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COMPUTER PROGRAMS FOR ESTIMATION OF STOL TAKEOFF, LANDING, AND STATIC PERFORMANCE

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INTRODUCTION

A set of computer programs has been developed for evaluating the performance of powered-lift STOL aircraft. Included are a static performance summary and dynamic calculations of takeoff and landing performance. This report describes the input, output, options, and calculations for each program. The programs are written in FORTRAN IV and are currently available on TSS 360.

This report is in three independent sections corresponding to the three programs:

(1) Static Performance

(2) Takeoff Performance

(3) Landing Performance

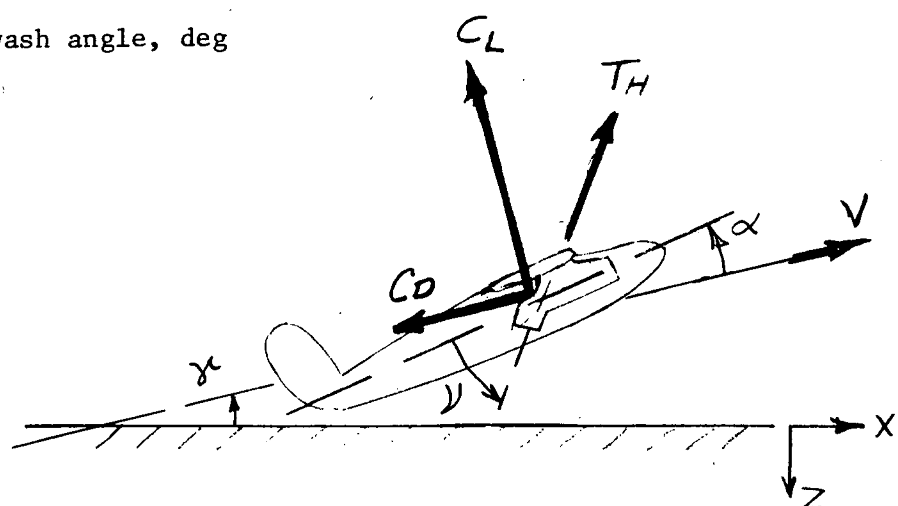
The static performance program computes sets of longitudinal equilibrium trimmed flight conditions and displays them in a convenient format. The takeoff program estimates the takeoff and climbout maneuver of an aircraft. It includes the effects of rotation technique, engine failure, emergency thrust, gear retraction and ground effects. The landing program estimates the flare and landing roll maneuver. It may also be used to estimate the braking distance portion of a rejected takeoff.

The programs are structured for powered-lift aircraft where the aerodynamics are functions of thrust and velocity as well as angle of attack and flap deflection. The engine model in each case will accommodate a thrust split between the fan air which interacts with the aerodynamics and a vectorable gas generator stream which contributes independently to the aircraft accelerations. The engine out capability of these programs is in general restricted to those airplanes where an engine failure and compensation produce insignificant lift and drag changes other than those directly related to the reduced thrust. The application of these programs to different powered-lift concepts is discussed in the text. The programs are not limited to a specific speed or lift coefficient range.

NOTATION

a_x	Horizontal acceleration, body or earth axis, ft/sec^2
a_z	Vertical acceleration, body or earth axis, ft/sec^2
B_S	Body station, increasing aft, ft
$\bar{c}$	Mean aerodynamic chord, ft
C_D	Drag coefficient
C_J	Jet thrust coefficient, Tc/qS
C_L	Lift coefficient
C_{Lmax}	Lift coefficient at stall
C_M	Pitching moment coefficient
g	Acceleration due to gravity, ft/sec^2
h,H	Altitude
I_{cg}	Moment of inertia in pitch about aircraft C.G., slug-ft^2
i_T	Incidence of the horizontal tail, deg or rad
i_W	Incidence of the wing, deg or rad
M	Pitching moment, ft lb
m	Mass of the aircraft, slugs
n	Load factor capability, g's
N	Number of engines
q	Dynamic pressure, psf
s	Range, ft
S, S_W	Wing area, ft^2
S_T	Horizontal tail area, ft^2
Sfc	Specific fuel consumption
T_c	Thrust (cold) interacting with aerodynamics
T_h	Thrust (hot) vectorable
V, V_a	Flight path velocity, ft/sec, kts

V_R	Rotation velocity, kts
V_x	Horizontal component of velocity, ft/sec
V_z	Vertical component of velocity, ft/sec
V_1	Velocity at initiation of engine failure, kts
W, Wt	Gross weight of airplane, lbs
W_L	Water line, increasing up, ft
X_A, X_S	Horizontal force, body and stability axes
Z_A, Z_S	Vertical force, body and stability axes
α_F, α_W	Angle of attack, fuselage and wing, deg
δ_e	Elevator deflection, positive with trailing edge down, deg
δ_f	(Augmentor) flap deflection, positive with trailing edge down, deg
γ	Flight path angle, deg or rad
μ_B	Braking coefficient
μ_R	Rolling friction coefficient
ν	Thrust deflection angle, positive down, deg
ρ	Air density, slugs/ft^3
θ	Pitch attitude, deg
ε	Downwash angle, deg



Sketch to Show Positive Directions

STOL STATIC PERFORMANCE

The computer program described in this section provides a static performance summary for a powered-lift aircraft, where the aerodynamic lift, drag, and moment coefficients are functions of thrust coefficient as well as angle of attack and flap deflection and where a portion of the engine thrust can also be deflected. A longitudinal equilibrium flight condition may be specified by angle of attack, flight path angle, thrust level and deflection, velocity, and flap deflection. With four of these flight variables prescribed by the user, the program varies the other two and elevator deflection in an iterative procedure until the equilibrium point is reached. The program includes the computation of stall speed and maneuver margin and the effects of temperature and altitude.

The program is an outgrowth of one set up specifically for the Augmentor Wing Research Aircraft early in 1971. That program was generated from the C8-A simulation program by S. M. Sinclair at Ames and then substantially revised by The Boeing Company.[1] When the need arose for a more generally applicable powered-lift trim program, some further modifications were made. In the current program there is a choice between using tail-on aerodynamic data or using tail-off data and providing a downwash routine. The number of engines can be varied. Although the program was derived for an augmentor wing, where the aerodynamics are related to the relatively cold thrust from the fan and there is a deflectable hot thrust stream, it is applicable to other powered-lift systems, as described in the program input section.

---

1. The Boeing Company program number TEA-282, documented in their letter 6-7240-00-152 from R. H. Ashleman to D. D. Few, February 18, 1971.

The sections which follow describe the trim algorithm, program input, program output, and the programmed equations.

Trim Algorithm and Stall Speed Calculation

The trim algorithm seeks a longitudinal equilibrium flight condition by iteratively reducing the body x- and z-axis accelerations of the aircraft below prescribed tolerance levels. The method is to vary two of the flight conditions, alpha, gamma, thrust, and thrust deflection, to reduce the accelerations, while varying elevator deflection to maintain zero pitching moment. At each stage in the iteration toward trim, the required change in acceleration is equal to minus the residual acceleration of the previous stage. If the two variables of the trim mode in use are designated V_1 and V_2 then the required change may be approximated:

$$-a_x = \Delta a_x \simeq \frac{\partial a_x}{\partial V_1} \Delta V_1 + \frac{\partial a_x}{\partial V_2} \Delta V_2$$

$$-a_z = \Delta a_z \simeq \frac{\partial a_z}{\partial V_1} \Delta V_1 + \frac{\partial a_z}{\partial V_2} \Delta V_2$$

where a_x, a_z are the residual accelerations from the previous stage

$\Delta a_x, \Delta a_z$ are the required acceleration changes to trim

V_1, V_2 are the trimming variables, two of α, γ, ν, T_h

$\frac{\partial a_x}{\partial V_i}, \frac{\partial a_z}{\partial V_i}$ are the sensitivities of the accelerations to changes in V_1 and V_2

These equations are solved for the adjustments to V_1 and V_2 to be applied before the residual accelerations are recalculated. The actual steps applied are somewhat smaller than these calculated values to avoid convergence problems due to nonlinearities in the system.

When the trim mode chosen is to vary flight path angle (or rate of climb), the program computes the stall speed in addition to the requested equilibrium conditions. The stall speed is found by a Newton-Raphson search for the velocity at which the load factor capability, n, is 1.0g.

Expressions for the partial derivatives and the accelerations from which they are taken are shown below. (Only partials with respect to the two variables of the trim mode in use are required.) The rest of the program equations are included in a separate equations section.

$$a_x = -\frac{qS_W}{m}\left[C_{D_{TOT}} \cos\alpha_F - C_{L_{TOT}} \sin\alpha_F\right] + \frac{1}{m} X_{eng} - g \sin\theta$$

$$a_z = -\frac{qS_W}{m}\left[C_{L_{TOT}} \cos\alpha_F + C_{D_{TOT}} \sin\alpha_F\right] + \frac{1}{m} Z_{eng} + g \cos\theta$$

$$\frac{\partial a_x}{\partial \alpha} = -\frac{qS_W}{m}\left[\left(-C_{D_{TOT}} - \frac{\partial C_L}{\partial \alpha}\right)\sin\alpha_F + \left(-C_{L_{TOT}} + \frac{\partial C_D}{\partial \alpha}\right)\cos\alpha_F\right] - g\cos\theta$$

$$\frac{\partial a_z}{\partial \alpha} = -\frac{qS_W}{m}\left[\left(-C_{L_{TOT}} + \frac{\partial C_D}{\partial \alpha}\right)\sin\alpha_F + \left(C_{D_{TOT}} + \frac{\partial C_L}{\partial \alpha}\right)\cos\alpha_F\right] - g\sin\theta$$

$$\frac{\partial a_x}{\partial \gamma} = -g\cos\theta \qquad \frac{\partial a_z}{\partial \gamma} = -g\sin\theta$$

$$\frac{\partial a_x}{\partial \nu} = -\frac{T_h}{m}\sin\nu \qquad \frac{\partial a_z}{\partial \nu} = -\frac{T_h}{m}\cos\nu$$

$$\frac{\partial a_x}{\partial Th} = \frac{1}{m}\cos\nu \qquad \frac{\partial a_z}{\partial Th} = -\frac{1}{m}\sin\nu$$

Program Input

The program input has been set up to facilitate parametric variations. The major part of the airplane data is input to the program through block data routines to be described later. These routines include airplane constants and all the aerodynamic and engine data in table lookup format. Then for any run, only a few data cards are required to select configurations, velocities, and trim mode, as described below.

A trimmed or equilibrium flight condition is specified by the following variables: angle of attack, flight path angle, thrust, thrust deflection angle, flight speed and flap deflection angle. During the trimming procedure two of these quantities are varied and the remaining four are held fixed at their input values. Elevator deflection is varied simultaneously to maintain zero pitching moment. In each of the three trim modes available, flap deflection and flight speed are held constant and angle of attack is varied. The modes are:

<u>Mode 1.</u> Thrust and thrust deflection are prescribed. Angle of attack and flight path angle are varied to trim.

<u>Mode 2.</u> Thrust deflection and flight path angle are prescribed. Angle of attack and thrust level are varied to trim.

<u>Mode 3.</u> Thrust and flight path angle are prescribed. Angle of attack and thrust deflection are varied to trim.

Equilibrium conditions are determined for all combinations of the prescribed variables. When the trim mode requested is to vary flight path angle, the stall velocity corresponding to C_{Lmax} is also computed.

The input for a run consists of a title card and a NAMELIST data set (INPUTS) which must conform to the 360 NAMELIST convention. The user need only set those variables for which he wishes to change from the default values. The most frequently used input variables are:

"INPUTS" NAME	DESCRIPTION	MAX. NO.	DEFAULT VALUE
DFLAP	Flap settings, deg.	10	0.
PWR	Power settings, in whatever units used in block data II	10	0.
GAMZ	Flight path angles, deg.	10	0.
RØC	Rates of Climb, ft/min	10	0.
DEFL	Hot thrust (Th) deflection angles, deg.	10	0.
VKNØTS	Flight path velocities, knts.	10	0.
HZ	Altitude, ft.	1	0.
WT	Gross weight, lbs	1	As set in block data IV
DELTAT	Std day temp deviation, °F	1	0.
CØNRØC	Constant r/c code	1	0.
	= 0. GAMZ input		
	= 1. ROC input		
MØDTRM	Trim condition code (Integer)	1	-2
	< 0 Vary α & γ	(Set PWR, DEFL)	
	= 0 Vary α & hot thrust	(Set GAMZ or ROC, DEFL)	
	> 0 Vary α & deflection angle	(Set PWR and GAMZ or ROC)	
IØEØ	Engine out code (Integer)	1	0
	= 0 All engines operating		
	= 1 One engine out (for propulsion systems where insignificant asymmetry is produced, see page 12)		

Additional variables may be changed in namelist INPUTS from their values set in the block data routines. These variables, as defined in the block data sections, are:

CDT, CDE, CLDE, IW, IT, AOT, AlT, SW, SHT, CBAR

Data sets may be stacked, but note that input values are carried over between input data sets.

Once the block data routines have been compiled, a run deck will be of the following form:

```
LOAD block data routines
CALL program
Title card
  $INPUTS
   Set desired variables  name = value  separated by commas
  $END
Additional title and input sets
%END
```

Aerodynamic Data

The program is most simply used if the aerodynamic data is available with tail on. If the data is not available in that form, then a downwash calculation must be provided by the user. Only a non-functioning dummy routine exists in the program, because the subroutine originally in the program was specific to the Augmentor Wing Research Aircraft. The user must provide a subroutine of the following form:

```
 SUBROUTINE DWNWSH
 COMMON/AERØXX/EPS,XA,ZA
 COMMON/TRMCØN/DF,NUR,CNU,SNU,THROTL,GAMMA,ALPHA,
1CA,SA,THETA,ALT,DELTAT,DE,MODTRM,GAIN,G,OMASS
     .
     .
     .
```

```
        :
        Any statements required to compute EPS = epsilon, the
        downwash angle, at the horizontal tail, in degrees.
        :
     RETURN
     END
```

Other labelled commons which may be needed appear in the block data description.

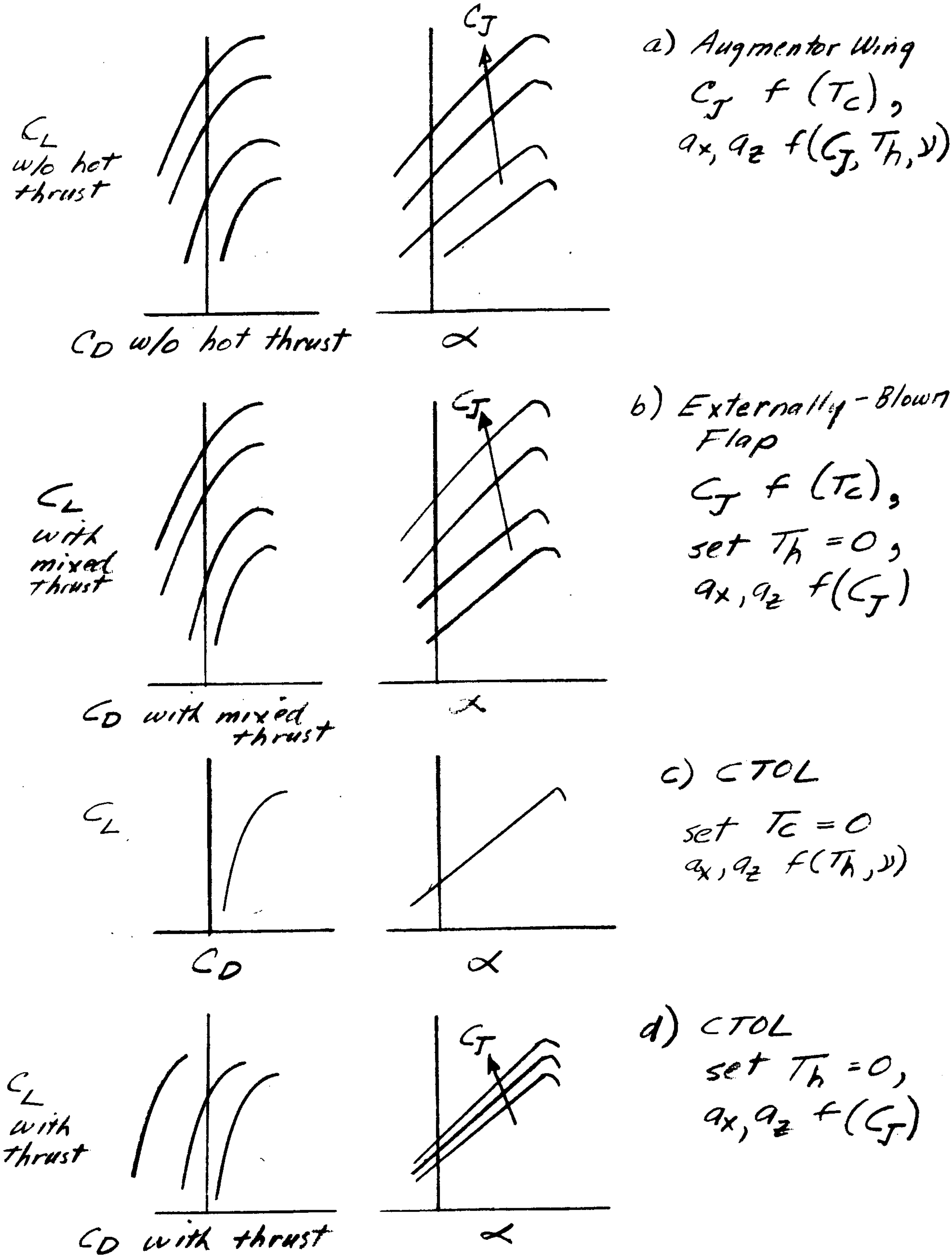
Effect of the Propulsion System

The program was derived for an augmentor-wing configuration where the aerodynamics are related to the relatively cold thrust from the engine fan. This thrust is labelled T_c. The aerodynamic coefficients are functions of jet thrust coefficient C_J, as well as angle of attack and flap deflection, where $C_J = T_c/qS$. The thrust from the hot core gases, which is labelled T_h, can be deflected through the angle ν, where zero ν is the undeflected case. The hot thrust T_h makes a separate contribution to the normal and longitudinal accelerations of the aircraft.

The program can be used for other powered-lift aircraft, or even for conventional airplanes, if one treats these other propulsion systems as special cases of the augmentor-wing situation. In externally blown flap configurations, the aerodynamics are functions of total thrust. To use this program set T_c to the total mixed thrust and T_h to zero. Then the calculated thrust coefficient will be (Total Thrust)/qS and there will be no deflected thrust. In this case, the user must select the power setting; and alpha, gamma, and elevator angle will be computed for equilibrium.

For configurations where the aerodynamics are unrelated to the propulsion system, use T_h as the total thrust and set T_c to zero. In this case the total thrust can be deflected through the angle ν. The thrust coefficient C_J is zero. All three trim modes are available in this situation. A conventional airplane would correspond to this second situation with no thrust deflection. The following sketch illustrates the different applications that can be made. These are applicable to the takeoff and landing performance programs as well.

The engine out capability of these programs is in general restricted to those airplanes where an engine failure and compensation produce insignificant lift and drag changes other than those directly related to the reduced thrust. In cases where a significant asymmetry is produced, a separate set of aerodynamic data must be provided for the engine out situation, including the required corrections for lateral and directional trim.



Sketch .— Illustration of applications with different propulsive systems.

Output

A set of trim conditions corresponding to the requested velocities is generated for each combination of the flaps, powers, flight path angles, and/or thrust deflections input. A summary of the output symbols is shown below.

Run Title Information:

Symbol		Dimension	Description
Wt	GW	LBS	Gross weight
	ALT	FT	Altitude
Δt	DELTA T	°F	Δt in reference to a standard day
δ_f	FLAPS	DEG	Flap setting
i_T	I TAIL	DEG	Tail incidence in ref. to W.L.
	AØT	RAD	Zero lift line of the tail
i_W	I WING	DEG	Wing incidence in ref. to W.L.
S_W	S WING	FT^2	Reference wing area
S_T	SH TAIL	FT^2	Horizontal tail area
	CBAR	FT	Mean aerodynamic chord

FROM C.G.	AFT	DOWN		Description
MOM CTR	xx	xx	CBAR	Positions with respect to the center of gravity of moment center, horizontal tail, engine thrust point, and engine inlet point
TAIL	xx	xx	CBAR	
ENG THR	xx	xx	CBAR	
ENG INL	xx	xx	CBAR	

Output Head Line:

Symbol		Dimension	Description
V_a	VEL	Knots TAS	Flight path velocity
γ	GAMMA	DEG	Flight path angle
	R/C	Ft/Min	Rate of climb
ν	NU	DEG	Hot thrust deflection angle
α_F	ALPHA F	DEG	Fuselage angle of attack
θ	THETA	DEG	Body attitude
δ_e	DE	DEG	Elevator deflection angle
α_T	ALPHA T if downwash used	DEG	Horizontal tail angle of attack
ε	EPS	DEG	Downwash angle at MAC horizontal tail
	CJ		Cold thrust coefficient
	AX	FT/SEC^2	Residual tangential acceleration
	AZ	FT/SEC^2	Residual normal acceleration
pwr	POWER SETTING		Power setting in units used in input
T_h	HOT THRUST	LBS	Hot thrust
T_c	COLD THRUST	LBS	Cold thrust

Symbol		Dimension	Description
	RAM DRAG	LBS	Ram drag
	CL TRIM		Trimmed lift coefficient
$C_{L_{wb}}$	CLWB		With downwash calculation: tail-off lift, drag, and moment coeff.
$C_{D_{wb}}$	CDWB		Without downwash calculation: tail-on untrimmed coefficients
$C_{M_{wb}}$	CMWB		
	CL M TRIM		Trimmed max. lift coefficient
	CL M WB		Tail off (or tail-on untrimmed) max. lift coeff.
$\alpha_{C_{Lmax}}$	ALPHA M	DEG	Fuselage angle of attack at C_{Lmax}
	N	G	Load factor capability
	V-VMIN	knots TAS	Difference between "VEL" and stall speed
	V/VMIN		Ratio of "VEL" and stall speed
	ENGINE LIMIT		(Blank) - No limit encountered
			MAX - Power setting limit exceeded
			TBLE - Power setting outside table range

Static Equations

$\rho = \rho_0 * (1. - .6856E-6 * alt)^{5.2559} / ((518.67 + \Delta t)/518.67)$

where Δt is the deviation from standard temperature, °F

$q = .5 \rho V_a^2$ where V_a is the flight path velocity in ft/sec

$C_J = T_c / q S_w$

$C_{L_{wb}} = \text{ftn}(\alpha_F + i_w;\ C_J;\ \delta_f)$

$C_{D_{wb}} = \text{ftn}(\alpha_F + i_w,\ C_J,\ \delta_f)$

$C_{m_{wb}} = \text{ftn}(\alpha_F + i_w,\ C_J,\ \delta_f)$

With tail-on aerodynamic data: $C_{L_{tail}} = 0.$

With tail-off data, downwash calculation required to get ε.

$$\alpha_T = \alpha_F - \varepsilon + i_T$$

$$C_{L_{tail}} = AIT * (\alpha_T - AOT) * \frac{S_T}{S_w}$$

Total lift and drag:

$$C_{L_{TOT}} = C_{L_{wb}} + C_{L_{tail}} + C_{L_{elev}}$$

$$C_{D_{TOT}} = C_{D_{wb}} + C_{D_{tail}} + C_{D_{elev}}$$

where $C_{D_{tail}}$ and $C_{D_{elev}}$ are input quantities and:

$$C_{L_{elev}} = \frac{\partial C_L}{\partial \delta_e} * \delta_e * \frac{S_T}{S_w} / 57.3$$

Thrust:

$$T_h = \text{ftn}(\text{pwr}, \text{alt}, V_a) * \text{loss factor} * \text{engines operating}$$

$$T_c = \text{ftn}(\text{pwr}, \text{alt}, V_a) * \text{loss factors} * \text{engines operating}$$

$$\text{Ramdrag}^{1)} = \text{ftn}(\text{pwr}, \text{alt}, V_a) * \text{engines operating}$$

Thrust deflection angles:

$$C5X = \cos\beta_N * \cos\vartheta * \cos\psi_N + \sin\beta_N * \sin\psi_N$$

$$C5Z = \cos\beta_N * \cos\vartheta * \sin\psi_N * \sin\phi_N - \sin\beta_N * \cos\psi_N * \sin\phi_N + \cos\beta_N * \sin\vartheta * \cos\phi_N$$

where β_N, ψ_N, ϕ_N are installation offset angles of the nozzle.

For $\beta_N = \psi_N = \phi_N = 0$, $C5X = \cos\vartheta$ and $C5Z = \sin\vartheta$.

Engine forces:

$$X_{eng} = T_h * C5X - \text{Ramdrag} \cos\alpha_F$$

$$Z_{eng} = -T_h * C5Z - \text{Ramdrag} \sin\alpha_F$$

Engine moment:

$$M_{eng} = T_h \left[\left(\frac{WL_{cg} - WL_{eng}}{\bar{c}} \right) C5X + \left(\frac{BS_{cg} - BS_{eng}}{\bar{c}} \right) C5Z \right] \bar{c}$$

$$- \text{Ramdrag} \left[\left(\frac{WL_{cg} - WL_{ei}}{\bar{c}} \right) \cos\alpha_F - \left(\frac{BS_{cg} - BS_{ei}}{\bar{c}} \right) \sin\alpha_F \right] \bar{c}$$

where ei denotes engine inlet and eng denotes hot thrust reaction point.

1) If ramdrag is included in the C_D input, this term is zero.

Elevator deflection to trim pitching moment:

$$\delta_e = \frac{S_W}{S_T}\left[C_{D_{wb}} * \left(\frac{WL_{cg} - WL_{mc}}{\bar{c}}\right)\cos\alpha_F - C_{m_{wb}}\right.$$

$$- C_{L_{wb}} * \left(\frac{BS_{cg} - BS_{mc}}{\bar{c}}\cos\alpha_F + \frac{WL_{cg} - WL_{mc}}{\bar{c}}\sin\alpha_F\right)$$

$$\left.- \frac{M_{eng}}{q S_W \bar{c}}\right] \Big/ \left[\frac{C_{L\delta_e}}{57.3}\left(\frac{BS_{cg} - BS_{tq}}{\bar{c}}\cos\alpha_F + \frac{WL_{cg} - WL_{tq}}{\bar{c}}\right.\right.$$

$$\left.\left.\sin\alpha_F\right)\right] - \frac{S_W}{S_T} C_{L_{tail}} \Big/ \left(\frac{C_{L\delta_e}}{57.3}\right)$$

where mc denotes moment center, tq denotes horizontal tail quarter-chord position. $\left(C_{L\delta_e} = \frac{\partial C_L}{\partial \delta_e}\right)$

Aerodynamic forces, stability axes:

$$X_S = -q\, S_W * C_{D_{TOT}}$$

$$Z_S = -q\, S_W * C_{L_{TOT}}$$

Aerodynamic forces, body axes:

$$X_A = X_S \cos\alpha_F - Z_S \sin\alpha_F$$

$$Z_A = Z_S \cos\alpha_F + X_S \sin\alpha_F$$

Total forces, body axes:

$$X_B = X_A + X_{eng}$$

$$Z_B = Z_A + Z_{eng}$$

Residual accelerations:

$$a_x = X_B/m - g \cos\theta$$

$$a_z = Z_B/m + g \sin\theta$$

Margin calculations:

$$\alpha_{C_{L max}} = \text{ftn}\,(C_J, \delta_f)$$

$$C_{L max} = \text{ftn}\,(C_J, \delta_f)$$

$$C_{L max\ trim} = C_{L max} + \Delta C_{L trim} \quad \text{where:}$$

$$\Delta C_{L trim} = \Big[C_{D wb} * \frac{W_{Lcg} - W_{Lmc}}{\bar{c}} \cos\alpha_F - C_{m_{wb}}$$

$$- C_{L wb} * \left(\frac{B_{scg} - B_{smc}}{\bar{c}} \cos\alpha_F + \frac{W_{Lcg} - W_{Lmc}}{\bar{c}} \sin\alpha_F \right)$$

$$- \frac{M_{eng}}{q S_w \bar{c}} \Big] \Big/ \left[\frac{B_{scg} - B_{stg}}{\bar{c}} \cos\alpha_F + \frac{W_{Lcg} - W_{Ltg}}{\bar{c}} \sin\alpha_F \right]$$

where $C_{D wb}, C_{m wb}, C_{L wb}, \alpha_F$, M_{eng} all at $\alpha_{C_{L max}}$

Load factor capability:

$$n = [q S_w * C_{L max\ trim} + T_h * (C5Z \cos\alpha_F + C5X \sin\alpha_F)]$$

$$/(W_t * \cos\gamma) \qquad \text{for } \alpha_F \text{ at } \alpha_{C_{L max}}$$

Flight path angle at stall speed:

$$\gamma = \sin^{-1}\Big[(T_h * (C5X \cos\alpha_F - C5Z \sin\alpha_F) - C_{D wb}\, q S_w$$

$$- \text{Ramdrag})/W_t \Big]$$

For $\beta_{iv} = \Psi_N = \phi_N = 0$: $C5Z \cos\alpha_F + C5X \sin\alpha_F = \sin(\alpha_F + \nu)$

$C5X \cos\alpha_F - C5Z \sin\alpha_F = \cos(\alpha_F + \nu)$

BLOCK DATA ROUTINES

A description of the block data subroutines required to input aerodynamic and engine data and airplane constants is given on the following pages. Each routine is of the form:

```
BLOCK DATA
COMMON statements
DATA statements to set all variables described
END
```

Block Data I. Aerodynamic Data

Common Statements:

```
COMMON/AROTB1/NARO(3),ATAB(31),CLTAB(900),CDTAB(900),CMTAB(900)
COMMON/ATBLS/CLTAB1(150), CLTAB2(150),CLTAB3(150),CLTAB4(150),
1CLTAB5(150),CDTAB1(150),CDTAB2(150),CDTAB3(150),CDTAB4(150),
2CDTAB5(150),CMTAB1(150),CMTAB2(150),CMTAB3(150),CMTAB4(150),
3CMTAB5(150),CLTAB6(150),CDTAB6(150),CMTAB6(150)
COMMON/CLMX/NCLX(2),TABCLX(21),CLWBMX(90),NAX(2),TABAX(21),ALPHMX(90)
COMMON/TLON/TAILON
```

Data to be Input:

Stability axis aerodynamic coefficients

$C_L, C_D, C_M = \text{ftn}(\alpha_W,\ C_J,\ \delta_f)$ $\qquad$ $C_J = T_c/qS$ (See section on propulsion system)
$\alpha_W = \alpha_F + i_W$

$C_{L_{max}}, \alpha_{C_{L_{max}}} = \text{ftn}(C_J,\ \delta_f)$

TAILON	= 1. to input tail-on data = 0. tail-off (In this case see section on aerodynamic data.)
NARO(1)	Number of values of α_W at which C_L, C_D, C_M to be input ($\geq$2)
NARO(2)	Number of values of C_J at which C_L, C_D, C_M to be input ($\geq$2)

NARO(3) Number of values of δ_f at which C_L,C_D,C_M to be input ($2 \leq$NARO(3)≤ 6)

NARO(1) + NARO(2) + NARO(3)$\leq$31 NARO(1) * NARO(2)$\leq$150

ATAB NARO(1) values of α_W, NARO(2) values of C_J, and NARO(3) values of δ_f, each set monotonically increasing ($\leq$31 entries)

CLTAB1 Matrix of lift coefficients C_L = ftn(α_W,C_J) for the first δ_f, α_W varying most rapidly

CDTAB1 Matrix of drag coefficients C_D = ftn(α_W,C_J) for the first δ_f, α_W varying most rapidly

CMTAB1 Matrix of pitching moment coefficients C_M = ftn(α_W,C_J) for the first δ_f, α_W varying most rapidly

CLTAB2-6, CDTAB2-6, CMTAB2-6 Aerodynamic coefficients at the remaining flap settings, parallel to the above. Use as many as required.

These data are combined into the vectors in common / AROTBL/ and three-dimensional lookup carried out (TVIN).

NCLX(1) Number of values of C_J at which C_{Lmax} to be input ($\geq$2)

NCLX(2) Number of values of δ_f at which C_{Lmax} to be input ($\geq$2)

NCLX(1) + NCLX(2)$\leq$21 NCLX(1) * NCLX(2)$\leq$90

TABCLX NCLX(1) values of C_J followed by NCLX(2) values of δ_f, each set monotonically increasing

CLWBMX Matrix of values of C_{Lmax} = ftn(C_J,δ_f), C_J varying most rapidly

NAX, TABAX Same as NCLX, TABCLX above for $\alpha_{C_{Lmax}}$, α_W at C_{Lmax}

ALPHMX Matrix of values of $\alpha_{C_{Lmax}}$ = ftn(C_J,δ_f), C_J varying most rapidly

<u>Block Data II</u> Thrust

<u>Common Statements</u>:

```
COMMON/PROTAB/NPRO(3),PTAB(22),HOTTH(300),COLDTH(300),
1EMFTAB(300),ETATAB(300),BLOSS(12),NOE,PMAX
COMMON/BOUND/V1,VG,V2
```

Data to be Input:

T_c, T_h Ramdrag = ftn(power setting, altitude, velocity)

(Be sure you have read section on effect of propulsion system.)

$T_c = T_{c_i}$ * eta * bloss * engines operating

$T_h = T_{h_i}$ * bloss * engines operating

Ramdrag = Ramdrag * engines operating

NOE Number of engines (at full power)

NPRO(1) Number of power settings at which thrusts to be input ($2 \leq$ NPRO(1) ≤ 12)

NPRO(2) Number of altitudes at which thrusts to be input (≥ 2)

NPRO(3) Number of velocities at which thrusts to be input (≥ 2)

NPRO(1) + NPRO(2) + NPRO(3) ≤ 22 NPRO(1) * NPRO(2) * NPRO(3) ≤ 300

PTAB NPRO(1) values of power setting, NPRO(2) values of altitude, NPRO(3) values of velocity at which thrusts to be input, each set monotonically increasing

PMAX Maximum allowable value of power setting

HOTTH Matrix of T_h = ftn(power, alt, vel) for one engine, in lbs, power varying most rapidly, then altitude, then velocity (TVIN 3-dimensional lookup)

COLDTH Matrix of T_c = ftn(power,alt,vel) parallel to T_h

EMFTAB Matrix of Ramdrag = ftn(power,alt,vel) parallel to T_h

ETATAB Matrix of cold thrust efficiency = ftn(power,alt,vel) parallel to T_h

BLOSS Bleed loss efficiency = ftn(power setting), NPRO(1) entries Applied to both hot and cold thrust

Bounds for stall velocity search.

V1 Minimum speed in ft/sec for which aerodynamic data is available, given the cold thrust data being input above. $C_J = (T_c)/(1/2\rho v^2 S)$ (Or speed to which any stall velocity search should be bounded.)

V2 Corresponding maximum speed

VG A starting velocity within the above range

Block Data III. Moment Arms

Common Statement:

COMMON/CGTRMS/CGT1,CGT2,CGT4,CGT5,CGT6,CGT7,XE,ZE

Data to be Input:

Distances from C.G. to various engine positions, tail and moment center in terms of mean aerodynamic chord.

WL = water line, increases up

BS = Body station, increases aft

CGT1	$(WLCG - WLMC)/\bar{c}$	Moment center position
CGT2	$(BSCG - BSMC)/\bar{c}$	
CGT4	$(BSCG - BSTQ)/\bar{c}$	Horizontal tail quarter chord position
CGT5	$(WLCG - WLTQ)/\bar{c}$	
CGT6	$(WLCG - WLEI)/\bar{c}$	Engine inlet position
CGT7	$(BSCG - BSEI)/\bar{c}$	
XE	$(BSCG - BSENG)/\bar{c}$	Engine hot thrust exit position or point of application of hot thrust vector
ZE	$(WLCG - WLENG)/\bar{c}$	

Note that on the program output these distances are shown as "how far" down, "how far" aft, so that for the horizontal positions the signs will be shown opposite to those input above.

Block Data IV. Airplane Constants and Initializations

Common Statements:

```
COMMON/APCON/IT,IW,SW,SHT,STOSW,CBAR,WT,AOT,AlT,ALPHT
REAL IT,IW
COMMON/COEFF/CLWB,CDWB,CMWB,PDCL(3),PDCD(3),TCLCOF,TCDCOF,CDT,CDE,
1CLT,CLDE
```

```
COMMON/NOZANL/BETNOZ,PHINOZ,PSINOZ
COMMON/TRMCON/DF,NUR,CNU,SNU,THROTL,GAMMA,ALPHA,CA,SA,THETA,ALT,
DELTAT,DE,MODTRM,GAIN,G,OMASS
COMMON/TRMPRM/DFLAPS(10),PWR(10),GAMZ(10),ROC(10),DEFL(10)
1VKNOTS(10),CONROC,HZ
COMMON/ENGN/TH,TC,CJ,XENG,ZENG,MENG,IOEO,RDRAG,C5X,C5Z
```

Required Initializations:

DATA HZ,MODTRM,DELTAT,G/0.,-2,0.,32.174/

Default altitude to zero, trim mode to varying gamma, standard-day temperature deviation to zero, and set g

DATA DFLAP,PWR,DEFL,GAMZ,ROC,VKNOTS/10*0.,10*0.,10*0.,10*0.,10*0.,10*0./

Default the input vectors to zero

DATA CONROC/0./

Default constant rate of climb flag to zero

DATA IOEO/0/

Default to no engine out

Data to be Input:

Airplane dimensions and derivatives:

WT	Default value for gross weight of airplane
SW	Wing area, ft^2
SHT	Horizontal tail area
CBAR	Mean aerodynamic chord, ft
IW	Incidence of the wing, radians
CDT	Contribution of tail to total drag coefficient in terms of wing area. (Zero for tail-on aero data.)
CDE	Contribution of elevator to total drag coefficient in terms of wing area

CLDE	$\partial C_L/\partial\delta_e$, per radian, in terms of tail area
IT	Incidence of the horizontal tail, radians. (Will be printed but only used with downwash calculations.)
BETNOZ PHINOZ PSINOZ	Installation offset angles of the hot thrust deflection nozzle, radians. (See equations.)

Following quantities only used with downwash calculation:

AOT	Zero lift angle of attack of the horizontal tail, radians
AIT	Linearized lift curve slope of the horizontal tail, per radian, in terms of tail area

STOL TAKEOFF PERFORMANCE

TAKOFF is a computer program for estimating the takeoff and climbout maneuver of a STOL aircraft with powered-lift characteristics. The program includes the effects of rotation technique, engine failure, emergency thrust, gear retraction, and ground effects. It is an outgrowth of a similar unpublished program for conventional aircraft by V. R. Corsiglia of Ames Research Center

For the powered-lift aircraft, aerodynamic lift, drag, and moment are functions of thrust level and velocity as well as angle of attack and flap deflection. Tail-on aerodynamic coefficients C_L, C_D, C_M are input to the program in tabular form as functions of thrust coefficient and angle of attack for a specified flap deflection. The engine model has been set up to accommodate the augmentor wing system, where the total thrust is split between a hot thrust part which is exhausted through vectorable nozzles and a cold thrust part which interacts with the aircraft aerodynamics. The program is applicable to other powered-lift aircraft, however, as described in the input section.

For purposes of the computer analysis, the takeoff maneuver is divided into four segments:

(1) ground roll to rotation velocity

(2) rotation to the commanded maximum angle of attack, usually including liftoff

(3) transition to the climbout condition

(4) climbout

The options available and calculations carried out will be described separately for each segment. The equations for all segments are included in the computations section.

Ground Roll to Rotation Speed

The first segment of the takeoff maneuver, to be called ground roll for convenience, extends from brake release until the aircraft has accelerated to the selected rotation velocity, V_R. The distance is integrated from an initial time, position, and velocity, which need not be brake release. This allows the calculations to be restarted, as demonstrated in the sample output. When the velocity, V_1, at which an engine fails is reached, thrust adjustment begins. Thrust and ramdrag from the failed engine are reduced to zero over the winddown interval, DT1. Meanwhile, after a delay, DT2, for the pilot to respond to the failure, the remaining engines are moved to full emergency thrust over a time period, DT3. This period of thrust change, shown schematically in figure 1, normally extends into the rotation segment.

Prior to rotation, angle of attack is held at a constant input value and elevator deflection is taken to be zero. Ground effect factors as a function of altitude are applied to C_L and C_D from the initiation of ground roll until the aircraft is out of ground effect.

Rotation

When the aircraft reaches the rotation velocity, V_R, an elevator step change δe_o is input. Provided this elevator step is sufficient to trim the aircraft pitching moment and still lift the nose gear at V_R, TAKOFF iterates to find the elevator pattern for which the aircraft will just rotate to the commanded maximum angle of attack. The quantity determined

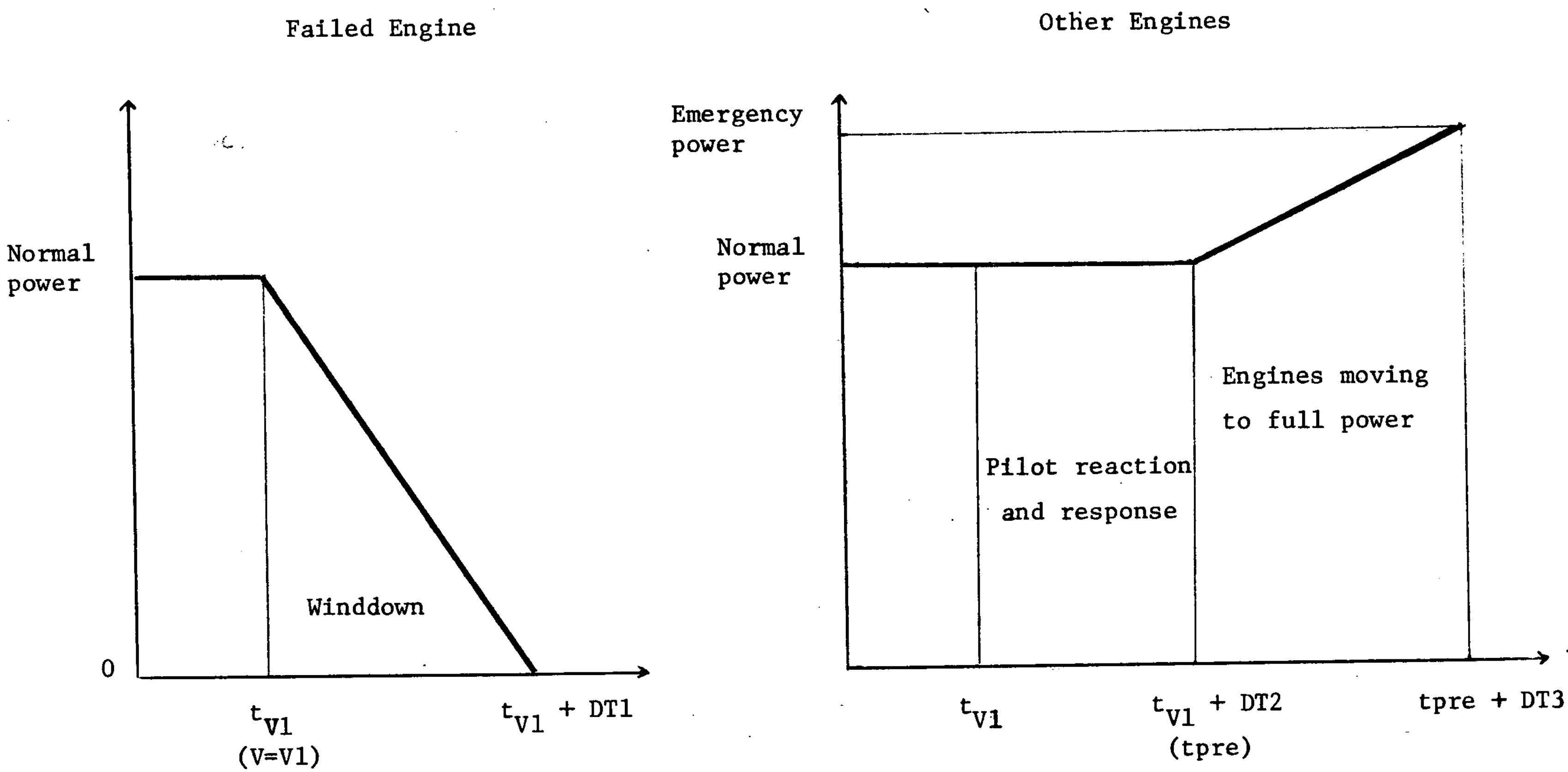
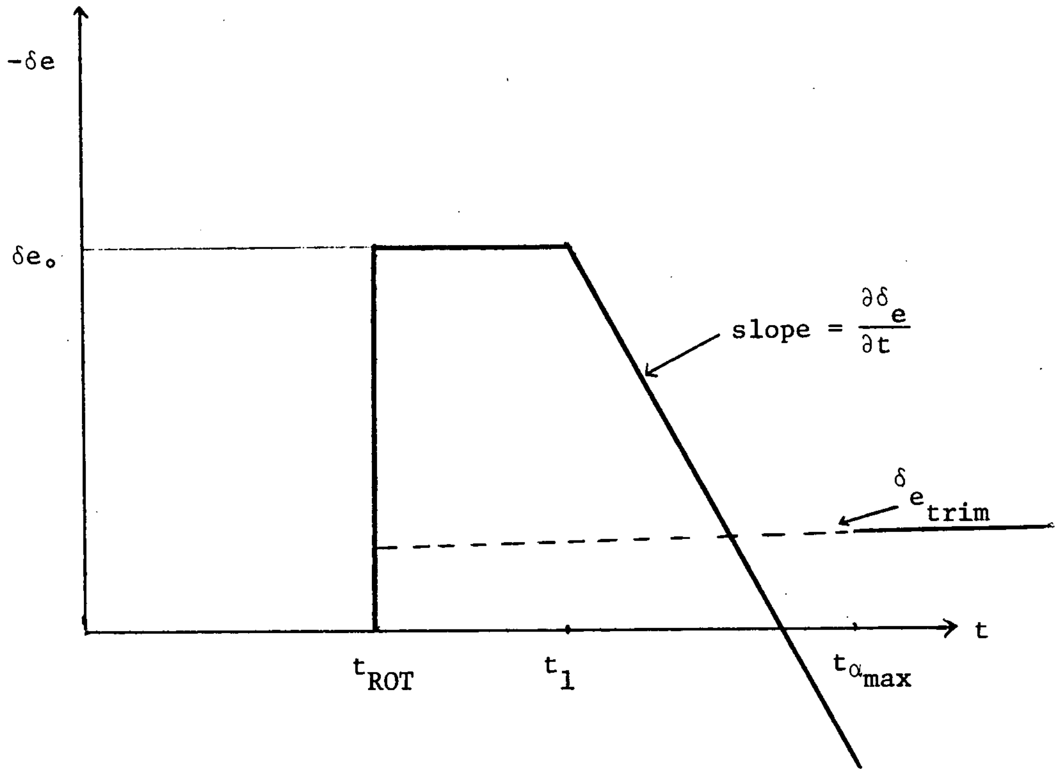


Figure 1.- Thrust changes when an engine fails.
(T_h, T_c, and Ramdrag)



Technique for Determining t_1

a. Initial guess $t_1 = t_{ROT}$ + DTR1

b. Compute rotation

c. If at $t = t_{\alpha_{max}}$ $\frac{d\alpha}{dt} > .03$ rad/sec, decrease t_1.

(if $t_1 < t_{ROT}$ reduce $\delta e_\circ$.)

If $\frac{d\alpha}{dt} < 0$ before $\alpha = \alpha_{max-rot}$, increase t_1.

d. Repeat b and c until $\left|\frac{d\alpha}{dt}\right| < .03$ rad/sec at $t = t_{\alpha_{max}}$

Figure 2. Time history of δ_e and trial and error technique for determining t_1.

by the program is the time period the full elevator step is to be held before the elevator is returned at a specified rate. The procedure is shown in figure 2. Liftoff usually occurs near the end of rotation.

Transition

During the transition segment, the aircraft moves from the maximum rotation position to the climbout condition. Ground effects can be included until the end of transition. Angle of attack is commanded by the user as a function of altitude during this segment. When the gear retraction height is reached, TAKOFF begins to retract the gear by removing the gear increment from the drag coefficient. After a time period, DT4, the gear is fully retracted. During transition and climbout, elevator deflection is that which is required to maintain zero pitching moment.

Climbout

Several modes of climbout are available: constant rate of climb, constant pitch attitude, constant load factor, constant flight path angle, and constant velocity. In each case TAKOFF adjusts angle of attack as required to maintain the climbout mode as closely as possible without losing velocity. Optionally the power setting may be reduced for climbout. There will be discontinuities between transition and climbout.

Program Input

Input to the program is in two sections. The aerodynamic coefficients and engine data are input through a block data subroutine described in the next section. Airplane constants and the variables to specify a particular takeoff situation are input on a series of twelve data cards as shown on the following pages.

Input Data Set

Card	Column	Format	Variable	Use
1	1-80	20A4	IDENT	Title information
2	1-8	F8.	SMAX	Terminal distance, ft.
	9-16	F8.	W	Airplane gross weight, lbs.
	17-24	F8.	SREF	Reference area for C_L,C_D,C_M in ft^2
	25-32	F8.	VR	Speed at which rotation begins, knots
	33-40	F8.	V1	Speed at which engine failure begins, knots (Enter high value if engine failure is to be omitted)
	41-48	F8.	ALMAX	α_{max}, maximum angle of attack reached in rotation
	49-56	F8.	SFC	Specific fuel consumption (lb of fuel/hr)/(lb of total thrust)
	57-64	F8.	HMAX	Terminal altitude above runway, ft
	65-72	F8.	PWR	Power setting during normal operation
	73-80	F8.	EPWR	Power setting during emergency operation after engine failure
3	1-8	F8.	NU	Angle of thrust vector from airplane reference line, deg. Positive down
	9-16	F8.	ALO	Angle of attack during ground roll prior to time VR reached, deg
	17-24	F8.	HGEAR	Altitude above runway at which to begin gear retraction, ft. Set = 0 for fixed gear
	25-32	F8.	DCDG	$\Delta C_{D_{gear}}$, C_D increment due to gear being down, a positive quantity. Set = 0. for fixed gear
	33-40	F8.	DT4	Time required for gear to retract, sec
	41-48	F8.	CBAR	Mean aerodynamic chord, ft

Card	Column	Format	Variable	Use
3	49-56	F8.	ICG	Moment of inertia in pitch about airplane C.G., slug-ft^2
	57-64	F8.	XCG	Dimensionless distance with respect to CBAR, from moment center aft to C.G.
	65-72	F8.	XGR	Dimensionless distance w.r.t. CBAR from moment center aft to main gear
	73-80	F8.	ZGR	Dimensionless distance w.r.t. CBAR from moment center down to main gear
4	1-8	F8.	ZCG	Dimensionless distance w.r.t. CBAR from moment center down to C.G.
	9-16	F8.	XEI	Dimensionless distance w.r.t. CBAR from C.G. aft to engine inlet
	17-24	F8.	ZEI	Dimensionless distance w.r.t. CBAR from C.G. down to engine inlet
5	1-8	F8.	DT1	Time from initial engine failure until complete loss of thrust, sec (≥ 0)
	9-16	F8.	DT2	Time from initial engine failure until pilot has reacted and completed throttle adjustments for emergency thrust, sec (≥ 0)
	17-24	F8.	DT3	Time required by engines to reach full emergency thrust after throttles adjusted, sec (≥ 0)
	25-32	F8.	MU	Rolling friction coefficient of gear on the runway
	33-40	F8.	CMDE	Derivative of C_M $\partial C_M/\partial \delta_e$, 1/deg, in terms of dimensionless distance
	41-48	F8.	CLDE	Derivative of C_L $\partial C_L/\partial \delta_e$, 1/deg
	49-56	F8.	CDDE	Derivative of C_D $\partial C_D/\partial \delta_e$, 1/deg
	57-64	F8.	DEO	Value of δ_e after step change at beginning of rotation, deg.
	65-72	F8.	DET	$\partial \delta_e/\partial t$, deg/sec
	73-80	F8.	NOE	Number of engines

Card	Column	Format	Variable	Use
6	1-5	I5	NOH	Number of altitude entries in transition tables for ALGE, FCLGE, FCDGE ($2 \leq NOH \leq 7$)
	6-10	I5	MXPRNT	= 1 to print trial rotation calculations. Otherwise not
	11-15	I5	TCPRNT	= 1 to print cold thrust, T_{c_T}. Defaults to print hot thrust, T_h
7	1-8	F8.	XTH	Dimensionless distance w.r.t. CBAR from C.G. aft to the engine hot thrust reaction point
	9-16	F8.	ZTH	Corresponding distance down from C.G.
	17-24	F8.	DTR1	Initial guess of length of time ($T1 - T_{ROT}$) that total elevator step will be held, seconds. Defaults to 1. second
	25-32	F8.	IW	Incidence of the wing.
	33-40	F8.	VZ	Initial velocity, kts ($VZ \leq VR$)
	41-48	F8.	HZ	Runway elevation, ft
	49-56	F8.	AUGRAT	Augmentation ratio. (Used in extrapolating C_L, C_D beyond table limits - see computations section. Set AUGRAT=0. for no extrapolation.)
	57-64	F8.	SZ	Initial distance, ft
	65-72	F8.	TZ	Initial time, sec
Transition:				
8	1-70	7F10.	H	NOH values of altitude above runway at which transition tables input, in ascending order and no two identical. The aircraft is out of ground effect and climbout begins at H(NOH).

Card	Column	Format	Variable	Use
9	1-70	7F10.	ALGE	NOH values of angle of attack as functions of altitude during transition
10	1-70	7F10.	FCLGE	NOH corresponding multiplicative corrections to C_L for ground effect
11	1-70	7F10.	FCDGE	NOH corresponding multiplicative corrections to C_D for ground effect

The factors FCLGE and FCDGE are also applied to C_L and C_D during ground roll and rotation.

Climbout:

Card	Column	Format	Variable	Use
12	1-6	A6	MODE	Designated mode of climbout. Values ROC, THETA, LDFCTR, GAMMA, VEL correspond to constant rate of climb, pitch attitude, load factor, flight path angle, and velocity, respectively.
	7-12	F6.	VALUE	The value of the mode of climbout with units ft/min (ROC), degrees (THETA, GAMMA), knots (VEL)
	13-16	F4.2	Thrust Factor	Multiplicative factor to reduce power setting for climbout. (Thrust is discontinuous from transition to climbout.)

Sets of data cards may be stacked. Follow the last set with: %END.

Effect of the Propulsion System

The program was set up for an augmentor-wing configuration where the aerodynamics are related to the relatively cold thrust from the engine fan. This thrust is labelled T_c. The aerodynamic coefficients are functions of jet thrust coefficient C_J, as well as angle of attack and flap deflection, where $C_J = T_c/qS$. The thrust from the hot core gases, which is labelled T_h, can be deflected through the angle ν, where zero ν is the undeflected case. The hot thrust T_h makes a separate contribution to the normal and longitudinal accelerations of the aircraft.

The program can be used for other powered-lift aircraft, or even for conventional airplanes, if one treats these other propulsion systems as special cases of the augmentor-wing situation. In externally blown flap configurations, the aerodynamics are functions of total thrust. To use this program set T_c to the total mixed thrust and T_h to zero. Then the calculated thrust coefficient will be (Total Thrust)/qS and there will be no deflected thrust.

For configurations where the aerodynamics are unrelated to the propulsion system, use T_h as the total thrust and set T_c to zero. In this case the total thrust can be deflected through the angle ν. The thrust coefficient C_J is zero. A conventional airplane would correspond to this second situation with no thrust deflection.

Limitations

The engine out capability of the takeoff program and the others is in general restricted to those airplanes where an engine failure and compensation produce insignificant lift and drag changes other than those directly related to the reduced thrust. In cases where a significant asymmetry is produced, a separate set of aerodynamic data must be provided for the engine-out situation, including the required corrections for lateral and directional trim. For the takeoff calculation, all-engine and engine-out results would have to be combined to estimate takeoff performance with failure at a particular speed. This would only be approximate.

Further limitations on the class of airplanes for which the programs are appropriate are minimum speed and rotation pattern. For the takeoff and landing calculations, extrapolation of aerodynamic data to high C_J values is provided to allow computation during ground roll. Nominal zero velocity is taken at one f.p.s. in calculating these coefficients. The takeoff calculation is restricted to that class of airplanes for which rotation for takeoff can be represented as a control input δ_i and estimates of $C_{M_{\delta_i}}$ and $C_{L_{\delta_i}}$ are available. While this does not require δ_i to be elevator deflection, the control input will be referred to as elevator (δ_e) throughout the report.

Engine and Aerodynamic Data

A block data subroutine is required to input the engine thrust and aerodynamic tables. It must include the following statements:

```
      BLOCK DATA
      COMMON /AERO/ TH1TAB(150), THCTAB(150), XTAB(25),
     1XYZ(3),  NXYZ(3), PARDER(3), NALCJ(2), ALCJ(25), XY(2),
     2CLTAB(150), CDTAB(150), CLOSS(150), BLOSS(10), NPWR,
     3NOTH, NOV, NAL, NCJ, RAMDR(150), DFLAP, CMTAB(150)
```

C_L, C_D, and C_M are defined as functions of alpha$_W$ and C_J, where C_J = (total cold thrust)/(Q * S_{ref}), tail-on untrimmed. To define C_L and C_D for a given flap setting, the following variables must be set:

NAL Number of values of alpha_W (where $\alpha_W = \alpha_F + i_W$) for aerodynamic tables C_L, C_D, C_M = ftn (α_W, C_J). Must be ≥ 2.

NCJ Number of values of C_J for aerodynamic tables. Must be ≥ 2. (NAL + NCJ $\leq$ 25 and NAL * NCJ $\leq$ 150)

ALCJ NAL values of alpha (in deg) followed by NCJ values of C_J, each set being in increasing order with no two identical.

CLTAB Table of C_L values as function (α_W, C_J), α_W varying most rapidly.

CDTAB Table of C_D values as function (α_W, C_J), α_W varying most rapidly. Gear down.

CMTAB Table of CM values as function (α_W, C_J) parallel to C_L, C_D.

DFLAP Flap setting for which C_L, C_D input, deg. Used in estimation of C_L, C_D when C_J out of range. See computations section.

The thrust provided by each engine is defined as a function of power, elevation, and velocity, modified by loss factors. For each engine:

$$T_h = \text{TH1(pwr, H, V) * BLOSS(pwr)}$$

$$T_c = \text{THC(pwr, H, V) * CLOSS(pwr, H, V) * BLOSS(pwr)}$$

$$\text{Ramdrag} = \text{RAMDR(pwr, H, V)}$$

The following variables must be set:

NPWR Number of power settings for thrust tables. Must be ≥ 2 and ≤ 10.

NOTH Number of elevation settings for thrust tables. Must be ≥ 2.

NOV Number of velocity settings for thrust tables. Must be ≥ 2. (NPWR + NOTH + NOV $\leq$ 25, NPWR * NOTH * NOV $\leq$ 150)

XTAB NPWR values of power followed by NOTH values of elevation above sea level (ft), followed by NOV values of velocity (knots). Each set must be in increasing order with no two identical.

TH1TAB	Table of hot thrust values for one engine as function (pwr,H,V), power varying most rapidly, then elevation, then velocity.
THCTAB	Parallel table of cold thrust values for one engine. Total cold thrust is used to compute C_J.
CLOSS	Parallel table of multiplicative correction factors for losses in cold thrust.
BLOSS	NPWR multiplicative correction factors for bleed valve loss as a function of power setting. Applied to both hot and cold thrust.
RAMDR	Table of ramdrag levels for each engine parallel to the thrust tables.

Program Output

Output from TAKOFF consists of a summary of the input data and a time history. The variables which are computed and printed at intervals of .1 second are:

velocity	gamma	distance	elevation
$\frac{dV}{dt}$	$alpha_F$	$\frac{d\alpha}{dt}$	$\frac{d^2\alpha}{dt^2}$
thrust	C_D	C_L	weight
δ_e	load factor		

In addition the time history shows the beginning of engine failure and rotation, liftoff, and the beginning of climbout. The thrust level printed is the hot thrust T_h unless the flag TCPRNT has been set to request T_c to be printed.

Optionally the output includes the repeated time histories calculated during the iteration of the rotation sequence. This is rarely required.

Computations

The following integrations are carried out by the program:

$V = \int \frac{dV}{dt}$ flight speed

$\gamma = \int \frac{d\gamma}{dt}$ flight path angle

$s = \int \frac{ds}{dt}$ range

$H = \int \frac{dH}{dt}$ elevation

$\alpha_F = \int \frac{d\alpha}{dt}$ angle of attack

$\frac{d\alpha}{dt} = \int \frac{d^2\alpha}{dt}$ time rate of change of angle of attack

The required derivatives at any time T are computed by the equations shown below. The expressions common to all segments of the takeoff maneuver are shown before those specific to certain segments.

Fuel consumption

$$W = W_{old} - Sfc * (T_h + T_c) * \frac{T - T_{old}}{3600}$$

Dynamic pressure

$$\rho = ftn(H)$$

$$q = .5\rho V^2$$

Thrust

$$T_h = ftn(pwr,H,V) * \text{bleed loss factor} * N$$

$$T_c = ftn(pwr,H,V) * \text{bleed loss factor} * \text{cold loss factor} * N$$

$$Ramdrag = ftn(pwr,H,V) * N$$

(Thrusts are adjusted at engine failure as shown in figure 1.)

$$C_J = T_c/qS$$

Trim elevator

$$\delta_{e_{trim}} = [C_L qS(xcg\ \cos\alpha_F - zcg\ \sin\alpha_F) + C_D qS(xcg\ \sin\alpha_F + zcg\ \cos\alpha_F) + C_M qS + T_h(zth\ \cos\nu - xth\ \sin\nu) - Ram(zei\ \cos\alpha_F + xei\ \sin\alpha_F)] / \left(-\frac{\partial C_M}{\partial \delta_e} qS\right)$$

On ground:

$$\delta_{e_{trim}} = \delta_{e_{trim}} + Ntfrc(xgr - xcg + \mu(zgr - zcg))/\left(-\frac{\partial C_M}{\partial \delta_e} qS\right)$$

where $Ntfrc = C_L qS + T_h \sin(\alpha_F + \nu) - W$

Aerodynamic adjustments

Gear drag reduction

$$FDCDG = -\left(\frac{T - T_g}{gear\ time}\right)\Delta C_{Dgear} \quad \text{for } T > T_g \text{ and limited to } -\Delta C_{Dgear}$$

Ground effect factors

FCL, FCD = ftn(H)

For climbout FCL, FCD = 1.

Extrapolation for C_J beyond table limit C_{J_I}

$$\Delta C_L = \text{Aug. Ratio} * (C_J - C_{J_I})\sin(\alpha_W + \delta_f)$$

$$\Delta C_D = -\text{Aug. Ratio} * (C_J - C_{J_I})\cos(\alpha_W + \delta_f)$$

Aerodynamic coefficients

$$C_L = [ftn(\alpha_W, C_J) + \Delta C_{L_{extrap}} + \frac{\partial C_L}{\partial \delta_e}\delta_e] * FCL$$

$$C_D = [ftn(\alpha_W, C_J) + \Delta C_{D_{extrap}} + FDCDG + \frac{\partial C_D}{\partial \delta_e}\delta_e] * FCD$$

$$C_M = ftn(\alpha_W, C_J)$$

Net force

$$Ntfrc = C_L qS + T_h \sin(\alpha_F + \nu) - W$$

Derivatives

$$\frac{dV}{dt} = \frac{g}{W}\,[T_h \cos(\alpha_F + \nu) - C_D qS - W\sin\gamma - \text{Ramdrag}]$$

On ground:

$$\frac{dV}{dt} = \frac{dV}{dt} + \mu * \text{Ntfrc} * g/W$$

$$\frac{d\gamma}{dt} = g[\text{Ntfrc}/W + 1. - \cos\gamma]/V$$

On ground:

$$\frac{d\gamma}{dt} = 0.$$

$$\frac{ds}{dt} = V\cos\gamma$$

$$\frac{dH}{dt} = V\sin\gamma$$

Quantities dependent on takeoff segment

Ground roll ($V < V_R$)

$$\delta_e = 0.$$

$$\alpha_F = \alpha_\circ$$

$$\frac{d\alpha}{dt} = \frac{d^2\alpha}{dt^2} = 0.$$

Rotation ($\alpha_F < \alpha_{max\ rotation}$)

$\delta_e = \delta_{e_\circ}$ step input

If $T > T_1$ $\delta_e = \delta_{e_\circ} + \frac{\partial\delta_e}{\partial t}(T - T_1)$

where T_1 is end of held elevator step

$$\text{Moment} = (\delta_e - \delta_{e_{trim}})\,\frac{\partial C_M}{\partial\delta_e}\,qS\bar{c}$$

$$\frac{d^2\alpha}{dt^2} = \text{Moment}/I_{cg}$$

Nose gear lifts if $\frac{d\alpha}{dt} = \int\frac{d^2\alpha}{dt^2}$ is positive.

Transition $(H < H_{max\ ground\ effect})$

$\delta_e = \delta_{e_{trim}}$

$\alpha_F = ftn(H)$

$\frac{d\alpha}{dt} = \frac{d^2\alpha}{dt^2} = 0.$

Climbout $(H \geq H_{max\ ground\ effect})$

Pwr = Pwr * thrust factor for climbout

Determine alpha according to climbout mode, updating

C_L, C_D at each iteration

$$C_L = ftn(\alpha_W, C_J) + \frac{\partial C_L}{\partial \delta_e} \delta_{e_{trim}}$$

$$C_D = ftn(\alpha_W, C_J) + FDCDG + \frac{\partial C_D}{\partial \delta_e} \delta_{e_{trim}}$$

$\frac{d\alpha}{dt} = \frac{d^2\alpha}{dt^2} = 0$

Reduce α if necessary to maintain $\frac{dV}{dt} \geq 0$.

Climbout modes

Constant velocity

Search for α such that $\frac{dV}{dt} = 0$.

Constant ROC

$$Eq = (C_L\cos\gamma - C_D\sin\gamma)qS/W + T_h\sin(\alpha_F+\nu+\gamma)/W - .1 - Ramdrag/W * \sin\gamma$$

Search for α such that Eq = 0.

Constant pitch attitude

$\alpha_F = \theta - \gamma$ where θ is the specified value

Constant load factor

Load factor = $(C_L qS + T_h \sin(\alpha_F+\nu))/(W\cos\gamma)$

Search for α such that Load factor = specified value

Constant gamma

Search for α such that $\frac{d\gamma}{dt} = 0$.

Summary of Moment Arm Definitions

XCG	Moment center aft to C.G.	$\frac{B_{S_{cg}} - B_{S_{mc}}}{\bar{c}}$
ZCG	Moment center down to C.G.	$\frac{W_{L_{mc}} - W_{L_{cg}}}{\bar{c}}$
XGR	Moment center aft to main gear	$\frac{B_{S_{gr}} - B_{S_{mc}}}{\bar{c}}$
ZGR	Moment center down to main gear	$\frac{W_{L_{mc}} - W_{L_{gr}}}{\bar{c}}$
XTH	C.G. aft to engine hot thrust reaction pt	$\frac{B_{S_{eng}} - B_{S_{cg}}}{\bar{c}}$
ZTH	C.G. down to engine hot thrust reaction pt	$\frac{W_{L_{cg}} - W_{L_{eng}}}{\bar{c}}$
XEI	C.G. aft to engine inlet point	$\frac{B_{S_{ei}} - B_{S_{cg}}}{\bar{c}}$
ZEI	C.G. down to engine inlet point	$\frac{W_{L_{cg}} - W_{L_{ei}}}{\bar{c}}$

where W_L = water line, increases up

B_S = body station, increases aft

STOL LANDING PERFORMANCE

LAND is a simple performance program with trimming, landing and open-loop longitudinal plane maneuvering capabilities. The program is specifically structured for a class of power-augmented lift aircraft for which the aerodynamic lift and drag coefficients are functions of thrust level and velocity as well as angle of attack and flap deflection. The mathematical model has only two longitudinal degrees of freedom with the pitching moment equation being replaced by a command angle of attack during the maneuvering flight computations. Tail-on lift, drag, and moment data must be tabulated in coefficient form as functions of angle of attack, thrust coefficient, and flap deflection. The thrust coefficient expresses the influence of engine thrust level on the aerodynamic effectiveness of the lifting surfaces. The engine model will accommodate a split in the total thrust between a hot thrust part which is exhausted through vectorable nozzles and a cold thrust part which interacts with the aircraft aerodynamics. It is applicable to other powered-lift systems as is described in the input section.

The program performs the iterative computation to trim the aircraft in an equilibrium flight condition prescribed by program input. At touchdown, the program executes a landing roll computation which may include braking, thrust reversal, thrust change and lift dumping, all prescribed by program input. Maneuvering flight segments are controlled by subroutine CNTRL. The supplied CNTRL maneuver is a simple flare control. It allows for increments in angle of attack and thrust specified by the user as a function of time. For any other flight maneuver the user may supply a subroutine specifying angle of attack as a function of time, height, range or any other flight variable(s) accessible to the computation.

The program description which follows includes an outline of the program input requirements, a discussion of the trimming technique, and description of the landing roll calculation and of the control subroutine.

Trim Algorithm

A trimmed or equilibrium flight condition is specified by: angle of attack, flight path angle, thrust, thrust deflection, flight speed, and flap deflection angle. During the trimming procedure, two of these variables and elevator are varied until the residual x- and z-axis accelerations of the aircraft have been reduced below prescribed tolerance levels. In the three programmed trim modes, angle of attack is varied along with gamma, thrust, or thrust deflection.

At each stage in the iteration toward trim, the required change in acceleration is equal to minus the residual acceleration of the previous stage. If the two variables of the trim mode in use are designated V_1 and V_2 then the required change may be approximated:

$$-a_x = \Delta a_x \simeq \frac{\partial a_x}{\partial V_1} \Delta V_1 + \frac{\partial a_x}{\partial V_2} \Delta V_2$$

$$-a_z = \Delta a_z \simeq \frac{\partial a_z}{\partial V_1} \Delta V_1 + \frac{\partial a_z}{\partial V_2} \Delta V_2$$

where a_x, a_z are the residual accelerations from the previous stage

Δa_x, Δa_z are the required acceleration changes to trim

V_1, V_2 are the trimming variables, two of α, γ, ν, T_h

$\frac{\partial a_x}{\partial V_i}$, $\frac{\partial a_z}{\partial V_i}$ are the sensitivities of the accelerations to changes in V_1 and V_2

These equations are solved for the adjustments to V_1 and V_2 to be applied before the residual accelerations are recalculated. The actual steps applied are somewhat smaller than these calculated values to avoid convergence problems due to nonlinearities in the system.

Expressions for the accelerations in stability axes and the required partial derivatives are shown in the equations list. (Only partials with respect to the two variables of the trim mode in use are required.)

Landing Calculation

In the normal mode of operation the aircraft is first trimmed in the equilibrium flight condition specified and flown through a maneuver prescribed by the control (CNTRL) subroutine. If the resulting flight path reaches ground level, a landing roll and braking sequence is initiated. The prescribed rolling friction coefficient takes effect immediately upon touchdown. The braking coefficient may be applied after a specified delay interval. Change in power setting, thrust reversal and lift dumping, if desired, begin after a reaction or delay time from touchdown and are completed within a time interval prescribed by input. The user specifies the final power setting and hot thrust vector angle to be used during braking. The flag NODUMP controls the thrust coefficient after touchdown, maintaining the appropriate value for the power setting (NODUMP=1) or reducing the coefficient to zero, simulating spoiling of the power induced lift (NODUMP=0).

The trimming and landing roll functions may be used independently by setting flag NOLAND (see input list).

The equations used are shown in the equations section.

LAND Input

Input to the program is in two sections. The engine and aerodynamic characteristics of the airplane are input in tabular form through a block data subroutine. Library routines BVIN and TVIN are used for two- and three-dimensional table lookup. Characteristics of a particular landing are input by a set of five control cards. Control sets may be stacked.

Input Data Set

Card	Column	Format	Variable	Use
1	1-80	20A4	TITLE	Any desired title
2	1-8	F8.	ZOBS	Obstacle height
	9-16	F8.	MUR	μ_R = rolling friction coefficient
	17-24	F8.	MUB	μ_B = braking coefficient
	25-32	F8.	DTB	Delay time after touchdown before brake applied
	33-40	F8.	W	Aircraft weight
	41-48	F8.	S	Reference area for aerodynamics
	49-56	F8.	DT	Time step for integration
	57-61	I5	NOLAND	= 1 Trim only = 0 Regular trim and land = -1 Omit trim and calculate braking distance (ZOBS should be 0)
3	1-8	F8.	VAPP	Approach speed, knots

Card	Column	Format	Variable	Use
	9-16	F8.	APPPWR	Approach power setting. If MODTRM = 0 (see card 4), this value of APPPWR will be replaced by trim value
Thrust reversal control				
	17-24	F8.	REVPWR	Power setting at completion of thrust reversal for braking
	25-32	F8.	DTREV	Delay time after touchdown to beginning of thrust reversal, sec
	33-40	F8.	REVTIM	Time interval for change in power, lift dumping, and deflection of thrust to reverse position, sec
	41-48	F8.	REVNU	Deflection of hot thrust at full reversal, deg
	49-53	I5	NODUMP	= 1 to prevent lift dumping = 0 to dump lift by sloping cold thrust (and thereby C_J) to zero at thrust reversal
	54-58	I5	NOREV	= 1 hot thrust not reversed. Nu maintained at nu trim. (Dump and power change continued) = 0 to reverse thrust (deflection to REVNU)
Trim control				
4	1-5	I5	MODTRM	= -1 to trim by varying alpha and gamma = 0 to trim by varying alpha and hot thrust, T_h = 1 to trim by varying alpha and thrust deflection ν.
	6-13	F8.	GAMMA	Fixed value of gamma for trim of MODTRM = 0 or 1
	14-21	F8.	NU	Fixed value of thrust deflection if MODTRM = -1 or 0
	22-29	F8.	DFLAP	Flap deflection
	30-34	I5	NOE	Number of engines

Card	Column	Format	Variable	Use
Flare control using provided subroutine CNTRL				
5	1-8	F8.	FLRTIM	Length of time over which $\Delta\alpha$ for flare is applied, secs
	9-16	F8.	ALPINC	$\Delta\alpha$ for flare, deg
	17-24	F8.	DTFLAR	Delay from T_o before begin flare, secs
	25-32	F8.	PWRTIM	Length of time over which power increment for flare applied, sec
	33-40	F8.	PWRINC	Power increment for flare, units of power setting
	41-48	F8.	DTPWR	Delay from T_o before flare power change begun, sec

Follow the last stacked data set with: %END

Effect of the Propulsion System

The program was derived for an augmentor-wing configuration where the aerodynamics are related to the relatively cold thrust from the engine fan. This thrust is labelled T_c. The aerodynamic coefficients are functions of jet thrust coefficient C_J, as well as angle of attack and flap deflection, where $C_J = T_c/qS$. The thrust from the hot core gases, which is labelled T_h, can be deflected through the angle ν, where zero ν is the undeflected case. The hot thrust T_h makes a separate contribution to the normal and longitudinal accelerations of the aircraft.

The program can be used for other powered-lift aircraft if one treats these other propulsion systems as special cases of the augmentor-wing situation. In externally blown flap configurations, the aerodynamics are functions of total thrust. To use this program set T_c to the total mixed thrust and T_h to zero. Then the calculated thrust coefficient will be

(Total Thrust)/qS and there will be no deflected thrust. In this case, the user must select the power setting, and equilibrium alpha, gamma, and elevator angle will be computed. (MODTRM = -1)

For configurations where the aerodynamics are unrelated to the propulsion system, use T_h as the total thrust and set T_c to zero. In this case the total thrust can be deflected through the angle ν. The thrust coefficient C_J is zero. All three trim modes are available in this situation.

Airplane Description

Engine and aerodynamic data are input in tabular form through a block data subroutine. Some geometric constants are also included in that routine. The subroutine must be of the following form:

```
 BLOCK DATA
 COMMON/C/CLTAB(400),CDTAB(400),NALCJ(3),ALCJ(25),
1DFLAP,AUGRAT
 COMMON/THR/THTAB(100),TCTAB(100),RAMTAB(100),NPV(2),
1PV(25),NOE,CLOSS(100),BLOSS(10)
 COMMON/M/CMTAB(400),DETRIM,XCG,ZCG,XTH,ZTH,
1CMDE,CLDE,CDDE,XEI,ZEI,IW
 REAL IW
 Data statements to set all input variables to be described.
   .
   .
   .
 END
```

The input variables to be included are defined below. Be sure you have read the section on the effect of the propulsion system before continuing.

Aerodynamics	(Tail on data, untrimmed, $C_J = T_c/qS$)
NALCJ(1)	Number of values of alpha$_W$ at which C_L, C_D, C_M to be input. ($\alpha_W = \alpha_F + i_W$) ($\geq 2$)

NALCJ(2)	Number of values of C_J at which C_L, C_D, C_M to be input. (≥ 2)
NALCJ(3)	Number of values of δ_f at which C_L, C_D, C_M to be input. (≥ 2)

NALCJ(1) * NALCJ(2) * NALCJ(3) $\leq$ 400,

NALCJ(1) + NALCJ(2) + NALCJ(3) $\leq$ 25

ALCJ	NALCJ(1) values of α_W (deg), followed by NALCJ(2) values of C_J, followed by NALCJ(3) values of δ_f (deg) at which C_L, C_D, C_M to be input, each set monotonically increasing
CLTAB	Matrix of C_L as a function of α_W, C_J, δ_f, α_W varying most rapidly, then C_J, then δ_f
CDTAB	Parallel matrix of C_D values, gear down
CMTAB	Parallel matrix of C_M values
AUGRAT	Augmentation ratio, used to extrapolate C_L, C_D for C_J beyond table range. The method of extrapolation is shown in the equations section. If no augmentation, input 1. To avoid extrapolation of C_L, C_D input 0.
CLDE	$\partial C_L / \partial \delta_e$, 1/deg
CDDE	$\partial C_D / \partial \delta_e$, 1/deg
CMDE	$\partial C_M / \partial \delta_e$, in terms of wing area, 1/deg

Geometry

XCG	$\dfrac{BS_{cg} - BS_{mc}}{\bar{c}}$	Distance from C.G. to moment center of data
ZCG	$\dfrac{WL_{cg} - WL_{mc}}{\bar{c}}$	
XTH	$\dfrac{BS_{cg} - BS_{eng}}{\bar{c}}$	Distance from C.G. to engine hot thrust exit point
ZTH	$\dfrac{WL_{cg} - WL_{eng}}{\bar{c}}$	

XEI $\dfrac{B_{S_{cg}} - B_{S_{ei}}}{\bar{c}}$

ZEI $\dfrac{W_{L_{cg}} - W_{L_{ei}}}{\bar{c}}$

Distance from C.G. to engine inlet point

W_L - Waterline, positive up

B_S - Body station, positive aft

Engine

NOE	Number of engines
NPV(1)	Number of power settings at which thrust to be input. ($\geq$2)
NPV(2)	Number of velocity settings at which thrust to be input. ($\geq$2)
PV	NPV(1) values of power level followed by NPV(2) values of velocity (knots) at which thrust to be input, each set monotonically increasing
THTAB	Matrix of hot thrust in pounds for one engine as a function of power and velocity, power varying most rapidly
TCTAB	Parallel matrix of cold thrust values
RAMTAB	Parallel matrix of ramdrag values
CLOSS	Parallel matrix of multiplicative cold loss factors
BLOSS	Vector of multiplicative bleed loss factors as function of power setting, applied to both T_h and T_c

T_h = NOE * THTAB(pwr,vel) * BLOSS(pwr)

T_c = NOE * TCTAB(pwr,vel) * CLOSS(pwr,vel) * BLOSS(pwr)

Note that NPV(1) * NPV(2)$\leq$100, NPV(1) + NPV(2)$\leq$25, NPV(1)$\leq$10.

The Control Subroutine

The control subroutine provided allows for flare control by increments in angle of attack and thrust as a function of time. The timing and increments are input by the user (see data card 5). This routine may be replaced by a user subroutine of the following form:

```
SUBROUTINE CNTRL
COMMON  /CNT/  ALTRIM, NUTRIM, FLRTIM, ALPINC, DTFLAR, PWRTIM,
1PWRINC, DTPWR
COMMON /D/ TDWN, TH, TC, MU, G, Q, OMASS, LIFT, DRAG, VEC(51),
1RAMDR, DTREV, NODUMP
COMMON /T/ VA, GM, ALPHA, NUR, APPPWR, PWR, MODE, S, W, DF, NOCONV
REAL NUR, NUTRIM

      Any desired manipulation of ALPHA (radians) or PWR setting
      based on altitude (VEC(6)), velocity (VA fps), time (VEC(2)),
      touchdown time (TDWN) etc.

RETURN
END
```

If no control statements are inserted, the trim value of alpha will be maintained. (ALTRIM (radians)) For a braking distance calculation without trim, zero alpha will be maintained.

Equations for Landing

Trim

Computation of residual accelerations:

$$q = .5\rho_o V^2$$

$$T_h, T_c, Ramdrag = ftns\,(pwr, vel) * N$$

$$C_J = T_c / q S$$

$$C_L, C_D, C_m = ftn\,(\alpha_W, C_J, \delta_f)$$

Extrapolation for C_J out of table range:

$$C_L = C_{L_{limit}} + Aug.\,Ratio * (C_J - C_{J_{limit}}) * \sin(\delta_f + \alpha_W)$$

$$C_D = C_{D_{limit}} - Aug.\,Ratio * (C_J - C_{J_{limit}}) * \cos(\delta_f + \alpha_N)$$

$$C_L = C_{L_{aero}} + \frac{\partial C_L}{\partial \delta_e} * \delta_e$$

$$C_D = C_{D_{aero}} + \frac{\partial C_D}{\partial \delta_e} * \delta_e$$

$$\delta_e = \Big[C_L q S * \left(\frac{Bscg - Bsmc}{\bar{c}} \cos\alpha_F + \frac{WLcg - WLmc}{\bar{c}} \sin\alpha_F \right)$$

$$+ C_D q S * \left(\frac{Bscg - Bsmc}{\bar{c}} \sin\alpha_F - \frac{WLcg - WLmc}{\bar{c}} \cos\alpha_F \right)$$

$$+ C_m q S + T_h \left(\frac{WLcg - WLeng}{\bar{c}} \cos\nu + \frac{Bscg - Bseng}{\bar{c}} \sin\nu \right)$$

$$- Ramdrag * \left(\frac{WLcg - WLei}{\bar{c}} \cos\alpha_F - \frac{Bscg - Bsei}{\bar{c}} \sin\alpha_F \right) \Big]$$

$$\Big/ \left(- \frac{\partial C_m}{\partial \delta_e} q S \right)$$

$$Lift = C_L q S$$

$$Drag = C_D q S + Ramdrag$$

$$a_x = \frac{T_h}{m} \cos(\alpha_F + \gamma + \nu) - \frac{1}{m}\,(Drag \cos\gamma + Lift \sin\gamma)$$

$$a_z = -\frac{T_h}{m} \sin(\alpha_F + \gamma + \nu) - \frac{1}{m}\,(Lift \cos\gamma - Drag \sin\gamma) + g$$

Partial derivatives of accelerations:

$$\frac{\partial a_x}{\partial \alpha} = -\frac{T_h}{m}\sin(\alpha_F+\gamma+\nu) - \frac{qS}{m}\left(\frac{\partial C_D}{\partial \alpha}\cos\gamma + \frac{\partial C_L}{\partial \alpha}\sin\gamma\right)$$

$$\frac{\partial a_z}{\partial \alpha} = -\frac{T_h}{m}\cos(\alpha_F+\gamma+\nu) - \frac{qS}{m}\left(\frac{\partial C_L}{\partial \alpha}\cos\gamma - \frac{\partial C_D}{\partial \alpha}\sin\gamma\right)$$

$$\frac{\partial a_x}{\partial \gamma} = -\frac{T_h}{m}\sin(\alpha_F+\gamma+\nu) + \frac{1}{m}(\text{Drag}\sin\gamma - \text{Lift}\cos\gamma)$$

$$\frac{\partial a_z}{\partial \gamma} = -\frac{T_h}{m}\cos(\alpha_F+\gamma+\nu) + \frac{1}{m}(\text{Lift}\sin\gamma + \text{Drag}\cos\gamma)$$

$$\frac{\partial a_x}{\partial T_h} = \frac{1}{m}\cos(\alpha_F+\gamma+\nu)$$

$$\frac{\partial a_z}{\partial T_h} = -\frac{1}{m}\sin(\alpha_F+\gamma+\nu)$$

$$\frac{\partial a_x}{\partial \nu} = -\frac{T_h}{m}\sin(\alpha_F+\gamma+\nu)$$

$$\frac{\partial a_z}{\partial \nu} = -\frac{T_h}{m}\cos(\alpha_F+\gamma+\nu)$$

Dynamic equations

Integrations:

$x = \int V_x$ Range

$h = \int V_z$ Altitude

$V_x = \int a_x$ Horizontal velocity

$V_z = \int a_z$ Vertical velocity

Flight path angle and velocity:

$$\gamma = -\tan^{-1}(V_z / V_x)$$

$$V_a = \sqrt{V_x^2 + V_z^2}$$

Computation of a_x and a_z:

Same as for trim if above ground.

After touchdown:

$$a_x = \frac{T_h}{m}\cos(\alpha_F + \nu) - \frac{1}{m}(\text{Drag} + \mu(W - \text{Lift}))$$

a_z, δ_e taken as zero

$\mu = \mu_{roll} + \mu_{brake}$ where μ_{brake} only included after brakes applied.

Changes with time according to user input:

Alpha increment for flare

Power increment for flare

Lift dump for braking by forcing T_c and C_J to zero

Thrust deflection for braking

Power change for braking

APPENDIX

Sample output from the three programs is shown on the following pages. The output corresponds to the baseline configurations of a jet-powered STOL augmentor wing design for which an analysis of takeoff and landing performance was previously reported.[1] All calculations for that analysis were done with the computer programs described in this report. The sample output in this appendix shows:

(1) Static performance - engine out full power in the take-off configuration, $41.1°\delta_f$ and thrust undeflected.

(2) Takeoff performance - nominal all engine takeoff to 35 foot barrier (initial portion of ground roll omitted).

(3) Landing performance - nominal landing from 35 foot barrier at $70.6°\delta_f$ and T/W = .2, hot thrust deflected 90°.

The aerodynamic data and engine assumptions used for these runs are available in the referenced report.

---

1. Post, S. E., Gambucci, B. J., and Holzhauser, C. A., An Analysis of the Takeoff and Landing Performance of a Jet-Powered STOL Augmentor Wing Design, NASA TM X-62,176, August 1972.

STATIC

```
&INPUTS
DFLAP= 41.09999, 9*0.0
PWR= 38.0, 9*0.0
GAMZ= 10*0.0
ROC= 10*0.0
DEFL= 10*0.0
VKNOTS= 50.0, 60.0, 70.0, 80.0, 90.0, 100.0, 110.0, 3*0.0
WT= 48000.0
HZ= 0.0
DELTAT= 0.0
CDT= 0.0
CDE= 0.0
CLDE= 1.695999
IW= 0.0
IT= 0.0
AOT= 0.0
AIT= 0.0
SW= 600.0
SHT= 156.0
CBAR= 9.679999
ZSTAR= 0.0
OR3= 0.0
OR3CC= 0.0
IOEQ= 1
CONROC= 0.0
MODTRM= -2
&END
```

STATIC

RUN TITLE - ENGINE OUT TRIM AT BASE THRUST FLAP 41.1

GW	48000. LBS	S WING	600.00 FT**2		SH TAIL	156.00 FT**2
ALT	0. FT	FROM C.G.	AFT	DOWN	CBAR	9.68 FT
DELTA T	0. DEG F	MOM CTR	-0.000	0.000 CBAR		
FLAPS	41.1 DEG	TAIL	4.080	-1.180 CBAR		
I TAIL	0.000 DEG	ENG THR	0.208	0.176 CBAR		
AOT	0.000 RAD	ENG INL	-0.775	0.176 CBAR		
I WING	0.000 DEG	CLWB IS TAIL-ON UNTRIMMED				

VEL (KNOTS)	GAMMA (DEG)	R/C (FT/MIN)	MU (DEG)	ALPHA F (DEG)	THETA (DEG)	DE (DEG)	ALPHA T (DEG)	EPS (DEG)	CJ	AX FT/SEC2	AZ FT/SEC2
53.9	-5.21	-495.4	0.0	*********	27.54	-25.70	********	********	1.640	*********	*********
60.0	-0.20	-21.1	0.0	22.13	21.94	-14.97	********	********	1.325	0.0049	0.0419
70.0	3.57	441.5	0.0	12.59	16.16	-5.51	********	********	0.978	0.0234	0.0470
80.0	5.61	792.0	0.0	5.82	11.43	0.48	********	********	0.753	0.0239	0.0343
90.0	6.31	1001.5	0.0	1.70	8.01	4.64	********	********	0.598	0.0179	0.0087
100.0	6.22	1097.9	0.0	-1.05	5.17	7.87	********	********	0.486	0.0126	-0.0233
110.0	5.81	1128.5	0.0	-3.10	2.72	10.37	********	********	0.404	0.0143	-0.0445

VEL (KNOTS)	POWER SETTING	HOT THRUST (LBS)	COLD THRUST (LBS)	RAM DRAG (LBS)	CL TRIM	CD TRIM	CLWB	CDWB	CMWB
53.9	38.0	3180.0	9690.0	1188.92	**********	0.9887	*********	0.9*87	-0.9543
60.0	38.0	3180.0	9690.0	1323.00	6.3910	0.2405	6.5055	0.2405	-0.5866
70.0	38.0	3195.0	9738.0	1499.40	4.7359	-0.1426	4.7779	-0.1426	-0.2358
80.0	38.0	3210.0	9786.0	1675.80	3.6450	-0.2472	3.6411	-0.2472	-0.0155
90.0	38.0	3225.0	9834.0	1852.20	2.8924	-0.2388	2.8567	-0.2388	0.1295
100.0	38.0	3240.0	9882.0	2028.60	2.3532	-0.1975	2.2927	-0.1975	0.2366
110.0	38.0	3255.0	9930.0	2205.00	1.9522	-0.1563	1.8726	-0.1563	0.3162

VEL (KNOTS)	CL M TRIM	CL M WB	ALPHA M (DEG)	N (G)	V-VMIN (KNOTS)	V/VMIN	ENGINE LIMIT
53.9	7.820	8.018	32.74	1.002	0.0	1.0000	
60.0	7.086	7.273	32.07	1.115	6.1	1.1128	
70.0	6.369	6.551	31.03	1.358	16.1	1.2982	
80.0	5.831	6.003	30.26	1.621	26.1	1.4837	
90.0	5.391	5.541	29.55	1.893	36.1	1.6692	
100.0	5.031	5.156	28.94	2.175	46.1	1.8546	
110.0	4.762	4.871	28.48	2.484	56.1	2.0401	

STOL TAKE-OFF SIMULATION
ROTATION WITH STICK POSITION ASSIGNED
TRANSITION WITH ASSIGNED CL,CD,ALPHA
CLIMBOUT WITH ASSIGNED RATE OF CLIMB,
THETA, LOAD FACTOR, FLIGHT PATH
ANGLE, OR VELOCITY

TAKEOFF

BASE CASE TAKEOFF T/W=38% ALL ENGINES

INPUT UNITS...VEL-KNOTS, TIME-SEC, DIST-FT, ANGLE-DEG, DENSITY-SLUGS/FT**3, THRUST,WEIGHT-LBS, RATE OF CLIMB-FT/MIN

SMAX	3000.	W	48000.	SREF	600.	VR	72.0	V1	999.0		
ALMAX	12.0	SFC	0.000	HMAX	40.0	NU	0.00	PWR	38.0	EPWR	38.0
ALO	0.0	HGEAR	5.	DCDG	0.020	DT4	5.00	CBAR	9.7	ICG	0.2300E 06
XCG	0.000	XGR	0.620	ZGR	1.240	DT1	1.0	DT2	1.0	DT3	1.0
MU	0.030	CMDE	-0.02930	CLDE	0.0078	CDDE	0.00000	DEO	-45.0	DET	45.00
NOE	4.	XEI	-0.775	ZEI	0.176						
XTH	0.207	ZTH	0.176	DTR1	1.000	IW	0.0	VZ	70.0	HZ	0.0
SFC	0.000	AUGRAT	1.3	ZCG	0.000	SZ	856.7	TZ	13.6		

H	0.	35.
ALGE	12.0	6.0
FCLGE	1.000	1.000
FCDGE	1.000	1.000

MODE= VEL VALUE= 79.70 THRUST FACTOR 1.00

TAKEOFF

TIME SEC	VEL KNOTS	GAMMA DEG	DIST FT	HT FT	DV/DT FT/SEC**2	ALPHA DEG	DAL/DT DEG/SEC	D**2AL DEG/SEC**2	THRUST LBS	CD	CL	W LBS	DE DEG	LOAD FACTOR
13.6	70.0	0.00	856.7	0.0	7.29	0.0	0.0	0.0	4260.	-0.905	3.427	48000.	0.0	0.713
13.7	70.4	0.00	868.6	0.0	7.27	0.0	0.0	0.0	4261.	-0.891	3.410	48000.	0.0	0.718
13.8	70.9	0.00	880.5	0.0	7.24	0.0	0.0	0.0	4262.	-0.876	3.394	48000.	0.0	0.723
13.9	71.3	0.00	892.5	0.0	7.21	0.0	0.0	0.0	4263.	-0.861	3.378	48000.	0.0	0.729
14.0	71.7	0.00	904.6	0.0	7.18	0.0	0.0	0.0	4263.	-0.847	3.362	48000.	0.0	0.734
BEGIN ROTATION														
14.1	72.0	0.00	912.8	0.0	7.09	0.0	0.0	5.4	4264.	-0.838	3.001	48000.	-45.0	0.660
T1= 14.5175			TR= 14.0675											
14.1	72.1	0.00	916.8	0.0	7.08	0.0	0.2	5.7	4264.	-0.833	2.996	48000.	-45.0	0.662
14.2	72.6	0.00	929.0	0.0	7.03	0.1	0.8	6.7	4265.	-0.818	2.989	48000.	-45.0	0.668
14.3	73.0	0.00	941.3	0.0	6.98	0.2	1.5	7.8	4266.	-0.801	2.992	48000.	-45.0	0.677
14.4	73.4	0.00	953.7	0.0	6.91	0.4	2.4	9.1	4267.	-0.781	3.008	48000.	-45.0	0.688
14.5	73.8	0.00	966.1	0.0	6.81	0.6	3.4	10.7	4268.	-0.759	3.039	48000.	-45.0	0.703
14.6	74.2	0.00	978.6	0.0	6.70	1.0	4.4	10.1	4268.	-0.733	3.117	48000.	-41.3	0.730
14.7	74.6	0.00	991.2	0.0	6.57	1.5	5.4	9.2	4269.	-0.705	3.215	48000.	-36.8	0.761
14.8	75.0	0.00	1003.8	0.0	6.41	2.1	6.3	8.5	4270.	-0.674	3.329	48000.	-32.3	0.797
14.9	75.3	0.00	1016.5	0.0	6.25	2.8	7.1	7.9	4271.	-0.642	3.453	48000.	-27.8	0.836
15.0	75.7	0.00	1029.3	0.0	6.10	3.5	7.9	7.3	4271.	-0.612	3.584	48000.	-23.3	0.877
15.1	76.1	0.00	1042.1	0.0	5.92	4.4	8.6	6.9	4272.	-0.580	3.727	48000.	-18.8	0.922
15.2	76.4	0.00	1055.0	0.0	5.72	5.2	9.2	6.5	4273.	-0.544	3.876	48000.	-14.3	0.969
LIFTOFF														
15.3	76.6	0.00	1063.7	0.0	5.54	5.9	9.7	6.2	4273.	-0.516	3.975	48000.	-11.3	1.000
15.3	76.7	0.00	1067.9	0.0	5.43	6.2	9.8	4.8	4273.	-0.502	4.025	48000.	-9.8	1.016
15.4	77.0	0.06	1080.9	0.0	5.07	7.2	10.1	0.7	4274.	-0.458	4.179	48000.	-5.3	1.064
15.5	77.3	0.19	1094.0	0.0	4.61	8.2	10.0	-3.5	4275.	-0.408	4.358	48000.	-0.8	1.119
15.6	77.6	0.39	1107.0	0.1	4.17	9.2	9.4	-7.8	4275.	-0.368	4.509	48000.	3.7	1.167
15.7	77.8	0.66	1120.2	0.2	3.71	10.1	8.4	-12.1	4276.	-0.329	4.651	48000.	8.2	1.211
15.8	78.0	0.98	1133.3	0.4	3.19	10.9	7.0	-16.4	4276.	-0.288	4.772	48000.	12.7	1.250
15.9	78.2	1.35	1146.5	0.7	2.70	11.5	5.1	-20.7	4276.	-0.254	4.873	48000.	17.2	1.283
16.0	78.3	1.77	1159.8	1.0	2.28	11.9	2.9	-25.0	4277.	-0.232	4.951	48000.	21.7	1.309
16.1	78.4	2.14	1170.8	1.4	2.01	12.0	0.6	-28.4	4277.	-0.223	4.992	48000.	25.5	1.324
16.1	78.5	2.19	1173.0	1.5	2.08	11.7	0.0	0.0	4277.	-0.235	4.712	48000.	-6.4	1.251
16.2	78.6	2.54	1186.3	2.0	1.91	11.6	0.0	0.0	4277.	-0.237	4.697	48000.	-6.3	1.251
16.3	78.7	2.89	1199.5	2.7	1.74	11.5	0.0	0.0	4277.	-0.240	4.681	48000.	-6.2	1.250
16.4	78.8	3.23	1212.8	3.4	1.59	11.4	0.0	0.0	4278.	-0.244	4.663	48000.	-6.1	1.248
16.5	78.9	3.58	1226.1	4.2	1.44	11.3	0.0	0.0	4278.	-0.249	4.645	48000.	-6.0	1.247
16.6	79.0	3.91	1239.4	5.1	1.30	11.1	0.0	0.0	4278.	-0.254	4.625	48000.	-5.9	1.244
16.7	79.0	4.25	1252.8	6.0	1.17	11.0	0.0	0.0	4278.	-0.261	4.603	48000.	-5.8	1.241
16.8	79.1	4.58	1266.1	7.0	1.06	10.8	0.0	0.0	4278.	-0.268	4.581	48000.	-5.6	1.237
16.9	79.2	4.90	1279.4	8.1	0.95	10.6	0.0	0.0	4278.	-0.277	4.557	48000.	-5.5	1.233
17.0	79.2	5.21	1292.7	9.3	0.86	10.4	0.0	0.0	4278.	-0.286	4.532	48000.	-5.4	1.228
17.1	79.3	5.52	1306.1	10.6	0.77	10.2	0.0	0.0	4279.	-0.295	4.506	48000.	-5.2	1.223
17.2	79.3	5.82	1319.4	11.9	0.69	10.0	0.0	0.0	4279.	-0.305	4.478	48000.	-5.1	1.217

17.3	79.3	6.12	1332.7	13.3	0.61	9.7	0.0	0.0	4279.	-0.314	4.446	48000.	-4.9	1.210
17.4	79.4	6.40	1346.1	14.7	0.53	9.5	0.0	0.0	4279.	-0.322	4.414	48000.	-4.8	1.202
17.5	79.4	6.67	1359.4	16.3	0.46	9.2	0.0	0.0	4279.	-0.332	4.380	48000.	-4.6	1.194
17.6	79.4	6.93	1372.7	17.9	0.40	8.9	0.0	0.0	4279.	-0.341	4.345	48000.	-4.5	1.186
17.7	79.5	7.17	1386.1	19.5	0.36	8.7	0.0	0.0	4279.	-0.351	4.308	48000.	-4.3	1.177
17.8	79.5	7.41	1399.4	21.2	0.32	8.4	0.0	0.0	4279.	-0.362	4.271	48000.	-4.2	1.167
17.9	79.5	7.63	1412.7	23.0	0.30	8.1	0.0	0.0	4279.	-0.373	4.233	48000.	-4.0	1.157
18.0	79.5	7.83	1426.0	24.8	0.28	7.8	0.0	0.0	4279.	-0.384	4.193	48000.	-3.8	1.147
18.1	79.5	8.03	1439.3	26.6	0.30	7.4	0.0	0.0	4279.	-0.398	4.143	48000.	-3.7	1.134
18.2	79.5	8.20	1452.6	28.5	0.31	7.1	0.0	0.0	4279.	-0.410	4.101	48000.	-3.5	1.123
18.3	79.6	8.36	1465.9	30.5	0.33	6.8	0.0	0.0	4279.	-0.422	4.059	48000.	-3.4	1.112
18.4	79.6	8.51	1479.2	32.4	0.35	6.4	0.0	0.0	4279.	-0.434	4.016	48000.	-3.2	1.101
18.5	79.6	8.63	1492.5	34.4	0.39	6.1	0.0	0.0	4279.	-0.447	3.972	48000.	-3.0	1.089

VELOCITY = 79.7 KNOTS BEGIN CONSTANT VELOCITY = 79.7
35 FT ABOVE RUNWAY

18.5	79.6	8.67	1496.1	35.0	0.41	6.0	0.0	0.0	4279.	-0.450	3.960	48000.	-2.9	1.086
18.6	79.6	8.78	1505.8	36.5	-0.00	7.1	0.0	0.0	4279.	-0.411	4.097	48000.	-3.5	1.125
18.7	79.6	8.95	1519.1	38.6	0.00	6.8	0.0	0.0	4279.	-0.422	4.062	48000.	-3.4	1.116
18.8	79.6	9.10	1532.4	40.7	0.00	6.6	0.0	0.0	4279.	-0.432	4.030	48000.	-3.2	1.107

40. FT ALTITUDE REACHED

18.8	79.6	9.05	1528.2	40.0	-0.00	6.6	0.0	0.0	4279.	-0.428	4.042	48000.	-3.3	1.110

W= 48000. LBS RHO= 0.002375 SLUGS/FT**3

LANDING T/W=.20 70.6 FLAP 68 KT

LANDING

WT=	48000.	MUR=	0.030	APPPWR=	20.0	VAPP=	68.	DFLAP =	70.6
S =	600.	MUB=	0.300	REVPWR=	20.0	REVTIM=	1.00	REVNU =	114.0
DT=	0.2	DTB=	1.0	DTREV=	0.0	ZOBS=	35.0	NODUMP =	0
MODE=	-1	GAMMA=	0.0	NU=	90.0	NOE=	4	NOREV =	0

FLARE CONTROL	TIME INT	INCREMENT	DELAY
ALPHA	2.0	7.0	0.0
POWER	2.0	3.0	1.0

Thrust deflection to 114° corresponds to thrust reversal 40% effective

TRIM CONFIGURATION

GAMMA= -6.90 ALPHA= 6.16 DE= 4.54 NU= 90.00

APPPWR= 20.0

AX= -0.003 AZ= 0.009

TIME	DIST	ALT	VEL	AX(G)	AZ(G)	TH	TC	LIFT	DRAG	GAMMA	ALPHA	NU	DE
0.0	0.0	35.0	68.0	-0.00	0.00	2240.	6826.	45410.4	5535.6	-6.90	6.16	90.00	4.54
0.2	22.8	32.2	68.0	-0.00	0.00	2240.	6826.	45410.4	5535.6	-6.90	6.16	90.00	4.54
0.4	45.6	29.5	68.0	-0.00	-0.01	2240.	6826.	46039.2	5772.4	-6.87	6.86	90.00	4.15
0.6	68.4	26.7	67.9	-0.01	-0.03	2240.	6826.	46729.4	6100.7	-6.79	7.56	90.00	3.74
0.8	91.1	24.0	67.9	-0.02	-0.04	2240.	6825.	47312.5	6331.3	-6.68	8.26	90.00	3.33
1.0	113.9	21.4	67.8	-0.02	-0.05	2239.	6825.	47875.1	6558.5	-6.54	8.96	90.00	2.91
1.2	136.6	18.8	67.7	-0.03	-0.06	2239.	6825.	48410.1	6781.1	-6.36	9.66	90.00	2.47
1.4	159.3	16.3	67.5	-0.04	-0.08	2273.	6927.	49070.5	7063.3	-6.14	10.36	90.00	1.79
1.6	181.9	13.9	67.3	-0.05	-0.09	2306.	7028.	49643.3	7369.8	-5.88	11.06	90.00	1.09
1.8	204.5	11.7	67.1	-0.06	-0.10	2339.	7129.	50170.3	7666.9	-5.58	11.76	90.00	0.38
2.0	227.0	9.5	66.8	-0.07	-0.12	2373.	7231.	50646.9	7953.1	-5.24	12.46	90.00	-0.36
2.2	249.4	7.5	66.5	-0.09	-0.13	2406.	7332.	51272.9	8471.1	-4.87	13.16	90.00	-1.13
2.4	271.7	5.7	66.1	-0.09	-0.12	2439.	7433.	50992.4	8275.8	-4.47	13.16	90.00	-1.54
2.6	293.9	4.0	65.7	-0.10	-0.12	2472.	7534.	50830.7	8274.0	-4.09	13.16	90.00	-1.98
2.8	316.0	2.5	65.3	-0.10	-0.12	2505.	7634.	50664.5	8271.6	-3.72	13.16	90.00	-2.43
3.0	337.9	1.2	64.9	-0.11	-0.11	2538.	7735.	50468.4	8264.9	-3.36	13.16	90.00	-2.91
TOUCHDOWN													
3.2	358.9	0.0	64.4	-0.12	-0.11	2571.	7836.	50250.3	8255.2	0.00	13.16	90.00	-3.41
3.2	359.7	0.0	64.3	-0.08	-0.00	2504.	6268.	35276.0	3403.1	0.00	0.00	94.80	0.00
3.4	381.3	0.0	64.0	-0.08	-0.00	2501.	6211.	35105.2	3404.9	0.00	0.00	94.98	0.00
3.6	402.9	0.0	63.6	-0.09	-0.00	2434.	4644.	30113.3	3555.4	0.00	0.00	99.78	0.00
3.8	424.3	0.0	63.3	-0.10	-0.00	2367.	3077.	24197.1	3622.0	0.00	0.00	104.58	0.00
4.0	445.6	0.0	62.9	-0.11	-0.00	2299.	1510.	15933.9	3529.0	0.00	0.00	109.38	0.00
4.2	466.7	0.0	62.1	-0.37	-0.00	2234.	0.	6986.0	3370.9	0.00	0.00	114.00	0.00
4.4	487.3	0.0	60.5	-0.37	-0.00	2234.	0.	6810.4	3301.0	0.00	0.00	114.00	0.00
4.6	507.6	0.0	59.1	-0.37	-0.00	2232.	0.	6467.9	3164.3	0.00	0.00	114.00	0.00
4.8	527.3	0.0	57.7	-0.37	-0.00	2232.	0.	6177.8	3045.5	0.00	0.00	114.00	0.00
5.0	546.5	0.0	56.3	-0.37	-0.00	2232.	0.	5886.2	2924.2	0.00	0.00	114.00	0.00

LANDING

5.2	565.3	0.0	54.9	-0.37	-0.00	2232.	0.	5602.1	2805.5	0.00	0.00	114.00	0.00
5.4	583.6	0.0	53.5	-0.37	-0.00	2232.	0.	5325.3	2689.4	0.00	0.00	114.00	0.00
5.6	601.4	0.0	52.1	-0.37	-0.00	2232.	0.	5056.0	2575.9	0.00	0.00	114.00	0.00
5.8	618.7	0.0	50.7	-0.37	-0.00	2232.	0.	4794.0	2464.9	0.00	0.00	114.00	0.00
6.0	635.6	0.0	49.3	-0.37	-0.00	2232.	0.	4539.3	2356.5	0.00	0.00	114.00	0.00
6.2	652.0	0.0	47.9	-0.37	-0.00	2232.	0.	4291.9	2250.6	0.00	0.00	114.00	0.00
6.4	667.9	0.0	46.5	-0.37	-0.00	2232.	0.	4051.8	2147.2	0.00	0.00	114.00	0.00
6.6	683.4	0.0	45.1	-0.37	-0.00	2232.	0.	3818.9	2046.4	0.00	0.00	114.00	0.00
6.8	698.4	0.0	43.7	-0.37	-0.00	2232.	0.	3593.2	1948.1	0.00	0.00	114.00	0.00
7.0	712.9	0.0	42.3	-0.36	-0.00	2232.	0.	3374.6	1852.2	0.00	0.00	114.00	0.00
7.2	726.9	0.0	40.9	-0.36	-0.00	2232.	0.	3163.2	1758.9	0.00	0.00	114.00	0.00
7.4	740.5	0.0	39.5	-0.36	-0.00	2232.	0.	2958.9	1668.0	0.00	0.00	114.00	0.00
7.6	753.6	0.0	38.1	-0.36	-0.00	2232.	0.	2761.7	1579.7	0.00	0.00	114.00	0.00
7.8	766.2	0.0	36.8	-0.36	-0.00	2232.	0.	2571.6	1493.7	0.00	0.00	114.00	0.00
8.0	778.4	0.0	35.4	-0.36	-0.00	2232.	0.	2388.4	1410.2	0.00	0.00	114.00	0.00
8.2	790.1	0.0	34.0	-0.36	-0.00	2232.	0.	2212.3	1329.2	0.00	0.00	114.00	0.00
8.4	801.4	0.0	32.6	-0.36	-0.00	2232.	0.	2043.1	1250.6	0.00	0.00	114.00	0.00
8.6	812.1	0.0	31.2	-0.36	-0.00	2232.	0.	1880.9	1174.4	0.00	0.00	114.00	0.00
8.8	822.4	0.0	29.9	-0.36	-0.00	2232.	0.	1725.5	1100.6	0.00	0.00	114.00	0.00
9.0	832.3	0.0	28.5	-0.36	-0.00	2232.	0.	1577.1	982.8	0.00	0.00	114.00	0.00
9.2	841.7	0.0	27.1	-0.36	-0.00	2232.	0.	1435.6	913.9	0.00	0.00	114.00	0.00
9.4	850.6	0.0	25.8	-0.36	-0.00	2232.	0.	1301.3	847.5	0.00	0.00	114.00	0.00
9.6	859.1	0.0	24.4	-0.36	-0.00	2232.	0.	1173.6	783.4	0.00	0.00	114.00	0.00
9.8	867.1	0.0	23.0	-0.36	-0.00	2232.	0.	1052.7	721.7	0.00	0.00	114.00	0.00
10.0	874.6	0.0	21.7	-0.36	-0.00	2232.	0.	938.5	662.3	0.00	0.00	114.00	0.00
10.2	881.7	0.0	20.3	-0.36	-0.00	2232.	0.	831.0	605.2	0.00	0.00	114.00	0.00
10.4	888.4	0.0	19.0	-0.36	-0.00	2232.	0.	730.1	550.5	0.00	0.00	114.00	0.00
10.6	894.5	0.0	17.6	-0.36	-0.00	2232.	0.	635.9	498.0	0.00	0.00	114.00	0.00
10.8	900.2	0.0	16.3	-0.35	-0.00	2232.	0.	548.3	447.9	0.00	0.00	114.00	0.00
11.0	905.5	0.0	14.9	-0.35	-0.00	2232.	0.	467.3	400.1	0.00	0.00	114.00	0.00
11.2	910.3	0.0	13.6	-0.35	-0.00	2232.	0.	392.9	354.6	0.00	0.00	114.00	0.00
11.4	914.7	0.0	12.2	-0.35	-0.00	2232.	0.	324.9	311.3	0.00	0.00	114.00	0.00
11.6	918.5	0.0	10.9	-0.35	-0.00	2232.	0.	263.5	270.3	0.00	0.00	114.00	0.00
11.8	922.0	0.0	9.5	-0.35	-0.00	2232.	0.	208.6	231.6	0.00	0.00	114.00	0.00
12.0	925.0	0.0	8.2	-0.35	-0.00	2232.	0.	160.2	195.1	0.00	0.00	114.00	0.00
12.2	927.5	0.0	6.8	-0.35	-0.00	2232.	0.	118.1	160.9	0.00	0.00	114.00	0.00
12.4	929.6	0.0	5.5	-0.35	-0.00	2232.	0.	82.6	128.9	0.00	0.00	114.00	0.00
12.6	931.2	0.0	4.2	-0.35	-0.00	2232.	0.	53.4	99.1	0.00	0.00	114.00	0.00
12.8	932.4	0.0	2.8	-0.35	-0.00	2232.	0.	30.5	71.6	0.00	0.00	114.00	0.00
13.0	933.1	0.0	1.5	-0.35	-0.00	2232.	0.	14.0	46.3	0.00	0.00	114.00	0.00
13.2	933.4	0.0	0.2	-0.35	-0.00	2232.	0.	3.9	23.1	0.00	0.00	114.00	0.00