N-96-01
II-A-158

AIRCRAFT FLIGHT PROCEDURES PROGRAM: MODIFIED COMPUTER PROGRAM MODEL - USER'S MANUAL -

BY:
LARRY A. RONK

DECEMBER 1981

PREPARED UNDER:
CONTRACT NO. 63-01-6267
TASK ORDER TFP-4

FOR THE
OFFICE OF NOISE ABATEMENT AND CONTROL
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

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50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. EPA/9-82-329	2.	3. Recipient's Accession No.

4. Title and Subtitle	5. Report Date
Aircraft Flight Procedures Program: Modified Computer Program Model - User's Manual -	December 1981
	6.
7. Author(s) Larry A. Ronk	8. Performing Organization Rept. No. ORI TR 1992
9. Performing Organization Name and Address ORI, Inc. 1400 Spring Street Silver Spring, Maryland 20910	10. Project/Task/Work Unit No. Task Order TFP-4 11. Contract(C) or Grant(G) No. (C) EPA 68-01-6267 (G)
12. Sponsoring Organization Name and Address Office of Noise Abatement and Control U.S. Environmental Protection Agency Washington, D.C. 20460	13. Type of Report & Period Covered Final 14.

15. Supplementary Notes A description of the development of the data bases used with the aircraft flight procedures models is presented in a separate report, ORI TR 1799
This report, as well as a computer tape of the programs and data bases are available from NTIS.

16. Abstract (Limit: 200 words)

This manual describes an aircraft flight procedures model used to construct aircraft flight paths and performance schedules for specified operational procedures. The computer model algorithms were derived from fundamental aircraft and engine performance relationships or from operational characteristics applicable to specific aircraft types.

The flight path and performance schedule data generated by the model are compatible with the input data requirements of the FAA's INM and the USAF's NOISEMAP.

The flight procedures model was developed and installed on the EPA's IBM 370/168MP computer system. The program was written in FORTRAN IV language and executed interactively under TSO.

17. Document Analysis a. Descriptors

Flight Procedures Computer Model
Flight Path
Flight Profile
Performance Schedules

Commercial Aircarrier Aircraft
Integrated Noise Model (INM)
NOISEMAP

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release Unlimited	Unclassified	
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

FOREWARD

The user is assumed to be familiar with the following documents:

- National Computer Center - IBM System, "NCC - IBM WYLBUR Guide"
- U.S. Environmental Protection Agency, "NCC - IBM User's Guide"
- IBM, "OS/VS2 TSO Command Language Reference Manual," GC28-0646-4

This manual describes the procedures for using the modified flight procedures model developed by ORI, Inc. as it existed on the NCC computer system on July, 1981.

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CORRECTION!

THE PREVIOUS DOCUMENT(S) MAY HAVE BEEN FILMED INCORRECTLY . . .

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SYMBOLS AND ABBREVIATIONS

Symbol/ Abbreviation	Units	Description
A/C	-	Aircraft
ALT	feet	Airport altitude above sea-level
ARPT	-	Airport
CT	ft/sec	Speed of sound
C_D	-	Aerodynamic drag coefficient
C_L	-	Aerodynamic lift coefficient
D	pounds	Aircraft drag
DS	feet	Horizontal distance between flight path section and points
E	-	Aircraft engine
EAS	knots, ft/sec	Equivalent air speed
EPR	-	Engine-Pressure-Ratio
EPA	-	Environmental Protection Agency
^oF	deg	Atmospheric temperature in degrees Fahrenheit

Symbol/ Abbreviation	Units	Description
FAA	-	Federal Aviation Administration
$\overline{F}_n$	pounds	Average total net thrust
$\overline{F}_{n_1}$	pounds	Average net thrust per engine at H1
$\overline{F}_{n_2}$	pounds	Average net thrust per engine at H2
FPM	ft/min.	Aircraft rate-of-climb or descent
fpm	ft/min.	Aircraft rate-of-climb
g	ft/sec/sec	Acceleration of gravity
HAA	feet	Height above airport
HBPR	-	High-by-pass ratio
HPALT	feet	Geopotential pressure altitude
H1	feet	Aircraft's altitude above the airport at section end point 1
H2	feet	Aircraft's altitude above the airport at section end point 2
IBM	-	International Business Machines Corporation
INM	-	Integrated Noise Model computer program
^{o}K	deg.	Atmospheric temperature in degrees kelvin
KEAS or	knots	Equivalent air speed
keas	knots	Equivalent air speed
Klbs	pounds	One thousand pounds
KTAS	knots,ft/sec	True air speed
L	pounds	Aircraft lift
LBPR	-	Low-by-pass ratio

Symbol/ Abbreviation	Units	Description
LR	^oK/foot	First-layer standard lapse rate
MACH	-	Mach number
MCT	pounds	Maximum climb thrust
N	-	Number of engines operating
N1	rpm	Low pressure fan rotational speed
NB	-	Narrow body
NCC	-	National Computer Center
NOISEMAP	-	NOISEMAP computer program
ONAC	-	Office of Noise Abatement and Control
R	feet	Flight track turn radius
Re	feet	Equivalent earth radius
RPM	rpm	Engine rotational speed
S_W	sq. feet	Reference wing area
T_o	^oK	Sea-level standard temperature
TAPTK	^oK	Airport temperature
TEMP	^oF	Airport temperature
TEMPF	^oF	Temperature
TEMPK	^oK	Temperature
THPK	^oK	Non-standard ambient temperature
TOT	pounds	Total net takeoff thrust per engine
TRAT	-	Ratio between the airport's actual ambient temperature and the sea-level standard temperature
TSO	-	Time Sharing Option
TSTA	^oK	Standard ambient temperature

Symbol/ Abbreviation	Units	Description
t_{FR}	sec	Flap retraction time
USAF	-	United States Air Force
V	ft/sec	Aircraft velocity
$\dot{V}$	ft/sec/sec	Aircraft acceleration
Ve	ft/sec	Equivalent air speed
Vs	knots	Equivalent air speed at stall
V_T	ft/sec	True air speed
VT1	ft/sec	True air speed at H1
VT2	ft/sec	True air speed at H2
VZ	fpm	Rate-of-climb
V2	knots	One-engine out takeoff safety speed
V35	knots	Equivalent air speed at 35 feet HAA
V_1	KEAS,KTAS	Aircraft air speed at H1
V_2	KEAS,KTAS	Aircraft air speed at H2
W	pounds	Aircraft weight
WB	-	Wide-body
α_B	degrees	Aircraft body angle of attack
γ	degrees	Aircraft flight path angle
ΔZ	feet	Change in vertical altitude from H1 to H2
δ	-	Ratio of ambient pressure to sea level reference pressure of 33.73 inches of mercury
δ_F	degrees	Aircraft flap position or setting

Symbol/ Abbreviation	Units	Description
δ_1	-	Altitude pressure ratio at H1
δ_2	-	Altitude pressure ratio at H2
δ_3	-	Altitude pressure ratio at (H1 + H2)/2
Θ	-	Altitude temperature ratio
Θ_c	deg	Flight track turn angle
$\dot{\Theta}_c$	radians/sec	Aircraft turning rate
ΘT_2	-	Ratio of the total temperature at the fan stage face to sea level reference temperature of 77^oF
ρ	$\frac{\text{lbs-sec}^2}{\text{ft}^4}$	Ambient air density
ρ_o	$\frac{\text{lbs-sec}^2}{\text{ft}^4}$	Air density at sea level
σ	-	Altitude density ratio
ϕ	deg	Aircraft banking angle

I. INTRODUCTION

BACKGROUND

Under Task 38 of EPA/ONAC Level-of-Effort Contract No. 68-01-6151, ORI, Inc. identified and collected performance and operational data and information required to construct flight paths and performance schedules for selected commercial aircraft types powered by turbofan engines.[1] As part of the task effort, ORI, Inc. also evaluated available flight procedure computer programs to identify existing analytical and computer programming work which could be used in developing a modified computer program model to generate aircraft flight path and performance schedule data which are compatible with the input data requirements of the FAA's INM and the USAF's NOISEMAP.[2,3]

In a follow-on task, ORI, Inc. developed modified analytical algorithms for constructing aircraft flight paths and performance schedules for specified operational procedures. These algorithms were derived from fundamental aircraft and engine performance relationships or from operational characteristics applicable to specific aircraft types. Based on these algorithms, a computer model was developed and installed on the EPA's IBM 360/370 computer system (NCC). The program was written in FORTRAN IV language and executed interactively under TSO.

In developing the modified flight procedures model, it was found that little of the existing analytical and computer programming work could be utilized. In general, the structure of the existing models and the models' algorithms were not compatible with the performance and operational data and information requirements described in Reference 1. In addition, the "simplified" relationships used in most of the existing models to describe the aircraft's performance and operational characteristics could not provide the specialized capabilities which were identified as requirements of the modified flight procedures model. Furthermore, incompatibility between the EPA's computer system and the systems used to operate many of the existing flight procedures models prevented the use of much of the existing computer programming work in the development of the modified flight procedures program.

OBJECTIVES

The objectives of this program effort were to: 1) develop modified analytical algorithms for constructing aircraft flight path and performance schedules for specific operational procedures, 2) develop a computer program model based on these modified analytical algorithms such that the output is compatible with the input data requirements for FAA's INM and the USAF's NOISEMAP, 3) install the computer program model on the EPA's IBM 360/370 computer system and demonstrate the operation of model, and 4) prepare a user's manual which provides a detailed description of the use and application of the computer program model. This report describes the work performed in accomplishing these objectives.

II. DESCRIPTION OF THE MODIFIED FLIGHT PROCEDURES MODEL

The modified flight procedures model can be used to construct aircraft flight paths and performance schedules for takeoff and for approach and landing operations performed in accordance with specified flight procedures. The aircraft types considered in the model are representative of all types of in-service commercial aircarrier aircraft powered by low-by-pass ratio (LBPR) and high-by-pass ratio (HBPR) turbofan engines. The current fleet of "narrow body" aircraft types are powered by LBPR engines and the "wide body" aircraft types are powered by HBPR engines. The following six generic aircraft classes are represented:

- 2-Engine LBPR-Narrow Body (2E-LBPR-NB)
- 3-Engine LBPR-Narrow Body (3E-LBPR-NB)
- 4-Engine LBPR-Narrow Body (4E-LBPR-NB)
- 2-Engine HBPR-Wide Body (2E-HBPR-WB)
- 3-Engine HBPR-Wide Body (3E-HBPR-WB)
- 4-Engine HBPR-Wode Body (4E-HBPR-WB)

Table 2-1 presents a listing of specific aircraft types which are representative of the above generic classes and identifies the aircraft selected to represent each generic class. The engines used to power the selected aircraft are also presented on Table 2-1.

TABLE 2-1

AIRCRAFT/ENGINE IDENTIFICATION AND SELECTION

Generic Aircraft Class	Representative Aircraft Types	Aircraft Selected To Represent Generic Class	Engine Used to Power Selected Aircraft
2-Engine LBPR-Narrow Body	737/DC-9/BAC-111	737-200 ADV.	JT8D-15
3-Engine LBPR-Narrow Body	727	727-200 ADV.	JT8D-15
4-Engine LBPR-Narrow Body	707/DC-8/720	707-300 B	JT3D-3B/C
2-Engine HBPR-Wide Body	A300/757/767	*	JT9D-20
3-Engine HBPR-Wide Body	DC-10/L-1011	DC-10-10	CF6-6D
4-Engine HBPR-Wide Body	747	747-200	JT9D-7

*A pseudo aircraft has been used to represent the generic class of 2-engine HBPR-wide body aircraft types. Aircraft performance and operational data and information for the pseudo aircraft were based on actual data and information for the DC-10-40. The pseudo aircraft is powered by two (2) JT9D-20 engines.

The range of airport, aircraft, and engine operational parameters for the aircraft types considered in the flight procedures model are shown on Table 2-2. The maximum operating speed allowed by the model for all aircraft types is limited to 250 KEAS. The minimum operating speed is considered to be the aircraft stall speed (Vs). The stall speeds are functions of flap setting and aircraft weight and can be determined from the operational data presented in Reference 1.

A detailed description of the flight procedures model is presented in the following sections.

TAKEOFF OPERATIONS

The takeoff operations which may be modeled include the following:

- Acceleration from brake release to point of lift-off with constant flap and thrust settings; landing gear extended
- Acceleration from point of lift-off to 35 feet height above airport (HAA) with constant flap and thrust settings; landing gear extended
- Acceleration from 35 feet HAA to 400 feet HAA with constant flap and thrust settings; initiate and complete landing gear retraction
- Climb at constant equivalent air speed (EAS), and constant flap and thrust settings; landing gear retracted
- Acceleration with changing flap setting, and with a constant thrust setting; landing gear retracted
- Acceleration with constant flap and thrust settings; landing gear retracted
- Acceleration with constant flap setting and with changing thrust setting; landing gear retracted

TABLE 2-2
RANGE OF AIRPORT, AIRCRAFT, AND ENGINE OPERATIONAL PARAMETERS
FOR THE AIRCRAFT TYPES CONSIDERED IN THE FLIGHT PROCEDURES MODEL

Aircraft Type	AIRPORT PARAMETERS: Pressure Altitude Range, Feet	AIRPORT PARAMETERS: Temp. Range, Degrees, °F	AIRCRAFT PARAMETERS: Flap Positions, Degrees, δ_F [1/]: Takeoff	Flap Positions: Approach	Weight Range, Klbs, W: Takeoff	Weight Range: Approach	Climb Speeds Above V2, Knots, KEAS
2E-LBPR-NB	0 to 6000	30 to 100	1,2,5,10,15,25	0,1,2,5,10,15 25,25D,30D,40D	70 to 125	70 to 110	15,20,30
3E-LBPR-NB	0 to 6000	30 to 100	5,15,20,25	0,2,5,15,20,25, 25D,30D,40D	110 to 230	100 to 160	10,20,30
4E-LBPR-NB	0 to 6000	30 to 100	14	0,14,25,25D 40D,50D	190 to 330	160 to 260	10,20,30
2E-HBPR-WB	0 to 6000	40 to 95	5,15,25	0,5,15,25,35 50,35D,50D	198.3 to 360	190 to 330	10,20,30
3E-HBPR-WB	0 to 6000	40 to 95	0,10,20	0,5,10,20,35, 50,35D,50D	260 to 440	240 to 380	10,20,30
4E-HBPR-WB	0 to 6000	30 to 100	10,20	0,1,5,10,20 20D,25D,30D	500 to 800	450 to 650	10,20,30

1/ Landing gear up for approach flaps except for those designated with a D.

TABLE 2-2 (Continued)

ENGINE PARAMETERS

Aircraft Type	Total Net Takeoff Thrust (TOT)			Maximum Climb Thrust Engine-Pressure-Ratio (EPR) Setting or Low Pressure Fan Speed Setting (N1)	
	Pressure Altitude Range, Feet	True Air Speed Range, Knots, KTAS	Ambient Temp. Range, Degrees, °F	Pressure Altitude Range, Feet	Ambient Temp. Range, Degrees, °F
2E-LBPR-NB	0 to 6000	100 to 300	0 to 122	0 to 30000	-4 to 122
3E-LBPR-NB	0 to 6000	100 to 300	0 to 100	0 to 30000	-4 to 122
4E-LBPR-NB	0 to 6000	0 to 300	-6.5 to 120	0 to 30000	-4 to 113
2E-HBPR-WB	0 to 8000	0 to 300	20 to 100	0 to 30000	-5 to 103
3E-HBPR-WB	0 to 8000	0 to 300	20 to 100	0 to 30000	0 to 100
4E-HBPR-WB	0 to 6000	100 to 300	-6.5 to 103	0 to 30000	-5 to 103

TABLE 2-2 (Continued)

ENGINE PARAMETERS

Aircraft Type	Referred Net Thrust, (F_n/δ)			Referred Low Pressure Fan Speed, $(N1/\sqrt{\theta T_2})$, RPM	
	EPR Range	$N1/\sqrt{\theta T_2}$ Range, RPM	MACH Number Range	EPR Range	MACH Number Range
2E-LBPR-NB	1.05 to 2.40	-	0.0 to 0.5	-	-
3E-LBPR-NB	1.00 to 2.40	-	0.0 to 0.5	-	-
4E-LBPR-NB	1.00 to 2.00	-	0.0 to 0.5	-	-
2E-HBPR-WB	1.00 to 1.55	-	0.0 to 0.5	1.00 to 1.65	0.0 to 0.5
3E-HBPR-WB	-	2060 to 3776	0.0 to 0.5	-	-
4E-HBPR-WB	1.00 to 1.75	-	0.1 to 0.5	1.00 to 1.75	0.1 to 0.5

- Climb at constant EAS and constant flap setting, and with changing thrust setting; landing gear retracted

- Climb at constant EAS with changing flap setting, and with constant thrust setting; landing gear retracted.

These nine takeoff operations can be used to model the takeoff flight procedures which are currently used or capable of being used in routine departures.* Each procedure consists of three flight path segments which are identified by their principal operational activities. The segments are defined as:

- Ground-roll and initial climb
- Thrust reduction
- Normal climb.

Each of these three segments may be comprised of several sections in which the aircraft performs various operational activities such as landing gear retraction, flap retraction, acceleration, and thrust adjustment. The location at which these activities are initiated and the sequence of their occurrence will depend on the specific flight procedure employed.

The operational procedures performed during the ground-roll and initial climb to 400 feet HAA are identical for all aircraft types considered in the model, i.e., constant thrust setting (all-engine takeoff thrust), constant flaps, and landing gear retracted by 400 feet HAA. The only variations to these operational parameters which the model will allow include the initial takeoff flap setting and initial climb speed. Starting with the section beginning at 400 feet HAA, eight takeoff operational procedures, or options, may be used to construct the complete flight path and performance schedule. Each of the eight options may be used to define a straight or curved flight path section. The following is a brief description of these options.

*A detailed description of these procedures is presented in References 1 and 4.

Option Number 1

This option defines a flight operation performed at constant equivalent speed, constant flap setting, constant thrust setting, and landing gear retracted. The average flight path angle is computed from the following flight path and performance variables: (1) height above airport, (2) true air speed, (3) average total net thrust, (4) flap setting, and (5) aircraft weight.

Option Number 2

This option defines a flight operation performed at constant equivalent speed, constant flap setting, constant thrust setting, and landing gear retracted. The average total net thrust is computed from the following flight path and performance variables: (1) height above airport, (2) true air speed, (3) rate-of-climb, (4) flap setting, and (5) aircraft weight.

Option Number 3

This option defines a flight operation performed at constant equivalent speed, constant flap setting, constant thrust setting, and landing gear retracted. The average total net thrust is computed from the following flight path and performance variables: (1) height above airport, (2) true air speed, (3) average flight path angle, (4) flap setting, and (5) aircraft weight.

Option Number 4

This option defines a flight operation performed at constant equivalent speed, constant flap setting, constant thrust setting, and landing gear retracted. The average flight path angle is computed from the following flight path and performance variables: (1) height above airport, (2) horizontal distance between flight path section end points, (3) true air speed, (4) average total net thrust, (5) flap setting, and (6) aircraft weight.

Option Number 5

This option can be used to define the following three (3) flight operations: a) acceleration with constant flap setting, and constant thrust setting, b) constant equivalent speed, constant flap setting, and changing thrust setting, c) acceleration with constant flap setting and changing thrust setting. All three flight operations are performed with the aircraft's landing gear retracted. The average flight path angle is computed from the following flight path and performance variables: (1) height above airport, (2) true air speed, (3) average total net thrust, (4) flap setting, (5) aircraft weight, and (6) rate-of-climb (optional for flight operations a and c).

Option Number 6

This option defines a flight operation performed with aircraft acceleration, constant flap setting, constant thrust setting, and landing gear retracted. The average flight path angle is computed from the following flight path and performance variables: (a) height above aiprort, (2) true air speed, (3) average total net thrust, (4) flap seeting, (5) aircraft weight, and (6) rate-of-climb (optional).

Option Number 7

This option defines a flight operation performed at constant equivalent speed, constant thrust setting, changing flap setting, and landing gear retracted. The average flight path angle is computed from the following flight path and performance variables: (1) height above airport, (2) true air speed, (3) average total net thrust, (4) flap setting, (5) flap retraction time, and (6) aircraft weight.

Option Number 8

This option defines a flight operation performed with aircraft acceleration, constant thrust setting, changing flap setting, and landing gear retracted. The average flight path angle is computed from the following flight path and performance variables: (1) height above airport, (2) true air speed, (3) average total net thrust, (4) flap setting, (5) flap retraction time, (6) aircraft weight, and (7) rate-of-climb.

APPROACH AND LANDING OPERATIONS

The approach and landing flight operations which may be modeled include the following:

- Descend at constant EAS, and constant flap and thrust settings; landing gear retracted or extended
- Descend at constant EAS or deceleration with constant flap setting and with changing thrust setting; landing gear retracted or extended
- Level flight at constant EAS, and constant flap and thrust settings; landing gear retracted or extended
- Level flight deceleration with constant flap setting and with changing thrust setting; landing gear retracted or extended.

The flight procedures model provides an option for each of the above approach and landing operations. Each of the four options may be used to define a straight or curved flight path section. Also, flap settings can be changed at section end points to represent "flap management" approach procedures. A description of these options is presented below.

Option Number 9

This option defines a flight operation performed at constant equivalent air speed, constant flap setting, constant thrust setting, and landing gear retracted or extended. The average flight path angle is computed from the following flight path and performance variables: (1) height above airport, (2) true air speed, (3) total net thrust, (4) flap setting, and (5) aircraft weight.

Option Number 10

This option defines a flight operation performed at constant equivalent air speed or aircraft deceleration with constant flap setting, changing thrust,setting, and landing gear retracted or extended. The average total net thrust is computed from the following flight path and performance variables: (1) height above airport, (2) true air speed, (3) rate-of-descent, (4) flap setting, and (5) aircraft weight.

Option Number 11

This option defines a flight operation performed at constant equivalent air speed or aircraft deceleration, with constant flap setting, changing thrust setting, and landing gear retracted or extended. The average total net thrust is computed from the following flight path and performance variables: (1) height above airport, (2) true air speed, (3) flight path angle, (4) flap setting, and (5) aircraft weight.

Option Number 12

This option can be used to define the following two (2) flight operations: a) level flight at constant equivalent air speed, constant flap setting, and constant thrust setting, or b) level flight deceleration with constant flap setting, and changing thrust setting. Both flight operations can be performed with the landing gear retracted or extended. The average total net thrust is computed from the folloiwng flight path and performance variables: (1) height above airport, (2) true air speed, (3) horizontal distance traveled during the flight operation, (4) flap setting, and (5) aircraft weight.

MODEL INPUTS

The flight procedures model uses an extensive aircraft and engine performance data base to construct flight path and performances schedules. Most of these data are stored internally on data base files which are read by the main program prior to program execution. The stored input data used by the model for both takeoff and approach and landing operational procedures include the following:

- Aircraft reference wing area
- All-engine distance from brake release to 35 feet HAA and 400 feet HAA over a wide range of aircraft weights, flap settings, airport temperatures, and airport pressure altitudes
- Equivalent air speeds for takeoff over a wide range of aircraft weights and flap settings*

*These include the all-engine EAS at 35 feet HAA (V35) and the one-engine out takeoff safety EAS (V2).

- Engine thrust parampters over a full range of takeoff and approach and landing conditions and thrust requirements. These parameters include: (a) all-engine net thrust as a function of air speed, temperature, and altitude (for takeoff operations), (b) referred (or corrected) net thrust (Fn/δ) as a function of engine-pressure-ratio (EPR) and air speed, (c) referred (or corrected) low pressure fan speed ($N1/\sqrt{\Theta T_2}$) as a function of EPR and air speed, and (d) referred (or corrected) net thrust as a function of low pressure fan speed and air speed
- Aircraft lift and drag coefficients as a function of takeoff flap settings and landing gear position.

Input data which are supplied or selected by the program user include the following:

- Airport temperature and pressure altitude
- Aircraft weight
- Engine thrust parameters
- Flap setting
- Climb and descent equivalent air speeds (including the climb speed above the one-engine out takeoff safety speed, V2)
- Flap retraction speed schedules and times
- Turn radius (when turning operations are performed).

MODEL OUTPUTS

Each aircraft flight profile consists of a number of flight path sections. The number of sections comprising each profile will depend upon the type of flight operation and the procedure used. The output from the flight procedures model provides aircraft and engine performance data for each section of the profile. Specific types of data presented depend upon the aircraft type considered. When turning operations are performed, the flight track turning angle is computed from a specified turn radius and is presented as part of the output. A complete listing of the model output data is presented below:

- Total time from brake release (or to touchdown), minutes - TOT.MIN.
- Horizontal distance from brake release (or touchdown), feet - DIS.(FT)
- Height above the airport, feet - HAA(FT)
- True air speed, KTAS - VT(KTAS)
- Equivalent air speed, KEAS - VE(KEAS)
- Rate-of-climb (or descent), feet/min. - ROC(FPM)
- Flight track turn angle, degrees - TURN ANG
- Average climb angle, degrees - CLM ANGL
- Average angle-of-attack, degrees - ALPHA
- Average aircraft body angle, degrees - BOD ANGL
- Flap setting (at section endpoints), degrees - FLAP1, FLAP2
- Thrust, (at section endpoints), lbs. - FN1(LBS), FN2(LBS)
- Referred net thrust (at section endpoints) lbs - FNDEL1, FNDEL2
- Engine-pressure-ratio (at section endpoints) - EPR1, EPR2
- Referred low pressure fan speed (at section endpoints), RPM - FAN SPD1, FAN SPD2

AIRCRAFT PERFORMANCE ALGORITHMS

The flight procedures model uses the following three aircraft performance equations to construct flight paths and performance schedules:

$$F_n \cos \alpha_B = D + \frac{W}{g} \dot{V} + W \sin \gamma \tag{2-1}$$

$$(L + F_n \sin \alpha_B) \cos \phi = W \cos \gamma \tag{2-2}$$

$$(L + F_n \sin \alpha_B) \sin \phi = \frac{W}{g} \dot{\theta}_c V \cos \gamma \tag{2-3}$$

where:

F_n = Total net thrust

W = Aircraft weight

g = Acceleration of gravity

D = Aircraft drag

L = Aircraft lift

V = Aircraft velocity along the flight path axis

$\dot{V}$ = Aircraft acceleration

α_B = Body angle-of-attack, degrees

γ = Climb angle, degrees

ϕ = Aircraft banking angle, degrees

θ_c = Aircraft turning angle in the horizontal plane, degrees

$\dot{\theta}_c$ = Aircraft turning rate, radians per second

Equation 2-1 describes the forces acting on the aircraft in a direction along the flight path axis. Equations 2-2 and 2-3 describe the forces acting normal to the flight path axis. Equations 2-1, 2-2, and 2-3 are general in that they are applicable to straight flight paths ($\phi = 0$) and to curved flight paths ($\phi \neq 0$) which result from turning operations. In deriving equations 2-1, and 2-2, two assumptions were made: 1) the net thrust can be considered to act along the aircraft body axis, i.e., the angle between the thrust vector and aircraft body axis is approximately equal to 0, and 2) the centrifugal force component, resulting from a change in flight path angle, is small compared to the other forces normal to the flight path axis. Both of these assumptions have been shown to be reasonable. Figures 2-1 and 2-2 identify the various forces acting on the aircraft during a turning operation. Figure 2-1 shows the forces acting normal to the flight path axis and Figure 2-2 shows the forces acting in the horizontal plane. From Figure 2-1, it can be seen that

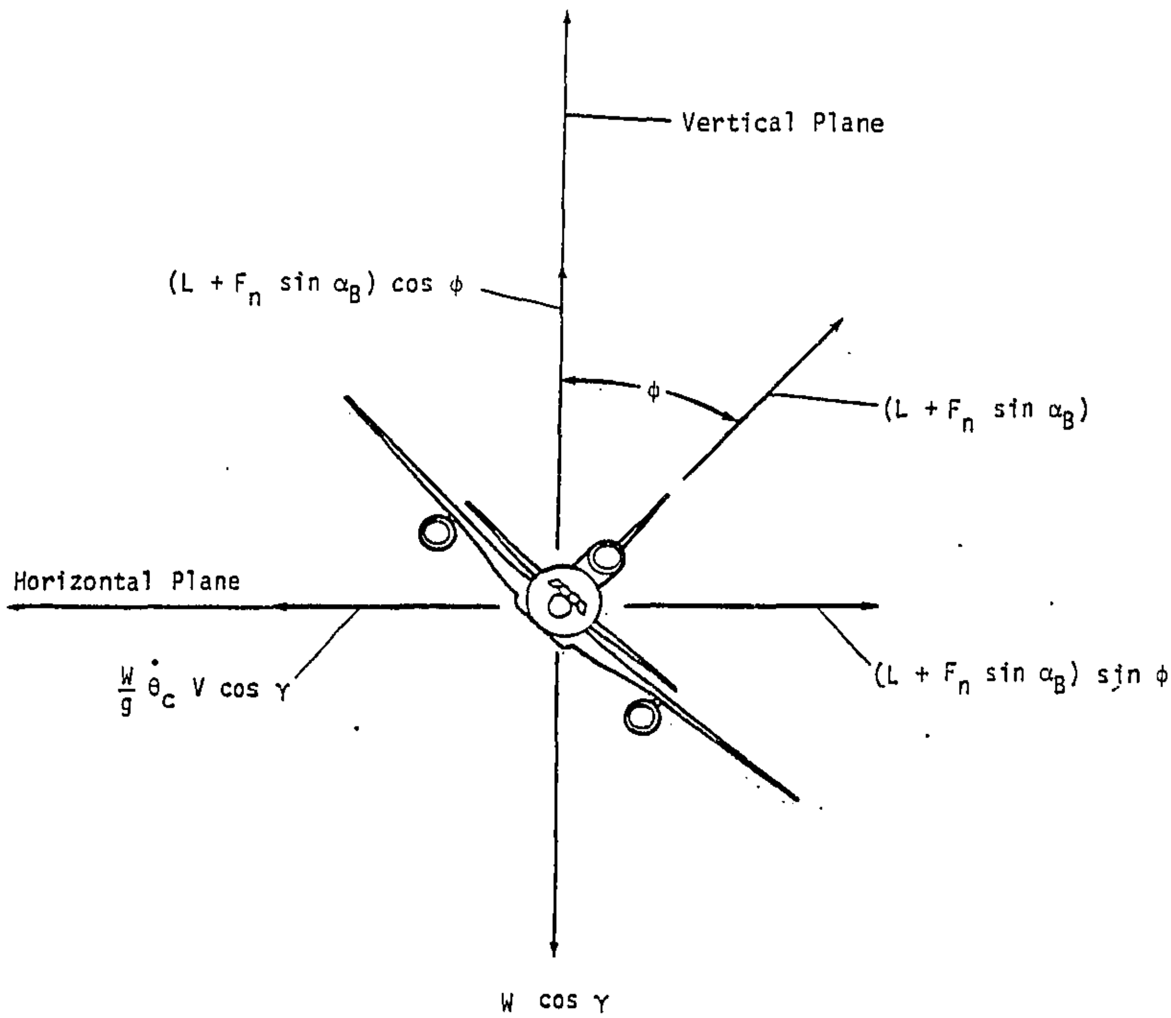


FIGURE 2-1. FORCES ACTING ON THE AIRCRAFT DURING TURNING OPERATIONS (NORMAL TO THE FLIGHT PATH AXIS)

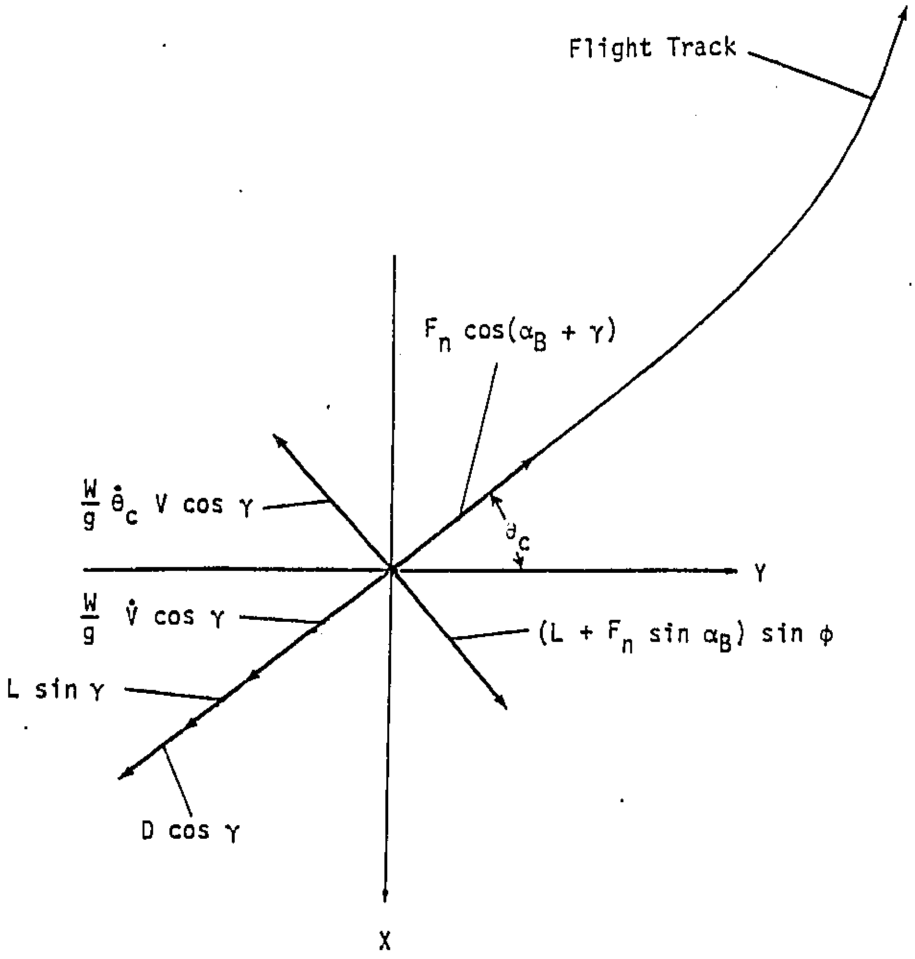


FIGURE 2-2. FORCES ACTING ON THE AIRCRAFT DURING TURNING OPERATIONS (IN THE HORIZONTAL PLANE)

an equation for the banking angle ϕ can be expressed as:

$$\phi = \arctan\left(\frac{\dot{\theta}_c V}{g}\right) \tag{2-4}$$

where $\dot{\theta}_C$ is the aircraft's turning rate in radians per sec. The turning rate can be expressed as[5]:

$$\dot{\theta}_c = \frac{V \cos \gamma}{R} \tag{2-5}$$

where R is the aircraft's turning radius as measured in the horizontal plane. Using equation 2-5, the banking angle can also be expressed as:

$$\phi = \arctan\left(\frac{V^2 \cos \gamma}{Rg}\right) \tag{2-6}$$

The aircraft lift and drag forces are defined by the following equations:

$$D = \frac{1}{2}\rho V_T^2 S_w C_D = \frac{1}{2}\rho_o V_e^2 S_w C_D \tag{2-7}$$

$$L = \frac{1}{2}\rho V_T^2 S_w C_L = \frac{1}{2}\rho_o V_e^2 S_w C_L \tag{2-8}$$

where:

ρ = ambient air density

ρ_o = air density at sea level

V_e = equivalent air speed of the aircraft

V_T = true air speed of the aircraft

S_w = aircraft wing area

C_D = aircraft drag coefficient

C_L = aircraft lift coefficient

For a given flap setting and landing gear position, the aircraft drag coefficient (C_D) is calculated as function of the lift coefficient (C_L). For a given flap setting and landing gear position, the aircraft lift coefficient (C_L) is calculated as a function of the body angle-of-attack (α_B). A description of the C_L and C_D computational algorithms is presented in Reference 1.

ATMOSPHERIC PARAMETERS

The atmosphere used with the flight procedures model was constructed using algorithms described in References 6 and 7. Sea-level pressure altitude and 77^{o}F were selected as the reference atmospheric conditions. The following sections discuss the components of the model atmosphere.

Geopotential Pressure Altitude

The geopotential pressure altitude is computed from:

$$HPALT = (ALT \cdot Re)/(ALT + Re) \qquad (2\text{-}9)$$

where:

HPALT = geopotential pressure altitude, feet

ALT = pressure altitude, feet

Re = equivalent earth radius (20,844,820 feet)

Standard Temperature

The standard ambient temperature is computed from:

$$TSTA = T_o - LR \cdot HPALT \qquad (2\text{-}10)$$

where:

TSTA = standard ambient temperature, ^{o}K

T_o = sea-level standard temperature, 298.15^{o}K

LR = first-layer standard lapse rate, 1.9812×10^{-3} ^{o}K/foot

Conversions from degrees Fahrenheit to degrees Kelvin were computed from:

$$TEMPK = (TEMPF + 459.67)/1.8 \qquad (2\text{-}11)$$

where:

TEMPK = temperature in ^{o}K

TEMPF = temperature in ^{o}F

Non-Standard Temperature

The non-standard ambient temperature is computed from:

$$THPK = TRAT \cdot TSTA \qquad (2\text{-}12)$$

where:

THPK = non-standard ambient temperature, ^{o}K

TRAT = ratio between the airport's actual ambient temperature and the sea-level standard temperature

Altitude Pressure Ratio

The altitude pressure ratio (δ) is computed from:

$$\delta = (TSTA/T_o)^{5.2588} \qquad (2\text{-}13)$$

Altitude Temperature Ratio

The altitude temperature ratio (θ) is computed from:

$$\theta = (TAPTK/T_o) \qquad (2\text{-}14)$$

where:

TAPTK = airport temperature, ^{o}K

Altitude Density Ratio

The altitude density ratio (σ) is computed from:

$$\sigma = \delta/\theta \qquad (2\text{-}15)$$

where:

δ = altitude pressure ratio

θ = altitude temperature ratio

Speed of Sound

The speed of sound is computed from:

$$CT = 65.783 \sqrt{THPK} \qquad (2\text{-}16)$$

where:

CT = speed of sound, feet/sec

III. PROGRAM EXECUTION

MODEL DESIGN

The basic structure of the modified flight procedures model is shown on Figure 3-1. The flight procedures computer model is totally interactive, i.e., it is designed to interact with low-speed remote terminals during its execution. During program execution, the model user is prompted for specific data required to construct the aircraft flight paths and performance schedules.

HOW TO RUN THE FLIGHT PROCEDURES MODEL

After the TSO logon procedure has been completed*, the computer system responds by displaying "READY". The user is now connected with the TSO interactive computer system and is ready to execute the flight procedures model. If the user is signed on under the user-ID EPATFP, the model is executed by typing:

EXEC FLYPRO(GOMAIN)

If the user is signed on under another user-ID, the model is executed by typing:

EXEC 'CN.EPATFP.MUSN.FLYPRO.CLIST(GOMAIN)'

---

*An example TSO logon procedure is presented in Appendix B.

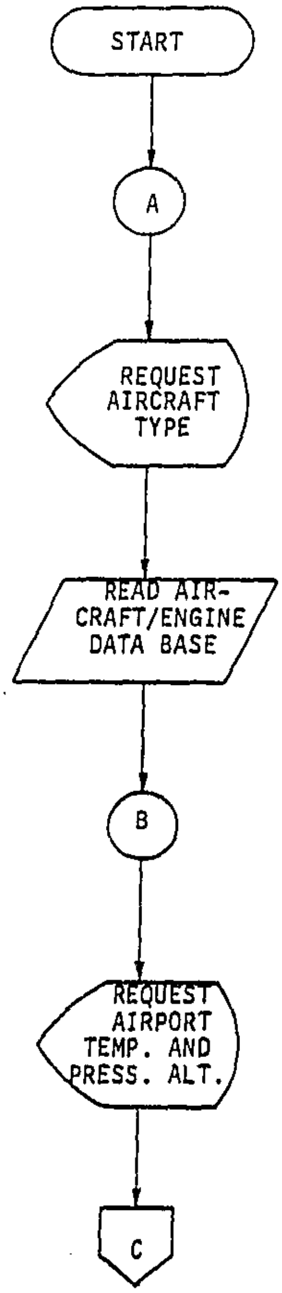


FIGURE 3-1. BASIC STRUCTURE OF THE MODIFIED FLIGHT PROCEDURES MODEL

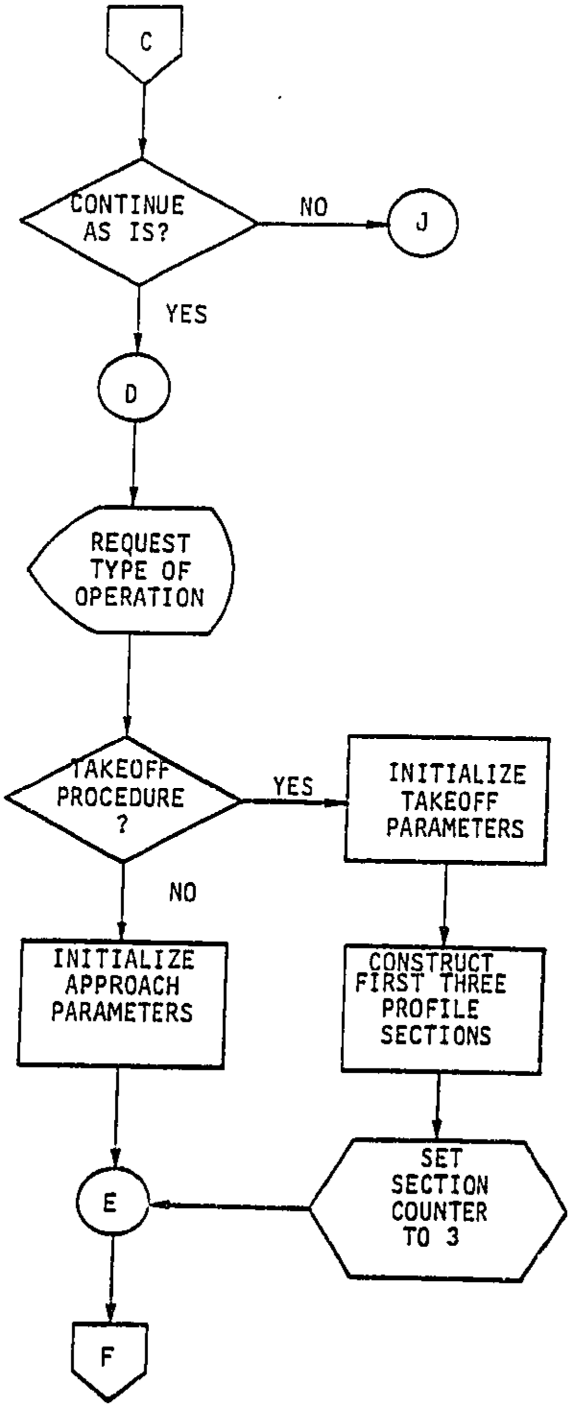


FIGURE 3-1. (CONT.)

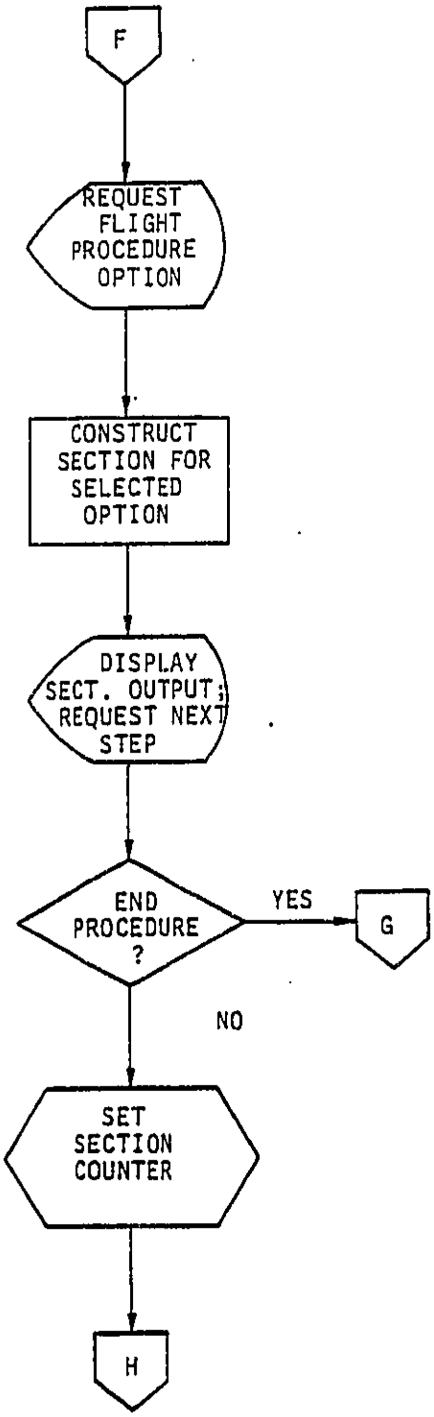


FIGURE 3-1. (CONT.)

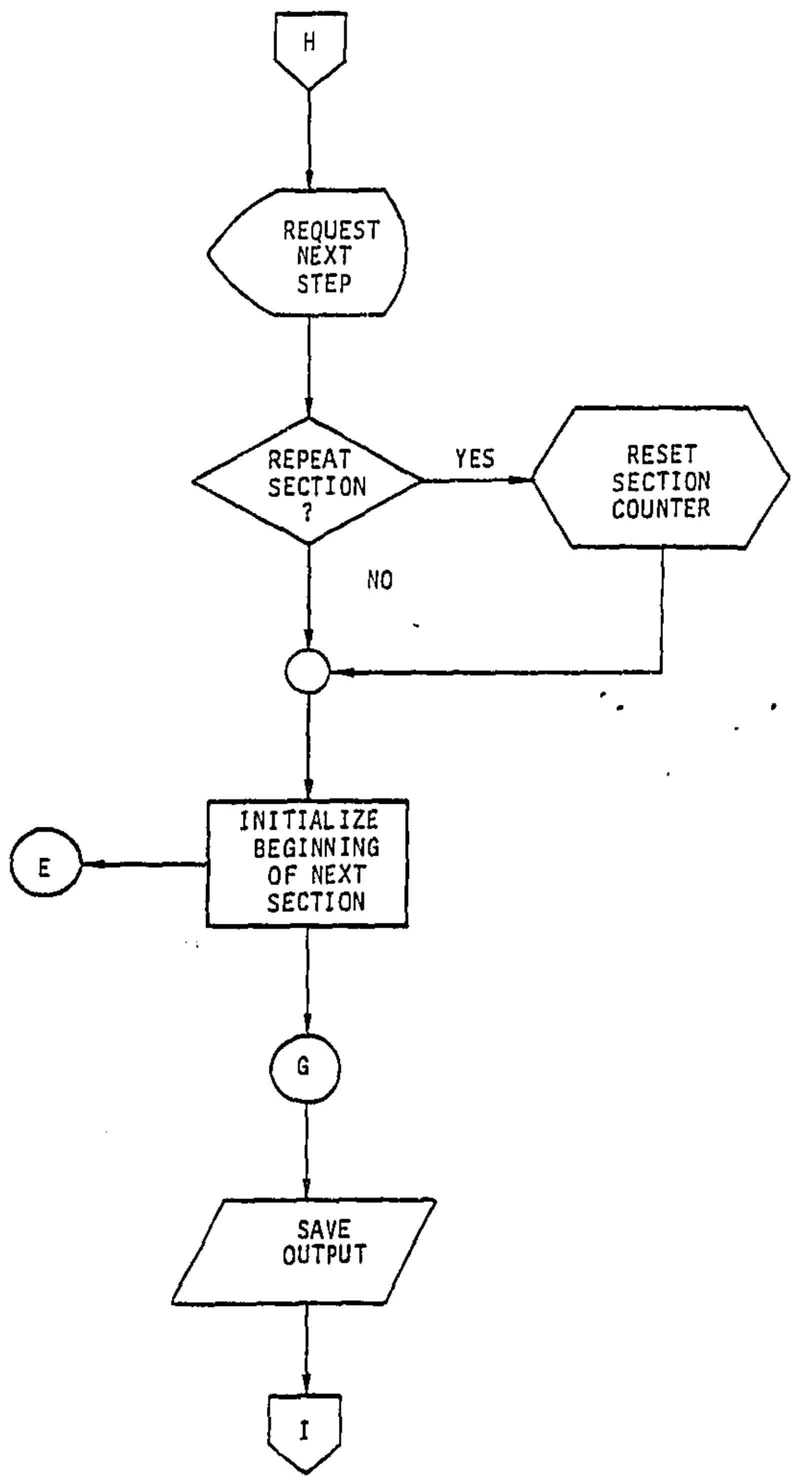


FIGURE 3-1. (CONT.)

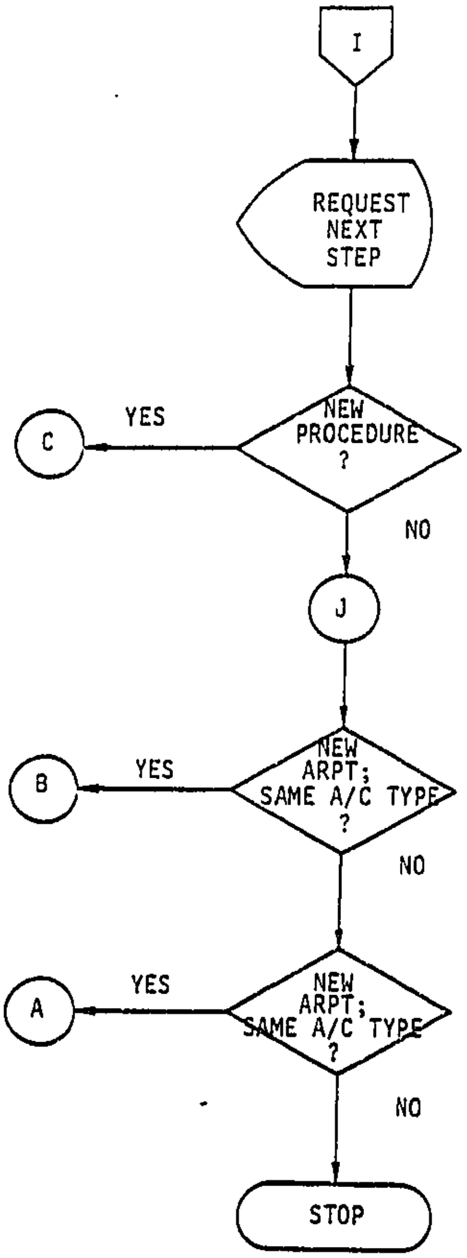


FIGURE 3-1. (CONT.)

After the execution command is typed, the system will respond with the following:

```
FOR ALL INPUTS: SEPARATOR IS COMMA, BLANK(S), OR TAB
TWO COMMAS ENTER NULL ITEM IN LIST, SLASH ENDS LIST
LITERALS ARE LEFT-JUSTIFIED.  ABBREVIATIONS ARE NOT ALLOWED.
NUMERICS MAY CONTAIN SIGN AND/OR DECIMAL POINT

THIS PROGRAM IS DESIGNED TO HANDLE THE FOLLOWING AIRCRAFT TYPES:
  1 - 2E-LBPR-NB      4 - 2E-HBPR-WB
  2 - 3E-LBPR-NB      5 - 3E-HBPR-WB
  3 - 4E-LBPR-NB      6 - 4E-HBPR-WB
SELECT PLANE TYPE 1-6
?
```

Next, the user selects the aircraft type be considered by the model and the airport temperature (^{o}F) and pressure altitude (feet). The user is then asked if the program execution is to "continue as is" using the selected aircraft type and airport parameters. If the user responds with "YES", the type of operational procedure, either a takeoff or an approach (and landing), is then selected. If a response of "NO" is given, the user is given the opportunity to select new airport parameters (with the same aircraft type), or new airport parameters and new aircraft type. An example of the interaction between the user and the computer system during the selection of the aircraft type, airport parameters, and type of operational procedure is shown below:

```
 SELECT PLANE TYPE 1-6
?
6
 ENTER AIRPORT TEMP(DEG-F),ALT(FT)
?
59,0
  PLANE TYPE 6 IS                    4E HBPR WB
  AIRPORT TEMP(DEG.F) =  59.0  ALTITUDE(FT) =     0.0
 DO YOU WANT  TO CONTINUE AS IS  ? YES OR NO
YES
 PROFILE TYPES ARE TAKEOFF OR APPROACH
 DO YOU WANT  TAKEOFF PROFILE    ? YES OR NO
YES
```

Takeoff Procedures

If the takeoff procedure is selected, the user is asked to select or provide the following information:

- Aircraft weight
- Initial takeoff flap setting
- Climb speed above the one-engine out takeoff safety speed (V2).

Based on these data, the aircraft's flight path and performance schedule for the ground-roll section and the initial climb sections (to 400 feet HAA) are determined.* From point of lift-off to 400 feet HAA, the following operational procedures are used for all aircraft considered in the model: 1) constant thrust setting (all-engine takeoff thrust), 2) constant flaps, and 3) at 400 feet HAA, landing gear retraction completed and final first segment climb speed achieved. An example of the interaction between the user and the computer system in constructing the first three sections of a takeoff flight procedure is shown below:

```
   ENTER TAKEOFF FLAP SETTING INDEX
     INPUT INDEX    FLAP SETTING, DEG

       1               10.000
       2               20.000
?
1
 ENTER AIRCRAFT WT(KLBS) :: WITHIN RANGE OF    500.0    TO    800.0
?
700
     INPUT INDEX    CLIMB SPEED ABOVE V2

       1               10.000
       2               20.000
       3               30.000
?
1
 INDEX OF   1 GIVES CLIMB SPEED ABOVE V2 =    10.000000
```

*Three sections are used to define the operation of the aircraft from brake release to 400 feet HAA. These sections are: 1) brake release to point of lift-off, 2) lift-off to 35 feet HAA, and 3) 35 feet HAA to 400 feet HAA.

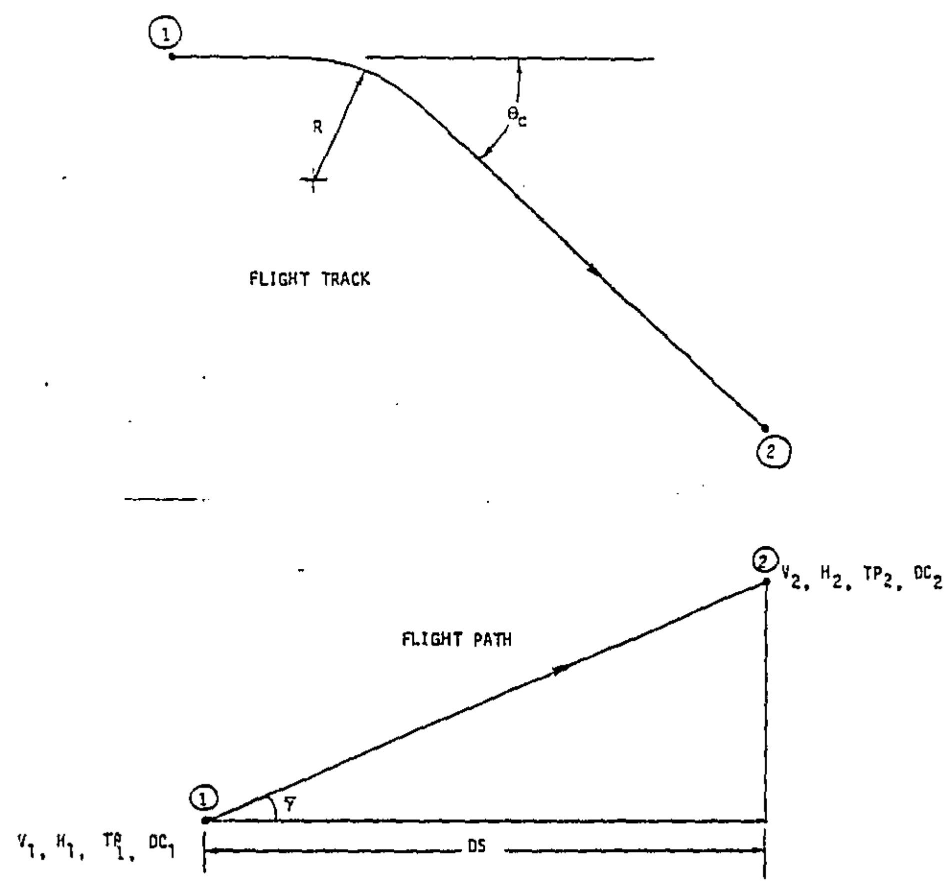
Starting at 400 feet HAA, eight takeoff operational procedures, or options, may be used to construct the complete flight path and performance schedule for an aircraft operating in accordance with a specified takeoff procedure. The complete flight path and performance schedule is comprised of a number of individual sections in which the aircraft performs various operational activities. The eight takeoff options considered in the flight procedures model represent the operational activities associated with the procedures currently used or capable of being used in routine departures.

Figure 3-2 presents a generalized flight path and flight track section and defines the section input and output parameters. Table 3-1 presents a brief description of each of the eight takeoff options and identifies specific input and output parameters associated with each option.

The specific form of the inputs required to exercise each option is defined for the user during the program execution. However, to facilitate a better understanding of the use of each option, a brief description of the key input parameters is presented below:

Thrust Setting Index. Engine thrust may be specified in terms of: 1) net pounds of thrust per engine, 2) all-engine takeoff thrust setting (TAKEOFF THR), 3) maximum or normal climb thrust setting (MAX CLIMB TR), 4) referred (or corrected) low pressure fan speed (REF FAN SPD) or, 5) engine-pressure-ratio (ENG PR RATIO). An example of the interaction between the user and the computer system in selecting the thrust setting is shown below:

```
 ENTER BEGINNING THRUST SETTING INDEX
FORM          INDEX
LBS/ENGINE      1
TAKEOFF  THR    2
MAX CLIMB TR    3
REF FAN SPD     4
ENG PR RATIO    5
?
2
```



①,② = Flight path and flight track section end points

V_1, V_2 = Aircraft speed, KEAS, KTAS

H_1, H_2 = Aircraft altitude above airport, feet

TP_1, TP_2 = Thrust parameter (Fn, Fn/δ, EPR, $N1/\sqrt{\theta T_2}$)

DC_1, DC_2 = Drag configuration (flap setting and landing gear position)

$\bar{\gamma}$ = Average flight path angle, deg.

DS = Horizontal distance between flight path section end points, feet

W = Aircraft weight, lbs

$\bar{V}_z$ = Rate-of-climb, FPM

t = Time to travel between flight path section end points, sec.

θ_c = Flight track turn angle, deg.

R = Flight track turn radius, feet

FIGURE 3-2. GENERALIZED FLIGHT PATH AND FLIGHT TRACK SECTION AND DEFINITION OF INPUT AND OUTPUT PARAMETERS

TABLE 3-1

TAKEOFF FLIGHT PROCEDURE OPTIONS

OPTION	DESCRIPTION OF OPERATION	INPUT PARAMETERS	OUTPUT PARAMETERS
1	Climb at constant equivalent speed, constant flap setting, and constant thrust setting; landing gear retracted	H_2, TP, DC, R[1/]	$\bar{\gamma}$, D, $\bar{V}_Z$, t, $\bar{\theta}_B$, $\bar{\alpha}_B$, θ_C[1/], V_1 (KTAS), V_2 (KTAS)
2	Climb at constant equivalent speed, constant flap setting, and constant thrust setting; landing gear retracted	H_2, DC, $\bar{V}_Z$, R[1/]	$\bar{\gamma}$, D, t, $\bar{\theta}_B$, $\bar{\alpha}_B$, θ_C[1/], V_1 (KTAS), V_2 (KTAS), TP_1, TP_2
3	Climb at constant equivalent speed, constant flap setting, and constant thrust setting; landing gear retracted	H_2, DC, $\bar{\gamma}$, R[1/]	D, $\bar{V}_Z$, t, $\bar{\theta}_B$, $\bar{\alpha}_B$, θ_C[1/], V_1 (KTAS), V_2 (KTAS), TP_1, TP_2
4	Climb at constant equivalent speed, constant flap setting, and constant thrust setting; landing gear retracted	H_2, D, TP, DC, R[1/]	$\bar{\gamma}$, $\bar{V}_Z$, t, $\bar{\theta}_B$, $\bar{\alpha}_B$, θ_C[1/], V_1 (KTAS); V_2 (KTAS)
5	a) Acceleration with constant flap setting, and constant thrust setting; landing gear retracted	TP, DC, V_2(KEAS), R[1/], $\bar{V}_Z$ (optional), H_2[2/]	$\bar{\gamma}$, D, t, $\bar{\theta}_B$, $\bar{\alpha}_B$, θ_C[1/], V_1 (KTAS), V_2 (KTAS), H_2[2/]
	b) Climb at constant equivalent speed, constant flap setting, and changing thrust setting; landing gear retracted	TP_2, DC, V_2(KEAS), R[1/], H_2	$\bar{\gamma}$, D, t, $\bar{\theta}_B$, $\bar{\alpha}_B$, θ_C[1/], V_1 (KTAS), V_2 (KTAS), $\bar{V}_Z$
	c) Acceleration with constant flap setting and changing thrust setting; landing gear retracted	TP_2, DC, V_2(KEAS), R[1/], $\bar{V}_Z$ (optional), H_2[2/]	$\bar{\gamma}$, D, t, $\bar{\theta}_B$, $\bar{\alpha}_B$, θ_C[1/], V_1 (KTAS), V_2 (KTAS), H_2[2/]

Notes:

[1/] Denotes input and output parameters for curved flight tracks

$\bar{\theta}_B$ = Average pitch attitude of the aircraft, degrees

$\bar{\alpha}_B$ = Aircraft body angle-of-attack, degrees

[2/] If $\bar{V}_Z$ is an input, H_2 is an output parameter; if $\bar{V}_Z$ is not an input, H_2 is an input parameter

[3/] If $\bar{V}_Z$ is an input, V_2 (KEAS) is an output parameter; if $\bar{V}_Z$ is not an input, V_2(KEAS) is an input parameter

TABLE 3-1 (Cont.)

TAKEOFF FLIGHT PROCEDURE OPTIONS

OPTION	DESCRIPTION OF OPERATION	INPUT PARAMETERS	OUTPUT PARAMETERS
6	Acceleration with constant flap setting, and constant thrust setting; landing gear retracted	H_2, TP, DC, R,[1/] $\bar{V}_Z$ (optional), V_2(KEAS)[3/]	$\bar{\gamma}$, D, t, $\bar{\theta}_B$, $\bar{\alpha}_B$, θ_C[1/], V_1(KTAS), V_2 (KTAS), V_2 (KEAS)[3/]
7	Climb at constant equivalent speed, constant thrust setting, and changing flap setting; landing gear retracted	DC_1, DC_2, TP, t_{FR}[4/], R[1/]	$\bar{\gamma}$, D, H_2, $\bar{V}_Z$, $\bar{\theta}_B$, $\bar{\alpha}_B$, θ_C[1/], V_1 (KTAS), V_2 (KTAS)
8	Acceleration with constant thrust setting and changing flap setting; landing gear retracted	DC_1, DC_2, TP, t_{FR}[4/], $\bar{V}_Z$, R[1/]	$\bar{\gamma}$, D, H_2, $\bar{\theta}_B$, $\bar{\alpha}_B$, θ_C[1/], V_1 (KTAS), V_2 (KTAS)

Notes:

[4/] t_{FR} = flap retraction time in seconds

All of the above thrust setting options are not available for all aircraft types considered in the model.

Aircraft Velocity. The aircraft input velocities in the direction of flight are specified in knots, equivalent air speed (KEAS). The rate-of-climb is specified in feet per minute (FPM).

Flap Setting Index and Retraction Time. The user selects an index number to specify a desired flap setting. A minus sign is used to indicate that the landing gear is extended. The flap retraction time is specified in seconds. An example of the interaction between the user and the computer system in selecting the flap setting is shown below:

```
ENTER FLAP SETTING
MINUS SIGN INDICATES LANDING GEAR DOWN
  INPUT INDEX    FLAP SETTING, DEG

   1               0.0
   2              14.000
   3              25.000
   4             -25.000
   5             -40.000
   6             -50.000

?
3
```

An example of the use of each of these options is presented in the following sections.

Option Number 1

```
ENTER OPTION NO.  1 THRU  8
?
1
DO YOU WANT  CURVED PATH(NO=STR)? YES OR NO
NO
ENTER END HEIGHT (FT)  ::: WITHIN RANGE OF    400.0     TO    1.000E+06
?
1000
  ENTER BEGINNING THRUST SETTING INDEX
 FORM          INDEX
 LBS/ENGINE      1
 TAKEOFF  THR    2
 MAX CLIMB TR    3
 REF FAN SPD     4
 ENG PR RATIO    5
?
2
```

Option Number 2

```
 ENTER OPTION NO.  1 THRU  8
?
2
 DO YOU WANT CURVED PATH(NO=STR)? YES OR NO
NO
 ENTER  END HEIGHT (FT) :: WITHIN RANGE OF    1000.       TO      1.000E+04
?
1500
 ENTER CLIMB SPEED (FT/MIN WITHIN RANGE OF    .0          TO      1.000E+04
?
1000
```

Option Number 3

```
 ENTER OPTION NO.  1 THRU  8
?
3
 DO YOU WANT  CURVED PATH(NO=STR)? YES OR NO
NO
 ENTER  END HEIGHT (FT)  :: WITHIN RANGE OF    1500.     TO    1.000E+04
?
2000
 ENTER  CLIMB ANGLE (DEG) : WITHIN RANGE OF    .0        TO    90.00
?
3
```

Option Number 4

```
 ENTER OPTION NO.  1 THRU  8
?
4
 DO YOU WANT  CURVED PATH(NO=STR)?  YES OR NO
NO
 ENTER SECTION LENGTH (FT) WITHIN RANGE OF     .0          TO      1.000E+05
?
10000
 ENTER END HEIGHT (FT)  ::: WITHIN RANGE OF    1500.       TO      1.000E+06
?
2000
 ENTER BEGINNING THRUST SETTING INDEX
 FORM         INDEX
 LBS/ENGINE     1
 TAKEOFF  THR   2
 MAX CLIMB TR   3
 REF FAN SPD    4
 ENG PR RATIO   5
?
2
```

Option Number 5a (Rate-of-Climb Not Specified)

```
 ENTER OPTION NO.  1 THRU  8
?
5
 DO YOU WANT  CURVED PATH(NO=STR)? YES OR NO
NO
 DO YOU WANT  TO SPECIFY VZ       ? YES OR NO
NO
 ENTER  ESTIMATE OF END HT. WITHIN RANGE OF    400.0     TO    1.040E+04
?
3549
 DO YOU WANT  CONSTANT EQ. VEL.   ? YES OR NO
NO
 ENTER  END EQ. VEL IN KNOT WITHIN RANGE OF    177.9     TO    250.0
?
207.93
 THRUST SETTING CAN BE CONSTANT
 DO YOU WANT  IT TO BE CONSTANT  ? YES OR NO
YES
  ENTER BEGINNING THRUST SETTING INDEX
 FORM          INDEX
 LBS/ENGINE      1
 TAKEOFF  THR    2
 MAX CLIMB TR    3
 REF FAN SPD     4
 ENG PR RATIO    5
?
2
```

Option Number 5a (Rate-of-Climb Specified)

```
 ENTER OPTION NO.  1 THRU  8
?
5
 DO YOU WANT  CURVED PATH(NO=STR)? YES OR NO
NO
 DO YOU WANT  TO SPECIFY VZ       ? YES OR NO
YES
 ENTER CLIMB SPEED FT/MIN   WITHIN RANGE OF    .0         TO    3000.
?
1000
 ENTER  ESTIMATE OF END HT. WITHIN RANGE OF    2893.      TO    1.289E+04
?
3000
 DO YOU WANT  CONSTANT EQ. VEL.  ? YES OR NO
NO
 ENTER  END EQ. VEL IN KNOT WITHIN RANGE OF    177.9      TO    250.0
?
207.93
 THRUST SETTING CAN BE CONSTANT
 DO YOU WANT  IT TO BE CONSTANT  ? YES OR NO
YES
  ENTER BEGINNING THRUST SETTING INDEX
 FORM          INDEX
 LBS/ENGINE      1
 TAKEOFF  THR    2
 MAX CLIMB TR    3
 REF FAN SPD     4
 ENG PR RATIO    5
?
2
```

Option Number 5b

```
 ENTER OPTION NO.  1 THRU  8
?
5
 DO YOU WANT  CURVED PATH(NO=STR)? YES OR NO
NO
 DO YOU WANT  TO SPECIFY VZ      ? YES OR NO
NO
 ENTER  ESTIMATE OF END HT. WITHIN RANGE OF    3549.     TO    1.355E+04
?
4000
 DO YOU WANT  CONSTANT EQ. VEL.  ? YES OR NO
YES
  ENTER BEGINNING THRUST SETTING INDEX
 FORM           INDEX
 LBS/ENGINE        1
 TAKEOFF  THR      2
 MAX CLIMB TR      3
 REF FAN SPD       4
 ENG PR RATIO      5
?
2
  ENTER END THRUST SETTING INDEX
 FORM           INDEX
 LBS/ENGINE        1
 TAKEOFF  THR      2
 MAX CLIMB TR      3
 REF FAN SPD       4
 ENG PR RATIO      5
?
3
```

Option Number 5c (Rate-of-Climb Not Specified)

```
 ENTER OPTION NO.  1 THRU  8
?
5
 DO YOU WANT  CURVED PATH(NO=STR)? YES OR NO
NO
 DO YOU WANT  TO SPECIFY VZ      ? YES OR NO
NO
 ENTER  ESTIMATE OF END HT. WITHIN RANGE OF    4500.     TO    1.450E+04
?
4600
 DO YOU WANT  CONSTANT EQ. VEL.  ? YES OR NO
NO
 ENTER  END EQ. VEL IN KNOT WITHIN RANGE OF    222.7     TO    250.0
?
227.93
 THRUST SETTING CAN BE CONSTANT
 DO YOU WANT  IT TO BE CONSTANT  ? YES OR NO
NO
  ENTER BEGINNING THRUST SETTING INDEX
 FORM          INDEX
 LBS/ENGINE       1
 TAKEOFF  THR     2
 MAX CLIMB TR     3
 REF FAN SPD      4
 ENG PR RATIO     5
?
2
  ENTER END THRUST SETTING INDEX
 FORM          INDEX
 LBS/ENGINE       1
 TAKEOFF  THR     2
 MAX CLIMB TR     3
 REF FAN SPD      4
 ENG PR RATIO     5
?
3
```

Option Number 5c (Rate-of-Climb Specified)

```
 ENTER OPTION NO.  1 THRU  8
?
5
 DO YOU WANT  CURVED PATH(NO=STR)? YES OR NO
NO
 DO YOU WANT  TO SPECIFY VZ       ? YES OR NO
YES
 ENTER CLIMB SPEED FT/MIN   WITHIN RANGE OF    .0        TO    3000.
?
1000
 ENTER  ESTIMATE OF END HT. WITHIN RANGE OF    400.0     TO    1.040E+04
?
1000
 DO YOU WANT  CONSTANT EQ. VEL.  ? YES OR NO
NO
 ENTER  END EQ. VEL IN KNOT WITHIN RANGE OF    177.9     TO    250.0
?
207.93
 THRUST SETTING CAN BE CONSTANT
 DO YOU WANT  IT TO BE CONSTANT  ? YES OR NO
NO
  ENTER BEGINNING THRUST SETTING INDEX
 FORM          INDEX
 LBS/ENGINE       1
 TAKEOFF  THR     2
 MAX CLIMB TR     3
 REF FAN SPD      4
 ENG PR RATIO     5
?
2
  ENTER END THRUST SETTING INDEX
 FORM          INDEX
 LBS/ENGINE       1
 TAKEOFF  THR     2
 MAX CLIMB TR     3
 REF FAN SPD      4
 ENG PR RATIO     5
?
3
```

Option Number 6 (Rate-of-Climb Not Specified)

```
 ENTER OPTION NO.  1 THRU  8
?
6
 DO YOU WANT  CURVED PATH(NO=STR)? YES OR NO
NO
 DO YOU WANT  TO SPECIFY VZ      ? YES OR NO
NO
 ENTER  END HEIGHT (FT)  ::: WITHIN RANGE OF     2407.        TO      1.241E+04
?
3000
 ENTER  ESTIMATE END EQ.VEL WITHIN RANGE OF      177.9        TO      250.0
?
215
 ENTER BEGINNING THRUST SETTING INDEX
 FORM          INDEX
 LBS/ENGINE       1
 TAKEOFF THR      2
 MAX CLIMB TR     3
 REF FAN SPD      4
 ENG PR RATIO     5
?
2
```

Option Number 6 (Rate-of-Climb Specified)

```
 ENTER OPTION NO.  1 THRU  8
?
6
 DO YOU WANT  CURVED PATH(NO=STR)? YES OR NO
NO
 DO YOU WANT  TO SPECIFY VZ      ? YES OR NO
YES
 ENTER CLIMB SPEED FT/MIN   WITHIN RANGE OF    .0       TO    3000.
?
1000
 ENTER  END HEIGHT (FT) ::: WITHIN RANGE OF    4141.     TO    1.414E+04
?
4500
 ENTER  ESTIMATE END EQ.VEL WITHIN RANGE OF    207.9     TO    250.0
?
215
 ENTER BEGINNING THRUST SETTING INDEX
 FORM         INDEX
 LBS/ENGINE      1
 TAKEOFF  THR    2
 MAX CLIMB TR    3
 REF FAN SPD     4
 ENG PR RATIO    5
?
2
```

Option Number 7

```
 ENTER OPTION NO.  1 THRU  8
?
7
 DO YOU WANT  CURVED PATH(NO=STR)?  YES OR NO
NO
 MINUS SIGN INDICATES LANDING GEAR DOWN
ENTER FLAP SETTING 1
   INPUT INDEX     FLAP SETTING, DEG

    1                 0.0
    2                 1.000
    3                 5.000
    4                10.000
    5                20.000
    6               -20.000
    7               -25.000
    8               -30.000
?
4
 ENTER FLAP SETTING 2
   INPUT INDEX    FLAP SETTING, DEG

    1                 0.0
    2                 1.000
    3                 5.000
    4                10.000
    5                20.000
    6               -20.000
    7               -25.000
    8               -30.000

?
3
 ENTER EST.OF END HT(FT)::: WITHIN RANGE OF    2407.        TO        1.241E+04
?
4200
 ENTER FLAP RETRACT. TIME   WITHIN RANGE OF    .0           TO        100.0
?
4.7
 ENTER BEGINNING THRUST SETTING INDEX
FORM          INDEX
LBS/ENGINE      1
TAKEOFF THR     2
MAX CLIMB TR    3
REF FAN SPD     4
ENG PR RATIO    5
?
2
```

Option Number 8

```
 ENTER OPTION NO.  1 THRU   8
?
8
 DO YOU WANT CURVED PATH(NO=STR)? YES OR NO
NO
 MINUS SIGN INDICATES LANDING GEAR DOWN
ENTER FLAP SETTING 1
    INPUT INDEX        FLAP SETTING, DEG
      1                   0.0
      2                   1.000
      3                   5.000
      4                  10.000
      5                  20.000
      6                 -20.000
      7                 -25.000
      8                 -30.000
?
3
 ENTER FLAP SETTING 2
    INPUT INDEX        FLAP SETTING, DEG

      1                   0.0
      2                   1.000
      3                   5.000
      4                  10.000
      5                  20.000
      6                 -20.000
      7                 -25.000
      8                 -30.000
?
2
 ENTER CLIMB SPEED (FT/MIN WITHIN RANGE OF     .0       TO      3000.0
?
1000
 ENTER FLAP RETRACT. TIME WITHIN RANGE OF      .0       TO      100.0
?
30.6
 ENTER ESTIMATE END EQ.VEL. WITHIN RANGE OF   177.9     TO      250.0
?
245
 ENTER BEGINNING THRUST SETTING INDEX
 FORM            INDEX
LBS/ENGINE         1
TAKEOFF THR        2
MAX CLIMB TR       3
REF FAN SPD        4
ENG PR RATIO       5
?
2
```

Option Number 1 (With Curved Flight Path)

```
 ENTER OPTION NO.    1 THRU   8
?
1
 DO YOU WANT  CURVED PATH(NO=STR)? YES OR NO
YES
 ENTER END HEIGHT (FT)   ::: WITHIN RANGE OF      400.0       TO       1.000E+06
?
1000
 ENTER BEGINNING THRUST SETTING INDEX
FORM          INDEX
LBS/ENGINE      1
TAKEOFF THR     2
MAX CLIMB TR    3
REF FAN SPD     4
ENG PR RATIO    5
?
2
 ENTER RADIUS OF CURVE (FT WITHIN RANGE OF       500.0       TO       5.000E+04
?
20000
```

Approach and Landing Procedures

If the approach (and landing) procedure is selected, the user is asked to select or provide the following information:

- Aircraft weight
- Initial approach height above the airport
- Initial approach air speed
- Initial approach flap setting

After the above data have been entered, the user is asked to select one of the four available approach and landing procedure options. These procedure options can be used to model the operational activities associated with typical approach and landing operational procedures. An example of the interaction between the user and the computer system during the initialization of the approach and landing parameters is shown below:

```
 PROFILE TYPES ARE TAKEOFF OR APPROACH
 DO YOU WANT  TAKEOFF PROFILE    ? YES OR NO
NO
 START OF APPROACH
 ENTER AIRCRAFT WT (KLBS)::WITHIN RANGE OF     450.0      TO       650.0
?
500
 ENTER INITIAL HEIGHT (FT) WITHIN RANGE OF     .0         TO       2.000E+04
?
5000
 ENTER INIT EQ. VEL. (KN):: WITHIN RANGE OF    .0         TO       250.0
?
214
 ENTER FLAP SETTING
 MINUS SIGN INDICATES LANDING GEAR DOWN
  INPUT INDEX       FLAP SETTING, DEG
    1                  0.0
    2                  1.000
    3                  5.000
    4                 10.000
    5                 20.000
    6                -20.000
    7                -25.000
    8                -30.000
?
1
```

Table 3-2 presents a brief description of each of the four approach and landing options (number 9 thru 12) and identifies specific input and output parameters associated with each option. An example of the use of each of these options is presented in the following sections.

TABLE 3-2
APPROACH AND LANDING FLIGHT PROCEDURE OPTIONS

OPTION		DESCRIPTION OF OPERATION	INPUT PARAMETERS	OUTPUT PARAMETERS
9		Descend at constant equivalent speed, constant flap setting and constant thrust setting; landing gear retracted or extended	H_1[1/], H_2, TP, DC(LG)[2/], R[4/]	$\bar{\gamma}$, D, V_2, t, $\bar{\sigma}_B$, $\bar{\alpha}_B$, σ_C[4/], V_1(KTAS), V_2(KTAS)
10		Descend at constant equivalent speed or deceleration with constant flap setting and changing thrust setting; landing gear retracted or extended	H_1[1/], H_2, DC(LG)[2/], V_Z, V_1(KEAS)[1/], V_2(KEAS)[3/], R[4/]	TP_1, TP_2, $\bar{\gamma}$, t, $\bar{\sigma}_B$, $\bar{\alpha}_B$, σ_C[4/], V_1(KTAS), V_2(KTAS)
11		Descend at constant equivalent speed or deceleration with constant flap setting and changing thrust setting; landing gear retracted or extended	H_1[1/], H_2, DC(LG)[2/], $\bar{\gamma}$, V_1(KEAS)[1/], V_2(KEAS)[3/], R[4/]	TP_1, TP_2, $\bar{V}_Z$, t, $\bar{\sigma}_B$, $\bar{\alpha}_B$, σ_C[4/], V_1(KTAS), V_2(KTAS)
12	(a)	Level flight at constant equivalent speed, constant flap setting and constant thrust setting; landing gear retracted or extended	H[1,5/], DC(LG)[2/], D, V_1(KEAS)[1/], R[4/]	TP_1, TP_2, $\bar{\gamma}$, $\bar{V}_Z$, t, $\bar{\sigma}_B$, $\bar{\alpha}_B$, σ_C[4/], V_1 (KTAS), V_2 (KTAS)
	(b)	Level flight deceleration with constant flap setting and changing thrust setting; landing gear retracted or extended	H[1,5/], DC(LG)[2/], D, V_1(KEAS)[1/], V_2(KEAS), R[4/]	TP_1, TP_2, $\bar{\gamma}$, V_Z, t, $\bar{\sigma}_B$, $\bar{\alpha}_B$, σ_C[4/], V_1,(KTAS), V_2 (KTAS)

Notes:

1/Denotes input parameter if this option is the initial section of the flight profile.
2/Denotes flap setting and landing gear position.
3/Denotes input parameter for deceleration operation.
4/Denotes input and output parameters for curved flight tracks.
5/$H = H_1 = H_2$

Option Number 9

```
 ENTER OPTION NO. · 9 THRU 12
?
9
 DO YOU WANT  CURVED PATH(NO=STR)?  YES OR NO
NO
 ENTER  END HEIGHT (FT) ::: WITHIN RANGE OF       .0        TO       5000.
?
3000
 ENTER FLAP SETTING
 MINUS SIGN INDICATES LANDING GEAR DOWN
   INPUT INDEX          FLAP SETTING, DEG

     1                    0.0
     2                    1.000
     3                    5.000
     4                   10.000
     5                   20.000
     6                  -20.000
     7                  -25.000
     8                  -30.000
?
4
 ENTER BEGINNING THRUST SETTING INDEX
 FORM          INDEX
LBS/ENGINE        1
REF FAN SPD       4
ENG PR RATIO      5
?
5
 ENTER EPR SETTING      WITHIN RANGE OF            1.000     TO       1.750
?
1.0
```

Option Number 10

```
 ENTER OPTION NO.  9 THRU 12
?
10
 DO YOU WANT CURVED PATH(NO=STR)?  YES OR NO
NO
 ENTER END HEIGHT (FT) ::: WITHIN RANGE OF     .0        TO         1000.
?
50
 DO YOU WANT CONSTANT EQ. VEL. ::? YES OR NO
YES
 ENTER DESCENT SPEED FT/MIN WITHIN RANGE OF    .0        TO         3000.
?
720
```

Option Number 11

```
 ENTER OPTION NO.  9 THRU 12
?
11
 DO YOU WANT CURVED PATH(NO=STR)?  YES OR NO
NO
 ENTER END HEIGHT (FT) ::: WITHIN RANGE OF      .0        TO       3000.
?
1000
 DO YOU WANT CONSTANT EQ. VEL. ::? YES OR NO
NO
 ENTER END EQ VEL (KN)   WITHIN RANGE OF        .0        TO       153.0
?
137
 ENTER FLAP SETTING
 MINUS SIGN INDICATES LANDING GEAR DOWN
    INPUT INDEX        FLAP SETTING, DEG

     1                     0.0
     2                     1.000
     3                     5.000
     4                    10.000
     5                    20.000
     6                   -20.000
     7                   -25.000
     8                   -30.000
?
7
 ENTER DESCENT ANGLE (DEG): WITHIN RANGE OF      .0        TO       90.00
?
3
```

Option Number 12a

```
 ENTER OPTION NO.  9 THRU 12
?
12
 DO YOU WANT CURVED PATH(NO=STR)?  YES OR NO
NO
 ENTER SECTION DIST (FT) : WITHIN RANGE OF      .0          TO       2.000E+04
?
15000
 DO YOU WANT CONSTANT EQ. VEL. :? YES OR NO
YES
 ENTER FLAP SETTING
 MINUS SIGN INDICATES LANDING GEAR DOWN
   INPUT INDEX      FLAP SETTING, DEG.

    1                   0.0
    2                   1.000
    3                   5.000
    4                  10.000
    5                  20.000
    6                 -20.000
    7                 -25.000
    8                 -30.000
?
4
```

Option Number 12b

```
 ENTER OPTION NO.  9 THRU 12
?
12
 DO YOU WANT CURVED PATH(NO=STR)? YES OR NO
NO
 ENTER SECTION DIST (FT) : WITHIN RANGE OF     .0        TO       2.000E+04
?
15000
 DO YOU WANT CONSTANT EQ. VEL. :? YES OR NO
NO
 ENTER END EQ.VEL. (KN) WITHIN RANGE OF        .0        TO       173.0
?
153
 ENTER FLAP SETTING
 MINUS SIGN INDICATES LANDING GEAR DOWN
   INPUT INDEX        FLAP SETTING, DEG
     1                    0.0
     2                    1.000
     3                    5.000
     4                   10.000
     5                   20.000
     6                  -20.000
     7                  -25.000
     8                  -30.000
?
7
```

Option Number 10 (with Curved Flight Path)

```
 ENTER OPTION NO.  9 THRU 12
?
10
 DO YOU WANT CURVED PATH(NO=STR)? YES OR NO
YES
 ENTER END HEIGHT (FT) : WITHIN RANGE OF     .0      TO     1000.
?
50
 DO YOU WANT CONSTANT EQ. VEL. :? YES OR NO
YES
 ENTER DESCENT SPEED FT/MIN WITHIN RANGE OF    .0      TO     3000
?
720
 ENTER RADIUS OF CURVE (FT WITHIN RANGE OF     500.0   TO     5.000E+04
?
30000.
```

Example Takeoff Flight Procedure

Figure 3-3 describes the flight profile and operational activities for the ALPA/NWA minimum thrust reduction takeoff procedure. Using the flight procedures model, the flight path and performance schedule for a 4-engine, HBPR-wide body aircraft type was constructed. The complete output from the flight procedures model is shown on Table 3-3. The operational parameters used in developing the flight path and performance schedule data presented on Table 3-3 are listed below:

- Airport ambient temperature - 59^{o}F
- Airport pressure altitude - mean sea level
- Aircraft weight - 700,000 lbs.
- Initial takeoff flap setting - 10 degrees
- Climb speed above the one-engine out takeoff safety speed (V2) - 10 KEAS

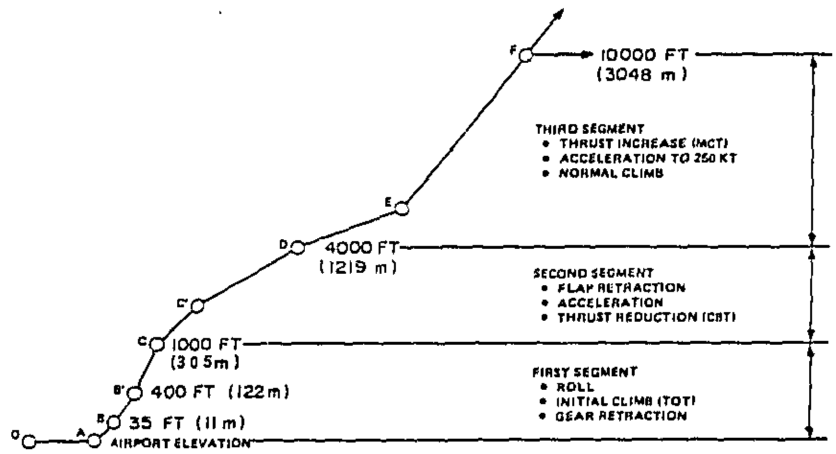
Example Approach and Landing Flight Procedure

Figure 3-4 describes the flight profile and the operational activities associated in a typical approach and landing operational procedure. The flight procedures model was used to construct the flight path and performance schedule for a 4-engine, HBPR-wide body aircraft type. The complete output from the flight procedures model is shown on Table 3-4. The operational parameters used in developing the flight path and performance schedule data presented on Table 3-4 are listed below:

- Aircraft weight - 500,000 lbs.
- Initial approach height above the airport - 5000 feet
- Initial approach air speed - 173 KEAS
- Maneuver flaps - 10 degrees
- Approach and landing flaps - 25 degrees

Program Termination

After the flight path and performance schedule data have been determined for each section, the user is asked if the flight profile is



ALPA/NWA MINIMUM THRUST REDUCTION PROCEDURE

First Segment (roll and initial climb)

- OAB Brake release; takeoff roll with takeoff thrust (TOT); rotate and climb to 35 ft (11 m) height above airport (HAA); and accelerate to V2 keas
- BB' Retract gear; climb to 400 ft (122 m) HAA; and accelerate to V2 + 10 keas
- B'C Climb to 1000 ft (305 m) HAA with thrust = TOT, speed = V2 + 10 keas (or greater if required), flaps = takeoff, and gear = retracted

Second Segment (thrust cutback)

- C At 1000 ft (305 m) HAA, lower nose and accelerate to zero flap speed (VZF), retract flaps per schedule, maintain TOT and a pitch attitude within 1/2 initial value plus 0 to 3 deg. and a rate of climb not less than 500 fpm (152 metres per minute)
- CC' Climb and accelerate to VZF with thrust = TOT, speed = V2 + 10 to VZF keas, flaps = retract, and gear = retracted
- C' When a speed of VZF and flap retraction are achieved, reduce thrust to maximum climb thrust (MCT)
- C'D Climb to 4000 ft (1219 m) HAA with thrust = MCT, speed = VZF keas, flaps = retracted, and gear = retracted

Third Segment (normal climb)

- D At 4000 ft (1219 m) HAA, maintain MCT and accelerate to 250 keas with 500 to 1000 fpm (152 to 305 metres per minute) rate of climb
- DE Climb and accelerate to 250 keas with thrust = MCT, speed = VZF to 250 keas, flaps = retracted, and gear = retracted
- E When a speed of 250 keas is achieved, maintain MCT and initiate normal climb schedule
- EF Climb to 10,000 ft (3048 m) HAA with thrust = MCT, speed = 250 keas, flaps = retracted, and gear = retracted
- F At 10,000 ft (3048 m) HAA continue climb at 250 keas or reduce thrust and proceed in horizontal flight at 250 keas

FIGURE 3-3. TAKEOFF FLIGHT PROFILE AND PROCEDURE DESCRIPTION FOR THE ALPA/NWA MIN. PROCEDURE

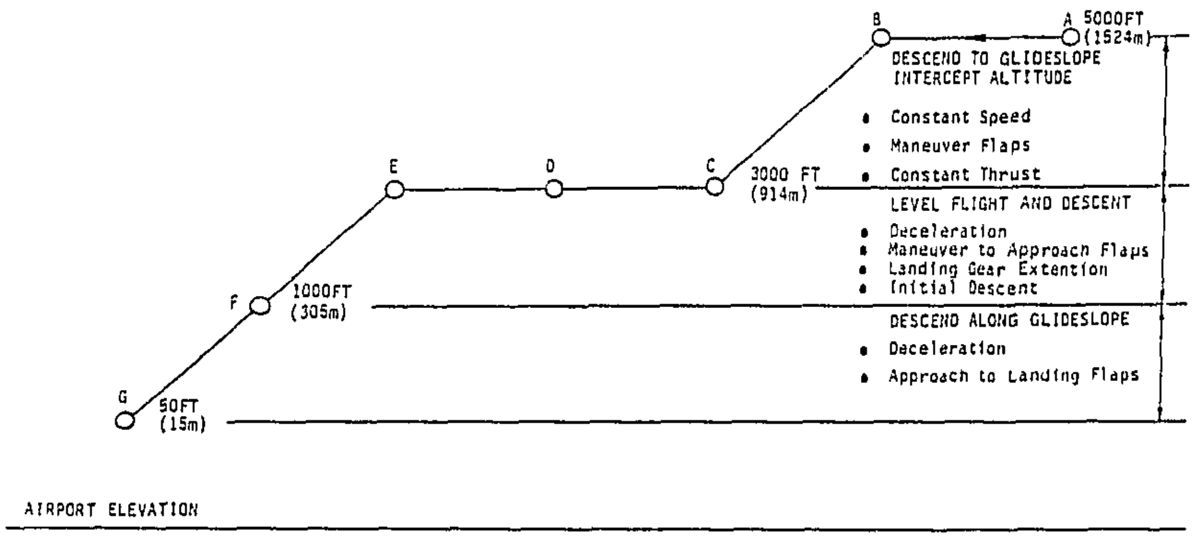
TABLE 3-3

TAKEOFF FLIGHT PATH AND PERFORMANCE SCHEDULE FOR A 4-ENGINE, HIGH-BY-PASS RATIO WIDE BODY AIRCRAFT TYPE; ALPA/NWA MIN. PROCEDURE

Profile End Points	A	B	B'	C						C'	D	E	F
SECTION NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13
TOT.MIN.	0.49	0.91	1.21	1.56	2.05	2.13	2.44	2.95	3.03	3.20	3.67	3.67	7.18
DIS.(FT)	7432.23	7934.34	13170.65	15368.24	28975.75	30664.16	37635.16	50017.40	51985.21	56292.30	68549.81	66725.87	165210.56
HAA(FT)	0.0	35.09	400.06	1000.00	1427.55	1505.89	1871.71	2585.71	2704.04	3070.71	4000.00	4007.32	10000.00
VT(KTAS)	166.65	168.69	175.91	177.42	208.60	213.40	230.12	249.52	253.33	256.49	259.96	260.30	284.50
VE(KEAS)	159.52	171.50	177.93	177.93	207.93	212.47	227.93	244.62	247.93	249.70	249.70	250.00	253.33
ROC(FPM)	0.0	1180.62	1213.45	1724.24	990.00	991.38	1239.90	1398.26	1500.00	2189.87	1978.85	1002.30	1710.24
TURN ANG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CLM ANGL	0.0	3.99	3.99	5.53	2.55	2.66	3.00	3.30	3.44	4.97	4.34	2.24	3.55
ALPHA	0.0	-999.00	9.98	9.53	7.79	6.87	6.41	6.03	5.60	5.44	5.43	5.44	5.43
NOD ANGL	0.0	-999.00	13.98	15.06	10.34	9.53	9.82	9.32	9.04	10.31	9.77	7.68	8.98
FLAP1	10.00	10.00	10.00	10.00	10.00	10.00	5.00	5.00	1.00	1.00	0.0	0.0	0.0
FLAP2	10.00	10.00	10.00	10.00	10.00	5.00	5.00	1.00	1.00	0.0	0.0	0.0	0.0
FN1(LBS)	-999.00	34037.98	33914.35	33191.80	32593.99	31352.68	31213.29	30691.71	29180.93	29005.34	24317.75	23957.37	23953.46
FN2(LBS)	34037.98	33914.35	33151.79	32593.98	31352.60	31213.29	30691.79	29180.92	29309.33	28640.36	23957.37	23953.46	19466.50
FNDEL1	-999.00	34037.98	33965.66	33659.63	33757.01	32964.11	32998.43	32779.48	31965.13	31911.16	27101.95	27602.72	27605.55
FNDEL2	34037.98	33955.86	33659.61	33757.00	32964.10	32908.43	32779.47	31965.11	31911.14	31919.45	27602.72	27605.55	27655.16
EPR1	-999.00	1.43	1.43	1.42	1.42	1.42	1.42	1.43	1.41	1.41	1.31	1.32	1.32
EPR2	1.43	1.43	1.42	1.43	1.42	1.42	1.43	1.41	1.41	1.41	1.32	1.32	1.33
FAN SPD1	-999.00	3291.53	3291.81	3292.89	3292.89	3292.89	3292.89	3292.89	3292.89	3292.89	3156.87	3179.76	3180.23
FAN SPD2	3291.53	3291.81	3292.69	3292.89	3292.89	3292.89	3292.89	3292.89	3292.89	3292.89	3173.76	3180.23	3221.40

NOTE:

Values of -999.00 indicate no data available for output parameter.



TYPICAL APPROACH AND LANDING FLIGHT PROCEDURE

Descend to Glideslope Intercept Altitude

AB Level flight at 5000 ft (1524 m) HAA; maneuver flaps and speed; thrust as required; gear retracted

BC Descend to 3000 ft (914 m) HAA; maneuver flaps and speed; thrust as required; gear retracted

Level Flight and Descent

C At 3000 ft (914 m) HAA, begin level flight; maneuver flaps and speed; thrust as required; gear retracted

CD Level flight at 3000 ft (914 m) HAA; maneuver flaps and speed; thrust as required; gear retracted

D Begin deceleration; set approach flaps; lower gear; thrust as required

DE Level flight at 3000 ft (914 m) HAA; approach flaps and speed; thrust as required; gear extended

EF Descend to 1000 ft (305 m) HAA at a glideslope of 3 degrees; approach flaps and speed; thrust as required; gear extended

Descend Along Glideslope

F At 1000 ft (305 m) HAA, begin deceleration; set landing flaps; thrust as required; gear extended

FG Descend to 50 ft (15 m) HAA at a glidescope of 3 degrees; landing flaps and speed; thrust as required; gear extended

FIGURE 3-4. FLIGHT PROFILE AND PROCEDURE DESCRIPTION FOR A TYPICAL APPROACH AND LANDING OPERATION

TABLE 3-4

APPROACH AND LANDING FLIGHT PATH AND PERFORMANCE SCHEDULE FOR A 4-ENGINE, HIGH-BY-PASS RATIO WIDE BODY AIRCRAFT TYPE; TYPICAL PROCEDURE

Profile End Points	B	C	D	E	F	G
SECTION NUMBER	1	2	3	4	5	6
TOT.MIN.	0.0	2.25	3.13	4.66	6.67	7.95
DIS.(FT)	0.0	40949.12	66787.12	72629.06	112791.31	129916.37
HAA(FT)	5000.00	3600.00	5900.00	2200.00	1200.00	50.00
VT(KTAS)	182.75	177.52	177.52	157.00	136.61	134.76
VE(KEAS)	173.03	173.00	173.00	153.00	137.05	137.09
ROC(FPM)	0.0	-890.01	0.0	0.0	-778.14	-719.24
TURN APP	0.0	0.0	0.0	0.0	0.0	0.0
CLM ANGL	0.0	2.80	0.0	0.0	3.00	3.00
ALPHA	6.76	6.80	6.76	3.13	5.92	7.53
BOD ANGL	6.76	4.01	6.76	3.13	2.92	4.53
FLAP1	10.00	10.00	10.00	-25.00	-25.00	-25.00
FLAP2	10.00	13.00	13.00	-25.00	-25.00	-25.00
FN1(LBS)	10055.61	4210.22	10055.61	10095.61	8598.31	8236.43
FN2(LBS)	10095.61	4330.57	11055.61	14190.69	8967.29	8399.14
FNDEL1	12058.21	5016.73	11223.13	11223.13	8558.61	8530.32
FNDEL2	12058.21	4814.23	11223.13	15764.68	9257.25	8413.84
EPR1	1.09	1.00	1.08	1.08	1.06	1.06
EPR2	1.09	1.00	1.06	1.14	1.00	1.05
FAN SPD1	2340.47	1796.93	2253.73	2253.73	2072.58	1950.00
FAN SPD2	2340.47	1761.11	2253.73	2505.59	2108.18	1936.77

NOTE:
Minus sign for flap setting indicate that landing gear is extended.

to be ended. If the user wishes to terminate the flight profile development, a "YES" response should be typed. The computer system will then allow the user to continue program execution by selecting one of the following changes:

- New flight profile using the same airport parameters and aircraft type, or
- New airport parameters with the same aircraft type, or
- New airport parameters and new aircraft type.

If the user wishes to terminate program execution, none of the above changes should be selected. When the computer system responds with "ready", the user can then disconnect from the system by typing "LOGOFF". An example of the interaction between the user and the computer system for program termination is shown below:

```
 DO YOU WANT  TO END PROFILE     ? YES OR NO
YES
 DO YOU WANT  NEW PROFILE ONLY   ? YES OR NO
NO
 DO YOU WANT NEW AIRPRT,OLD PLANE? YES OR NO
NO
 DO YOU WANT  NEW PLANE & AIRPORT? YES OR NO
NO
 END
READY
LOGOFF
```

Program Limitations

The aircraft, engine, and airport operational limitations for the flight procedures model are identified on Table 2-2. During program execution, the user will be required to select or provide input data which are within the limits of the operational parameters shown on Table 2-2. Other program limitations which the user should keep in mind include the following:

- The equivalent air speed cannot exceed 250 KEAS
- The user can repeat sections of a flight procedure. However, only the last completed section can be repeated. For takeoff procedures, the first section which can be repeated is section number four.

- Flap and landing gear extentions performed during approach and landing operations are assumed to occur instantaneously.

Program Execution Errors

There are two general types of errors which can occur during program execution. The first type of error will result in the rejection of the section under consideration, but the results from previous sections are unaffected. The second type of error will result in the termination of the program execution.* Both types of errors are generally caused by incorrect or improper input data entry. For example, the user may specify input data which are not within the operational limits of the model (see Table 2-2) or are not consistent with the physical capabilities of the aircraft type being considered. If either error type occurs during program execution, the user can retrieve all section results up to the point of termination. These data, along with the results from most of the computational algorithms, are stored on a file during program execution. The file name is CN.EPATFP.MUSN.FLYPRO.TEXT. With the listing of this file, the user can determine the location and source of the error.** It is recommended that the user clear the FLYPRO.TEXT file before each new run. Clearing this file can be done by typing "FREE ALL" after the "READY" response is given by the computer system.

*If the program is terminated, the system will respond with "READY".

**A listing of the FLYPRO.TEXT file is obtained using the IBM WYLBUR system. The logon procedures for accessing WYLBUR are discussed in Appendix B.

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APPENDIX A

COMPUTATIONAL ALGORITHMS USED
BY THE FLIGHT PROCEDURES MODEL

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COMPUTATIONAL ALGORITHMS USED BY THE FLIGHT PROCEDURES MODEL

TAKEOFF OPERATIONS

The computational algorithms used to compute the first three sections for takeoff operations are described in Reference 1. Most of the flight path and performance schedule data for these sections are obtained from the internal aircraft and engine data base files stored on the computer system. Starting with section number four, eight takeoff options may be used to construct the complete flight path and performance schedule. A description of the key computational algorithms used with each of these options is presented in the following sections.

Option Number 1

The flight path angle, γ, is computed from:

$$\gamma = \arcsin\left[\frac{(\bar{F}_n \cos \alpha_B) - D}{W\left(\frac{VT2^2 - VT1^2}{2g\Delta Z} + 1\right)}\right] \qquad \text{(A-1)}$$

where:

$\overline{F}_n$ = average total net thrust, pounds

VT2 = true air speed at altitude H2, feet/sec

VT1 = true air speed at altitude H1, feet/sec

ΔZ = change in aircraft altitude (H2-H1), feet

The other variables shown in equation A-1 are defined in Section 2. Equation A-1 was derived from equation 2-1 using the relationship:

$$\dot{V} = \frac{VT2^2 - VT1^2}{2\Delta Z} \sin\gamma \tag{A-2}$$

Equation A-2 can also be expressed as:

$$\dot{V} = \frac{(VT2 - VT1)\ VZ}{\sin\gamma} \tag{A-3}$$

where VZ is the aircraft rate-of-climb.

<u>Option Number 2</u>

The average total net thrust, $\overline{F}_n$, is computed from:

$$\overline{F}_n = \left\{ D + W + \left[\frac{(VT2 - VT1)\ VZ}{g\ \Delta\ Z} + \sin\gamma \right] \right\} \frac{1}{\cos\alpha_B} \tag{A-4}$$

The flight path angle is computed from:

$$\gamma = \arcsin\left(\frac{2\ VZ}{VT1 + VT2} \right) \tag{A-5}$$

The average total net thrust per engine at aircraft altitudes H1 and H2 is expressed as:

$$\overline{F}_{n1} = \frac{2\overline{F}_n}{N} \left[\frac{\frac{1}{\delta_2} - \frac{1}{\delta_3}}{\frac{1}{\delta_2} - \frac{1}{\delta_1}} \right] \tag{A-6}$$

and

$$\overline{F}_{n_2} = \frac{2\overline{F}_n}{N}\left[\frac{\frac{1}{\delta_3} - \frac{1}{\delta_1}}{\frac{1}{\delta_2} - \frac{1}{\delta_1}}\right] \tag{A-7}$$

where:

$\overline{F}_{n_1}$ = average net thrust per engine at H1, pounds

$\overline{F}_{n_2}$ = average net thrust per engine at H2, pounds

N = number of engines operating

δ_1 = altitude pressure ratio at H1

δ_2 = altitude pressure ratio at H2

δ_3 = altitude pressure ratio at (H1 + H2)/2

Option Number 3

The average total net thrust, $\overline{F}_n$, is computed from:

$$\overline{F}_n = \left[D + W \sin\gamma\left(\frac{VT2^2 - VT1^2}{2g\Delta Z} + 1\right)\right]\frac{1}{\cos\,\alpha_B} \tag{A-8}$$

The average total net thrust per engine at aircraft altitudes H1 and H2 is computed using equations A-6 and A-7, respectively.

Option Number 4

The flight path angle is computed using equation A-1. The initial guess for the aircraft's final altitude, H2, is an input parameter provided by the model user. An interation procedure is used to compute the value for H2 which satisfies the following equation:

$$H2 = (DS \tan\gamma) + H1 \tag{A-9}$$

where DS is the horizontal distance between flight path section end points.

Option Number 5

If the rate-of-climb is an input parameter specified by the model user, the flight path angle is computed using equation A-1. The initial guess for the aircraft's final altitude, H2, is an input parameter provided by the model user. An iteration procedure is used to compute the value for H2 which satisfies the following equation:

$$H2 = \frac{VZ(VT2 - VT1)}{g\left[\frac{\overline{F}_n \cos \alpha_B - D}{W} - \sin \gamma\right]} + H1 \qquad \text{(A-10)}$$

If the rate-of-climb is not specified as an input parameter, the user selects a final aircraft altitude, and the flight path angle is also computed using equation A-1.

Option Number 6

If the rate-of-climb is an input parameter specified by the model user, the flight path angle is computed using equation A-1. The initial guess for the aircraft's final equivalent air speed is an input parameter provided by the model user. An iteration procedure is used to compute the value for true air speed, VT2, which satisfies the following equation:

$$VT2 = \frac{g\Delta Z}{VZ}\left[\frac{\overline{F}_n \cos \alpha_B - D}{W} - \sin \gamma\right] + VT1 \qquad \text{(A-11)}$$

If the rate-of-climb is not specified as an input parameter, the user selects the aircraft's final equivalent air speed, and the flight path angle is also computed using equation A-1.

Option Number 7

The flight path angle is computed using equation A-1. The initial guess for the aircraft's final altitude, H2, is an input parameter provided by the model user. An iteration procedure is used to compute the value for H2 which satisfies the following equation:

$$H2 = 0.5 \left[t_{FR} \; (VT2 + VT1) \sin \gamma \right] \qquad \text{(A-12)}$$

where t_{FR} is the flap retraction time.

Option Number 8

The flight path angle is computed using equation A-1. The initial guess for the aircraft's final equivalent air speed is an input parameter provided by the model user. An iteration procedure is used to computer the value for true air speed, VT2, which satisfies the following equation:

$$VT2 = \frac{g \Delta Z}{VZ} \left[\frac{\overline{F}_n \cos \alpha_B - D}{W} - \sin \gamma \right] + VT1 \qquad \text{(A-13)}$$

APPROACH AND LANDING PROCEDURES

A description of the key computational algorithms used with the four approach and landing procedure options is presented in the following sections.

Option Number 9

The flight path angle is computed from:

$$\gamma = \arcsin \left[\frac{(\overline{F}_n \cos \alpha_B) - D}{W \left(\frac{(VT2^2 - VT1^2}{2 g \Delta Z} - 1 \right)} \right] \qquad \text{(A-14)}$$

Equation A-14 was derived from equation 2-1 by replacing $\sin \gamma$ with $- \sin \gamma$.

Option Number 10

The average total net thrust, $\overline{F}_n$, is computed from:

$$\overline{F}_n = \left\{ D + W + \left[\frac{(VT2 \quad VT1) \; VZ}{g \Delta Z} - \sin \gamma \right] \right\} \frac{1}{\cos \alpha_B} \qquad \text{(A-15)}$$

The average net thrust per engine at aircraft altitudes H1 and H2 is computed from equations A-6 and A-7, respectively.

Option Number 11

The average total net thrust, $\overline{F}_n$, is computed from:

$$\overline{F}_n = \left[D + W \sin \gamma \left(\frac{VT2^2 - VT1^2}{2g\Delta Z} - 1 \right) \right] \frac{1}{\cos \alpha_B} \qquad \text{(A-16)}$$

The average net thrust per engine at aircraft altitudes H1 and H2 is computed from equations A-6 and A-7, respectively.

Option Number 12

The average total net thrust, $\overline{F}_n$, is computed from:

$$\overline{F}_n = \left[D + \frac{W}{2gDS} \left(VT2^2 - VT1^2 \right) \right] \frac{1}{\cos \alpha_B} \qquad \text{(A-17)}$$

where DS is the horizontal distance between flight path section end points.

APPENDIX B

LOGON AND LOGOFF PROCEDURES FOR THE EPA'S IBM COMPUTER SYSTEM AT NCC

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LOGON AND LOGOFF PROCEDURES FOR
THE EPA'S IBM COMPUTER SYSTEM AT NCC

LOGON PROCEDURES

The following steps describe the LOGON procedures for interactive access to the IBM computer system at NCC:

1. Turn the terminal on and set its switches for remote session.
2. Dial the appropriate telephone access number and wait for ringing, an answer, and a data tone.
3. Couple the terminal to the telephone line:
   a. For terminals with acoustic couplers, place the telephone handset firmly in the coupler, orienting it as marked on the coupler.
   b. For modems (Bell 103, 113, 212A), depress the DATA button.

4. The following message will appear at your terminal (although it will appear garbled at speeds other than 3ØØ or 12ØØ bps):

    PLEASE TYPE YOUR TERMINAL IDENTIFIER

5. Type your terminal identifying character (type the letter A).

6. The computer system will then display:

    -XXXX-YYY-
    PLEASE LOG IN:

    (XXXX is a code for the node to which you are connected, and YYY is the port on that node.)

   NOTE: This message sent from the system has no parity. If your terminal is checking for parity, this message may be garbled.

   Respond by typing IBMPEA1, followed by a carriage return.

   To suppress echoing of input characters, a CONTROL H is typed before entering IBMEPA1.

7. The computer system will prompt for the password associated with IBMPEA1:

    PASSWORD:

   Respond by typing the correct password, followed by a carriage return. (Passwords are not echoed.)

   The password for IBMEPA1 is:

    NCC

8. Once the connection is made to the computer, you will receive:

    P### (### is a code for the computer port) and:

    IBM IS ON LINE

CONNECTING TO TSO

The following steps describe the procedure for connecting with TSO:

1. After receiving the message IBM IS ON LINE, the user must enter:

TSO (followed by a carriage return)

2. After receiving the message "enter LOGON for TSO or Wylbur terminal type", the user must enter:

   LOGON

   or

   LOGON userid/password

   to initiate a TSO session.

An example of the TSO connecting procedure is presented below:

```
1 {please type your terminal identifierA
  {-1011-000-                           <-- 2
3 {please log in:IBMEPA1;NCC
  {P  3          <-- 4
5  IBM1 IS ON LINE
   TSO <-- 6
7  enter LOGON
   LOGON <-- 8
9  IKJ56700A ENTER USERID -
   EPATFP <-- 10
11 ENTER CURRENT PASSWORD FOR EPATFP-
   :XXXXXX <-- 12
13 READY
```

<u>Notes for TSO Example Steps</u>

1. Computer prompt/response
2. User selects terminal identifier
3. Computer prompt/response
4. User keys in CTRL H immediately followed by IBMEPA1; NCC to select IBM system
5. Computer response
6. User selects TSO
7. Computer prompt
8. User keys in LOGON to start TSO session
9. Computer prompt

10. User enters EPA user-ID

11. Computer prompt

12. User enter a password

13. Computer responds with READY

CONNECTING TO WYLBUR

The following steps describe the procedure for connecting with WYLBUR:

1. After receiving the message IBM IS ON LINE, the user must enter:

   WYL (followed by a carriage return)

2. After receiving the message "enter LOGON for TSO or Wylbur terminal type", the user must enter the appropriate WYLBUR terminal type. A single carriage return will provide, as a default, MODEL 37/38 TELETYPE.

An example of the WYLBUR connecting procedure is presented below:

```
 1  please type your terminal identifierA
    -1011-012-                                  2
 3  please log in:IBMEPA1;NCC
    P 24                           4
 5  IBM1 IS ON LINE
    WYL                                      6
 7  enter wylbur terminal type
    38                                    8
 9  MODEL 37/38 TELETYPE

    WYLBUR AT EPA NCC-IBM   PORT 66  TUESDAY   07/28/81    12:23:36  P.M.

10  USERID  ? EPATFP
    ACCOUNT ? MUSN      11
    PASSWORD? XXXXXX
12  SPECIFY GLOBAL FORMAT FOR SAVE COMMANDS
    REPLY - DEFAULT, EDIT, TSO, CARD, OR PRINT
    FORMAT?CARD                                      13
14  "LOGON" NOT FOUND IN "WYLIB"  ON USER60
    COMMAND ?
```

Notes for WYLBUR Example Steps

1. Computer prompt
2. User selects terminal identifier
3. Computer prompt/response
4. User keys in CTRL H immediately followed by IBMEPA1; NCC to select IBM system
5. Computer response
6. User selects WYL (WYLBUR)
7. Computer response
8. User selects WYLBUR terminal type
9. Computer response
10. Computer prompt
11. User keys in EPA user-ID, account, and password
12. Computer response/prompt
13. User selects save format
14. Computer response/prompt

LOGOFF PROCEDURES

After a terminal session is completed under TSO or WYLBUR, the user initiates logoff procedures by typing "LOGOFF". If the user is in WYLBUB, the user must also clear the workspace prior to terminating a terminal session. Thereoff, the complete logoff command under WYLBUR is "LOGOFF CLEAR".

After a TSO or WYLBUR LOGOFF, the user may simply hand up or initiate a new TSO or WYLBUR session. To initiate a new TSO or WYLBUR session, type TSO or WYL and proceed accordingly.