don't think that the longitudinal is affected by the lateral-directional very much except that I guess if you wanted a very precise attitude change in turbulence you might get some cross coupling in there, mainly because you're holding such high forces on the aileron. In other words, it would be difficult to sense small inputs longitudinally when you're holding such heavy forces on the aileron.

EFFECT OF RUNWAY CLOSURE RATE

The closure rate, a couple of those approaches were fairly steep, was somewhat noticeable but not a big factor. You do have to round out soon enough here so that you're not too concerned or aware of the rate of sink which really, is a way is saying if you had a very steep approach, this could certainly be a factor. I think if you keep the rate of descent down around 1000 ft. or 1200 ft. a minute and you start your flare soon enough, it's probably okay without making that a major item in your evaluation.

GOOD FEATURES

The good features are that this is apparently a well behaved airplane, well damped, all the way around I can't see anything particularly bad about it.

OBJECTIONABLE FEATURES

The objectionable feature is the fact that it takes so much aileron force to maintain a bank angle when you use rudder to maintain the heading and so maybe this is the Y_β effect that's causing the problem.

SPECIAL PILOTING TECHNIQUES

So the special piloting technique, the only one I can say is special is the fact that I had let go of the throttles, used both hands just before touchdown, then I was able to successfully land the airplane.

PILOT RATING AND PRIMARY REASON

So all in all, it was not a specially easy airplane to fly right close to touchdown because of the aileron forces but everything else as far as I could see was pretty acceptable on the airplane so it's going to fall into the deficiencies warrant improvement category I think and in the last few seconds of the touchdown. You do have to make quite a bit of compensation because of the need for using two hands and so that is the key point here in the rating. Otherwise, except for that fact, I would think that this would be a pretty good. You might say, I don't like it and it would be better if I could land it with less effort but it would still be acceptable. It would probably be a 4. With this much force required though I think I would have to rate it down around a 5 or 6. I'm sort of hedging because I would like to see -- maybe see the same configuration with lighter aileron forces and see if then I would remove the objection. I'm going to rate it a 5.

TURBULENCE EFFECT RATING

And as far as the turbulence, I can't comment on the turbulence. I suspect that it would be downgraded down to a 6 if we added turbulence, so you might consider that as being the rating. I can't say anything at all about the turbulence so we'll let it go at that.

CONFIGURATION 10 NO DSFC	PILOT A	PR 4.5	TR C+	EVAL. FLT. NO. 17

INITIAL IMPRESSION AND GENERAL COMMENTS

General feeling about the airplane is that its a reasonable amount of work to try to kill a 15 knot crosswind with this airplane. I think the aileron forces get reasonably high. The airplane is reasonably stiff directionally. Dutch roll damping is not too bad. You don't have very strong oscillatory tendencies. It seemed to me to have some tendency to couple with the longitudinal mode in establishing the proper bank angle and heading.

ABILITY TO TRIM

There was no real problem in trimming the airplane.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Forces in up and away flight were pretty good. As I said, the force required in aileron is somewhat on the high side. Control sensitivities are not bad in up and away flight. There is certainly enough control available to fly the airplane to a touchdown. However, I just felt that the precision with which I could actually line the airplane up and also kill the drift was not as good as I would like.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll control, initial response and predictability are pretty good. You could fly the airplane pretty much with ailerons alone. I don't think you need very much in the way of rudder. However, in a steady state turn you do need some bottom rudder. I don't think the airplane was too loose directionally. I thought it was pretty good as a matter of fact. Turn coordination requirements are sort of minor. Pitch attitude control, again, I think it is a big sluggish airplane, not unusual. Somewhat sluggish but for this class airplane not bad.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind turning final was no problem.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

I used crab primarily and I think on the second approach I used a little bit of sideslip but mainly crab and then tried to decrab the airplane from about roughly 2 to 300 ft. before touchdown. It probably would have been wise to make an approach with a little combination of the two, a little more sideslip rather than just all crab, because maybe from 2 to 300 ft. there may not be enough time really to establish a good attitude. Might be a little better to try to establish the landing attitude as far as bank angle and rudder a little earlier. The alignment, as I said, I used crab. My performance, I didn't think was good. I think it was passable. The second approach and the second landing I actually drifted off to the left of the centerline, 35 ft. or something like that. That is a little bit too much probably.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

The lateral directional control inputs I thought did affect my longitudinal a little bit and there is some cross coupling primarily because the aileron forces are somewhat high in holding the bank angle when you put the rudder in there. It takes a reasonable amount of concentration really to set up properly for a good touchdown. So, if you don't pay close enough attention to pitch attitude you can couple. I suspect that there is a little bit the other way too here. If you catch yourself behind the airplane as far as the pitch attitude is concerned and you try to correct that you don't pay as much attention to the lateral. Unless you are pretty well stabilized, you may very well deteriorate your lateral directional control. The overall pilot effort requirements here are substantial so that you have to work fairly hard to get all the axes under complete control.

GOOD FEATURES

Good features are I think the fact that the airplane is reasonably well damped. It isn't so loose directionally that you are sloshing around in yaw.

OBJECTIONABLE FEATURES

Probably the biggest problem is the fact that the aileron forces get up fairly high, that there is coupling, and the fact that I had to work fairly hard with the turbulence in, to establish a good touchdown. I wasn't too happy with the performance on this. I might learn to fly this.

SPECIAL PILOTING TECHNIQUES

No real special piloting techniques.

PILOT RATING AND PRIMARY REASON

I would say that desired performance requires at least moderate pilot compensation or considerable. And moderately objectionable deficiencies when I consider the forces. I suspect with this particular configuration if you modified the gearing a little bit so that the aileron forces don't get quite that high, again the criteria being a one-hand on the wheel here, it probably would improve it some. In one way I didn't see anything especially bad about it except for the fact that it seemed that I had to work so hard to set up the attitude. Possibly, I suspect that if I change my technique and combine a little crab with sideslipping approach, it might be a little better. Okay, I will settle on 4.5.

TURBULENCE EFFECT RATING

There did seem to be more effort required. The performance was somewhat deteriorated but there wasn't a very large difference between no turbulence and turbulence. There is more effort required I think, there is no question about that. But is it minor or moderate. I'm going to call it a C+ on that because I think I had about almost the same kind of troubles without the turbulence.

CONFIGURATION 10 MAN DSFC PILOT A PR 3 TR C EVAL. FLT. NO. 5

INITIAL IMPRESSION AND GENERAL COMMENTS

This is the approaches with manual side force control available and we did this one with and without turbulence inputs. They cut down, I'm sure, the beta gusts on the turbulence so we were able to stay on the system. It sure is much better to make the approach . You don't have to worry about aileron forces at all obviously and I thought that two of the approaches were pretty good, the middle one I ballooned a little bit. As far as the crosswind, I don't really think it was any problem at all.

ABILITY TO TRIM

Ability to trim is no particular problem.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics I guess were adequate and the harmony, I liked the harmony. With the aid of the crosswind controller, there was no problem with the ailerons at all.

AIRPLANE RESPONSE TO PILOT INPUTS

Response to inputs, roll control, I think I've already commented on that. When I had the side force surface in there, I didn't notice any particular difference compared to when I didn't have it in there so everything is about the same. It's a little bit noticeable that in the turn, for coordination, you do have to hold I think a little bit of bottom rudder and maybe -- or some aileron occasionally, but nothing, you know, that is excessive in any way. It's noticeable once in a while. Maybe I'm just out of trim. I don't know.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final is no problem.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

On the landing approach I did have some difficulty really in finding where I should put the crosswind controller. Maybe I was getting confused or there's a wind shear out there because farther out, I thought I had the thing pretty well going down the centerline. As I got down lower I seemed to start drifting to the right a couple of times and as I recall, I looked at the position of the controller after the end of the second approach and I really didn't have very much control in, maybe half. This last approach, however, I think I ended up with full side-force control in there. I was pretty well lined up. I was pretty happy with the last approach and touchdown. So, the problem I had here was in the alignment because of some drift and that was caused by the fact that I wasn't able to pinpoint exactly what my drift was and maybe it was variable in the final. That wouldn't surprise me.

CONTROL TECHNIQUE

So the control technique of course is just normal. There is no particular problem.

CONTROL OF SIDESLIP WITH DSFC

It seemed that I had an adequate amount of side force available.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

The side force control didn't affect my directional or lateral control that I could tell.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I don't really think that there was any particular particular problem by cross coupling. Although, I do have a tendency still to PIO a little bit in pitch when I get close to the ground, but I don't know that I'd really want to make the elevator stick forces any heavier than that. I think they're pretty good the way they are, for this kind of a longitudinal response. I think I have pretty good harmony with the ailerons so I wouldn't want to change it but, I suppose if you want to optimize these forces and gearings, you'd have to spend quite a bit more time looking at them and the only way you can optimize them is to do that in the final 200 ft. or so of the approach and the actual touchdown. You just aren't going to be able to tell the difference in up and away flight. You can accept a pretty wide variation in forces and gearings. Down close where it all pays off; that is the criteria for choosing the stick forces and gearings you'd have to just make repeated approaches. That's the only way. Of course we don't have that kind of time so we'll just have to accept a course or rough approximation of what might be acceptable. That all had to do with the longitudinal motions but the overall impression was that there wasn't any significant cross coupling.

EFFECT OF RUNWAY CLOSURE RATE

The only closure rate that I'm concerned about is the vertical sink rate and it all ties in with when you start your flare and how steep your approach is. I've been checking the vertical rate here and as long as I stay down around 1100 ft. or 1200 ft. a minute, it doesn't seem to be too bad but on a number of occasions I've seen as much as 1600 ft. a minute or almost as much as 2000. That's farther away from the runway, of course. Then there is a tendency to slow down that rate of descent a little bit so that maybe you start your flare with about 1200 ft. a minute. If you start a little late then you do tend to hurry it. I think that is probably the biggest factor in generating a ballooning or the PIO in trying to find where the runway is.

GOOD FEATURES

I think it's a well behaved airplane.

OBJECTIONABLE FEATURES

No really very strong objectionable features at all, on this airplane with the side force controller using the side force available.

PILOT RATING AND PRIMARY REASON

I think this would be a certainly acceptable airplane, it's in the 1, 2, 3 category, minimum pilot compensation. I would say that when you start rating it a 2, that to me is almost like perfect. I hardly ever even consider rating anything a 1 anyhow, cause that's supposedly perfect. There's nothing that's any better. There is some pilot compensation in the performance, even with the side controller that you do maybe have to do a little bit of hunting, especially if you have wind shear problems. So that there is a certain amount of effort. I suppose we're going to have to rate this acceptable minimal pilot compensation required for the desired performance. Sounds pretty accurate to me so we'll call it a 3. In the turbulence, maybe you do work a little harder. I didn't think I had a lot of difference between no turbulence and turbulence that time. So I'm goint to rate it a "C" for turbulence.

CONFIGURATION 10 AUTO DSFC PILOT A PR 3 TR C EVAL. FLT. NO. 5

INITIAL IMPRESSION AND GENERAL COMMENTS

The first one, was I thought a pretty darn good landing and it was right down the centerline. We still have a certain amount of this hunting, you might call it, of the aircraft around the centerline of the runway. The second one, the only reason the landing was not too good is I had ballooned a little bit. I had leveled off, I guess, and overcontrolled in pitch a little high and that one it did tend to bring me down left of centerline but still on the runway so it wasn't too bad. I would rate the touchdown and the final portions of the approach pretty darn good on the first one. The second one I thought it was a little poor because of the centerline problem but as far as the pilot effort was concerned on the second approach, I think I had a much better glide path. It was steadier, more steady state, had control of airspeed better than the first one as a matter of fact. The thing that I didn't like on the automatic control was that at one time, the side force was very high. The ball was sitting up against the pocket on the right side and this looked like a combination, probably of a gust and a bend in the localizer beam and that was pretty uncomfortable. From the standpoint of riding quality, this kind of side force control at least might create some undesirable motions and forces on the passengers, if this were a passenger aircraft. We ought to do something a little better than that. You might have alarmed people that aren't used to flying by these fairly large side force inputs. So that would be something that you probably would want to consider.

ABILITY TO TRIM

Trimmability was okay.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel force characteristics are all okay as far as I can see. I wouldn't change the sensitivities of the controls.

AIRPLANE RESPONSE TO PILOT INPUTS

The responses to inputs; lateral of course you are fighting the auto pilot attitude hold practially speaking. That of course creates problems as far as forces are concerned. It's very difficult to displace the airplane consciously. These are the same kind of comments I think you're going to get everytime when you get on the automatic control. Turn coordination was pretty good.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

I noticed again that a little bit of bottom rudder is required during the turn but I could make turns pretty well without trouble.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The technique essentially was just to allow the automatic feature to bring me down the centerline and all I did was control the glide path although again I had a tendency to try to help the thing a little bit by putting aileron and a little rudder in it and I think this is just something that the pilot is going to do naturally anyway.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

The interference with other control aspects because of the automatic direct side force I think I've already mentioned. You do have obviously some interference there. Just the heavy forces. You're trying to overpower the control of the autopilot.

CONTROL OF GLIDE SLOPE

As far as the throttle and elevator control though, I don't think that that is a problem.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Cross coupling between the longitudinal and the lateral-directional controls; there may be a slight amount of that especially if the thing doesn't take you right down the centerline, you will try to help it. When you do that, maybe you do get a tendency to cross couple with the longitudinal which is I think what happened that last time. I was on the left side of centerline and therefore I was trying to help it and when I did that I think I didn't pay enough attention to my pitch attitude, and therefore ballooned the airplane.

EFFECT OF RUNWAY CLOSURE RATE

The closure rates again I think it's the old business of get the rate of sink under control and start your flare soon enough so that you don't have to have that last minute large attitude change with a high rate of sink, which is very uncomfortable. And again, of course, our closure rates are associated with vertical closure rates.

GOOD FEATURES

The pilot effort to maintain runway heading and alignment was no problem and so that's a good feature.

OBJECTIONABLE FEATURES

The objectionable features are basically that the side forces that are generated sometimes are pretty large which could be caused by bends in the localizer circuits.

SPECIAL PILOTING TECHNIQUES

None really except the somewhat unnatural requirements of heavy aileron rudder forces to try to displace the airplane when you're trying to overpower the automatic feature.

PILOT RATING AND PRIMARY REASON

I was very happy with the first landing. I was not especially happy with the second one but I think that was explainable by the fact that we weren't down the centerline. However, for an automatic system following the localizer, you do have to consider that as being a reasonable expected kind of a difficulty. So there is certainly some compensation required by the pilot. I still think that overall the manual system was more desirable because it has less of these extraneous objectionable features like this large side force application to try to hold the localizer which is what you get with the automatic side force control. So I don't think I will rate this any worse than the manual. I think I'll still call it acceptable without improvements. Some minimal pilot compensation for desired performance so we'll call it a 3.

TURBULENCE EFFECT RATING

Maybe turbulence is part of the problem on the misalignment. I would say that it's minor compensation though. I didn't really think that I was working that much harder. So we'll call that a "C" for the turbulence.

Appendix III.3

CONFIGURATIONS WITH N_β = 0.42 AND L_β = -1.57

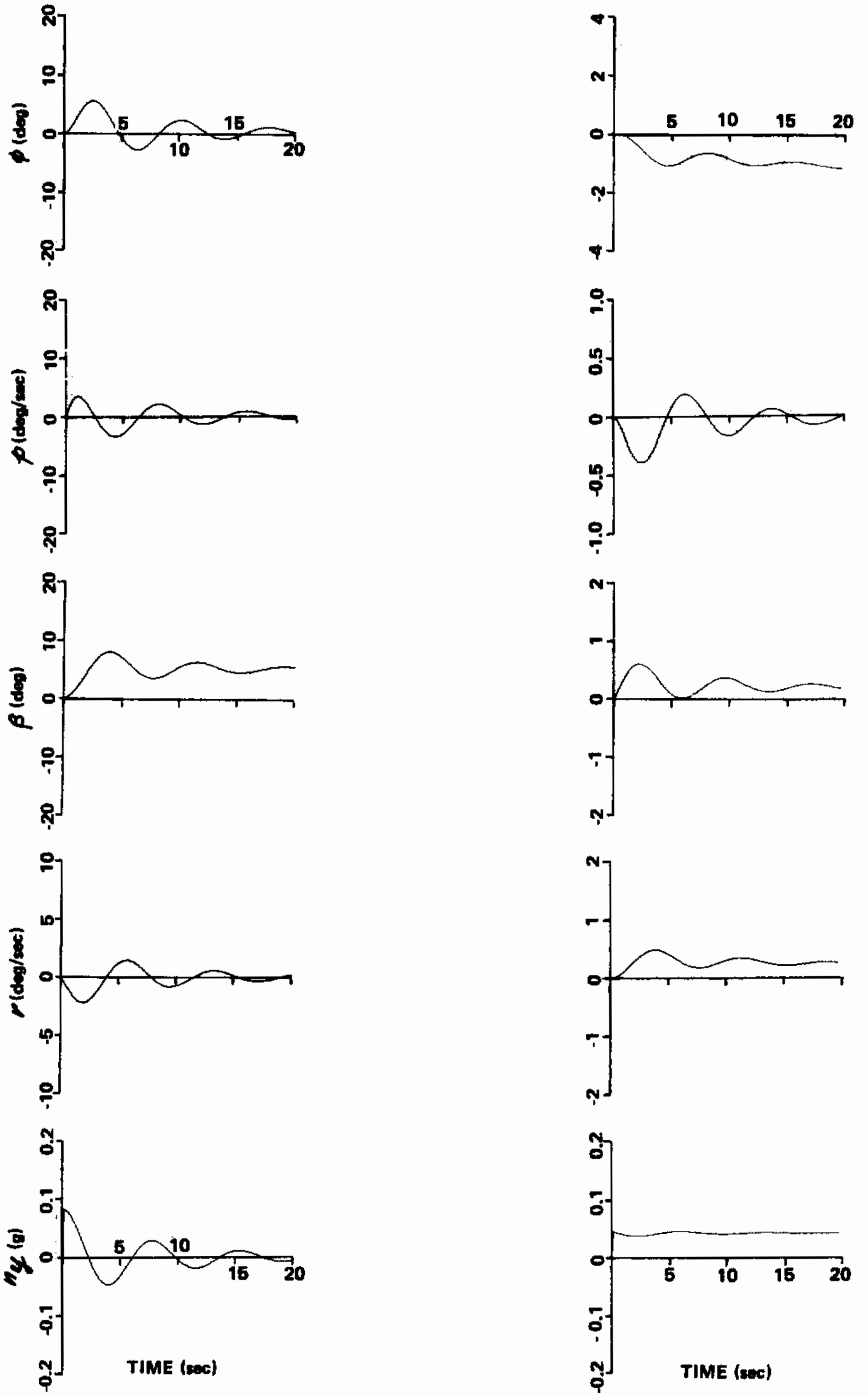
(CONFIGURATIONS 3, 7 and 11)

DIGITAL RESPONSES WITH AND WITHOUT INTERCONNECTS

FLIGHT DATA TABULATION

IN-FLIGHT RESPONSES DURING LANDING

PILOT COMMENTS



(a) δ_y = 10.0 deg, δ_a = -5.99 deg, δ_r = 5.96 deg (b) δ_y = 10.0 deg, δ_a = 0.0 deg, δ_r = 0.0 deg

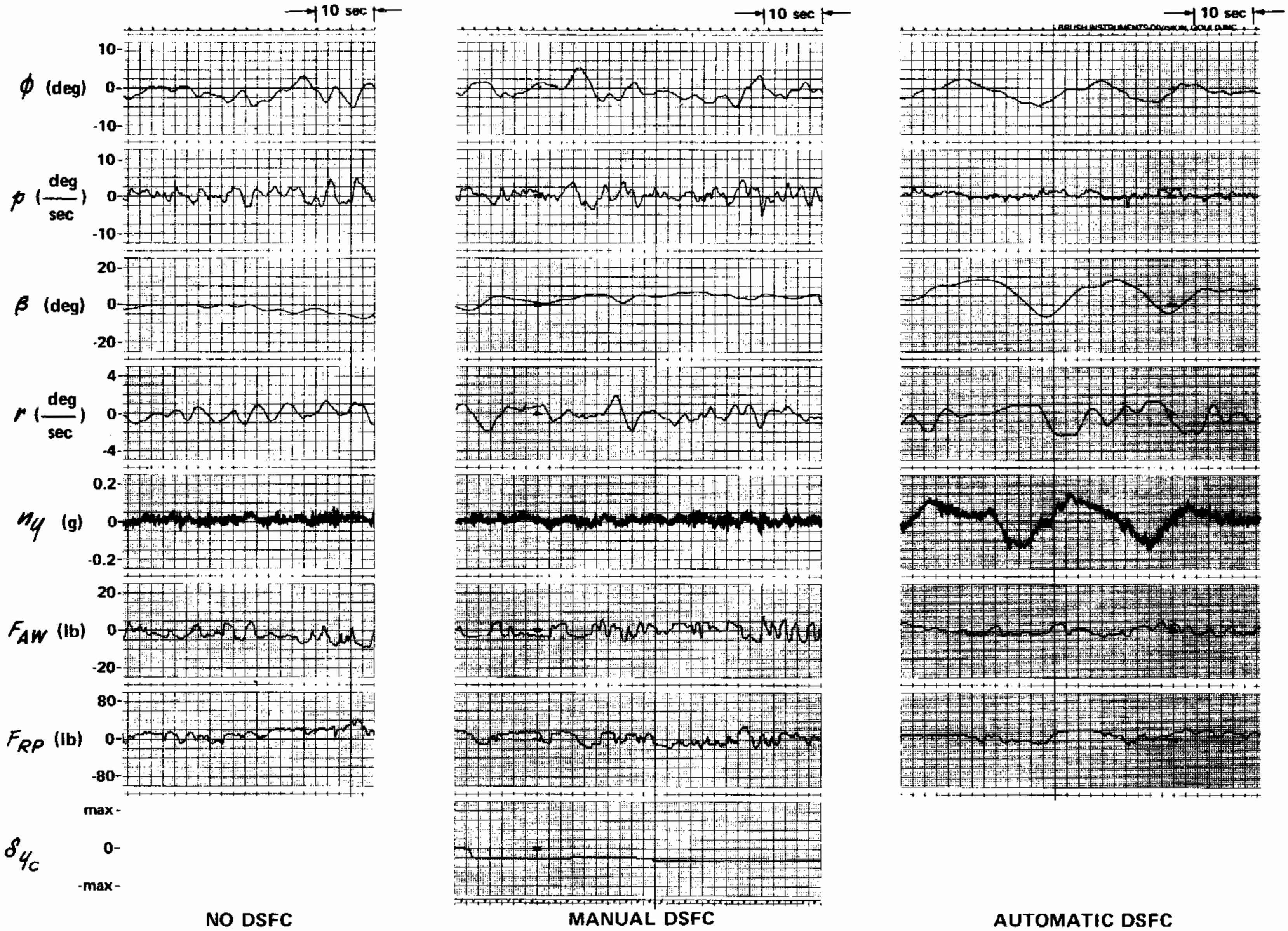
MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO THE AILERON AND RUDDER (CONFIGURATION 3)

CONFIGURATION 3 FLIGHT TEST DATA TABULATION
(EVALUATION FLIGHT NO. 11 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	-2.32	1.62	-4.51	1.07	-4.51	2.81	24.3	7.59	0	5	D
MANUAL	-0.42	1.95	4.30	0.88	-0.53	3.69	5.12	11.5	8	4	D
AUTOMATIC	-0.36	0.90	7.48	1.11	-0.79	1.55	15.8	4.30	14	4	

CONFIGURATION 3 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	320	02	1.96	1.36	2.05	280
MANUAL	360	05	1.92	1.75	2.68	280
AUTOMATIC	310	06	1.67	1.32	1.96	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN
CONFIGURATION 3

CONFIGURATION 3 NO DSFC PILOT A PR 5 TR D+ EVAL. FLT. NO. 11

INITIAL IMPRESSION AND GENERAL COMMENTS

The first approach in smooth air was with the wind from the right. I made the comment at that time that it's not a very difficult one, but it's not an easy one either, and it does make a difference, to me at least, whether I have a crosswind from the left or from the right. It's easier, for me to hold aileron, to the left and right rudders than it is the other way around, with my hands on the throttle. And that's the way I'm making all my approaches. So I think there would be a tendency on the difficult ones, to downgrade them when the crosswind is from the right. This is just a conjecture, but it does seem to be verified some by that one approach.

ABILITY TO TRIM

I didn't have any particular problems with ability to trim.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The feel characteristics; I accepted whatever I've been flying with. Probably this is one of these approaches where I think the aileron forces are getting fairly heavy, although not extraordinary, but they're fairly heavy. There is some coupling between the rudder and the aileron, maybe some with the elevator, although the touchdown seemed to be reasonable on all of those approaches.

AIRPLANE RESPONSE TO PILOT INPUTS

So, the roll control, it seems to be adequate. The directional control, I don't have any particular complaints. This does appear to be a high roll to sideslip ratio configuration. Y_β is maybe moderate, I suppose. We were doing a sampling of the aircraft above a cloud deck and I had some disorientation, in trying to establish a heading since you don't have the real world to look at. The impression was that this is probably not an exceptionally high Y_β case, although maybe the problem that I had was all associated with the roll to sideslip ratio rather than the forces. The turn coordination requirements, there aren't any specific one. Pitch attitude is the usual thing, it's sort of a slow airplane.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind turning final, I don't know what I had. Everyone of my final approach turns was done on instruments. We've been extending each one of these approaches because of some traffic and so I've been essentially capturing the localizer at just about the outer marker. So we're making these approaches fairly long and I stay on instruments till I get to be until about 3 or 4 miles TACAN distance and then I go visual.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The landing approach method was a crab. It's a fairly substantial wind, it seems to me. It seems easier to do it that way than to combine it with sideslip. Runway alignment, well, I'd say it was fair. In each case I think I was angling in from the right to the left, the wind was from the left, and then going ahead on the flare and starting to decrab the aircraft. However, in each case I think I decrabbed more than I should have, or I didn't have enough aileron in and I ended up drifting off to the right a little bit. So each one of the touchdowns, I think, was right of centerline, except when the wind was from the right. That one, I think was fairly well on the centerline.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I think there's a small amount of cross-coupling there, but fairly small. I do have a little difficulty establishing a proper input and bank angle combination to align myself. I had a tendency, to overcontrol with the rudder which would indicate that my aileron forces are pretty high at the point just before touchdown.

EFFECT OF RUNWAY CLOSURE RATE

The closure rates were not too bad, except on one of those, I was a little bit late with the flare, and I think as a consequence the airspeed dropped off a little bit lower than I would have liked. But it wasn't that rushed a flare.

GOOD FEATURES

It was a fairly reasonable airplane, as far as damping goes I think the Dutch roll damping is not very high, but it's probably somewhere around a tenth I would imagine.

OBJECTIONABLE FEATURES

The roll-to-sideslip ratio, the rolly character of the configuration is probably the most bothersome feature of the configuration. The response of this aircraft to turbulence is substantial, it certainly does disturb the airplane. It's not high frequency stuff, this is fairly low frequency stuff that we're getting, with the turbulence and sometimes I do have to work fairly hard to overcome just the disturbance from the turbulence. So that is sort of an objectionable feature with this airplane, the highly responsive nature of the configuration to turbulence inputs.

SPECIAL PILOTING TECHNIQUES

There's no particularly special piloting techniques.

PILOT RATING AND PRIMARY REASON

I certainly would say that we're getting to the point where the aileron forces and rudder coordination for alignment for touchdown is getting to be somewhat on the high side and the turbulence does certainly downgrade the configuration. I have to work quite a bit more when we have turbulence, so we're really debating here between a 4 and a 5. Is it moderate pilot compensation or considerable? I would say one thing, that the touchdowns were reasonable. I think that I didn't really have the feeling that I had a real precise control of the airplane. I was happy to establish a reasonable attitude and then not really fight it from there, hoping that I could touchdown with a good attitude. I suspect that there would be a dispersion in the ratings for the touchdown. If I were rating that, I'd say that maybe it does require considerable pilot compensation to be able to be consistent and have good touchdowns. I think I'll rate it a 5 and I think basically the 5 is more a function of turbulence than anything else. If it hadn't been for turbulence, I think the no-turbulence approaches, I made one practice and another one, were fairly reasonable. Although I didn't particularly like the crosswinds to the right.

TURBULENCE EFFECT RATING

I certainly think that there's more effort required, moderate at least in the turbulence. I'm not sure that we're talking about best efforts required. So, I'm debating between a Delta and an E, so why don't we just rate it on the line and call it a D+.

CONFIGURATIONS 3 MAN DSFC   PILOT A   PR 4   TR D+   EVAL. FLT. NO. 11

INITIAL IMPRESSION AND GENERAL COMMENTS

There is a tendency, I think to hunt for the proper setting on the side force control and in addition to that, the turbulence does disturb the airplane quite a bit. It's a lot of rolling and whatnot going on, and that has a tendency to degrade the ability of the pilot to establish an alignment. In turbulence I do have a problem in maintaining proper airspeed and rate of climb attitude. It just feels like the low frequency, wavy kind of turbulence that you might get. It's fairly realistic, I think. I'm drifting to the left a little bit. The most annoying part, is this tendency to have the Dutch roll disturbed just about the time you want to land the thing in the turbulence. I think generally, I liked it better than I did when trying to make the crosswind landing with no side force control. I had some difficulty in alignment, primarily due to the fact that we're flying IFR most of the time. As far as I'm concerned, I'm flying on the gauges. I think in the final portions of it, just before touchdown, there is certainly less effort involved by the pilot because the heading of the aircraft is well established, for a few seconds at least before touchdown.

ABILITY TO TRIM

There was no particular problem in trimming.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The feel characteristics are certainly adequate. No changes in sensitivities.

AIRPLANE RESPONSE TO PILOT INPUTS

The roll control is the same. Fairly good initial response, especially a fairly good rate of response if you use rudder. Apparently this is a fairly high roll to sideslip ratio, as far as the pilot is concerned, he feels he's got a very effective rudder. And the directional control, I don't really see any particular problem in the no-turbulence case. When we do have this turbulence in there, the airplane is disturbed quite a bit and it does feel a little bit squishy. I'm sort of hunting to try to damp it out. I'm sure that this rolling, or the lateral characteristics of the airplane are affecting my ability to damp the airplane. Turn coordination, didn't seem to be a problem, especially on the gauges. It looks fairly simple to do. Pitch control is a problem in the turbulence. I commented on the fact that the airspeed is changing quite a bit and the rate of climb is difficult to pin down, but I think that the responsiveness of the airplane to the turbulence is the big factor here.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

The crosswind, turning final, well I can't really say because I don't see it visually and I guess I undershot once when I had the wind from the right and I overshot once, so it's just strictly a matter of my own interpretation of the instruments and also the fact that we have had traffic on the final approach a number of times. So there is a little bit of a hesitancy to start turning in until you definitely know that the traffic is out of the way.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

Landing approach method was establishing the crab, and then trying to establish a zero heading error around the centerline with no drift. And as I said before, there was certainly a lot more difficulty in turbulence trying to establish what the side force position should be, but even without it, it was a little bit of a hassle because of the rather poor visibility in trying to establish what the alignment actually was. So, aside from the workload involved in establishing the proper approach, I also had some effort involved in trying to establish the proper rate of descent. I wasn't too repetitive on where I started the descent, or power settings because I was straining actually to see the runway and make the corrections, usually last minute corrections for alignment. Anyway, the final portion of it, at least I thought, was certainly better performance with a little more precision and I felt I had things under better control with the manual control.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

I don't think that it interfered, in any way that I could see, with the trimming of the airplane or in the bank angle or throttle control.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I didn't think that there was much in the way of cross-coupling and the touchdowns are okay. Although on one of those with the manual control, the Dutch roll does get into the act and there's a tendency to be a little bit wobbly which is not really good, so that there is a little bit of a problem laterally here.

EFFECT OF RUNWAY CLOSURE RATE

The closure rates are no particular difficulty. You notice it when you're in a little close and your rate of descent is around 2000 or 1800 feet/minute, so you're working fairly hard in establishing a reasonable rate of descent starting your flare fairly higher though. And then you you have to sort of find the proper power to maintain the airspeed.

GOOD FEATURES

The fact that you are relieved a lot by the alignment once you establish the side force surface position.

OBJECTIONABLE FEATURES

The most objectionable feature is the rolling characteristics of the airplane. So that there is always a certain amount of work.

PILOT RATING AND PRIMARY REASON

Because of the turbulence effect, I would certainly think that we should have some improvement of the lateral characteristics, maybe more damping or something like that might help. So there is a moderate pilot compensation because of the turbulence. I'm going to rate this one a 4 and it might even approach a 3, but I didn't feel that comfortable when I get close to ground and get this rolling, sloshing kind of feel out of it, especially when you're trying to establish a zero side velocities and a zero rate of sink. The last couple or three seconds there, I wasn't too happy a couple of times. The airplane was doing something in spite of what I was trying to do, so in effect, I had the feeling I had some lack of precision of control. So that's the main reason for rating it a 4.

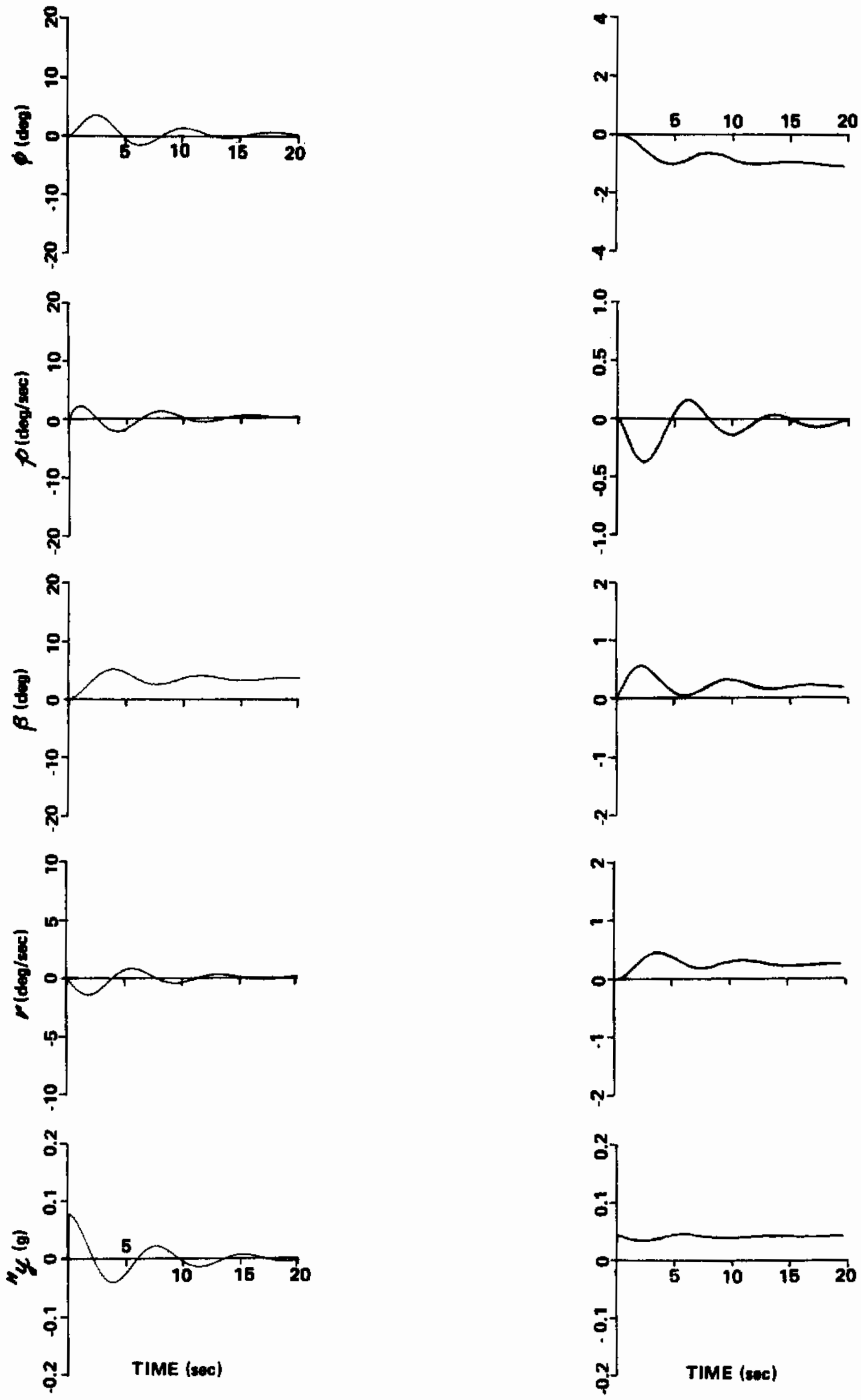
TURBULENCE EFFECT RATING

The turbulence rating certainly is moderate, more effort is required and a moderate amount of more effort in the turbulence and maybe it might even be best efforts if you're really trying to lock in very close on the thing. So I think I'll stick with the D+ in the turbulence rating.

CONFIGURATION 3 AUTO DSFC PILOT A PR 4 TR - NONE EVAL. FLT. NO. 11

INITIAL IMPRESSION AND GENERAL COMMENTS

[Only one approach was accomplished.] That was done in no turbulence and it was what I would consider to be not a very good approach. The heading was held very well, but the hunting on both sides of the centerline, more towards the left than to the right, did certainly downgrade it from the standpoint of comfort, ability to feel that we had it made. There was a fairly large transient just before the flare but then it seemed to steady out, and it did have us down fairly close to the left edge of the runway, but the actual touchdown, I thought, was quite reasonable. Again, we're running into this business of would I downgrade because of the deficiencies of the localizer, or you just worry about the fact that the pilot just has to fly the elevator. I though the touchdown was pretty good. I felt comfortable in it, but I would probably have objected even more with the turbulence in there. I'm sure we would have had quite an uncomfortable ride because of the combination of turbulence and the hunting on the localizer. So I would give this tentatively, with the automatic system, the touchdown portion of it in smooth air, I'd call that certainly a 3 or a 4. I don't think I should rate it better than the manual system, because I don't think it was any better touchdown and, of course, somehow or other, you can't just keep wiping out the effect of the hunting on the localizer, so I think I'll just say that it's about the same as the manual, only because the last part of it was okay. I certainly don't like to be going down that close to the left edge of the runway and you do begin to be conscious of these large sideslip and large lateral accelerations during final which occur fairly close to the ground. I'm going to say that I'm going to eliminate those as objections and rate it a 4.



(a) δ_y = 10.0 deg, δ_a = -3.99 deg, δ_r = 3.97 deg (b) δ_y = 10.0 deg, δ_a = 0.0 deg, δ_r = 0.0 deg

MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO THE AILERON AND RUDDER (CONFIGURATION 7)

CONFIGURATION 7 FLIGHT TEST DATA TABULATION

(EVALUATION FLIGHT NO. 9 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	-2.53	1.54	-2.67	0.56	-3.66	3.42	14.5	5.50	0	2	C
MANUAL	-0.87	1.58	-7.20	1.43	-2.39	3.35	5.37	9.43	-13	3	D
AUTOMATIC	-0.45	1.66	-5.45	1.56	0.02	4.29	6.97	7.61	-12	3.5	C+

CONFIGURATION 7 WIND AND GUST DATA

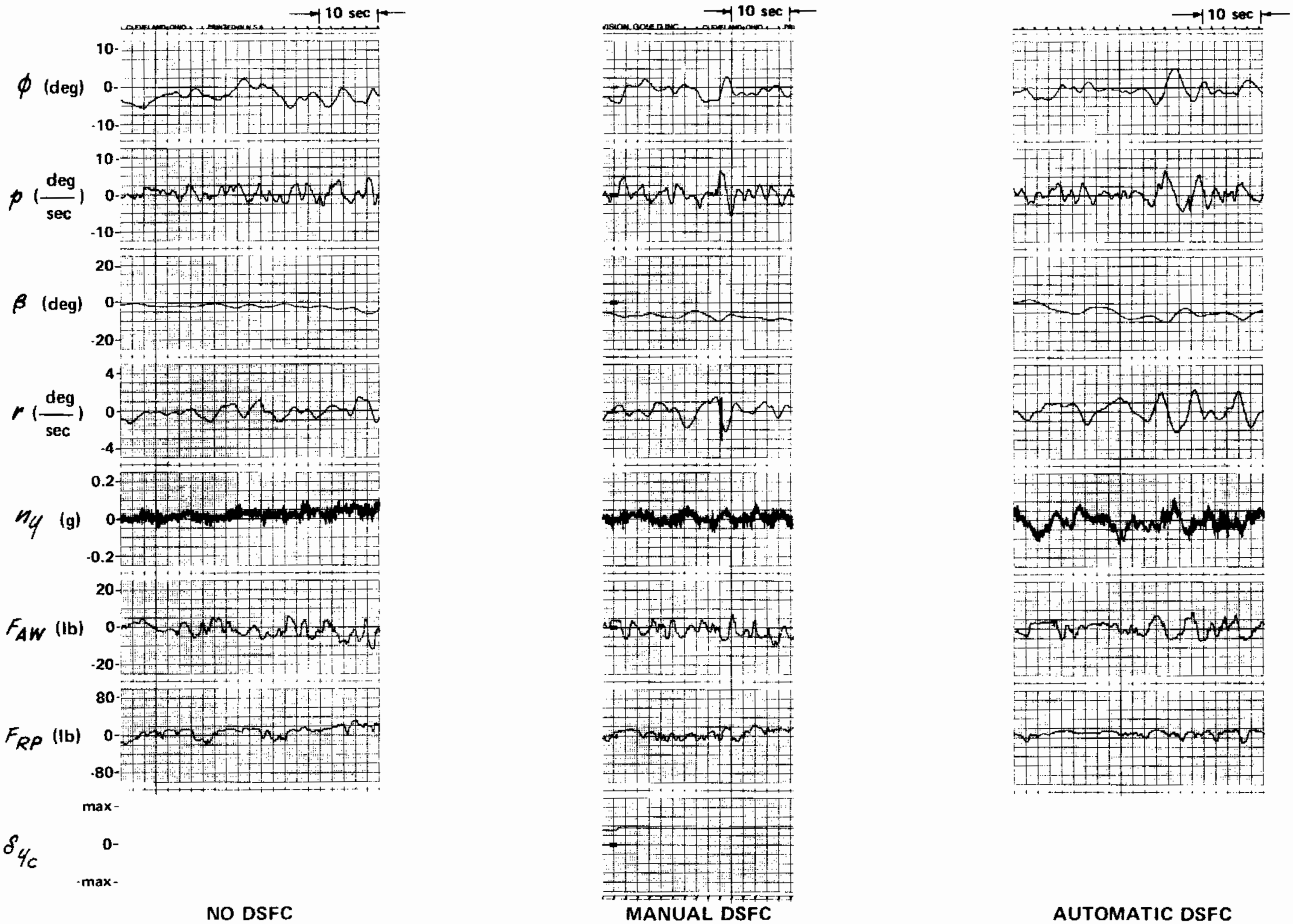
	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	230	10	1.39	2.32	2.05	280
MANUAL	210	10	3.50	1.92	2.99	280
AUTOMATIC	190	10	3.48	1.47	2.19	280

CONFIGURATION 7 FLIGHT TEST DATA TABULATION
(EVALUATION FLIGHT NO. 17 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	1.97	2.21	2.04	1.14	2.73	5.53	-18.9	8.11	0	5	E
MANUAL	-0.68	0.93	6.82	0.44	0.51	2.34	-10.0	6.00	17	3	C

CONFIGURATION 7 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	350	13	4.35	1.53	2.50	280
MANUAL	340	15	1.54	1.02	2.00	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN
CONFIGURATION 7

CONFIGURATION 7 NO DSFC PILOT A PR 2 TR C EVAL. FLT. NO. 9

INITIAL IMPRESSION AND GENERAL COMMENTS

That was a relatively easy job. With turbulence I had a little bit of a rolling oscillation, but didn't really have any particular troubles with establishing attitude. So, generally it was a pretty good airplane. The only thing is that I might have wanted to change the gearings, maybe cut it down, the control deflections by maybe a factor of 50%, it's hard to say. Generally it was a pretty easy airplane and the disturbance due to the turbulence was pretty mild I thought. This is a pretty good airplane though and maybe that's why we are not being disturbed so much.

ABILITY TO TRIM

There's no trim problems either longitudinal or lateral.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The forces are certainly adequate, they feel a little bit on the light side if anything this morning. The harmony is okay and the displacements are high, maybe quite a bit high but certainly adequate for what I was doing.

AIRPLANE RESPONSE TO PILOT INPUTS

The roll control; the initial response is okay, but I did notice that the gearings were not quite as desirable as they could be as it seemed to take quite a bit of aileron wheel displacement to get the roll, but the roll response is adequate. It's certainly not a very snappy airplane in any case, but it's good enough. Directional control, the airplane feels a little bit loose, maybe loose is not the word. The forces on the rudder seem to be fairly light this morning. I did have a tendency in trying to kick out the crab angle, just before landing, to over-control a little bit with the rudders. So, maybe the rudder pedal forces might be better if they were little bit higher. I didn't seem to have any difficulty with turn coordination. I think in all these cases it does seem like I need bottom rudder in the turn but it certainly is a minor complaint. Pitch attitude control, the pitch response is the same on all of these and it's a little on the slow side but not bad.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final doesn't cause any difficulty as far as controlling the aircraft. The only thing on turning final, usually you have to establish what the crab angle is for the particular wind and it's quite often that I overshoot or undershoot a little bit, depending on which side the crosswind is from. But it's something that you normally have to do in any case and it's not that big a problem to establish a reasonable crab angle, although on these close end approaches, you don't usually stabilize too well on the crab angle. So, there is a tendency really to angle in one direction or the other, a very small amount. Sometimes this complicates things right at the flare but I think this is a normal dispersion.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

Runway alignment, today at least I didn't have much in the way of difficulty, we are in fairly smooth air.

CONTROL TECHNIQUE

Control techniques; no problem, just standard.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Lateral control inputs don't really affect the longitudinal. Just on one of those landings I had a tendency to flare a little high, but heck that's just poor judgment I suppose, still it's fairly close to touchdown. Longitudinal inputs don't really affect the lateral, if anything there's only a little bit of cross coupling possibly between the rudder and the aileron.

EFFECT OF RUNWAY CLOSURE RATE

Closure rates once in a while, as I say, I start a little late. I'm trying to hit the end of the runway so I increase the rate of sink, to generally between 1200 and 1600 ft/min, sometimes a little higher, sometimes a little lower but it's in that range mostly on these approaches. That's a pretty good rate of sink to kill at the bottom so you have to be a little careful and I always add a little power because usually I have to get the power pretty far back to get to the end of the runway. I don't want the airspeed to drop below 120 at least on my clock. I try to keep it higher than that. So, only when you are late in the flare does the closure rate enter into it.

GOOD FEATURES

The good features are certainly that the airplane is well damped and the forces are light enough that you don't really have to work very hard.

OBJECTIONABLE FEATURES

Objectionable features, I couldn't see any except that it's my own choice here that the gearings are maybe a little bit on the low side but if I tried them with higher gearings we might end up maybe not having as good an airplane. I don't know.

SPECIAL PILOTING TECHNIQUES

No special piloting technique.

PILOT RATING AND PRIMARY REASON

The pilot rating, I think it certainly has to be satisfactory without improvement. I didn't have any difficulties either in turbulence or in smooth air. I would say that pilot compensation was not a factor for the desired performance. I'm going to rate this pretty good airplane as a 2. The gearings I think might be a mental hazard in my mind but it was just a pretty easy task to handle the crosswind. The fact that we are in pretty smooth air, light turbulence, maybe also enters into it. It seems like it's a low side force kind of an airplane. Dutch roll damping seems good, roll to sideslip ratio is moderate I guess and fairly decent, so I guess we'll call it a 2.

TURBULENCE EFFECT RATING

In the turbulence I would certainly say it's just a minor deterioration. As I mentioned I think I had a little bit of a roll oscillation, just about the time that I was lining up the airplane for a touchdown but very small bank angle amplitude in oscillation, so I would say that it's minor. I will call it Charlie. It's really pretty much the same with or without turbulence.

CONFIGURATION 7 MAN DSFC   PILOT A   PR 3   TR D   EVAL. FLT. NO. 9

INITIAL IMPRESSION AND GENERAL COMMENTS

That was the manual controller, made one approach in smooth air which I thought was very good one. Made one in turbulence which was also pretty good but a little bit off centerline, everybody tells me. I was aware of that, but I just didn't bother. Next one I tired to get it right down the centerline and I decided to get it down the centerline, so I worked a little harder at that and I got into a little bit of a lateral-directional oscillation with this one. I was really trying to fly this thing pretty tight. I actually ended up, either I hit some heavy gusts right near the end there and I was overcontrolling and I guess I levelled off a little high again and I was feeling for the ground the last couple feet, so the airspeed got a little bit low and the airplane got to be feeling a little bit squirrelly as far as the lateral-directional. So, I think it was primarily my own overcontrolling problem there. I'm a little bit on the fence here as to how I'm going to rate this because of that last approach. Generally speaking, however, I felt I had control of the airplane but the turbulence that time plus the fact that I got down low on airspeed caused me some difficulty.

ABILITY TO TRIM

There's no trim problems.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

I still feel that the forces may be okay, but the displacements are a little high.

AIRPLANE RESPONSE TO PILOT INPUTS

I don't know if I should be blaming the roll response on the airplane, during the approach with turbulence where I had this Dutch roll going, especially the roll. Maybe there is a lag in the response that could cause that kind of a problem, but when you get external disturbances, it shows up more. I wasn't really as happy about the side force controller approaches, the last one in particular, as I was with the no sideforce controller approaches. This is the first time I think, I almost felt that my performance was worse having side control available than I did without it. This is a problem I guess, I'll just have to call it as I see it.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

The crosswind turning final was no problem again.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

I did hunt around again a little bit about where the heck to put the side force. I think in every case I ended up putting in more than I really needed and finding myself actually drifting to the left and then I would make a correction. In the turbulence, of course, it's a little bit difficult to really see immediately what's going on because you are rocking around a little bit. The fact that you are banking, if the bank angle persists for any length of time, will of course give you an indication that you might be drifting, so you make corrections. So, there's the same problem that I've always commented on that you do hunt a little bit for the proper side force position when you are being disturbed by turbulence. But basically, I guess the alignment was not really any particular problem. Of course, the fact that you can keep the nose of the airplane down the runway is pretty good.

CONTROL OF SIDESLIP WITH DSFC

The control of sideslip with the side force, apparently we had lots of side force available here because I noticed on the go-around I really only had less than 1/2 of the side force actually cranked in; that is, the side force controller.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

I don't know that the side force interferes with the lateral-directional. I didn't really notice anything particularly bad about it. I don't think the side force surface interferes with any other inputs.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

No, whether there is a lateral and longitudinal cross coupling, and maybe directional, I got the feeling there at least on the last approach that possibly there was. Also, on one of those approaches I was concentrating trying to make my alignment perfect down the centerline that I actually ended up with a fairly high rate of sink and late on the flare.

EFFECT OF RUNWAY CLOSURE RATE

You have to start this flare between 200 and 150 feet to be able to feel comfortable - I think about 150 feet. It's inside the middle marker, but not very much inside.

GOOD FEATURES

The good features are that I do have a fairly well damped airplane.

OBJECTIONABLE FEATURES

The only objectionable feature I could see on that one was the lateral oscillation which the pilot has some overcontrol with the rudder. If we have time here, and I think we will, I want to take a look at this thing with cutting down the gearings.

SPECIAL PILOTING TECHNIQUES

I don't think there was any special piloting technique.

PILOT RATING AND PRIMARY REASON

Somehow I just didn't feel as good about this one as I did the one without sideforce control. Now, there has been an increase in the turbulence. So, there is the variable here that we had heavier, essentially higher gust inputs with the manual controller than we had with the airplane being flown without it. So, that, I think maybe explains my increased difficulty so I still think you could make these landings all right, as I said, I wasn't too happy about the last one. I might even say it's a little squirrely, maybe I should downgrade it, but I think that basically you could probably land it all the time. I'm on the fence between a 3 and a 4, so I think I'll rate it a 3 but I think I am leaning a little bit towards a 4. As I said, this is the first time I've seen a situation where I didn't like the manual sideforce controller better than no sideforce controller at all, just flying the airplane normally. I'll have to stick with that. I will rate it a 3.

TURBULENCE EFFECT RATING

The turbulence rating - I certainly have to downgrade that and there is certainly at least a moderate effort. I don't know whether it's the best effort, I don't think I was working quite that hard. But, I'll call it a Delta on the turbulence.

CONFIGURATION 7 AUTO DSFC	PILOT A	PR 3.5	TR C	EVAL. FLT. NO. 9

INITIAL IMPRESSION AND GENERAL COMMENTS

The automatic coupling was better than I remember on previous flights. The lateral accelerations appear to be less objectionable. There still is hunting, now part of that hunting could just be the system and part of it could be just the raw localizer having bends in it. It doesn't take a very big bend actually to make this thing hunt. The first approach without the turbulence took me a little bit off the centerline but I thought the attitude finally was okay, I just didn't try to overpower the coupler. I did have a tendency to put some ailerons in there, though. I wasn't doing anything to the rudder, not consciously anyway. But, I thought that was pretty good. Then, the second one, I don't know if the natural turbulence was higher, it probably was, and I had the same kind of a feeling that I did when I was attempting to make the last approach with the manual side controller, it looked about the same. Sort of a rolly kind of Dutch roll disturbance, some sideslip going a little bit and then it stopped. I think this is a last minute attempt by the automatic system to correct to the center of the localizer, so I think that was the problem on that one. So, that made me feel like the turbulence approach was not really as nice as the no turbulence approach.

ABILITY TO TRIM

I think the ability to trim was not a problem.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The forces of course are not really a very noticeable part of this. The aileron forces felt heavier when I was working them, but the elevator force is the only thing that stays normal and I think that was okay, I guess possibly a little bit on the sensitive side but not noticeably different of course than before, since we didn't do anything to the sensitivities of the controls.

AIRPLANE RESPONSE TO PILOT INPUTS

I don't have any particular comments on the responses except in pitch that was okay.

DIFFICULTIES ON TURNING FINAL WITH CORSSWIND

Crosswind turning final, both times I engaged the system pretty much on heading, pretty much on localizer and the initial side force inputs seemed to be very mild. Now, whether that new technique is it, or whether the fact that we've got these changes in the time lag and in the rudder available, all of these things I'm sure enter into it, but anyway, it was fairly mild. However, the hunting is still there and it's better, but it still could be better than that.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The landing approach of course was just on the automatic system and I was willing to accept whatever we had far out, but then close in these last minute corrections that I'm sure are caused by trying to align the airplane automatically are disconcerting and it's really difficult, if not maybe impossible to smooth those out very much although I tried on that second approach with the turbulence. But, again there may be some cross coupling there because I was trying to put some aileron in and also some rudder and I did have a tendency again to balloon a little bit. It's hard to tell whether this is just a natural tendency on my part, which could be, or whether this ballooning tendency is really tied in directly with the control cross coupling, either due to control sensitivities or due to the dynamics of the aircraft. Anyway, it was a minor, mild tendency on that particular case. But I wasn't happy about the fact that if I had touched down say a couple seconds earlier, we would have had a pretty fair amount of side velocity and of course, that's not too desirable for most landing gears.

GOOD FEATURES

I guess the good feature was the fact that your workload is reduced.

OBJECTIONABLE FEATURES

The objectionable feature is primarily the lateral-directional oscillation at the end there. And, the fact that there always is a tendency to be off to the left and the automatic tries to correct you, just before touchdown. It's difficult to overcome it.

SPECIAL PILOTING TECHNIQUES

I don't think there is any special piloting technique involved, unless you consider the fact that you're only flying elevator special.

PILOT RATING AND PRIMARY REASON

I felt about the same about this automatic thing as I did about the manual. As a matter of fact, it's somewhat worse. I'm thinking about between 3 and a 4 again. I was sort of comparing the manual with the automatic. The deficiency with the automatic is that it's difficult to make precise corrections, superimposed precise corrections over the auto pilot, so that would tend to downgrade it some. I don't like this as well as I liked the manual, so I think I'm going to call this a 3.5. This is just to differentiate this between the automatic and the manual. I think it's probalby easier to learn the manual than to try to fly this where you are stuck with the automatic feature. Maybe the philosophy of this rating is wrong but I call it as I see it. I'll call it 3.5.

TURBULENCE EFFECT RATING

Is there more effort required? Well, there is certainly this tendency for the pilot to introduce himself into the loop, certainly a lot more strong feeling than you would get without the turbulence. So, there is certainly more effort required. Slightly more, maybe just in the roundout, but if you ignore the lateral-directional changes that are created by the automatic feature [Tape ended]. (Turbulence rating of C+ was recorded by flight engineer.)

CONFIGURATION 7 NO DSFC PILOT A PR 5 TR E EVAL. FLT. NO. 17

INITIAL IMPRESSION AND GENERAL COMMENTS

We have the crosswind from the right which I don't like as well as I do from the left. Turbulence level is pretty low, I would say this was light turbulence, an occasional bump, and that didn't feel too bad. I was able to keep the wing down and the nose pretty well pointed down the centerline. I was a little bit left of the centerline on that one but all in all I thought the performance was reasonable. The second approach was quite a bit more work. When I actually got into the touchdown landing attitude I sort of had to work at it. I guess I probably lucked out on that one. I was pretty well lined up. There was quite a bit of activity however on my part to get the thing set up. It seemed actually the closer I got to touchdown the worse that turbulence got, so it did give me quite a bit of a problem. The configuration really was not very difficult but there certainly was an increase in pilot effort with turbulence. I thought the touchdowns generally were fair. The last one I think was probably the worse one. I ballooned a little bit. I had a little bit of cross coupling between the aileron and the elevator control that time. But, generally speaking, I feel that I do have sufficient control to be able to land the airplane. But it does require quite a bit of control input to keep the airplane pretty well on the centerline to the left since the wind is from the right. Apparently I wasn't really able to precisely hold it on the centerline, but in each case, I think I had the drift killed.

ABILITY TO TRIM

I didn't have any difficulty. The directional mode seems to be a little bit loose to me. Longitudinally the basic airplane is a little sluggish, but no real problem for this particular kind of approach.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The feel characteristics I thought were quite good. I didn't have any particular trouble in maintaining steady state sideslip about 6 - 7° and holding the heading. The rudder does seem to generate quite a bit of sideslip for what appeared to be fairly low forces. But overall I thought the harmony was pretty good and the sensitivities are adequate.

AIRPLANE RESPONSE TO PILOT INPUTS

You can fly this airplane with the ailerons, without worrying too much about coordination. It does seem that if you try to use rudder there is a tendency to over control with the rudder a little bit. Directional control, the only complaint I have is that maybe it is a little bit loose directionally. I think it should be stiffened. Turn coordination, I've already mentioned I am a rudder man so I did have a tendency to sideslip the airplane plus or minus maybe a couple of degrees a number of times.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind turning final didn't cause any problems that I could see. I think mainly we have almost enough natural crosswind today.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The first one I did was completely I thought with the crab angle. The next two I really had a combination of sideslip and crab although not much in the way of sideslip. I found myself inadvertently putting rudder in and so I noticed that I did have maybe half a ball width or something like that. Runway alignment technique was part bank angle and sideslips and part heading or crab angle. There was really no particular difficulty on the way down. However, close to the runway where precision of control of course goes way up, I did find that I had to work fairly substantially to get the proper landing attitude. It seemed to me that the bank angle was fairly large, to maintain the runway heading and also kill the drift.

CONTROL TECHNIQUE

Control technique was pretty standard.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

The lateral directional inputs did affect my longitudinal at least once on these landings. There is a substantial amount of aileron deflection and, although the forces are not objectionably high, they are somewhat high or they feel somewhat high, so I did have a slight tendency to couple. I didn't really think I had the opposite problem. That is no lateral cross couplings due to longitudinal inputs.

EFFECT OF RUNWAY CLOSURE RATE

Closure rates, I didn't really notice any particular effect of that.

GOOD FEATURES

I do have adequate control power to place the airplane in the landing attitude, the forces are reasonable. I do feel that the rudder does seem to over power the aileron a little bit. In other words, I did have a maybe a slight tendency to use more rudder than I needed.

OBJECTIONABLE FEATURES

The damping is a little bit on the low side although it is not extremely low. It could be better. This is particularly noticeable when the turbulence was in and the closer I got to touchdown it did seem that the turbulence level did increase. So, I think we had a substantial difference between the normal turbulence and the taped turbulence that is fed into the model.

SPECIAL PILOTING TECHNIQUES

There is no really special piloting technique.

PILOT RATING AND PRIMARY REASON

There are deficiencies that probably warrant some improvement on this airplane. But they are not very extreme. In other words I think maybe you can improve the airplane by possibly stiffening the directional mode and possibly increasing the Dutch roll damping, but it's really not really bad, so I think the desired performance requires between moderate and considerable compensation. We are talking about a 4 or 5. In turbulence there is quite a change in the level of pilot effort required, so that tends to bring me down towards considerable compensation rather than moderate. In other words, I think you will probably be working too hard. I think I am going to rate it a 5. I may even be a little charitable on that but I felt that I could have landed the airplane every time. With a little more practice I think I certainly would improve it. But the turbulence I think is the one that makes me downgrade the airplane.

TURBULENCE EFFECT RATING

There's at least a moderate increase in pilot effort required, between more effort and best effort. We are debating here between a D and E. I really will rate this an E because turbulence is a big factor in downgrading the airplane.

CONFIGURATION 7 MAN DSFC PILOT A PR 3 TR C EVAL. FLT. NO. 17

INITIAL IMPRESSION AND GENERAL COMMENTS

On the first approach I used almost the full side force available, probably three-quarters of it anyway. I did have a little bit of difficulty in trying to find the exact position. I made several inputs all the way down the final. I ended up on the right side of the centerline so I probably started out with a little bit too much side force. As a matter of fact, I think I had to use a little bit of left wing down for one short period, a couple of seconds or so. I may have over controlled a little bit but as far as the final touchdown there was no real problem although I did balloon just slightly I think just before touchdown. As far as alignment it was okay, and rate of sink was under control. Generally I think the workload on the pilot certainly is reduced substantially between the no side force and side force control available.

ABILITY TO TRIM

The ability to trim the airplane certainly hasn't changed. The lateral-directional and longitudinal modes are about the same as before.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Nothing was really changed here. The only difference, of course, is that I do put the side force surface in to eliminate the crosswind, but that doesn't seem to change the feel characteristics of the airplane or the sensitivities. Of course, it's not really that noticeable anyway because there is very little need for aileron input although in the turbulence there is enough disturbance that I had to make some correction with the aileron.

AIRPLANE RESPONSE TO PILOT INPUTS

You can fly the airplane with ailerons only without worrying about coordination. There seems to be a tendency to over control when using the rudder. The coordination requirements are practically eliminated because there is no need to use any bank angle to turn the airplane. I can usually displace the airplane pretty much with the side force once I've got on the final pretty close to the centerline. Pitch attitude control is a little sluggish and it's well damped however.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind turning final didn't cause any problems that I could see.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The technique was to get on the centerline with a crab angle to eliminate the drift and then to bring the nose around to be pointed down the runway. That does pose a little bit of a problem with the pilot because the wind is somewhat variable today and also I believe there is a wind sheer.

CONTROL TECHNIQUE

I had to make a fair number of side force control inputs to establish zero drift and have the airplane on the centerline.

CONTROL OF SIDESLIP WITH DSFC

I don't think I was right on the centerline but slight to the right on that last approach and I think the first one was the same way, I ended up to the right a little bit. The wind is from the right so maybe I am overcontrolling a little bit. Certainly the amount of work required to do this is much reduced from the normal no side force control airplane.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I didn't really have any tendency to cross couple between the aileron and the elevator that time, basically there is very little aileron input. There is some, I think, small amounts due to the turbulence in particular.

EFFECT OF RUNWAY CLOSURE RATE

I think the last landing I did have a little more rate of sink than I would normally like. I think I was a little bit late in trying to flare and I also think the airspeed was down a little bit so there was some effect of this so called closure rate which I think is primarily a function of rate of sink rather than the horizontal velocity.

GOOD FEATURES

The good features about the airplane is the fact that having control of the crosswinds and eliminating the crosswind with the side force surface, the airplane becomes a one control airplane, pitch only and throttles. That is pretty good.

OBJECTIONABLE FEATURES

The airplane still has a tendency to oscillate due to turbulence so I think that it is still noticeable that the Dutch roll damping is probably is lower than you would like. You would probably increase it some and make a much better airplane out of it.

SPECIAL PILOTING TECHNIQUES

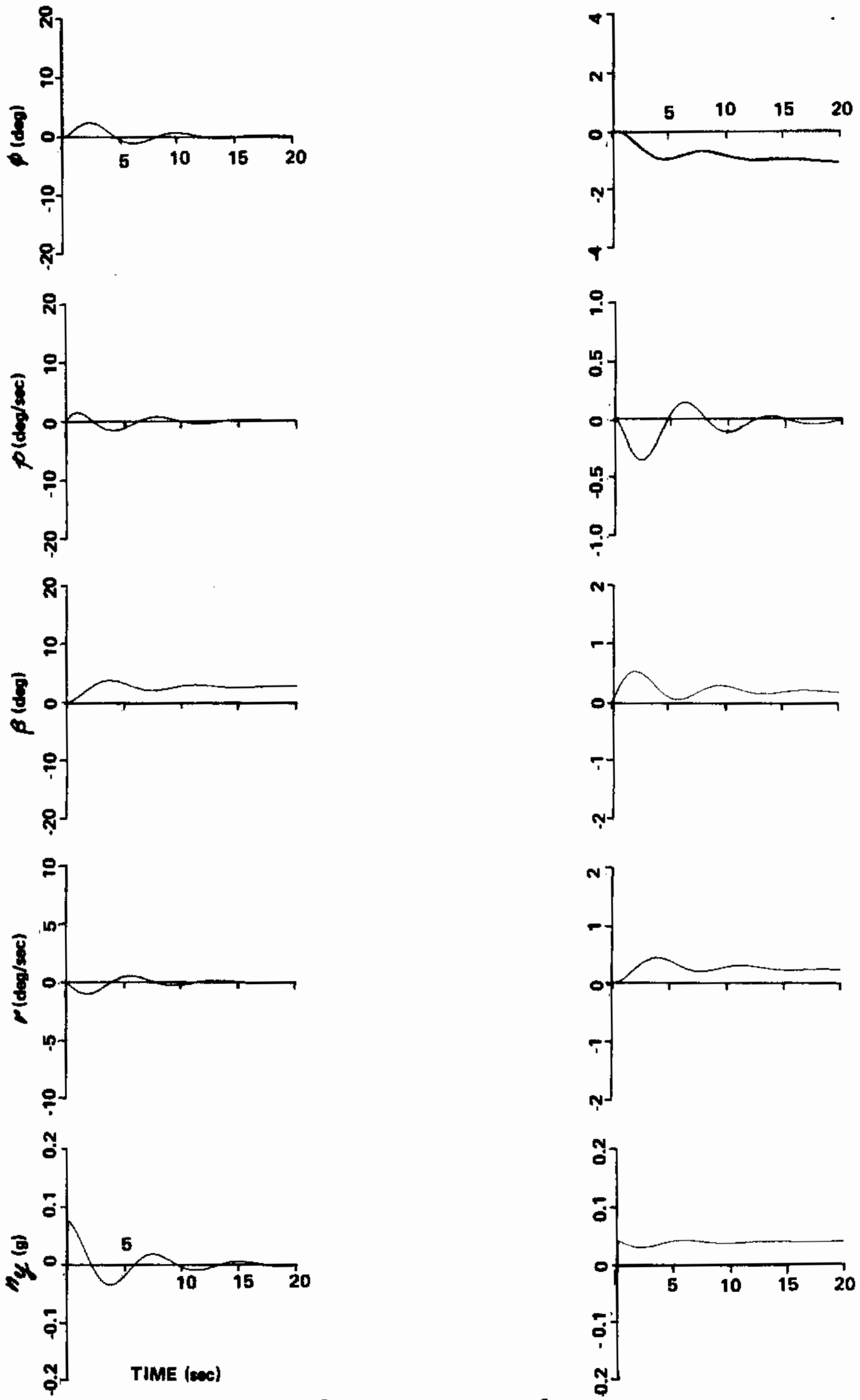
There is no real special piloting technique involved here except the hunting in finding the proper side force displacement. The side force requirements on these approaches is a very substantial amount of what is available. I would say, my guess is a little over 75% of it.

PILOT RATING AND PRIMARY REASON

I certainly think this is a much better airplane than I had without the side force available. We are talking here of upgrading the basic airplane, now, maybe a couple of units. There is compensation required by the pilot. The fact you do have to pay attention where the side force surface is, of course, a task. In turbulence you still have to fly the airplane some to keep the wings level, not a lot, but certainly some effort is required. So I am really saying here, is the pilot compensation moderate or is it minimal, and these unpleasant deficiencies, are they just unpleasant or are they minor and here I think we are talking about the dynamics of the aircraft rather than control activity requirements. Obviously you can't separate the two. What I am really saying, here is if the Dutch roll damping was a little better, the pilot compensation would be decreased so I am really debating here between minimal and moderate. Oh hell, I can't really downgrade the airplane too much. I was pretty happy with the end results. The performance I think was pretty good. It certainly is a much more comfortable way to land the airplane than with-the side force. I think I am going to bring it up to an acceptable, no improvement required so that will make it a 3.

TURBULENCE EFFECT RATING

There is more effort required in the turbulence than without the turbulence. The actual performance of the task however really is not substantially different between no turbulence and turbulence. So we are talking between a minor and a moderate maybe, a C or a D. I'm going to call it a C+ because I don't think it falls into either one. It's not quite a moderate.



(a) δ_y = 10.0 deg, δ_a = -3.00 deg, δ_r = 2.98 deg (b) δ_y = 10.0 deg, δ_a = 0.0 deg, δ_r = 0.0 deg

MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO THE AILERON AND RUDDER (CONFIGURATION 11)

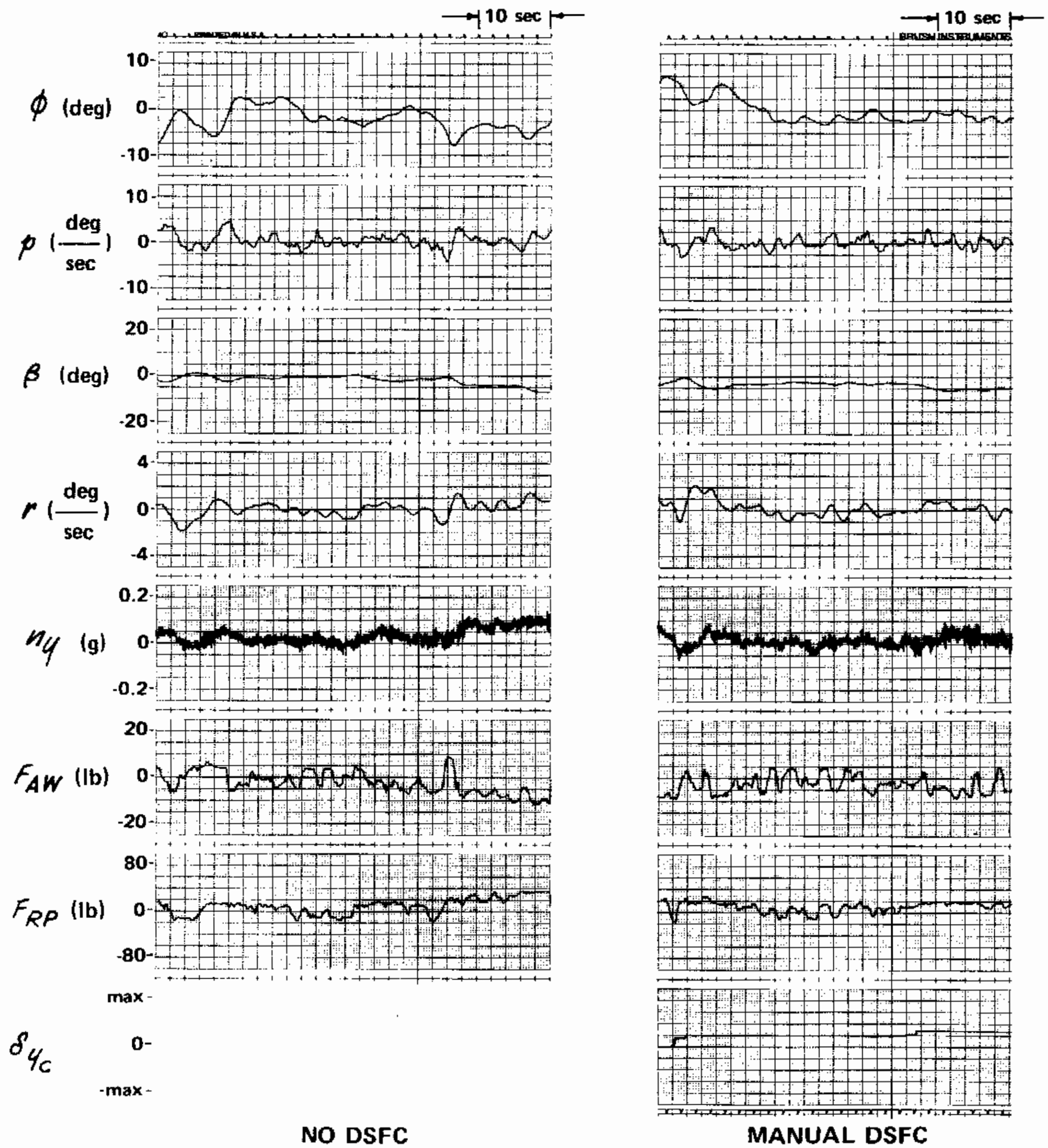
CONFIGURATION 11 FLIGHT TEST DATA TABULATION

(EVALUATION FLIGHT NO. 6 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	-3.63	0.64	-3.85	0.25	-7.00	1.19	21.7	5.41	0	3	A+
MANUAL	-0.86	0.76	-4.89	0.73	-4.22	3.09	16.6	2.36	-10	2	A

CONFIGURATION 11 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	250	10	0.86	1.13	1.57	280
MANUAL	220	13	0.93	1.14	1.46	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN
CONFIGURATION 11

CONFIGURATION 11 NO DSFC PILOT A PR 3 TR A+ EVAL. FLT. NO. 6

INITIAL IMPRESSION AND GENERAL COMMENTS

Initial impression was that yes, I can land this airplane in this amount of crosswind and apparently I can do a fairly reasonable job. We are operating under some adverse conditions. The visibility is pretty low and I don't really pick up the runway until I'm about 2 miles or so where I have a good reference at least, and usually I am starting too far off centerline or a pretty fair amount off the centerline before I actually can start my approach. So considering the handicaps of the low visibility, I was still able to bring the airplane down fairly well. The approaches appear a little bit steeper mainly because I have to get in closer before I actually start my descent. I suppose I could start at a lower altitude but the tendency at least is to be a little higher.

ABILITY TO TRIM

I didn't have any trouble trimming either laterally or longitudinally.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics, I accepted whatever I had in up and away flight. I tried to check to see whether I could hold a heading with a sideslip with one hand and I got up to a sideslip of about 5 or 6°. It seemed reasonable so I accepted it. Displacements are okay. The harmony seems to be adequate although I had the feeling this morning that the elevator forces were a little lighter than I remember them but the aileron and elevator forces I think were okay.

AIRPLANE RESPONSE TO PILOT INPUTS

The initial response in roll seems to be reasonably snappy. I don't seem to have any trouble with precision of control of bank angle. Directional control, I don't really feel much problem there. It seems to be fairly easy to coordinate so that coordination in a turn seems to be fairly reasonable. Pitch attitude control, not much that I can say about it. The airplane is somewhat slow in responding but it's well damped. The Dutch roll damping appears to be adequate. The frequency seems moderate I guess, moderate to low but it's reasonable.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

The crosswind turning on final, I cannot tell any difference because of visibility but I don't think it's a problem in any of these approaches.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

It's difficult again to establish a visual reference so I'm usually angling in. That's what I did on all three of those approaches I think except possibly the first one which was started out on the ILS quite a ways out. Okay, so runway alignment I do seem to have to work a little bit to get it around to the centerline but it's not really any problem.

CONTROL TECHNIQUE

The control technique is to try to establish centerline by crabbing or heading changes and then close to the runway I tried to set up a sideslip with the airplane pointing down the runway. I think both times, or all three times I ended up to the right of centerline but I was willing to accept this only because aileron forces were getting to be somewhat heavy but not really what I would consider extraordinary, certainly acceptable.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Lateral-directional inputs didn't seem to affect the longitudinal motion that time. I didn't have any tendency to balloon on any of these approaches, or on the landing attitude, close to the ground so apparently it's a fairly good, reasonable airplane.

EFFECT OF RUNWAY CLOSURE RATE

The closure rate, on one of those, I did let the airspeed get down a little bit. I was rounding out from a fairly steep angle. I think a little steeper than the 5° and I didn't add some power at that time so I did get the airspeed down but I got the feeling I was sinking pretty fast. However, I guess it's not a really big problem. On the second approach we had just a natural turbulence fed into the model and that didn't disturb the airplane much. The next one, they fed the tape into the model in addition to a gust of the natural turbulence and that really didn't seem to be much either. At least it didn't seem to make any significant difference I don't believe between the no turbulence or turbulence situation.

GOOD FEATURES

Good features is that the airplane is fairly well behaved, it's well damped. The frequencies are within the range that the pilot can accept for this kind of a task.

OBJECTIONABLE FEATURES

I didn't really see any particularly objectionable features of this airplane.

SPECIAL PILOTING TECHNIQUES

I don't think there were any.

PILOT RATING AND PRIMARY REASON

The primary reason that I'm going to rate this a pretty good airplane. I think it's the satisfactory without improvement and to get the desired performance you would say minimal compensation or pilot compensation not a factor. Well, in the crosswind, as I said, I think I was beginning to feel that the forces were beginning to build up pretty good and I didn't really feel that I could kill the drift completely or as readily as I would have liked, so there is some pilot compensation but it is fairly minor. So I think I'll rate it a 3. I think it's a pretty good airplane.

TURBULENCE EFFECT RATING

In the turbulence rating, I didn't think there was any deterioration, I'm nor really even sure there was some more effort required but I suspect there was a little bit more control input activity so really I'm debating between an "A" and a "B" on the turbulence so I think I'll just rate it an "A+".

CONFIGURATION 11 MAN DSFC PILOT A PR 2 TR A EVAL. FLT. NO. 6

INITIAL IMPRESSION AND GENERAL COMMENTS

I made the sideslip correction with the side force surface pretty close in that time. I even made another one even closer down, the fact that you can keep the wings level makes it really not difficult at all. The pilot effort here is merely to find the proper pitch attitude for the landing and that's about as easy as it is. I think the turbulence is quite light. I don't think there is sufficient intensity to give you a significant difference between no turbulence and turbulence, at least not that I could really rate or downgrade here.

ABILITY TO TRIM

Ability to trim again is no problem.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics are good. Selection of control sensitivities was discussed previously. Didn't make any changes.

AIRPLANE RESPONSE TO PILOT INPUTS

Response to inputs okay. I can't complain about the ability to fly either to the ILS which I did, or whether it's a visual. Everything seems to be okay, there's no coordination problem that I could see.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

The crosswind turning on final is a little bit of a problem in these close approaches where the visibility is low like it is today. The problem is trying to get lined up with the runway and establish a heading although I made a pretty long one coming in the first time and that was the first one I made and I had, you might say, mixed feelings on where the hell the wind was coming from. I worked at it for a while but it was close enough so that once I got in to the outer marker, I was reasonably well aligned.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

Landing approach was essentially killing the crab although that was a problem because I was angling in so I didn't know how much was crab angle and how much was heading correction. The alignment near the last mile and a half or so was okay. I didn't have any difficulty but the rate of descent was pretty darn high.

CONTROL TECHNIQUE

No particular control technique, that was any different than a normal airplane.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

The side force surface did not interfere in any way that I could tell.

CONTROL OF GLIDE SLOPE

It didn't interfere with elevator control or throttle.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I didn't really disturb the longitudinal with the lateral inputs at all or vice versa.

EFFECT OF RUNWAY CLOSURE RATE

The closure rates, on the runway, are somewhat high, mainly because of these high rates of descent but I wouldn't say that I got any uncomfortable feeling at all except for one of those approaches. Not this one but on the previous set where I let the airspeed get down some and the fact that the safety pilot was calling off low speeds made me work a little harder.

GOOD FEATURES

The good features is that it's a well behaved, well damped airplane as far as I could see.

OBJECTIONABLE FEATURES

I couldn't see anything wrong with it.

SPECIAL PILOTING TECHNIQUES

No special piloting technique required.

PILOT RATING AND PRIMARY REASON

Here was a case where I thought that the pilot compensation was really not a factor for the performance. In other words, it seemed like I could pull that thing right in so I'm going to rate this one a 2 only because, as I say, I didn't have to hold the bank angle and I didn't have to work even a little bit, to try to kill the drift like I did without the side force. So that's a pretty darn good airplane. I just wanted to make a comment thinking a little bit about that last rating. I think I rated it a 2 because it's not a factor in the pilot compensation for performance and I guess what I was debating in my mind is why didn't I rate it a 1. "Excellent, highly desirable," rather than good and negligible deficiencies." I don't really know. As I said, I don't think I saw any particular deficiencies in the airplane. The only thing is with this visibility problem and the fact that I was working in each case trying to get the airplane aligned with the centerline. I was usually angling in a little bit when I actually picked up the runway well enough to decide what the alignment problem was. It does seem like you have to work some to get the airplane displaced. I don't really know. It might even be better than a 2, is what I'm really saying. I would prefer to have a little more responsive airplane in the sense that I can displace it laterally a little bit easier than I have. But I don't think I'll make it a 1. I think I'll leave it as a 2 but I definitely want it to go on record saying that I don't see any particular or any one thing that would make it a 2 rather than a 1. So I'm leaning towards a 1 on this one.

TURBULENCE EFFECT RATING

I'm going to have to say that I can't really say that the turbulence was significant. I only made two approaches, one with and one without the turbulence but I couldn't really see any difference so I'm going to call it an "A" and I think the previous set I called it an "A+" but that's sort of splitting hairs in a way. So that's what we'll call it .

Appendix III.4

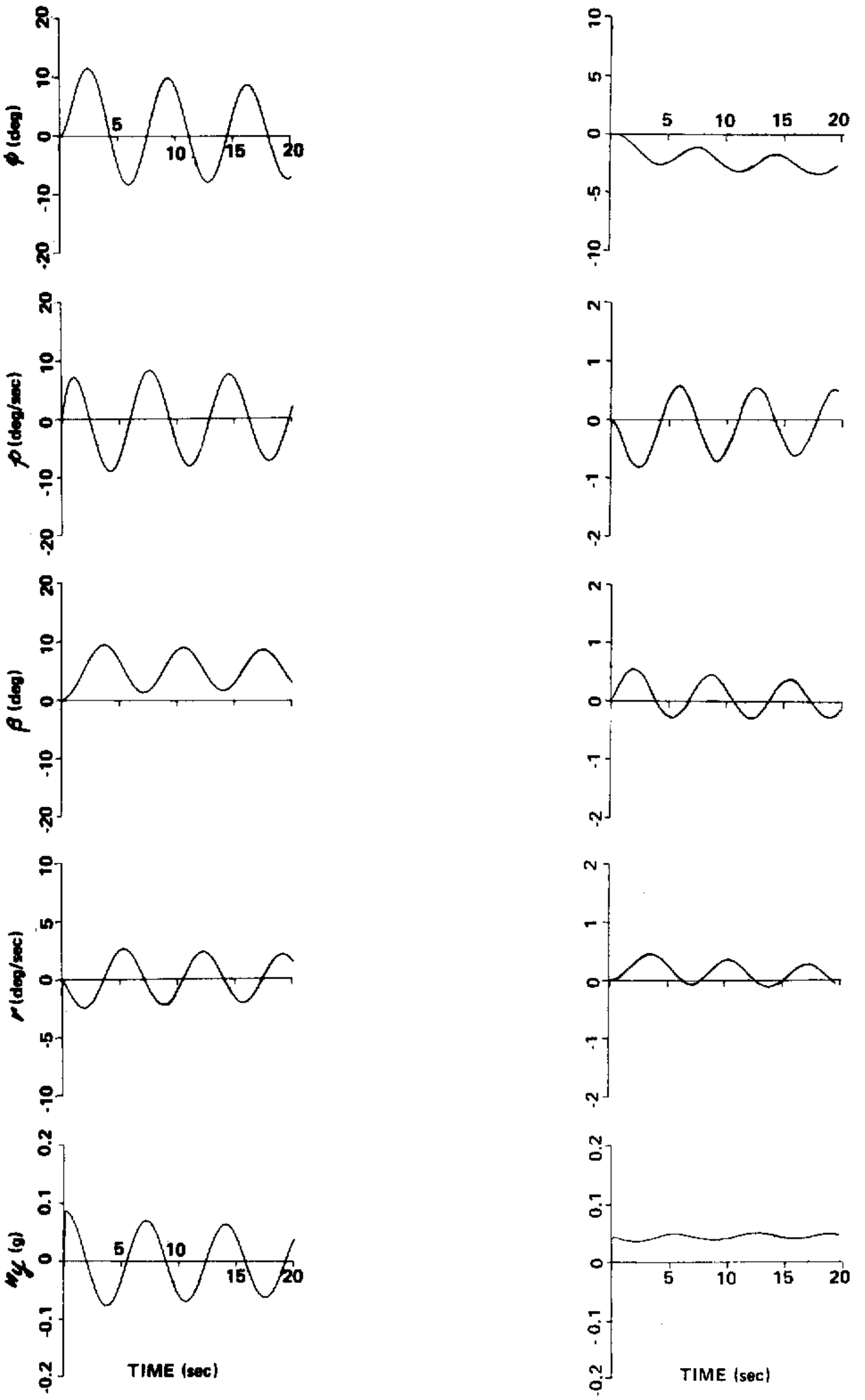
CONFIGURATIONS WITH N_β = 0.42 AND L_β = -2.95
(CONFIGURATIONS 4, 8 AND 12)

DIGITAL RESPONSES WITH AND WITHOUT INTERCONNECTS

FLIGHT DATA TABULATION

IN-FLIGHT RESPONSES DURING LANDING

PILOT COMMENTS



(a) δ_y = 10.0 deg, δ_a = -12.35 deg, δ_r = 7.02 deg (b) δ_y = 10.0 deg, δ_a = 0.0 deg, δ_r = 0.0 deg

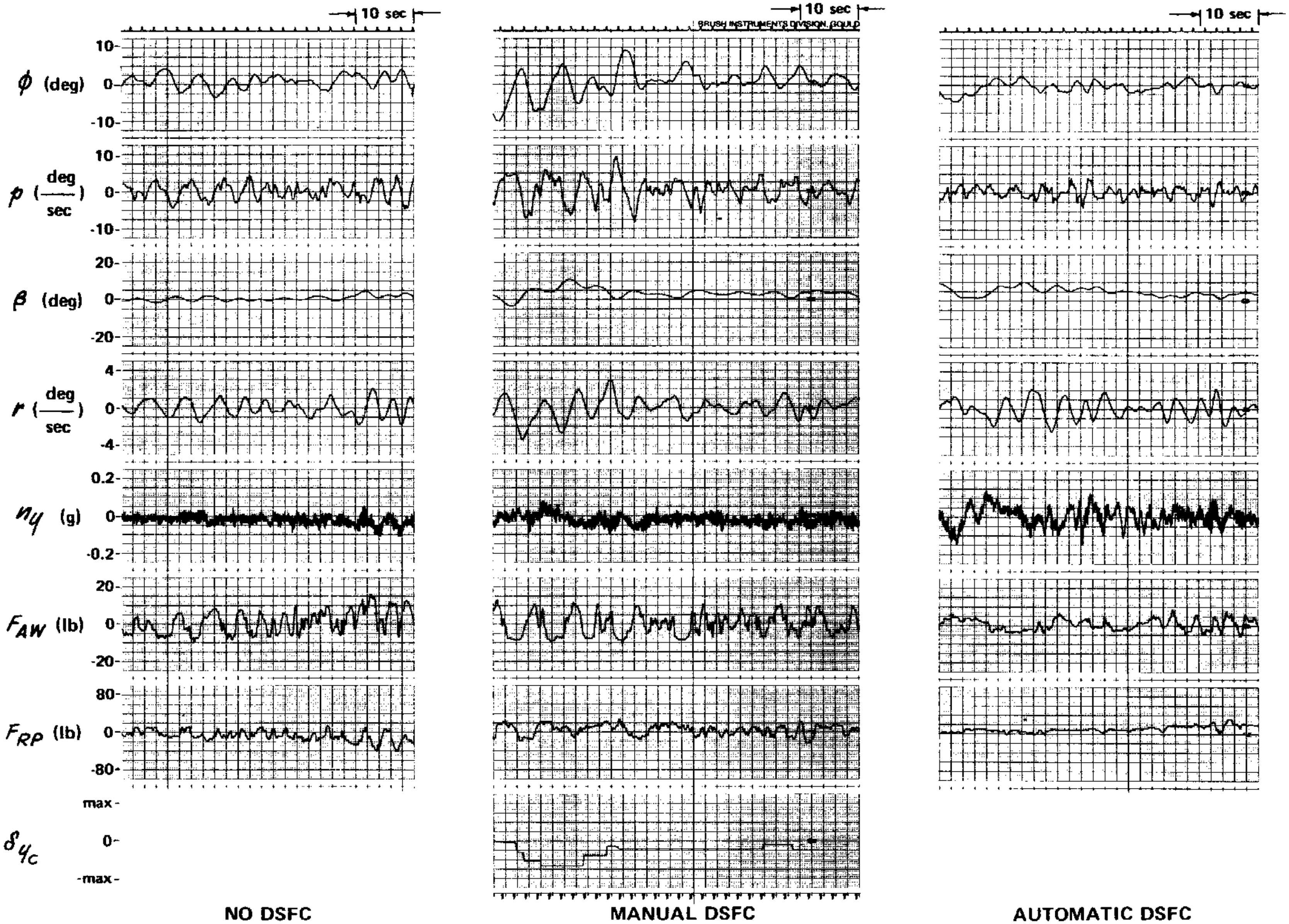
MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO THE AILERON AND RUDDER (CONFIGURATION 4)

CONFIGURATION 4 FLIGHT TEST DATA TABULATION
(EVALUATION FLIGHT NO. 2 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	1.76	0.88	2.60	0.62	6.00	3.0	-22.0	8.81	0	6	D
MANUAL	0.91	1.23	3.61	0.86	0.51	3.0	0.11	9.3	6.0	4	C+
AUTOMATIC	0.11	0.50	3.21	0.68	0.52	2.17	15.2	5.04	8.0	5	D

CONFIGURATION 4 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	310	10	1.92	1.28	2.27	280
MANUAL	320	10	1.86	1.28	1.50	280
AUTOMATIC	310	10	1.79	0.82	2.66	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN
CONFIGURATION 4

CONFIGURATION 4 NO DSFC | PILOT A | PR 6 | TR D | EVAL. FLT. NO. 2

INITIAL IMPRESSION AND GENERAL COMMENTS

Without any side force aid and crosswind from the right, I thought I would have made a reasonably good landing. Slightly cocked a little bit, I didn't get all the crab out, but it certainly wasn't an unacceptable airplane. It was okay. I do have a little bit of tendency to oscillate in the Dutch roll. Forces seemed to be reasonable. The only problem I really had that time was controlling the airspeed, I still don't have the exact throttle position. I don't know exactly where to set the power in other words. Apparently the only annoying feature is the fact that I have difficulty with the Dutch roll, it's oscillating almost continuously and I have a problem damping it out. The lateral-directional is not very good, it's quite oscillatory. You suspect that it's a combination of low damping which is not as good as I would like and it's probably combined with a high roll to sideslip ratio. I also get the feeling that it may have a moderate Y beta on this thing.

ABILITY TO TRIM

I didn't really have any particular difficulty with either the lateral or longitudinal

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

I just accepted what I had here, they seem reasonable. Let's say that the harmony is adequate. I did not make any changes on the stick forces or the gearings.

AIRPLANE RESPONSE TO PILOT INPUTS

It seems to respond quite readily in roll, I suspect that it's a combination here of rudder and aileron because I'm a rudder man basically and so I think I'm helping the roll We are getting some fairly good initial response in roll. The final response isn't predictable, apparently because I do get into a roll oscillation but the initial pilot input required doesn't seem to be extraordinary. No particular complaint on directional control. Turn coordination is not particularly difficult in the initial coordination. I think the big problem is in trying to stop the bank angle with precision and then this is where I get into probably a pilot induced oscillation. Pitch attitude control was a little sluggish, but acceptable.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final doesn't cause any particular difficulties that I could see.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

I've been making these approaches with crab angle into the wind and then when I get close to the runway I start taking some of the crab angle out and try to establish a sideslip. This is usually where I get into trouble. The second approach I think my technique was a little faulty. I started taking the crab angle out a little too soon and I really didn't establish the zero drift with the wind down. I always did this about the time I got in close to the ground and I had a tendency each time to balloon the airplane so then I started fighting the longitudinal in addition to try to establish a sideslip and zero crab angle. That's when I really wasn't happy with either of the landings [approaches 2 and 3]. The first one that I made didn't have turbulence in it, and I thought that was pretty good. I had everything pretty well under control. So maybe it's the turbulence, but anyway my second approaches I didn't like. The alignment didn't seem to be a problem at least until I got into this close to the ground situation that I just described.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Lateral control inputs did affect longitudinal motions, I think at least in the last two approaches I made, but I suspect that it's more the other way around. I think the fact that I had somewhat of a longitudinal oscillation, it took too much of my time so that the lateral-directional then suffered. I don't know which way you want to put it.

EFFECT OF RUNWAY CLOSURE RATE

Closure rates didn't seem to bother me.

GOOD FEATURES

I suppose the good feature is that I was able to control the heading. I was able to control the alignment with the runway. I was able to control the airspeed reasonably well considering there are some gusts here so that ±5 knots is probably as good as you would want.

OBJECTIONABLE FEATURES

The biggest one I guess is the lateral-directional situation where you get into oscillations and whether that is caused by faulty pilot technique, I don't know. Maybe I'm overdriving with the rudders and so I'm causing most of the problem, I can't really tell.

PILOT RATING AND PRIMARY REASON

Is it controllable? Yes, it's controllable. Is adequate performance attainable with a tolerable pilot workload? For the landing itself I would say no, well, I can't say no on that. I don't think I would want to put that into the unacceptable category, but it's close to it is what I'm trying to say. Deficiencies warrant improvement? Yes, and is it very objectionable, but tolerable? I think with some proficiency and practice I suppose, this probably would be tolerable. But it does require extensive pilot compensation I would say in close proximity to the ground when you are trying to set up attitude and zero drift so I guess I'm talking myself into a 6. I'm going to call it a 6 with one reservation, that is maybe it's just my lack of proficiency in these approaches but for now we will call it a 6.

TURBULENCE EFFECT RATING

More pilot effort is required. We'll call that a D with turbulence into the model.

CONFIGURATION 4 MAN DSFC   PILOT A   PR 4   TR C+   EVAL. FLT. NO. 2

INITIAL IMPRESSION AND GENERAL COMMENTS

This is a kind of rolly-polly airplane. I thought that was a decent enough touchdown on the end but the lateral-directional characteristics are very poor as far as any large amplitude maneuvering is concerned. I tried to make a turn inbound that time with about a 30° bank angle and I'm sure I was overcontrolling with the rudders, and that Dutch roll is certainly unacceptable. However, from the standpoint of landing, controlling the cross wind with the side force worked out okay. One of the problems I had though was trying to determine how much side force I needed because of this large oscillatory tendency of the airplane. I'm making a more general turn here about 15 to 20 degree bank angle and I'm cautiously trying to stay off of the rudders and that does help quite a bit, so apparently probably the biggest factor in the lateral-directional oscillation has been overcontrolled by the pilot with the rudder. The impressions were that I didn't like the configuration, lateral-directional configuration, but certainly the side force control was a great help in aligning myself. I would say that all of the touchdowns at least would have been successful and pretty good although there is still some thought in my mind that I'm always slightly nose right or slightly nose left. I suppose that with some more practice with the sideforce control I'll find the right amount for what I should be expecting in the way of correction for the crosswind.

ABILITY TO TRIM

Ability to trim was okay longitudinally. Lateral-directional I guess it really wasn't that bad. The biggest problem lateral-directional is that with an oscillation going most of the time it caused some problems.

FEEL CHARACTERISTICS AND CONTROL SENSITITIVITIES

The forces I think were okay, displacements were okay and the harmony okay.

AIRPLANE RESPONSE TO PILOT INPUTS

I get the impression that the aileron forces are a little bit high, so that you'd like to help yourself with the little bit of rudder when you start rolling into a turn. The only trouble with that is you have to be very careful that you don't overcontrol. The directional control problem is the rudder effectiveness in generating roll is quite high in comparison to the aileron. Turn control requirements are again all tied in with this sensitive high effectiveness of the rudder. It's a sluggish airplane in pitch, sort of a slow response but well damped and so I don't really have any particular complaints.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

The crosswind on turning final is no problem.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

I was trying to establish myself on the centerline pretty well and then taking a reading on the crab angle and then wiping it out with the sideforce control. That was really not that successful. I was always a little bit off centerline. Maybe part of the problem was in trying to determine exactly how much side force control I should put in there. Runway alignment was a little bit of a problem, but not basically, that's not a big point. Down close to the ground, I was much more successful but then I played the side force surface a little bit so, I think maybe it's just the poor lateral directional characteristic. I was never happy with having established a good steady state alignment and approach. This complicated the correction of the crosswind with the side force control and also the alignment.

CONTROL TECHNIQUE

I think I've finally found the proper, or the best technique in controlling this Dutch roll oscillation and what it amounts to is that you have to be very stingy with the rudder and essentially use the aileron in most everything you do. The control technique is that you have to use more aileron than rudder. The side force required was just a moderate amount.

CONTROL OF SIDESLIP WITH DSFC

The control of the sideslip was adequate, without any bank angle required although I tended to make some pilot inputs at the end without touching the side control. I think that was probably caused by the turbulence input.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

No, I didn't really think so.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

If you get into an oscillation you do have some tendency to bobble maybe in pitch, but I don't think that was really any significant thing. Do longitudinal control inputs affect the lateral? Not really, I think the biggest factor in the lateral was inadvertent rudder inputs possibly at times or just overcontrol.

EFFECT OF RUNWAY CLOSURE RATE

Closure rates didn't bother me particularly.

GOOD FEATURES

The fact that I can wipe out the crosswind very nicely and stay pretty well down the centerline with a little bit of effort.

OBJECTIONABLE FEATURES

The biggest objectionable feature I think was the lateral-directional characteristics. The high roll to sideslip ratio. I suspect possibly the gearing on the rudder. I possibly could have helped that situation by cutting down the overcontrol tendency by changing either the forces or gearings of the rudder, one or the other or both.

SPECIAL PILOTING TECHNIQUES

Just to try to not disturb the Dtuch roll by over controlling with the rudder.

PILOT RATING AND PRIMARY REASON

I have to rate the landing performance pretty fair. I had to work some because of the lateral-directional characteristics but rating it in a crosswind as compared to not having the sideforce capability certainly makes the airplane better. I would say that the performance requires moderate pilot compensation or minimal compensation. I am debating here between a 3 and a 4. I think that it took enough effort on the pilot's part that I would have to say we should try to do something about the dynamics of the aircraft. As far as being able to land the airplane, it was not a very difficult thing to do, but you do have to, watch that lateral-directional. So, I think I'm going to downgrade to a poor, minor but annoying deficiencies. I was happy with the touchdowns, but I was not too happy with the lateral-directional and this oscillatory tendency. I had to pay too much attention to it. So, that's the main reason for rating it a 4.

TURBULENCE EFFECT RATING

There is some natural turbulence. It was a little bit hard really to tell if I had any significant difference. I suspect that there is certainly more effort involved in turbulence than smooth air with this thing because of this rolling tendency and I would certainly have to rate it either a C or a D. I suspect that more effort is required and whether it is minor or moderate, it's hard for me to say, so I'm going to rate it a C+.

CONFIGURATION 4 AUTO DSFC   PILOT A   PR 5   TR D   EVAL. FLT. NO. 2

INITIAL IMPRESSION AND GENERAL COMMENTS

We only made really two full approaches with this configuration. I'll try to rate it anyway. I really would like to have seen this last one again. The general impression of course is that the system certainly relieves the pilot of the responsibility of aligning the airplane. Whether it's caused by turbulence or what, we were hunting on either side of the localizer with fairly large amplitude excursions, and it was very distracting to feel the side forces and have the airplane go back and forth on the localizer. It almost looked like a limit cycle at times.

ABILITY TO TRIM

No particular problem.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

I don't think I have to comment on that except that again I did not try this time to switch out the automatic side forces and have the system hold it's last position, as we have it set up now, and then try to make my last minute correction with aileron and rudder. It was just too much activity going on at all times with the side forces that I hated to do that, so I didn't. When I did try to make a correction, the aileron forces and in particular the rudder forces seemed to be higher than they would be without this automatic feature.

AIRPLANE RESPONSE TO PILOT INPUTS

Obviously we still have this lateral-directional problem that is, it's easy to induce the Dutch roll, and I don't like that. I was getting used to flying it essentially staying off the rudders, so the riding qualities seemed to improve some but in turbulence it's next to impossible to prevent quite a bit of rolling oscillation and the coordination, of course, is even more difficult in the turbulence than it is without the turbulence. Pitch control I didn't have any particular problems.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

I don't think there was any particular difficulty there.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

I just turned on the automatic side force control and allowed it to take me down to the localizer and then all I did was play around with the power and I did try to damp out some of the rolling motions.

CONTROL OF GLIDE SLOPE

Does the side force interfere with throttle or elevator control? I don't think so.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Lateral-directional control inputs affect the longitudinal? No, I don't think so. Except, right close to the ground where I have this tendency to balloon. If I get closer, I'm descending, and then I try to kill the rate of descent by pulling nose up a little bit more, that's where I always balloon. The technique should be like a mirror landing on a carrier deck, once you establish your rate of sink and attitude, just hold it. Maybe that's what I'm doing wrong, I don't know. The longitudinal control affect the lateral? Yes, to some extent, again that there is a cross coupling I think very close to the ground and also there is a tendency at that time, for me to, without thinking, use rudder.

EFFECT OF RUNWAY CLOSURE RATE

I don't think it's a big problem.

GOOD FEATURES

The good feature obviously is the fact that I don't have to worry about alignment.

OBJECTIONABLE FEATURES

The most objectionable feature I could see was this oscillating around the center line of the runway, which was done automatically by the side force control, and also the rather poor lateral-directional, or at least lateral characteristics. Those were the two major objectionable features.

SPECIAL PILOTING TECHNIQUES

The piloting technique was fairly simple as I said, you just worried more about the glide path and airspeed than you did about the alignment except near the bottom. Just before the touchdown the localizer displacements seemed to bring me over to the left, or vice-versa. It does require that the pilot enter the loop and try to make some correction at the same time so it's not a really constant thing. The pilot would have to use different inputs, different technique, maybe slightly different for each approach.

PILOT RATING AND PRIMARY REASON

I thought the touchdowns were okay. I certainly didn't like that oscillation about centerline. I think I would have to degrade that as compared to the manual input as having moderately objectionable deficiencies. I think you can get adequate performance without the considerable pilot compensation, so I'm really hung up between a 4 or a 5. I'm going to downgrade this because I certainly didn't like oscillating down the localizer and this last minute thing where we don't know whether you're down the centerline exactly or down the edge of the runway. The touchdowns themselves, after I got rid of that ballooning, were adequate. I'm going to rate this a 5 and say that I'm leaning toward a 4.

TURBULENCE EFFECT RATING

There is certainly moderate effort required because of the turbulence and so we will call it a D.

CONFIGURATION 4 NO DSFC | PILOT B | PR 6 | TR E | EVAL. FLT. NO. 18

INITIAL IMPRESSION AND GENERAL COMMENTS

My initial impressions were that the control, handling qualities of the aircraft were subpar lateral-directionally and adequate longitudinally. I'll go down the comment card and expand on whatever comments I have.

ABILITY TO TRIM

The trimability, longitudinally was adequate. I didn't use that much trim. I didn't have a need to. I didn't make any large bank angle turns and so I didn't note any requirements for longitudinal trim other to establish my rate of descent and attitude. Laterally though I did note that the trim required was not that large but that the trim control itself was slow, the rate was slow. I didn't feel the effect, I ran it either way for a second or two and hardly felt any resultant effect. Directionally I didn't use rudder trim.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics longitudinally were okay. I felt that the force gradient felt comfortable enough and was easily adapted to the displacements were average, but I did notice a slight tendency to PIO establishing a flare and making any precise corrections in pitch attitude. Laterally, I felt that it required a bit of wheel throw to feel the force gradient. I felt that there was a lot of free play about the center. A matter of interest, I didn't feel a good control harmony because the overall control harmony was destroyed by the aileron force gradient, or lack there of. Control sensitivities were okay except laterally. There was quite a lot of free play and a lag in response.

AIRPLANE RESPONSE TO PILOT INPUTS

Initial response in roll was slow, there was some delay and I wasn't able to predict the final response in bank precisely. The more I used lateral control the more I felt that I was just pumping it back and forth and wasn't really getting the aircraft attitude changes that I desired. I did try to make rudder only turns, small corrections in heading on my final, but they seemed to excite the Dutch roll which was very apparent and not very well damped. Pitch attitude control was all right. Initial response, I didn't note much of a lag and I could predict final response all right. However, there was some tendency to PIO down at the bottom establishing a flare.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Turning final in the crosswind didn't cause any significant difficulties. However, the turbulence fed in, did cause some problems because it excited what appeared to be the Dutch roll and there were resultant yaw and roll oscillations.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

My approach method was to establish a crab on final approach and then kick out the crab just prior to establishing the flare attitude. This just feels more comfortable for me. I can line up [the flight path] with the runway and just pull the aircraft nose over with proper control inputs to align the aircraft with the runway. Runway alignment was not difficult. However, there were some oscillations and I didn't feel that I had the aircraft fully under control in azimuth. Although, I did align with the runway there was oscillation, a continuous oscillation, as a result of either the large gross aileron inputs I was making and whatever turbulence disturbances there were. I did have some difficulties making precise alignment with the runway and holding my heading.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

The lateral directional control inputs did seem to affect longitudinal motions. I did have some noticeable attitude changes longitudinally and I had some difficulty with airspeed control, on final it varied 5 knots either way.

EFFECT OF RUNWAY CLOSURE RATE

Runway closure rate doesn't seem to affect the task accomplishments, I guess I've just compensated for it.

GOOD FEATURES

The aircraft felt good initially.

OBJECTIONABLE FEATURES

Objectionable features are the lateral control systems, the dynamics and the control system combination. I felt that I couldn't have made a very precise touchdown and felt that like I would have some kind of roll rate because of the large aileron inputs that I was making, I felt that I was PIOing laterally.

SPECIAL PILOTING TECHNIQUES

No special piloting technique other than the method I used on final approach.

PILOT RATING AND PRIMARY REASON

Overall I would rate this as a 6, primarily because of the poor lateral control-ability combination of the control system, I guess, and the dynamics. I felt that the lateral control feel destroyed the overall handling of the aircraft. I wouldn't rate it any lower than a six, if anything I would lean to the higher side.

TURBULENCE EFFECT RATING

And turbulence did have a marked effect on the performance of the task. It deteriorated it to the point of my rating it an E, because of the disturbances laterally that I saw and felt.

CONFIGURATION 4 MAN DSFC   PILOT B   PR 3.5   TR D   EVAL. FLT. NO. 18

INITIAL IMPRESSION AND GENERAL COMMENTS

Initial impressions of the lateral directional, longitudinal handling qualities were such that longitudinally the aircraft was all right, and lateral-directionally had some deficiencies. I will comment on these as I go down the comment card.

ABILITY TO TRIM

Ability to trim, longitudinally was fine. Laterally I felt that I was not getting adequate trim rate response and in conjunction with the elevator it didn't give me a good feel. Elevator trim was a little faster, I felt that trim rate was a little faster. At least it appeared that way. I tended to use a lot more aileron trim, as a result I did use rudder trim a couple of times, trimming the aircraft up to align with the runway before I started my rate of descent.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics were okay longitudinally and directionally. Laterally the overall system bothered me a little because of apparent free play and large wheel throw required to acquire desired bank angle and roll response.

AIRPLANE RESPONSE TO PILOT INPUTS

Sensitivity felt all right once I felt the response begin but initially there was some lag, excessive, in my estimation, and it made it very difficult to predict the final response in roll. Directionally I had no complaints. Turn coordination was adequate, however, I felt that whether I was making a turn coordinated or with rudder only or aileron only it always resulted in some yaw, roll oscillation. Pitch attitude was much more noticeable for some reason. Maybe in an effort to establish a good flare attitude, I did have a tendency to PIO in the flare although the control system felt all right coming down final. I was able to establish the desired pitch attitude and maintain it.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final didn't cause any difficulties, however, the turbulence effects were felt significantly and added with other lateral-directional inputs of my own and tended to increase the yaw and roll oscillations.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

My method during the approach was to establish the crab and gauge the crosswind and the correction and, using side force controller, I was able to align the aircraft with the runway, at least parallel to it, and runway alignment was a fairly easy task. Although, because of the oscillations in yaw and roll, I wasn't able to maintain a constant alignment with the runway and I did have some difficulties there.

CONTROL TECHNIQUE

Control technique, I did use the side force controller to my satisfaction. I aligned the aircraft with the runway. I felt that I did have a good feel for the direct side force controller, how much control was necessary to align, trim the aircraft with the runway heading. I didn't tend to overshoot at all and I made very minor corrections on final approach. Very minor in nature so that the initial runway alignment and initiation of side force deflection, the control deflection was an easy task, and it really aided me in making the approach, in performing the task.

CONTROL OF SIDESLIP WITH DSFC

Control of side slip was easy with the side force controller. I didn't require any bank angle.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

Manual control did not interfere with lateral-directional control. I didn't feel it induced any oscillations. I may have unconsciously counteracted any response on the lateral axis, but I don't think so. I prefer using the switch on the throttle rather than on the wheel column. It just feels more comfortable there. However, one minor defect that I see is that the detent is not as pronounced as it is on the one on the wheel. So that I really don't feel, I have to feel where the detent is. The task was much more easily performed with the side force controller because I had less requirement for lateral directional inputs during the final approach.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I didn't note any significant longitudinal motions as a result of lateral-directional control inputs and vice versa.

EFFECT OF RUNWAY CLOSURE RATE

Runway closure rate is really no effect now. The rate is easily compensated for.

GOOD FEATURES

Overall the most significant one is the direct side force controller. What it does is just eliminate another problem in another portion of the task. It does it quite handily.

OBJECTIONABLE FEATURES

Any objectionable features were primarily the ailerons, the lateral control responses or lack of responses.

SPECIAL PILOTING TECHNIQUES

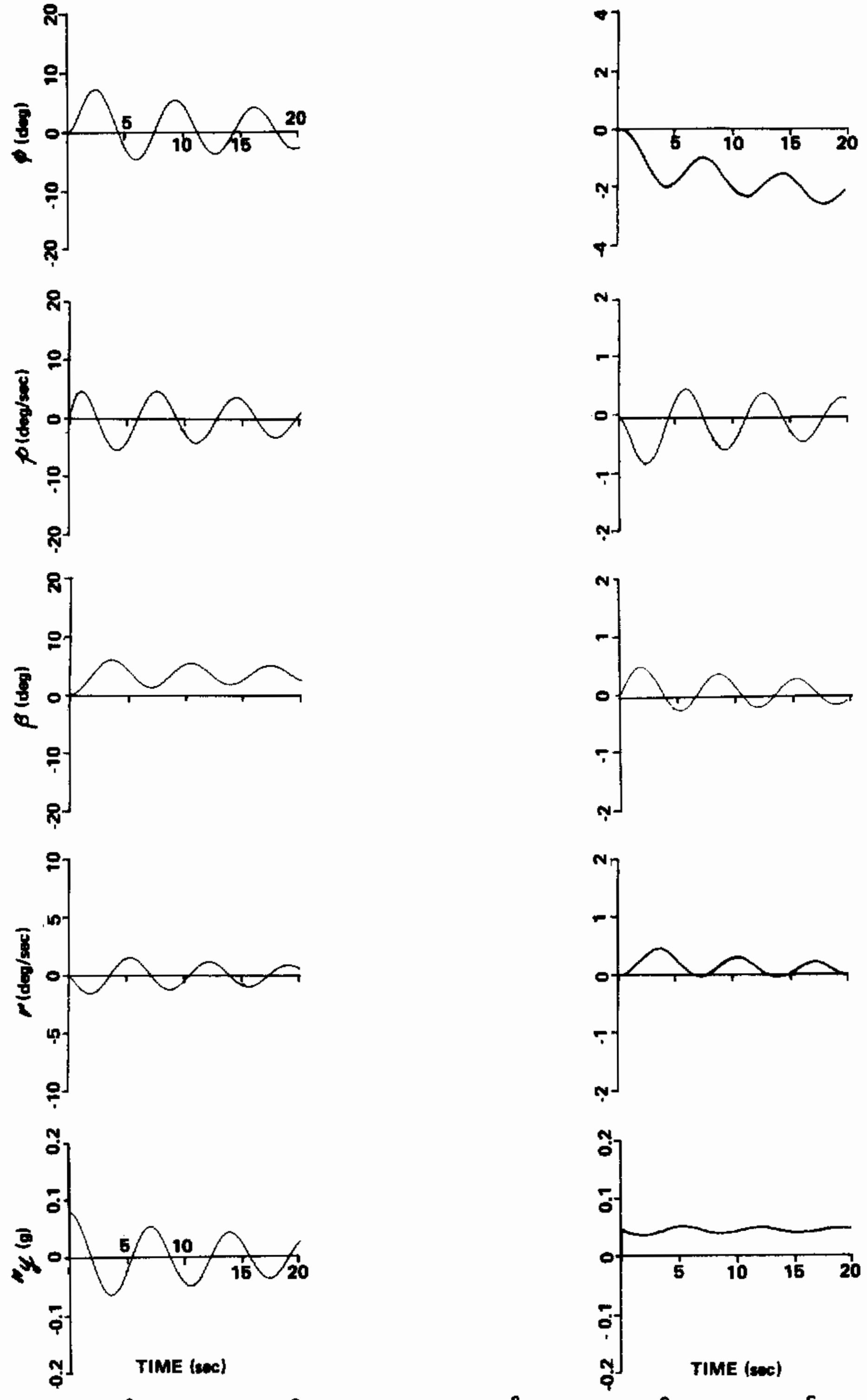
I've already discussed how I used the direct side force controller and runway alignment.

PILOT RATING AND PRIMARY REASON

I give this system a 3.5, not a 3 because of the increase in workload required by the lateral control system dynamics. I still felt like I was pumping ailerons coming down final and I still did have the oscillations. However, the direct side force control did increase or improve the task performance. So I gave it a 3.5.

TURBULENCE EFFECT RATING

Turbulence was a factor in that still induced oscillations about yaw and roll axis. I didn't feel too much longitudinally. Overall, I'd give it a turbulence rating of D because it did excite the yaw roll motions and was the only significant contribution to deteriorating the performance of the task.



(a) δ_y = 10.0 deg, δ_a = -8.24 deg, δ_r = 4.68 deg (b) δ_y = 10.0 deg, δ_a = 0.0 deg, δ_r = 0.0 deg

MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO THE AILERON AND RUDDER (CONFIGURATION 8)

CONFIGURATION 8 FLIGHT TEST DATA TABULATION
(EVALUATION FLIGHT NO. 7 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	-2.56	1.76	-3.49	0.86	-11.48	4.09	23.1	6.13	0	7	D

CONFIGURATION 8 WIND AND GUST DATA

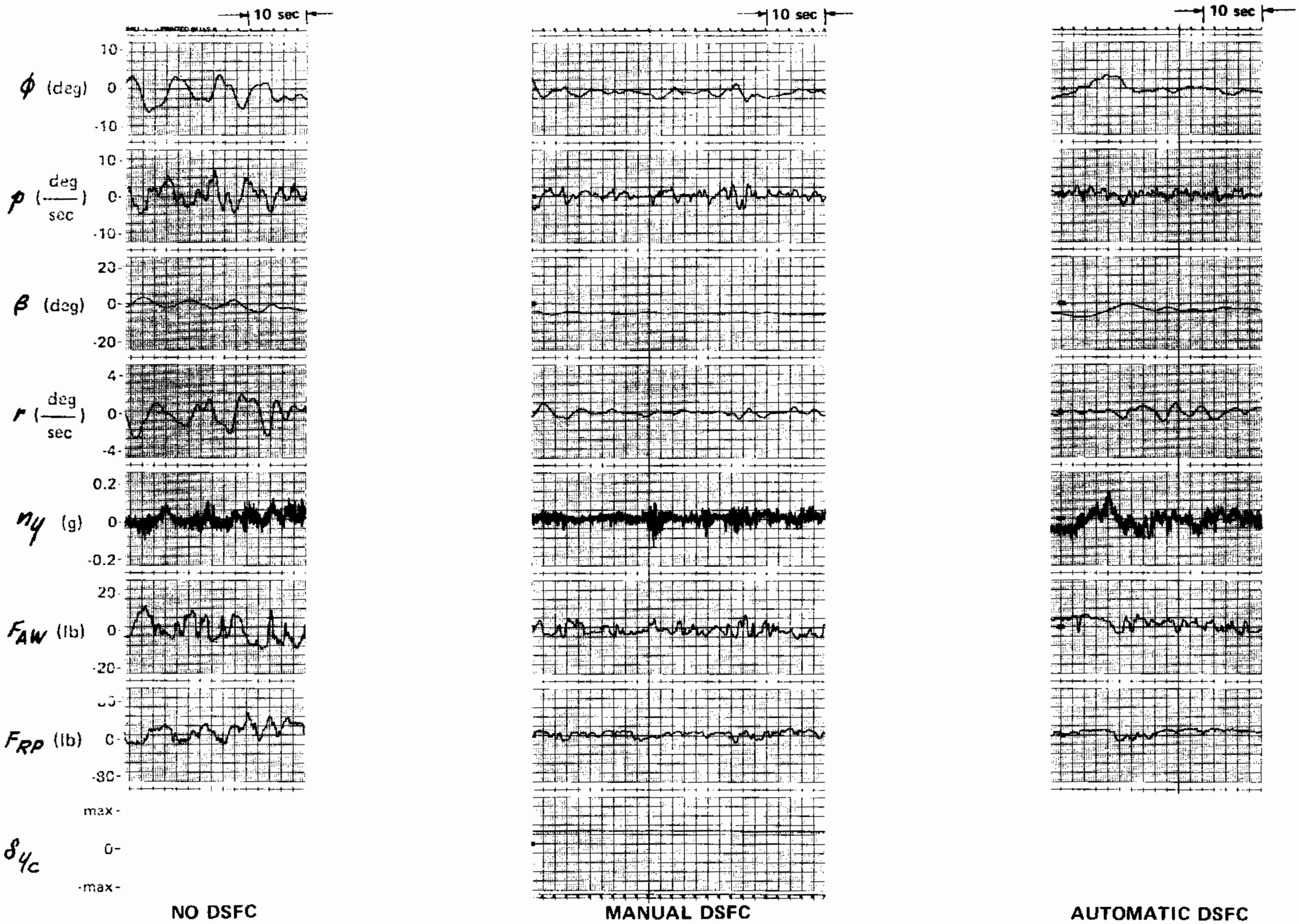
	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	240	12	0.77	1.37	1.89	280

CONFIGURATION 8 FLIGHT TEST DATA TABULATION
(EVALUATION FLIGHT NO. 16 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	-1.38	1.73	-2.18	0.92	-5.63	5.08	19.0	13.72	0	8.5	D
MANUAL	-0.95	0.95	-4.97	0.29	-1.87	2.56	3.85	6.36	-8	3	C
AUTOMATIC	-0.69	0.52	-3.01	0.50	-0.70	2.15	11.1	1.95	-5	3	A

CONFIGURATION 8 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	210	17	1.31	1.06	2.39	280
MANUAL	210	15	1.42	2.17	2.90	280
AUTOMATIC	230	17	1.10	1.32	3.90	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN
CONFIGURATION 8

CONFIGURATION 8 NO DSFC PILOT A PR 7 TR D EVAL. FLT. NO. 7

INITIAL IMPRESSION AND GENERAL COMMENTS

The visibility again is really very, very marginal. I'm worried more about trying to find the darn alignment to the runway. I think this does make me work quite a bit harder. I made two approaches with the turbulence in. I seem to have gotten one in without turbulence. With the turbulence, I worked quite a bit harder. The first one with the turbulence, I just felt that I would have had to make a missed approach. The second one, I think, would have been all right but I did balloon again and I think this is a cross coupling between the lateral and longitudinal because of the very heavy aileron forces that I have to hold.

ABILITY TO TRIM

The trimmability is okay, all axes.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics in just flying the airplane on the approach are okay but in trying to control the crosswind, the aileron forces get to be quite high. They're fairly marginal. I was able actually to kill the drift on that second approach with the turbulence in. However, again the turbulence does affect me. It doesn't really seem to affect me maybe as much as I remember with natural turbulence. The natural turbulence is fairly mild, I think, generally. And the canned turbulence apparently doesn't disturb the airplane as much as the natural does, therefore, there's some question as to whether the airplane is actually being disturbed sufficiently but all I can do is read what I see. Okay, the selection of the control sensitivities, I just accepted what I had in up and away flight. I attempted to do a steady state sideslip maneuver and trying to hold the heading. It's a little difficult, on the heading hold, that is maintaining steady state with sideslip in there. I think basically because it's so difficult to establish a good bank angle, steady state bank angle because of the very light Dutch roll damping which appears to be pretty darn close to zero.

AIRPLANE RESPONSE TO PILOT INPUTS

The roll control, certainly the airplane rolls initially very well but you do have to consciously damp the airplane out. Directional control, I guess it does feel sort of loose both directionally and lateral and as I say, the biggest problem is the damping of the Dutch roll. Pitch attitude control, initial response is sort of sluggish, somewhat slow let's say. However, it's adequate.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final, you can't really tell. There doesn't seem to be much in the way of disturbance that you can feel.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

I definitely have to land in a crab. It's at least, I notice, something like 5° or better, somewhere in that area. The runway alignment, I kept drifting to the right a little bit. I was having some difficulties with the alignment but I have so little time really to align myself because the final turn usually is in very close and I have to worry more about the setting up. I'm working too fast really. I think that you're compromising maybe a little bit the pilot's ability to evaluate these points because we're coming in too close. The visibility is officially 2-1/2 miles. It looks at least that from up here if not worse and it's sort of a spotty situation. So I think we're really in a ragged edge on the weather here.

CONTROL TECHNIQUE

Control technique, just as I said before, just trying to get yourself aligned soon enough so you can see what you're doing.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

The lateral-directional control inputs affect longitudinal, I think I would say definitely in both of the landings with the turbulence in, I ballooned the airplane. I think partly it's because I'm coming in with a very steep angle and I have to have the power way off and then as I start my round out which is fairly soon, I have to start it a pretty fair distance out. Then I have to add power and I suspect that I'm probably adding a little more power than I really should and so that when I get in close, if I just make a slight error in attitude, I just climb back up again, I guess. I haven't really got time to be looking at my thrust. I look at it once and try to set it and after that I just, by feel, just put in a small amount of what I think is a small amount of thrust and then doing a good approach. So anyway, I think there is some cross coupling and I'm not too happy with the whole situation.

EFFECT OF RUNWAY CLOSURE RATE

The closure rate, certainly the rates of descent are somewhat higher than you would like but it's not a big item. I think the biggest item is that I don't have the drift and alignment all squared away by the time I start my flare, which is as I said before, fairly far out relatively speaking.

GOOD FEATURES

So the good features I guess basically it's longitudinally, I do have some reasonably good airspeed control it seems even with the turbulence in. I didn't particularly find that that was very erratic.

OBJECTIONABLE FEATURES

Objectionable features, basically I think it's the Dutch roll damping and the heavy aileron forces required to establish the bank angle when I have to establish a sideslip to kill the drift. As I said before, out of the two approaches with the turbulence, the first I thought was a missed approach. It would have had to have been a missed approach. I was off to the right of the centerline and I was oscillating and I really wasn't -- I was behind the airplane. I don't think I had it under good enough control to make a landing unless I would have made the landing way down the runway. Those are the primary objectionable features.

PILOT RATING AND PRIMARY REASON

The pilot rating I think certainly has to be, "deficiencies require improvement." Certainly major deficiencies, adequate performance not attainable with maximum tolerable pilot compensation. Okay, controllability not in question. I suppose that probably answers the question better than any of them since out of three approaches, the first one with no turbulence, I thought I had it, I could have made the landing. I think you can learn some with this though. Maybe if you eliminate some of these side issues like visibility and, you know, time for alignment and so forth, things might work better. You might do it better. Maybe you can almost say that extensive pilot compensation can give you adequate performance so you're really on a ragged edge between a 6 and a 7 I think on that. I think I'm going to rate it a 7.

TURBULENCE EFFECT RATING

I would say that in the turbulence definitely more effort is required. Moderate. Well, certainly moderate and maybe best efforts required with moderate effort, deterioration of task, maybe that's also another. So really I'm debating between a D and an E. I guess I'll call it a D for the turbulence.

CONFIGURATION 8 NO DSFC	PILOT A	PR 8.5	TR D	EVAL. FLT. NO. 16

INITIAL IMPRESSION AND GENERAL COMMENTS

In general it's a lousy airplane. That's the best I can say for it. The Dutch roll damping seems to be pretty darn light. As a matter of fact when we first looked at it at 6000 ft., it looked like almost it was divergent but it's slightly positive. The directional stiffness of the airplane seems also to be quite low. At least I can generate a large sideslip with what appears to be fairly light rudder inputs. I'm assuming that the gearings are the same here for all the configurations because I haven't changed them. And if that's the case, the only thing I can say is that it's quite loose directionally. You can fly the airplane fairly well with just the ailerons. But when you get in turbulence, there is some tendency to slosh around a little bit so you do use the rudder. Anyway, the first approach I just dished out of the whole thing. I really didn't have the airplane under good control and that was a practice one so I've made three more approaches and I got successively a little better but never really felt that I had good solid control of the airplane. It was just one of those things where if you happened to be close, you can set it up and maybe you can let the thing touch down. But you wouldn't really know whether you touched down with zero side velocity or not and whether you were lined up with the runway or not either. So it is not a good feeling airplane. The last approach I made, I tried using two hands on the wheel. The problem here is that when you try to kill the drift with bank angle and holding the rudder in, the rudder seems to overpower the aileron, is the best way I can describe it. When you try to align the airplane and you put some rudder in, the aileron requirements, at least as far as force is concerned, is so high that you can just barely do it with one hand but that's just not very good. Then there's a tendency there to couple a little bit with the pitch and so the whole thing goes to pot so it's not a good airplane.

ABILITY TO TRIM

I was able to trim okay on downwind both lateral and longitudinal, not really too bad but we were in what I would have called light turbulence at the 1700, 1800, 1900 ft. level and there is no need really for any rudder inputs at that point so that you can keep the sideslip, or the sideslip stays, let's say, ±1 or 2 degrees, not too bad. Longitudinally there is no problem at all.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The forces and displacements in up and away flight seemed to be quite good. I was able to make 30° bank turns with damn good precision. As a matter of fact, I had the feeling that the damping or something in the turn made the airplane feel much better than it did in straight and level.

AIRPLANE RESPONSE TO PILOT INPUTS

The airplane does respond in roll quite snappily if you use rudder, almost gives you the feeling, for example, that maybe this N_{δ_a} is largely adverse but I'm pretty sure that's not true. It didn't look like it. And so I guess you would have to tie this in with $|\phi/\beta|$ possibly. It's not a bad feeling airplane if you're just up and away and making turns. Roll control seemed to be okay until I get down too close to the ground. Trying to keep the direction with rudder, in other words proper heading, the roll control seems to be degraded. It's just an overpowering of the roll control with the rudder I imagine, rolling moment due to sideslip. Directional control, I think the best way I can describe it is the airplane is quite loose directionally so it's quite easy to generate some fairly large sideslip and also heading changes are easy to generate. In making turns there was hardly any coordination problem but it does enter in when you're trying to make very precise correction down close to the ground. There I'm sure it's not a coordination problem but rather the ability to generate a precise bank angle and heading with this particular set of dynamics. The pitch control was no particular trouble. I did have some coupling.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

I hardly noticed it.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

Landing approach was done with a crab and then I tried to eliminate the crab with a sideslip and bank angle just before touchdown. The alignment again was done with rudder and aileron and here's where the difficulties came in. The performance by the pilot, I think, was very poor. There were, let's say, a couple of successful touchdowns but I think it was more a matter of luck and not really the pilot feeling that he had complete control of the airplane.

CONTROL TECHNIQUE

I tried to minimize the use of rudder as much as possible until my approach is down to the point where I started my flare and tried to decrab. The approaches were not really bad. I really wasn't having that much trouble with it but everything happens when you start decrabbing the aircraft for touchdown.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

The lateral control inputs did affect my longitudinal a couple of times because the aileron forces are so damn high when you use sideslip and rudder to align the airplane with the centerline.

EFFECT OF RUNWAY CLOSURE RATE

No I don't think so. I get the feeling that my approaches are not quite as steep as I've been making them and maybe that's cheating a little bit. Maybe that's not even true but the closure rates I was not really aware of.

GOOD FEATURES

I don't know that there are really any good features. Longitudinally it's okay. Approaches with just using aileron seemed to be reasonable.

OBJECTIONABLE FEATURES

The main thing that hits you on this thing is this business of trying to place the aircraft in a wing-down position with the nose pointed down the runway. This is a very difficult task and I think it's primarily a function of rudder effectiveness and Dutch roll damping. In other words, it seems to me that I'm overcontrolling with the rudder and if I'm not overcontrolling, the force on the aileron required to generate a bank angle for alignment purposes gets much, much too high and yet in up and away flight the aileron forces are fine.

SPECIAL PILOTING TECHNIQUES

There's no special piloting technique that I could see except that in most of the pattern work, you minimize the amount of rudder you put in, use ailerons primarily but there comes a time when you can't just do that.

PILOT RATING AND PRIMARY REASON

The airplane is controllable but marginally. It's in the "deficiencies definitely require improvement," and these are major deficiencies and compensation required to retain control is pretty damn high. It isn't that you're losing control. It's just that the precision gets to the point where the pilot feels uncomfortable, that he just doesn't feel that he can repeat the performance. If you happen to land the airplane, you wonder whether it was a matter of dumb luck or whether you actually were the cause of it; that is, whether you're flying the airplane or the airplane is flying you. So, considerable compensation certainly is required, I'm debating between an 8 and a 9. So much of that pattern was not bad that you begin to feel oh well, it's not that bad an airplane but the actual touchdowns I didn't particularly like. When I got two hands on it, I was able to feel fairly good about having the airplane under control. So maybe there's a limitation on the gearings that I picked. I'm sort of torn between an 8 and a 9 so I'm going to rate it an 8.5.

TURBULENCE EFFECT RATING

The deterioration in turbulence was noticeable. I don't know that it was a large amount. I would say probably moderate. I don't think that I had any great big troubles in turbulence vs. non-turbulence, although we do have turbulence to begin with. I would call it more effort is required but couldn't tell a hell of a lot of difference between no turbulence and turbulence except that the airplane feels more uncomforatable when you're just flying along and you're sloshing around. So I guess I'll call it moderate so we'll call it a D.

CONFIGURATION 8 MAN DSFC PILOT A PR 3 TR C EVAL. FLT. NO. 16

INITIAL IMPRESSION AND GENERAL COMMENTS

This is the same configuration of course with manual side force control. Boy there's a difference of night and day in the performance. The pilot really had a fairly easy time of landing the airplane. It makes the airplane acceptable now. As long as you don't have to use aileron and rudder to establish landing attitude.

ABILITY TO TRIM

The ability to trim hasn't changed any. I'm able to trim the airplane all right. I flew it for long periods of time after the aircraft was given to me hands off. In other words, the engaging was done and I let the airplane fly itself for a matter of at least a minute or two and so there's no question that the airplane, I think, was stable. With the gusts in, there was one time there where it almost seemed like the lateral or Dutch roll oscillation was building up but it did damp out.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics are quite comfortable. It's like up and away flight in effect, because the aileron required for these landings once the side force surface is properly placed is essentially zero. There are very small aileron inputs required, there is essentially no rudder required and so that is really the crux of it. I'm able to use the ailerons for small corrections and I don't need to use any rudder so the ailerons feel fairly normal.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll control is quite adequate. Directional control is no problem at all because I can use the side force to align me on the final approach. With the turbulence in, however, there is definitely a problem in trying to establish what the heck the position of the side force surface should be. On one with turbulence I continued to make corrections with the side force surface almost right down to the landing attitude. There was some tendency to overcontrol. I ended up needing a right bank angle and so then that's when I decided to go ahead and use the side force in small increments all the way down.

DIFFICULTIES ON TURNING FINAL WITH CORSSWIND

The crosswind turning final was no problem.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

The landing approach was made, trying to establish an alignment with the centerline using the side force control. So the runway alignment was very, very good. I though the pilot performance of the task was reasonable. I did have some difficulty in establishing exactly where the sideforce control should be, but never off more than maybe a degree or so, maybe two but pretty close.

CONTROL TECHNIQUE

Control technique, I used only the elevator and some small amount of aileron, no rudder at all and obviously there is no coordination problem involved here once you're on final.

CONTROL OF SIDESLIP WITH DSFC

Control of sideslip with the side force is adequate and as I say very minor bank angles were needed on occasion to overcome some gusts or something but that's all.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

There is no interference with the lateral-directional control due to the side force surface.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I didn't really have any particular tendency to PIO in pitch that time. I suspect it's because I didn't have to put in any aileron, or there was no large aileron input required especially forcewise. I don't know how much aileron is in there but the forces without this crosswind [sideforce] control were pretty high.

EFFECT OF RUNWAY CLOSURE RATE

Closure rates, were no problem. I thought I made two excellent landings with and without the turbulence.

GOOD FEATURES

The good features obviously are the fact that practically all of the problems that the pilot had without the crosswind controller all of those problems disappeared essentially completely.

OBJECTIONABLE FEATURES

I don't really see too much in the way of objectionable features although, on occasion, I had to do some damping of the roll with a small amount of aileron but that was a fairly minor part of the task.

SPECIAL PILOTING TECHNIQUES

The special piloting technique was of course using the crosswind controller and really not using any rudder at all.

PILOT RATING AND PRIMARY REASON

I would have to rate this airplane as satisfactory without improvement. I really think that this is an amazing thing compared to without this controller where I was rating it an 8 or a 9, 8.5, whatever it was. Minimal pilot compensation required for desired performance. That probably answers the question so I'm going to rate this a 3. I think it's acceptable. It would help some I think if we had some damping of the Dutch roll but I can't fault the airplane hardly at all. The minimal compensation I think has to do with trying to damp out roll oscillations when the turbulence hits you but I must say though that the turbulence input was fairly minor on this one. It probably would have been better to increase the turbulence input on this one. You might downgrade the airplane some if that actually happened. Maybe it would take a moderate pilot compensation but I can't conceive of the thing being degrading if you increase say the turbulence to moderate.

TURBULENCE EFFECT RATING

Between no turbulence and turbulence, there is some slight deterioration but I think it's minor. At least it looked that way to me so I'm going to call that a "C".

CONFIGURATION 8 AUTO DSFC   PILOT A   PR 3   TR A   EVAL. FLT. NO. 16

INITIAL IMPRESSION AND GENERAL COMMENTS

I threw the automatic switch even though we were quite a ways off the localizer and the heading was off a little bit and it still brought us back down in pretty good shape. We made the approach and the landing - I had a rate of descent on landing which I think would have been a slightly hard landing but not really by normal definition of hard landing, just a slightly modified Navy-type landing is the best way I can describe it.

ABILITY TO TRIM

Ability to trim again is no problem.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics are good, except that on the final, because this is an attitude hold kind of a situation the forces are fairly heavy. I do have a tendency to keep putting aileron in when the wing drops due to the turbulence or whatever. I don't really know whether I'm modifying it very much because my inputs are not exactly large. The control sensitivities you can't really discuss that on the final except in the sense that it takes fairly heavy forces and even then it's hard to say whether you're actually displacing the airplane. The turbulence level I think was light to moderate what was being put into the model. I didn't notice quite as much hunting that time as I did before, I thought that was pretty good. We were just slightly off centerline to the left and outside of that it was pretty good. I was a little bit behind the airplane but everything else looked pretty comfortable so I thought I had good control of attitude that time. I didn't really do very much at all in trying to overcome the system.

GOOD FEATURES

Good features obviously is the fact that the pilot workload is decreased substantially because everything is taken care of. The wings level, alignment with the centerline, incidentally the alignment that time looked pretty good.

OBJECTIONABLE FEATURES

The only objectionable things I can see is still this business that the airplane does want to hunt on either side of the localizer but it certainly is quite a bit milder right now. The side acceleration I guess is the thing that is decreased substantially now and so it's sort of a gently sloshing back and forth. You can feel it in the seat of the pants but it's not nearly as objectionable as I remember.

SPECIAL PILOTING TECHNIQUES

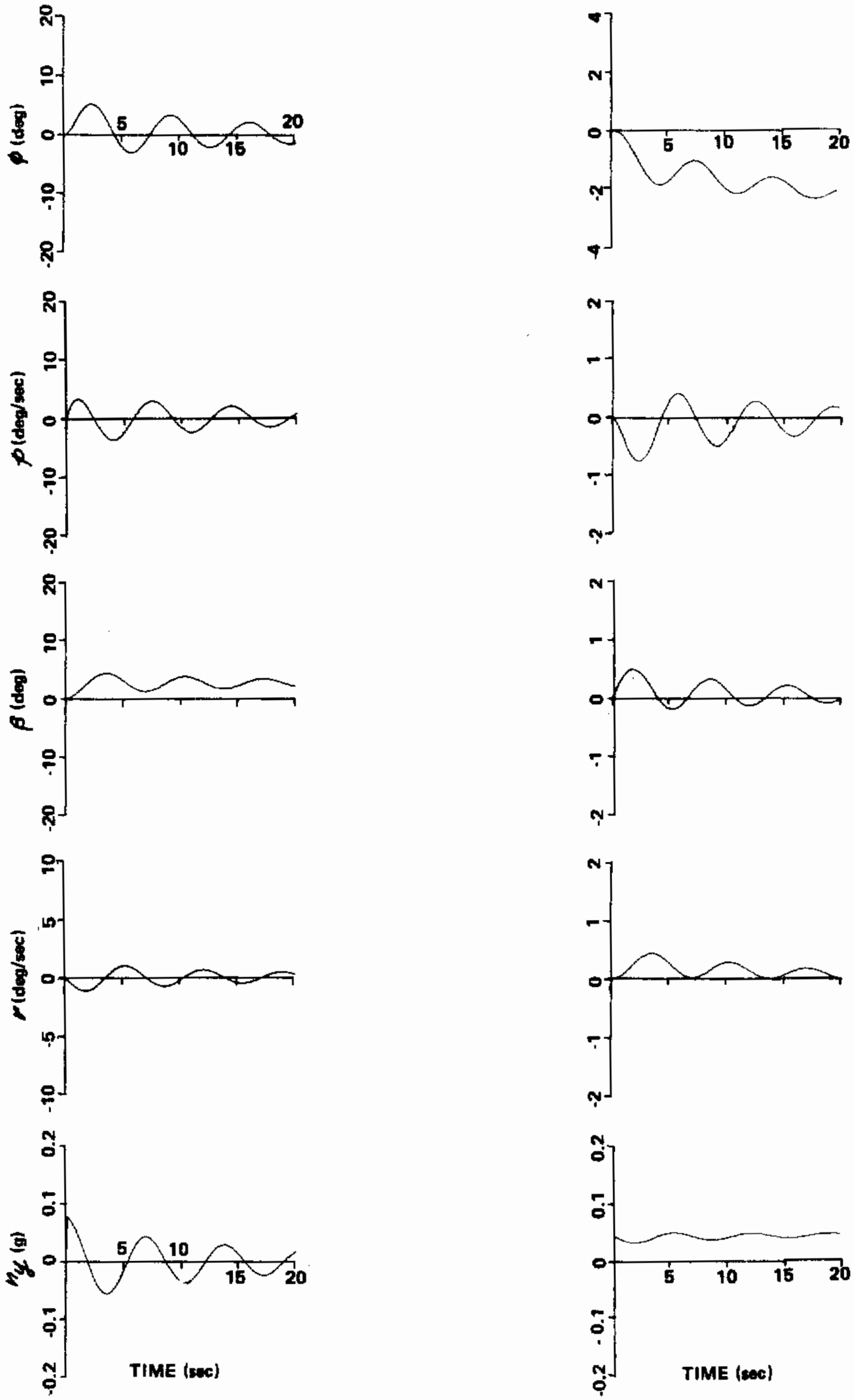
The only special piloting technique is in effect just go ahead and fly the pitch and the power, or course. It's a one axis airplane.

PILOT RATING AND PRIMARY REASON

I think I'd have to rate this thing acceptable. The mildly unpleasant deficiencies I think are more related to the automatic system, the way it works rather than the dynamics of the airplane although it's hard to say but the thing that's more noticeable to me is the fact that the airplane goes from one side to the other of the localizer. It's a pretty good airplane and I think it's probably just as good as it was with manual control although on manual control, it's more comfortable, it's more airplanelike because you don't have these extreme motions about the localizer. I think I'll stick to the rating of 3. I don't think I'll upgrade this from the manual and I don't think I'll downgrade it either. I'll just wipe out the effect of the hunting along the both sides of the localizer.

TURBULENCE EFFECT RATING

I really didn't see any significant difference between turbulence and no turbulence. I really can't see any difference. So I'm going to rate that an "A" for the turbulence which is a very, very unusual but I really couldn't see where I had to work any different.



(a) δ_y = 10.0 deg, δ_a = -6.16 deg, δ_r = 3.51 deg (b) δ_y = 10.0 deg, δ_a = 0.0 deg, δ_r = 0.0 deg

MODEL RESPONSES TO A 10 DEGREE SIDE FORCE GENERATOR INPUT WITH AND WITHOUT INTERCONNECTS TO THE AILERON AND RUDDER (CONFIGURATION 12)

CONFIGURATION 12 FLIGHT TEST DATA TABULATION

(EVALUATION FLIGHT NO. 4 PILOT A)

	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
DSFC MODE	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE	-3.70	2.24	-3.61	1.02	-11.9	7.97	25.6	10.1	0	8.5	E+
MANUAL	2.50	1.76	-6.19	1.17	1.01	4.65	-2.42	7.93	-20	4	D
AUTOMATIC	0.07	0.56	3.16	0.55	- 0.21	2.55	9.17	2.16	-12	4	C+

CONFIGURATION 12 WIND AND GUST DATA

	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
DFSC MODE	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE	200	12	3.01	1.54	2.60	280
MANUAL	200	11	1.93	1.70	4.52	280
AUTOMATIC	180	8	2.40	1.44	2.29	280

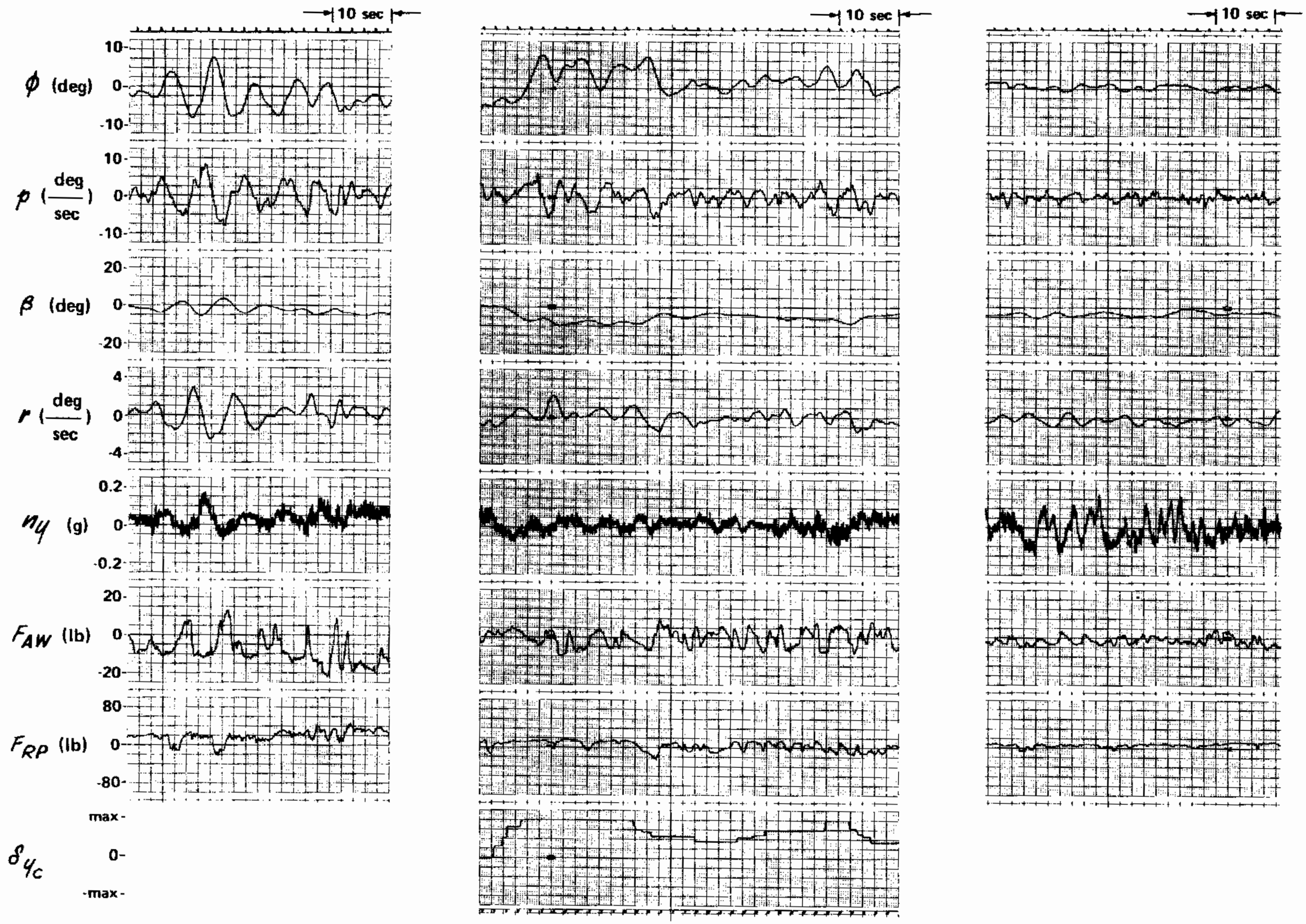
CONFIGURATION 12 FLIGHT TEST DATA TABULATION

(EVALUATION FLIGHT NO. 21 PILOT B)

DSFC MODE	ϕ deg		β deg		F_{AW} lb		F_{RP} lb		δ_y deg	PR	TR
	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	RMS	MEAN	–	–
NONE				(DATA NOT AVAILABLE)							
MANUAL	2.08	1.90	9.20	0.64	6.8	3.99	-16.0	7.35	15	5	D

CONFIGURATION 12 WIND AND GUST DATA

DFSC MODE	NATURAL WIND		GUST COMPONENTS (RMS ft/sec)			RUNWAY HEADING (deg)
	DIRECTION (deg)	SPEED (knots)	v_g	w_g	u_g	
NONE		(DATA NOT AVAILABLE)				280
MANUAL	360	10	2.54	1.15	1.51	280



TIME HISTORIES OF LANDING APPROACH AND FLARE TO TOUCHDOWN
CONFIGURATION 12

CONFIGURATION 12 NO DSFC PILOT A TR 8.5 TR E+ EVAL. FLT. NO. 4

INITIAL IMPRESSION AND GENERAL COMMENTS

We sure have a pretty good crosswind from the left. The Dutch roll is sure not very good. Just before touchdown, the forces were very high and almost felt to the pilot like he was not really running out of control but that he was losing the effect of control at least to kill the drift. I wasn't too happy, the touchdown would have been with some side velocities. I couldn't really find what kind of a combination I should use. The rudder is quite effective and it seems that I get the feeling that the aileron forces are so high for the amount of force I'm putting in seems to be not really acceptable. It's a very marginal thing. To get this airplane down on the runway without drift and also trying to displace the airplane and holding it on the centerline is quite a task. So, it's not very good. My initial reaction is that this is one hell of an airplane to try to line up with the centerline and to land it. I made three approaches. First two completely unacceptable. The lateral-directional characteristics are so poor that the pilot is always working trying just to hopefully smooth out the Dutch roll. There certainly is a big difference between the turbulence input and the no turbulence input condition. On the last approach I finally succeeded in landing the airplane. The only thing is it took two hands on the wheel, that's not very good.

ABILITY TO TRIM

I don't think that is really a problem, either lateral or longitudinal.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The displacements look okay. The forces for normal flying are fine, however, the aileron forces get to be almost overpowering it seems in the crosswind in attempting to land the airplane. Rudder seems much more effective than the aileron. I suspect what we have here is a large Y-beta kind of a model, I'm not really sure, but I can't displace the airplane sideways, against the cross wind very easily. I didn't change any control sensitivities because it felt pretty good in up-and-away flight and I don't think you want to pick the forces just so you would be able to land in a crosswind and then have them much too light in up-and-away flight, so this is sort of a compromise.

AIRPLANE RESPONSE TO PILOT INPUTS

Roll initial response isn't too bad. I can't really tell whether we had proverse or adverse yaw due to aileron. I think it's either zero. Almost looks like it was adverse a little bit, but I couldn't tell really. It's not a factor, I think. The airplane feels quite loose in the lateral-directional case. It's easy to get the Dutch roll going. Obviously, the Dutch roll damping is very low and I don't like it. In smooth air, it's probably not a big problem but in turbulence it certainly shows up. The turn coordination requirements are not really noticeably difficult. The only problem you have of course is trying to damp out the Dutch roll oscillation when it occurs and then I think you just forget about coordination. What you are really trying to do is just add some damping and you do whatever you have to do. I didn't have any particular problem in pitch although on the second approach I ballooned the airplane because I just happened to start my flare about the time that I hit a pretty hard lateral gust and this was a problem and so there is some coupling between the lateral and the longitudinal.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

No difficulty, I think you almost eliminate that question.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

First one I tried crabbing completely and on the second one I tried a combination. It seemed that the crab angle is pretty large and then when you try to make the last minute correction to kick out the crab angle and drop the wing because of these heavy aileron forces, I wasn't successful in doing it so I thought, well, if I set myself up where I've already established some sideslip it might be better. I think it would have worked out better, but we dumped on that one. On the last one I did that and it still really didn't work out much better than the other until I finally let go of the throttles, put two hands on the wheel, then I could manhandle the airplane down to the centerline. I still ended up to the right a little bit, but as I said before, trying to get the airplane moving laterally is a big job. I think that really describes the runway alignment problems there.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Lateral-control inputs do affect longitudinal motions. At least one time it did and I'm sure that it would down close. Up-and-away I mean down to about the last 100 to 150 feet there is no problem, but in close this could be a problem. Longitudinal control inputs do not affect the lateral, I think it's probably the other way around.

EFFECT OF RUNWAY CLOSURE RATE

On one of those I started a little late on the flare and the closure rate added to the difficulty because I was having lots of troubles with the heading, trying to get it right, and the lateral attitude, wings attitude. So yes, it does sort of snowball on you. It adds up to an uncomfortable feeling so I didn't particularly like that closure rate when I tried to make a rather rapid flare. I think that particular approach still was a little steeper than the average.

GOOD FEATURES

I don't think there were any, specifically. The longitudinal is probably a good feature, the longitudinal characteristics are reasonable.

OBJECTIONABLE FEATURES

The objectionable feature basically is the low Dutch roll damping. I don't think it's exceptionally high roll to sideslip. I don't think the aileron or the yawing moment due to aileron inputs is a significant feature. The other big feature is the fact that I cannot, with the ailerons and rudder combination, really set up a good sideslip just before touchdown.

SPECIAL PILOTING TECHNIQUES

I don't think there were any. You either try the combination of sideslip and bank angle approaches or you did just a crab and tried to take it out on the end, so this is a standard technique I think. But one special piloting technique and I consider it special that is if I can't land the airplane without putting two hands on the ailerons, on the wheel, I don't like that, but it does seem to be necessary.

PILOT RATING AND PRIMARY REASON

The pilot rating I think has to be way down. Is it controllable? Yes, I think it's controllable. Is it adequate with tolerable workload? I don't think so. It certainly has major deficiencies. Considerable pilot compensation required for control? Almost intense at the end probably answers it, so I'm going to rate this between an 8 and a 9. I might have been able to handle something even a little worse, again using the two hands and maybe with some help from the co-pilot to maintain airspeed, or reset the power if necessary, which of course, is not what you really want to do. I am really agonizing a little bit between an 8 and a 9. I don't want to be too unfair with it. So I will call it an 8.5.

TURBULENCE EFFECT RATING

The difference between smooth air and turbulence certainly was noticeable, particularly because of the Dutch roll damping and because of the continuous disturbance with the lateral mode. The pilot certainly does have to expend more effort and I think we are talking between a D and an E, because of few big heavy gusts that I got. They appeared to be heavy, the response of the airplane was certainly very large amplitude on that last one. I would certainly think that some best efforts might be required here and it's moderate. We are talking about an E or an F. So I will call it an E+.

CONFIGURATION 12 MAN DSFC   PILOT A   PR 4   TR D   EVAL. FLT. NO. 4

INITIAL IMPRESSION AND GENERAL COMMENTS

I did quite a bit of manipulating on the side force that time. The basic problem is that the lateral-directional characteristics are giving me quite a bit of oscillation and so it's difficult to determine when the nose is really pointing down the runway, until you get pretty close. I guess I could have saved myself some trouble by waiting a little bit before really establishing where I should be but all in all I thought the touchdown was okay. Generally there's just no question that this is a much better task for the pilot. The first touchdown I thought was pretty good, the second one I thought was also pretty good, although on the first one I probably had slightly different crosswind because the side force control was all the way over and I just left it there for the whole approach and that seemed to be about right. The second time around I needed less side force. I think the wind must have shifted, but I also had to hunt around for where it was, it might just have been a variation in the wind direction. But, you can stay with it and generally speaking you should make these corrections near the end.

ABILITY TO TRIM

No problems.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Certainly didn't feel that the aileron was any problem that time.

AIRPLANE RESPONSE TO PILOT INPUTS

Responses to inputs to perform the task -- were adequate. No particular complaints on directional control. The turn coordination, except in the oscillation, is no problem. Pitch attitude control as usual is a sort of sluggish, little bit sluggish airplane. It's well damped though for the purposes at least for reasonably large airplane is perfectly adequate.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind turning on final was no problem particularly.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

Landing approach method was just to wipe out the crosswind with the side force control. If it's a steady state wind, you can probably set it up pretty close, maybe a mile and a half or so out. If you have a variation in wind, combined with possibly an oscillatory response, especially yawing response, then what you have to do is wait until you get close in and go ahead and keep using the side force control. I think the pilot can align it successfully each time. The runway alignment was a little bit of a problem on the second approach, basically because I was over-controlling with the side force surface. First I was drifting left and then I was drifting right and back again. That was the only alignment problem.

CONTROL TECHNIQUE

As I said before, it's normal - coordination normal.

CONTROL OF SIDESLIP WITH DSFC

The control surface was adequate although on the first one, it almost seemed like I could have used a little more. As a matter of fact, I think a very slight amount of bank angle was needed, but no more than the normal kind of landings. You don't normally hit both wheels at the same time anyway, so you may have bank each time.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

There was no particular interference with the side force and the lateral-directional control.

CONTROL OF GLIDE SLOPE

It's sort of variable. I still don't really set up this rate of descent and maintain it all the way down. It always seems like at some point I have to make some kind of a power correction. One of the problems, of course, is the gusts. The airspeed is changing quite a bit and so there is some tendency to chase it, because the changes in airspeed are as much as 5, 6, 7 knots.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

Lateral-directional control doesn't really affect the longitudinal motions to any great extent at all. I really had a fairly easy time of it.

GOOD FEATURES

The good features are the fact that I could align the airplane. I could keep the wings level with the side force control and essentially do what I would consider a decent job of landing the airplane.

OBJECTIONABLE FEATURES

I think the most noticeable one is the lateral-directional lack of damping of the Dutch roll. It's also objectionable to have the turbulence inputs because the Dutch roll is disturbed all the time. Could also be a combination of roll to sideslip ratios that might be maybe 2 or something like that. It's a little hard to tell.

SPECIAL PILOTING TECHNIQUES

There was no special piloting technique that I could tell. You just get rid of the crosswind and go ahead and land it.

PILOT RATING AND PRIMARY REASON

The pilot rating I think is going to be "deficiencies warrant improvement, minor but annoying deficiencies." The only deficiencies that I could see, as I said, were the Dutch roll characteristics, so I can't really say that I would like to land this airplane, especially if we had heavy turbulence. The pilot would have to work fairly hard, so I think you should really improve the lateral-directional. As far as the crosswind control is concerned, great. So I'm going to rate it a 4 and the main reason I'm going to rate it a 4, downgrading it from a completely acceptable one, is the lateral-directional characteristics, oscillatory characteristics in turbulence. As far as the side force control is concerned, I would say it was excellent compensation for the crosswind and so I would certainly rate the airplane completely acceptable, on that basis. I'm going to downgrade it some because you still have to work maybe a little too hard in landing the airplane with this kind of lateral-directional characteristic.

TURBULENCE EFFECT RATING

There is some more effort required and I would think it's going to be minor to moderate, so I'm going to rate it about a Delta on the turbulence.

CONFIGURATION 12 AUTO DSFC PILOT A PR 4 TR C+ EVAL. FLT. NO. 4

INITIAL IMPRESSION AND GENERAL COMMENTS

I think because of the lateral accelerations that we get on the automatic system, the manual side force control case seemed to be better to me, but the actual performance down close to the ground wasn't much different. The only thing is that when you get close to the ground, then you're getting some of these lateral accelerations by the automatic system that it's distracting. It's not really nice to have.

PILOT RATING AND PRIMARY REASON

I'll rate it a 4. I don't think I'll downgrade it any and I don't think I'll upgrade it either for that matter. I probably should have seen a couple more close to the ground.

TURBULENCE EFFECT RATING

Yes, you do work a little more with the turbulence than you do without the turbulence but again it was minor to moderate. I don't know, it just didn't seem like the turbulence was quite as bad during the automatic approaches as before, so I'm going to call the rating there a C+. I don't know if I rated it the same before, but it's minor to moderate I suppose, so that's what we will do.

CONFIGURATION 12 NO DSFC PILOT B PR 7 TR F EVAL. FLT. NO. 20

INITIAL IMPRESSION AND GENERAL COMMENTS

I just completed normal system approaches without side force controller. We had a restriction of visibility due to precipitation, haze, and low ceiling. The winds were gusting 22-28 knots and an effective crosswind of about 15 knots - 20 knots and natural turbulence. My initial impressions of the handling qualities of the aircraft: longitudinally they were adequate, lateral-directional I had some comments to make particularly in the lateral axis.

ABILITY TO TRIM

I felt the longitudinal and directional trim system was fine, the lateral trim system was just a little slow but not too bad. I had a little more aileron trim rate than I felt before. I was able to trim out aileron forces.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

The force gradient in the lateral system was all right. I felt there was a definite force system there, I mean, a feel as well as on the longitudinal axis. Directionally I thought it was just a little bit high. This was felt more down at the bottom when I was getting ready to flare. I'll expand on that later on. Control sensitivities, longitudinally, directionally were okay. I felt the aileron, force gradient at flare was heavy, but for that amount of wheel throw that I had in it was not excessive. Lateral control sensitivity I felt was poor, low.

AIRPLANE RESPONSE TO PILOT INPUTS

Response to roll control inputs were an initial lag and then not much response as far as rate and I didn't feel that I was acquiring the amount of roll response that was required especially in the flare after I had kicked out my crab and tried to align the aircraft with the runway. I had a wheel throw of, ball park figures, 60°. Directionally, I noted that I didn't have any complaints about the directional system other than it did excite or induce a lot of roll, and destroyed overall turn coordination. I wasn't able to change heading by making vernier heading changes with rudder pedals because this excited the roll mode and I found myself even trying to make coordinated turns overshooting at desired bank angle of 10° by as much as 5° before I got established on the bank angle that I wanted. It would oscillate back and forth plus or minus 5°. So, there wasn't any real predictability in bank angle control. I didn't see anything unusual on the pitch control. Initial response was okay, and the final response was well predictable.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Crosswind on turning final didn't cause any difficulties at all. Turbulence effects, both with natural and artificial turbulence, which incidentally could be differentiated by me, were such that the roll mode was excited easily and I did feel some minor side force gust along the lateral axis. And I felt the heave significantly and I saw the airspeed deviations caused by the turbulence and the airspeed control was very difficult so that the turbulence did have an overall effect on just about all axes. I wasn't able to control airspeed within 5 knots continuously.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

In aligning with the runway, the low visibility prevented any line up far out, but once I had the runway lights in sight, I'd set up a crab and held the crab till about 200 ft. above the surface. On my last approach I tried to kick it out earlier to establish my proper attitudes for landing and I should have probably used a combination of wing low and crab down final so that it wouldn't have had such an abrupt change in yaw and roll at that point close to the surface because of the large roll control displacements required when I did kick out the crab.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I noticed some coupling from lateral directional inputs affecting longitudinal motions but not vice veras. I'm not sure about that, but I felt there was some coupling between the axes. It may have been the gust effects.

EFFECT OF RUNWAY CLOSURE RATE

Runway closure did not affect the task. Runway closure rate did not affect task accomplishment.

GOOD FEATURES

About all I can say is that the trim systems felt good and were comfortable.

OBJECTIONABLE FEATURES

Longitudinally the aircraft handled well except down at the bottom. I don't know whether it was trying to make precise corrections in the flare or just during the flare, just prior to it, or if it was caused by coupling with other axes motion, but it was a definite PIO tendency in longitudinal axis. And because of the low roll control sensitivity there was a distinct PIO tendency laterally. Directionally this felt all right other than the fact that it did excite the roll mode to the extent that it destroyed the aircraft's handling qualities.

PILOT RATING AND PRIMARY REASON

I didn't feel that I had the aircraft under control at an acceptable level to make touchdown adequately. I felt that I would have had rates primarily in roll on the aircraft, in the flare, because of the PIO tendency, low sensitivity. So an overall 7.

TURBULENCE EFFECT RATING

What turbulence did was to generate these oscillations and it did in fact deteriorate it to quite an extent. It's kind of hard to say, somewhere between a D and an F. The evaluation task could still be accomplished but I felt that it increased the pilot workload to an extent. I'll go with Foxtrot.

CONFIGURATION 12 MAN DSFC PILOT B PR 5 TR D EVAL. FLT. NO. 21

INITIAL IMPRESSION AND GENERAL COMMENTS

My initial impressions of the longitudinal handling qualities were fine. Lateral-directionally I saw some problems which became magnified during the approach, I'll comment on specific items as I go down the comment card.

ABILITY TO TRIM

Ability to trim felt good on all axes except the aileron trim, I felt, was a little slow and had possibly a lag. Also I didn't feel the effects of trim until I had hit the trim button on several times. I still haven't got the feel for the aileron trim although I may be compensating for it.

FEEL CHARACTERISTICS AND CONTROL SENSITIVITIES

Feel characteristics on the longitudinal axis were okay and the directional axis seemed just a bit heavy. Aileron, lateral force gradient was just a little bit light I thought. Overall harmony was okay, however displacements on the lateral axis were excessively large I thought. This was probably due to the low control sensitivity on the lateral axis I think.

AIRPLANE RESPONSE TO PILOT INPUTS

I would put in an initial wheel throw laterally and there would be some lag before the roll rate was initiated so that the predictability of the response was difficult. The input required was to put in aileron control and then as the rate increased you come back out a little bit in the opposite direction to arrest the roll rate. Directional control I felt was okay. I could not make small heading changes using rudder only because it appeared to excite a roll rate. I looked at it in a little more detail and it seemed that the roll rate was not with rudder deflection but with yaw rate. After some yaw rate was initiated then the roll rate resulted and accelerated and felt like when I rolled over on the side and then I had to come in with some opposite aileron. Turn coordination was all right. I was able to make aileron only turns in this configuration. For a 20° bank the ball was about an eighth ball width to the inside of the turn. I was not able to do the same with rudder only. Pitch attitude and control was okay. No big problems there.

DIFFICULTIES ON TURNING FINAL WITH CROSSWIND

Nothing pertaining to crosswind on turning final. No difficulties there. Turbulence effects were not too marked except once I was down in the last couple of hundred feet of my approach and tried to make precise corrections and align myself to the runway. I felt that the turbulence entered into it there. I was counteracting the gust disturbances as well as trying to make precise corrections and tended overcontrol, which resulted in a PIO tendency. That's speaking laterally and somewhat longitudinally.

LANDING APPROACH TECHNIQUE AND RUNWAY ALIGNMENT

My landing approach method was to align myself with the runway in the crab and then use the direct side force controller on the throttle to align aircraft heading with the runway heading. I was required to use some additional crab coming down final and I kicked it out about 200 ft. above the runway surface.

CONTROL OF SIDESLIP WITH DSFC

The uses of the side force controller was not as comfortable as I would like. I tried not to make very many corrections, and had some difficulty aligning the aircraft with the runway heading with the direct side force controller. I did need some bank angle but of minor significance.

INTERFERENCE OF DSFC WITH OTHER ASPECTS OF AIRCRAFT CONTROL

It did seem to interfere somewhat with lateral directional control. It seemed to excite some roll response when I did use the side force controller. I used the side force controller on the throttle because it is more comfortable to me. I prefer that over the one on the control column.

LATERAL-DIRECTIONAL AND LONGITUDINAL COUPLING EFFECTS OF CONTROL INPUTS

I didn't note that any lateral directional control inputs affects longitudinal motions, nor vice versa.

EFFECTS OF RUNWAY CLOSURE RATE

Runway closure rate did not affect my task accomplishment.

GOOD FEATURES

The task was much easier I felt, not much easier, but easier, using the side force controller. It gives me the ability to align myself with the runway using a minimum amount of crab. The ability to make aileron only turns and stay off the rudders was good. The longitudinal system felt good, but the aileron trim rate was slow. I didn't get any feel for the trim rate.

OBJECTIONABLE FEATURES

The biggest objection was the roll rate excited by any yaw rate. I would suspect that it is spirally unstable and it felt like it was going to continue to roll had I not arrested it with quite a large opposite aileron wheel deflection.

SPECIAL PILOTING TECHNIQUES

Special piloting technique was to, on the final approach, use the sideforce controller. I was required to use some bank angle on crab even though I used side force controller.

PILOT RATING AND PRIMARY REASON

I'll rate this a 5 because of the basic response of the aileron control system and how easily the roll rate was excited by the directional mode which appeared to be yaw rate rather than rudder deflections. There was some delay in the roll response to rudder deflection. The lateral-directional control system, especially in turbulence requires some extensive increase in pilot workload. Enough to rate it, I think, an overall 5.

TURBULENCE EFFECT RATING

There was some significant deterioration of task performance with turbulence. In that it did require that I compensate for gust disturbances on the lateral-directional axis and have rated it a Delta for that reason.

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13. ABSTRACT

The application of Direct Side Force Control (DSFC) during crosswind landings of an airplane having the characteristics of a Class II STOL was investigated in the USAF Total In-Flight Simulator (TIFS) airplane. The primary prupose was to evaluate the usefulness of DSFC during the crosswind landing. Other objectives were to investigate the type of cockpit controller or mechanization scheme for use with DSFC, and to define parameters which affect pilot workload during crosswind landings with DSFC. Landing approaches to simulated touchdown were flown both without and with the aid of DSFC. The approach speed was 130 knots. Two modes of DSFC control were investigated, an independent manual control of DSFC through a cockpit mounted thumbwheel proportional controller, and an automatic scheme which tracked the ILS localizer signal. Evaluations were performed for three values of the bank angle per unit crosswind, ϕ/v_{cw} , required for conventional sideslipping, crosswind landings, and for two values of each of the derivatives L_β and N_β.

Fifty-four evaluations were accomplished: twenty-one with no DSFC, twenty with manual DSFC, and thirteen with automatic DSFC. With the exception of three cases there was always an improvement in pilot rating with manual DSFC as opposed to no DSFC. The automatic DSFC resulted in a pilot rating improvement in nine of the thirteen cases evaluated. The greatest improvement in pilot rating occurred for those configurations which had the least desirable

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handling qualities when evaluated without DSFC. The pilots' main objections when performing crosswind landings without DSFC centered around large control forces. The objections were alleviated with DSFC. The capability to land, wings level, in a 15 knot crosswind was demonstrated. The ability to make a crosswind correction with DSFC and land the airplane with a small or zero bank angle was considered a significant improvement over having to hold a steady bank angle and sideslip with aileron and rudder. The automatic DSFC system relieved the pilot of all lateral-directional control tasks, but was found somewhat objectionable because of DSFC induced lateral accelerations and frequently unsatisfactory runway alignment error at touchdown. In view of its potential, further development of the automatic DSFC would seem warranted. It was concluded that DSFC significantly improved the pilot's ability to perform the crosswind landing. DSFC was particularly beneficial when the basic airplane exhibited degraded flying qualities.

14. KEY WORDS

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