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16. Abstract

A piloted simulation study has been made of typical landing approaches with an externally blown flap STOL aircraft to ascertain a realistic dispersion of parameter values at both the flare window and touchdown. The study was performed on a fixed-base simulator using standard cockpit instrumentation. Six levels of stability and control augmentation were tested during a total of 60 approaches (10 at each level). A detached supplement containing computer printouts of the flare-window and touchdown conditions for all 60 runs has been prepared and is available upon request from the Flight Dynamics and Control Division, Langley Research Center.

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SUMMARY

A fixed-base piloted simulation study has been made of typical landing approaches with an externally blown flap STOL aircraft to ascertain a realistic dispersion of parameter values at both the flare window and touchdown. Standard aircraft-type instrumentation was used and six levels of stability and control augmentation were tested during a total of 60 approaches (10 at each level). Only the longitudinal control problem was considered in detail; thus, the simulated approaches began with the aircraft already on the localizer. The primary results of the study included the following:

(1) The glide slope could be acquired and tracked with any of the six control systems tested. The best results, however, were obtained when using the three systems which possessed automatic speed control (AUTOSPEED).

(2) Relatively poor touchdown conditions were achieved with all except the most fully augmented control system. This system included both AUTOSPEED and "pitch hold." Pitch control was a particular problem when these two features were missing.

These results are derived from analysis of the simulation data which have been compiled in a detached supplement. This supplement contains computer printouts of the flare-window and touchdown conditions for all 60 runs and is available upon request from the Flight Dynamics and Control Division, Langley Research Center.

INTRODUCTION

The pilot's task of maintaining precise control of a short take-off and landing (STOL) aircraft during steep-approach landings is generally more difficult than with a similar size conventional take-off and landing (CTOL) aircraft. Inherent control difficulties arise from the combination of relatively high inertia, low landing speed, and short flaring time (proportionally shorter as the glide-slope angle is steepened). The problem is further aggravated by the so-called "negative ground effects" (lift losses due to air recirculation as aircraft nears the runway). To be assured of passenger acceptance, however, the STOL landings must be no less comfortable or safe than present CTOL landings.

Improved information display systems to aid the STOL pilot in more precise landing control are presently being developed and evaluated. References 1 and 2 are fixed-base simulation studies describing the flight characteristics and some display formats used in an externally blown flap STOL aircraft. The present study is a continuation of this work. In particular, this simulation was used to examine the control problems during the approach and flare maneuvers. The throttle was used as the primary control for both speed and flare. Reference 3 is an analytical study to investigate the information and display requirements for adequate control of STOL landings. The analysis in reference 3 combines human-response theory with optimal control and estimation theory to predict the landing performance (statistically) of a STOL aircraft. The predicted values are then compared with fixed-base simulation values. Only the longitudinal control problem is considered in detail, and, in particular, system values at flare initiation and at touchdown are used to make the primary comparisons. (System values at flare initiation are referred to as "flare-window conditions.")

This report presents a compilation and analysis of the fixed-base simulation data used in reference 3. Even though final flare and touchdown are not normally accomplished solely on instruments, the present tests investigated this technique.

SYMBOLS AND DEFINITIONS

In order to facilitate international usage of the data presented, dimensional quantities are presented in both the International System of Units (SI) and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

C_D	drag coefficient
C_L	lift coefficient
C_m	pitching-moment coefficient
$\bar{c}$	mean aerodynamic chord, meters (feet)
f_1,f_2,f_3	forward, middle, and rearward segments, respectively, of the wing flaps
H	altitude, meters (feet)

I_X, I_Y, I_Z moments of inertia about X, Y, and Z body axes, respectively, kilogram-meters^2 (slug-feet^2)

I_{XZ} product of inertia, kilogram-meters^2 (slug-feet^2)

K system gain

s Laplace operator

T_{bias} thrust change (calculated) required to change flight path from level flight (at 75 knots) to one parallel (descending) to glide slope, newtons (pounds force)

T_c commanded thrust, newtons (pounds force)

$\Delta T = (\text{Thrust} - T_c)$, newtons (pounds force)

V_A airspeed, knots

x distance down runway measured from threshold, meters (feet)

$\delta_{f1}, \delta_{f2}, \delta_{f3}$ deflection of f_1, f_2, and f_3, respectively, deg

ϵ_{zh} glide-slope error measured vertically, meters (feet)

σ standard deviation

τ time constant, seconds

Dots over symbols denote differentiation with respect to time.

DESCRIPTION OF SIMULATED AIRCRAFT

A three-view drawing of the high-wing, high-horizontal-tail STOL aircraft simulated in this study is shown in figure 1 along with assumed full-scale mass and dimensional characteristics. Corresponding maximum control-surface deflections and deflection rates are given in table I. The nondimensional aerodynamic characteristics for this aircraft were obtained from the wind-tunnel data curves of references 4 and 5. The ground effects

TABLE I.- RANGE OF CONTROL-SURFACE DEFLECTIONS AND MAXIMUM DEFLECTION RATES

Control surface	Maximum deflection angle, deg	Maximum deflection rate, deg/sec
Horizontal tail	±10	50
Trailing-edge flap	0 to 90	5
Spoilers	0 to 60	50
Aileron	±20	50
Rudder	±40	50

(changes in C_L, C_D, and C_m) used in this report were determined from the data curves of reference 6.

Four commercial high-bypass-turbofan engines which generate a combined maximum thrust of approximately 147 058 N (33 060 lbf) were assumed. The engine characteristics are presented in reference 2. The engines were pod-mounted to the underside of the wings and canted so that the exhaust impinged directly onto the trailing-edge flap system (see fig. 2) when deployed for landing.

The wing incorporated blown leading-edge flaps (see ref. 2), which were deflected 60°, and full-span, triple-slotted trailing-edge flaps, which were set at $\delta_{f1}/\delta_{f2}/\delta_{f3} = 25^\circ/10^\circ/60^\circ$ for the approach and landing condition. A drawing of the flap assemblies is shown in figure 2. The first two chordwise elements, f_1 and f_2, were fixed at 25° and 10°, respectively, but the third chordwise element f_3 was implemented for active control (operating about the $\delta_{f3} = 60^\circ$ reference position). An automatic speed control function was achieved by deflecting all six f_3 elements (three on each wing) symmetrically.

Even though roll and yaw control were seldom required in this study, the STOL aircraft configuration included implementation for the middle f_3 elements on each wing to be deflected differentially for aileron roll control and for top-wing spoilers (see fig. 2) to be geared to these ailerons to produce additional roll control. The rudder could be deflected up to ±40° for yaw control.

The elevator flaps on the horizontal tail were fixed at a 50° up-angle for primary pitch trim of the STOL in the high-lift landing configuration. Then the entire horizontal tail was servo-driven from the column or pitch-trim button to achieve active pitch control.

The simulation was performed on the Langley Real-time Dynamic Simulator (RDS). A photograph of the simulator is shown in figure 3. Figure 4 shows an inside view of the simulated STOL cockpit.

TEST PROGRAM AND DATA

The primary purpose of the test program was to determine a realistic range of flare-window and touchdown conditions for a medium-range STOL aircraft. The final approaches were made at approximately 75 knots on a 6° glide slope. Short time histories of selected parameters just prior to the flare maneuver and the touchdown values for 60 simulated instrument landing approaches are compiled in a supplement which can be obtained from the Flight Dynamics and Control Division, Langley Research Center. An example of the data format presented in the supplement is given in the appendix.

Three primary control configurations – designated BASIC, BASIC + SAS, and FULL AUGMENTATION – were each simulated with and without automatic speed control (AUTOSPEED); thus, the simulation included six systems. The BASIC configuration contained no stability augmentation system (SAS). The column, wheel, and rudders were programed as position-command devices for pitch, lateral, and directional control, respectively. When the aircraft assumed the high-lift externally blown flap configuration for the landing approach, the elevators were fixed at a 50° up-angle for gross pitch trim; the column then commanded movement of the entire horizontal tail for active pitch control. Vernier pitch trim was achieved also by repositioning the entire tail. The wheel commanded top-wing spoilers for "normal" roll control; however, if a spoiler (right or left) deflected more than 30°, the rearmost elements of the inboard flaps deflected differentially (as ailerons). This deflection was proportional to the continued deflection of the spoiler so that the ailerons reached their $\pm 20^{\circ}$ limits at the same time that the spoiler reached its 60° limit. The pedals controlled the rudder.

The "BASIC + SAS" system consisted of the BASIC system with a SAS system added. The SAS included both longitudinal and lateral-directional augmentation. The longitudinal SAS consisted of pitch damping and decoupling (namely, automatic repositioning of the horizontal tail to preclude pitch changes due to changes in thrust, flaps, spoilers, and roll angle). The lateral-directional augmentation described in reference 2 was operational in the present study but seldom became active.

The FULL AUGMENTATION system consisted of a modified SAS which provided well-damped responses to pilot inputs with the column (or pitch trim button) and inherent pitch stability (that is, "pitch hold") when no pilot inputs were made. The lateral-directional part of this system was again available in the present study but seldom became active. Each of these systems was developed and optimized during the reference 2 study. (They are described in detail in appendix B of ref. 2.)

All the test runs were started with the aircraft in level flight at 121.9 meters (400 feet) altitude, trimmed for final landing approach, stabilized on the localizer and about to intercept the glide slope. The piloting task was to (1) capture the glide slope, (2) track it to the designated flare-initiation altitude of 16.2 meters (53 feet), and (3) then flare to a "soft" touchdown within a 137.2-meter (450-foot) section of the runway (beginning at the glide-slope intercept with the runway). The throttles were the primary control for flare.

The primary instrument for each of the runs was the conventional cross-pointer-type flight director shown in figure 5. The information displayed on it during this study falls into three groups: attitude, situation, and command. The attitude group consists of the horizon line, pitch and roll attitude sphere, miniature airplane symbol, and roll-attitude pointer. The situation group consists of a glide-slope pointer, expanded localizer pointer, and the radio altitude bar. The command group consists of the pair of flight director bars. (The other functions on this instrument were inactive.) Additional information displays included an altimeter, flap meter, airspeed meter, angle-of-attack meter, and rate-of-climb meter.

The principal instrumentation included pitch angle, radio altitude, and the horizontal command bar. The command bar was specially programed to give thrust-command information for tracking the glide slope by using only the throttles prior to the flare maneuver. A block diagram showing the generated thrust-command signal is presented in figure 6. Upon reaching the prescribed flare altitude of 16.2 meters (53 feet), the bar became useless for tracking the glide slope. To improve the precision of initiating the flares, a pair of small lights located above the altimeter was provided; the first lit at 17.8 meters (58 feet) altitude as a warning cue and the second lit at 16.2 meters (53 feet) as the initiation cue.

Additional ground rules required that the aircraft land on every approach; that is, no "go-arounds" were permitted.

RESULTS AND DISCUSSION

The complete longitudinal data from all six groups of runs designated groups A, B, C, D, E, and F have been compiled and are contained in the previously mentioned supplement. An example of the supplement data is presented in the appendix. Ten parameters were used in establishing sets of typical "flare window" conditions for STOL aircraft landing under the range of conditions simulated. In addition, the touchdown values of five of these parameters were analyzed and are presented in this report. In the tables that follow, the 10 parameters are listed by their common names.

TABLE II.- FLARE-WINDOW CONDITIONS

[Upper value of each pair is mean value and lower value is standard deviation]

(a) SI Units

Group	Altitude, meters	Sink rate, m/sec	Airspeed, m/sec	Distance from threshold, meters	Glide-slope error, meters	Longitudinal acceleration, g units	Normal acceleration, g units	Pitch angle, deg	Pitch rate, deg/sec	Angle of attack, deg
A*	17.22 .26	-4.17 .06	38.58 .01	-38.39 4.60	1.51 .38	0.0358 .0065	0.9996 .0007	2.05 .37	0.597 1.374	8.20 .43
B*	17.9 .33	-4.13 .10	38.59 .02	-46.19 5.85	0.57 .38	0.0297 .0106	1.0018 .0016	1.70 .60	0.030 .030	7.81 .61
C*	17.00 .34	-4.08 .08	38.57 .02	-43.46 5.02	0.77 .36	0.0386 .0085	0.9994 .0014	2.22 .49	0.010 .023	8.26 .46
D	17.19 .27	-3.96 .45	38.46 1.41	-35.13 18.66	1.73 1.71	-0.0661 .0122	1.0013 .0235	-3.96 .96	-0.031 .320	1.90 1.03
E	17.16 .33	-3.92 .25	38.31 1.05	-38.15 14.15	1.38 1.31	-0.0631 .0083	1.0035 .0080	-3.68 .82	0.178 .279	2.15 .62
F	17.08 .26	-3.98 .10	38.32 .43	-38.32 5.01	1.38 .53	-0.0650 .0032	0.9972 .0040	-3.92 .17	-0.000 .008	2.00 .19
Reference run	17.07	-4.03	38.64	-48.50	≈0	0	≈1.000	----	≈0	---

(b) U.S. Customary units

Group	Altitude, feet	Sink rate, ft/sec	Airspeed, ft/sec	Distance from threshold, feet	Glide-slope error, feet	Longitudinal acceleration, g units	Normal acceleration, g units	Pitch angle, deg	Pitch rate, deg/sec	Angle of attack, deg
A*	56.48 .84	-13.67 .21	126.56 .02	-125.94 15.10	4.96 1.25	0.0358 .0065	0.9996 .0007	2.05 .37	0.597 1.374	8.20 .43
B*	56.40 1.07	-13.55 .34	126.61 .06	-151.55 19.20	1.87 1.25	0.0297 .0106	1.0018 .0016	1.70 .60	0.030 .030	7.81 .61
C*	55.78 1.11	-13.40 .26	126.55 .05	-142.58 16.47	2.51 1.18	0.0386 .0085	0.9994 .0014	2.22 .49	0.010 .023	8.26 .46
D	56.40 .89	-12.99 1.49	126.18 4.62	-115.25 61.22	5.67 5.62	-0.0661 .0122	1.0013 .0235	-3.96 .96	-0.031 .320	1.90 1.03
E	56.29 1.09	-12.86 .82	125.70 3.45	-125.16 46.44	4.53 4.31	-0.0631 .0083	1.0035 .0080	-3.68 .82	0.178 .279	2.15 .62
F	56.03 .86	-13.06 .33	125.73 1.41	-125.73 16.43	4.54 1.74	-0.0650 .0032	0.9972 .0040	-3.92 .17	-0.000 .008	2.00 .19
Reference run	56	-13.23	126.77	-159.13	≈0	0	≈1.000	----	≈0	---

*AUTOSPEED used.

TABLE III.- TOUCHDOWN CONDITIONS

[Upper value of each pair is mean value and lower value is standard deviation]

Group	Sink rate		Airspeed		Distance from threshold		Normal acceleration, g units	Pitch angle, deg
	m/sec	ft/sec	m/sec	ft/sec	meters	feet		
A*	-0.94 .52	-3.10 1.70	38.74 .02	127.09 .06	212.51 125.16	697.20 410.62	1.0527 .0513	1.70 .50
B*	-1.56 .37	-5.12 1.23	38.77 .04	127.19 .14	175.10 85.99	574.46 282.12	1.0424 .0649	0.40 1.56
C*	-1.12 .45	-3.69 1.47	38.79 .04	127.28 .12	167.25 40.75	548.71 133.70	1.0135 .0738	0.22 1.52
D	-1.96 .91	-6.42 3.00	38.59 1.94	126.61 6.36	229.99 142.02	754.55 465.94	1.0960 .1370	-1.96 3.88
E	-1.55 .64	-5.07 2.11	37.85 1.83	124.18 6.01	184.07 71.61	603.91 234.95	1.0437 .1240	1.25 4.27
F	-1.58 1.11	-5.18 3.65	35.46 4.29	116.34 14.07	277.34 161.25	909.90 529.03	0.9849 .0743	3.90 2.55
Reference run	≈0	≈0	38.64	126.77	≦213.36	≦700	≈1.0700	≈2

*AUTOSPEED used.

The flare-window conditions are listed in table II in terms of mean values and standard deviations (σ's) of the 10 parameters mentioned above. The data samples were taken from the print intervals (see appendix) in which the altitude is nearest to 17.1 meters (56 feet) or about 0.9 meter (3 feet) above the nominal flare altitude selected for the study. Mean values and standard deviations of five of the parameters at touchdown were also computed; these values appear in table III. Then as a basis for comparison, a reference (nonerror) landing trajectory was computed and values of pertinent parameters were determined for the flare window and touchdown. These values are included at the bottom of tables II and III. No reference values are listed for pitch angle θ or angle of attack α because the pitch attitude is an arbitrary choice of the pilot, within a small range. However, it was suggested that a target value of $\theta \geqq 2^{\circ}$ be used for touchdown to insure that the main landing gear contacts the runway prior to the nose gear (simultaneous contact occurs for $\theta \approx 1^{\circ}$).

The following general observations are made with respect to the flare-window results of table II:

(a) The mean values and standard deviations are generally near nominal for all six groups of data. The primary exceptions are in distance from threshold and glide-slope error. The pilot tended to bias all his trajectories above the glide slope and consequently his aircraft was closer to the runway threshold than nominal when it reached the flare window. Another exception is the pitching rate $\dot{\theta}$ for group A. In this case, the AUTOSPEED system (for the wing flaps) interacted rather actively with the command augmentation system which was continuously attempting to correct the pitch angle to values established by the "pitch hold" feature of command system. Possibly, more compatible dual-system gains could have been determined, but the two systems worked together effectively as tested.

(b) The three groups of runs with AUTOSPEED appear to have generally better values (closer to reference) than the groups without AUTOSPEED. For example, the pilot was able (or willing) to track the glide slope consistently closer when he had AUTOSPEED. Also, he was able to establish his touchdown attitude ($\theta \approx 2^{\circ}$) prior to reaching the flare window, whereas without AUTOSPEED he had to hold θ at a down angle to maintain airspeed (at the 60° flap setting) and then pitch up about 5° or 6° during the throttle-controlled flare.

The touchdown data are not nearly as good or consistent as the window data. This trend was not unexpected, partly because of the study requirement to make the landings (including touchdown) totally on instruments. Reference to table III shows that the sink rates at touchdown were considered to be high (unsatisfactory for the non-AUTOSPEED runs), the airspeeds were near nominal (as expected) for the AUTOSPEED runs but rather scattered for the non-AUTOSPEED runs, the ranges were widely scattered for all sets, and the touchdown attitude varied from satisfactory to unacceptable (nose-wheel-first landings). In fact, the only consistently good touchdown attitudes occurred in groups A and F where command systems having the "pitch hold" feature were used.

Only 60 runs were made in the test program and all were included in the averages. Possibly several runs should have been omitted because they were nontypical. For example, if the pilot overflared badly, drastic action was necessary to set the aircraft down, because as mentioned earlier, he did not have the option to go around. One such example (run 55 in the supplement) is evidenced by a low airspeed $\left(V_A = 24.4 \text{ m/sec} \right.$ $\left.(80 \text{ ft/sec})\right)$ and a high pitch angle (8°) at touchdown. If this run is removed from group F, then the 9-run average for range becomes a more respectable 229.35 meters (752.47 feet) and σ drops to 57.84 meters (189.76 feet). Other overflares which normally would result in "go-arounds" occurred in runs 5, 8, 10, 32, 44, and 53. (See supplement.)

This study did not present a strict statistical analysis of the data. However, as an alternative, the following longitudinal criteria were applied to each run to establish whether it resulted in a "satisfactory" touchdown:

(a) $\dot{H}$ between 0 and -1.5 m/sec (-5 ft/sec)

(b) θ greater than 1°

(c) x between 76 and 213 meters (250 and 700 feet)

A satisfactory touchdown must satisfy all three conditions. The results for each group are listed under the "Primary" column of table IV. The value "5" for group A indicates that 5 of the 10 runs resulted in satisfactory touchdowns. Similarly, the 11 (total successes) indicates that only 11 of the 60 total runs ended with a satisfactory touchdown. Of these 11 runs, only 3 occurred with the reduced augmentation systems.

TABLE IV.- NUMBER OF RUNS ENDING WITH "SATISFACTORY" TOUCHDOWNS

Group	Augmentation system	Successes	
		Primary	Secondary
A	FULL*	5	7
B	BASIC + SAS*	0	2
C	BASIC*	1	3
D	BASIC	0	1
E	BASIC + SAS	2	2
F	FULL	3	5
Total	-----------	11	20

*AUTOSPEED used.

A second look at the data was taken to determine whether some touchdowns just missed being "satisfactory" because one of the three parameters was marginal. The following relaxed criterion values were used during this observation:

(a) $\dot{H}$ between 0 and -1.8 m/sec (-6 ft/sec)

(b) θ greater than 0°

(c) x between 76 and 305 meters (250 and 1000 feet)

The results are listed under the "Secondary" column of table IV. The total success score improves to 20, with one new run qualifying because of the relaxed $\dot{H}$ value and 4 runs each because of the relaxed x and θ values.

In summary, the results in tables II, III, and IV indicate that fairly consistent flare-window conditions can be achieved with any of the stability and control systems tested, but generally undesirable touchdown conditions result with all except the "FULL AUGMENTATION" system (including AUTOSPEED). This general situation points to the need for improved flaring techniques, better information displays, or part-to-full automation of the flare maneuver. It should be noted, however, that the flare was done under instrument flight rule (IFR) conditions to obtain data for the model in reference 4. Thus, if a good visual scene had been present, the touchdown conditions might have been different.

CONCLUDING REMARKS

A fixed-base simulation study of an instrument flight rule (IFR) approach and landing has been made to determine and compile data for a realistic range of flare-window and touchdown conditions for a typical medium-range STOL aircraft on 6°-glide-slope flying at approximately 75 knots. The data are presented in a supplement and a sample is included herein as an appendix. Only the longitudinal control problem was considered in detail; therefore, the approach began with the aircraft on the center line of the localizer and no lateral disturbances were introduced. The following conclusions were drawn from the results of the simulated landings:

1. The glide slope can be acquired and adequately tracked by using any of the stability and control systems tested. Even though most parameter values were near nominal as the aircraft reached the flare window, improvement was attained as the degree of stability and control augmentation was increased. The most significant improvement came with the addition of AUTOSPEED.

2. The pilot tracked the glide slope in a conservative manner with each of the control systems tested. That is, he biased his trajectories slightly above the glide slope and thus displaced the flare maneuver farther down the runway.

3. Relatively poor touchdown conditions were achieved except for the most fully augmented stability and control systems. These poor conditions resulted primarily from the variability of the flare maneuvers. (The flare-window conditions were consistently near nominal.)

4. Pitch control was a problem during the runs having neither AUTOSPEED nor "pitch hold." The problem was most acute during the flare maneuver because the pilot had to divide his attention between a thrust program and pitching the aircraft from approximately -4° to 2°. (The down angle was required for speed control with the selected flap setting.) The problem was further compounded near touchdown by the pitch-down moment due to the negative ground effects. When AUTOSPEED was used, the 2° (desired pitch angle for touchdown) pitch angle could be established prior to flare initiation. When "pitch hold" was also added, pitch control became an easy task and the pilot could concentrate on the thrust program.

5. The results suggest that if this aircraft were expected to fly under the conditions tested, frequent go-arounds would occur.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., January 25, 1974.

APPENDIX

FLARE-WINDOW AND TOUCHDOWN DATA

Two excerpts from the data printouts of one of the 60 simulation runs are included in this appendix. The first excerpt consists of short time histories (six data arrays at 0.25-second intervals) of parameter values as the subject STOL aircraft approaches the selected altitude for flare initiation (16.2 meters (53 feet)). The array for the sixth interval (that is, the printout for the interval just prior to reaching the flare initiation altitude) is herein designated "flare-window conditions." The five preceding intervals are included to permit potential users of the data to select flare-window conditions for flare maneuvers initiated at higher altitudes. The second excerpt from each run consists of the data array at touchdown or the "touchdown conditions."

The format for the printout arrays (in terms of the computer-program names of the parameters) is as follows:

```
DELC           DELLT                                                  BDP
               THRUST        DCRM
                             AX                           DELT        DELF3
THETAD         QD
EPSZ           EZRM          HDOT          AN                         ALPHA
               GAMMA         EPSZH         ZHRM           HT          X
               CLTCT         UA                           WA          CAPVA
T              THR VOLTS
```

This format was developed for a more general study; thus, a number of irrelevant program names have been deleted. However, the associated parameter values (mostly zeros) have not been deleted from the data arrays on the pages that follow. (In the definitions of the program names only the U.S. Customary Units are included because the parameter values in the data printouts (on the following pages) are only given in such units.) The program names remaining in the preceding format are defined as follows:

DELC	control-column deflection, positive for pull force, degrees
THETAD	pitch angle, degrees
EPSZ	glide-slope error, degrees
T	time, seconds
DELLT	longitudinal-trim controller, degrees
THRUST	thrust, pounds-force
QD	pitch rate, deg/sec

EZRM	root mean square of EPSZ, beginning at glide-slope capture
GAMMA	flight-path angle, degrees
CLTOT	lift coefficient $\left(C_L\right)$
THR VOLTS	sum of outputs of the four throttles, volts $\times$ 0.01
DCRM	root mean square of DELC, beginning at glide-slope capture
AX	longitudinal acceleration of aircraft, g units
HDOT	altitude rate, ft/sec
EPSZH	glide-slope error (in vertical direction), feet
UA	component of aerodynamic velocity of airplane in direction of its longitudinal axis, ft/sec
AN	normal acceleration of aircraft, g units
ZHRM	root mean square of EPSZH, beginning at glide-slope capture
DELT	horizontal-tail deflection, positive when trailing edge is deflected down, degrees
HT	altitude, feet
WA	component of aerodynamic velocity of aircraft in direction of its normal axis, ft/sec
BDP	thrust-command signal to horizontal command bar of flight director, volts $\times$ 0.01
DELF3	deflection angle of rearward segment of wing flaps from 60°, positive when flap deflection greater than 60°, degrees
ALPHA	angle of attack, degrees
X	distance down runway from threshold, feet
CAPVA	aerodynamic velocity of aircraft (also used for airspeed), ft/sec

GROUP A; "FULL" AUGMENTATION WITH AUTOSPEED; RUN 1

FLARE-WINDOW CONDITIONS:

0.	-2.38490210E+00	0.	0.	0.	-3.58708508E-02
0.	1.35666241E+04	0.	1.23750000E+01	0.	0.
0.	-3.58708508E-02	3.10492357E-02	0.	-3.86226674E+00	-9.61415858E+00
0.	0.	0.	0.	0.	0.
1.77722266E+00	1.49668042E-04	0.	0.	0.	0.
4.98004595E-01	2.44054707E-01	-1.35144465E+01	9.99579102E-01	0.	7.86413549E+00
0.	-6.08651283E+00	4.68636876E+00	5.54366383E+00	7.26836327E+01	-2.82780443E+02
0.	3.41224691E+00	1.25381525E+02	0.	1.73180696E+01	1.26571886E+02
3.75000000E+01	-1.23370361E+00				

0.	-2.38490210E+00	0.	0.	0.	-3.53911924E-02
0.	1.35666241E+04	0.	1.23750000E+01	0.	0.
0.	-3.53911924E-02	3.10452962E-02	0.	-3.86217381E+00	-9.61387483E+00
0.	0.	0.	0.	0.	0.
1.77725860E+00	1.40912124E-04	0.	0.	0.	0.
5.21162143E-01	2.48903936E-01	-1.35139607E+01	9.99577573E-01	0.	7.86394060E+00
0.	-6.08668200E+00	4.61486102E+00	5.53386485E+00	6.93050741E+01	-2.51318934E+02
0.	3.41223012E+00	1.25381786E+02	0.	1.73176709E+01	1.26572090E+02
3.77500000E+01	-1.23364258E+00				

0.	-2.38490210E+00	0.	0.	0.	-3.48972523E-02
0.	1.35666241E+04	0.	1.23750000E+01	0.	0.
0.	-3.48972523E-02	3.10421719E-02	0.	-3.86207578E+00	-9.61372438E+00
0.	0.	0.	0.	0.	0.
1.77729348E+00	1.37665645E-04	0.	0.	0.	0.
5.47434021E-01	2.54151303E-01	-1.35134843E+01	9.99574769E-01	0.	7.86375138E+00
0.	-6.06545790E+00	4.54348005E+00	5.52357959E+00	6.59266361E+01	-2.19851165E+02
0.	3.41221135E+00	1.25382008E+02	0.	1.73172797E+01	1.26572256E+02
3.80000000E+01	-1.23376465E+00				

0.	-2.38490210E+00	0.	0.	0.	-3.43693739E-02
0.	1.35666241E+04	0.	1.23750000E+01	0.	0.
0.	-3.43693739E-02	3.10371007E-02	0.	-3.86197629E+00	-9.61320775E+00
0.	0.	0.	0.	0.	0.
1.77732779E+00	1.36124495E-04	0.	0.	0.	0.
5.77489563E-01	2.59870919E-01	-1.35130225E+01	9.99574830E-01	0.	7.86356785E+00
0.	-6.08624006E+00	4.47222177E+00	5.51283359E+00	6.25483155E+01	-1.88386448E+02
0.	3.41220241E+00	1.25382191E+02	0.	1.73168956E+01	1.26572385E+02
3.82500000E+01	-1.23370361E+00				

0.	-2.38490210E+00	0.	0.	0.	-3.38676936E-02
0.	1.35666241E+04	0.	1.23750000E+01	0.	0.
0.	-3.38676936E-02	3.10362901E-02	0.	-3.86190108E+00	-9.61341365E+00
0.	0.	0.	0.	0.	0.
1.77735947E+00	1.18355376E-04	0.	0.	0.	0.
6.12205085E-01	2.66156663E-01	-1.35125953E+01	9.99569417E-01	0.	7.86340529E+00
0.	-6.08604581E+00	4.40108013E+00	5.50165106E+00	5.91701070E+01	-1.56921686E+02
0.	3.41217881E+00	1.25382366E+02	0.	1.73165573E+01	1.26572512E+02
3.85000000E+01	-1.23386672E+00				

0.	-2.38490210E+00	0.	0.	0.	-3.33320580E-02
0.	1.35666241E+04	0.	1.23750000E+01	0.	0.
0.	-3.33320580E-02	3.10356548E-02	0.	-3.86183900E+00	-9.61364051E+00
0.	0.	0.	0.	0.	0.
1.77738770E+00	1.05747144E-04	0.	0.	0.	0.
6.52749002E-01	2.73125618E-01	-1.35122081E+01	9.99563747E-01	0.	7.86324955E+00
0.	-6.08586164E+00	4.33004491E+00	5.49005496E+00	5.57520007E+01	-1.25456885E+02
0.	3.41215465E+00	1.25382516E+02	0.	1.73162307E+01	1.26572616E+02
3.87500000E+01	-1.23386672E+00				

TOUCHDOWN CONDITIONS:

0.	-2.38490210E+00	0.	0.	0.	-1.41756395E+00
0.	2.26049172E+04	0.	1.23750000E+01	0.	0.
0.	-1.41756396E+00	3.00930930E-02	0.	-4.89859131E+00	-2.73934521E+00
0.	0.	0.	0.	0.	0.
1.39788621E+00	6.92255238E-02	0.	0.	0.	0.
-1.35997186E+02	4.87138072E+01	-1.30946523E+00	1.04943763E+00	0.	2.00275716E+00
0.	-6.04870956E-01	3.03154324E+01	7.65062049E+00	1.19823390E+01	5.38601225E+02
0.	3.56742634E+00	1.27113441E+02	0.	4.44500642E+00	1.27191135E+02
4.40000000E+01	-2.05987549E+00				

REFERENCES

1. Grantham, William D.; Sommer, Robert W.; and Deal, Perry L.: Simulator Study of Flight Characteristics of a Jet-Flap STOL Transport Airplane During Approach and Landing. NASA TN D-6225, 1971.

2. Grantham, William D.; Nguyen, Luat T.; Patton, James M., Jr.; Deal, Perry L.; Champine, Robert A.; and Carter, C. Robert: Fixed-Base Simulator Study of an Externally Blown Flap STOL Transport Airplane During Approach and Landing. NASA TN D-6898, 1972.

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4. Parlett, Lysle P.; Greer, H. Douglas; Henderson, Robert L.; and Carter, C. Robert: Wind-Tunnel Investigation of an External-Flow Jet-Flap Transport Configuration Having Full-Span Triple-Slotted Flaps. NASA TN D-6391, 1971.

5. Grafton, Sue B.; Parlett, Lysle P.; and Smith, Charles C., Jr.: Dynamic Stability Derivatives of a Jet Transport Configuration With High Thrust-Weight Ratio and an Externally Blown Jet Flap. NASA TN D-6440, 1971.

6. Vogler, Raymond D.: Wind-Tunnel Investigation of a Four-Engine Externally Blowing Jet-Flap STOL Airplane Model. NASA TN D-7034, 1970.

Weight, N (lbf)	245 096 (55 100)
Wing area, m^2 (ft^2)	78 (843)
Wing span, m (ft)	24 (78)
Mean aerodynamic chord, $\bar{c}$, m (ft)	3.58 (11.74)
Center-of-gravity location, percent $\bar{c}$	40
I_X, kg-m^2 (slug-ft^2)	331 103 (244 212)
I_Y, kg-m^2 (slug-ft^2)	334 637 (246 819)
I_Z, kg-m^2 (slug-ft^2)	625 677 (461 482)
I_{XZ}, kg-m^2 (slug-ft^2)	27 690 (20 423)

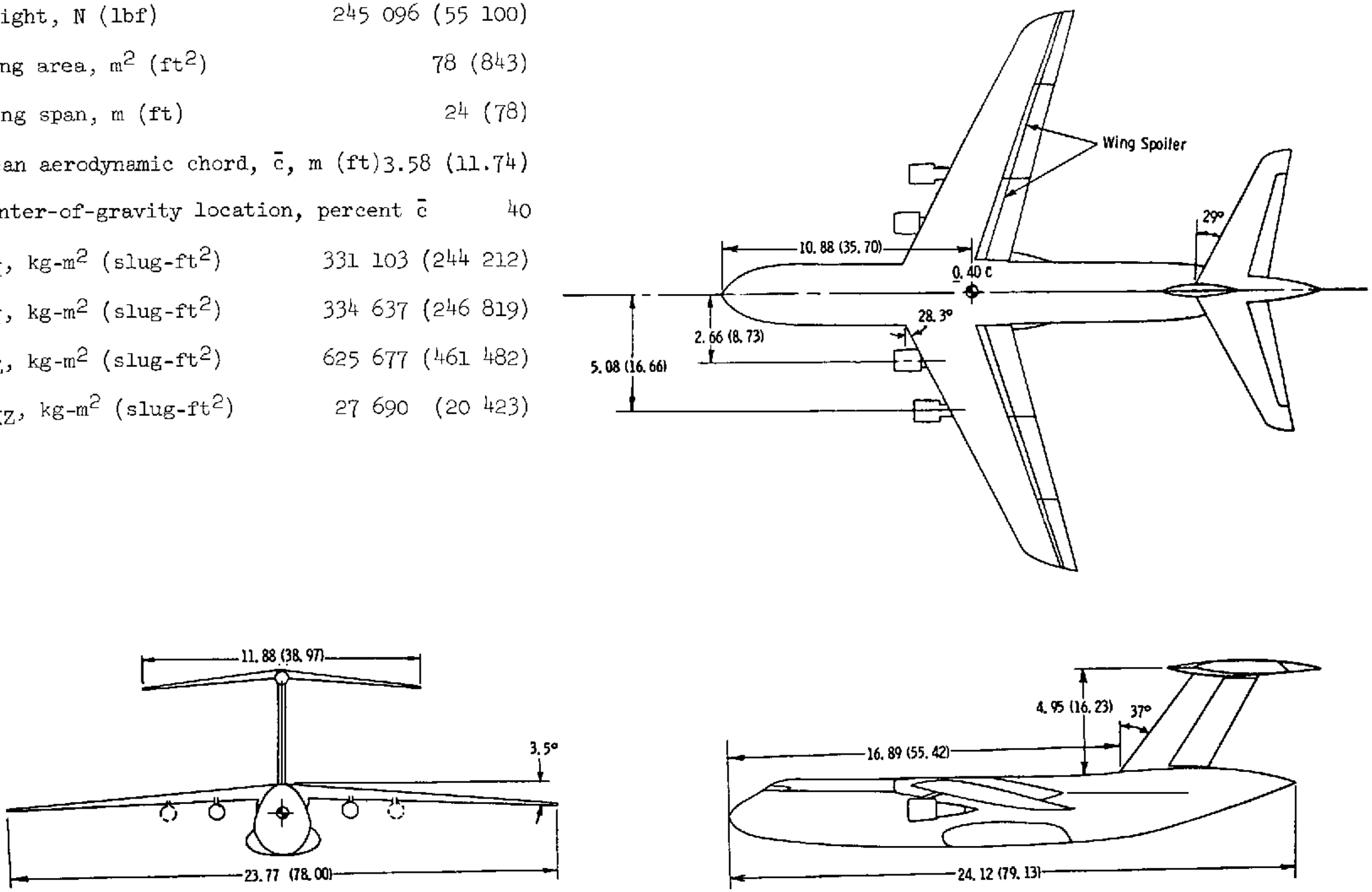

Figure 1.- Three-view drawing of simulated airplane. All linear dimensions are in meters (feet).

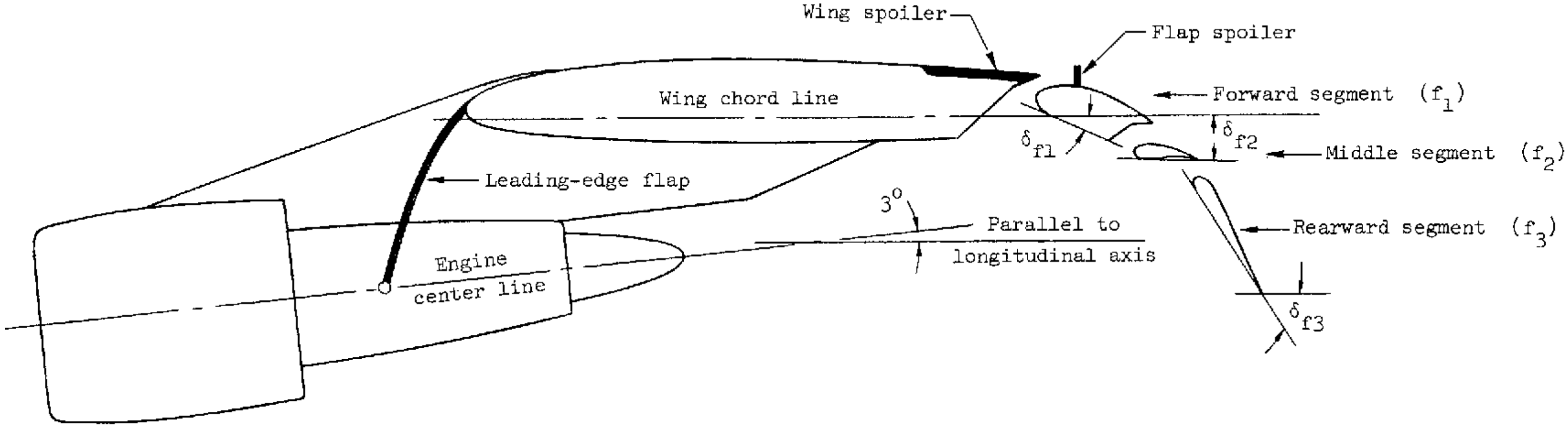

Figure 2.- Flap assembly and engine pylon detail. $\delta_{f1}/\delta_{f2}/\delta_{f3} = 25^{\circ}/10^{\circ}/60^{\circ}$.

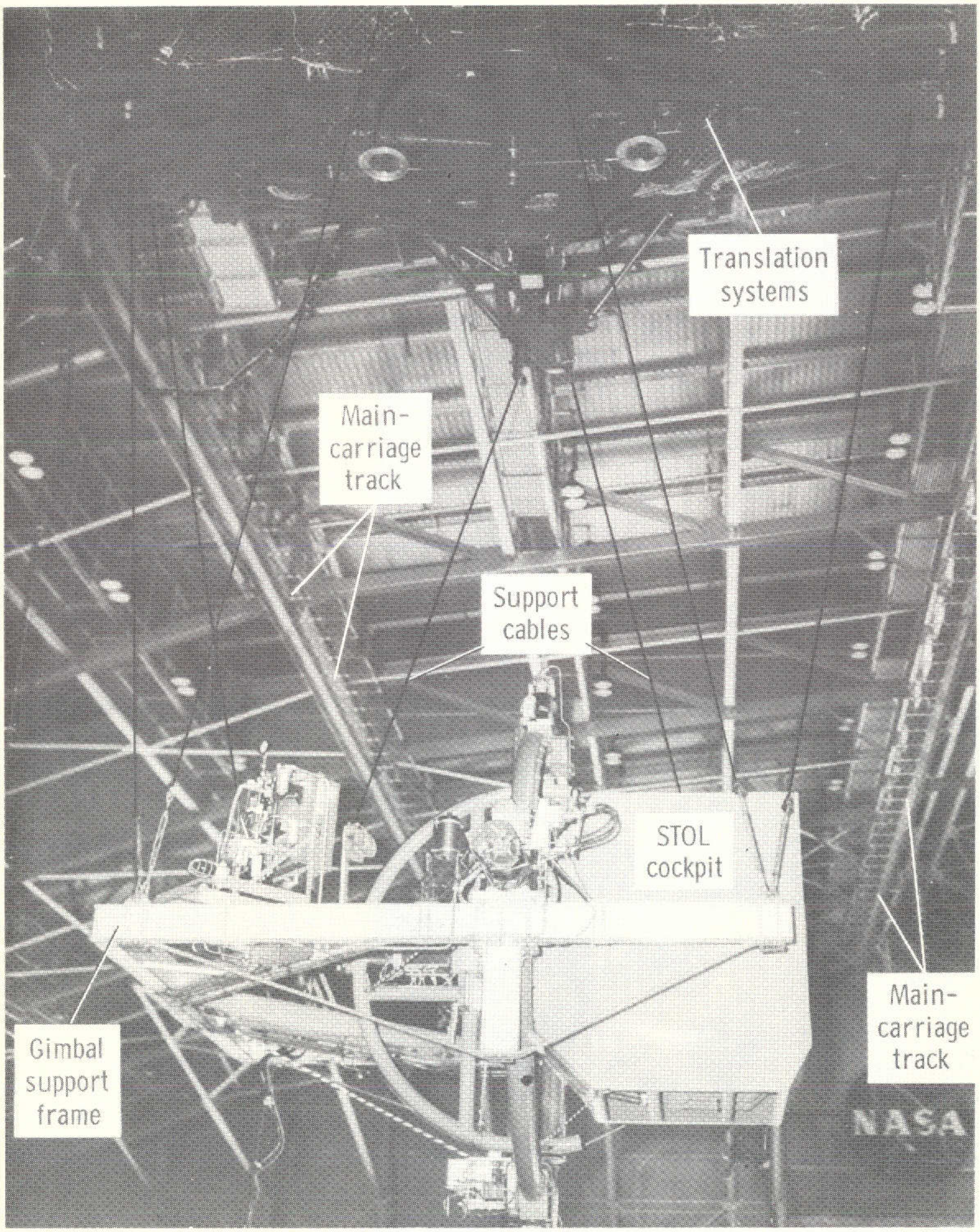

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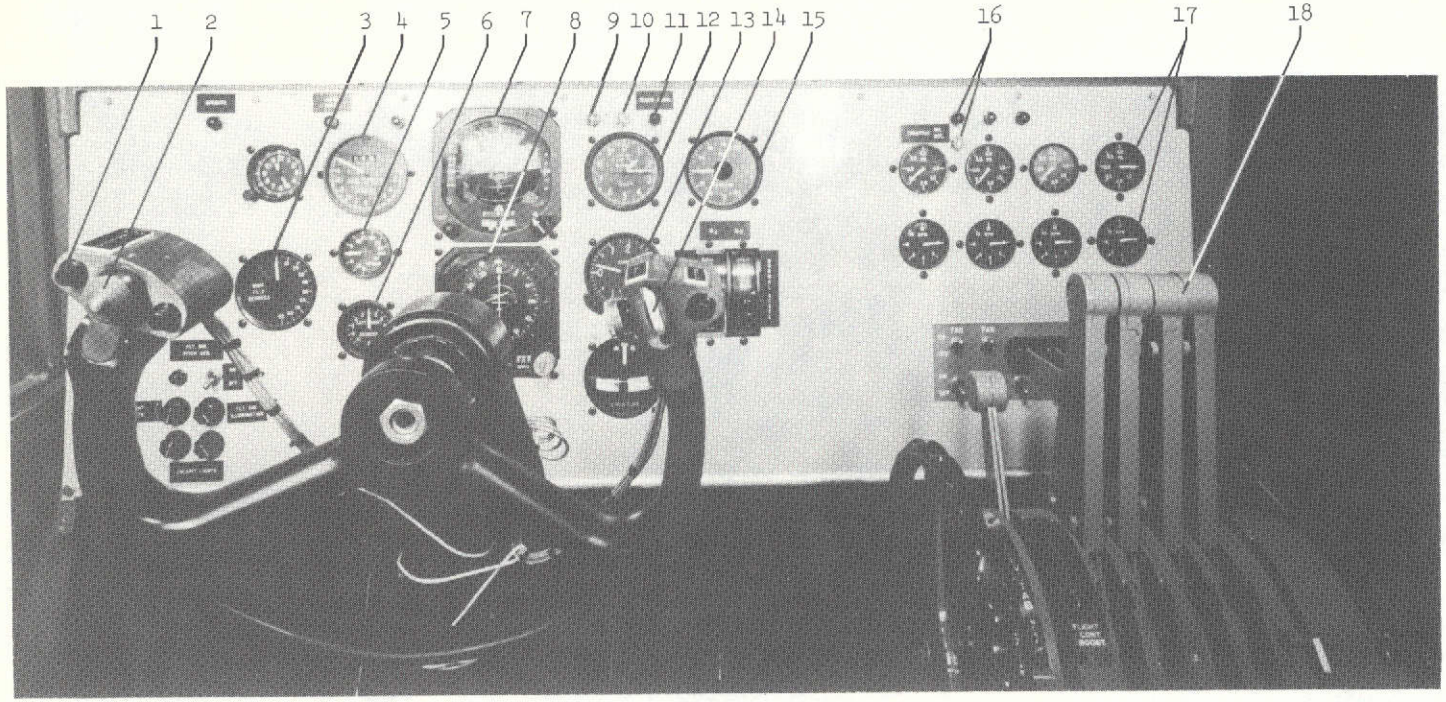
Figure 3.- Langley Real-time Dynamic Simulator (RDS) with STOL cockpit mounted in the gimbals.



1 Autospeed button
2 Pitch and roll trim
3 δ_{f3} flap
4 Airspeed
5 Angle of attack
6 Sideslip
7 Flight director
8 Horizontal situation indicator
9 Flare warning light
10 Flare initiation light
11 Touchdown light
12 Altimeter
13 Rate of climb
14 Direct-lift-control wheel
15 Direct-lift-control meter
16 Thrust trim lights
17 Engine instruments
18 Throttles

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Figure 4.- Pilot's view of cockpit interior.

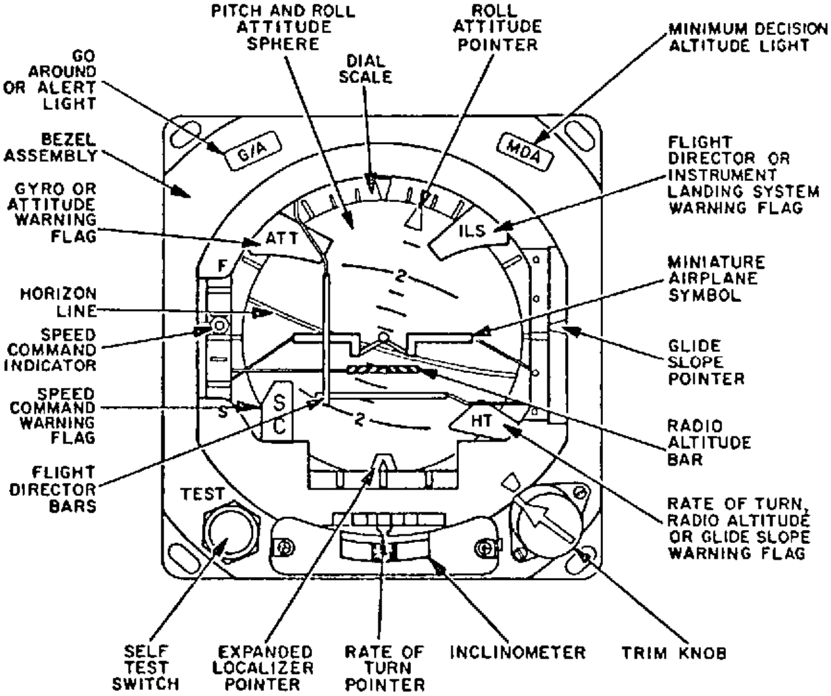
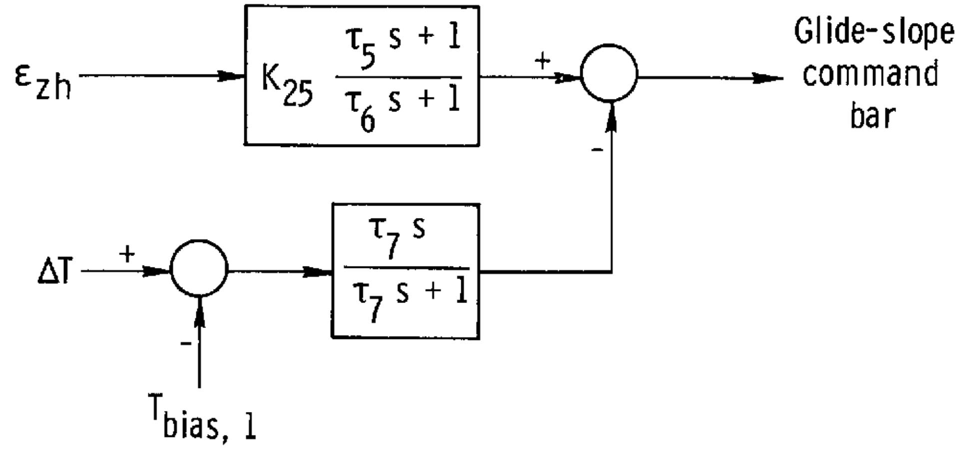


Figure 5.- Flight director and attitude indicator.



K_{25} = 2.64 kN/m (181 lbf/ft)

τ_5 = 3.33 sec

τ_6 = 0.4 sec

τ_7 = 10 sec

Figure 6.- Flight director command bar signal (glide-slope channel).

NASA-Langley, 1974 L-9142