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APPLICATIONS OF ADVANCED V/STOL AIRCRAFT CONCEPTS TO CIVIL UTILITY MISSIONS

Final Report

Volume II

(Appendix to Volume I, NASA CR 151987)

February 1977

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By

THE AEROSPACE CORPORATION
El Segundo, California

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16. Abstract This Volume consists of the Appendices to Volume I, "Applications of Advanced V/STOL Aircraft Concepts to Civil Utility Missions," NASA CR 151987. These Appendices include the linear performance definition curves for the lift fan aircraft, tilt rotor aircraft, and advanced helicopter studied in Volume I. The computer program written to perform the mission analysis for this study is also documented and examples of its use are shown. Methods used to derive the performance coefficients for use in the mission analysis of the lift fan aircraft are described.

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Foreword

These appendices are a limited distribution supplement to the final report on the subject study and are the repository of important details relative to the study and its analyses which are not of general reader interest, yet which are necessary to completely document the study approach and results.

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VOLUME II

APPENDICES

GLOSSARY OF TERMS

The following is a list of terms consisting of symbols, acronyms, and abbreviations used throughout this report.

TERMS	DEFINITION
APL	A Programming Language used in operator interactive mode
ASW	Anti-Submarine Warfare
BV	Boeing Vertol Company
CT	Rotor Thrust Coefficient
CTOL	Conventional Takeoff and Landing Aircraft
DOC	Direct Operating Costs
F	Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
ft	Feet
HESCOMP	Computer program to calculate the operational and economic parameters of a design helicopter
h	Altitude, feet (meters)
HLH	Heavy Lift Helicopter
hr	Hour
ISA	International Standard Day (Sea Level Pressure 29.92 Inches Mercury, Temperature 59 degrees, F.
IAS	Indicated Airspeed, Knots (meters per sec)
K	Thousands
kg	Kilogram
km	Kilometer
kt	Knot - Nautical Mile Per Hour
lb	Pounds (Mass)
M	Mach Number, ratio of aircraft velocity to velocity of sound (under same conditions)
MCAIR	McDonnell Aircraft Company
m	Meters

TERMS	DEFINITION
min	Minute (Time
N/A	Not Applicable or Not Available
NASA	National Aeronautics and Space Administration
nm	Nautical Mile (6080 ft, 1852 m)
σ	Rotor Solidity
No.	Number
NRP	Normal Rated Power
RC	Rate of Climb, ft/min (m/min)
ROI	Return on Investment
SL	Sea Level or Short Landing
sm	Statute Mile
STO	Short Takeoff
USFS	U.S. Forest Service
UTTAS	Utility Tactical Transport Aircraft System
VASCOMP	Computer program to calculate the operational and economic parameters of a design aircraft
VL	Vertical Landing
V_{mc}	Maximum Cruise Speed, kts (m/sec)
V_{me}	Maximum Endurance Cruise Speed, kts (m/sec)
V_{mr}	Maximum Range Cruising Speed, kt (m/sec)
VOD	Vertical Onboard Delivery (Navy Mission)
V/STOI	Vertical or Short Takeoff and Landing Aircraft
VTO	Vertical Takeoff
$\overset{o}{W}_a$	Airflow Rate, lbs/sec (kg/sec)
W_{fc}	Fuel Flow Rate @ Normal Cruise, lbs/min (kg/min)
$\overset{o}{W}_{fcl}$	Fuel Flow Rate @ Climb, lbs per min (kg/min)
$\overset{o}{W}_{fh}$	Fuel Flow Rate @ Hover, lbs/min (kg/min)
$\overset{o}{W}_{fl}$	Fuel Flow Rate @ Loiter, lbs/min (kg/min)
$\overset{o}{W}_{fmc}$	Fuel Flow Rate @ Maximum Cruise Speed, lbs/min (kg/min)

TERMS	DEFINITION
$\overset{o}{W}_{fme}$	Fuel Flow Rate @ Maximum Endurance Cruise Speed, lbs/min (kg/min)
$\overset{o}{W}_{fmr}$	Fuel Flow Rate @ Maximum Range Cruise, lbs/min (kg/min)
$\overset{o}{W}_{fmrp}$	Fuel Flow Rate @ Maximum Rated Power, lbs/min (kg/min)
$\overset{o}{W}_{fto}$	Fuel Flow Rate @ Takeoff, lbs/min (kg/min)

A. ADVANCED CONCEPT V/STOL AIRCRAFT LINEAR DEFINITION CURVES

In developing a methodology and the computer programs for conducting mission analysis, it was found that problem solving was facilitated if the aircraft performance parameters were expressed as coefficients of linear expressions. In this manner all integrations were possible in closed form and the programming was more easily developed. This step was not taken, however, without first ascertaining that it was not only a practical means of expressing the parameters, but that it was also valid within the accuracy constraints of the calculations being performed. Performance data of a contemporary helicopter was obtained from the Operations handbook and converted to linear expressions. These linear expressions were used to derive such operational information as time, fuel consumed and distance traveled to climb and descend; and time and fuel consumed in flying a given distance as applied to a defined flight profile. The results of the "linearized" solution compared favorably with the solution to the flight problem when solved directly from the operational tables. The two results differed by three to four percent. Thus, it was concluded that it was feasible for the purposes of this study to linearize the performance data.

Parameters linearized included the aircraft speeds, rates of climb and fuel flow rates and the expressions took the following form:

$$\text{Function} = K_1 + K_2 \times \text{altitude (ft)} + K_3 \times \text{weight (lbs)}$$

In the figures which follow, it will be seen that speeds generally have positive values for K_2 and K_3; rates of climb have negative values for K_2 and K_3; while fuel flow rates have negative values for K_2.

The principal intent of this appendix is to provide the curves not presented in Volume I so as to complete the data set for readers possibly interested in understanding the deviations of the assumed values from those calculated for these parameters. As was pointed out in Volume I, linear representations were made to match the computed curves in the regions where the results tend to be most critically influenced by the parameter being linearized. For example, for an aircraft which generally cruise at high altitudes and would seldom see prolonged cruise in the lower levels, linear curves were matched at the high altitudes to minimize the error here. This sometimes resulted in significant errors in the curves at lower altitudes, but did not affect the results since the curves were not used at the lower altitudes. However, if missions specified low altitude cruise, it was necessary to redefine the parameters for the low end of the altitude range to minimize the error. This action was seldom required, however.

In some instances relative to the tilt rotor and the advanced helicopter speed and fuel parameters, it was necessary to define two segment linear curves to provide a reasonable match between the assumed and calculated performance curves. When this requirement became apparent, the analysis programs were modified to accept two segment curves using a specified altitude at which the change over would be accomplished.

For each concept an analysis of the linear coefficient parameters versus the original non-linear functions was performed. This was done by using the Aerospace methodology to "fly" the design missions used by the Navy study design contractors. In this appendix, following the series of curves for the performance parameters for each concept are tables* and figures which define the design mission parameters and indicate the differences in the results of the Aerospace computations from those provided by the design contractors. In a few instances, these comparative analyses permitted the calibration of the Aerospace values to those of the contractors. When this was practical, it was done to better match the contractor data.

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* A table comparing the advanced helicopter performance is not available since the contractor report did not contain the necessary tabular information. The advanced helicopter mission profile was similar to that of the tilt rotor; however, ranges, times, and fuel consumed differed considerably.

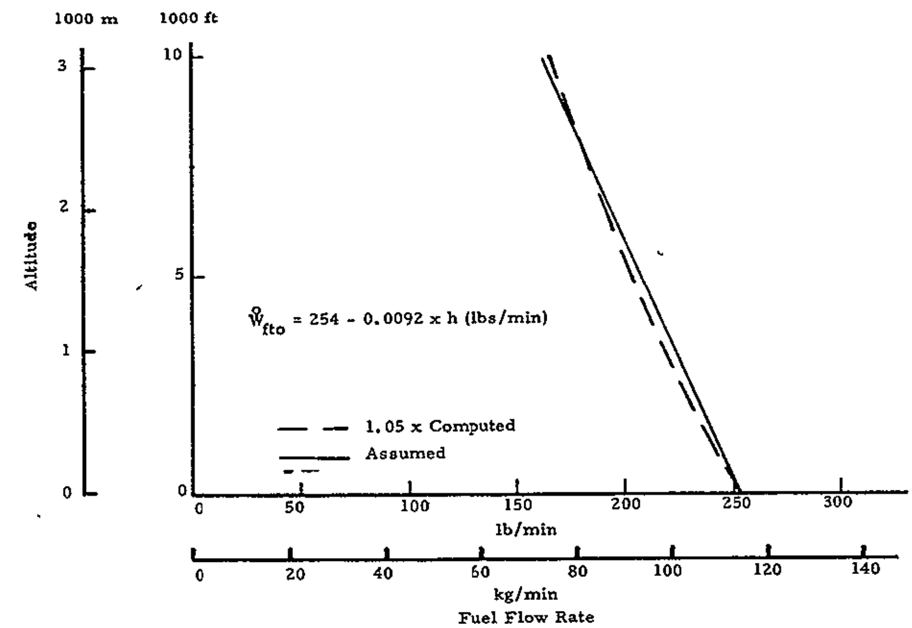

Figure A1-1 Lift Fan Takeoff Fuel Consumption Rate

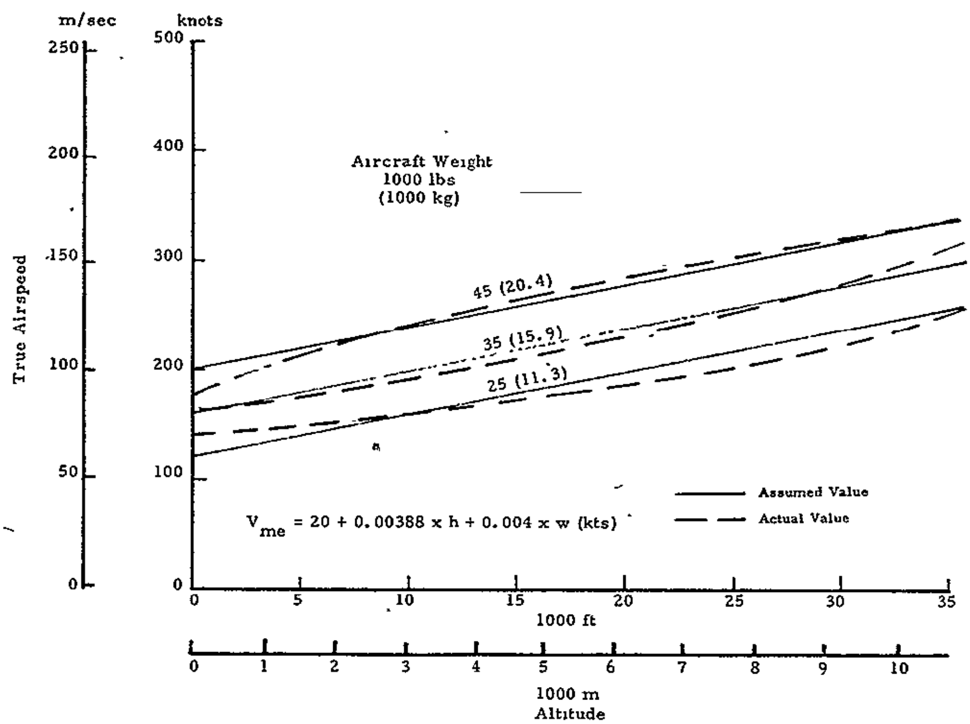

Figure A1-2 Lift Fan Maximum Endurance Cruise Speed

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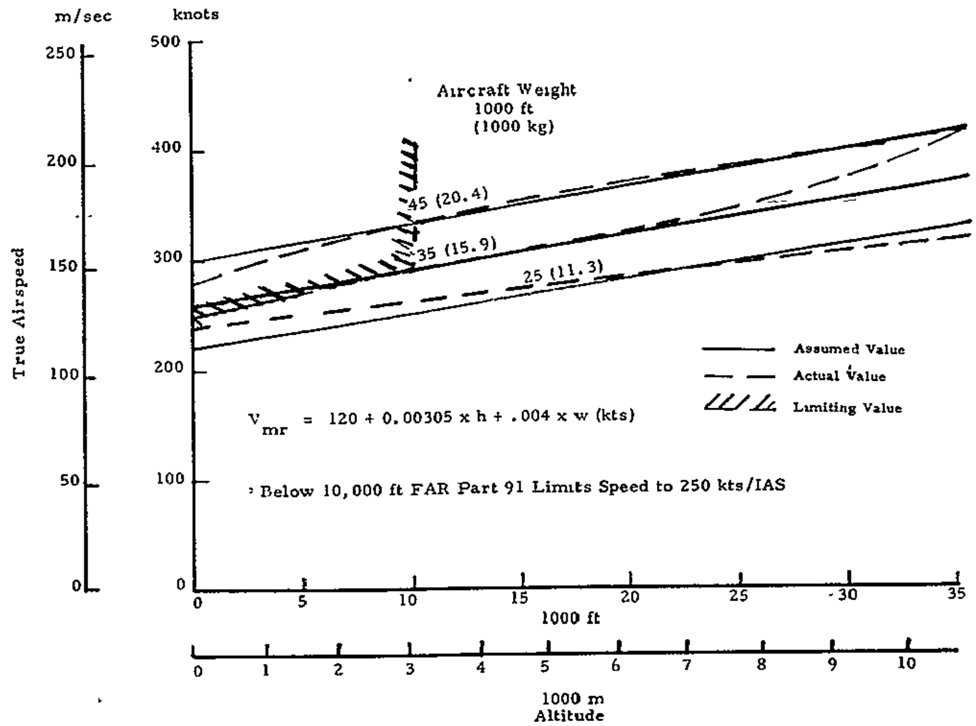


Figure A1-3 Lift Fan Maximum Range Cruise Speed

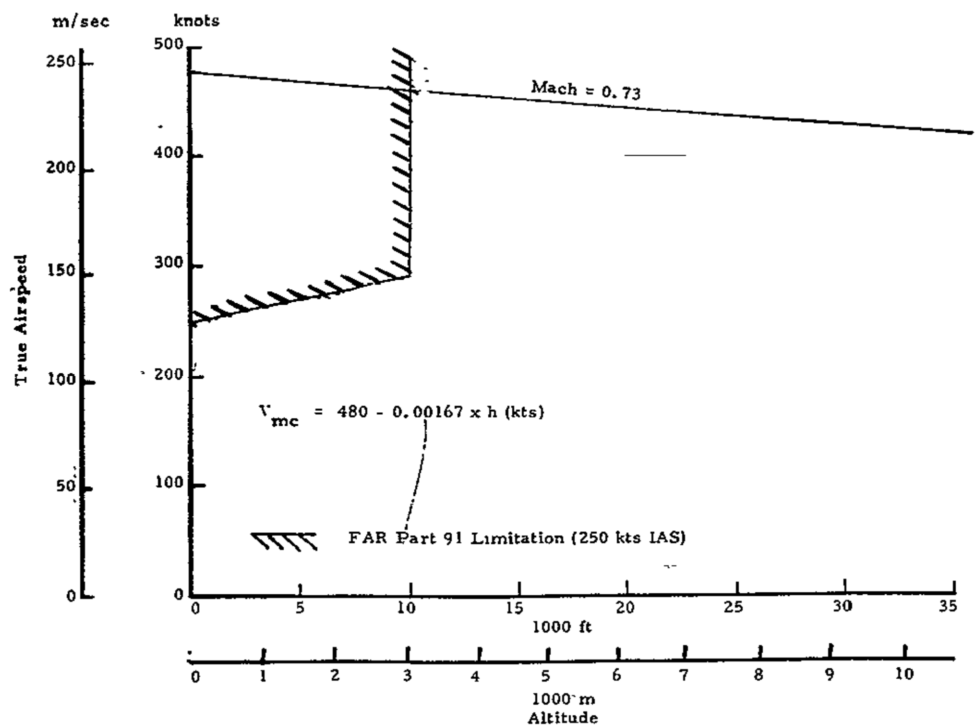


Figure A1-4 Lift Fan Maximum Cruise Speed

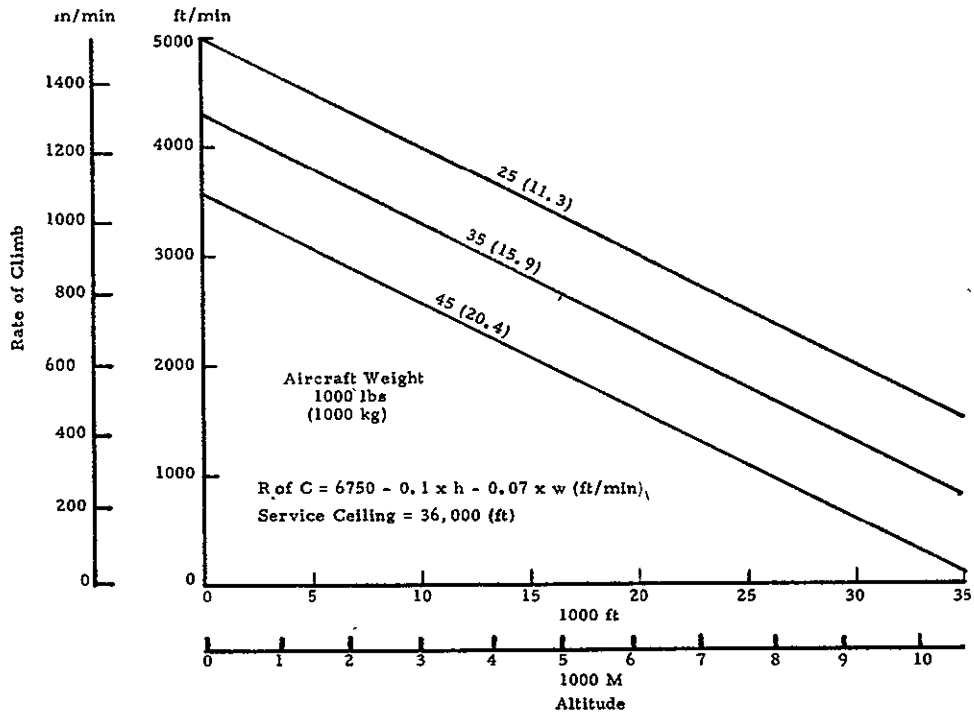


Figure A1-5 Lift Fan Climb Rate

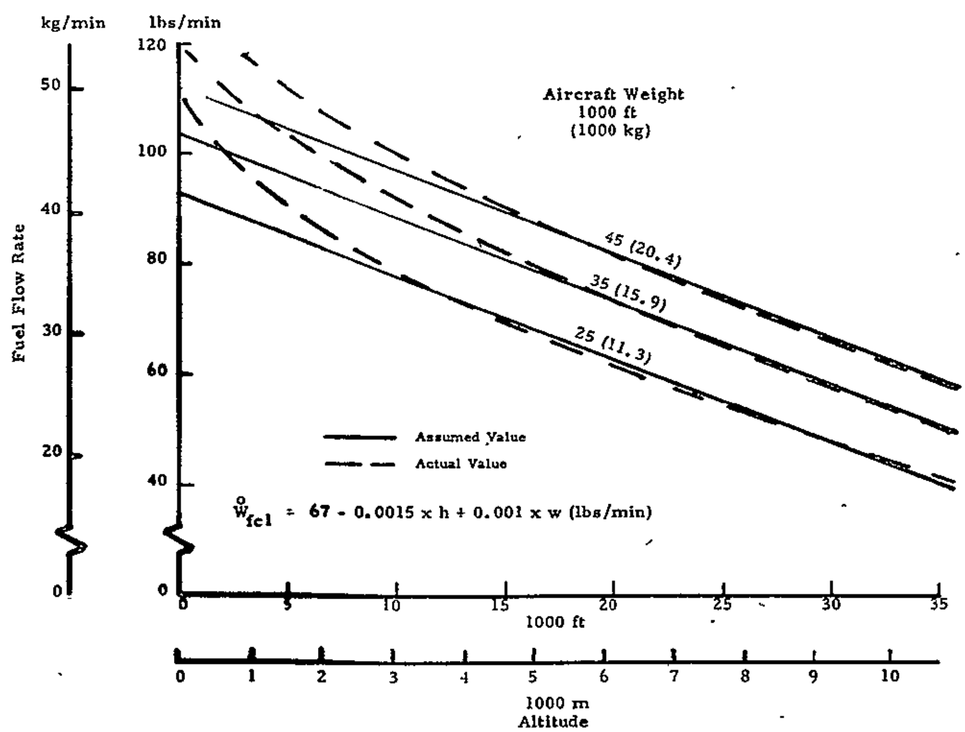


Figure A1-6 Lift Fan Climb Fuel Consumption Rate

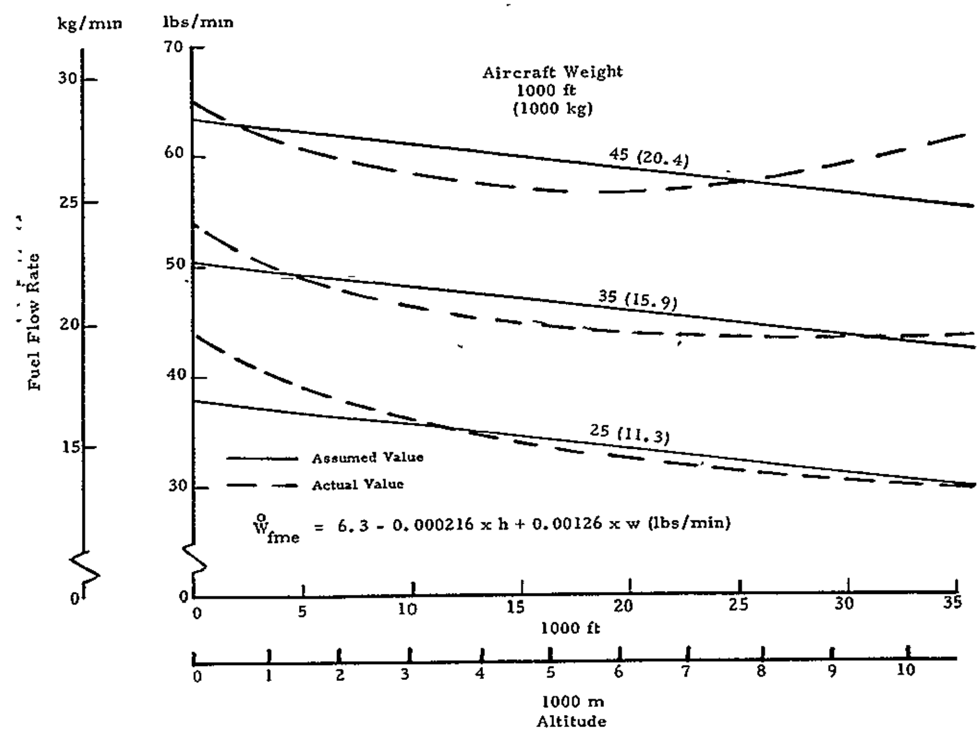


Figure A1-7 Lift Fan Maximum Endurance Fuel Consumption Rate

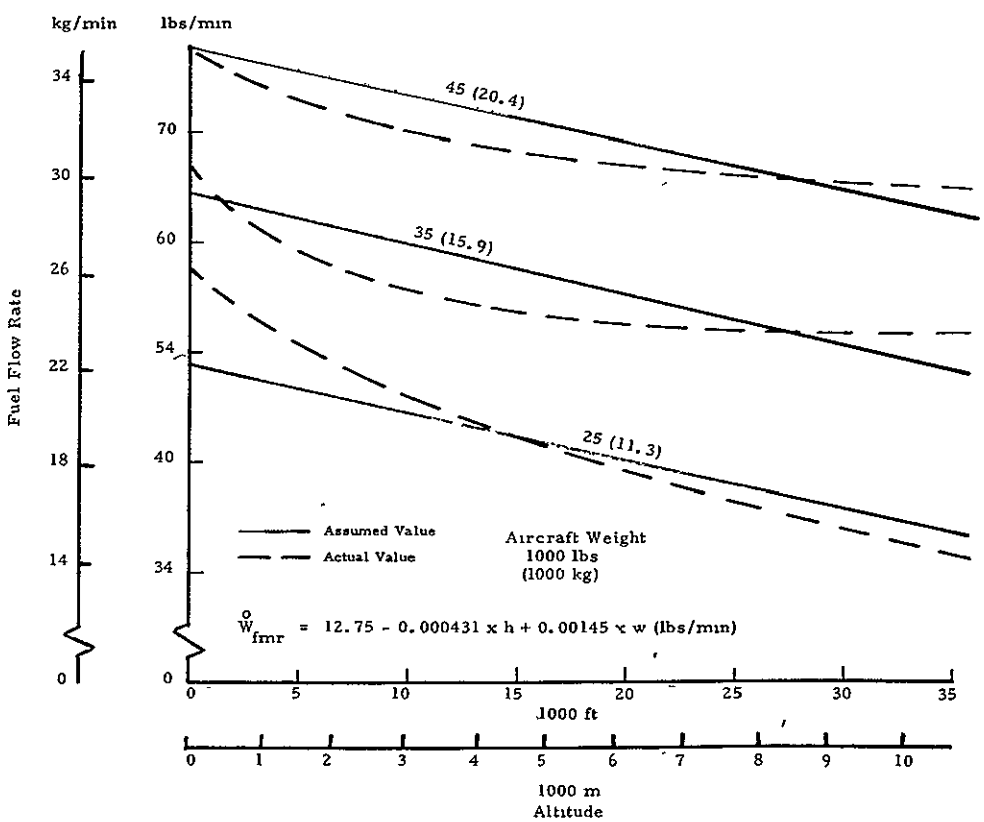


Figure A1-8 Lift Fan Maximum Range Fuel Consumption Rate

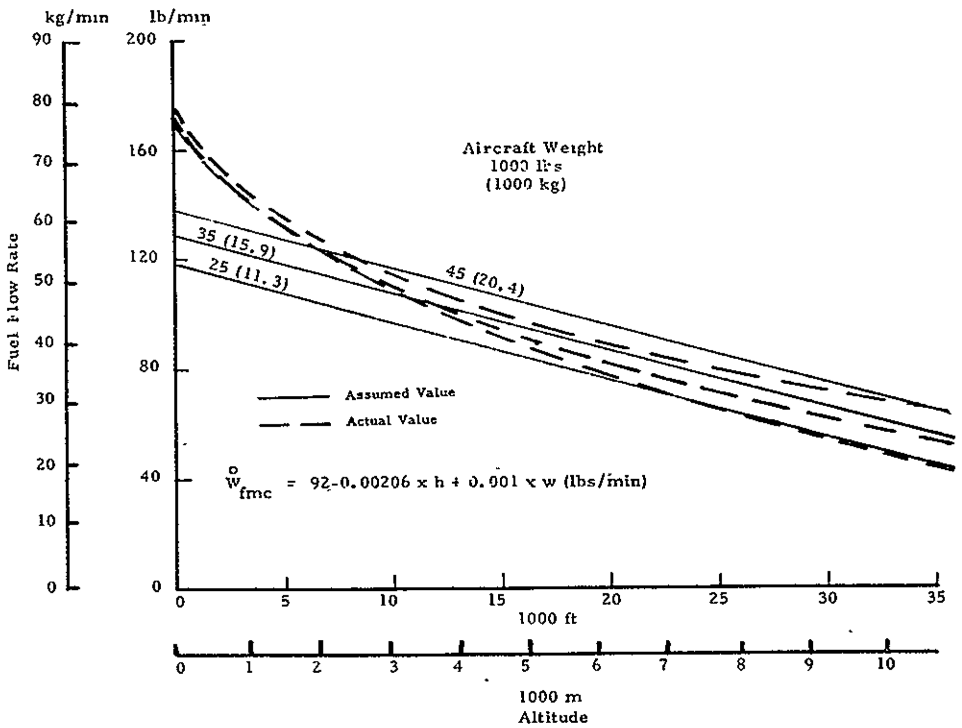


Figure A1-9 Lift Fan Maximum Cruise Fuel Consumption Rate

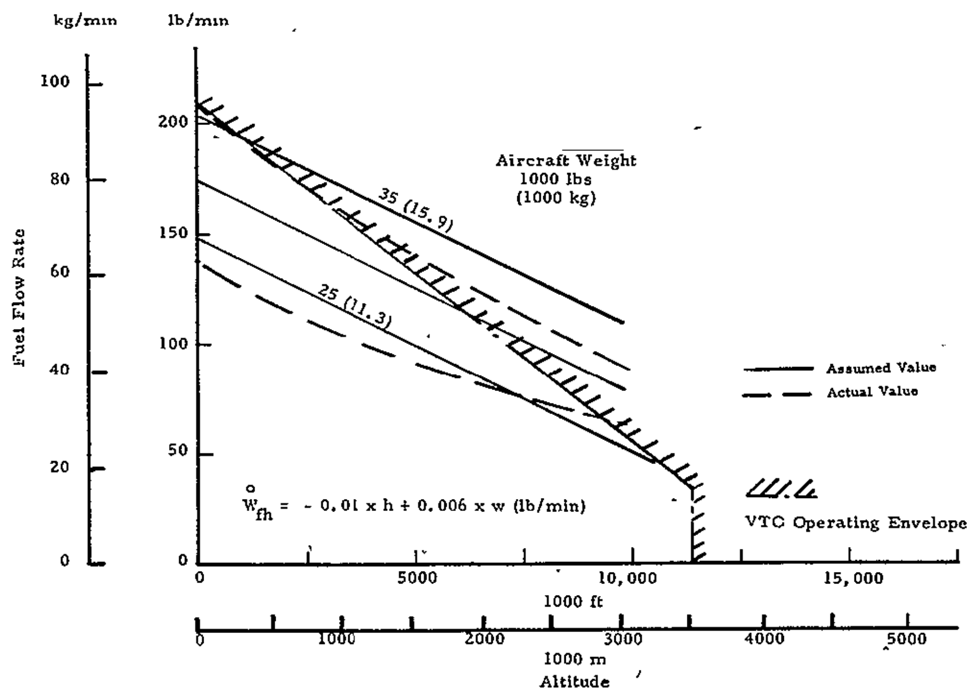


Figure A1-10 Lift Fan Hover Fuel Consumption Rates

Table A1 - 1 Lift Fan Mission Performance Comparison VOD Design Mission (Payload 5000 lbs)

MISSION SEGMENT	MCAIR Study				Aerospace Analysis			
	Wt[a] (lb)	Fuel (lb)	Dist (nm)	Time (hrs)	Wt (lb)	Fuel (lb)	Dist (nm)	Time (hrs)
T.O. Wt.	45,000				45,000			
Warmup and Takeoff	44,345	645	--	0.042	44,593	407	--	0.04
Climb	42,969	1,376	82	0.227	42,304	2,288	160	0.53
Cruise	28,385	14,594	1918	4.640	30,651	11,654	1570	3.75
Descent to S.L.	b	--	--	--	38,461	2,190	370	0.60
Loiter[c]	--	--	--	--	27,629	832	--	0.33
Landing	26,511	950	--	.333	27,472	165	--	0.02
Reserves		924				953		
TOTAL	--	18,489	2000	5.24	--	18,489	2000	5.27

a At end of segment

b No distance credit, no time or fuel allowance

c Included in landing

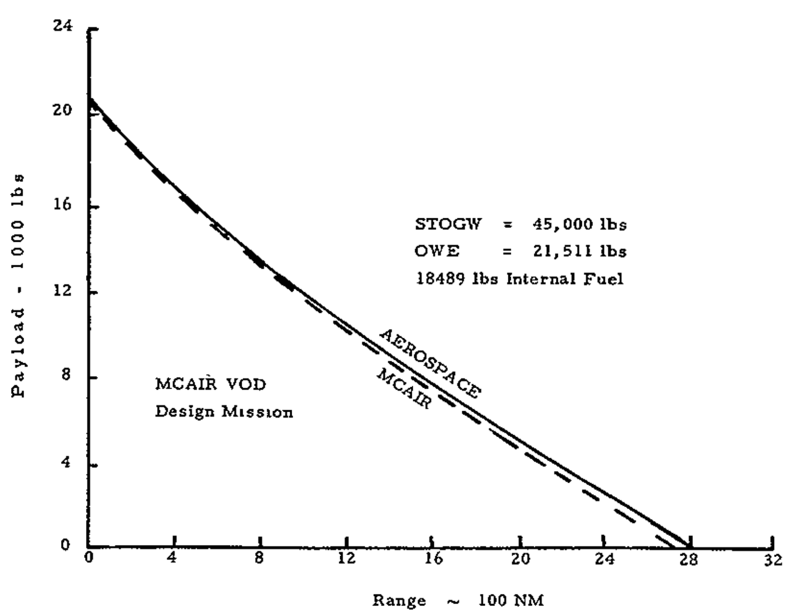
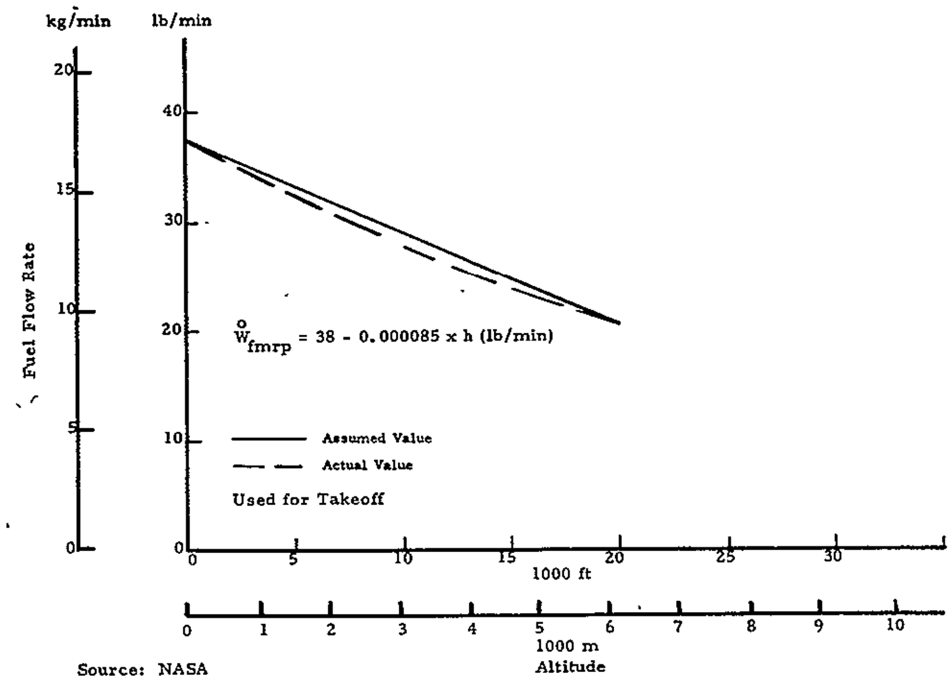


Figure A1 - 11 Payload/Range Comparison - MCAIR Design vs. Aerospace

Note. The mission performance shown here differs from that shown in Figure 5-1 due to different mission parameters, fuel reserves, and cruise speed assumptions.



Source: NASA

Figure A1-12 Tilt Rotor Maximum Rated Power Fuel Consumption Rate

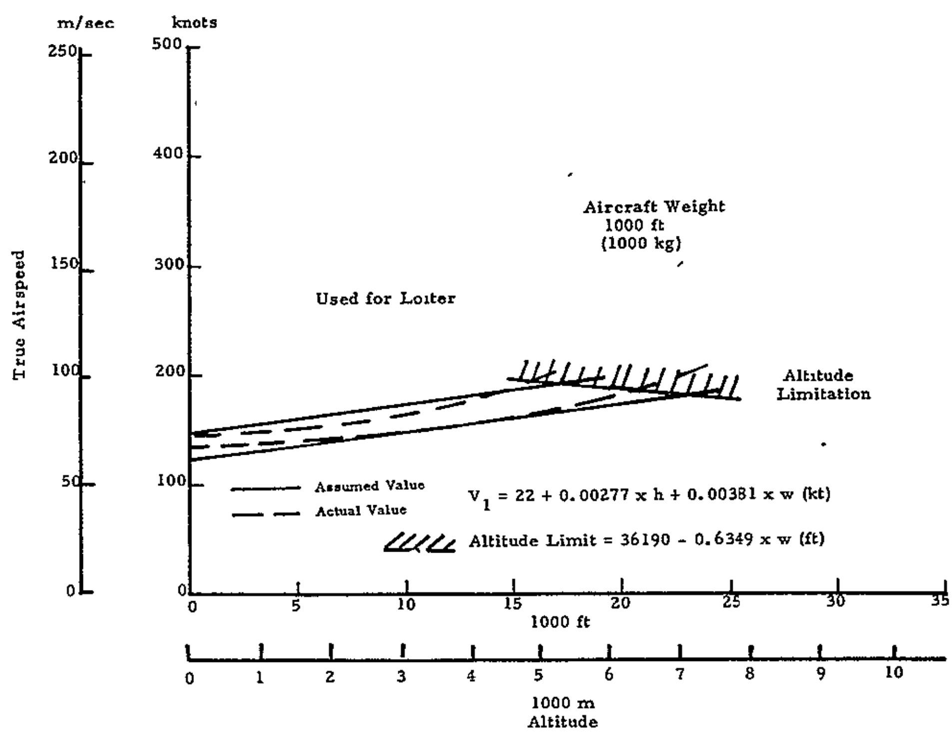


Figure A1-13 Tilt Rotor Maximum Endurance Cruise Speed

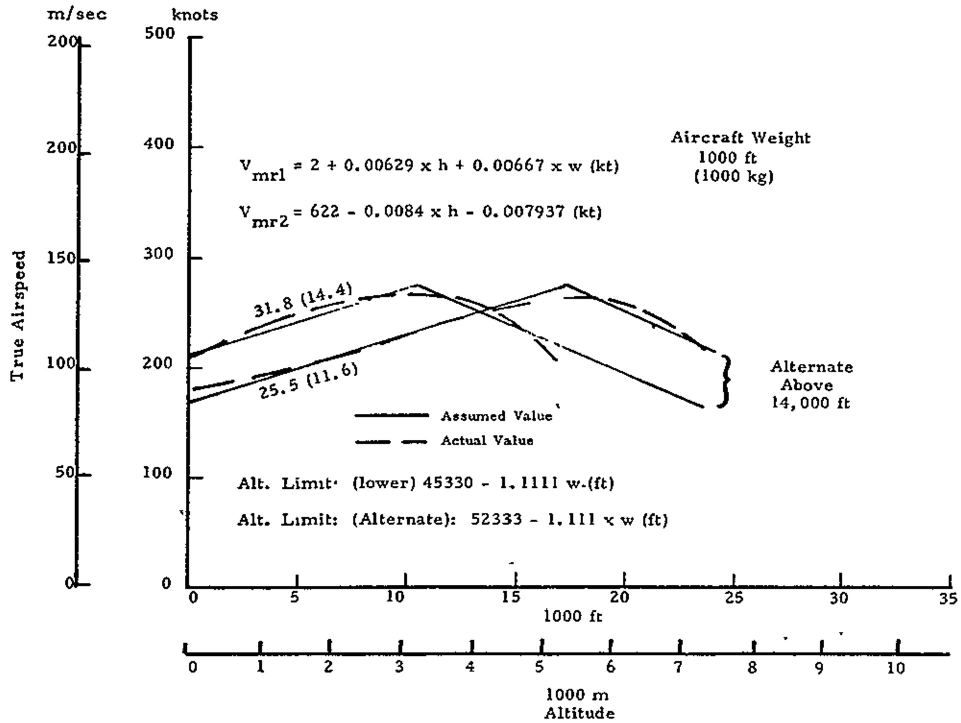


Figure A1-14 Tilt Rotor Maximum Range Cruise Speed

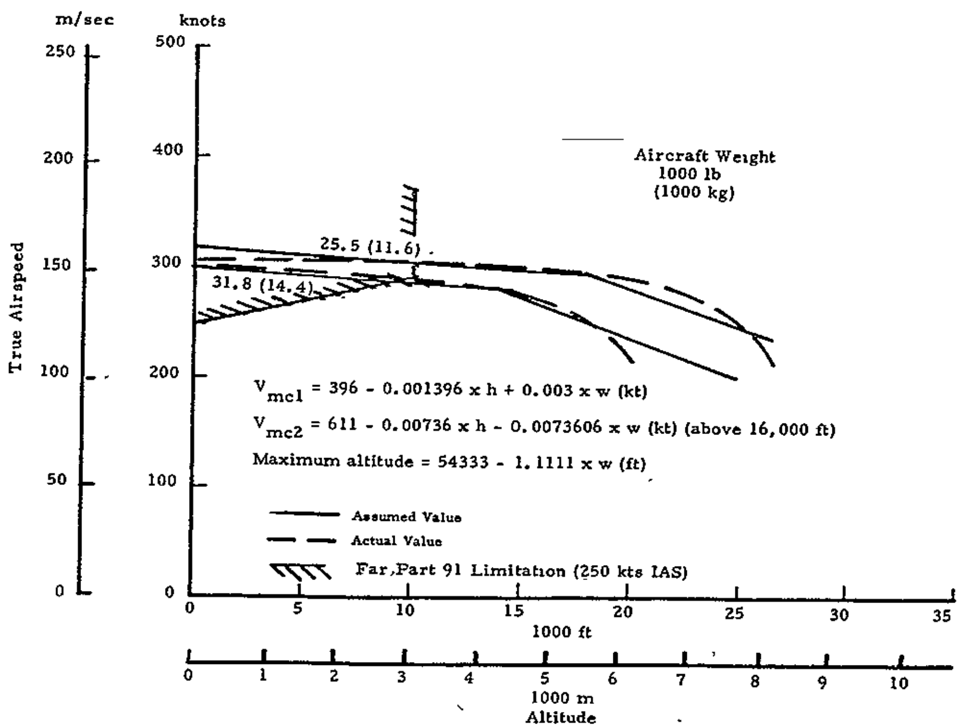


Figure A1-15 Tilt Rotor Maximum Cruise Speed

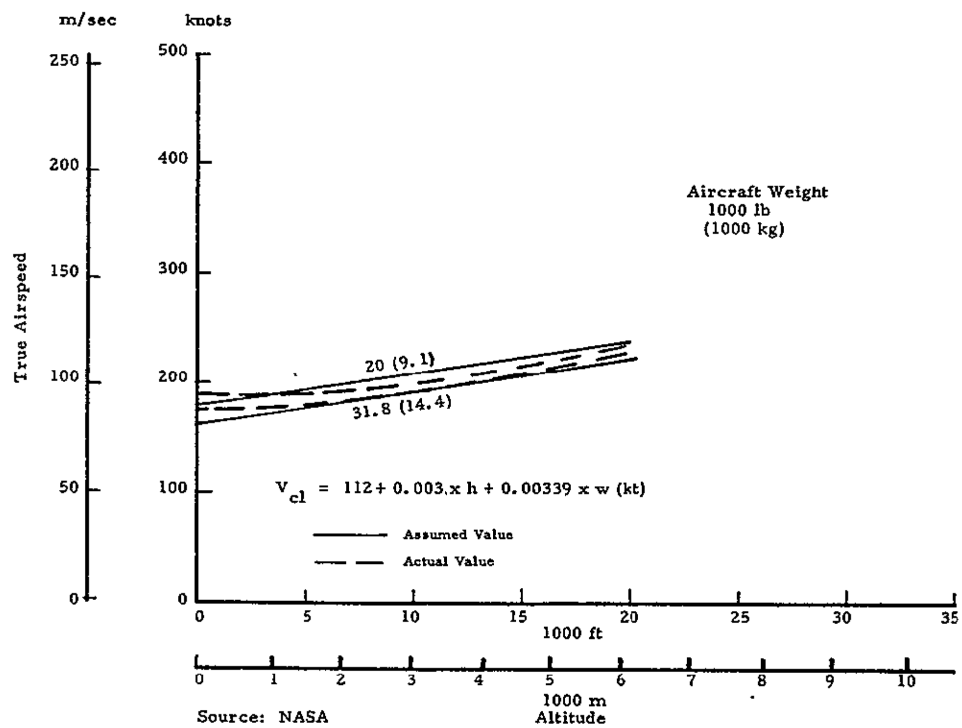


Figure A1-16 Tilt Rotor Climb Speed

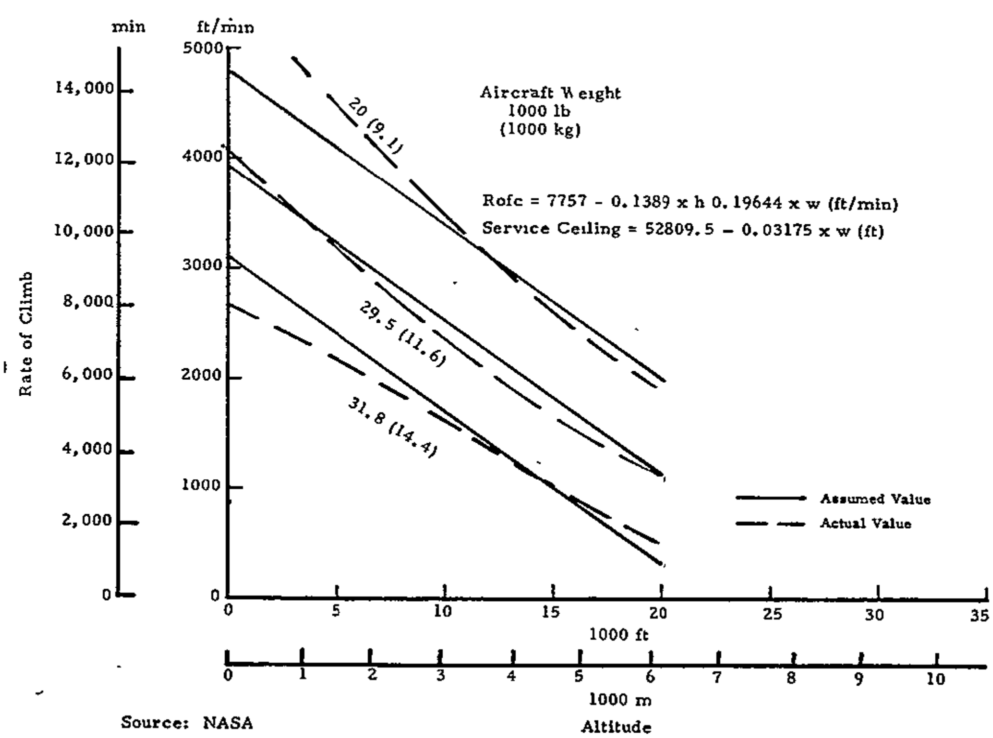


Figure A1-17 Tilt Rotor Climb Rate

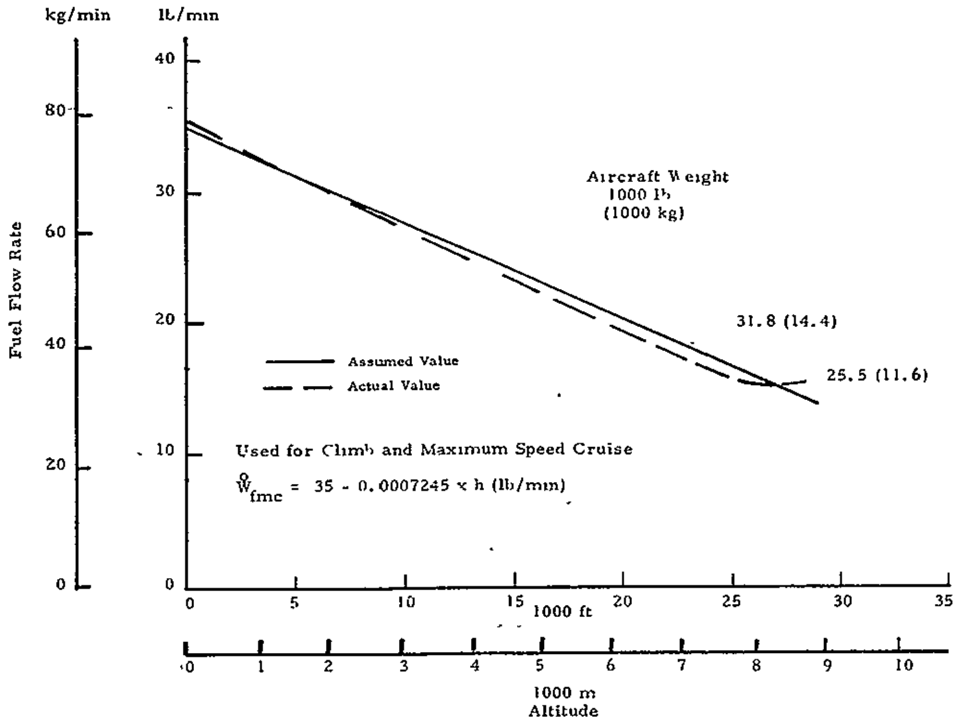


Figure A1-18 Tilt Rotor Normal Rated-Power Fuel Consumption Rate

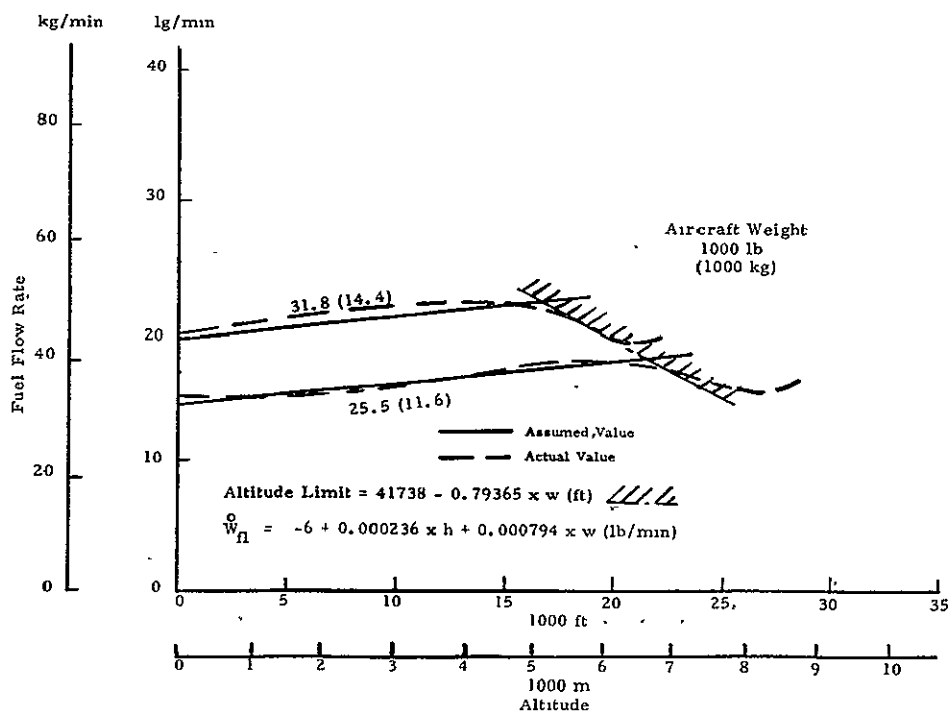


Figure A1-19 Tilt Rotor Maximum Endurance Fuel Consumption Rate

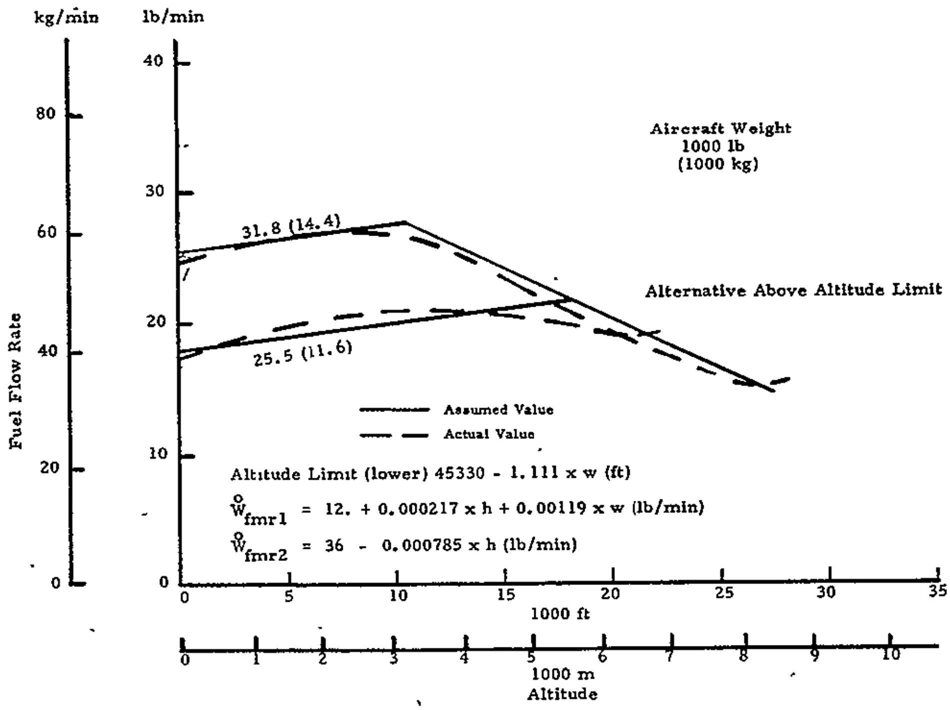
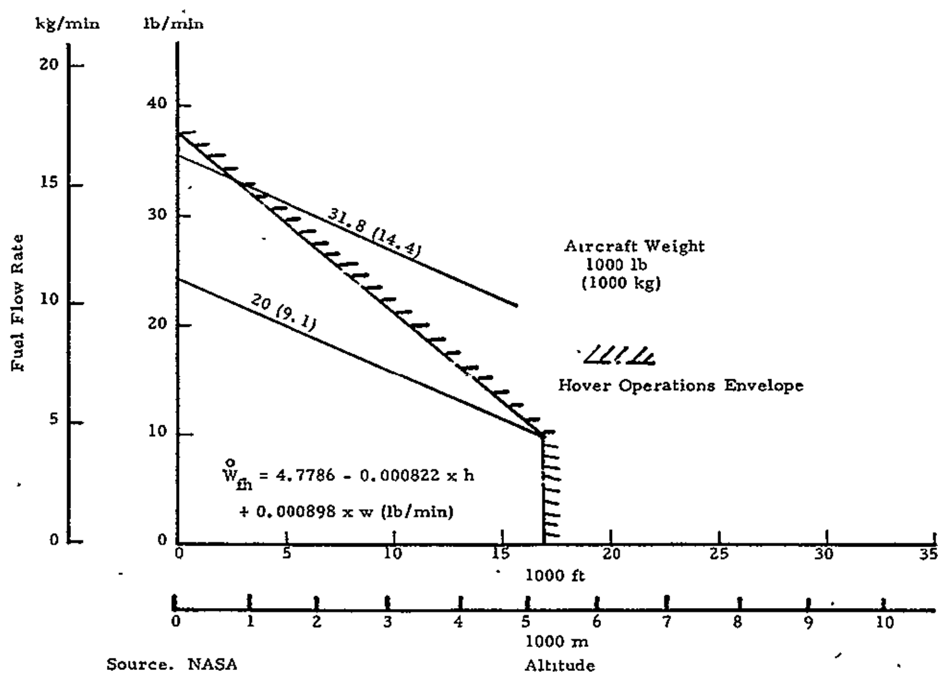


Figure A1-20 Tilt Rotor Maximum Range Fuel Consumption Rate



Source. NASA

Figure A1-21 Tilt Rotor Hover Fuel Consumption Rate

Table A1 - 2 Boeing Vertol Tilt Rotor Design Mission Summary

SEGMENT	BOEING VERTOL			AEROSPACE		
	Time Min	Fuel Lb	Speed Kts	Time Min	Fuel Lb	Speed Kts
1. Load	N/A	N/A	N/A	5	N/A	N/A
2. Warm up	N/A	99.1	N/A	5	28	N/A
3. Takeoff (sl 90°)	N/A					
4. Cruise Out (150 nm, sl-ISA)	37.5[a]	1052.4	240	39	1087	219
5. 1st Loiter (sl-ISA)	90	1637.8	139	90	1602	136
6. Hover (sl-ISA)	60	1780.1	N/A	60	1779[b]	N/A
7. 2nd Loiter (sl-ISA)	90	1427.1	132	90	1369	123
8. Cruise Back (150 nm, sl-ISA)	46.4[a]	881.3	194	47	955	174
9. Land	N/A	N/A	N/A	1	27	N/A
Reserve	---	756	---	---	753	---
Total	323.9	7641.2	---	338	7638	---

[a] Derived - not given in Reference

[b] Ames data calibrated to BV data

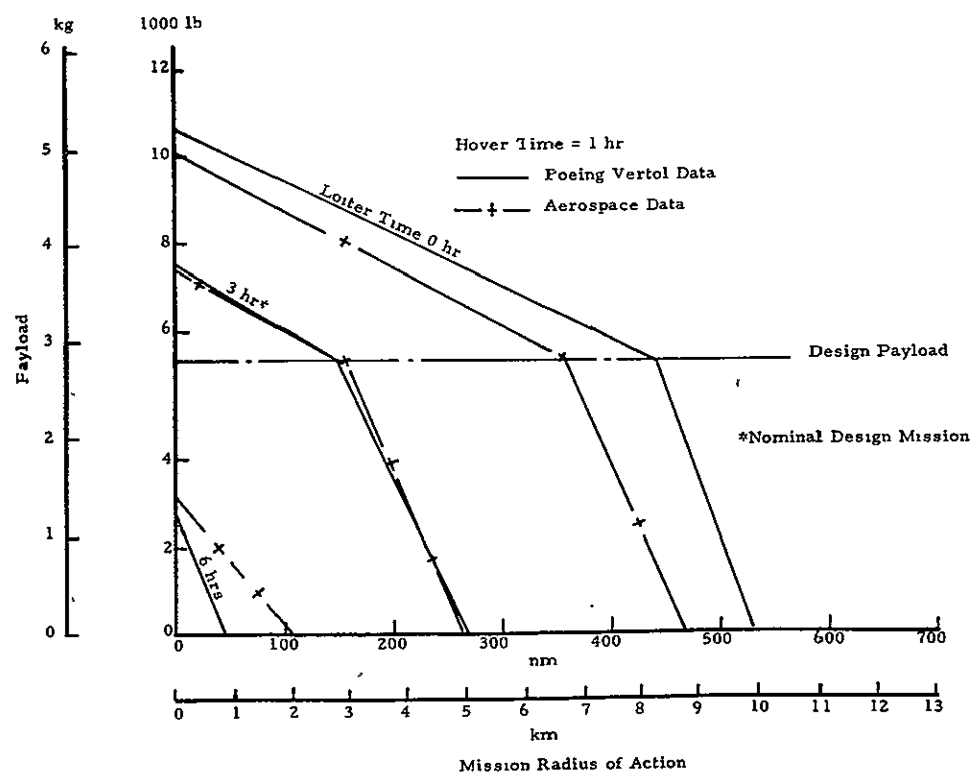


Figure A1-22 Tilt Rotor Variation in Loiter Time

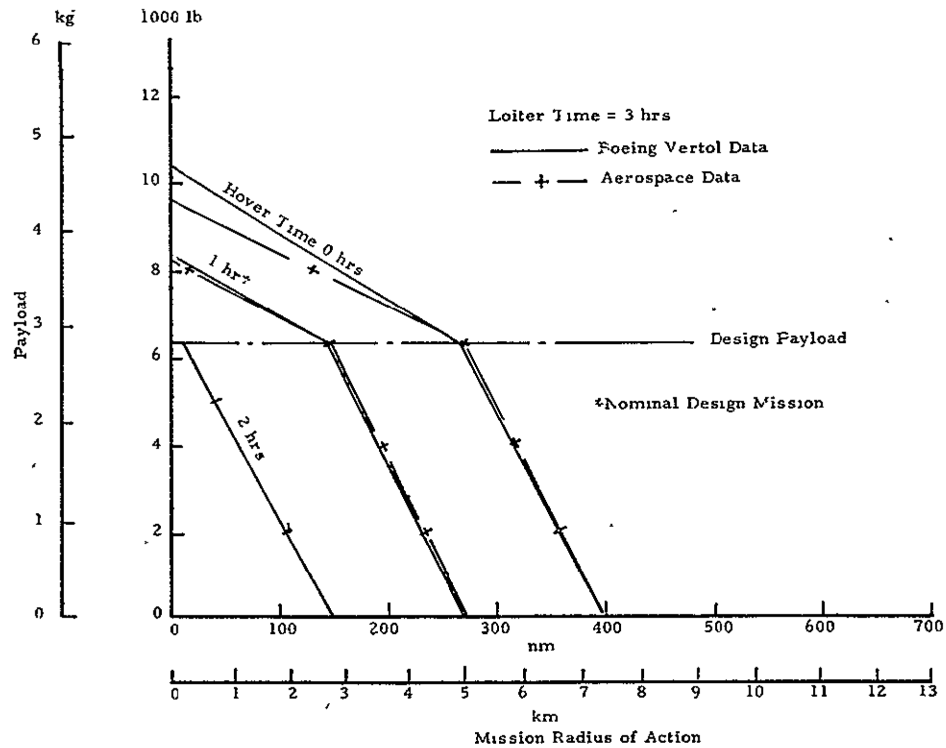


Figure A1-23 Tilt Rotor Performance - Variation in Hover Time

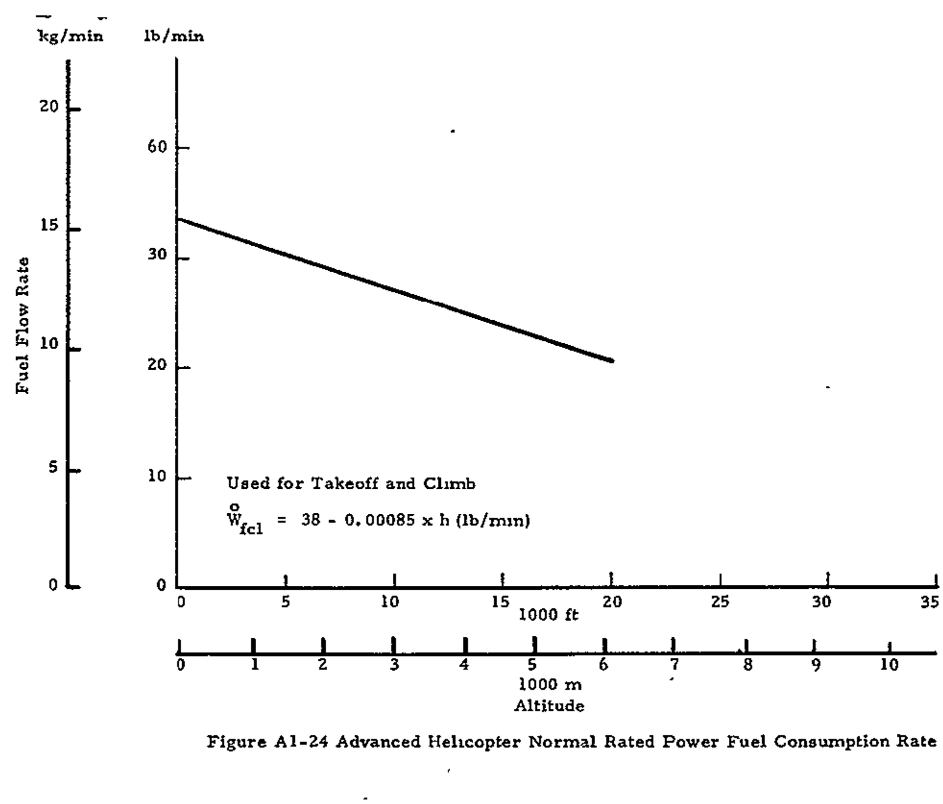


Figure A1-24 Advanced Helicopter Normal Rated Power Fuel Consumption Rate

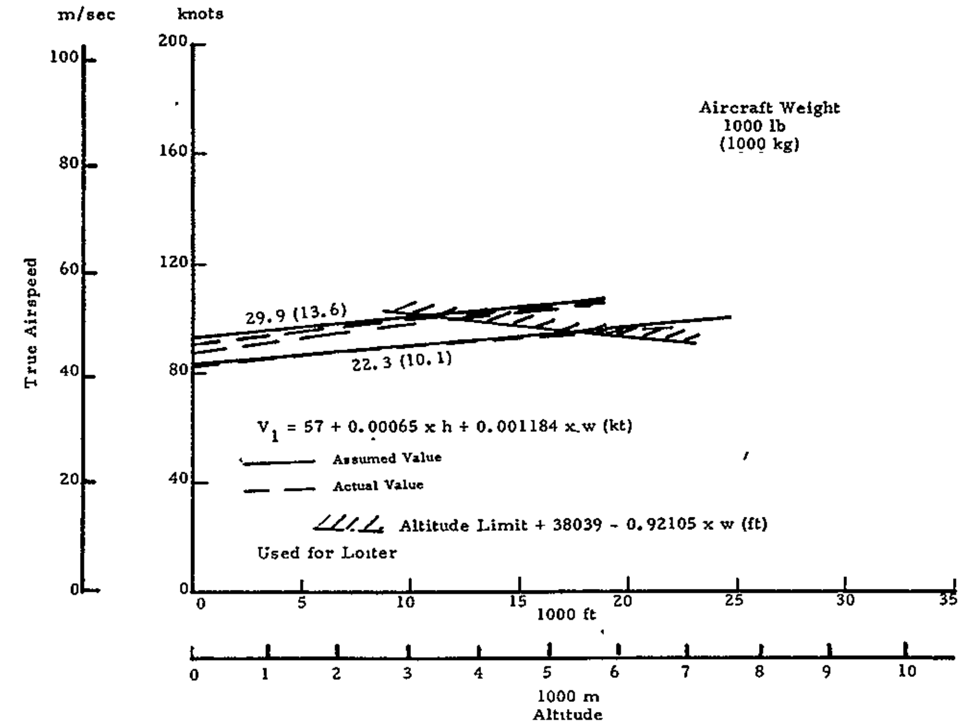


Figure A1-25 Advanced Helicopter Maximum Endurance Speed

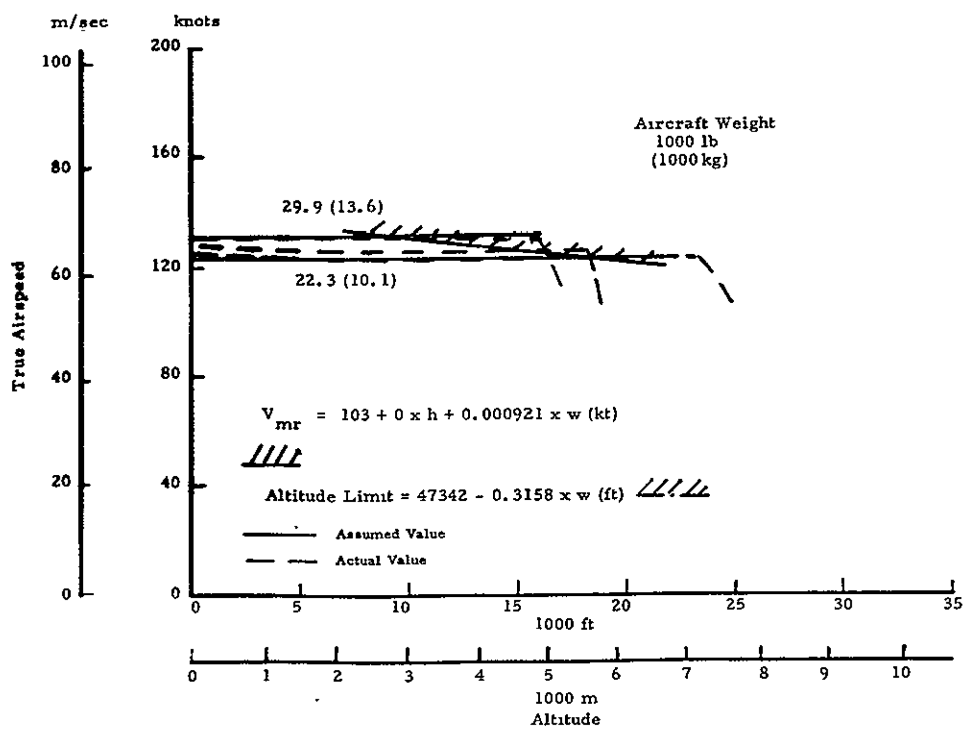


Figure A1-26 Advanced Helicopter Maximum Range Cruise Speed

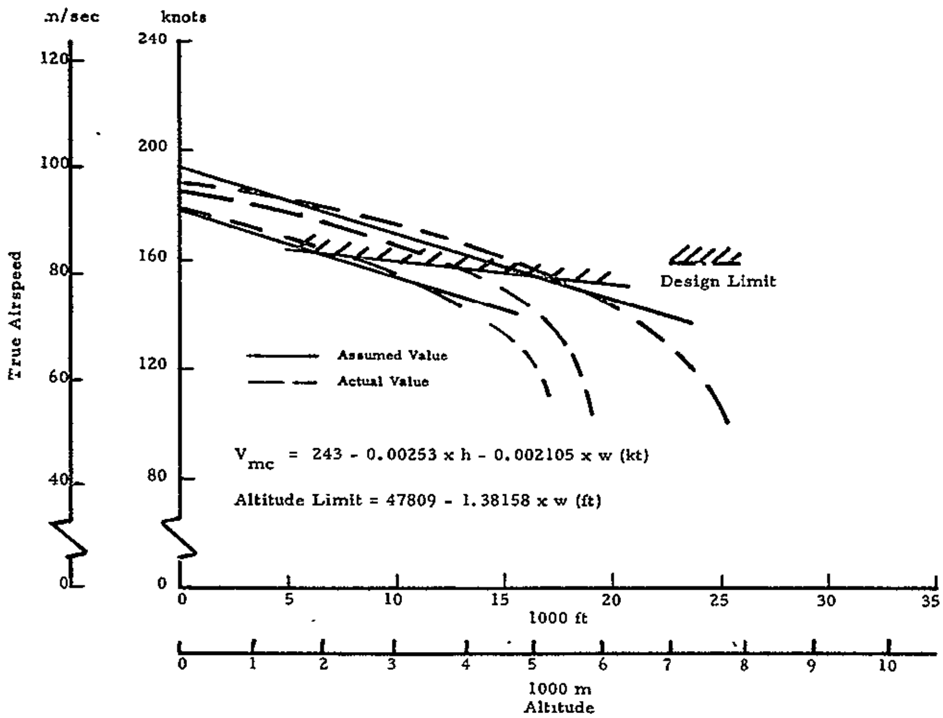


Figure A1-27 Advanced Helicopter Maximum Cruise Speed

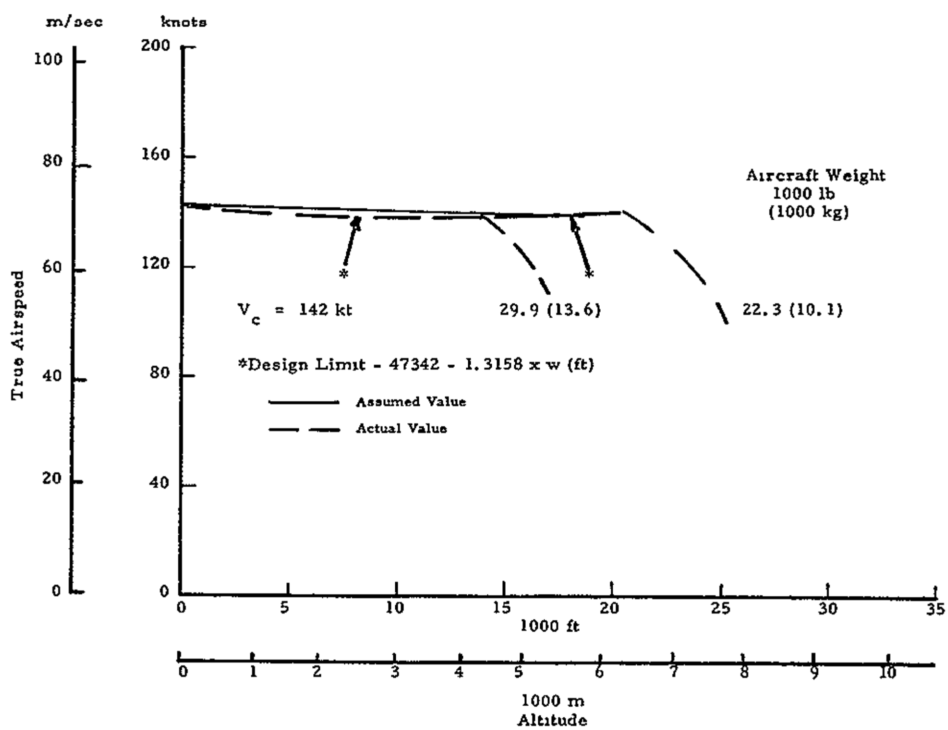


Figure A1-28 Advanced Helicopter 99% Maximum Range Cruise Speed

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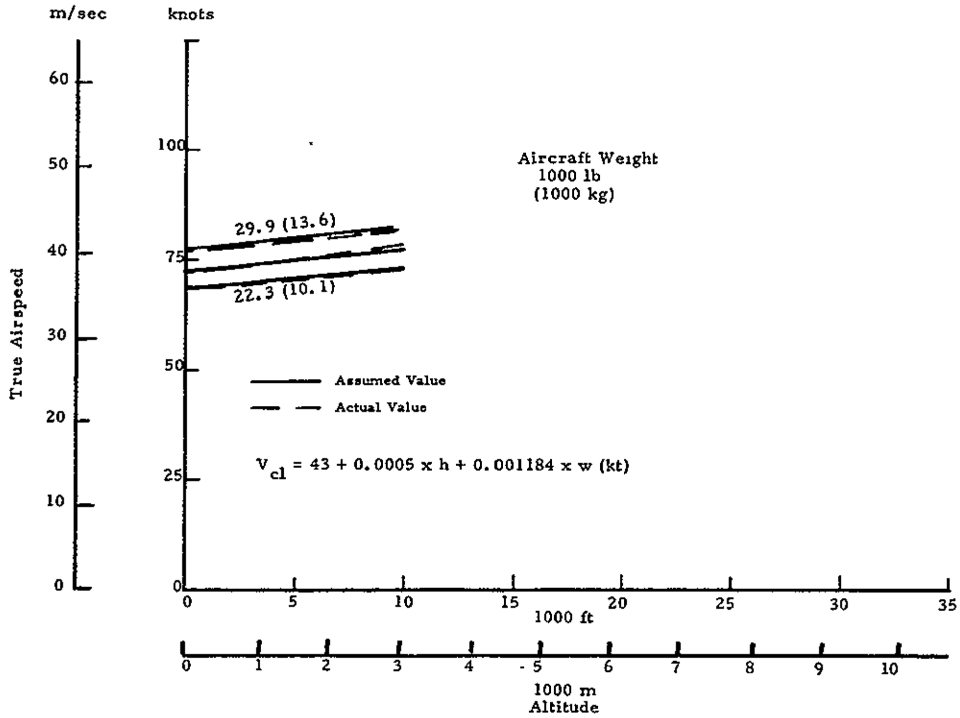
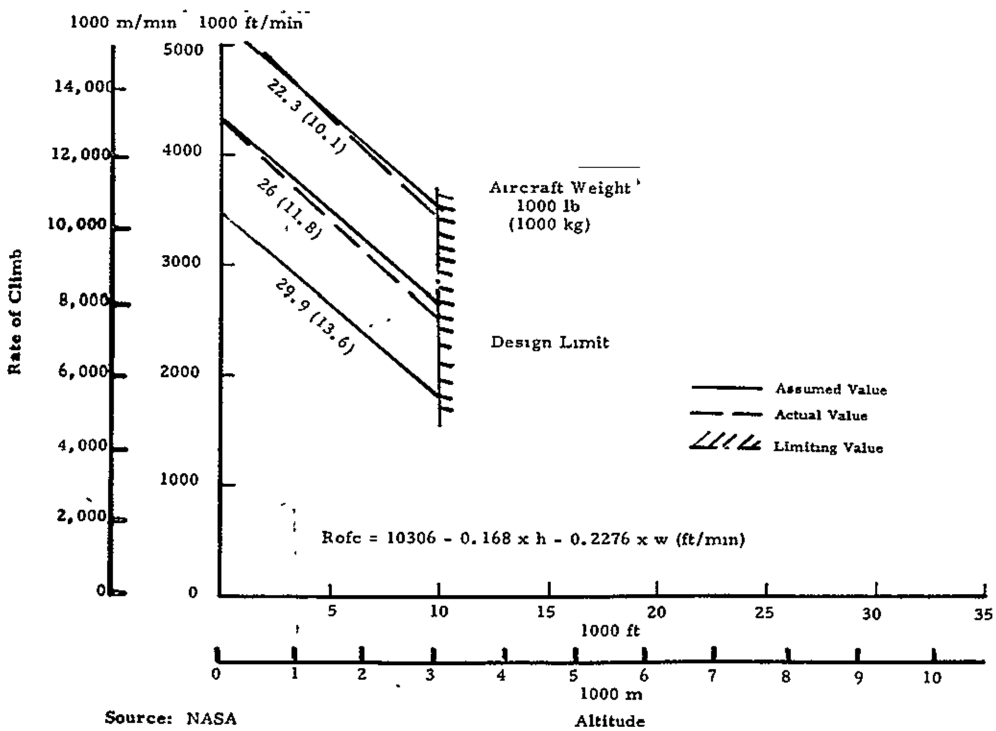


Figure A1 - 29 Advanced Helicopter Climb Speed



Source: NASA

Figure A1-30 Advanced Helicopter Climb Rate

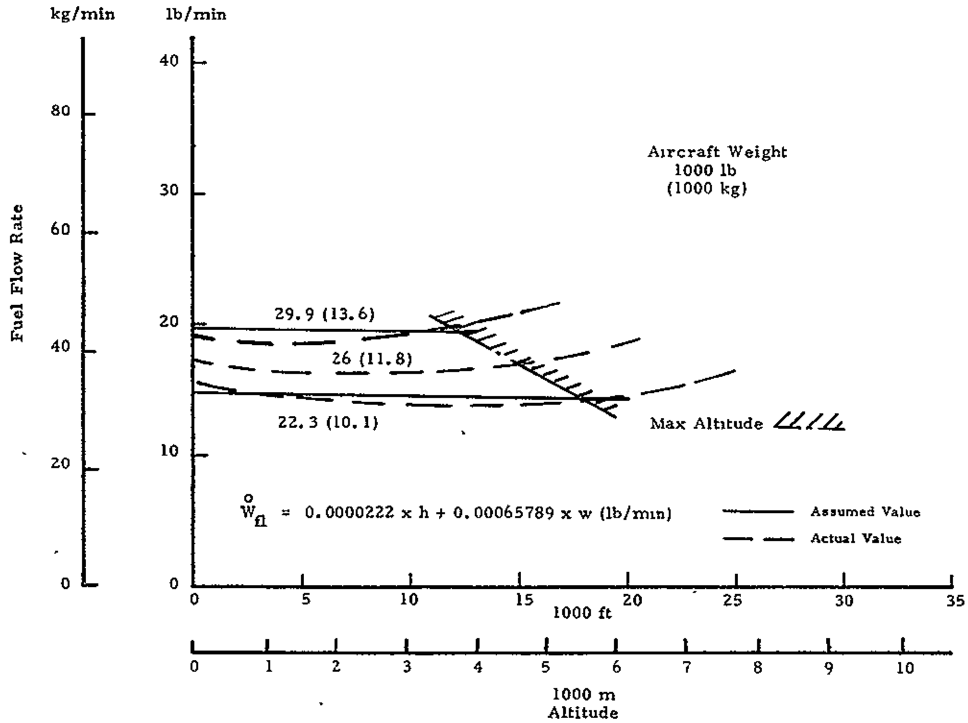


Figure A1-31 Advanced Helicopter Maximum Endurance Fuel Consumption Rate

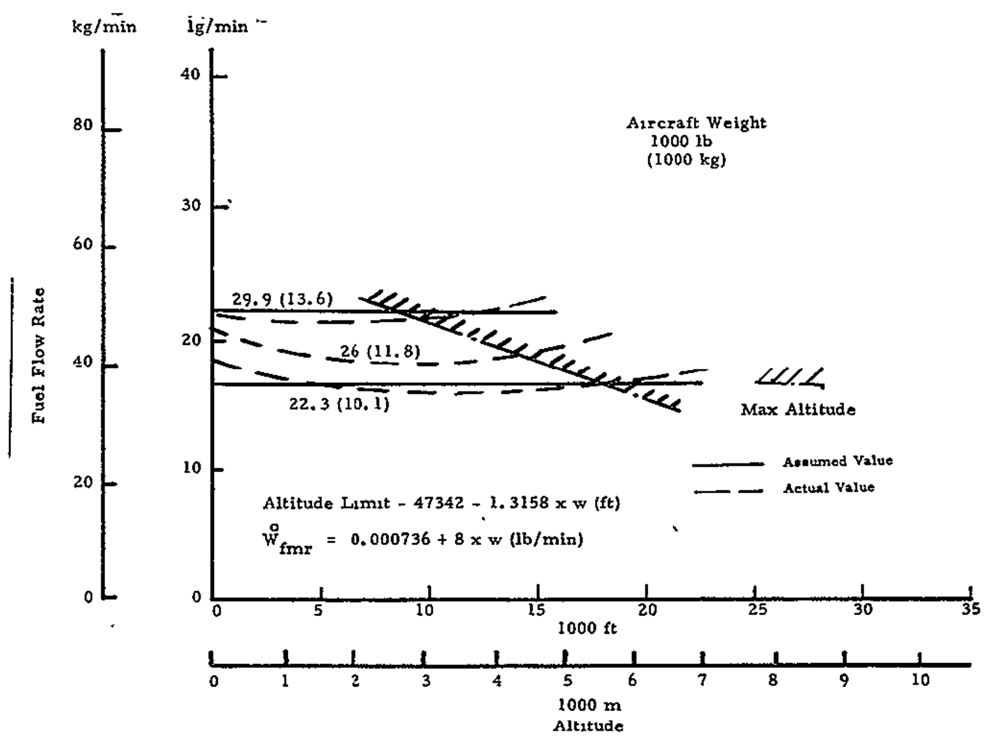


Figure A1-32 Advanced Helicopter Maximum Range Fuel Consumption Rate

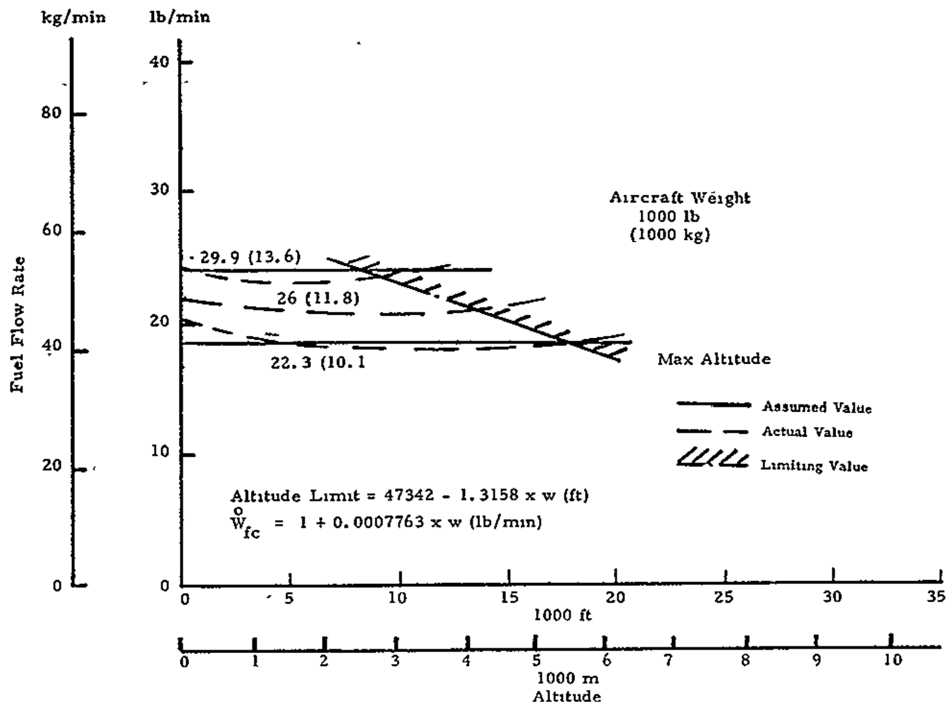


Figure A1-33 Advanced Helicopter Normal Cruise Fuel Consumption Rate

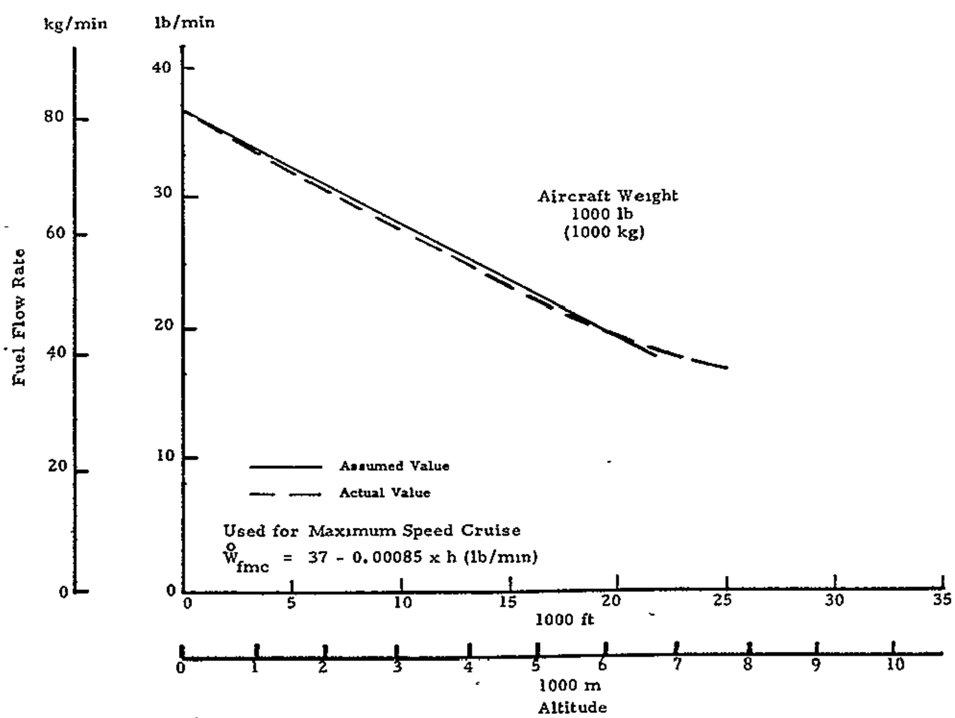


Figure A1-34 Advanced Helicopter Rates Power Fuel Consumption Rate

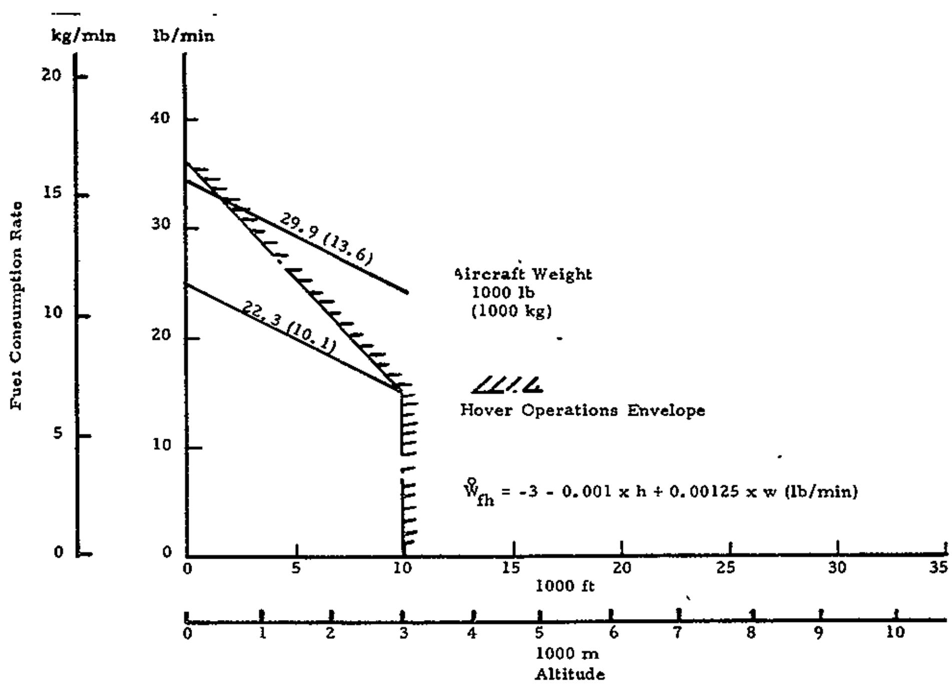


Figure A1-35 Advanced Helicopter Hover Fuel Consumption Rate

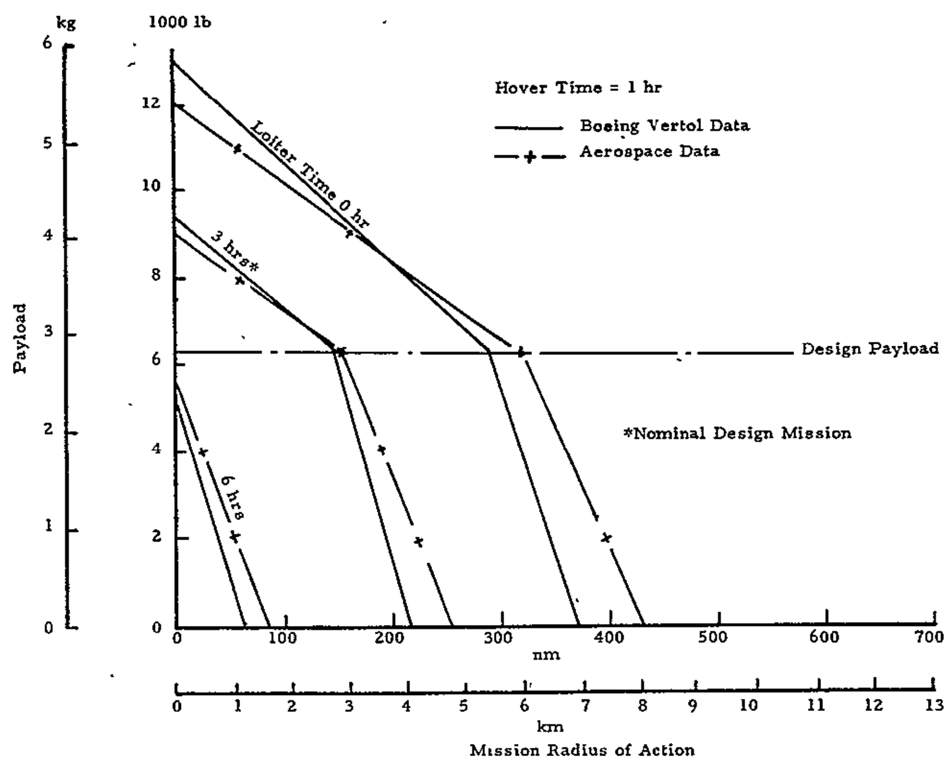


Figure A1-36 Advanced Helicopter Performance - Variations in Loiter Time

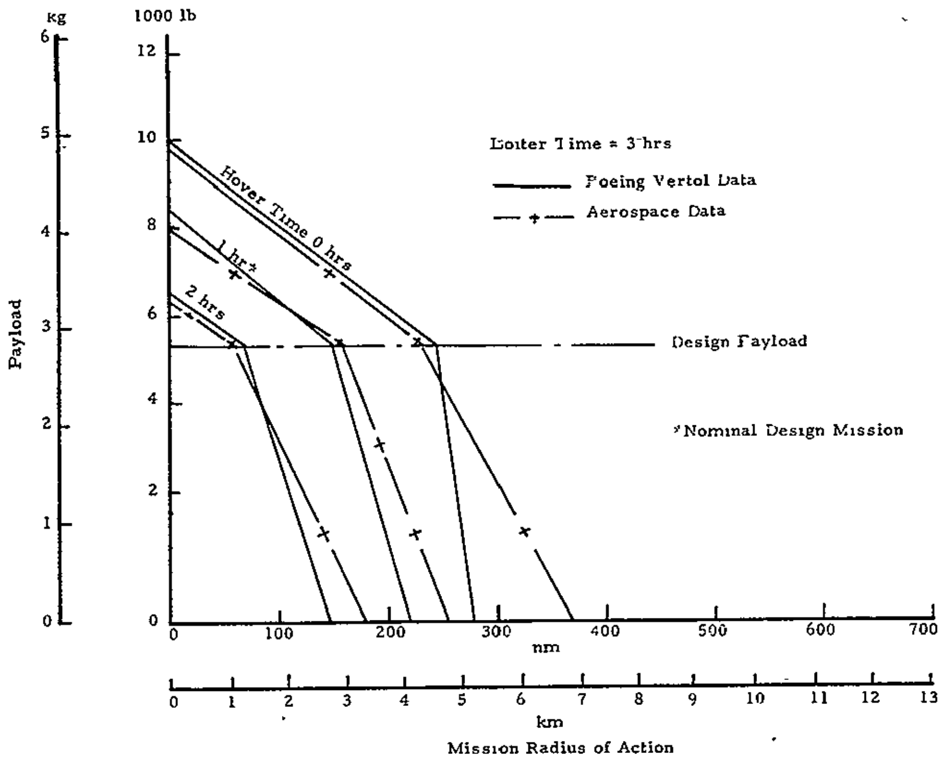


Figure A1-37 Advanced Helicopter Performance - Variation in Hover Time

A.2 MISSION ANALYSIS COMPUTER PROGRAM DOCUMENTATION

Formal documentation of computer programs developed during this study, and the programs themselves, are not deliverable items under the contract. Therefore, the documentation of this appendix is principally to provide the interested reader with additional detail of the programs, and to refresh operator understanding of these programs in the event of significant time lapses between use. It is written to fulfill those needs only, and does not attempt to conform to any standard specification in presentation of detail.

The programs were specified to provide a capability to solve mission analysis problems of a general nature. Since they were developed at the same time mission and aircraft were being defined, it was necessary to "second guess" what features would be required. As missions and aircraft definition became available, additional features were specified and added to the programs. Although all program features have been checked out, the missions defined in this study did not necessarily employ all of the programs' broad range of capabilities.

These programs were developed by Mr. Richard W. Bruce of The Aerospace Corporation. He may be contacted in the event that additional information regarding their development or operation is desired.

1.0 OVERVIEW

The following sections contain the technical descriptions of the computer programs developed to analyze the aircraft and mission combinations. These programs have been written in APL for use in an interactive mode of operation via a typewriter console. This interactive approach provides the user with an extremely versatile analysis capability by allowing modifications to aircraft or missions to be made within moments of the time the output results have been displayed. In this manner, parameter studies of a wide variety may be made on the spot by eliminating the long turnaround times more typical of batch computer operation.

Three basic programs have been developed. The first, program AIRCRAFT, serves as the input device for all necessary aircraft data to be later analyzed. The second, program MISSION, plays a similar role for all necessary mission data. The last, program FLIES, provides the bridge to merge any aircraft with any mission, and also provides the analysis of the characteristics, performance, and economics of the combination.

All three programs are simple to operate, and take only a few seconds of computer central processor time. However, the mathematical treatment used in the merge analysis in program FLIES is quite sophisticated and provides results with demonstrated accuracy.

2.0 PROGRAM AIRCRAFT

2.1 Purpose

Program AIRCRAFT is an interactive program written in APL designed to serve as the mechanism for inputting and storing all necessary aircraft configuration, performance, and cost data which will later be analyzed. Everything that must be known about the aircraft to be analyzed is systematically requested of the user and then stored via program AIRCRAFT under a designated I.D. Program AIRCRAFT performs a task analogous to that of manually filling out load sheets for use as input to a batch (e.g. FORTRAN) computer program. But AIRCRAFT does it automatically by prompting the user to input requested data in an interactive manner. In summary, program AIRCRAFT performs the following:

a) Interactively requests all required aircraft configuration, performance, and cost data needed for analysis.

b) Assigns desired I.D. to aircraft.

c) Stores the aircraft data in the computer system in a form suitable for analysis.

d) Provides a hard copy of all the data suitable for recording and publishing.

2.2 Input/Output

The Input/Output of program AIRCRAFT is accomplished via a typewriter console which has been connected to a computer with an APL compiler. Upon execution of AIRCRAFT (see Sect. 2.5) the first data entry will be requested of the user via the console. When the first data entry is completed, the program will request the second data entry and so on until the user is notified that all required aircraft inputs are complete.

Shown in Table 2.1 is a typical Input/Output for program AIRCRAFT. All of the information to the left of the equal signs (=) comprises the requests by program AIRCRAFT to the user. All information to the right comprises the user responses to the requests. Table 2.1 represents the actual hard copy product of program AIRCRAFT since it identifies all the data together with the designated aircraft I.D. This output is suitable for use as a record of this particular aircraft's configuration, performance, and cost coefficients and can be included in published reports if desired.

For analysis purposes, however, the data are stored in the computer disc file for later use in the form of a vector whose elements contain the aircraft data in known locations (see Sect's. 2.3 and 2.4). The vector corresponding to the aircraft described here is shown in Table 2.2 and can be called up at any time by simply typing in the aircraft I.D., in this case TILTROTOR.

2.3 Nomenclature - Symbols and Subprograms

Program AIRCRAFT performs virtually no mathematical operations and therefore requires very few symbols. There are no subprograms contained in AIRCRAFT. A number of symbols have been created for identification or bookkeeping purposes, however, such as those that are shown in Table 2.1. For example,

WTO = Normal Mode Maximum Takeoff Weight - lbs.

WXL = Alternate Mode Maximum Takeoff Weight - lbs.

etc.

```
AIRCRAFT


INPUT THE FOLLOWING AIRCRAFT PARAMETERS AS REQUESTED.
IF NOT APPLICABLE, ENTER ZERO.


  NORMAL MODE MAXIMUM TAKEOFF WEIGHT - LBS.      WTO=33000

  ALTERNATE MODE MAXIMUM TAKEOFF WEIGHT - LBS.   WXL=33000

  OPERATING WEIGHT EMPTY - LBS.                  WEM=18738

  MAXIMUM PASSENGER CAPACITY - NO.               PMX=23

  MAXIMUM FUEL CAPACITY - GALS.                  MFC=1140
```

Table 2.1 Program AIRCRAFT Input/Output

```
CLIMB SPEED,VCL,IN KNOTS FOR GIVEN ALTITUDE
H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:

VCL = V1 + V2×H + V3×W    ;   NORMAL MODE

VCL = V4 + V5×H + V6×W    ;   ALTERNATE MODE

     ENTER V1 - KTS.                          V1=112

     ENTER V2 - KTS./FT.                      V2= 003

     ENTER V3 - KTS./LB.                      V3=.00339

     ENTER V4 - KTS.                          V4=112

     ENTER V5 - KTS./FT.                      V5=.003

     ENTER V6 - KTS./LB.                      V6=.00339
```

Table 2.1 Cont.

```
CRUISE SPEED,VCR,IN KNOTS FOR GIVEN ALTITUDE
H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:

VCR = V7 + V8×H + V9×W     ;   NORMAL MODE
                                            ;  H < H1
VCR = V10 + V11×H + V12×W ;   ALTERNATE MODE

VCR = V16 + V17×H + V18×W                   ;  H ≥ H1

     ENTER H1 - FT.                              H1=16000

     ENTER V7 - KTS.                             V7=396

     ENTER V8 - KTS./FT.                         V8=¯.001396

     ENTER V9 - KTS./LB.                         V9=¯.003

     ENTER V10 - KTS.                           V10=¯2

     ENTER V11 - KTS./FT.                       V11=.00629

     ENTER V12 - KTS./LB.                       V12=.00667

     ENTER V16 - KTS.                           V16=611

     ENTER V17 - KTS./FT.                       V17=¯.00736

     ENTER V18 - KTS./LB.                       V18=¯.0073606
```

Table 2.1 Cont.

```
SEARCH SPEED,VLS,IN KNOTS FOR GIVEN ALTITUDE
H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:

VLS = V13 + V14×H + V15×W

     ENTER V13 - KTS.                                V13=22

     ENTER V14 - KTS./FT.                            V14=.00277

     ENTER V15 - KTS./LB.                            V15=.00381


RATE OF CLIMB,ROC,IN FEET PER MINUTE FOR GIVEN ALTITUDE
H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:

ROC = R1 + R2×H + R3×W    ;   NORMAL MODE

ROC = R4 + R5×H + R6×W    ;   ALTERNATE MODE

     ENTER R1 - FT./MIN.                             R1=7757

     ENTER R2 - FT./MIN./FT.                         R2=¯.1389

     ENTER R3 - FT./MIN./LB.                         R3=¯.1464[illegible]

     ENTER R4 - FT./MIN.                             R4=7757

     ENTER R5 - FT./MIN./FT.                         R5=¯.1389

     ENTER R6 - FT./MIN./LB.                         R6=¯.1464[illegible]
```

Table 2.1 Cont.

RATE OF DESCENT,ROD,IN FEET PER MINUTE IS:

ROD = R7 ; NORMAL MODE

ROD = R8 ; ALTERNATE MODE

ENTER R7(AS POSITIVE VALUE) - FT./MIN	R7=1000
ENTER R8(AS POSITIVE VALUE) - FT./MIN.	R8=1500

IDLE AND TAXI FUEL CONSUMPTION,FIT,IN POUNDS PER MINUTE FOR GIVEN ALTITUDE,H,IN FEET IS:

FIT = K1 + K2×H

ENTER K1 - LBS./MIN.	K1=5.6
ENTER K2 - LBS /MIN./FT.	K2=0

Table 2.1 Cont.

```
TAKEOFF FUEL CONSUMPTION,FTO,IN POUNDS PER MINUTE FOR GIVEN
ALTITUDE,H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:

FTO = K3 + K4×H + K5×W    ;   NORMAL MODE

FTO = K6 + K7×H + K8×W    ;   ALTERNATE MODE

     ENTER K3 - LBS./MIN.                         K3=38

     ENTER K4 - LBS./MIN./FT.                     K4=¯.00085

     ENTER K5 - LBS./MIN./LB.                     K5=0

     ENTER K6 - LBS./MIN.                         K6=38

     ENTER K7 - LBS./MIN./FT.                     K7=¯.00085

     ENTER K8 - LBS./MIN./LB                      K8=0


CLIMB FUEL CONSUMPTION,FCL,IN POUNDS PER MINUTE FOR GIVEN
ALTITUDE,H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:

FCL = K9 + K10×H + K11×W     ;   NORMAL MODE

FCL = K12 + K13×H + K14×W    ;   ALTERNATE MODE

     ENTER K9 - LBS./MIN.                         K9=38

     ENTER K10 - LBS./MIN./FT.                   K10=¯.00085

     ENTER K11 - LBS./MIN./LB.                   K11=0

     ENTER K12 - LBS./MIN.                       K12=38

     ENTER K13 - LBS./MIN./FT.                   K13=¯.00085

     ENTER K14 - LBS./MIN./LB.                   K14=0
```

Table 2.1 Cont.

```
CRUISE FUEL CONSUMPTION,FCR,IN POUNDS PER MINUTE FOR GIVEN
ALTITUDE,H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:

FCR = K15 + K16×H + K17×W ;   NORMAL MODE
                                           ;  H < H1
FCR = K18 + K19×H + K20×W ;   ALTERNATE MODE

FCR = K27 + K28×H + K29×W                  ;  H ≥ H1

     ENTER K15 - LBS./MIN.                       K15=35

     ENTER K16 - LBS./MIN./FT.                   K16=¯.0007245

     ENTER K17 - LBS./MIN./LB.                   K17=0

     ENTER K18 - LBS./MIN.                       K18=¯12

     ENTER K19 - LBS./MIN./FT.                   K19=.000217

     ENTER K20 - LBS./MIN./LB.                   K20=.00119

     ENTER K27 - LBS./MIN.                       K27=35

     ENTER K28 - LBS./MIN./FT.                   K28=¯.0007245

     ENTER K29 - LBS./MIN./LB.                   K29=0
```

Table 2.1 Cont.

HOVER FUEL CONSUMPTION,FHO,IN POUNDS PER MINUTE FOR GIVEN
ALTITUDE,H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:

FHO = K21 + K22×H + K23×W

ENTER K21 - LBS./MIN. K21=4.78

ENTER K22 - LBS./MIN./FT. K22=¯.00082216

ENTER K23 - LBS./MIN./LB. K23=.00089864

LOITER/SEARCH FUEL CONSUMPTION,FLS,IN POUNDS PER MINUTE FOR
GIVEN ALTITUDE,H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:

FLS = K24 + K25×H + K26×W

ENTER K24 - LBS./MIN. K24=¯6

ENTER K25 - LBS./MIN./FT. K25=.000236

ENTER K26 - LBS./MIN./LB. K26= 000794

Table 2.1 Cont.

AIRCRAFT COST NEW - DOLLARS	CAC=2830000
AUXILIARY EQUIPMENT COST - DOLLARS	CAX=50000
INSURANCE PREMIUM - PERCENT VALUE/YEAR	INS=8
CREW SALARY - DOLLARS/YEAR EACH	SCR=20000
MAINTENANCE,LABOR - HRS./FLT.HR.	MLA=0
MAINTENANCE,PARTS - DOLLARS/FLT.HR.	MPT=300
NOMINAL FLIGHT CREW (W/O EXTRAS) - NO.	NFC=2
TYPE FUEL USED - ENTER AVGAS OR JP	TPF=JP
FUEL COST - DOLLARS/GAL.	CFL=.5
LUBRICATION COST - DOLLARS/HR.	CLU=1

Table 2.1 Cont.

IS NORMAL MODE FUEL CONSUMPTION TO
BE USED TO COMPUTE FUEL RESERVE?
ENTER YES OR NO NMF=NO

AIRCRAFT SERVICE CEILING ALTITUDE,HSC,IN FEET
FOR GIVEN AIRCRAFT WEIGHT,W,IN POUNDS IS:

HSC = Y1 + Y2×W

ENTER Y1 - FT. Y1=54333

ENTER Y2 - FT./LB. Y2=¯1.1111

ENTER THE DESIGNATED I.D. FOR THIS AIRCRAFT AID=TILTROTOR

ALL REQUIRED AIRCRAFT INPUTS ARE NOW COMPLETE.

Table 2.1 Cont.

```
      TILTROTOR
33000 33000 18738 23 1140 112 0.003 0.00339 112 0.003 0.00339 396 ¯0.001396 ¯0.003 ¯2 0.00629 0.00667 22
      0.00277 0.00381 7757 ¯0.1389 ¯0.14644 7757 ¯0.1389 ¯0.14644 1000 1500 5.6 0 38 ¯0.00085 0 38 ¯0.00085
      0 38 ¯0.00085 0 38 ¯0.00085 0 35 ¯0.0007245 0 ¯12 0.000217 0.00119 4.78 ¯0.00082216 0.00089864 ¯6 0.000236
      0.000794 2830000 50000 8 20000 0 300 2 1 0.5 1 0 1.01 54333 ¯1.1111 16000 611 ¯0.00736 ¯0.0073606 35
      ¯0.0007245 0
```

Table 2.2 Data Vector Stored by Program AIRCRAFT

The total list of bookkeeping symbols is defined in Table 2. 1 and therefore does not need to be redefined here.

2.4 Detailed Description

Program AIRCRAFT has been written in APL to operate in an interactive mode via a typewriter console in communication with a computer. The purpose of this description is to detail the specific operation of this program and equations used without getting into the details of APL programming. AIRCRAFT has no equations to be solved which makes it rather simple to describe under these ground rules. For the record, a copy of program AIRCRAFT is contained in Table 2. 3 and will present no difficulty in being understood by someone familiar with APL.

Basically, upon execution of AIRCRAFT, a 75 element vector, AID, is set up, and requests for data from the user begin. As the desired data are entered they are systematically placed in designated locations in AID. For example, WTO is placed in AID [1] , WXL in AID [2] , etc. These locations are evident by inspection of the program listing in Table 2. 3. When all the required data has been entered, an aircraft I. D. is requested, i. e., TILTROTOR. The program then terminates and the data may be saved for later use.

A complete description of the way the aircraft configuration, performance, and cost data are used is contained in Sect. 4. What is meant by some of the data required, e. g. Alternate Mode Maximum Takeoff Weight, is described in Sect. 4 as well. It may provide some clarification at this point, however, to note that the general aircraft performance equations describing speed and fuel consumption are represented as linear functions of altitude and aircraft weight. For example,

$$VCL = V1 + V2 \cdot H + V_3 \cdot W$$

where

VCL = climb speed - knots

H = altitude - feet

W = aircraft weight - lbs

$V1, V2, V3$ = empirical coefficient

2.5 Execution of Program

Program AIRCRAFT is executed by simply typing AIRCRAFT on the APL console. The program then carries the user through its operation in an interactive manner. The user need only to have the desired aircraft data inputs at his disposal to be entered as requested by the program.

```
     ∇ AIRCRAFT
[1]    JP←1
[2]    AVGAS←0
[3]    AID←⍳75
[4]    AID[]←0
[5]    AID[66]←1
[6]    YES←1
[7]    NO←0
[8]    ''
[9]    ''
[10]   ''
[11]   ''
[12]   ''
[13]   ''
[14]   ''
[15]   'INPUT THE FOLLOWING AIRCRAFT PARAMETERS AS REQUESTED.'
[16]   'IF NOT APPLICABLE, ENTER ZERO.'
[17]   ''
[18]   ''
[19]   ''
[20]   ''
[21]   ''
[22]   ⍞←'      NORMAL MODE MAXIMUM TAKEOFF WEIGHT - LBS.       WTO='
[23]   AID[1]←⍎⍞
[24]   ''
[25]   ''
[26]   ⍞←'      ALTERNATE MODE MAXIMUM TAKEOFF WEIGHT - LBS.    WXL='
[27]   AID[2]←⍎⍞
[28]   ''
[29]   ''
[30]   ⍞←'      OPERATING WEIGHT EMPTY - LBS                    WEM='
```

Table 2.3 Program AIRCRAFT Listing

```
[31]  AID[3]←⍎⎕
[32]  ''
[33]  ''
[34]  ⎕←'     MAXIMUM PASSENGER CAPACITY - NO.                         PNX='
[35]  AID[4]←⍎⎕
[36]  ''
[37]  ''
[38]  ⎕←'     MAXIMUM FUEL CAPACITY - GALS.                            MFC='
[39]  AID[5]←⍎⎕
[40]  ''
[41]  ''
[42]  ''
[43]  'CLIMB SPEED,VCL,IN KNOTS FOR GIVEN ALTITUDE'
[44]  'H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:'
[45]  ''
[46]  ''
[47]  'VCL = V1 + V2×H + V3×W   ;   NORMAL MODE'
[48]  ''
[49]  'VCL = V4 + V5×H + V6×W   ;   ALTERNATE MODE'
[50]  ''
[51]  ⎕←'     ENTER V1 - KTS.                                           V1='
[52]  AID[6]←⍎⎕
[53]  ''
[54]  ⎕←'     ENTER V2 - KTS./FT.                                       V2='
[55]  AID[7]←⍎⎕
[56]  ''
[57]  ⎕←'     ENTER V3 - KTS./LB.                                       V3='
[58]  AID[8]←⍎⎕
[59]  ''
[60]  ⎕←'     ENTER V4 - KTS.                                           V4='
```

Table 2.3   Cont.

```
[61]  AID[9]←⍎⍞
[62]  ''
[63]  ⍞←'      ENTER V5 - KTS./FT.                                V5='
[64]  AID[10]←⍎⍞
[65]  ''
[66]  ⍞←'      ENTER V6 - KTS./LB.                                V6='
[67]  AID[11]←⍎⍞
[68]  ''
[69]  ''
[70]  ''
[71]  ''
[72]  'CRUISE SPEED,VCR,IN KNOTS FOR GIVEN ALTITUDE'
[73]  'H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:'
[74]  ''
[75]  ''
[76]  'VCR = V7 + V8×H + V9×W    ;   NORMAL MODE'
[77]  '                                              ;  H < H1'
[78]  'VCR = V10 + V11×H + V12×W ;   ALTERNATE MODE'
[79]  ''
[80]  'VCR = V16 + V17×H + V18×W                     ;  H ≥ H1'
[81]  ''
[82]  ⍞←'      ENTER H1 - FT.                                     H1='
[83]  AID[69]←⍎⍞
[84]  ''
[85]  ⍞←'      ENTER V7 - KTS.                                    V7='
[86]  AID[12]←⍎⍞
[87]  ''
[88]  ⍞←'      ENTER V8 - KTS./FT.                                V8='
[89]  AID[13]←⍎⍞
[90]  ''
```

Table 2.3 Cont.

```
⍞←'      ENTER V9 - KTS./LB.                                        V9='
AID[14]←⍎⍞
''
⍞←'      ENTER V10 - KTS.                                           V10='
AID[15]←⍎⍞
''
⍞←'      ENTER V11 - KTS./FT.                                       V11='
AID[16]←⍎⍞
''
⍞←'      ENTER V12 - KTS./LB.                                       V12='
AID[17]←⍎⍞
''
⍞←'      ENTER V16 - KTS.                                           V16='
AID[70]←⍎⍞
''
⍞←'      ENTER V17 - KTS./FT.                                       V17='
AID[71]←⍎⍞
''
⍞←'      ENTER V18 - KTS./LB.                                       V18='
AID[72]←⍎⍞
''
''
''
'SEARCH SPEED,VLS,IN KNOTS FOR GIVEN ALTITUDE'
'H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:'
''
''
'VLS = V13 + V14×H + V15×W'
''
⍞←'      ENTER V13 - KTS.                                           V13='
```

Table 2.3 Cont.

```
AID[18]←⍎⍞
''
⍞←'     ENTER V14 - KTS./FT.                                       V14='
AID[19]←⍎⍞
''
⍞←'     ENTER V15 - KTS./LB.                                       V15='
AID[20]←⍎⍞
''
''
''
'RATE OF CLIMB,ROC,IN FEET PER MINUTE FOR GIVEN ALTITUDE'
'H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:'
''
''
'ROC = R1 + R2×H + R3×W   ;   NORMAL MODE'
''
'ROC = R4 + R5×H + R6×W   ;   ALTERNATE MODE'
''
⍞←'     ENTER R1 - FT./MIN.                                          R1='
AID[21]←⍎⍞
''
⍞←'     ENTER R2 - FT./MIN./FT                                       R2='
AID[22]←⍎⍞
''
⍞←'     ENTER R3 - FT./MIN./LB                                       R3='
AID[23]←⍎⍞
''
⍞←'     ENTER R4 - FT./MIN.                                          R4='
AID[24]←⍎⍞
''
```

Table 2.3 Cont.

```
[151] ⍞←'      ENTER R5 - FT./MIN./FT.                             R5='
[152] AID[25]←⍎⍞
[153] ''
[154] ⍞←'      ENTER R6 - FT./MIN./LB.                             R6='
[155] AID[26]←⍎⍞
[156] ''
[157] ''
[158] ''
[159] 'RATE OF DESCENT,ROD,IN FEET PER MINUTE IS:'
[160] ''
[161] ''
[162] 'ROD = R7    ;    NORMAL MODE'
[163] ''
[164] 'ROD = R8    ;    ALTERNATE MODE'
[165] ''
[166] ⍞←'      ENTER R7(AS POSITIVE VALUE) - FT./MIN.              R7='
[167] AID[27]←⍎⍞
[168] ''
[169] ⍞←'      ENTER R8(AS POSITIVE VALUE) - FT./MIN.              R8='
[170] AID[28]←⍎⍞
[171] ''
[172] ''
[173] ''
[174] 'IDLE AND TAXI FUEL CONSUMPTION,FIT,IN POUNDS PER'
[175] 'MINUTE FOR GIVEN ALTITUDE,H,IN FEET IS:'
[176] ''
[177] ''
[178] 'FIT = K1 + K2×H'
[179] ''
[180] ⍞←'      ENTER K1 - LBS./MIN.                                K1='
```

Table 2.3 Cont.

```
[181] AID[29]←⍎⍞
[182] ''
[183] ⍞←'      ENTER K2 - LBS./MIN./FT:                          K2='
[184] AID[30]←⍎⍞
[185] ''
[186] ''
[187] ''
[188] 'TAKEOFF FUEL CONSUMPTION,FTO,IN POUNDS PER MINUTE FOR GIVEN'
[189] 'ALTITUDE,H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:'
[190] ''
[191] ''
[192] 'FTO = K3 + K4×H + K5×W    ;   NORMAL MODE'
[193] ''
[194] 'FTO = K6 + K7×H + K8×W    ;   ALTERNATE MODE'
[195] ''
[196] ⍞←'      ENTER K3 - LBS./MIN.                              K3='
[197] AID[31]←⍎⍞
[198] ''
[199] ⍞←'      ENTER K4 - LBS./MIN./FT.                          K4='
[200] AID[32]←⍎⍞
[201] ''
[202] ⍞←'      ENTER K5 - LBS./MIN./LB.                          K5='
[203] AID[33]←⍎⍞
[204] ''
[205] ⍞←'      ENTER K6 - LBS./MIN.                              K6='
[206] AID[34]←⍎⍞
[207] ''
[208] ⍞←'      ENTER K7 - LBS./MIN./FT.                          K7='
[209] AID[35]←⍎⍞
[210] ''
```

Table 2.3 . Cont.

```
⍞←'      ENTER K8 - LBS./MIN./LB.                                    K8='
AID[36]←⍎⍞
''
''
''
'CLIMB FUEL CONSUMPTION,FCL,IN POUNDS PER MINUTE FOR GIVEN'
'ALTITUDE,H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:'
''
''
'FCL = K9 + K10×H + K11×W     ;   NORMAL MODE'
''
'FCL = K12 + K13×H + K14×W    ;   ALTERNATE MODE'
''
⍞←'      ENTER K9 - LBS./MIN.                                        K9='
AID[37]←⍎⍞
''
⍞←'      ENTER K10 - LBS./MIN./FT                                   K10='
AID[38]←⍎⍞
''
⍞←'      ENTER K11 - LBS./MIN./LB                                   K11='
AID[39]←⍎⍞
''
⍞←'      ENTER K12 - LBS./MIN.                                      K12='
AID[40]←⍎⍞
''
⍞←'      ENTER K13 - LBS./MIN./FT                                   K13='
AID[41]←⍎⍞
''
⍞←'      ENTER K14 - LBS./MIN./LB                                   K14='
AID[42]←⍎⍞
```

Table 2.3 Cont.

```
''
''
''
'CRUISE FUEL CONSUMPTION,FCR,IN POUNDS PER MINUTE FOR GIVEN'
'ALTITUDE,H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:'
''
''
'FCR = K15 + K16×H + K17×W ;   NORMAL MODE'
'                                                   ;  H < H1'
'FCR = K18 + K19×H + K20×W ;   ALTERNATE MODE'
''
'FCR = K27 + K28×H + K29×W                          ;  H ≥ H1'
''
⍞←'     ENTER K15 - LBS./MIN.                            K15='
AID[43]←⍎⍞
''
⍞←'     ENTER K16 - LBS./MIN./FT.                        K16='
AID[44]←⍎⍞
''
⍞←'     ENTER K17 - LBS./MIN./LB.                        K17='
AID[45]←⍎⍞
''
⍞←'     ENTER K18 - LBS./MIN.                            K18='
AID[46]←⍎⍞
''
⍞←'     ENTER K19 - LBS./MIN./FT.                        K19='
AID[47]←⍎⍞
''
⍞←'     ENTER K20 - LBS./MIN./LB.                        K20='
AID[48]←⍎⍞
```

Table 2.3   Cont.

```
[271] ''
[272] ⍞←'       ENTER K27 - LBS./MIN.                                   K27='
[273] AID[73]←⍎⍞
[274] ''
[275] ⍞←'       ENTER K28 - LBS./MIN./FT.                               K28='
[276] AID[74]←⍎⍞
[277] ''
[278] ⍞←'       ENTER K29 - LBS./MIN./LB.                               K29='
[279] AID[75]←⍎⍞
[280] ''
[281] ''
[282] ''
[283] 'HOVER FUEL CONSUMPTION,FHO,IN POUNDS PER MINUTE FOR GIVEN'
[284] 'ALTITUDE,H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:'
[285] ''
[286] ''
[287] 'FHO = K21 + K22×H + K23×W'
[288] ''
[289] ⍞←'       ENTER K21 - LBS./MIN.                                   K21='
[290] AID[49]←⍎⍞
[291] ''
[292] ⍞←'       ENTER K22 - LBS./MIN./FT.                               K22='
[293] AID[50]←⍎⍞
[294] ''
[295] ⍞←'       ENTER K23 - LBS./MIN./LB.                               K23='
[296] AID[51]←⍎⍞
[297] ''
[298] ''
[299] ''
[300] 'LOITER/SEARCH FUEL CONSUMPTION,FLS,IN POUNDS PER MINUTE FOR'
```

Table 2.3 Cont.

```
[301] 'GIVEN ALTITUDE,H,IN FEET AND AIRCRAFT WEIGHT,W,IN POUNDS IS:'
[302] ''
[303] ''
[304] 'FLS = K24 + K25×H + K26×W
[305] ''
[306] ⍞←'      ENTER K24 - LBS./M.                              K24='
[307] AID[52]←⍎⍞
[308] ''
[309] ⍞←'      ENTER K25 - LBS./MIN./FT.                        K25='
[310] AID[53]←⍎⍞
[311] ''
[312] ⍞←'      ENTER K26 - LBS./MIN./LB.                        K26='
[313] AID[54]←⍎⍞
[314] ''
[315] ''
[316] ''
[317] ''
[318] ⍞←'      AIRCRAFT COST NEW - DOLLARS                      CAC='
[319] AID[55]←⍎⍞
[320] ''
[321] ''
[322] ⍞←'      AUXILIARY EQUIPMENT COST - DOLLARS               CAX='
[323] AID[56]←⍎⍞
[324] ''
[325] ''
[326] ⍞←'      INSURANCE PREMIUM - PERCENT VALUE/YEAR           INS='
[327] AID[57]←⍎⍞
[328] ''
[329] ''
[330] ⍞←'      CREW SALARY - DOLLARS/YEAR EACH                  SCR='
```

Table 2.3 Cont.

```
[331] AID[58]←⍎⍞
[332] ''
[333] ''
[334] ⍞←'      MAINTENANCE,LABOR - HRS./FLT.HR.                    MLA='
[335] AID[59]←⍎⍞
[336] ''
[337] ''
[338] ⍞←'      MAINTENANCE,PARTS - DOLLARS/FLT.HR.                 MPT='
[339] AID[60]←⍎⍞
[340] ''
[341] ''
[342] ⍞←'      NOMINAL FLIGHT CREW (W/O EXTRAS) - NO               NFC='
[343] AID[61]←⍎⍞
[344] ''
[345] ''
[346] ⍞←'      TYPE FUEL USED -'ENTER AVGAS OR JP                  TPF='
[347] AID[62]←⍎⍞
[348] ''
[349] ''
[350] ⍞←'      FUEL COST - DOLLARS/GAL.                            CFL='
[351] AID[63]←⍎⍞
[352] ''
[353] ''
[354] ⍞←'      LUBRICATION COST - DOLLARS/HR.                      CLU='
[355] AID[64]←⍎⍞
[356] ''
[357] ''
[358] '     IS NORMAL MODE FUEL CONSUMPTION TO'
[359] '     BE USED TO COMPUTE FUEL RESERVE?'
[360] ⍞←'      ENTER YES OR NO                                     NMF='
```

Table 2.3   Cont.

```
[361] AID[65]←⍎⍞
[362] ''
[363] ''
[364] 'AIRCRAFT SERVICE CEILING ALTITUDE,HSC,IN FEET'
[365] 'FOR GIVEN AIRCRAFT WEIGHT,W,IN POUNDS IS:'
[366] ''
[367] ''
[368] 'HSC = Y1 + Y2×W'
[369] ''
[370] ⍞←'      ENTER Y1 - FT.                                    Y1='
[371] AID[67]←⍎⍞
[372] ''
[373] ⍞←'      ENTER Y2 - FT./LB.                                Y2='
[374] AID[68]←⍎⍞
[375] ''
[376] ''
[377] ''
[378] ''
[379] ''
[380] ⍞←'ENTER THE DESIGNATED I.D. FOR THIS AIRCRAFT           AID='
[381] ⍎⍞,'←AID'
[382] ''
[383] ''
[384] ''
[385] 'ALL REQUIRED AIRCRAFT INPUTS ARE NOW COMPLETE.'
[386] ''
[387] ''
[388] ''
[389] ''
      ∇
```

Table 2.3 Cont.

3.0 PROGRAM MISSION

3.1 Purpose

Program MISSION is an interactive program written in APL designed to serve as the mechanism for inputting and storing all necessary mission characteristics and data which will later be analyzed. Everything that must be known about the mission profile to be analyzed is systematically requested of the user and then stored via program MISSION under a designated I. D. Program MISSION performs a task analagous to that of manually filling out load sheets for use as input to a batch (e.g., FORTRAN) computer program. But MISSION does it automatically by prompting the user to input requested data in an interactive manner. In summary, program MISSION performs the following:

a) Interactively requests all required mission characteristics and data needed for analysis.

b) Assigns desired I. D. to mission.

c) Stores the mission data in the computer system in a form suitable for analysis.

d) Provides a hard copy of all the mission profile data suitable for recording and publishing.

3.2 Input/Output

The Input/Output of program MISSION is accomplished via a typewriter console which has been connected to a computer with an APL compiler. Upon execution of MISSION (see Sect. 3.5) the first data entry will be requested of the user via the console. When the first data entry is completed, the program will request the second data entry, and so on, until the user is notified that all required mission profile inputs are complete.

The mission profile is comprised of mission segments shown in Table 3.1 which can be arranged in any desired order and repeated in any desired manner. The mission profile is communicated to the program by the use of segment I.D.'s shown in this table. For example, if the desired mission is a LOAD followed by WARMUP, TAXI, CONVENTIONAL TAKEOF ENROUTE, and CONVENTIONAL LAND, the I.D. sequence 1, 2, 3, 4, 7, 9 would be specified. If the mission is one in which the same sequence of segments is repeated a number of times a convenient option exists to accomplish this in the program without having to re-input the repeated segments over and over again. For example, if the mission profile is,

V/STOL SEGMENT	SEGMENT I.D.	
LOAD	1	
WARMUP	2	
TAXI	3	
SHORT TAKEOFF	5	
ENROUTE	7	
SHORT LAND	10	
SHORT TAKEOFF	5	3 repeats of previous 3 segments
ENROUTE	7	
SHORT LAND	10	
SHORT TAKEOFF	5	
ENROUTE	7	
SHORT LAND	10	
SHORT TAKEOFF	5	
ENROUTE	7	
SHORT LAND	10	
UNLOAD	12	

the simplified input option used to replace the above segment I.D. string is,

V/STOL MISSION SEGMENT	SEGMENT I.D
LOAD	1
WARMUP	2
TAXI	3
CONVENTIONAL TAKEOFF	4
SHORT TAKEOFF	5
VERTICAL TAKEOFF	6
ENROUTE*	7
DESCENT**	8
CONVENTIONAL LAND	9
SHORT LAND	10
VERTICAL LAND	11
UNLOAD	12
REFUEL	13
LOITER	14
HOVER	15
SEARCH	16
STANDBY	17
INACTIVE	18

*ENROUTE INCLUDES MANEUVERING,CLIMB,
CRUISE, AND DESCENT

**DESCENT SEGMENT IS ONLY TO BE USED
FOLLOWING LOITER,HOVER,OR SEARCH

Table 3.1 Mission Segments and Segment I.D.'s

1	1st part of mission
2	
3	
5	
7	
10	
99	99 character signals a repeat.
3	3 designates number of previous segments to be repeated.
3	3 designates number of times previous 3 will be repeated.
12	Conclusion of mission.

Shown in Table 3.2 is the Input/Output for program MISSION. The Input/Output is shown for all 18 mission segments that can be used to construct a mission to illustrate the type of mission data required for each segment. The 18 segment string illustrated does not, of course, represent a possible mission. All of the information to the left of the equal signs (=) comprises the requests by program MISSION to the user. All information to the right comprises the user responses to the requests. Table 3.1 represents the actual hard copy product of program MISSION since it identifies all the data together with the designated mission I.D. This output is suitable for use as a record of this particular mission's profile, characteristics, and cost, and can be included in published report if desired.

For analysis purposes, however, the data are stored in the computer disc file for later use in the form of a matrix whose elements contain the mission data in known locations (see Sect's. 3.3 and 3.4). The matrix corresponding to the mission segment string just described is shown in Table 3.3 and can be called up at any time by simply typing in the mission I.D., in this case DESCRIPTION.

```
MISSION 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18


INPUT THE FOLLOWING MISSION PARAMETERS AS REQUESTED:


SEGMENT NO. 1  LOAD

     TIME TO LOAD - MINUTES                                TLO=15
     PASSENGERS LOADED - NO.                               NPL=5
     CARGO LOADED - LBS.                                   WCL=2000
     IS AIRCRAFT CONFIGURATION NORMAL?
     ENTER YES OR NO                                       NAC=YES


SEGMENT NO. 2  WARMUP

     TIME TO WARMUP - MINUTES                              TWU=5


SEGMENT NO. 3  TA

     TIME TO TAXI - MINUTES                                TTX=2
```

Table 3.2   Program MISSION Input/Output

```
SEGMENT NO. 4  CONVENTIONAL TAKEOFF

     TIME TO TAKEOFF - MINUTES                          TTO=1
     ALTITUDE AT TAKEOFF - FEET                         HTO=0
     IS TAKEOFF MODE NORMAL?  ENTER YES OR NO           NTO=YES


SEGMENT NO. 5  SHORT TAKEOFF

     TIME TO TAKEOFF - MINUTES                          TTO=1
     ALTITUDE AT TAKEOFF - FEET                         HTO=0
     IS TAKEOFF MODE NORMAL?  ENTER YES OR NO           NTO=YES


SEGMENT NO. 6  VERTICAL TAKEOFF

     TIME TO TAKEOFF - MINUTES                          TTO=1
     ALTITUDE AT TAKEOFF - FEET                         HTO=0
     IS TAKEOFF MODE NORMAL?  ENTER YES OR NO           NTO=YES


SEGMENT NO. 7  ENROUTE

     ENROUTE DISTANCE - N.MI.                           XTR=100
     MAXIMUM ALTITUDE - FEET                            HMX=10000.
     MINIMUM ALTITUDE - FEET                            HMN=1000
     IS CLIMB MODE NORMAL?  ENTER YES OR NO             NCL=YES
     IS CRUISE MODE NORMAL?  ENTER YES OR NO            NCR=YES
     IS DESCENT MODE NORMAL?  ENTER YES OR NO           NDC=YES


SEGMENT NO. 8  DESCENT

     DESCENT DISTANCE - N.MI.                           XDC=10
```

Table 3.2   Cont'd.

SEGMENT NO. 9 CONVENTIONAL LAND

TIME TO LAND - MINUTES	TLD=1
ALTITUDE AT LANDING - FEET	HLD=0

SEGMENT NO. 10 SHORT LAND

TIME TO LAND - MINUTES	TLD=1
ALTITUDE AT LANDING - FEET	HLD=0

SEGMENT NO. 11 VERTICAL LAND

TIME TO LAND - MINUTES	TLD=1
ALTITUDE AT LANDING - FEET	HLD=0

SEGMENT NO. 12 UNLOAD

TIME TO UNLOAD - MINUTES	TUL=15
PASSENGERS UNLOADED - NO.	NPU=5
CARGO UNLOADED - LBS.	WCU=2000
IS AIRCRAFT CONFIGURATION NORMAL? ENTER YES OR NO	NAC=YES

SEGMENT NO. 13. REFUEL

TIME TO REFUEL - MINUTES	TRF=20
FILL TO MAXIMUM ALLOWABLE CAPACITY? ENTER YES OR NO	MXC=YES

Table 3.2 Cont'd.

SEGMENT NO. 14 LOITER

LOITER TIME - MINUTES	TLT=15
LOITER ALTITUDE - FEET	HLT=5000

SEGMENT NO. 15 HOVER

HOVER TIME - MINUTES	THO=5
HOVER ALTITUDE - FEET	HHO=0

SEGMENT NO. 16 SEARCH

SEARCH TIME - MINUTES	TSR=60
SEARCH ALTITUDE - FEET	HSR=1000

GMENT NO. 17 STANDBY

STANDBY TIME - MINUTES	TSB=45

SEGMENT NO. 18 INACTIVE

INACTIVE TIME - MINUTES	TIN=600

REQUIRED MISSION SEGMENT INPUTS ARE NOW COMPLETE.

Table 3.2 Cont'd.

IS AIRCRAFT FUELED TO MAXIMUM ALLOWABLE CAPACITY AT START OF MISSION? ENTER YES OR NO .	MAC=YES
ENTER AVERAGE DAILY HOURS AVAILABLE FOR OPERATIONS	OPS=16
IS MISSION HAZARDOUS? ENTER YES OR NO	HZM=NO
ENTER EXTRA CREW REQUIRED - NO.	EXC=0
ENTER REQUIRED FUEL RESERVE - MIN.	RSV=45
ENTER MISSION RELATED COSTS - DOLLARS/FLT.HR.	MRC=0
ENTER THE DESIGNATED I.D FOR THIS MISSION	MID=DESCRIPTION

ALL REQUIRED MISSION INPUTS ARE NOW COMPLETE.

Table 3.2 Cont'd.

DESCRIPTION

1	1	15	5	2000	1	0	0
2	2	5	0	0	0	0	0
3	3	2	0	0	0	0	0
4	4	1	0	0	0	1	0
5	5	1	0	0	0	1	0
6	6	1	0	0	0	1	0
7	7	100	10000	1000	1	1	1
8	8	10	0	0	0	0	0
9	9	1	0	0	0	0	0
10	10	1	0	0	0	0	0
11	11	1	0	0	0	0	0
12	12	15	-5	-2000	1	0	0
13	13	20	1	0	0	0	0
14	14	15	0	0	5000	0	0
15	15	5	0	0	0	0	0
16	16	60	0	0	1000	0	0
17	17	45	0	0	0	0	0
18	18	600	0	0	0	0	0
19	0	0	0	0	16	0	0
20	0	0	0	0	45	1	0

Table 3.3 Data Matrix Stored by Program MISSION

3.3 Nomenclature - Symbols and Subprograms

Program MISSION performs virtually no mathematical operations and therefore requires very few symbols. There are no subprograms contained in MISSION. A number of symbols have been created for identification or bookkeeping purposes, however, such as those that are shown in Table 3.2. For example,

TLO = Time to Load - Minutes

NPL = Passengers Loaded - No.

etc.

The total list of bookkeeping symbols is defined in Table 3.2 and therefore does not need to be redefined here.

3.4 Detailed Description

Program MISSION has been written in APL to operate in an interactive mode via a typewriter console in communication with a computer. The purpose of this description is to detail the specific operation of this program and equations used without getting into the details of APL programming. MISSION has no equations to be solved which makes it rather simple to describe under these ground rules. For the record, a copy of program MISSION is contained in Table 3.4 and will present no difficulty in being understood by someone familiar with APL.

Basically, upon execution of MISSION, an (NM + 2) x 8 matrix, MID, is set up (where NM is the number of segments in the mission to be characterized) and requests for data from the user begin. As the desired data are entered they are systematically placed in designated element locations in matrix MID. For example, TLO is placed in MID [J;3] and NPL is placed in MID [J; 4] where the row number J corresponds to the mission segment corresponding to a LOAD. These locations are evident by inspection of the program listing in Table 3.4. When all the required data has been entered, a mission I.D. is requested, e.g., DESCRIPTION. The program then terminates and the data may be saved for later use.

A complete description of the way the mission profile, characteristic, and cost data are used is contained in Sect. 4.

3.5 Execution of Program

Program MISSION is executed by typing MISSION followed by the numerical string corresponding to the mission segment I.D.'s desired on the APL console. The program then carries the user through its operation in an interactive manner. The user need only to have the desired mission data inputs at his disposal to be entered as requested by the program.

It is important to note that a mission must begin with a LOAD mission segment. This is required for purposes of initialization (see Sect. 4.4.1).

```
      ∇ MISSION OMS
[1]    YES←1
[2]    NO←0
[3]    NM←ρOMS
[4]    MM←NM+2
[5]    DIM←8×MM
[6]    MID←ιDIM
[7]    MID←(MM,8)ρMID
[8]    MID[;]←0
[9]    MID[;1]←ιMM
[10]   MID[;2]←OMS, 0 0
[11]   ''
[12]   ''
[13]   ''
[14]   ''
[15]   ''
[16]   ''
[17]   ''
[18]   ''
[19]   'INPUT THE FOLLOWING MISSION PARAMETERS AS REQUESTED:'
[20]   ''
[21]   J←1
[22]   TT←(∨/OMS=99
[23]   →C0×ι~TT
[24]   NM←NM-3
[25]   MM←NM+2
[26]   DIM←8×MM
[27]   MID←ιDIM
[28]   MID←(MM,8)ρM
[29]   MID[;]←0
[30]   MID[;1]←ιMM
```

Table 3.4   Program MISSION Listing

```
XXI←OMS⍳99
MID[MM;3]←XXI
MID[MM;4]←OMS[XXI+1
MID[MM;5]←OMS[XXI+2
B1←XXI-MID[MM;4]
B2←XXI-1
G←MID[MM;5]
OMS1←(XXI-1)↑OMS
OMS2←(XXI+2)↓OMS
OMS←OMS1,OMS2
MID[;2]←OMS, 0 0
''
''
'MISSION SEGMENTS ';B1;' THROUGH ';B2;' WILL BE CYCLED ';G;' TIMES.'
'CORRESPONDING MISSION PARAMETERS WILL BE INPUT ONLY ONCE.'
C0:''
''
'SEGMENT NO. ';J;'  ';SID[OMS[J];]
→(C1,C2,C3,C4,C4,C4,C5,C17,C6,C6,C6,C7,C8,C9,C10,C11,C12,C13)[OMS[J]]
C1:''
⍞←'     TIME TO LOAD - MINUTES                                  TLO='
MID[J;3]←⍎⍞
⍞←'     PASSENGERS LOADED - NO.                                 NPL='
MID[J;4]←⍎⍞
⍞←'     CARGO LOADED - LBS.                                     WCL='
MID[J;5]←⍎⍞
'     IS AIRCRAFT CONFIGURATION NORMAL?'
⍞←'     ENTER YES OR NO                                         NAC='
MID[J;6]←⍎⍞
''
```

Table 3.4   Cont'd.

```
[61]  →C0×ι(NM≥J←J+1)
[62]  →C14
[63] C2:''
[64]  ⍞←'      TIME TO WARMUP - MINUTES                              TWU='
[65]  MID[J;3]←⍎⍞
[66]  →C0×ι(NM≥J←J+1)
[67]  →C14
[68] C3:''
[69]  ⍞←'      TIME TO TAXI - MINUTES                                TTX='
[70]  MID[J;3]←⍎⍞
[71]  →C0×ι(NM≥J←J+1)
[72]  →C14
[73] C4:''
[74]  ⍞←'      TIME TO TAKEOFF - MINUTES                             TTO='
[75]  MID[J;3]←⍎⍞
[76]  ⍞←'      ALTITUDE AT TAKEOFF - FEET                            HTO='
[77]  MID[J;6]←⍎⍞
[78]  ⍞←'      IS TAKEOFF MODE NORMAL?  ENTER YES OR NO              NTO='
[79]  MID[J;7]←⍎⍞
[80]  →C0×ι(NM≥J←J+1)
[81]  →C14
[82] C5:''
[83]  ⍞←'      ENROUTE DISTANCE - N.MI.                              XTR='
[84]  MID[J;3]←⍎⍞
[85]  ⍞←'      MAXIMUM ALTITUDE - FEET                               HMX='
[86]  MID[J;4]←⍎⍞
[87]  ⍞←'      MINIMUM ALTITUDE - FEET                               HMN='
[88]  MID[J;5]←⍎⍞
[89]  ⍞←'      IS CLIMB MODE NORMAL?  ENTER YES OR NO                NCL='
[90]  MID[J;6]←⍎⍞
```

Table 3.4   Cont'd.

```
⍞←'      IS CRUISE MODE NORMAL?  ENTER YES OR NO        NCR='
MID[J;7]←⍎⍞
⍞←'      IS DESCENT MODE NORMAL?  ENTER YES OR NO       NDC='
MID[J;8]←⍎⍞
→C0×⍳(NM≥J←J+1)
→C14
C17:''
⍞←'      DESCENT DISTANCE - N.MI.                       XDC='
MID[J;3]←⍎⍞
→C0×⍳(NM≥J←J+1)
→C14
C6:''
⍞←'      TIME TO LAND - MINUTES                         TLD='
MID[J;3]←⍎⍞
⍞←'      ALTITUDE AT LANDING - FEET                     HLD='
MID[J;6]←⍎⍞
→C0×⍳(NM≥J←J+1)
→C14
C7:''
⍞←'      TIME TO UNLOAD - MINUTES                       TUL='
MID[J;3]←⍎⍞
⍞←'      PASSENGERS UNLOADED - NO.                      NPU='
MID[J;4]←-⍎⍞
⍞←'      CARGO UNLOADED - LBS.                          WCU='
MID[J;5]←-⍎⍞
'     IS AIRCRAFT CONFIGURATION NORMAL?'
⍞←'      ENTER YES OR NO                                NAC='
MID[J;6]←⍎⍞
''
→C0×⍳(NM≥J←J+1)
```

Table 3.4 Cont'd.

```
[121] →C14
[122]C8:''
[123] ⎕←'     TIME TO REFUEL - MINUTES                              TRF='
[124] MID[J;3]←⍎⎕
[125] ''
[126] '     FILL TO MAXIMUM ALLOWABLE'
[127] ⎕←'     CAPACITY?  ENTER YES OR NO                            MXC='
[128] MID[J;4]←⍎⎕
[129] →C15×⍳(MID[J;4]=1)
[130] ''
[131] ⎕←'     ENTER MINUTES OF FUEL DESIRED                         MFD='
[132] MID[J;5]←⍎⎕
[133]C15:→C0×⍳(NM≥J←J+1)
[134] →C14
[135]C9:''
[136] ⎕←'     LOITER TIME - MINUTES                                 TLT='
[137] MID[J;3]←⍎⎕
[138] ⎕←'     LOITER ALTITUDE - FEET                                HLT='
[139] MID[J;6]←⍎⎕
[140] →C0×⍳(NM≥J←J+1)
[141] →C14
[142]C10:''
[143] ⎕←'     HOVER TIME - MINUTES                                  THO='
[144] MID[J;3]←⍎⎕
[145] ⎕←'     HOVER ALTITUDE - FEET                                 HHO='
[146] MID[J;6]←⍎⎕
[147] →C0×⍳(NM≥J←J+1)
[148] →C14
[149]C11:''
[150] ⎕←'     SEARCH TIME - MINUTES                                 TSR='
```

Table 3.4   Cont'd.

```
[151] MID[J;3]←⍎⍞
[152] ⍞←'      SEARCH ALTITUDE - FEET                                  HSR='
[153] MID[J;6]←⍎⍞
[154] →C0×⍳(NM≥J←J+1)
[155] →C14
[156]C12:''
[157] ⍞←'      STANDBY TIME - MINUTES                                  TSB='
[158] MID[J;3]←⍎⍞
[159] →C0×⍳(NM≥J←J+1)
[160] →C14
[161]C13:''
[162] ⍞←'      INACTIVE TIME - MINUTES                                 TIN='
[163] MID[J;3]←⍎⍞
[164] →C0×⍳(NM≥J←J+1)
[165]C14:''
[166] ''
[167] ''
[168] ''
[169] 'REQUIRED MISSION SEGMENT INPUTS ARE NOW COMPLETE.'
[170] ''
[171] ''
[172] ''
[173] ''
[174] ''
[175] ''
[176] ''
[177] '    IS AIRCRAFT FUELED TO MAXIMUM ALLOWABLE'
[178] '    CAPACITY AT START OF MISSION?'
[179] ⍞←'     ENTER YES OR NO                                         MAC='
[180] MID[MM;7]←⍎⍞
```

Table 3.4   Cont'd.

```
[181] ''
[182] ''
[183] →C16×⍳(MID[MM;7]=1)
[184] '      ENTER MINUTES OF FUEL DESIRED'
[185] ⍞←'      AT START OF MISSION                                          MFD='
[186] MID[MM;8]←⍎⍞
[187] ''
[188] ''
[189]C16:'      ENTER AVERAGE DAILY HOURS'
[190] ⍞←'      AVAILABLE FOR OPERATIONS                                     OPS='
[191] MID[MM-1;6]←⍎⍞
[192] ''
[193] ''
[194] ⍞←'      IS MISSION HAZARDOUS?  ENTER YES OR NO                       HZM='
[195] MID[MM-1;3]←⍎⍞
[196] ''
[197] ''
[198] ⍞←'      ENTER EXTRA CREW REQUIRED - NO.                              EXC='
[199] MID[MM-1;4]←⍎⍞
[200] ''
[201] ''
[202] ⍞←'      ENTER REQUIRED FUEL RESERVE - MIN.                           RSV='
[203] MID[MM;6]←⍎⍞
[204] ''
[205] ''
[206] ⍞←'      ENTER MISSION RELATED COSTS - DOLLARS/FLT.HR.  MRC='
[207] MID[MM-1;5]←⍎⍞
[208] ''
[209] ''
[210] ''
```

Table 3.4 Cont'd

```
[211] ''
[212] ''
[213] ⍞←'ENTER THE DESIGNATED I.D. FOR THIS MISSION          MID='
[214] ⍎⍞,'←MID'
[215] ''
[216] ''
[217] ''
[218] 'ALL REQUIRED MISSION INPUTS ARE NOW COMPLETE.'
[219] ''
[220] ''
[221] ''
      ∇
```

Table 3.4 Cont'd

4.0 PROGRAM FLIES

4.1 Purpose

Program FLIES is an interactive program written in APL designed to merge and analyze the aircraft and mission data contained in programs AIRCRAFT and MISSION discussed in the previous sections. Program FLIES computes the distance, time, fuel consumption, and cost for a specified aircraft to perform a specified mission. It presents a complete running and summary account of all important parameters of the merged aircraft and mission combination to enable performance and cost analyses and comparisons to be made. In summary, program FLIES performs the following:

a) Merges the aircraft and mission.

b) Computes performance and costs.

c) Provides diagnostic information such as, RAN OUT OF GAS, MINIMUM ALTITUDE NOT ATTAINED, etc., to aid program user to make required modifications.

d) Provides a hard copy of all the data suitable for recording and publishing.

4.2 Input/Output

The Input/Output of program FLIES is accomplished via a typewriter console which has been connected to a computer with an APL compiler. Upon execution of FLIES (see Sect. 4.5) the first data entry will be requested of the user via the console. When all requested data have been entered program FLIES will begin execution of all computations and will output all performance and cost data to completion. The time taken to complete a run will depend upon the complexity of the mission being analyzed but is typically about 5 minutes. The actual computer time is much less, usually a few seconds for a single pass through one aircraft/mission combination. The output for the run is exhibited in hard copy printout obtained at the typewriter console during execution. Some output is saved within the computer corresponding to the most recent case analyzed to aid the user in making adjustments or modifications if necessary or as an aid in diagnostic analysis of the program.

Shown in Table 4.1 is a representative Input/Output for program FLIES. The first entry shown, i.e., TILTROTOR FLIES OFFSHOREOIL, is the command required to execute FLIES for the case where it is desired to merge and analyze the aircraft TILTROTOR with the mission OFFSHOREOIL (see Sect. 4.5). Following the execution command, all information to the left of the equal signs (=) comprises the requests by program FLIES to the user. All information to the right comprises the user responses to the requests. All subsequent output shown in Table 4.1 represents the results of computations performed automatically without further user interaction required. Table 4.1 contains the actual hard copy product of program FLIES. This is suitable for use as a record of this particular aircraft/mission merge and can be included in published reports if desired.

Four output options are available to the user for convenience and flexibility. They are designated

1. Total
2. Performance
3. Economic
4. Summary

The total output format is that shown in Table 4.1. The remaining formats are subsets of the total output and are shown in Tables 4.2 through 4.4 respectively.

TILTROTOR FLIES OFFSHOREOIL

OUTPUT FORMATS ARE: 1. TOTAL 2. PERFORMANCE
3. ECONOMIC 4. SUMMARY.
ENTER 1,2,3,OR 4 1

IS AIRCRAFT UTILIZATION KNOWN? ENTER YES OR NO YES
ENTER AIRCRAFT UTILIZATION - HRS./YR. U=1000

MODE COMPLETED	ELAPSED DISTANCE N.MI.	ELAPSED TIME HRS.	FUEL USED LBS.	FUEL REMAINING LBS.	CARGO ONBOARD LBS.	PASSENGERS ONBOARD NO.	AIRCRAFT WEIGHT LBS.	LOAD FACTOR -
LOAD	.0	.25	0	7638	500	15	29876	.53
WARMUP	.0	.03	11	7627	500	15	29865	.53
TAXI	.0	.02	6	7621	500	15	29859	.53
SHORT TAKEOFF	.0	.02	38	7583	500	15	29821	.53
ENROUTE	100.0	.36	538	7045	500	15	29283	.53
CLIMB(14000 FT. MAX)	(24.0)	(.10)	(190)					
CRUISE	(6.5)	(.02)	(34)					
DESCENT	(69.5)	(.23)	(314)					
VERTICAL LAND	.0	.02	31	7014	500	15	29252	.53
UNLOAD	.0	.25	0	7014	0	0	25752	.00
STANDBY	.0	.75	0	7014	0	0	25752	.00
LOAD	.0	.25	0	7014	500	10	28252	.34
VERTICAL TAKEOFF	.0	.02	38	6976	500	10	28214	.34
ENROUTE	100.0	.35	528	6448	500	10	27686	.34
CLIMB(14000 FT. MAX)	(21.2)	(.09)	(172)					
CRUISE	(8.2)	(.03)	(42)					
DESCENT	(70.6)	(.23)	(314)					
VERTICAL LAND	.0	.02	30	6418	500	10	27656	.34
UNLOAD	.0	.25	0	6418	0	0	25156	.00
REFUEL	.0	.25	0	7638	0	0	26376	.00
STANDBY	.0	.75	0	7638	0	0	26376	.00

×=ALTERNATE AIRCRAFT CONFIGURATION

Table 4.1 Program FLIES Input/Output - Total Format

TOTAL MISSION	ELAPSED DISTANCE N.MI.	ELAPSED TIME HRS.	FUEL USED LBS.	LOAD FACTOR
	200.0	3.58	1220	.44

AIRCRAFT UTILIZATION HRS./MISSION	AIRCRAFT UTILIZATION HRS./YR.	MISSIONS PER YEAR MAXIMUM	MISSIONS PER YEAR ACTUAL	AVAILABLE PAYLOAD TON MILES	MISSION PAYLOAD TON MILES
.83	1000	1460	1209	694	300

DIRECT OPERATING COSTS	PER MISSION	PER FLIGHT HOUR
FLIGHT CREW	33.08	40.00
FUEL+OIL	91.86	111.07
INSURANCE	80.03	96.77
MAINTENANCE,LABOR	.00	.00
MAINTENANCE,PARTS	248.12	300.00
DEPRECIATION	101.23	122.40
TOTAL DOC	554.34	670.24
MISSION RELATED COSTS		
TOTAL MRC	.00	.00
OTHER COSTS		
INTEREST	38.59	46.66
TOTAL OC	38.59	46.66
TOTAL COSTS	PER MISSION	PER FLIGHT HOUR
	592.93	716.89
DOC/MISSION PAYLOAD TON MILE	1.85	

Table 4.1 Cont'd.

TILTROTOR FLIES OFFSHOREOIL

OUTPUT FORMATS ARE: 1. TOTAL 2. PERFORMANCE
3. ECONOMIC 4. SUMMARY
ENTER 1,2,3,OR 4 2

IS AIRCRAFT UTILIZATION KNOWN? ENTER YES OR NO YES
ENTER AIRCRAFT UTILIZATION - HRS./YR. U=1000

MODE COMPLETED	ELAPSED DISTANCE N.MI.	ELAPSED TIME HRS.	FUEL USED LBS.	FUEL REMAINING LBS.	CARGO ONBOARD LBS.	PASSENGERS ONBOARD NO.	AIRCRAFT WEIGHT LBS.	LOAD FACTOR -
LOAD	.0	.25	0	7638	500	15	29876	.53
WARMUP	.0	.03	11	7627	500	15	29865	.53
TAXI	.0	.02	6	7621	500	15	29859	.53
SHORT TAKEOFF	.0	.02	38	7583	500	15	29821	.53
ENROUTE	100.0	.36	538	7045	500	15	29283	.53
CLIMB(14000 FT. MAX)	(24.0)	(.10)	(190)					
CRUISE	(6.5)	(.02)	(34)					
DESCENT	(69.5)	(.23)	(314)					
VERTICAL LAND	.0	.02	31	7014	500	15	29252	.53
UNLOAD	.0	.25	0	7014	0	0	25752	.00
STANDBY	.0	.75	0	7014	0	0	25752	.00
LOAD	.0	.25	0	7014	500	10	28252	.34
VERTICAL TAKEOFF	.0	.02	38	6976	500	10	28214	.34
ENROUTE	100.0	.35	528	6448	500	10	27686	.34
CLIMB(14000 FT. MAX)	(21.2)	(.09)	(172)					
CRUISE	(8.2)	(.03)	(42)					
DESCENT	(70.6)	(.23)	(314)					
VERTICAL LAND	.0	.02	30	6418	500	10	27656	.34
UNLOAD	.0	.25	0	6418	0	0	25156	.00
REFUEL	.0	.25	0	7638	0	0	26376	.00
STANDBY	.0	.75	0	7638	0	0	26376	.00

x=ALTERNATE AIRCRAFT CONFIGURATION

Table 4.2 Program FLIES Input/Output - Performance Format

TOTAL MISSION	ELAPSED DISTANCE N.MI.	ELAPSED TIME HRS.	FUEL USED LBS.	LOAD FACTOR -
	200.0	3.58	1220	.44

AIRCRAFT UTILIZATION HRS./MISSION	AIRCRAFT UTILIZATION HRS./YR.	MISSIONS PER YEAR MAXIMUM	MISSIONS PER YEAR ACTUAL	AVAILABLE PAYLOAD TON MILES	MISSION PAYLOAD TON MILES
.83	1000	1460	1209	694	300

TOTAL COSTS	PER MISSION	PER FLIGHT HOUR
	592.93	716.89
DOC/MISSION PAYLOAD TON MILE	1.85	

Table 4.2 Cont'd.

```
        TILTROTOR FLIES OFFSHOREOIL


OUTPUT FORMATS ARE: 1. TOTAL        2. PERFORMANCE
                    3. ECONOMIC     4. SUMMARY
ENTER 1,2,3,OR 4                                          3

IS AIRCRAFT UTILIZATION KNOWN? ENTER YES OR NO             YES
ENTER AIRCRAFT UTILIZATION - HRS./YR.                    U=1000
```

TOTAL MISSION	ELAPSED DISTANCE N.MI.	ELAPSED TIME HRS.	FUEL USED LBS.	LOAD FACTOR -
	200.0	3.58	1220	

AIRCRAFT UTILIZATION HRS./MISSION	HRS./YR.	MISSIONS PER YEAR MAXIMUM	MISSIONS PER YEAR ACTUAL	AVAILABLE PAYLOAD TON MILES	MISSION PAYLOAD TON MILES
.83	1000	1460	1209	694	300

Table 4.3 Program FLIES Input/Output - Economic Format

DIRECT OPERATING COSTS	PER MISSION	PER FLIGHT HOUR
FLIGHT CREW	33.08	40.00
FUEL+OIL	91.86	111.07
INSURANCE	80.03	96.77
MAINTENANCE,LABOR	.00	.00
MAINTENANCE,PARTS	248.12	300.00
DEPRECIATION	101.23	122.40
TOTAL DOC	554.34	670.24
MISSION RELATED COSTS		
TOTAL MRC	.00	.00
OTHER COSTS		
INTEREST	38.59	46.66
TOTAL OC	38.59	46.66
TOTAL COSTS	PER MISSION	PER FLIGHT HOUR
	592.93	716.89
DOC/MISSION PAYLOAD TON MILE	1.85	

Table 4.3 Cont'd.

```
TILTROTOR FLIES OFFSHOREOIL

OUTPUT FORMATS ARE: 1. TOTAL        2. PERFORMANCE
                    3. ECONOMIC     4. SUMMARY
ENTER 1,2,3,OR 4                                        4
IS AIRCRAFT UTILIZATION KNOWN?  ENTER YES OR NO         YES
ENTER AIRCRAFT UTILIZATION - HRS./YR.                   U=1000

TOTAL MISSION            ELAPSED    ELAPSED   FUEL                     LOAD
                         DISTANCE   TIME      USED                     FACTOR
                         N.MI.      HRS.      LBS.                     -

                         200.0      3.58      1220                     .44


        AIRCRAFT                  MISSIONS          AVAILABLE     MISSION
      UTILIZATION                 PER YEAR        PAYLOAD TON   PAYLOAD TON
  HRS./MISSION   HRS./YR.     MAXIMUM   ACTUAL       MILES         MILES

     .83         1000         1460      1209         694           300


                 TOTAL COSTS                  PER MISSION    PER FLIGHT HOUR

                                                592.93          716.89

                 DOC/MISSION PAYLOAD TON MILE    1.85
```

Table 4.4   Program FLIES Input/Output - Summary Format

4.3 Nomenclature - Symbols and Subprograms

Program FLIES performs a large variety of functions including iterative solution of simultaneous differential equations that describe aircraft performance involving climb, cruise, descent, loiter, hover, and search. This has required the use of subprograms and the creation of numerous mathematical symbols. The subprograms and symbols are identified in this section to serve as a reference to the detailed program description contained in Sect. 4.4. Table 4.5 lists the subprograms used in program FLIES by name and the functions they perform. Table 4.6 lists the important symbols used throughout together with their meaning. Additional symbols used in program FLIES that are used for intermediate computations only are not included in Table 4.6. Also not included in Table 4.6 are the symbols that have been previously defined in Tables 2.1 and 3.2.

4.4 Detailed Description

Program FLIES has been written in APL to operate in an interative mode via a typewriter console in communication with a computer. The purpose of this description is to detail the specific operation of this program and equations used without getting into the details of APL programming. FLIES is designed via branch instructions to compute mission and aircraft characteristics, performance, and costs, for each separate mission segment in the order they occur. In a sense, FLIES has been modularized into separate sections to accomplish this. For example, one module is used for the LOAD and UNLOAD mission segments, another for the ENROUTE segment, etc. For each of these modules all of the following quantities are calculated as indicated in Table 4.1:

Table 4.5 Subprograms Used In Program FLIES

Subprogram Name	Function
OUTPUT	Formats aircraft and mission output as each mission segment and associated parameters are calculated.
CLIMB	Calculates aircraft climb performance for general case.
CLIMB 1	Calculates aircraft climb performance for special case.
ITCL	Iteration routine used to calculate time to climb in CLIMB and SUBCLIMB.
ITCL 1	Iteration routine used to calculate time to climb in CLIMB 1.
CRUISE	Calculates aircraft cruise performance.
DESCENT	Calculates aircraft descent performance based on specified descent rate, variable descent distance.
SUBALT	Computes aircraft altitude reached when trip distance does not permit cruise altitude to be reached.
SUBCLIMB	Computes aircraft climb performance when trip distance does not permit cruise altitude to be reached.
SUBDESCENT	Computes aircraft descent performance when trip distance does not permit cruise altitude to be reached.
DOWN	Computes aircraft descent performance based on unknown but constant descent rate and specified descent distance.
ECON	Computes summary total mission performance, direct, indirect, and other costs of operation.

Table 4.6 Important Symbols Used in Program FLIES

(Refer also to Tables 2.1 and 3.2 for previously defined symbols not included here)

SYMBOL	DEFINITION	UNITS
CAR	Amount of cargo	lb
CM	Cargo - miles	lb - mi
CRX	Maximum available cargo	lb
DELF	Fuel consumed in mission segment	lb
DELT	Elapsed time in mission segment	hr
DELX	Elapsed distance in mission segment	mi
FMX	Maximum fuel allowable	lb
FTOT	Total fuel consumed in mission	lb
HCL	Altitude at maximum point in climb	ft
HCR	Altitude of cruise	ft
HF	Final altitude after descent	ft
L6	Flight crew direct operating cost per mission	$
L7	Flight crew direct operating cost per flight hour	$/hr
L8	Fuel and oil direct operating cost per mission	$
L9	Fuel and oil direct operating cost per flight hour	$/hr
L10	Insurance direct operating cost per mission	$
L11	Insurance direct operating cost per flight hour	$/hr
L12	Maintenance, labor, direct operating cost per mission	$
	Maintenance, labor, direct operating cost per flight hour	$/hr

Table 4.6 Cont'd.

SYMBOL	DEFINITION	UNITS
L14	Maintenance, parts, direct operating cost per mission	$
L15	Maintenance, parts, direct operating cost per flight hour	$/hr
L16	Depreciation direct operating cost per mission	$
L17	Depreciation direct operating cost per flight hour	$/hr
L18	Total direct operating cost per mission	$
L19	Total direct operating cost per flight hour	$/hr
L20	Mission related costs per mission	$
L21	Mission related costs per flight hour	$/hr
L22	Total costs per mission	$
L23	Total costs per flight hour	$/hr
L24	Load factor for mission segment	--
L25	Direct operating cost per payload ton mile	$/ton - mi
L26	Load factor for mission	--
L27	Mission payload ton miles	ton - mi
L30	Available ton miles	ton - mi
MIX	Maximum possible mission per year	no/yr
MPY	Actual missions per year	no/yr
PAX	Number of passengers	no
PM	Passenger miles	pass mi
REMF	Fuel remaining on aircraft	lb
ROD	Rate of descent	ft/min

Table 4.6 Cont'd.

SYMBOL	DEFINITION	UNITS
S1	Interest cost per flight hour	$/hr
S2	Interest cost per mission	$
SID	Character matrix containing mission segment names	--
TCL	Time to climb	min
TCR	Time to cruise	min
TDC	Time to descend	min
TMR	Fuel reserve	min
TTOT	Total mission elapsed time	hr
U	Aircraft utilization per year	hr/yr
UPM	Aircraft utilization per mission	hr
WFCL	Fuel consumed during climb	lb
WFCR	Fuel consumed during cruise	lb
WFDC	Fuel consumed during descent	lb
WLF	Weight left for fuel (after payload)	lb
WMX	Maximum takeoff weight allowable	lb
WO	Aircraft weight at beginning of mission segment	lb
WWF	Aircraft weight without fuel	lb
XCL	Climb distance	mi
XCR	Cruise distance	mi
XDC	Descent distance	mi
XTOT	Total mission elapsed distance	mi

Elapsed distance
Elapsed time
Fuel used
Fuel remaining
Cargo onboard
Passengers onboard
Aircraft weight
Load factor

When these calculations have been completed for all the segments comprising the mission the following summary quantities and calculations are performed:

Total elapsed distance
Total elapsed time
Total fuel used
Aircraft utilization per mission and year
Missions per year - maximum and actual
Available payload ton miles
Mission payload ton miles

Finally, the direct operating, mission related, and other costs are computed (see Table 4.1) together with the direct operating cost per payload ton mile, which is a parameter that can be regarded as a single valued measure of overall combined cost and performance.

Throughout program FLIES diagnostic information is provided to the user as an aid in making design modifications. The diagnostics are provided only if certain necessary conditions are violated. For example, if the fuel onboard the aircraft is exhausted during execution of one of the mission segments the diagnostic RAN OUT OF GAS results. Information is provided to enable modification to the input to be made, in this example, the amount of gas short of that required. Diagnostic information as it applies to each module in program FLIES is discussed in each appropriate section and is summarized in Sect. 4.4.11.

In the following paragraphs, the separate modules and subprograms are described in detail. Shown in Tables 4.7 through 4.17 are the complete program listings for program FLIES and its subprograms. The details of this description will be mostly involved with the solution to the simultaneous differential equations used for aircraft performance in the ENROUTE, DESCENT, LOITER, HOVER, and SEARCH mission segments.

4.4.1 Initialization

To initialize the aircraft/mission merge accomplished in program FLIES, the takeoff weight and altitude, passengers, cargo, and fuel onboard for the beginning of the mission are determined by the following equations. Those parameters that are not defined by equations are inputs (see Tables 2.1 and 3.2). Independent variables are defined in Table 4.6.

$$WO = WEM + REMF + WCL + 200\ (NPL + EXC) \tag{1}$$

If the aircraft is fueled to maximum capacity at the start of the mission, MAC = 1, and

$$REMF = FMX \ ; \quad WLF \geq FMX \tag{2}$$

$$= WLF \ ; \quad WLF < FMX \tag{3}$$

If maximum capacity fueling is not desired, MAC = 0, and

$$REMF = MFD\ ((K15 + K16\ (10000) + K17\ (WWF)) \tag{4}$$

where

$$FMX = 6\ (MFC) \ ; \quad TPF = 0 \text{ (Aviation gasoline)} \tag{5}$$

$$= 6.7\ (MFC) \ ; \quad TPF = 1 \text{ (JP jet fuel)} \tag{6}$$

$$WLF = WMX - WWF \tag{7}$$

$$WMX = WTO \ ; \quad NAC = 1 \text{ (Yes answer to normal aircraft configuration)} \tag{8}$$

$$= WXL \ ; \quad NAC = 0 \text{ (No answer)} \tag{9}$$

$$WWF = WEM + WCL + 200\ (NPL + EXC) \tag{10}$$

Equation 4 is an estimate of the initial fuel based on the aircraft cruise condition fuel consumption rate defined in Table 2.1.

For the purpose of this estimate a cruise altitude of 10,000 ft is assumed and the aircraft weight is assumed to be WWF. Equations 5 and 6 allow flexibility in the choice of fuel used, either aviation gas or JP (jet fuel), and account for their different weights, namely, 6 and 6.7 lbs per gallon, respectively. Equations 8 and 9 allow either a "normal" or alternate aircraft configuration to be used at the option of the user depending on the input specified (NAC) in program MISSION. The passengers loaded, NPL, extra crew, EXC, and cargo loaded, WCL, used for initialization are obtained from the first mission segment which is always specified as a LOAD segment (see Sect. 3.5). Passengers and extra crew are assumed to weigh 200 lbs each. The weight of the nominal crew is included in the empty operating weight of the aircraft. Finally,

$$HO = HTO \tag{11}$$

where HTO is obtained from the first takeoff segment occurring in the mission. Equations 1 through 11 appear in statements [38] through [57] of program FLIES.

4.4.2 LOAD and UNLOAD

Aside from the requirement that a LOAD segment must start the mission for initialization purposes, LOADS and UNLOADS may occur at any point in the mission any number of times. The same logic module is used in program FLIES for both LOAD and UNLOAD since the only difference between the two involves whether weight is being added or subtracted from the aircraft. Besides doing the bookkeeping on the status of the number of passengers, PAX, and amount of cargo, CAR, onboard at any time, the LOAD and UNLOAD module accounts for the time taken to load or unload, DELT. The mission segment load factor, L24, is computed in this module according to the following relationship.

$$L24 = ((CAR + 200\ (PAX))/(WMX - WEM - REMF - 200\ EXC) \tag{12}$$

This, of course, is the ratio of the actual payload to the available payload. Other quantities computed are the required fuel reserve, TMR, and the maximum weight available for cargo, CRX. These parameters are calculated to provide diagnostic information to the program user. TMR is defined as,

$$TMR = RSV\ ((T1 + T2\ (10000) + T3\ (WO)) \tag{13}$$

where

$$T1 = K15 \quad ; \quad NMF = 1 \tag{14}$$

$$= K18 \quad ; \quad NMF = 0 \tag{15}$$

$$T2 = K16 \quad ; \quad NMF = 1 \tag{16}$$

$$= K19 \quad ; \quad NMF = 0 \tag{17}$$

$$T3 = K17 \quad ; \quad NMF = 1 \tag{18}$$

$$= K20 \quad ; \quad NMF = 0 \tag{19}$$

This required fuel reserve is based on either the normal (NMF = 1) or alternate (NMF = 0) mode aircraft cruise fuel consumption rate coefficients defined in Table 2.1, a cruise altitude of 10,000 ft and the current aircraft weight, WO. If after a LOAD, WO has increased such that the fuel remaining, REMF, is less than the required fuel reserve, TMR, the program halts and provides diagnostic information to this effect. Other diagnostic information is provided if necessary and is discussed shortly.

CRX is defined by the relationship,

$$CRX = WMX - WEM - REMF - 200\ (PAX + EXC) \tag{20}$$

If at any time the cargo loaded exceeds the maximum available weight for cargo defined by Equation 20, program FLIES halts and provides diagnostic notification to the user. Diagnostic information of this nature is of value to the user of an interactive program in that it allows him or her to make the necessary input modifications with minimum turn around time.

The conditions under which diagnostic notification will be given to the user in the LOAD and UNLOAD module are shown below.

$$\text{If} \quad \left\{ \begin{array}{l} PAX > PMX \\ CAR > CRX \\ WO > WMX \\ REMF \leq O \\ REMF \leq TMR \\ PAX < O \\ CAR < O \\ REMF > FMX \\ REMF > WFL \end{array} \right. \longrightarrow \text{halt}$$

The principle logic for the LOAD and UNLOAD module is contained in statements [61] through [84] of program FLIES.

4.4.3 WARMUP and TAXI

Segment time, DELT, fuel consumed, DELF, fuel remaining, REMF, etc., involve similar computations for WARMUP and TAXI and therefore a single module is used for both of these mission segments. In this case,

$$DELT = TWU/60 \text{ or } TTX/60 \tag{21}$$

$$DELF = TWU \; ((K1 + K2 \; (HO)) \tag{22}$$

$$\text{or } TTX \; ((K1 + K2 \; (HO)) \tag{23}$$

TMR is also updated (recalculated) using Equations 13 through 19. The following condition will result in diagnostic notification to the user.

$$\text{If } REMF < TMR \longrightarrow \text{halt}$$

Statements [90] through [99] of program FLIES contain the logical operations for this module.

4.4.4 CONVENTIONAL, SHORT, and VERTICAL TAKEOFF

All computations for segment time, fuel consumed, fuel remaining, etc., are performed in a single module for each of these mission segments. However, it is recognized that these segments are different from one another in performance and for this reason an alternate takeoff mode option is provided. For example, the user may designate the conventional takeoff mode as "normal" and a short takeoff mode as "alternate." Similarly, the short takeoff may be designated normal and the vertical takeoff as alternate. This flexibility allows any combination of these segments to be used in a mission with distinct performance characteristics allocated to each. In this way, higher fuel consumption rate coefficients can be used for vertical takeoff, if desired, in combination with lower rates for short takeoff within the same mission. Takeoff times may also be adjusted to suit the particular takeoff mode and will be handled appropriately by this module. For this case,

$$\text{DELT} = \text{TTO}/60 \tag{23}$$

$$\text{DELF} = \text{TTO}\ ((\text{K3} + \text{K4}\ (\text{HO}) + \text{K5}\ (\dot{\text{W}}\text{O}));\ \text{NTO} = 1 \tag{24}$$

$$= \text{TTO}\ ((\text{K6} + \text{K7}\ (\text{HO}) + \text{K8}\ (\dot{\text{W}}\text{O}));\ \text{NTO} = 0 \tag{25}$$

$$\text{HO} = \text{HTO} \tag{11}$$

TMR is updated using Equations 13 through 19. The following condition results in diagnostic notification to the user.

If REMF < TMR ⟶ halt

Statements [247] through [259] of program FLIES contain the logical operations for this module.

4.4.5 ENROUTE

The principal calculations performed in this module are those made to determine the following quantities:

TCL, TCR, TDC	Time to climb, cruise, descend
XCL, XCR, XDC	Climb, cruise, descent distance
WFCL, WFCR, WFDC	Climb, cruise, descent fuel consumed

The climb, cruise, and descent profile adopted for analysis is schematically illustrated in Figure 4.1.

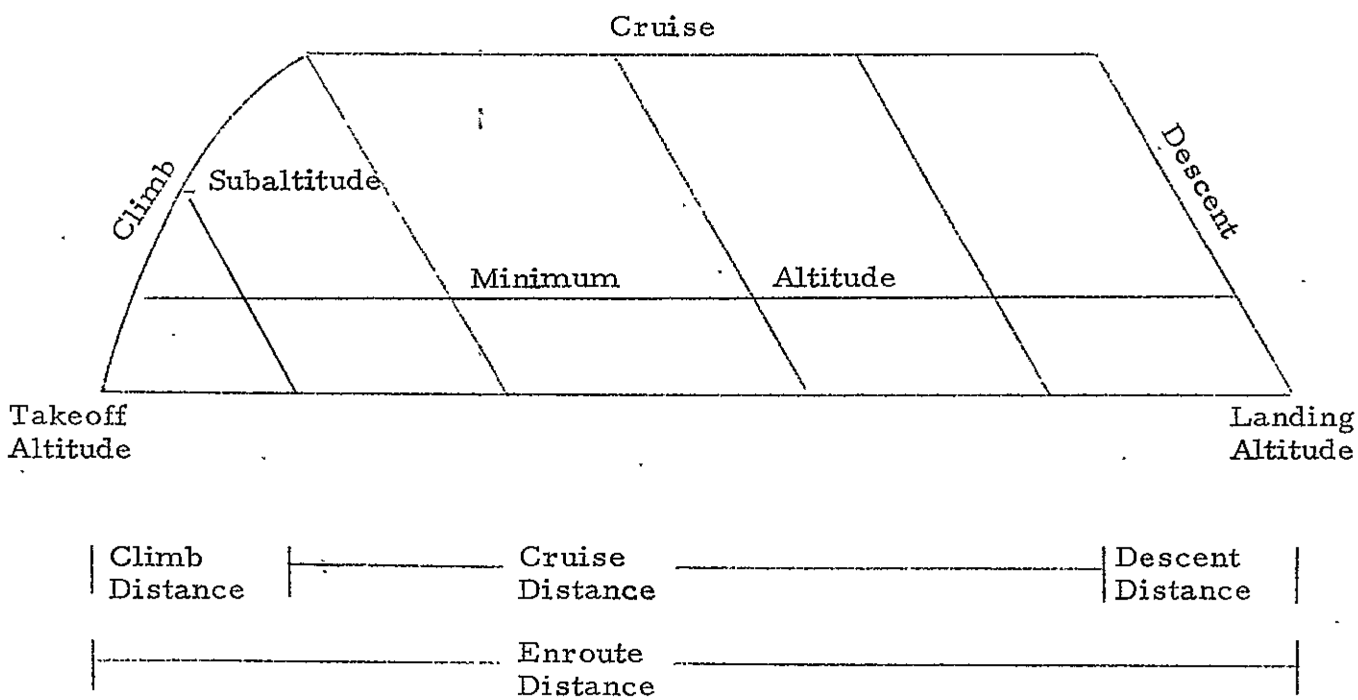


Figure 4.1 Schematic Climb, Cruise, and Descent Profile

The climb profile is determined assuming that the best rate of climb is maintained until the desired climb altitude is reached. In general, the rate of climb is not constant, but rather is a linear function of altitude, H, and aircraft weight, W, as defined in Table 2. 1, namely,

$$ROC = \dot{H} = R1 + R2\ (H) + R3\ (W) \tag{26}$$

This results in the monotonically decreasing climb rate shown in Figure 4. 1.

Cruise is assumed to occur at constant altitude. In some missions the en route distance is too short to allow the aircraft to reach cruise altitude. In this case no cruise is performed and the aircraft climbs to a lower subaltitude as indicated. In either case descent is assumed to occur at a constant rate, ROD.

The takeoff and landing altitudes need not be the same although they are shown that way for simplicity in Figure 4. 1. The minimum altitude shown in the schematic profile is a constraint placed on the climb portion of the en route segment. It represents a mountain or other altitude obstacle that must be overcome by the aircraft. Takeoff or landing altitudes are not affected by this constraint.

In the ENROUTE mission segment, time to climb, TCL, is first calculated through simultaneous solution of the rate of climb (Eq. 26) and climb fuel consumption rate, FCL, where

$$FCL = \dot{WF} = K9 + K10\ (H) + K11\ (W) \tag{27}$$

$$WF = \text{fuel consumed} \tag{28}$$

$$W = WO - WF \tag{29}$$

Rewriting the above,

$$\dot{H} - R2\,(H) + R3\,(WF) = R1 + R3\,(WO) \tag{30}$$

$$K10\,(H) - \dot{WF} - K11\,(WF) = -K9 - K11\,(WO) \tag{31}$$

Multiplying Eq. 31 by R3/K11 and then adding Eq. 30 results in,

$$\dot{H} + \left(R3\,\frac{K10}{K11} - R2\right)H - \frac{R3}{K11}\,\dot{WF} = R1 - R3\,\frac{K9}{K11} \tag{32}$$

Differentiating Eq. 30,

$$\ddot{H} - R2\,\dot{H} + R3\,\dot{WF} = 0 \tag{33}$$

$$\therefore\ \dot{WF} = \frac{R2\,\dot{H} - \ddot{H}}{R3} \tag{34}$$

Substituting Eq. 34 into Eq. 32 and clearing terms,

$$\ddot{H} + (K11 - R2)\,\dot{H} + (R3\,K10 - R2\,K11)\,H = R1K3 - R3K1 \tag{35}$$

The nature of the coefficients in Eq. 35 results in a solution of the general form,

$$H = C_1\,e^{m_1 t} + C_2\,e^{m_2 t} + A \tag{36}$$

where C_1 and C_2 are determined from the initial conditions,

$$H = HO \text{ at } t = 0 \tag{37}$$

$$W = WO \text{ at } t = 0 \tag{38}$$

$$WF = 0 \text{ at } t = 0 \tag{39}$$

It can be shown that,

$$m_1 = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \tag{40}$$

$$m_2 = \frac{-b - \sqrt{b^2 - 4ac}}{2A} \tag{41}$$

where,

$$a = 1 \tag{42}$$

$$b = K11 - R2 \tag{43}$$

$$c = R3K10 - R2K11 \tag{44}$$

Finally, it can be shown that,

$$A = \frac{R1\ K11 - R3K9}{R3\ K10 - R2K11} \tag{45}$$

$$C_2 = \frac{R1 + R2\ HO + R3WO - m_1\ HO + m_1\ A}{m_2 - m_1} \tag{46}$$

$$C_1 = HO - A - C_2 \tag{47}$$

Equation 36 is solved interatively for $t = TCL$ when $H = HCL$. All computations shown in the above equations leading to the iterative solution for TCL appear in statements [1] through [19] of program CLIMB, statements [1] through [6] of ITCL, statements [1] through [10] of CLIMB1, and statements [1] through [6] of ITCL1.

Simultaneous solution of Eqs. 26 and 27 also provides a second order differential equation for WF, namely,

$$\ddot{WF} + (K11 - R2)\ \dot{WF} + (K10R3 - K11R2)\ WF$$
$$= - K9R2 + K10R1 + (K10R3 - K11R2)\ WO \tag{48}$$

The nature of the coefficients in Eq. 48 results in a solution of the general form,

$$WF = f_1\ e^{m_1 t} + f_2\ e^{m_2 t} + B \tag{49}$$

By employing the initial conditions of Eqs. 37, 38, and 39 it can be shown that,

$$B = \frac{K10\ R1 - K9\ R2}{K10\ R3 - K11\ R2} + WO \tag{50}$$

$$f_2 = \frac{K9 + K10\ HO + K11\ WO + Bm_1}{m_2 - m_1} \tag{51}$$

$$f_1 = -f_2 - B \tag{52}$$

Equation 49 then provides

$$WF = WFCL \text{ at } t = TCL \tag{53}$$

The above equations leading to solution for WFCL are contained in statement [8] of program ITCL, statements [7] and [17] of CLIMB1, and statement [10] of ITCL1.

The solution for XCL is obtained by integration of the equation for climb speed in Table 2.1. Then

$$XCL = \int_O^{TCL} VCL\ dt \tag{54}$$

$$= \int_O^{TCL} [K1 + K2H + K3W]\ dt \tag{55}$$

where

$$W = WO - WF \tag{29}$$

Substitution of Eqs. 36 and 49 into the above expression results in,

$$XCL = \int_{0}^{TCL} \left\{ V1 + V2 \left(C_1 e^{m_1 t} + C_2 e^{m_2 t} + A \right) + V3 \left(WO - f_1 e^{m_1 t} - f_2 e^{m_2 t} - B \right) \right\} dt \tag{56}$$

Subsequent integration leads to

$$\begin{aligned} XCL = {} & V1\,(TCL) + \frac{V2}{m_1} C_1 e^{m_1 TCL} + \frac{V2}{m_2} C_2 e^{m_2 TCL} + V2(A)\,(TCL) \\ & + V3\,(WO)\,(TCL) - \frac{V3}{m_1} f_1 e^{m_1 TCL} - \frac{V3}{m_2} f_2 e^{m_2 TCL} \\ & - V3\,(B)\,(TCL) - \frac{V2\ C_1}{m_1} - \frac{V2\ C_2}{m_2} \\ & + \frac{V3\ f_1}{m_1} + \frac{V3\ f_2}{m_2} \end{aligned} \tag{57}$$

Computation of XCL takes place in statements [24] and [25] of CLIMB, and statements [6], [12], [13], and [16] of CLIMB1.

Cruise takes place at H = HCR = constant. Solution for TCR, XCR, and WFCR is obtained from integration of the cruise fuel consumption rate,

$$FCR = \dot{WF} = K15 + K16\ (HCR) + K17(W) \tag{58}$$

and cruise speed,

$$VCR = V7 + V8\ (HCR) + V9(W) \tag{59}$$

Substituting Eq. 29 into Eq. 58 and incorporating appropriate initial conditions yields upon integration,

$$WF = a_1 e^{m_3 t} + D \tag{60}$$

where

$$D = \frac{K15}{K17} + \frac{K16}{K17} (HCR) + WO \tag{61}$$

$$a_1 = -D \tag{62}$$

$$m_3 = -K17 \tag{63}$$

At $t = TCR$, $WF = WFCR$

Substituting Eq. 29 and 60 into Eq. 59 and then integrating provides a solution for XCR, namely,

$$XCR = V7\,(TCR) + V8\,(HCR)\,(TCR) + V9\,(WO)\,(TCR) - V9\,(A)\,(TCR) - D\left(\frac{V9}{K17}\right)\left(e^{m_3 TCR} - 1\right) \tag{64}$$

At this point in the solution to the en route equations, XCR and WFCR cannot be evaluated because TCR is not known. However, TCR must have the value such that the cruise and descent portion of the enroute segment can be completed in the distance remaining after climb. Therefore, the cruise and descent equations must be solved together iteratively to meet this condition. When this is done, Eqs. 60 and 64 provide the cruise fuel consumption and distance, respectively.

The next step, then, is to develop the equations for descent. As mentioned previously, the rate of descent, ROD, is a constant and is input via program AIRCRAFT. Then, for a specified landing altitude, HLD,

$$ROD = -\dot{H} = -\left(\frac{HCR - HLD}{TDC}\right) = -R7 \qquad (65)$$

and therefore (since R7 is input positive),

$$TDC = \frac{HCR - HLD}{R7} \qquad (66)$$

Integrating Eq. 65 gives,

$$H = -R7\,t + HCR \qquad (67)$$

For the descent, the fuel consumption rate, FDC, is obtained from the normal cruise fuel consumption rate, FCR, such that FDC is 75% of FCR when the rate of descent is 1000 ft/min. The relationship is shown in Figure 4.2, where FAC is the ratio of descent to cruise fuel consumption rates.

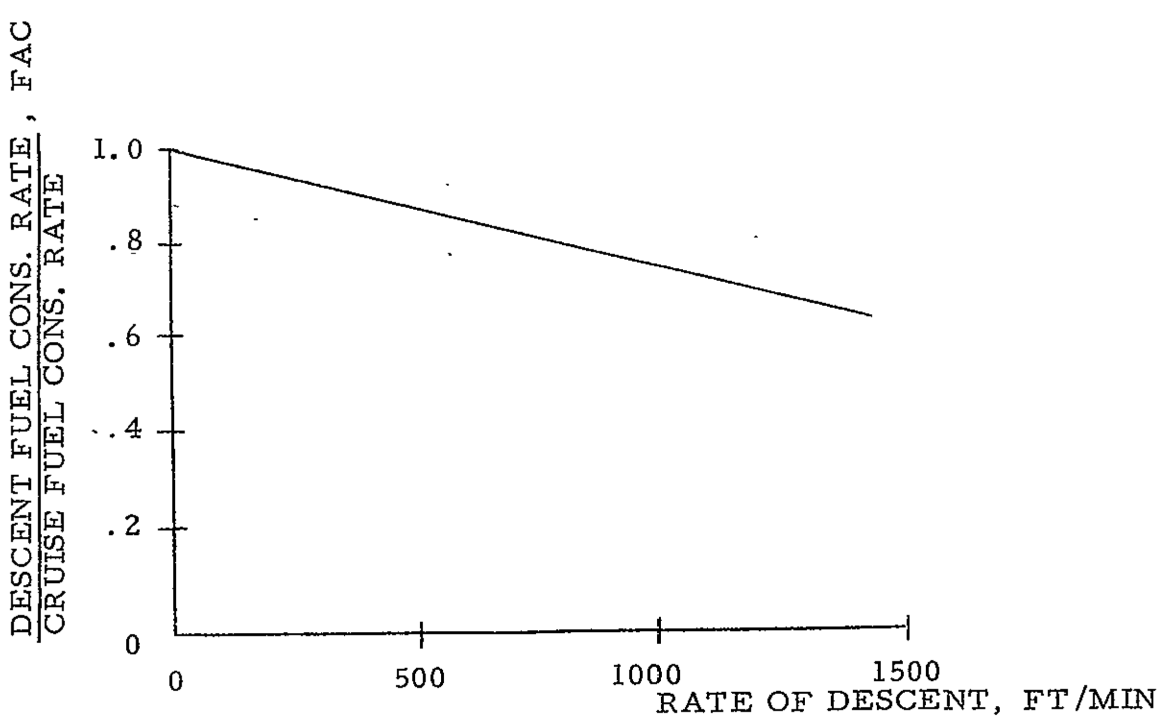


Figure 4.2 Descent Fuel Consumption Rate Factor

Making use of the above relationship, wher

$$FAC = 1 - .00025\ ROD \tag{68}$$

then,

$$FDC = FAC\ (FCR) \tag{69}$$

$$= FAC\ (K15 + K16H + K17 \cdot W) \tag{70}$$

Substituting Eqs. 29 and 67 into Eq. 70 yields,

$$\dot{WF} = FAC\ ((K15 + K16\ (-R7\ t + HCR) + K17\ (WO - WF)) \tag{71}$$

Upon integration,

$$\dot{WF} = g_1 e^{m_4 t} + Et + F \tag{72}$$

where,

$$F = \frac{K15}{K17} + \frac{K16}{K17} HCR + WO + \frac{K16}{K17^2} \frac{R7}{FAC} \tag{73}$$

$$E = -\frac{K16}{K17} R7 \tag{74}$$

$$g_1 = -F \tag{75}$$

$$m_4 = -K17\ (FAC) \tag{76}$$

At $t = TDC$ (Eq. 66), $WF = WFDC$ (77)

For purposes of this analysis, the descent speed is assumed to be the same as the normal cruise speed. Therefore,

$$VDC = VCR = V7 + V8\ H + V9\ W \tag{78}$$

Substituting Eq. 29, 67, and 72 into the above results in,

$$\begin{aligned} VDC = {} & V7 + V8\ (-R7t + HCR) \\ & + V9\ (WO - g_1 e^{m_4 t} - Et - F) \end{aligned} \tag{79}$$

Integration of Eq. 79 provides the descent distance,

$$
\begin{aligned}
XDC = {} & V7\,(TDC) - \frac{V8R7}{2}(TDC)^2 + V8\,(HCR)\,(TDC) \\
& + V9\,(WO)\,(TDC) + \frac{V9}{K17}\, g_1 e^{m_4 TDC} - V9\,(F)\,(TDC) \\
& - \frac{V9}{2}(E)\,(TDC)^2 - \frac{V9}{K17}\, g_1
\end{aligned}
$$

The method used to solve for the cruise and descent parameters derived above proceeds through the following steps:

a) Estimate (guess) a value of TCR
b) Solve for XCR (Eq. 64)
c) Solve for XDC (Eq. 80)
d) Compare XCR + XDC with XTR - XCL
e) If (d) not arbitrarily small, choose new value of TCR and repeat process to convergence.

The method used to provide successive approximations to TCR makes use of Newton's Rule. This method has provided very rapid, fool proof, convergence for all parameters discussed previously, in addition to TCR, in which iterative solution was required. In Newton's Rule, if $X = X_k$ is the first approximation to the solution $X = \xi$ of $f(X) = 0$, then the sequence

$$X_{k+1} = X_k - \frac{f(X_k)}{f'(X_k)} \tag{81}$$

will converge quadratically to $X = \xi$ for the class of solutions discussed in this analysis.

Computation of XCR takes place in statements [25] and [46] of program CRUISE. Computation of WFCR is contained in statements [24] and [45] of CRUISE. XDC is computed in statements [11] , [12] ,

[13] , [19] , [20] , and [21] of program DESCENT and again in the iteration routine statements [29] through [31] [34] through [36] , and [48] through [50] of program CRUISE. WFDC is computed in statements [14] and [17] of DESCENT and [32] , [37] , and [51] of CRUISE.

As mentioned previously, some missions will have en route distances too short to allow the aircraft to climb to the desired cruise altitude. In such cases no cruise is performed, and a subaltitude is reached at which time descent begins. The program modules SUBALT, SUBCLIMB, and SUBDESCENT perform the necessary performance computations in this instance. The performance parameters, i.e., time, distance, and fuel consumed, obey the solutions previously derived. The basic logic for the subaltitude computations is simply an iteration routine (Newton's Method of Successive Approximations) to solve for the subaltitude, HCL, such that the resulting climb and descent distance, XCL + XDC, is equal to the specified en route distance, XTR.

Throughout the development of the previous equations describing the aircraft climb, cruise, and descent performance, the most general solutions have been presented. It should be noted that numerous singularities (cases where these solutions blow up) exist that have not been discussed. For example, if K17 = 0 in the expression for cruise fuel consumption rate, FCR, (Eq. 58), the solution presented here (Eq. 60) would appear to "blow up", since there are terms being divided by K17. It should not be interpreted from this that a problem exists. When K17 = 0, for this example, there is a different mathematical solution for WFCR which has been derived and accounted for within the program but has not been included in this discussion for the sake of brevity. All possible solutions to the aircraft performance equations have been incorporated within the analysis but only the most general solutions have been discussed here. The interested user may refer to the program listings for the special solution equations if desired.

Summary calculations performed in the ENROUTE module are segment time, DELT, fuel consumed, DELF, fuel remaining, REMF, etc. In this case

$$DELT = (TCL + TCR + TDC)/60 \tag{82}$$

$$DELF = WFCL + WFCR + WFDC \tag{83}$$

DELX, the segment distance, need not be computed since the individual distances XCL, XCR, and XDC have been determined such that their sum is equal to DELX = XTR as input.

Additional computations made are cargo miles, CM, and passenger miles, PM, where

$$CM = CAR\ (DELX) \tag{84}$$

$$PM = PAX\ (DELX) \tag{85}$$

TMR, the fuel reserve estimate, is also updated according to Eqs. 13 through 19. The following conditions will result in diagnostic notification to the user.

$$\text{if} \begin{cases} REMF \leq O \\ REMF < TMR \longrightarrow \text{halt} \\ HCL < HMN \end{cases}$$

Statements ⌊123⌋ through ⌊140⌋ of program FLIES contain the logical operations for the ENROUTE module.

4.4.6 LOITER, HOVER, SEARCH

After an ENROUTE mission segment has been performed it may be desired to LOITER, HOVER, or perform a SEARCH mission before landing (or beginning another en route segment). Each of these mission segments takes place at a constant specified altitude as input by program MISSION. Therefore, the aircraft performance equations have identical solutions to those developed for aircraft cruise, however, the coefficients have different values. For LOITER and SEARCH, the aircraft speed is given by,

$$VLS = V13 + V14\ (H) + V15\ (W) \tag{86}$$

and the fuel consumption by,

$$FLS = K24 + K25\ (H) + K26\ (W \tag{87}$$

Therefore, for a specified loiter altitude, HLT, or search altitude, HSR, Eqs. 60 through 63 can be used to determine fuel consumption with an appropriate change in coefficient values. Similarly, search distance, XSR can be obtained from Eq. 64 where V7 is now V13, HCR is HSR, TCR is TSR, etc. Otherwise the solution has the same form. It is reasonably stipulated that the loiter segment takes place in zero elapsed distance.

For HOVER, the speed is zero and the fuel consumption rate is given by,

$$FHO = K21 + K22\ (H) + K23\ (W) \tag{88}$$

Again, for a specified hover altitude, HHO, and hover time, THO, Eqs. 60 through 63 are used with appropriate change in coefficients i.e., HCR becomes HHO, K15 becomes K21, TCR becomes THO, etc.

Summary calculations performed in this module are,

$$\text{DELT} = (\text{TLO or THO or TSR})/60 \tag{89}$$

$$\text{DELX} = \text{XSR for SEARCH} \tag{90}$$

$$= \text{O for LOITER, HOVER} \tag{91}$$

TMR is updated via Eqs. 13 through 19. The following conditions will result in diagnostic notification to the user.

$$\text{If} \quad \left\{ \begin{array}{l} \text{REMF} \le \text{O} \\ \text{REMF} < \text{TMR} \end{array} \right. \longrightarrow \text{halt}$$

Statements [197] through [219] of program FLIES contain the logical operations for the LOITER, HOVER, SEARCH module.

4.4.7 DESCENT

The DESCENT mission segment is a special segment to be used only after a LOITER, HOVER, or SEARCH. It is not to be confused with the descent that takes place in the ENROUTE segment. The DESCENT module is designed to be used for those situations in which it is desired to descend at a constant but <u>unspecified</u> rate in a specified distance, whereas the descent that takes place in the normal ENROUTE segment is at a constant <u>specified</u> rate but in an unspecified distance.

If the "special" descent begins at H = HO and ends at H = HLD, then the rate of descent is,

$$\dot{H} = - \left(\frac{\text{HO - HLD}}{\text{TDC}} \right) \tag{92}$$

The altitude at any time t is then,

$$H = \text{HO} - \left(\frac{\text{HO - HLD}}{\text{TDC}} \right) \tag{93}$$

The fuel consumption rate for descent is,

$$FDC = FAC\ (K15 + K16H + K17W) \tag{70}$$

Substitution of Eqs. 29 and 93 into Eq. 70 results in,

$$\dot{W}F = FAC \left[K15 + K16 \left\{ HO - \left(\frac{HO - HLD}{TDC} \right) t \right\} + K17\ (WO - WF) \right] \tag{94}$$

Integration of Eq. 94 yields,

$$WFDC = b_1\ (e^{m_5 TDC} - 1) + Gt + L \tag{95}$$

where,

$$L = \frac{K15}{K17} + \frac{K16}{K17}\ HO + WO + \frac{K16}{K17^2\ FAC} \left(\frac{HO - HLD}{TDC} \right) \tag{96}$$

$$G = -\frac{K16}{K17} \left(\frac{HO - HLD}{TDC} \right) \tag{97}$$

$$b_1 = -L \tag{98}$$

$$m_5 = -FAC\ (K17) \tag{99}$$

The descent speed is assumed to be the same as the cruise speed, therefore,

$$VDC = K7 + K8\ H + K\ 9\ W \tag{78}$$

Integration of Eq. 78, after substitution of Eqs. 29, 93, and 95, results in

$$XDC = V7\ (TD) + V8\ (HO)(TDC) - V8 \left(\frac{HO - HLD}{2} \right) TDC + V9\ (WO)(TDC) - \frac{V9}{m_5}\ b_1 e^{m_5 TDC} - V9\ (L)(TDC) - \frac{V9\ (G)(TDC)^2}{2} + \frac{V9}{m_5} b_1 \tag{100}$$

Equation 100 is iterated using Newton's Method of Successive Approximation to obtain TDC such that XDC is satisfied. Once TDC has been determined, Eq. 92 is evaluated to obtain the resulting descent rate, and Eq. 95 is used to obtain the fuel consumed during descent.

Summary calculations performed in the DESCENT module are,

$$\text{DELT} = \text{TDC}/60 \tag{101}$$

$$\text{DELX} = \text{XDC} \tag{102}$$

$$\text{DELF} = \text{WFDC}$$

TMR is updated via Eqs. 13 through 19. The following conditions result in diagnostic notification to the user.

$$\text{If} \left\{ \begin{array}{l} \text{REMF} \leq 0 \\ \text{REMF} < \text{TMR} \end{array} \right. \longrightarrow \text{halt}$$

Solution for TDC, XDC, and WFDC is contained in subprogram DOWN. Statements [178] through [191] contain the logical operations for the DESCENT module.

4.4.8 REFUEL

A REFUEL may be performed at any point during the mission that the aircraft is on the ground, i.e., either before takeoff or after landing. Two refuel options exist. The first fills the aircraft to the maximum allowable subject to tank capacity or takeoff weight constraints. The second fills the aircraft such that a specified number of flying minutes can be achieved. The option selected is made by the user during execution of program MISSION. If the first option is selected, MXC = 1 (See Table 3.2) and,

$$DELF = FMX - REMF \; ; \; WLF < FMX \tag{103}$$

$$= WLF - REMF \; ; \; WLF \leq FMX \tag{104}$$

If the second option is selected, MXC = O, and,

$$DELF = MFD\ ((K15 + K16\ (10000) + K17\ (WO)) \tag{105}$$

where

$$MFD = \text{minutes of fuel desired} \tag{106}$$

For the REFUEL module, DELF is interpreted as the fuel loade on the aircraft. L24, the aircraft load factor, is updated in this module according to Eq. 12. The following conditions result in diagnostic notification to the user.

$$\text{If} \quad \left\{ \begin{array}{l} REMF > FMX \\ REMF > WLF \longrightarrow \text{halt} \\ WO \quad > WMX \end{array} \right.$$

Statements [146] through [172] of program FLIES contain the logical operations for the REFUEL module.

4.4.9 CONVENTIONAL, SHORT, and VERTICAL LAND

All computations for segment time, fuel consumed, fuel remaining, etc., are performed in a single module for each of these mission segments. However, for the purpose of this analysis, conventional and short landing fuel consumption is based upon cruise fuel consumption rates, and vertical landing fuel consumption is based on hover fuel consumption rates. For this case,

$$DELT = TLD/60 \tag{107}$$

$$DELF = TLD\ ((K15 + K16\ (HLD) + K17\ (WO)) \tag{108}$$

$$; \quad \text{Conventional and Short Land}$$

$$DELF = TLD\ ((K21 + K22\ (HLD) + K23\ (WO)) \tag{109}$$

$$; \quad \text{Vertical Land}$$

TMR is updated using Eqs. 13 through 19. The following condition results in diagnostic notification to the user.

If REMF < TMR halt

Statements [105] through [117] of program FLIES contain the logical operations for this module.

4.4.10 STANDBY and INACTIVE

During a mission there are occasions when the aircraft will be active but in a STANDBY mode. These times, TSB, are included as part of the total mission time, but do not enter into aircraft utilization (engine on) calculations.

There are also periods of time that occur within those hours of the day that are normally available for aircraft operation but are clearly unrelated to a mission. During these time periods, TIN, the aircraft is considered to be INACTIVE. For these cases,

$$DELT = TSB/60 \quad ; \text{ Standby} \tag{110}$$

$$= TIN/60 \quad ; \text{ Inactive} \tag{111}$$

Statements [225] through [230] and [236] through [241] contain the logical operations for the STANDBY and INACTIVE modules.

4.4.11 Summary of Diagnostics

Diagnostic information is provided to the user if certain necessary conditions have been violated. This information serves as an aid in making design modifications interactively. Diagnostic information as it applies to each module in program FLIES has been discussed in the previous sections and is summarized in Table 4.18.

```
    ∇ A FLIES M
  ''
  ''
  ''
  YES←1
  NO←0
  MPY←U←0
  'OUTPUT FORMATS ARE: 1. TOTAL      2. PERFORMANCE'
  '                    3. ECONOMIC   4. SUMMARY'
  ⍞←'ENTER 1,2,3,OR 4
  B1←⍎⍞
  ''
  ⍞←'IS AIRCRAFT UTILIZATION KNOWN?  ENTER YES OR NO
  L5←⍎⍞
  →D11×⍳(L5=0)
  ⍞←'ENTER AIRCRAFT UTILIZATION - HRS./YR.
  U←⍎⍞
  →D13
D11:⍞←'ENTER NUMBER OF MISSIONS PER YEAR                    MPY='
  MPY←⍎⍞
D13:→C1×⍳((B1=3)∨(B1=4))
  ''
  ''
  ''
  ''
  ''
  'MODE COMPLETED            ELAPSED   ELAPSED  FUEL   FUEL       CARGO    PASSENGERS  AIRCRAFT  LOAD'
  '                          DISTANCE  TIME     USED   REMAINING  ONBOARD  ONBOARD     WEIGHT    FACTOR'
  '                          N.MI.     HRS.     LBS.   LBS.       LBS.     NO.         LBS.      -'
  ''
  ''
```

Table 4.7 Program FLIES Listing

```
[31] C1:DD←ρM[;1]
[32]  NBS←DD-2
[33]  XXI←M[DD;3]
[34]  CC←M[DD;4]
[35]  NN←M[DD;5]
[36]  NAS←NBS+(CC×NN)
[37]  J←1
[38]  WWF←A[3]+M[J;5]+200×M[J;4]+M[DD-1;4]
[39]  WMX←A[2]+(A[1]-A[2])×M[J;6]
[40]  FMX←A[5]×6-(6-6.7)×A[62]
[41]  WLF←WMX-WWF
[42]  T1←A[46]+(A[43]-A[46])×A[65]
[43]  T2←A[47]+(A[44]-A[47])×A[65]
[44]  T3←A[48]+(A[45]-A[48])×A[65]
[45]  →D1×ι(M[DD;7]=0)
[46]  REMF←FMX
[47]  →D9×ι(WLF≥FMX)
[48]  REMF←WLF
[49]  →D9
[50] D1:REMF←M[DD;8]×A[43]+(A[44]×10000)+A[45]×WWF
[51] D9:XTOT←TTOT←FTOT←CM←PN←PAX←CAR←TSB←TIN←TLO←TRF←L26←L30←0
[52]  W0←A[3]+REMF+200×M[DD-1;4]
[53]  L1←M[;2]ι4
[54]  L2←M[;2]ι5
[55]  L3←M[;2]ι6
[56]  L4←⌊/(L1,L2,L3)
[57]  H0←M[L4;6]
[58]  J1←0
[59]  SN←1
[60] P0:→(P1,P2,P2,P11,P11,P11,P4 ¯ ¯ P3,P3,P1,P5,P8,P8,P8,P9,P10)[M[J;2]]
```

Table 4.7 Cont'd.

```
[61] P1:DELX←0
[62]  DELT←M[J;3]÷60
[63]  NOR←M[J;6]
[64]  TLO←TLO+DELT
[65]  DELF←0
[66]  PAX←PAX+M[J;4]
[67]  CAR←CAR+M[J;5]
[68]  W0←W0+M[J;5]+200×M[J;4]
[69]  TMR←M[DD;6]×T1+(T2×10000)+T3×W0
[70]  TTOT←TTOT+DELT
[71]  WMX←A[2]+(A[1]-A[2])×M[J;6]
[72]  CRX←WMX-A[3]+REMF+200×PAX+M[DD-1;4]
[73]  AP←0.0005×WMX-A[3]+REMF+200×M[DD-1;4]
[74]  L24←(CAR+200×PAX)÷WMX-A[3]+REMF+200×M[DD-1;4]
[75]  OUTPUT
[76]  →Z1×ι(PAX>A[4])
[77]  →Z8×ι(CAR>CRX)
[78]  →Z2×ι(W0>WMX)
[79]  →Z4×ι(REMF≤0)
[80]  →Z3×ι(REMF<TMR)
[81]  →Z5×ι(PAX<0)
[82]  →Z6×ι(CAR<0)
[83]  →Z7×ι(REMF>FMX)
[84]  →Z10×ι(REMF>WLF)
[85]  SN←SN+1
[86]  →PW×ι((J=XXI-1)∧(J1<NN))
[87]  J←J+1
[88]  →P0×ι(NAS≥SN)
[89]  →PX
[90] P2:DELX←0
```

Table 4.7 Cont'd.

```
[91]  DELT←M[J;3]÷60
[92]  DELF←M[J;3]×A[29]+A[30]×H0
[93]  REMF←REMF-DELF
[94]  W0←W0-DELF
[95]  TTOT←TTOT+DELT
[96]  FTOT←FTOT+DELF
[97]  TMR←M[DD;6]×T1+(T2×10000)+T3×W0
[98]  OUTPUT
[99]  →Z3×ι(REMF<TMR)
[100] SN←SN+1
[101] →PW×ι((J=XXI-1)∧(J1<NN))
[102] J←J+1
[103] →P0×ι(NAS≥SN)
[104] →PX
[105]P3:DELX←0
[106] DELT←M[J;3]÷60
[107] H0←M[J;6]
[108] DE1←M[J;3]×A[49]+(A[50]×H0)+A[51]×W0
[109] DE2←M[J;3]×A[43]+(A[44]×H0)+A[45]×W0
[110] DELF←DE2+(DE1-DE2)×(M[J;2]=11)
[111] REMF←REMF-DELF
[112] W0←W0-DELF
[113] TTOT←TTOT+DELT
[114] FTOT←FTOT+DELF
[115] TMR←M[DD;6]×T1+(T2×10000)+T3×W0
[116] OUTPUT
[117] →Z3×ι(REMF<TMR)
[118] SN←SN+1
[119] →PW×ι((J=XXI-1)∧(J1<NN))
[120] J←J+1
```

Table 4.7 Cont'd.

```
[121] →P0×ι(NAS≥SN)
[122] →PX
[123]P4:CLIMB
[124] DESCENT
[125] DELX←M[J;3]
[126] DELT←(TCL+TCR+TDC)÷60
[127] DELF←WFCL+WFCR+WFDC
[128] REMF←REMF-DELF
[129] XTOT←XTOT+DELX
[130] TTOT←TTOT+DELT
[131] FTOT←FTOT+DELF
[132] CM←CM+CAR×DELX
[133] PN←PN+PAX×DELX
[134] TMR←M[DD;6]×T1+(T2×10000)+T3×W0
[135] OUTPUT
[136] L26←L26+L24×DELX
[137] L30←L30+DELX×AP
[138] →Z4×ι(REMF≤0)
[139] →Z3×ι(REMF<TMR)
[140] →Z9×ι(HCL<M[J;5])
[141] SN←SN+1
[142] →PW×ι((J=XXI-1)∧(J1<NN))
[143] J←J+1
[144] →P0×ι(NAS≥SN)
[145] →PX
[146]P5:DELX←0
[147] DELT←M[J;3]÷60
[148] TRF←TRF+DELT
[149] WWE←A[3]+CAR+200×PAX+M[DD-1;4]
[150] WLE←WMX-WWE
```

Table 4.7 Cont'd.

```
[151] DE1←FMX-REMF
[152] DE2←WLF-REMF
[153] DE3←(M[J;5]×A[43]+(A[44]×10000)+(A[45]×W0))-REMF
[154] →D10×ι(M[J;4]=0)
[155] REMF←FMX
[156] DELF←DE1
[157] →D12×ι(WLF≥FMX)
[158] REMF←WLF
[159] DELF←DE2
[160] →D12
[161]D10:REMF←M[J;5]×A[43]+(A[44]×10000)+A[45]×W0
[162] DELF←DE3
[163]D12:W0←W0+DELF
[164] DELF←0
[165] TTOT←TTOT+DELT
[166] CRX←WMX-A[3]+REMF+200×PAX+M[DD-1;4]
[167] AP←0.0005×WMX-A[3]+REMF+200×M[DD-1;4]
[168] L24←(CAR+200×PAX)÷WMX-A[3]+REMF+200×M[DD-1;4]
[169] OUTPUT
[170] →Z7×ι(REMF>FMX)
[171] →Z10×ι(REMF>WLF)
[172] →Z2×ι(W0>WMX)
[173] SN←SN+1
[174] →PW×ι((J=XXI-1)∧(J1<NN))
[175] J←J+1
[176] →P0×ι(NAS≥SN)
[177] →PX
[178]P6:DOWN
[179] W0←W0-DELF
[180] DELX←M[J;3]
```

Table 4.7 Cont'd.

```
[181] DELT←TDC÷60
[182] ROD←(H0-HF)÷TDC
[183] REMF←REMF-DELF
[184] XTOT←XTOT+DELX
[185] TTOT←TTOT+DELT
[186] FTOT←FTOT+DELF
[187] TMR←M[DD;6]×T1+(T2×10000)+T3×W0
[188] OUTPUT
[189] L26←L26+L24×DELX
[190] →Z4×ι(REMF≤0)
[191] →Z3×ι(REMF<TMR)
[192] SN←SN+1
[193] →PW×ι((J=XλI-1)∧(J1<NN))
[194] J←J+1
[195] →P0×ι(NAS≥SN)
[196] →PX
[197]P8:DELT←M[J;3]÷60
[198] H0←M[J;6]
[199] Q1←A[52]+(A[49]-A[52])×(M[J;2]=15)
[200] Q2←A[53]+(A[50]-A[53])×(M[J;2]=15)
[201] Q3←A[54]+(A[51]-A[54])×(M[J;2]=15)
[202] Q4←A[18]÷60
[203] Q5←A[19]÷60
[204] Q6←A[20]÷60
[205] →D19×ι(Q3=0)
[206] S1←(Q1+(Q2×H0)+Q3×W0)÷Q3
[207] DELF←S1×1-*-Q3×M[J;3]
[208] DELX←(M[J;2]=16)×(Q6×DELF÷Q3)+M[J;3]×Q4+(Q5×H0)+Q6×W0-S1
[209] →D2
[210]D19:DELF←M[J;3]×Q1+Q2×H0
```

Table 4.7   Cont'd.

```
DELX←(M[J;2]=16)×M[J;3]×Q4+(Q5×H0)+(Q6×W0)-M[J;3]×0.5×Q6×Q1+Q2×H0
D2:W0←W0-DELF
REMF←REMF-DELF
TTOT←TTOT+DELT
FTOT←FTOT+DELF
TMR←M[DD;6]×T1+(T2×10000)+T3×W0
OUTPUT
→Z4×ι(REMF≤0)
→Z3×ι(REMF<TMR)
SN←SN+1
→PW×ι((J=XXI-1)∧(J1<NN))
J←J+1
→P0×ι(NAS≥SN)
→PX
P9:DELX←0
DELF←0
DELT←M[J;3]÷60
TSB←TSB+DELT
TTOT←TTOT+DELT
OUTPUT
SN←SN+1
→PW×ι((J=XXI-1)∧(J1<NN))
J←J+1
→P0×ι(NAS≥SN)
→PX
P10:DELX←0
DELF←0
DELT←M[J;3]÷60
TIN←TIN+DELT
TTOT←TTOT+DELT
```

Table 4.7 Cont'd.

```
[241] OUTPUT
[242] SN←SN+1
[243] →PW×ι((J=XXI-1)∧(J1<NN))
[244] J←J+1
[245] →P0×ι(NAS≥SN)
[246] →PX
[247]P11:DELX←0
[248] DELT←M[J;3]÷60
[249] H0←M[J;6]
[250] DE1←M[J;3]×A[31]+(A[32]×H0)+A[33]×W0
[251] DE2←M[J;3]×A[34]+(A[35]×H0)+A[36]×W0
[252] DELF←DE2+(DE1-DE2)×M[J;7]
[253] REMF←REMF-DELF
[254] W0←W0-DELF
[255] TTOT←TTOT+DELT
[256] FTOT←FTOT+DELF
[257] TMR←M[DD;6]×T1+(T2×10000)+T3×W0
[258] OUTPUT
[259] →Z3×ι(REMF<TMR)
[260] SN←SN+1
[261] →PW×ι((J=XXI-1)∧(J1<NN))
[262] J←J+1
[263] →P0×ι(NAS≥SN)
[264] →PX
[265]PW:J←J+1-CC
[266] J1←J1+1
[267] →P0
[268]PX:L26←L26÷XTOT
[269] ECON
[270] →0
```

Table 4.7 Cont'd.

```
[271]Z1:''
[272] ''
[273] '***MAXIMUM PASSENGER CAPACITY EXCEEDED BY ';PAX-A[4]
[274] →0
[275]Z2:''
[276] ''
[277] '***TAKEOFF WEIGHT LIMITATION EXCEEDED BY ';⌈W0-WMX;' LBS.'
[278] →0
[279]Z3:TTT←(TMR-REMF)÷T1+(T2×10000)+T3×W0
[280] ''
[281] ''
[282] '***FUEL ONBOARD INSUFFICIENT FOR ';M[DD;6];' MINUTE RESERVE BY ';⌈TTT;' MIN.'
[283] →0
[284]Z4:''
[285] ''
[286] '***RAN OUT OF GAS BY ';⌈-REMF;' LBS.'
[287] →0
[288]Z5:''
[289] ''
[290] '***UNLOADED TOO MANY PASSENGERS BY ';-PAX
[291] →0
[292]Z6:''
[293] ''
[294] '***UNLOADED TOO MUCH CARGO BY ';-CAR;' LBS.'
[295] →0
[296]Z7:''
[297] ''
[298] '***MAXIMUM FUEL CAPACITY EXCEEDED BY ';⌈REMF-FMX;' LBS.'
[299] →0
[300]Z8:''
[301] ''
```

Table 4.7   Cont'd.

```
[301] ''
[302] '***MAXIMUM CARGO CAPACITY EXCEEDED BY ';⌈CAR-CRX;' LBS.'
[303] →0
[304]Z9:''
[305] ''
[306] '***MINIMUM ALTITUDE NOT ATTAINED BY ';⌈M[J;5]-HCL;' FT.'
[307] →0
[308]Z10:''
[309] ''
[310] '***TAKEOFF WEIGHT LIMITATION EXCEEDED BY ';⌈REMF-WLF;' LBS.'
      ∇
```

Table 4.7 Cont'd.

```
    ∇ OUTPUT
[1]   →C0×ι((B1=3)∨(B1=4))
[2]   →U1×ι(NOR=1)
[3]   AST←'×'
[4]   →U2
[5]  U1:AST←' '
[6]  U2:→U3×ι(M[J;2]=7)
[7]   →U4×ι(M[J;2]=8)
[8]   OUT←(,SID[M[J;2];]),(10 1 DFT DELX),(9 2 DFT DELT),(9 0 DFT DELF),(9 0 DFT REMF)
[9]   OUT←OUT,(12 0 DFT CAR),(10 0 DFT PAX),(13 0 DFT W0),AST,(8 2 DFT L24)
[10]  OUT
[11]  →C0×ι(NAS>SN)
[12]  '×=ALTERNATE AIRCRAFT CONFIGURATION'
[13]  →C0
[14] U3:''
[15]  OUT←'ENROUTE',(23 1 DFT DELX),(9 2 DFT DELT),(9 0 DFT DELF),(9 0 DFT REMF)
[16]  OUT←OUT,(12 0 DFT CAR),(10 0 DFT PAX),(13 0 DFT W0),AST,(8 2 DFT L24)
[17]  OUT
[18]  OUT←'  CLIMB(',(5 0 DFT HCL),' FT. MAX) (',(6 1 DFT XCL),')   (',(4 2 DFT TCL÷60),')   (',(5 0 DFT WFCL),')'
[19]  OUT
[20]  OUT←'  CRUISE              (',(6 1 DFT XCR),')   (',(4 2 DFT TCR÷60),')   (',(5 0 DFT WFCR),')'
[21]  OUT
[22]  OUT←'  DESCENT             (',(6 1 DFT XDC),')   (',(4 2 DFT TDC÷60),')   (',(5 0 DFT WFDC),')'
[23]  OUT
[24]  ''
[25]  →C0×ι(NAS>SN)
[26]  '×=ALTERNATE AIRCRAFT CONFIGURATION'
[27]  →C0
[28] U4:OUT←'DESCENT(',(5 0 DFT ROD),' FT/MIN)',(9 1 DFT M[J;3]),(9 2 DFT DELT),(9 0 DFT DELF),(9 0 DFT REMF)
[29]  OUT←OUT,(12 0 DFT CAR),(10 0 DFT PAX),(13 0 DFT W0),AST,(8 2 DFT L24)
[30]  OUT
[31]  →C0×ι(NAS>SN)
[32]  '×=ALTERNATE AIRCRAFT CONFIGURATION'
[33] C0:→ι0
    ∇
```

Table 4.8   Subprogram OUTPUT Listing

```
    ∇  CLIMB
[1]    Q1←A[24]+(A[21]-A[24])×M[J;6]
[2]    Q2←A[25]+(A[22]-A[25])×M[J;6]
[3]    Q3←A[26]+(A[23]-A[26])×M[J;6]
[4]    Q4←A[40]+(A[37]-A[40])×M[J;6]
[5]    Q5←A[41]+(A[38]-A[41])×M[J;6]
[6]    Q6←A[42]+(A[39]-A[42])×M[J;6]
[7]    Q7←(A[9]+(A[6]-A[9])×M[J;6])÷60
[8]    Q8←(A[10]+(A[7]-A[10])×M[J;6])÷60
[9]    Q9←(A[11]+(A[8]-A[11])×M[J;6])÷60
[10]   HCL←⌊/(M[J;4],(A[67]+A[68]×W0))
[11]   →D14×⍳((Q3×Q5)=Q2×Q6)
[12]   S1←Q6-Q2
[13]   S2←(Q3×Q5)-Q2×Q6
[14]   S3←(S1×S1)-4×S2
[15]   S4←((S3*0.5)-S1)×0.5
[16]   S5←-((S3*0.5)+S1)×0.5
[17]   S6←((Q1×Q6)-Q3×Q4)÷S2
[18]   S7←(Q1+((Q2-S4)×H0)+(Q3×W0)+(S4×S6))÷(S5-S4)
[19]   S8←H0-(S6+S7)
[20]   S9←W0+((Q5×Q1)-Q4×Q2)÷S2
[21]   S10←(Q4+(Q5×H0)+(Q6×W0)+S9×S4)÷S5-S4
[22]   S11←-(S10+S9)
[23]    ITCL
[24]   XCL←(Q7×TCL)+(Q8×((S8××S4×TCL)÷S4)+((S7××S5×TCL)÷S5)+(S6×TCL))+Q9×(S11÷S4)+S10÷S5
[25]   XCL←XCL+(Q9×W0×TCL)-(Q9×((S11××S4×TCL)÷S4)+((S10××S5×TCL)÷S5)+(S9×TCL))+Q8×(S8÷S4)+S7÷S5
[26]   →D30
[27] D14: CLIMB1
[28] D30:WFCR←WFCL
[29]   HCR←HCL
    ∇
```

Table 4. 9   Subprogram CLIMB Listing

```
    ∇ CLIMB1
[1]    →D15×⍳(Q2≠Q6)
[2]    →D16×⍳((Q2=Q6)∧(Q3=0))
[3]    Q10←Q1+Q3×W0
[4]    Q11←((Q10×Q10)+2×Q3×Q4×H0-HCL)*0.5
[5]    TCL←(Q10-Q11)÷Q3×Q4
[6]    XCL←(TCL×(Q7+(Q8×H0)+Q9×W0))+(TCL×TCL×0.5×((Q8×Q1)+(Q8×Q3×W0)-Q9×Q4))-TCL×TCL×TCL×Q8×Q3×Q4÷6
[7]    WFCL←Q4×TCL
[8]    →D31
[9]  D15:Q10←((Q1×Q6)-Q3×Q4)÷Q6-Q2
[10]  Q11←(Q1+(Q2×H0)+(Q3×W0)-Q10)÷Q6-Q2
[11]  ITCL1
[12]  XCL←(Q7×TCL)+(Q8×H0×TCL)+(Q8×Q10×TCL×TCL×0.5)+(Q9×W0×TCL)+(Q9×Q16÷(Q6-Q2))+(Q8×Q11××(Q6-Q2)×TCL)÷Q6-Q2
[13]  XCL←XCL+(Q9×Q16×TCL)-(Q8×Q11×TCL)+(Q8×Q11÷(Q6-Q2))+(Q9×Q15×TCL×TCL×0.5)+(Q9×Q16××(Q6-Q2)×TCL)÷Q6-Q2
[14]  →D31
[15] D16:TCL←(HCL-H0)÷Q1
[16]  XCL←(TCL×((Q7+Q8×H0)+Q9×W0))+(TCL×TCL×0.5×(Q8×Q1)-(Q9×Q4)+(Q9×Q5×H0))-TCL×TCL×TCL×Q9×Q5×Q1÷6
[17]  WFCL←TCL×Q4+(Q5×H0)+Q5×Q1×TCL×0.5
[18] D31:→⍳0
    ∇
```

Table 4.10   Subprogram CLIMB1 Listing

```
     ∇ ITCL
[1]    TCL←HCL÷(Q1+Q3×W0)
[2]   B0:S13←TCL
[3]    S14←(S6-HCL)+(S8××S4×S13)+S7××S5×S13
[4]    S15←(S4×S8××S4×S13)+S5×S7××S5×S13
[5]    TCL←S13-S14÷S15
[6]    S16←|TCL-S13
[7]    →B0×ι(S16>0.01)
[8]    WFCL←S9+(S11××S4×TCL)+S10××S5×TCL
     ∇
```

```
     ∇ ITCL1
[1]    TCL←HCL÷(Q1+Q3×W0)
[2]   D17:T←TCL
[3]    Q12←H0+(Q10×T)+(Q11××(Q6-Q2)×T)-(Q11+HCL)
[4]    Q13←Q10+(Q6-Q2)×Q11××(Q6-Q2)×T
[5]    TCL←T-Q12÷Q13
[6]    Q14←|TCL-T
[7]    →D17×ι(Q14>0.01)
[8]    Q15←((Q5×Q1)-Q4×Q2)÷Q6-Q2
[9]    Q16←(Q4+(Q5×H0)+(Q6×W0)-Q15)÷Q6-Q2
[10]   WFCL←(Q15×TCL)+(Q16××(Q6-Q2)×TCL)-Q16
     ∇
```

Table 4.11 Subprograms ITCL and ITCL1 Listings

```
    ∇ CRUISE
[1]   →D3×ι(HCR≥A[69])
[2]   Q1←A[46]+(A[43]-A[46])×M[J;7]
[3]   Q2←A[47]+(A[44]-A[47])×M[J;7]
[4]   Q3←A[48]+(A[45]-A[48])×M[J;7]
[5]   Q4←(A[15]+(A[12]-A[15])×M[J;7])÷60
[6]   Q5←(A[16]+(A[13]-A[16])×M[J;7])÷60
[7]   Q6←(A[17]+(A[14]-A[17])×M[J;7])÷60
[8]   →D4
[9]  D3:Q1←A[73]
[10]  Q2←A[74]
[11]  Q3←A[75]
[12]  Q4←A[70]÷60
[13]  Q5←A[71]÷60
[14]  Q6←A[72]÷60
[15] D4:XCR←M[J;3]-XCL+XDC
[16]  T←XCR÷Q4+(Q5×HCR)+Q6×W0
[17]  DET←¯1
[18]  WFCR←0
[19] D0:W0←W0+WFCR
[20]  TCR←T+DET
[21]  R14←XCL+XCR+XDC-M[J;3]
[22]  →D1×ι(Q3=0)
[23]  S1←(Q1+(Q2×HCR)+Q3×W0)÷Q3
[24]  WFCR←S1×1-*-Q3×TCR
[25]  XCR←(Q6×WFCR÷Q3)+TCR×Q4+(Q5×HCR)+Q6×W0-S1
[26]  W0←W0-WFCR
[27]  →D5×ι(Q13=0)
[28]  S13←(Q11+(Q12×HCR)+(Q13×W0)-S12)÷Q13
[29]  XDC←(TDC×A[12]+(A[13]×HCR)+A[14]×W0-S13)÷60
[30]  XDC←XDC+(TDC×TDC×0.5×(A[13]×Q10)-A[14]×S12)÷60
```

Table 4.12 Subprogram CRUISE Listing

```
[31]  XDC←XDC+(A[14]×S13÷Q13×60)×1-*-Q13×TDC
[32]  WFDC←S13+(TDC×S12)-S13×*-Q13×TDC
[33]  →D6
[34] D5:XDC←(TDC×A[12]+(A[13]×HCR)+A[14]×W0)÷60
[35]  XDC←XDC+TDC×TDC×0.5×((A[13]×Q10)-(A[14]×Q11)+A[14]×Q12×HCR)÷60
[36]  XDC←XDC-(TDC×TDC×TDC×A[14]×Q12×Q10)÷60×6
[37]  WFDC←TDC×(Q11+Q12×HCR)+TDC×0.5×Q12×Q10
[38] D6:R15←XCL+XCR+XDC-M[J;3]
[39]  R16←R14-R15
[40]  R17←R16÷DET
[41]  DET←R15÷R17
[42]  T←TCR+DET
[43]  →B0×ι((|R15)>0.01)
[44]  →D2
[45] D1:WFCR←TCR×Q1+Q2×HCR
[46]  XCR←TCR×Q4+(Q5×HCR)+(Q6×W0)-TCR×0.5×Q6×Q1+Q2×HCR
[47]  W0←W0-WFCR
[48]  XDC←(TDC×A[12]+(A[13]×HCR)+A[14]×W0)÷60
[49]  XDC←XDC+TDC×TDC×0.5×((A[13]×Q10)-(A[14]×Q11)+A[14]×Q12×HCR)÷60
[50]  XDC←XDC-(TDC×TDC×TDC×A[14]×Q12×Q10)÷60×6
[51]  WFDC←TDC×(Q11+Q12×HCR)+TDC×0.5×Q12×Q10
[52]  R15←XCL+XCR+XDC-M[J;3]
[53]  R16←R14-R15
[54]  R17←R16÷DET
[55]  DET←R15÷R17
[56]  T←TCR+DET
[57]  →B0×ι((|R15)>0.01)
[58] D2:→ι0
      ∇
```

Table 4.12 Cont'd.

```
    ∇ DESCENT
      Q10←-A[28]+(A[27]-A[28])×M[J;8]
      FAC←1+Q10×0.00025
      W0←W0-WFCR
      Q11←FAC×A[43]
      Q12←FAC×A[44]
      Q13←FAC×A[45]
      TDC←(M[J+1;6]-HCR)÷Q10
      →D32×ι(Q13=0)
      S12←Q12×Q10÷Q13
      S13←(Q11+(Q12×HCR)+(Q13×W0)-S12)÷Q13
      XDC←(TDC×A[12]+(A[13]×HCR)+A[14]×W0-S13)÷60
      XDC←XDC+(TDC×TDC×0.5×(A[13]×Q10)-A[14]×S12)÷60
      XDC←XDC+(A[14]×S13÷Q13×60)×1-*-Q13×TDC
      WFDC←S13+(TDC×S12)-S13×*-Q13×TDC
      →D33×ι(M[J;3]>XCL+XDC)
      →D34×ι(M[J;3]=XCL+XDC)
      SUBALT
      →D34
    D32:XDC←(TDC×A[12]+(A[13]×HCR)+A[14]×W0)÷60
      XDC←XDC+TDC×TDC×0.5×((A[13]×Q10)-(A[14]×Q11)+A[14]×Q12×HCR)÷60
      XDC←XDC-(TDC×TDC×TDC×A[14]×Q12×Q10)÷60×6
      WFDC←TDC×(Q11+Q12×HCR)+TDC×0.5×Q12×Q10
      →D33×ι(M[J;3]>XCL+XDC)
      →D34×ι(M[J;3]=XCL+XDC)
      SUBALT
      →D34
    D33:CRUISE
    D34:W0←W0-WFDC
    ∇
```

Table 4.13 Subprogram DESCENT Listing

```
    ∇ SUBALT
[1]   H←⌊/(M[J;4],(A[67]+A[68]×W0))
[2]   DELH←¯1000
[3]   W0←W0+WFCR
[4]   WFCL←0
[5]  B0:W0←W0+WFCL
[6]   HCL←HCR←H+DELH
[7]   R14←XCL+XDC-M[J;3]
[8]   SUBCLIMB
[9]   W0←W0-WFCL
[10]  SUBDESCENT
[11]  R15←XCL+XDC-M[J;3]
[12]  R16←R14-R15
[13]  R17←R16÷DELH
[14]  DELH←R15÷R17
[15]  H←HCL+DELH
[16]  →B0×⍳((|DELH)>0.01)
[17]  TCR←0
[18]  WFCR←0
[19]  XCR←0
```

Table 4.14 Subprogram SUBALT Listing

```
    ∇ SUBCLIMB
[1]   →D14×⍳((Q3×Q5)=Q2×Q6)
[2]   ITCL
[3]   XCL←(Q7×TCL)+(Q8×((S8××S4×TCL)÷S4)+((S7××S5×TCL)÷S5)+(S6×TCL))+Q9×(S11÷S4)+S10÷S5
[4]   XCL←XCL+(Q9×W0×TCL)-(Q9×((S11××S4×TCL)÷S4)+((S10××S5×TCL)÷S5)+(S9×TCL))+Q8×(S8÷S4)+S7÷S5
[5]   →D30
[6]  D14:CLIMB1
[7]  D30:→⍳0
    ∇
```

```
    ∇ SUBDESCENT
[1]   TDC←(M[J+1;6]-HCR)÷Q10
[2]   →D32×⍳(Q13=0)
[3]   S13←(Q11+(Q12×HCR)+(Q13×W0)-S12)÷Q13
[4]   XDC←(TDC×A[12]+(A[13]×HCR)+A[14]×W0-S13)÷60
[5]   XDC←XDC+(TDC×TDC×0.5×(A[13]×Q10)-A[14]×S12)÷60
[6]   XDC←XDC+(A[14]×S13÷Q13×60)×1-*-Q13×TDC
[7]   WFDC←S13+(TDC×S12)-S13×*-Q13×TDC
[8]   →D34
[9]  D32:XDC←(TDC×A[12]+(A[13]×HCR)+A[14]×W0)÷60
[10]  XDC←XDC+TDC×TDC×0.5×((A[13]×Q10)-(A[14]×Q11)+A[14]×Q12×HCR)÷60
[11]  XDC←XDC-(TDC×TDC×TDC×A[14]×Q12×Q10)÷60×6
[12]  WFDC←TDC×(Q11+Q12×HCR)+TDC×0.5×Q12×Q10
[13] D34:→⍳0
    ∇
```

Table 4.15 Subprograms SUBCLIMB and SUBDESCENT Listings

```
    ∇ DOWN
[1]   H0←M[J-1;6]
[2]   Q1←A[43]
[3]   Q2←A[44]
[4]   Q3←A[45]
[5]   Q4←A[12]÷60
[6]   Q5←A[13]÷60
[7]   Q6←A[14]÷60
[8]   HF←M[J+1;6]
[9]   T←M[J;3]÷Q4+(Q5×H0)+Q6×W0
[10]  DET←¯1
[11]  XDC←M[J;3]
[12] B0:TDC←T+DET
[13]  R14←XDC-M[J;3]
[14]  FAC←1-(H0-HF)×0.00025÷TDC
[15]  →D1×ι(Q3=0)
[16]  S1←Q2×(HF-H0)÷Q3×TDC
[17]  S2←(Q1+(Q2×H0)+(Q3×W0)-S1÷FAC)÷Q3
[18]  XDC←TDC×Q4+(Q5×H0)+(Q5×0.5×HF-H0)+Q6×W0-S2
[19]  XDC←XDC+Q6×S2×(1-*-FAC×Q3×TDC)÷FAC×Q3
[20]  XDC←XDC-TDC×TDC×0.5×Q6×S1
[21]  DELF←(TDC×S1)+S2×1-*-FAC×Q3×TDC
[22]  R15←XDC-M[J;3]
[23]  R16←R14-R15
[24]  R17←R16÷DET
[25]  DET←R15÷R17
[26]  T←TDC+DET
[27]  →B0×ι((|R15)>0.01)
[28]  →D2
[29] D1:XDC←TDC×Q4+(Q5×0.5×HF+H0)+Q6×W0
[30]  XDC←XDC-TDC×TDC×0.5×Q6×Q1+Q2×H0+(HF-H0)÷3
```

Table 4.16   Subprogram DOWN Listing

```
[31]  DELF←TDC×Q1+Q2×H0+0.5×(HF-H0)
[32]  R15←XDC-M[J;3]
[33]  R16←R14-R15
[34]  R17←R16÷DET
[35]  DET←R15÷R17
[36]  T←TDC+DET
[37]  →B0×ι((|R15)>0.01)
[38] D2:→10
```

Table 4.16 Cont'd.

```
     ∇ ECON
[1]   ''
[2]   ''
[3]   'TOTAL MISSION                ELAPSED   ELAPSED   FUEL                                             LOAD'
[4]   '                             DISTANCE   TIME     USED                                            FACTOR'
[5]   '                              N.MI.     HRS.     LBS.                                             -'
[6]   ''
[7]   (30 1 DFT XTOT),(9 2 DI  TTOT),(9 0 DFT FTOT),(53 2 DFT L26)
[8]   ''
[9]   ''
[10]  ''
[11]  UPM←TTOT-TLO+TRE+TIN+TSB
[12]  U←U-(~L5)×U-MPY×UPM
[13]  MPY←U÷UPM
[14]  L7←(M[DD-1;4]+A[61])×A[58]÷U
[15]  L6←L7×UPM
[16]  L9←FTOT÷6-(6-6.7)×A[62]
[17]  L9←A[64]+L9×A[63]÷UPM
[18]  L8←L9×UPM
[19]  L11←(A[57]+(A[57]×M[DD-1;3]))×(A[55]+A[56])×0.0042÷U
[20]  L10←L11×UPM
[21]  L13←A[59]×10
[22]  L12←L13×UPM
[23]  L15←A[60]
[24]  L14←L15×UPM
[25]  L17←(0.0425×A[55]+A[56])÷U
[26]  L16←L17×UPM
[27]  L19←L7+L9+L11+L13+L15+L17
[28]  L18←L19×UPM
[29]  L21←M[DD-1;5]
[30]  L20←L21×UPM
```

Table 4.17 Subprogram ECON Listing

```
[31]  L27←(0.1×PM)+CM×0.0005
[32]  →D2×ι(L27=0)
[33]  L25←L18÷L27
[34] D2:MIX←365×⌊M[DD-1;6]÷TTO
[35]  S1←(0.0162×A[55]+A[56])÷
[36]  S2←S1×UPM
[37]  L23←L19+L21+S1
[38]  L22←L18+L20+S2
[39]  '        AIRCRAFT                  MISSIONS        AVAILABLE       MISSION'
[40]  '      UTILIZATION                 PER YEAR       PAYLOAD TON    PAYLOAD TON'
[41]  '  HRS./MISSION   HRS./YR.     MAXIMUM   ACTUAL       MILES          MILES'
[42]  ''
[43]  (10 2 DFT UPM),(13 0 DFT U),(11 0 DFT MIX),(10 0 DFT MPY),(11 0 DFT L30),(14 0 DFT L27)
[44]  ''
[45]  ''
[46]  ''
[47]  →D1×ι((B1=2)∨(B1=4))
[48]  '                        DIRECT OPERATING COSTS       PER MISSION     PER FLIGHT HOUR'
[49]  ''
[50]  '                           FLIGHT CREW',(23 2 DFT L6),(16 2 DFT L7)
[51]  '                           FUEL+OIL',(26 2 DFT L8),(16 2 DFT L9)
[52]  '                           INSURANCE',(25 2 DFT L10),(16 2 DFT L11)
[53]  ''
[54]  '                           MAINTENANCE,LABOR',(17 2 DFT L12),(16 2 DFT L13)
[55]  '                           MAINTENANCE,PARTS',(17 2 DFT L14),(16 2 DFT L15)
[56]  ''
[57]  '                           DEPRECIATION',(22 2 DFT L16),(16 2 DFT L17)
[58]  ''
[59]  '                           TOTAL DOC',(25 2 DFT L18),(16 2 DFT L19)
[60]  ''
```

Table 4.17 Cont'd.

```
[61]  '                        MISSION RELATED COSTS'
[62]  ''
[63]  '                            TOTAL MRC',(25 2 DFT L20),(16 2 DFT L21)
[64]  ''
[65]  '                        OTHER COSTS'
[66]  ''
[67]  '                            INTEREST',(26 2 DFT S2),(16 2 DFT S1)
[68]  ''
[69]  '                            TOTAL OC',(26 2 DFT S2),(16 2 DFT S1)
[70]  ''
[71] D1:'                         TOTAL COSTS                 PER MISSION     PER FLIGHT HOUR'
[72]  ''
[73]  (60 2 DFT L22),(16 2 DFT L23)
[74]  ''
[75]  →D3×⍳(L27=0)
[76]  '                        DOC/MISSION PAYLOAD TON MILE',(10 2 DFT L25)
[77] D3:→10
      ∇
```

Table 4.17. Cont'd.

Table 4.18 Summary of Diagnostic Information

CONDITION	DIAGNOSTIC
PAX > PMX	Maximum passenger capacity exceeded by (PAX - PMX)
WO > WMX	Takeoff weight limitation exceeded by (WO - WMX) lbs
REMF < TMR	Fuel onboard insufficient for (RSV) minute reserve by (TMR - REMF)/((T1 + T2 (10000) + T3 (WO)) min
REMF ≤ O	Ran out of gas by (-REMF) lbs
PAX < O	Unloaded too many passengers by (-PAX)
CAR < O	Unloaded too much cargo by (-CAR) lbs
REMF > FMX	Maximum fuel capacity exceeded by (REMF - FMX) lbs
CAR > CRX	Maximum cargo capacity exceeded by (CAR - CRX) lbs
HCL < HMN	Minimum altitude not attained by (HMN - HCL) ft
REMF > WLF	Takeoff weight limitation exceeded by (REMF - WLF) lbs

4.4.12 Total Mission Summary

Upon completion of the individual mission segment analysis, the following mission summary parameters are computed and output.

Total mission elapsed distance
Total mission elapsed time
Total mission fuel used
Total mission load factor
Aircraft utilization per year and mission
Missions per year, maximum and actual
Payload ton miles, available and mission

Total mission elapsed distance, XTOT, is,

$$XTOT = DELX_1 + DELX_2 \ldots + DELX_n \tag{112}$$

where the DELX are the individual mission segment elapsed distances.

Similarly, total mission elapsed time is,

$$TTOT = DELT_1 + DELT_2 + \ldots + DELT_n \tag{113}$$

and total mission fuel used is,

$$FTOT = DELF_1 + DELF_2 + \ldots + DELF_n \tag{114}$$

The total mission load factor, L26, is a distance weighted function of the individual segment load factors, namely,

$$L26 = \frac{L24_1 DELX_1 + L24_2 DELX_2 + \ldots + L24_n\, DELX_n}{DELX_1 + DELX_2 + \ldots + DELX_n} \tag{115}$$

Aircraft utilization per year, U, is either input to the program, or calculated if it is not known beforehand. In the latter case, it is necessary to input the actual missions per year, MPY, anticipated. If U is calculated,

$$U = MPY\ (UPM) \tag{116}$$

where

UPM = utilization per mission

$$= TTOT - \sum(TLO + TRF + TIN + TSB) \tag{117}$$

If U is input, MPY is calculated from

$$MPY = U/UPM \tag{118}$$

Maximum missions per year, MIX, is obtained from the average daily hours available for aircraft operation OPS, by the relationship,

$$MIX = 365 (\downarrow (OPS/TTOT) \tag{119}$$

Where $\downarrow$ denotes the next lowest integer value of OPS/TTOT. This disallows the use of fractional missions computed on a daily basis to be included in the yearly total. For example, if OPS = 16 hrs and TTOT = 3 hrs the number of missions that can be completed in a day (mathematically) is 16/3 = 5.33. But, the actual number of missions that can be completed in a day is 5 (or $\downarrow$ 5.33).

Mission payload ton miles, L27, is obtained from the relationship,

$$L27 = \frac{200\ PM + CM}{2000} \tag{120}$$

It is recalled that passengers are assumed to weigh 200 lbs each. Division by 2000 converts lbs to tons.

Available ton miles, L30, is

$$L30 = AP_1\ DELX_1 + AP_2 DELX_2 + \ldots + AP_n DELX_n \tag{121}$$

where, AP is the available payload given by,

$$AP = \frac{WMX - WEM - REMF - 200\ EXC}{2000} \tag{122}$$

and the subscripts in Eq. 121 refer to individual mission segments.

XTOT, TTOT, FTOT, L24, and L26 are accumulated sequentially in each individual mission segment module in program FLIES.

L30 and AP are calculated in statements [73], [137] and [167] of FLIES. U (or MPY), UPM and MIX are calculated in statements [11], [12], [13], and [34] of program ECON.

4.4.13 Direct Operating, Mission Related, and Other Costs

Economics of operation of a mission and aircraft combination are broken down into direct operating, mission related, and other costs.

Direct operating costs involve expenses for the flight crew, aircraft fuel, oil, insurance, maintenance requiring parts and labor, and depreciation. Flight crew cost per flight hour, L7, is related to crew salary, SCR, and crew size, NFC, by the expression

$$L7 = (NFC + EXC)(SCR)/U$$

Fuel and oil cost per hour, L9, is

$$L9 = \frac{CFL\ (FTOT)}{6\ UPM} + CLU \quad ; \text{ Aviation gas}$$

$$= \frac{CFL\ (FTOT)}{6.7\ UPM} + CLU \quad ; \text{ JP jet fuel}$$

where CFL is fuel cost per gallon, and CLU is lubrication cost per flight hour.

Insurance is based on the value of the aircraft for any give year. When the aircraft is new the insurance premium is much higher than in later years after depreciation. The approach taken in this study was to base the yearly insurance costs on the average value of the aircraft over a useful lifetime of 20 years. Therefore, this approach does not differentiate between the insurance premium of a 10 year old contemporary aircraft and a new advanced concept.

Representative aircraft value data, for two medium lift helicopters and two business jets, were found to yield an average aircraft value equal to 42% of its new price over a 20 year period. Insurance costs per flight hour, L11, are based on this average value by,

$$L11 = 0.42\ INS\ (CAC + CAX)/100$$

where INS is the annual insurance premium rate in percent, CAC and CAX are the aircraft new cost and auxiliary equipment costs respectively.

Aircraft maintenance labor cost, L13, and maintenance parts cost, L15, per flight hour are,

$$L13 = 10\ MLA$$

$$L15 = MPT$$

Here, it is assumed that hourly labor costs are \$10 based on contacts with various operators.

Depreciation costs per flight hour, L17, have been based on the same representative aircraft data used to obtain average aircraft values for insurance purposes. In this case it is found that over a 20 year period a typical aircraft, if properly maintained, depreciates to a level salvage value equal to about 15% of its new cost. For this analysis, the total 85% depreciation has been assumed to be equally spread over the 20 year life resulting in a straight line 4.25% per year depreciation value. Then,

$$L17 = 0.0425\ (CAC + CAX)/U$$

Mission related costs fall into a separate category from direct operating costs. For example, an operator of a helicopter airline, also engaged in construction work, can expect higher costs to result for his heavy lift work missions due to reduced engine and transmission life. On the other hand, his airline service missions will not place the extra strain on engines and transmissions and will therefore be less costly. The extra costs associated with the heavy work missions typify an example of the mission related cost category. Mission related costs per flight hour, MRC, are input via program MISSION.

Interest costs are not generally included within the direct operating cost category. In this study they have been listed as other costs. For this purpose, interest cost has been based upon 80% financing of the new cost of the aircraft and auxiliary equipment over an 8 year period at 8 1/4 percent simple interest per year. This results in total interest costs equal to 32.4% of the original investment, or 1.62% per year over a 20 year span. The interest cost per flight hour, S1, is then

$$S1 = 0.0162\ (CAC + CAX)/U$$

Finally, a parameter that can be regarded as a single valued measure of overall combined cost and performance has been defined to be the direct operating cost per mission payload ton mile, L25, according to the relation

$$L25 = (L7 + L9 + L11 + L13 + L15 + L17)(UPM)/L27$$

where L27 is defined by Eq. 120.

All equations for direct operating, mission related, and other costs, together with total direct operating cost per mission payload ton mile are contained in statements [14] through [35] of program ECON.

4.5 Execution of Program

Program FLIES is executed by typing the aircraft I.D. designated by program AIRCRAFT, followed by FLIES, followed by the mission I.D. designated by program MISSION. Using the example shown in Table 4.1, the typed execution sequence would be TILTROTOR FLIES OFFSHOREOIL. Program FLIES then carries the user through its operation.

A.3 Ad Hoc Modification to Computer Program FLIES

This appendix briefly describes the on-line modifications made to the basic programs in order to expedite the analysis, or to provide additional output options. It is not necessary to be highly skilled in APL to make these changes. Average user familiarity with APL and with these programs are the only prerequisites. (A listing of these program modifications are on file at The Aerospace Corporation).

Mod. 1. Parametric Changes to Aircraft Definition Parameters

To avoid time consumed in changing single aircraft parameters (i.e., fuel capacity) and utilizing program FLIES on successive runs, an input routine that set successive values for an identified aircraft parameter was written to modify program FLIES to cause it to recycle the specified number of times.

Mod. 2. Parametric Changes to Mission Definition Parameters

For the same reasons which prompted Mod. 1. three mission parameters were identified as being the principal ones requiring parametric study, namely, enroute distance, passengers, and cargo. This Mod allows any, or all three, of these parameters to be set to n values and the program cycled n times.

Mod. 3. Estimated Fuel Requirement

As written, the analysis programs either fuels the aircraft for a specified number of minutes, or tops the tanks. Unless the analyst can estimate the correct fuel load, the mission is run for an aircraft with a full fuel load. This sometimes results in an unrealistic situation. This mod causes the program FLIES to execute once without providing output. The fuel required as determined by the first run is used to set the aircraft fuel capacity for a second run. Thus, the second run is made with an approximately correct fuel load. Since the weight of the aircraft is different between the two runs, its performance will be different on the second run compared to the first.

This at times can result in insufficient fuel and causes the violation of the reserve fuel constraint. To preclude this, a fuel estimating factor is defined in the aircraft parameters (parameter No. 66) which may be used to increase the estimated fuel load by a few percent to account for any increased fuel consumption. Normally the fuel estimating factor is set at one (no increase) until shown that it must be increased a few percent.

Mod. 4. Supplemental Output

When running FLIES for parametric studies it is generally more expeditious to select the summary output mode to save time since all of the detailed output is not generally required. However, some of the output suppressed in the summary mode is useful. This mod collects selected output parameters such as take off weights, cruise altitudes, computes average cruise speeds, fuel consumed, and appends them to the normal summary output.

A. 4 LIFT FAN V/STOL AIRCRAFT PERFORMANCE CALCULATIONS

The lift Fan V/STOL aircraft data provided by NASA Ames Research Center was in the form of design, rather than operational performance data. Therefore, it was necessary to use the basic aerodynamic design and engine data available to develop the required information such as aircraft climb and cruise performance as a function of weight and altitude. Additionally, fuel consumption data for the various flight conditions was required. This appendix describes the methodology in deriving these operational data.

In Section A4a the mathematical derivation of performance by use of the aerodynamic equations is explained. This development was done by Dr. Julian Wolkovitch, a consultant to The Aerospace Corporation.

Section A 4b describes how the Wolkovitch equations were used to develop a program in APL language to perform the calculations required to give the coefficients used in the aircraft mission analysis programs. This development was done by Mr. Arnold Hansen of The Missile System Design Department, The Aerospace Corporation.

Section A4c contains an example calculation using the computer programs, while Section A4d contains a listing of the programs for reference.

DERIVATIONS

A. 4. a Performance Derivations

Introduction

The performance calculation method summarized here is based on that used by Lippisch (Ref. A. 1) for performance estimation of ducted fan aircraft. The essential feature of Lippisch's method is that engine lift and drag effects are represented as the sum of two terms:

(1) An internal mass flow term representing the change in the momentum vector of the air that actually passes through the engine and fan. This air has a mass flow m_j slugs/sec and a jet exit velocity V_j fps. The fully developed cross-sectional area of this flow is assumed to equal the total fan area A_j ft^2.

(2) An external mass flow term representing a hypothetical mass flow m_o which is initially parallel to the relative wind vector V_o and which is deflected through an angle $\theta_j + \alpha$, parallel to the direction of the internal mass flow (see Fig. A. 4-1). This external mass flow is not accelerated, it is assumed to remain at speed V_o throughout.

Aerodynamic Equations

The lift and drag due to the engine-induced internal and external mass flows are denoted L_p and D_p respectively. From Fig. A. 1, resolving normal and parallel to the flight path we have:

$$D_p = m_j V_o - m_j V_j \cos(\theta_j + \alpha) + m_o V_o - m_o V_o \cos(\theta_j + \alpha) \quad (A.1)$$

$$L_p = m_j V_j \sin(\theta_j + \alpha) + m_o V_o \sin(\theta_j + \alpha) \quad (A.2)$$

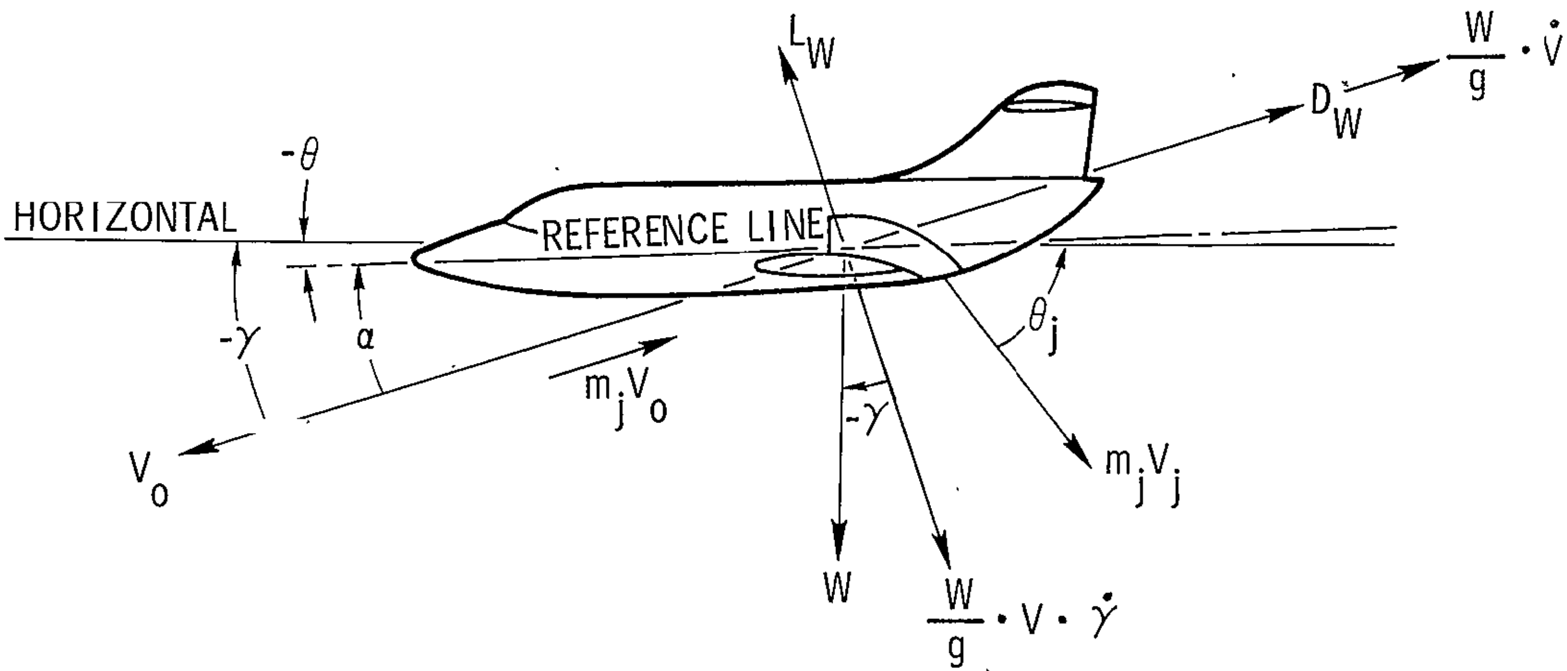


FIGURE A 4-1 Forces Acting on A Lift-Fan Aircraft where θ_j = jet deflection angle relative to fuselage reference line

α = angle of attack measured relative to fuselage reference line

Neglecting the effects of pitching moment trim requirements, the power-off lift and drag L_W and P_W can be calculated from the standard expressions:

$$D_W = \left(C_{D_o} + \frac{C_L^2}{\pi e A} \right) \times 1/2 \; \rho \; V_o^2 \, S \qquad (A.3)$$

$$L_W = \frac{dC_L}{d\alpha} (\alpha - \alpha_o) \cdot \frac{1}{2} \rho V_o^2 \, S, \text{ for } \alpha < \alpha \text{ stall} \qquad (A.4)^1$$

where $\frac{dC_L}{d\alpha}$ = lift-curve slope $\frac{2 \pi A}{2 + (A/0.87)} \times \cos \Lambda_{1/4}$

α_o = zero-lift angle of attack

ρ = air density, slugs/ft^3

S = wing reference area, ft^2

C_{D_o} = drag coefficient at zero lift

C_L = power-off lift coefficient = $L_W/(1/2) \; \rho \; V_o^2 S$

e = span efficiency factor.

A = aspect Ratio

$\Lambda_{1/4}$ = sweep angle of quarter-chord line

Given the airplane geometry, plus the airspeed and air density, the constants in Eqs. A.1 through A.4 can be calculated from standard handbooks (e.g., Ref. A.3) except for m_j, m_o, and θ_j. It is assumed that m_j and θ_j are selected by the pilot to meet specified trim conditions; this then leaves m_o as the sole remaining quantity to be specified.

It is convenient to express m_o in terms of m_o/m_j which is the ratio of entrained to internal mass flow. The following empirical formula

[1] At low Mach Numbers - Reference A.2

was found to match manufacturer's data on total lift and power-off lift for given m_j and θ_j.

$$\frac{m_o}{m_j} = 0.035647 + 6.363896\left(\frac{V_o}{V_j}\right) - 16.8803\left(\frac{V_o}{V_j}\right)^2 + 19.9242\left(\frac{V_o}{V_j}\right)^3 - 9.44418\left(\frac{V_o}{V_j}\right)^4 \qquad \text{(A. 5)}$$

m_j is related to V_j by the continuity equation.

$$m_j = \rho_j \; A_j \; V_j \qquad \text{(A. 6)}$$

where A_j = jet exit area, ft^2

ρ_j = jet density, slug-ft^{-3}

The jet has been assumed to be "cold"; that is, it has the same density as the ambient atmosphere, and A_j has been set equal to the total area of all fans.

Trim Equations

Trim equations are obtained by equating the total lift and drag to the inertial and gravitational forces acting normal and parallel to the flight path respectively. This gives, from Fig. A. 1,

$$L_p + L_w = \frac{W}{g} \cdot V_o \; \dot{\gamma} + W \; \cos(-\gamma) \qquad \text{(A. 7)}$$

$$D_p + D_w = -\frac{W}{g} \cdot \dot{V}_o + W \sin(-\gamma) \qquad \text{(A. 8)}$$

where the dot denotes differentiation with respect to time

W = gross weight, lbs.

g = acceleration due to gravity, fps^2

γ = flight path angle to the horizontal, positive for climb

The airplane flight deck attitude to the horizontal, θ, is given by

$$\theta = \alpha + \gamma$$

Thrust and Power Equations

The net propulsive force of all engines including aerodynamic induced effects, T, is given by:

$$T = (L_p^2 + D_p^2)^{1/2} \qquad (A.10)$$

The ideal gas power, i. e., the power that is required to produce the thrust T, assuming no losses in the airflow (e. g. no swirl, uniform jet velocity), and no engine losses, is given by:

$$P_i = 1/2\, m_j \,(V_j^2 - V_o^2) \qquad (A.11)$$

where P_i is measured in lb-ft-sec^{-1}.

Performance Calculation

Based on engine manufacturer's data, curve-fit formulas were derived for engine fuel consumption as a function of ϱ, T, and V. A digital computer program was written to solve Eqs. A-1 through A-11. The input to the program includes the trim conditions V_o, $\dot{V}_o$, γ, $\dot{\gamma}$, W, ρ, and the airplane geometric and aerodynamic parameters, C_{D_o}, α_o, e, etc. The program iterates on θ_j and m_j until the specified trim conditions are satisfied. It then calculates the fuel consumption.

Unlike conventional aircraft, a lift-fan aircraft can be flown at various airspeeds while maintaining a constant attitude and altitude. This can be achieved by controlling the jet deflection θ_j so that the jet provides the difference between weight and wing lift. For flight conditions when the wing can provide all the required lift, the program results indicate that it is most economical in terms of fuel consumption to direct the jet approximately parallel to the flight path.

REFERENCES

Appendix A 4

A. 1 Lippisch, A. M., Research in the field of Wingless VTOL Aircraft. Institute of the Aeronautical Sciences Paper No. 808, January 1958.

A. 2 Piercy, N. A. V., Aerodynamics, 2nd Edition, The English Universiti Press, London, 1947.

A. 3 Wood, K. D., Aerospace Vehicle Design, Vol. I. Aircraft Design, 3rd Edition, Johnson Publishing Co., Boulder, Co.

A. 4. b Computer Programs FLYER and FLYERCRIT

1. 0 Introduction

This section of Appendix A-4 describes two groups of computer programs which have been developed to determine the performance characteristics of lift-fan vectored-thrust VSTOL aircraft. These programs utilize aircraft design information and operating conditions as input data and deliver as output performance parameters such as thrust, power, fuel consumption, and specific range. The first program group, called FLYER, computes performance for airspeeds below and including critical velocity for a given value of attack angle. (Critical airspeed is maximum airspeed, attained when the sum angle of attack and jet deflection angle is zero; thus, is the powered lift phase of flight). The second program group, called FLYERCRIT, computes performance only for critical airspeeds for a range of attack angles (aerodynamic phase of flight). Performance is determined from relationships given in Section a of this appendix, suitably rearranged for computer solution. The programs have been tested and were successfully used in the VSTOL design studies described in Volume I of this report.

The following paragraphs discuss the input data required and the method of submitting the data; the calculations performed; and the output data produced. Appendices define terms and symbols; show sample calculations and program outputs; and present program listings and descriptions.

2. 0 Input Data

Table A 4-1 lists the input data required to operate the FLY and FLYCRIT programs, and Figure A 4-2 depicts the VSTOL aircraft and some of the variables involved in describing its performance.

The coefficients listed in Table A 4-1 are used to determine certain variables as functions of other variables. For example, COEFWSCAL contains eight constants used to calculate scaled fuel consumption rate as a function of scaled engine thrust and Mach No. The equations for these functions are presented in later sections of this report. These coefficients are placed in the computer workspace (for APL computation) prior to program execution.

The remaining input quantities are specified by the operator during program execution via the FLYIN or FLYINCRIT subroutines. The computer "asks" two questions in the initial portions of each run and requires responses from the operator:

(1) Question: SHOULD SEARCH BE FOR GIVEN VELOCITY OR GIVEN ATTACK ANGLE ("ARSPD' or 'ALFA')?

This question is asked only during execution of FLYCRIT. The response ARSPD causes attack angles to be computed for given airspeeds, whereas the response ALFA causes critical velocities to be computed for given attack angles.

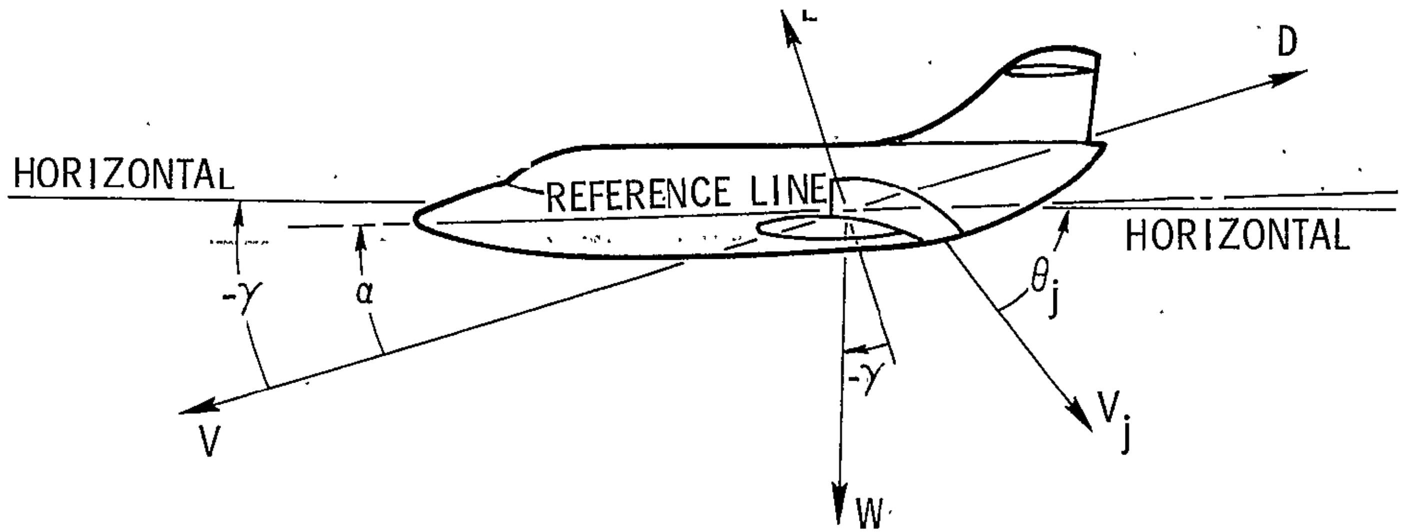
(2) Question: IS COMPLETE OR PARTIAL INPUT DESIRED?

The response COMPLETE activates a mode in which the input quantities are requested by name and the subsequent values entered by the operator are automatically assigned to the appropriate variables. The response PARTIAL causes this mode to be bypassed and results in the comment SPECIFY NEW INPUT AND THEN PUNCH→0. The operator may then input changes to previously specified variables in the normal APL manner (e.g., W←10000) since no automatic assignments are provided in this mode. After completing input, the operator types →0 and execution is resumed. The bypass mode is provided to obviate the need for complete respecification of input when only a few changes are desired.

TABLE A 4-1 INPUT DATA

Item	Symbols: Algebraic	Symbols: APL Programs	No. of Values
Coefficients:			
Atmospheric Density		COEFRHO	
Entrained-to-Jet Mass Flow Ratio		COEFMOMJ	
Reduced Pressure		COEFPR	
Reduced Temperature		COEFTR	
Mach No.		COEFVS	
Scaled Fuel Flow		COEFWSCAL	
Aircraft Gross Weight	W	W	1
Wing Area	S	S	1
Wing Aspect Ratio	A	A	1
Wing Span Efficiency	e	E	1
Zero-Lift Drag Coefficient	C_{DO}	CDO	1
Quarter-Chord Line Sweep A	$\Omega_{\frac{1}{4}}$	OMEGA 14	1
Zero-Lift Attack Angle	α_o	ALFO	1
Attack Angle	α	ALF	*
No. of Fans Operating	N	NOFA	1
Jet Density	ρ_j	RHOJ	1
Altitude	h	ALT	1 or more
Airspeed	V	ASPD	1 or more
Flight Path Angle	γ	GAM	1
Flight Path Angle Ratio	$\dot{\gamma}$	BAMD	1
Flight Path Acceleration	$\dot{V}$	VDOT	1

* 1 only in FLYIN (group FLYER); 1 or more in FLYINCRIT (group FLYERCRIT)



D	-	drag	W	-	weight
L	-	lift	α	-	attack angle
V	-	velocity (airspeed)	γ	-	flight path angle
V_j	-	jet velocity	θ_j	-	jet deflection angle

FIGURE A 4-2 Schematic of Lift Fan VSTOL Aircraft

The final column in Table A 4-1 lists the number of values which may be input for each variable. Most of the variables are restricted to single values. However, multiple values may be specified for altitude, airspeed, or attack angle subject to the following conditions:

(1) Only a single value of attack angle can be input in executing FLY.

(2) Multiple values may be input for either attack angle or airspeed in executing the FLYERCRIT group. If the response ARSPD was given to the above question involving SEARCH, then the inputs for attack angle will merely be ignored. However, at least one input must be specified to avoid execution problems.

(3) If problem execution time exceeds a certain limit (typically 30 seconds), the computer system will automatically suspend operations and require a command from the operator in order to resume execution. This automatic suspension causes two problems: (1) in some computing routines, resumption of execution may not occur exactly where suspension occurred, and may introduce computing errors; (2) the output format will be cluttered with undesirable information. These problems can be avoided by limiting the number of values for altitude, airspeed, and/or attack angle so that execution is completed in less than 30 seconds of computer time. The operator can determine the approximate limiting number of input values by performing trial runs and noting elapsed computer time. The latter information is obtained by typing ⎕AI both before and after program execution.

Some additional comments regarding operator input are as follows:

(1) Some of the input requests ask for inputs to more than one variable in a single line. The operator must type a vector string in conventional APL manner containing exactly the number of elements requested.

(2) The request for jet density may be answered either by typing a number or by entering the literal vector 'RHO'. The latter response makes jet density equal to atmospheric density.

(3) The operator need not be concerned with avoiding airspeeds greater than the critical speed since such values are automatically discarded during the computations.

3.0 Calculations

Three groups of calculations are performed in both programs: (1) Atmosphere-Related Properties; (2) Jet Characteristics, and (3) Performance. Symbols used are summarized in Table A 4-2.

3.1 Atmosphere-Related Properties

Atmospheric density, reduced pressure, reduced temperature, and sonic velocity are functions of altitude. The following relationships were derived via regression analysis using data from the 1969 NASA Standard Atmosphere tables.

Density: (1-1)

$$\rho = \frac{-1.668}{10^{16}} h^3 + \frac{2.735}{10^{11}} h^2 - \frac{2.266}{10^6} h + 0.0765 \ \text{lb/cu ft}$$

Reduced Pressure: (1-2)

$$\delta_A = - \frac{2.844}{10^{-15}} h^3 + \frac{5.020}{10^{-10}} h^2 - \frac{3.592}{10^5} h + 0.9997$$

Reduced Temperature: (1-3)

$$\theta_A = \frac{1.857}{10^{15}} h^3 - \frac{8.729}{10^{11}} h^2 - \frac{5.862}{10^6} + 0.9982$$

Sonic Velocity: (1-4)

$$V_S = \frac{1.174}{10^{12}} h^3 - \frac{6.306}{10^8} h^2 - \frac{3.180}{10^3} h + 1115.3 \ \text{fps}$$

Table A 4-2 Symbols

TERMS	ALGEBRAIC	APL	COMMENTS
Aspect Ratio	A	A	
Jet Area	A_j	AJ	
Jet Area per Fan	A_{j1}	AJ1	
Quadratic Coefficient	A_q	AQ	
Quadratic Coefficient	B_q	BQ	
Zero-Lift Drag Coefficient	C_{DO}	CDO	
Lift Coefficient (Power-Off)	C_L	CL	
Quadratic Coefficient	C	CQ	
Weight Coefficient	C_w	W÷K3	Located in DOMISC [9] and DOMISCCRIT [13]
Lift Curve Slope	$dC_L/d\alpha$	DCL	
Drag	D	D	
Drag Attributed to Propulsic	D_p	DP	
Span Efficiency	e	E	
Gravitational Acceleration	g	32.2	
Altitude	h	ALT	
Climb Rate	$\dot{h}$	60 x Y x SIN GAM	Located in DOMISC [9] and DOMISCCRIT [13]
Interim Computing Factors	K_N	KN	For example, K_{32} corresponds to K32
Lift	L	L	
Lift from Propulsion	L_p	LP	
Jet Mass Flow	M_j	MJ	
Entrained Mass Flow	M_o	MO	
Mach Number	M	MACH	
No. of Fans	N	NOFAN	
Power	P	PWR	

Table A 4-2 Symbols (Cont'd)

TERMS	ALGEBRAIC	APL	COMMENTS
Specific Range	R_s	V [J]x 0.5925-FC	Located in DOMISC[9]and DOMISCCRIT[13]
Wing Area	S	S	
Specific Fuel Consumption	$\overline{SFC}$	FC ÷ TH	
Thrust	T	TH	
Scaled Thrust	T_s	THSCAL	
Velocity, Airspeed	V	V, ASPD	V is in fps; ASPD is in n. mi /hr.
Acceleration	$\dot{V}$	VDOT	
Critical Velocity	V_{cr}	VCR	
Jet Velocity	V_j	VJ	
Aircraft-to-Jet Velocity Ratio	V/V_j	VR	Located in DOMOMJP[1]
Sonic Velocity	V_s	VS	Not explicit in listing but computed in DOMISC [6] and DOMISCCRIT [7]
Weight	W	W	
Fuel Consumption Rate	$\dot{W}$	FC	
Scaled Fuel Consumption Rate	$\dot{W}_s$	FCSCAL	Not explicit in listing but computed in DOMISC [7] and DOMISCCRIT [11]
Attack Angle	α	ALF	
Zero-Lift Attack Angle	α_o	ALFO	
Flight Path Angle	γ	GAM	
Flight Path Angle Rate	$\dot{\gamma}$	GAMD	
Reduced Pressure	δ_A	PR	
Reduced Temperature	θ_A	TR	
Jet Deflection Angle	θ_j	THETAJ	
Entrained-to-Jet Flow Ratio	μ	MOMJ	
Circular Function: Pi	π	PI	

Table A 4-2 Symbols (Cont'd)

TERMS	ALGEBRAIC	APL	COMMENTS
Atmospheric Density	ρ	RHO	
Jet Density	ρ_j	RHOJ	
Quarter-Chord Line Sweep Angle	$\Omega_{\frac{1}{4}}$	OMEGA14	
Coefficients for.			
$\rho = f\ (h)$	–	COEFRHO	
$\mu = f\ (V/V_j)$	–	COEFMOMJ	
$\delta_A = f\ (h)$	–	COEFPR	
$\theta_A = f\ (h)$	–	COEFTR	
$V_s = f\ (h)$	–	COEFVS	
$\dot{W}_s = f\ (M,\ T_s)$	–	COEFWSCAL	

3.2 Jet Characteristics

Equations in Section a of this appendix define the lift and drag necessary to operate with given flight path characteristics:

$$L = \frac{W}{g} V\dot{\gamma} + W \cos(-\gamma) \tag{2-1}$$

$$D = -\frac{W}{g} \dot{V} + W \sin(-\gamma) \tag{2-2}$$

where:

- L ~ lift
- D ~ drag
- W ~ gross weight
- g ~ gravitational acceleration
- V ~ airspeed
- $\dot{V}$ ~ acceleration
- γ ~ flight path angle
- $\dot{\gamma}$ ~ flight path angle rate

Lift and drag are also related to aircraft design characteristics, jet properties, and flight conditions:

$$L = m_j V_j \sin(\theta_j + \alpha) + m_o V \sin(\theta_j + \alpha) + 1/2 \rho V^2 S C_L \tag{2-3}$$

$$D = m_j V - m_j V_j \cos(\theta_j + \alpha) + m_o V - m_o V \cos(\theta_j + \alpha) + 1/2 \rho V^2 S C_{DO} + 1/2 \rho V^2 S \frac{C_L^2}{\pi e A} \tag{2-4}$$

where:

- m_j ~ jet mass flow
- v_j ~ jet velocity

θ_j ~ jet angle

α ~ attack angle

m_o ~ entrained mass flow

S ~ wing area

α_o ~ zero - lift attack angle

e ~ wing span efficiency

A ~ aspect ratio

C_{DO} ~ zero - lift drag coefficient

ρ ~ atmospheric density

C_L ~ lift coefficient (power off) = $\frac{dC_L}{d\alpha}(\alpha - \alpha_o)$ (2-5)

$$\frac{dC_L}{d\alpha} = \frac{2 \pi A}{\left(2 + \frac{A}{0.87}\right)} \cos \Omega_{1/4} \qquad (2\text{-}6)$$

Where $\Omega_{1/4}$ = sweep angle of quarter - chord line

Another pertinent relation is the continuity equation for the jet:

$$\dot{m}_j = \rho_j A_j V_j \qquad (2\text{-}7)$$

where:

ρ_j ~ jet density (2-8)

A_j ~ jet area

$= N \times A_{j1}$

N ~ number of fans operating

A_{j1} ~ jet area per fan

The preceding equations were combined and rearranged into forms suitable for computer solution, as follows:

(1) An expression for critical velocity was derived by combining equations (2-1) and (2-3), setting ($\theta_j + \alpha = 0$), and solving for V ($V = V_{cr}$):

$$V_{cr} = \frac{K_{32} + \sqrt{K_{32}^2 + 2K_{31} \;W \;\cos(-\gamma)}}{} \tag{2-9}$$

where:

$$K_{31} = C_L \quad S \tag{2-10}$$

$$K_{32} = \frac{W\gamma}{g}$$

(2) An expression for jet velocity at critical aircraft velocity was derived by combining equations (2-2), (2-4), and (2-7):

$$V_j = \frac{V_{cr} + \sqrt{V_{cr}^2 - 4\;\frac{(D - k_3 k_4)}{k_{20}}}}{2} \tag{2-12}$$

(3) For airspeeds less than the critical velocity, it was necessary to derive an expression for jet velocity assuming jet deflection angle is known. This was done by combining equations (2-3), (2-4), and (2-7):

$$V_j = \frac{-B_q + \sqrt{B_q - 4A_q C_q}}{2A_q} \tag{2-13}$$

where:

$$A_q = k_5 k_{20} \tag{2-14}$$

$$B_q = k_2 k_5 k_{20} \tag{2-15}$$

$$C_q = k_3 \; k_6 \; - L \qquad (2\text{-}16)$$

$$k_2 = \mu V \qquad (2\text{-}17)$$

$$\mu = m_o \; / \; m_j = f\,(V/V) \text{ (see Section A. 4. c for a specific e} \qquad (2\text{-}18)$$

$$k_3 = 1/2\, \rho V^2 S \qquad (2\text{-}19)$$

$$k_5 = \sin\,(\theta_j + \alpha \qquad (2\text{-}20)$$

$$k_6 = C_L \qquad (2\text{-}21)$$

$$k_{20} = \rho_j \; A_j \qquad (2\text{-}22)$$

Equations (2-9) and (2-12) were programmed directly. However, since jet deflection angle (θ_j) is not known, it is necessary to follow a six step iterative procedure, which was programmed in subroutine SOLV3:

Step 1: Select a range of values for jet deflection angle, all values greater than attack angle. Then execute Steps 2 through 4 for each angle.

Step 2: Solve equations (2-13) and (2-18) for jet velocity and mass flow ratio. This is performed by successive approximation in an iteration loop until consistent values are produced.

Step 3: Solve equation (2-7) for jet mass flow rate.

Step 4: Solve equation (2-23) for drag. (This equation is equivalent to equation (2-4):

$$D = m_j \; V + m_j V_j \,(K_1 - 1) + m_j K_1 K_2 + K_3 K_4 \qquad (2\text{-}23)$$

where:

$$K_1 = 1 - \cos\,(\theta_j + \alpha) \qquad (2\text{-}24)$$

$$K_4 = C_{DO} + \frac{K_6^{\,2}}{\pi e A} \qquad (2\text{-}25)$$

Step 5: Solve equation (2-2) for drag.

Step 6: Subtract the results of Step 4 from the results of Step 5 and call the differences "drag errors". Select by interpolation that value of jet deflection angle which gives zero drag error.

This six-step procedure was repeated twice with successively smaller ranges of jet deflection angle in order to reduce interpolation errors. Subsequently, values of jet velocity and flow rate were determined for the selected jet deflection angle and then performance calculations were executed.

3.3 Performance

The following performance characteristics are computed in subroutines DOMISC and DOMISCCRIT:

Power:

$$P = 1/2 \; m_j \; (V_j^2 - V^2) \tag{3-1}$$

Thrust:

$$T = (L_P^2 + D_P^2)^{1/2} \tag{3-2}$$

where:

$L_P \sim$ lift from propulsion system

$$= (m_j V_j + m_o V) \sin(\theta_j + \alpha) \tag{3-3}$$

$$= m_j K_5 (V_j + K_2) \quad * \tag{3-4}$$

$D_P \sim$ drag attributed to propulsion system

$$= m_j V - m_j V \cos(\theta_j + \alpha) + \dot{m}_o V (1 - \cos(\theta_j + \alpha)) \tag{3-5}$$

$$= m_j \left[V - V_j (1 - K_1) + K_1 K_2 \right] \tag{3-6}$$

* Includes induced effects

Fuel Consumption:

Figure A 4-3 is a schematic of a fuel consumption chart showing scaled fuel consumption per fan as a function of thrust per fan amd Mach No. The following calculations are performed to derive total fuel consumption:

Scaled Thrust:

$$T_s = \frac{T}{N} \frac{1}{\delta_A} \quad * \qquad (3\text{-}7)$$

where N ~ No. of fans

Scaled Fuel Consumption: (3-8)

$$W_s = f\ (T_s,\ h,\ M)$$

where M ~ Mach No. $= V/V_S$ ** (3-9)

(A specific example of equation (3-8) is shown in Table A 4-3)

Total Fuel Consumption: (3-10)

$$\dot{W} = \dot{W}_s\ N\ \delta_A\ \sqrt{\theta_A}$$

Specific Fuel Consumption: (3-11)

$$\overline{SFC} = \frac{T}{\dot{W}}$$

Specific Range: (3-12)

$$R_s = \frac{V}{\dot{W}}$$

Weight Coefficient: (3-13)

$$C_W = \frac{W}{1/2\ \rho V^2 S} = \frac{W}{K_3}$$

Climb Rate: (3-14)

$$\dot{h} = V \sin \gamma$$

* Includes induced effects.

** Approximation for small induced effects.

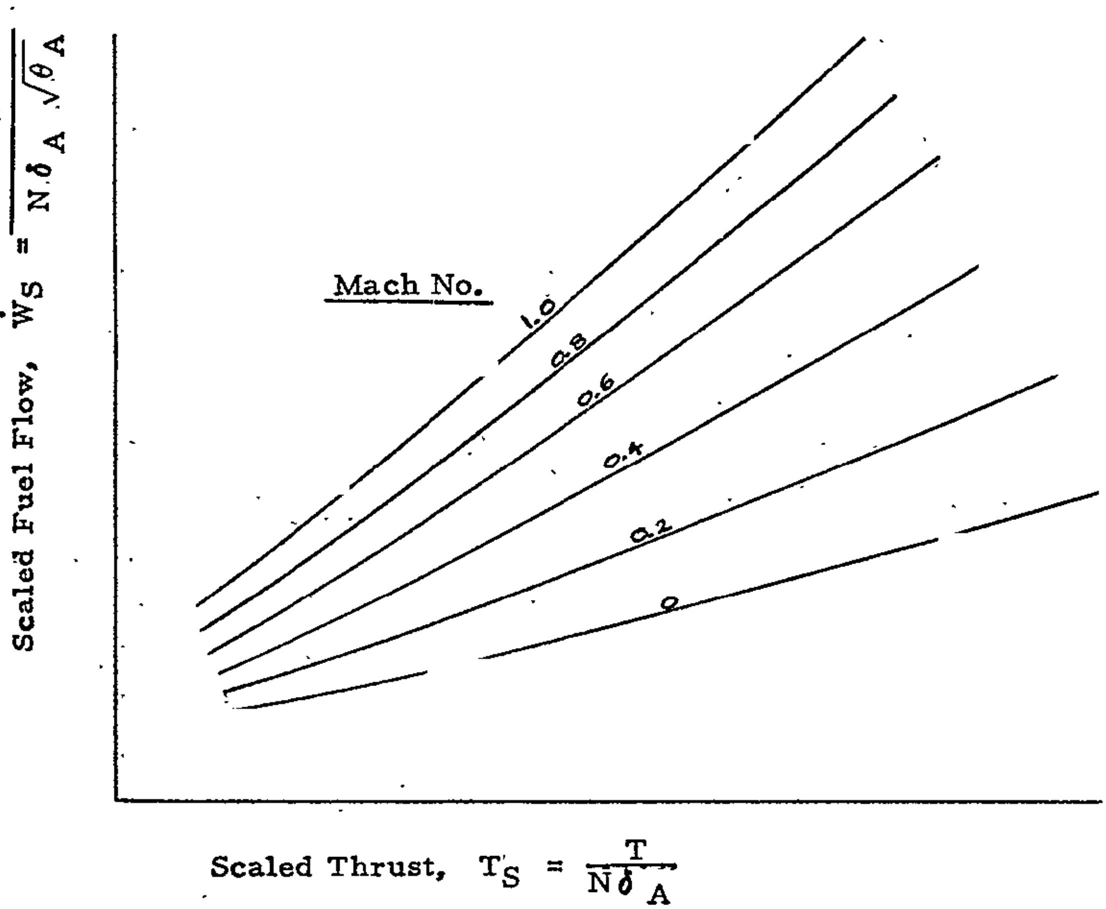


FIGURE A 4-3 - Schematic of Fuel Consumption Chart

4.0 Program Outputs

Table A 4-3 lists the parameters that appear as program outputs; Table A 4-4 illustrates the output format. Output consists of both computed results and a partial relisting of input data, with separate tabulations made for each altitude. The number of parameters listed is restricted by printing width limitations and the desire to avoid unnecessarily detailed output. Outputs for the FLYER and FLYERCRIT differ only slightly:

(1) Jet deflection angle is not listed for FLYERCRIT since it is the opposite of attack angle ($\theta_j = -\alpha$). The space thus made available is used to print Mach Number.

(2) Drag error is a diagnostic which shows the degree of convergence achieved in the search for jet deflection angle in FLYER execution, and is not pertinent to FLYERCRIT. Small values of drag error correspond to superior convergence. Convergence errors tend to be largest for near-zero and near-critical airspeeds.

TABLE A 4-3 PROGRAM OUTPUTS

Items	Symbols Algebraic	APL	Comments
Weight, lb	W	W	
Flight Path Angle, deg	γ	GAM	
Flight Path Angle, deg/sec	$\dot{\gamma}$	GAMD	
Acceleration, ft/sec^2	$\dot{V}$	VDOT	
Attack Angle, deg	α	ALF	
Airspeed, m mi. /hr	V	ASPD	
Fan (Jet) Mass Flow, slugs/sec	m_j	MJ	
Jet Velocity, fps	V_j	VJ	
Jet Deflection Angle, deg	θ_j	THETAJ	In FLY Only
Mass Flow Ratio	μ	MOMJ	
Engine Power, I.G. HP	P	PWR	
Scaled Thrust, lb_f	T_s	THSCAL	
Specific Fuel Consumption, $lb_m/hr/lb_f$	$\overline{SFC}$	FC ÷ TH	
Fuel Rate, lb_m/hr	$\dot{W}$	FC	
Specific Range m mi. /lb_m	R_s	60 x V x SIN GAM	
Weight Coefficient	C_w	W ÷ K3	
Climb Rate, fpm	h	60 x V x SIN GAM	
Drag Error, lb_f	–	DRAG - DODRAG	Diagnostic in FLYER Only
Mach Number	M	MACH	In FLYERCRIT Only

A. 4. c Sample Calculations

Sample calculations were performed using the FLYER and FLYERCRIT groups of programs for the following expressions for scaled fuel consumption rate and entrained-to-jet mass flow ratio.

$$
\begin{aligned}
W_s = {} & 509.1 + 1371 \times M + 0.183 \times T_s + 0.556 \times M \times T_s \\
& + 1.189 \times 10^{-5} \times T_s^{2} + 4.434 \times 10^{-6} \times M - T_s^{2} \\
& - 1.199 \times 10^{-10} \times T_s^{3} - 1.53 \times 10^{-10} \times M \times T_s^{3}
\end{aligned}
\qquad \text{(B-1)}
$$

$$
\begin{aligned}
\mu = {} & 0.0356 + 6.364 \times V_r - 16.88 \times V_r^{2} \\
& + 19.92 \times V_r^{3} - 9.444 \times V_r^{4} \quad \text{for } 0 \le V_r \le 1
\end{aligned}
\qquad \text{(B-2)}
$$

$$
\text{where } V_r = \frac{V}{V_j} \qquad \text{(B-3)}
$$

$$
\mu = 0 \text{ for } V_r < 0 \text{ and } V_r \ge 1
$$

Three program outputs are shown in Table A 4-4. The first shows results for a 3 degree attack angle, airspeeds of 100, 200, and 327. 7 (critical) n. mi. /hr, and altitudes of 0 and 10, 000 ft. Complete input is shown. The second example shows results for critical velocities at attack angles of 2, 4, and 6 degrees, also with complete input. The third example shows results for 200, 327. 7, and 400 n. mi. /hr critical airspeeds and with only partial input.

Table A 4-4 Example Computer Program Runs for Determination of VSTOL Performance


```
      WHENCE
THIS IS WORKSPACE VSTOL IN ACCOUNT NO. 10306
IT IS 10:41 A.M. ON TUESDAY, NOVEMBER 11, 1975

      FLYCRIT
SHOULD SEARCH BE FOR GIVEN AIRSPEEDS OR GIVEN ATTACK ANGLES ('ARSPD' OR 'ALFA')? ARSPD

IS 'COMPLETE' OR 'PARTIAL' INPUT DESIRED? PARTIAL

SPECIFY NEW INPUT AND THEN PUNCH '→0'

FLYINCRIT[19]
      ASPD←200 327.7 400
      →0
WT= 28000 LB ;  FLIGHT PATH ANGLE= 2 DEG
FLIGHT PATH ANGLE RATE= 0.05 DEG/SEC ;  ACC= 1 FPSPS
```

ALTITUDE IS 0 FT.

ATTACK ANGLE, DEGREES	CRITICAL AIRSPEED, N.MI./HR	MACH	FAN FLOW, SLUGS/SEC	JET VELOCITY, FPS	MASS FLOW RATIO	ENGINE POWER, I.G.HP.	SCALED THRUST, LB	SFC, LBM/HR/LBF	FUEL RATE, LB/HR	SPECIFIC RANGE, N.MI./LB	WEIGHT COEF.	CLIMB RATE, FPM
8.01	200.0	.303	57.2	422	.6567	3337	4834	.945	4566	.0438	.479	706.8
3.00	327.7	.496	86.0	635	.5016	7582	7023	.998	7006	.0468	.178	1158.1
2.02	400.0	.605	103.5	764	.4670	12007	9181	.999	9170	.0436	.120	1413.7

ALTITUDE IS 10000 FT.

ATTACK ANGLE, DEGREES	CRITICAL AIRSPEED, N.MI./HR	MACH	FAN FLOW, SLUGS/SEC	JET VELOCITY, FPS	MASS FLOW RATIO	ENGINE POWER, I.G.HP.	SCALED THRUST, LB	SFC, LBM/HR/LBF	FUEL RATE, LB/HR	SPECIFIC RANGE, N.MI./LB	WEIGHT COEF.	CLIMB RATE, FPM
10.86	200.0	.313	57.1	422	.6556	3320	6992	.763	3669	.0545	.649	706.8
4.07	327.7	.513	84.5	624	.4579	6364	8648	.896	5333	.0614	.242	1158.1
2.74	400.0	.626	101.4	749	.4126	9640	10826	.928	6909	.0579	.162	1413.7

Table A 4-4 Example Computer Program runs for Determination of VSTOL Performance (Cont'd)

```
      WHENCE
THIS IS WORKSPACE VSTOL IN ACCOUNT NO. 10306
IT IS 10:36 A.M. ON TUESDAY, NOVEMBER 11, 1975

      FLYCRIT
SHOULD SEARCH BE FOR GIVEN AIRSPEEDS OR GIVEN ATTACK ANGLES ('ARSPD' OR 'ALFA')? ALFA

IS 'COMPLETE' OR 'PARTIAL' INPUT DESIRED? COMPLETE

AIRPLANE WEIGHT (LBS) IS 28000

(1) WING AREA (SQ.FT), (2) ASPECT RATIO, AND (3) SPAN EFFICIENCY ARE 432 4.7 .75

(1) ZERO-LIFT DRAG COEFFICIENT AND (2) 1/4 CHORD LINE SWEEP ANGLE (DEG.) ARE .03 30

ZERO-LIFT ANGLE OF ATTACK (DEG.) IS 0

NOMINAL ANGLE(S) OF ATTACK (DEG.) ARE 2 3 4

(1) NUMBER OF FANS OPERATING AND (2) JET AREA PER FAN (SQ.FT.) ARE 3 19

JET DENSITY IS EITHER 'RHO'(AMBIENT) OR THE FOLLOWING (SLUGS/CU.FT): RHO

FLIGHT ALTITUDE(S) (FT.) ARE 0 10000

AIRSPEED(S) (N.MI/HR) ARE 100 200 400

FLIGHT PATH (1) ANGLE (DEG), (2) ANG. RATE (DEG/SEC), AND (3) ACCELERATION (FTSPS) ARE 2 .05 1

WT= 28000 LB ;  FLIGHT PATH ANGLE= 2 DEG
FLIGHT PATH ANGLE RATE= 0.05 DEG/SEC ;  ACC= 1 FPSPS
```

ALTITUDE IS 0 FT.

ATTACK ANGLE, DEGREES	CRITICAL AIRSPEED, N.MI./HR	MACH	FAN FLOW, SLUGS/SEC	JET VELOCITY, FPS	MASS FLOW RATIO	ENGINE POWER, I.G.HP.	SCALED THRUST, LB	SFC, LBM/HR/LBF	FUEL RATE, LB/HR	SPECIFIC RANGE, N.MI./LB	WEIGHT COEF.	CLIMB RATE, FPM
2.00	402.0	.608	104.0	767	.4663	12153	9248	.999	9239	.0435	.118	1420.7
3.00	327.7	.496	86.0	635	.5016	7581	7023	.998	7006	.0468	.178	1158.0
4.00	283.5	.429	75.6	558	.5361	5642	5991	.997	5972	.0475	.238	1001.9

ALTITUDE IS 10000 FT.

ATTACK ANGLE, DEGREES	CRITICAL AIRSPEED, N.MI./HR	MACH	FAN FLOW, SLUGS/SEC	JET VELOCITY, FPS	MASS FLOW RATIO	ENGINE POWER, I.G.HP.	SCALED THRUST, LB	SFC, LBM/HR/LBF	FUEL RATE, LB/HR	SPECIFIC RANGE, N.MI./LB	WEIGHT COEF.	CLIMB RATE, FPM
2.00	468.8	.734	117.8	870	.3876	13996	13472	.958	8880	.0528	.118	1656.8
3.00	382.0	.598	97.2	717	.4215	8709	10223	.920	6472	.0590	.178	1350.1
4.00	330.5	.517	85.1	628	.4556	6467	8719	.898	5385	.0614	.238	1167.9

Tables A 4-4 Example Computer Program runs for Determination of VSTOL Performance (Cont'd)


```
      WHENCE
THIS IS WORKSPACE VSTOL IN ACCOUNT NO. 10306
IT IS 10:31 A.M. ON TUESDAY, NOVEMBER 11, 1975

      FLY
IS 'COMPLETE' OR 'PARTIAL' INPUT DESIRED? COMPLETE

AIRPLANE WEIGHT (LBS) IS 28000

(1) WING AREA (SQ.FT), (2) ASPECT RATIO, AND (3) SPAN EFFICIENCY ARE 432 4.7 .75

(1) ZERO-LIFT DRAG COEFFICIENT AND (2) 1/4 CHORD LINE SWEEP ANGLE (DEG.) ARE .03 30

(1) ZERO-LIFT AND (2) NOMINAL ANGLES OF ATTACK (DEG.) ARE 0 3

(1) NUMBER OF FANS OPERATING AND (2) JET AREA PER FAN (SQ.FT.) ARE 3 19

JET DENSITY IS EITHER 'RHO'(AMBIENT) OR THE FOLLOWING (SLUGS/CU.FT): RHO

FLIGHT ALTITUDE(S) (FT.) ARE 0 10000

AIRSPEED(S) (N.MI/HR) ARE 100 200 400

FLIGHT PATH (1) ANGLE (DEG), (2) ANG. RATE (DEG/SEC), AND (3) ACCELLERATION (FPSPS) ARE 2 .05 1

WT= 28000 LB ;  ANGLE OF ATT= 3 DEG ;  FLIGHT PATH ANGLE= 2 DEG
FLIGHT PATH ANGLE RATE= 0.05 DEG/SEC ;  ACC= 1 FPSPS
```

ALTITUDE IS 0 FT.

AIRSPEED, N.MI./HR	FAN FLOW, SLUGS/SEC	JET VELOCITY, FPS	JET•DEFL. ANGLE, DEGREES	MASS FLOW RATIO	ENGINE POWER, T.O.HP.	SCALED THRUST, LB	SFC, LBM/HR/ LBF	FUEL RATE, LB/HR	SPECIFIC RANGE, N.MI./LB	WEIGHT COEF.	CLIMB RATE, FPM	DRAG ERROR LB
100.0	57.1	422	47.8	.9104	7744	25578	.448	11447	.0087	1.915	353.4	.0
200.0	62.0	458	20.6	.7458	5403	18061	.578	10438	.0192	.479	706.8	.0
327.7	86.0	635	¯3.0	.5016	7581	7023	.998	7006	.0468	.178	1158.0	¯.0

ALTITUDE IS 10000 FT.

AIRSPEED, N.MI./HR	FAN FLOW, SLUGS/SEC	JET VELOCITY, FPS	JET•DEFL. ANGLE, DEGREES	MASS FLOW RATIO	ENGINE POWER, T.O.HP.	SCALED THRUST, LB	SFC, LBM/HR/ LBF	FUEL RATE, LB/HR	SPECIFIC RANGE, N.MI./LB	WEIGHT COEF.	CLIMB RATE, FPM	DRAG ERROR LB
100.0	57.7	426	48.5	.9103	8013	38159	.448	11761	.0085	2.596	353.4	¯.0
200.0	63.1	466	23.6	.7599	5919	30081	.548	11335	.0176	.649	706.8	.0
382.0	97.2	717	¯3.0	.4215	8709	10223	.920	6472	.0590	.178	1350.1	¯.0

A. 4. d <u>Program Descriptions and Listings</u>

This section presents listings and brief descriptions of the 15 programs and subprograms and the utility functions used in the computer solution of VSTOL performance. It also lists the six groups of coefficients employed. The descriptions are given below and the listings are presented thereafter in Table A 4-5.

The <u>group FLYER</u> contains nine programs and subprograms and the six groups of coefficients used to compute VSTOL performance for single values of attack angle and for airspeeds less than or equal to the critical velocity:

<u>Program FLY</u>

Program FLY is the main or driving program. The following line-by-line description refers to symbols listed in Table A. 4-3 and to equation numbers contained in the main text of this Appendix:

<u>(1)</u> Subprogram FLYIN is called and operator-supplied input is received.

<u>(2)</u> Subprogram RUNVAL is called to provide a partial listing of input data. (This is most useful when only partial input is supplied in FLYIN.)

<u>(3)</u> Output double spacing is commanded.

<u>(4)</u> M is set equal to 5 to specify a fifth-order curve fit in executing the utility function FIT at line 20 of SOLV3.

<u>(5-7)</u> DRAG, DCL, K4, and K6 are determined via equations 2-2, -6, -24, and -21. These lines perform or call for computations for a single value of altitude and constitute the outermost (No. 1) loop of the program.

<u>(8)</u> I is the counter for altitude values. Here it is initialized by setting it equal to zero.

(9) This line both updates the counter I and performs conditional branching. If computations have been made for all submitted values of altitude, the program terminates.

(10-11) RHO, VCR, K32, and K31 are computed via equations 1-1, 2-9, -10, and -11.

(12) A vector (number string of velocities is formed by catenating VCR to another vector of airspeeds specified in input. This operation eliminates all airspeeds greater than the critical velocity and thus obviates concern for submitting airspeeds greater than critical airspeed in input.

(13-14) LIFT, K20, and AJ are computed via equations 2-1, -22, and -8.

(15-19) These lines call for computations of MJ, VJ, and THETAJ for a single value of airspeed less than critical velocity, and constitute the inner (No. 2) loop of FLY.

(15) J is the counter for velocity values and VOUT is a vector used to assemble output data as it is computed. Here they are initialized by equating to zero and to an empty vector, respectively.

(16) This line both updates the counter J and performs conditional branching. If computations have been made for all airspeeds less than the critical velocity, execution branches to line 20.

(17) Subprogram SOLV3 is called and MJ, VJ, and THETAJ are determined for one value of airspeed.

(18) Subprogram DOMISC is called and PWR, TH, MACH, and FC are computed for this same value of airspeed. Additionally, output data is assembled by catenation to the vector VOUT.

(19) Execution is returned to line 16.

(20-24) After completion of the loops in lines 16 - 19, values of K3, K1, and K5 are computed via equations 2-19, -24, and -20 for critical velocity. (Note that K1 and K5 are equal to zero.) THETAJ is set equal to negative ALFA, and MJ and VJ are determined via equations 2-7 and -12. Finally, subprogram DOMOMJP is called and the results are assigned to MOMJP (MOMJP is described below under SOLV3).

(25) DOMISC is called again and the variables listed above (line 18) are determined for the critical velocity.

(26) Another double space is called for output.

(27) Subprogram FLYOUT is called and output is displayed for a single value of altitude (ALT).

(28) Execution is returned to line 9.

Subprogram FLYIN

FLYIN is called by FLY for submission of input data. Lines 1 - 3 permit the operator to either input all data requested in lines 4 - 12 (listed in Table 1 of the text) or to enter a suspended mode in which input can be submitted for selected variables by conventional APL assignment methods. With the exceptions of ALT and ASPD, only single values can be submitted for each variable. A combined number of up to eight sets of values can be submitted for ALT and ASPD (e.g., two values of ALT and four values of ASPD can be specified). Submission of a greater number of values causes computing time to exceed 30 seconds and triggers an automatic program interruption. This is undesirable since: (1) resumption of execution may cause inadvertent updating of some variables; and (2) program output becomes cluttered.

Subprogram RUNVAL

This program lists input values of W, ALF, GAM, GAMD and VDOT, which are useful information when executing repeated or parametric runs using the partial input mode in FLYIN.

Subprogram SOLV3

SOLV3 is called by FLY to solve for MJ, VJ, and THETAJ for ALT(I) and ASPD(J) (the Ith value of ALT and Jth value of ASPD) for ASPD less than VCR. It contains an outer loop which is executed four times to refine the selection of THETAJ and an inner loop which is executed as many times as required (typically 20 to 25) to refine the computation of MOMJ. The following is a line-by-line description.

(1) CNTR is a counter used to identify the number of executions of the outer loop. It is initialized at 3 and subsequent updating is decremental.

(2) CQ and K3 are computed via equations 2-19 and -16.

(3) This step specifies an initial set of THETAJ values as a vector quantity. It selects values in ten one-degree increments greater than ALF and in ten degree increments beyond that to a maximum value of 90 degrees.

(4-23) These lines constitute the outer loop mentioned above.

(4) MOMJ typically has a value between zero and unity. This step initializes MOMJ by setting it equal to 0.5.

(5-15) These steps constitute the inner loop mentioned above.

(5) DOAQBQ is called and values of AQ, BQ, and K5 are computed via equations 2-14, -15, and -20.

(6) The range of THETAJ values is reduced to include only those values which yield positive values of the term (TERM) inside the radical in equation 2-13 because imaginary solutions are not acceptable.

(7-8) The range of values of TERM and MOMJ are also reduced to be consistent with the THETAJ range.

(9) DOAQBQ is repeated to reduce the range of AQ, BQ, and K5 also.

(10-11) K1, MJ, and VJ values are determined for each THETAJ via equations 2-24, -7, and -13.

(12) DOMOMJP is called to define MOMJP as a function of ASPD and VJ via equation B-2 in Appendix B. MOMJP is a "primed" MOMJ which is a vector of trial values for MOMJ.

(13) This line tests the difference (error) between the MOMJ value (either from line 4 or from previous passes through the loop) and the MOMJP determined in line 12. If the differences are less than 0.01, execution branches to line 16; otherwise, execution passes to line 14.

(14) Refined values of MOMJ are computed for each value of THETAJ. The rate of change is limited to prevent solution divergence.

(15) Execution returns to line 5 for further passes through the inner loop.

(16) This line terminates execution of SOLV3 (returns to line 17 of FLY) if three executions of the outer loop have been performed. Otherwise, execution passes to line 17 of SOLV3.

(17) This line branches execution to line 20 if two passes through the outer loop have been completed. Otherwise, execution falls through to line 18.

(18) Subprogram DODRAG is called and drag is computed for each value of THETAJ via equation 2-23. That value of THETAJ which produced the least error between the drag thus computed and that determined in line 5 of FLY is selected as a nominal value of THETAJ for further computations.

(19) Execution is branched to line 21.

(20) Subprogram DODRAG is called and drag is computed for each value of THETAJ via equation 2-23, as in line 18. A new nominal value of THETAJ is determined by performing a fifth order curve fit to the

data. This method is more costly in computing time, but produces results superior to the method used in line 18. It is used only for the final pass through the outer loop.

(21) This line returns execution to line 4 if the outer loop has been executed fewer than four times. Otherwise execution falls through to line 22.

(22) A range of THETAJ values is defined using the nominal THETAJ defined in lines 18 or 20 as a central value. The range is narrower for later passes through the outer loop.

(23) Execution is returned to line 4.

SUBPROGRAM DOAQBQ: See line 9 of SOLV3

SUBPROGRAM DOMOMJB: See line 12 of SOLV3

SUBPROGRAM DODRAG: See line 18 of SOLV3

SUBPROGRAM DOMISC:

DOMISC performs various "miscellaneous" computations which are possible once values for MJ, VJ, and THETAJ have been determined; it also assembles output data in a suitable form:

(1) PWR is computed via equation 3-1.

(2) LP is computed via equation 3-4.

(3) DP is computed via equation 3-6.

(4) PR is computed via equation 1-2.

(5) TR is computed via equation 1-3.

(6) MACH is computed via equation 3-9.

(7) THSCAL and TH are computed via equations 3-7 and -2.

(8) FC is computed via equation 3-10.

(9) Output data is assembled in the vector VOUT.

Subprogram FLYOUT

FLYOUT prepares the output data in the proper format and provides appropriate headings and descriptors. Appendix B illustrates the output.

Group FLYERCRIT -- contains six programs and subprograms and the six groups of coefficients used to compute VSTOL performance for multiple values of attack angle or multiple values of critical velocity:

Program FLYCRIT

Program FLYCRIT is the main program. The following is a line-by-line description. A comparison with program FLY will reveal that FLYCRIT is a similar but much simpler program.

(1) Subprogram FLYINCRIT is called and operator-supplied input is received.

(2) Subprogram RUNVALCRIT is called to provide a partial listing of input data (most useful when only partial input is specified in FLYINCRIT).

(3) Output double space is commanded.

(4-6) DRAG, DCL, K4, and K6 are computed via equations 2-2, -6, -24, and -21.

(7) VCR is determined by converting ASPD (in n. mi/sec) to fps, since it is assumed that specified airspeed are critical velocities when this program is executed.

(8-24) These lines perform or call for computations for a single value of altitude and constitute the only loop used in the program.

(8) I is the counter for altitude values. Here it is initialized by setting it equal to zero.

(9) This line updates the counter I and performs conditional branching. If computations have been made for all submitted values of altitude, the program terminates.

(10) RHO is computed via equation 1-1.

(11) DOVCRIT is called and either VCR of ALF values are determined, according to a specification submitted in executing FLYINCRIT. (See the descriptions of these subprograms.)

(12-13) LIFT and K20 are computed via equations 2-1 and -22.

(14) VOUT is the vector used to assemble output for display. This line initializes VOUT by establishing it as an empty vector.

(15-19) K3, K1, and K5 are computed via equations 2-19, -24, and -20; note that K1 and K5 are equal to zero. THETAJ is set equal to negative ALF, and MJ and VJ are determined via equations 2-7 and -12. Finally, DOMOMJP is called and the results are assigned to MOMJ and MOMJP (MOMJP was described earlier under SOLV3).

(20) Subprogram DOMISCCRIT is called and PWR, TH, MACH, and FC are computed.

(21) This line calls for a double spacing.

(22) Subprogram FLYOUTCRIT is called and output is displayed for a single value of altitude (ALT).

(23) Execution is returned to line 9.

Subprogram FLYINCRIT

FLYINCRIT is called by FLYCRIT for data input and is similar to subprogram FLYIN. Lines 1 and 2 permit the operator to specify whether ASPD or ALF will be the independent variable. Lines 3 - 5 permit the operator to either submit all data requested in lines 6 - 15 or to enter a suspended mode in which input can be specified for selected variables by conventional APL assignment methods. With the exceptions of ALT, ASPD and ALF, only single values can be submitted for each variable. A combined number of up to 100 values can be submitted for ALT and either ASPD or AFL without exceeding a 30 second computing time and thereby receiving an automatic interrupt (see the discussion of FLYIN). If ASPD was specified as the independent variable in line 2, the values of ALF specified in line 10 are ignored. Conversely, if ALF was specified in line 2, the values of ASPD specified in line 14 are ignored.

Subprogram RUNVALCRIT

This program lists input values of W, GAM, GAMD, and VDOT, which are useful information when executing repeated or parametric runs using the partial input mode in FLYINCRIT.

Subprogram DOVCRIT

DOVCRIT responds to the instruction given in FLYINCRIT as to whether ASPD or ALF is the independent variable. If ALF was specified, the branch from line 1 transfers execution to line 2 where VCR, K32, and K31 are computed via equations 2-9, -10, and -11. If ASPD was specified, line 1 branches execution to lines 4 - 6 where K6, ALF, and K4 are determined using variations of equations 2-9 and -5 and equation 2-25.

Subprogram DOMISCRIT

This subprogram performs the same computations executed in DOMISC (see description of DOMISC). The primary difference resides in that it executes a loop in lines 9 - 12 in order to determine FC values.

Subprogram FLYOUTCRIT

FLYOUTCRIT prepares the output data in the proper format and provides appropriate headings and descriptors. Figure A 4-4 illustrates the output.

Table A 4-5 Computer Program for Determination of VSTOL Performance

```
      WHENCE
THIS IS WORKSPACE VSTOL IN ACCOUNT NO. 10306
IT IS 10:44 A.M. ON TUESDAY, NOVEMBER 11, 1975

      )GRP FLYER
FLY     FLYIN   FLYOUT  SOLV3   DOAQBQ  DODRAG  DOMOMJP DOMISC  RUNVAL  COEFRHO COEFPR  COEFTR  COEFVS  COEFWSCAL       COEFMOMJ

      ∇FLY[⎕]∇
    ∇ FLY
[1]   FLYIN
[2]   RUNVAL
[3]   ''
[4]   M←5
[5]   DRAG←W×(SIN-GAM)-VDOT-32.2
[6]   DCL←(2×PI×A-2+A-0.87)×COS OMEGA14
[7]   K4←CDO+(-PI×E×A)×(K6←DCL×PI×(-180)×ALF-ALFO)*2
[8]   I←0
[9]  TESTI:→((1↑ρALT)≤I←I+1)/0
[10]  RHO←(-3220)×ALT[I]⊥COEFRHO
[11]  VCR←(K32+(((K32←W×GAMD×PI-32.2×180)*2)+2×K31×W×COS-GAM)*-2)-K31←RHO×S×K6
[12]  V←((VCR≥V+4)/V←ASPD-0.5925),VCR
[13]  LIFT←W×(COS-GAM)+V×GAMD×PI-32.2×180
[14]  K20←(AJ←NOFAN×AJ1)×RHOJ
[15]  VOUT←⍳J←0
[16] TESTJ:→((ρV)≤J←J+1)/DOLAST
[17]  SOLV3
[18]  DOMISC
[19]  →TESTJ
[20] DOLAST:K3←0.5×RHO×S×VCR*2
[21]  K1←K5←0
[22]  THETAJ←-ALF
[23]  MJ←K20×VJ←0.5×V[J]+((V[J]*2)-(DRAG-K4×K3)×4-K20)*-2
[24]  MOMJ←MOMJP←DOMOMJP
[25]  DOMISC
[26]  ''
[27]  FLYOUT
[28]  →TESTI
    ∇
      ∇FLYIN[⎕]∇
    ∇ FLYIN
[1]   COMPLETE←1+PARTIAL←0
[2]   INTYPE←⍎INPUT 'IS ''COMPLETE'' OR ''PARTIAL'' INPUT DESIRED? '
[3]   →(INTYPE=0)/PARTIN
[4]   W←⍎INPUT 'AIRPLANE WEIGHT (LBS) IS '
[5]   'S A E' ASSIGN⍎INPUT '(1) WING AREA (SQ.FT), (2) ASPECT RATIO, AND (3) SPAN EFFICIENCY ARE '
[6]   'CDO OMEGA14' ASSIGN⍎INPUT '(1) ZERO-LIFT DRAG COEFFICIENT AND (2) 1/4 CHORD LINE SWEEP ANGLE (DEG.) ARE '
[7]   'ALFO ALF' ASSIGN⍎INPUT '(1) ZERO-LIFT AND (2) NOMINAL ANGLES OF ATTACK (DEG.) ARE '
[8]   'NOFAN AJ1' ASSIGN⍎INPUT '(1) NUMBER OF FANS OPERATING AND (2) JET AREA PER FAN (SQ.FT.) ARE '
[9]   RHOJL←INPUT 'JET DENSITY IS EITHER ''RHO''(AMBIENT) OR THE FOLLOWING (SLUGS/CU.FT): '
[10]  ALT←VECTOR⍎INPUT 'FLIGHT ALTITUDE(S) (FT.) ARE '
[11]  ASPD←VECTOR⍎INPUT 'AIRSPEED(S) (N.MI/HR) ARE '
[12]  'GAM GAMD VDOT' ASSIGN⍎INPUT 'FLIGHT PATH (1) ANGLE (DEG), (2) ANG. RATE (DEG/SEC), AND (3) ACCELERATION (FPSPS) ARE '
[13]  →0
[14] PARTIN:'SPECIFY NEW INPUT AND THEN PUNCH ''→0'''
[15]  S∆FLYIN←INP
[16] INP:''
    ∇
      ∇RUNVAL[⎕]∇
    ∇ RUNVAL
[1]   'WT= ',(⍕W),' LB ;  ANGLE OF ATT= ',(⍕ALF),' DEG ;  FLIGHT PATH ANGLE= ',(⍕GAM),' DEG'
[2]   'FLIGHT PATH ANGLE RATE= ',(⍕GAMD),' DEG/SEC ;  ACC= ',(⍕VDOT),' FPSPS'
    ∇
```

Table A 4-5 Computer Program for Determination of VSTOL Performance (Cont'd)

```
      WHENCE
THIS IS WORKSPACE VSTOL IN ACCOUNT NO. 10306
IT IS 10:48 A.M. ON TUESDAY, NOVEMBER 11, 1975

      ∇SOLV3[⎕]∇
    ∇ SOLV3
[1]   CNTR←3
[2]   CQ←-LIFT[J]-K6×K3←0.5×RHO×S×V[J]*2
[3]   THETAJ←THETAJ,((THETAJ←-ALF-⍳10)[10]<NOMTH)/NOMTH←¯40+5×⍳30
[4]  DOMOMJ1:MOMJ←0.5
[5]  REDO:DOAQBQ
[6]   THETAJ←(LNTH←0≤TERM←(BQ*2)-4×AQ×CQ)/THETAJ
[7]   TERM←LNTH/TERM
[8]   MOMJ←LNTH/MOMJ
[9]   DOAQBQ
[10]  K1←1-COS THETAJ+ALF
[11]  MJ←K20×VJ←(¯BQ-TERM*-2)-2×AQ
[12]  MOMJP←DOMOMJP
[13]  →(0=+/0.01≤|MOMJP-MOMJ)/SKIP2
[14]  MOMJ←(MOMJ×1-MOMJP⌈0.4)+MOMJP×MOMJP⌈0.4
[15]  →REDO
[16] SKIP2:→(CNTR=0)/0
[17]  →(CNTR≤1)/FITDRAG
[18]  THETAJ←THETAJ[K41⍳⌊/|K41←|DRAG-DODRAG]
[19]  →TESTCNTR
[20] FITDRAG:THETAJ←(⍟DRAG+2×DDRAG)⊥⌽THETAJ FIT⍟DRAGP+2×DDRAG←|⌊/DRAGP←DODRAG
[21] TESTCNTR:→(0=CNTR←CNTR-1)/DOMOMJ1
[22]  THETAJ←THETAJ+(-0.5×CNTR*3)+0.05×(CNTR*3)×⍳21
[23]  →DOMOMJ1
    ∇
      ∇DOAQBQ[⎕]∇
    ∇ DOAQBQ
[1]   BQ←(K2←V[J]×MOMJ)×AQ←K20×K5←SIN THETAJ+ALF
    ∇
      ∇DOMOMJP[⎕]∇
    ∇ Z←DOMOMJP
[1]   Z←((1≥VR)∧0≤VR)×COEFMOMJ+.×⍉(VR←V[J]-VJ)∘.*0,⍳4
    ∇
      ∇DODRAG[⎕]∇
    ∇ Z←DODRAG
[1]   Z←(MJ×V[J]-VJ×1-K1)+(K3×K4)+K1×K2×MJ
    ∇
      ∇DOMISC[⎕]∇
    ∇ DOMISC
[1]   PWR←(-1100)×MJ×(VJ*2)-V[J]*2
[2]   LP←MJ×K5×VJ+K2
[3]   DP←MJ×V[J]-(VJ×1-K1)-K2×K1
[4]   PR←ALT[I]⊥COEFPR
[5]   TR←ALT[I]⊥COEFTR
[6]   MACH←V[J]-ALT[I]⊥COEFVS
[7]   THSCAL←(÷PR×NOFAN)×TH←((LP*2)+DF*2)*-2
[8]   FC←NOFAN×(TR*-2)×PR×(,(THSCAL*0,⍳3)∘.×1,MACH)+.×COEFWSCAL
[9]   VOUT←VOUT,(0.5925×V[J]),MJ,VJ,THETAJ,MOMJ,PWR,(TH-PR),(FC-TH),FC,(V[J]×0.5925-FC),(W-K3),(60×V[J]×SIN GAM),DRAG-DODRAG
    ∇
```

Table A 4-5 Computer Program for Determination of VSTOL Performance (Cont'd)

```
      WHENCE
THIS IS WORKSPACE VSTOL IN ACCOUNT NO. 10306
IT IS 10:51 A.M. ON TUESDAY, NOVEMBER 11, 1975

      ∇FLYOUT[⎕]∇
    ∇ FLYOUT;FLD
[1]   'ALTITUDE IS ';ALT[I];' FT.'
[2]   ''
[3]   MATT←(((⍴VOUT)÷13),13)⍴VOUT
[4]   FLD← 8 1 11 1 11 0 11 1 9 4 8 0 9 0 9 3 9 0 10 4 10 3 9 1 12 1
[5]   ' FAN JET JET∘DEFL. MASS ENGINE SCALED SFC, FUEL SPECIFIC  CLIMB DRAG' CENTER MATT
[6]   'AIRSPEED, FLOW, VELOCITY, ANGLE, FLOW POWER, THRUST, LBM/HR/ RATE, RANGE, WEIGHT RATE, ERROR,' CENTER MATT
[7]   'N.MI./HR SLUGS/SEC FPS DEGREES RATIO I.G.HP. LB LBF LB/HR N.MI./LB COEF. FPM LB' CENTER MATT
[8]   ''
[9]   FLD⍕MATT
[10]  ''
    ∇

      COEFRHO
¯1.667561117E¯14 2.735323504E¯9 ¯0.000226566253 7.652574995
      COEFPR
¯2.844375221E¯15 5.025133639E¯10 ¯3.591680244E¯5 0.9997492340
      COEFTR
1.856681712E¯15 ¯8.728952366E¯11 ¯5.862065147E¯6 0.9981874825
      COEFVS
1.173801514E¯12 ¯6.306282581E¯8 ¯0.003183153124 1115.326511
      COEFWSCAL
  5.090909091E2
  1.370699301E3
  1.830555556E¯1
  5.564976690E¯1
  1.189393939E¯5
  4.434731935E¯6
 ¯1.199494949E¯10
 ¯1.529720280E¯10
      COEFMOMJ
0.03564736884 6.363896005 ¯16.88032326 19.9242402 ¯9.444179612
```

Table A 4-5 Computer Program for Determination of VSTOL Performance (Cont'd)

```
      WHENCE
THIS IS WORKSPACE VSTOL IN ACCOUNT NO. 10306
IT IS 10:52 A.M. ON TUESDAY, NOVEMBER 11, 1975

      )GRP FLYERCRIT
FLYCRIT FLYINCRIT       FLYOUTCRIT      DOMISCCRIT      DOVCRIT RUNVALCRIT      COEFRHO COEFPR  COEFTR  COEFVS  COEFMOMJ
COEFWSCAL
      ∇FLYCRIT[⎕]∇
    ∇ FLYCRIT
[1]   FLYINCRIT
[2]   RUNVALCRIT
[3]   ''
[4]   DRAG←W×(SIN-GAM)-VDOT÷32.2
[5]   DCL←(2×PI×A÷2+A÷0.87)×COS OMEGA14
[6]   K4←CD0+(÷PI×E×A)×(K6←DCL×PI×(÷180)×(ALF←VECTOR ALF)-ALF0)⋆2
[7]   VCR←ASPD÷0.5925
[8]   I←0
[9]  TESTI:→((1+⍴ALT)≤I←I+1)/0
[10]  RHO←(÷3220)×ALT[I]⊥COEFRHO
[11]  DOVCRIT
[12]  LIFT←W×(COS-GAM)+VCR×GAMD×PI÷32.2×180
[13]  K20←(AJ←NOFAN×AJ1)×RHOJ
[14]  VOUT←''
[15]  K3←0.5×RHO×S×VCR⋆2
[16]  K1←K5←0
[17]  THETAJ←-ALF
[18]  MJ←K20×VJ←0.5×VCR+((VCR⋆2)-(DRAG-K4×K3)×4÷K20)⋆÷2
[19]  DOMISCCRIT
[20]  ''
[21]  FLYOUTCRIT
[22]  →TESTI
    ∇
      ∇FLYINCRIT[⎕]∇
    ∇ FLYINCRIT
[1]   ALFA←1+ARSPD←0
[2]   SRCHTYPE←⍎INPUT 'SHOULD SEARCH BE FOR GIVEN AIRSPEEDS OR GIVEN ATTACK ANGLES (''ARSPD'' OR ''ALFA'')? '
[3]   COMPLETE←1+PARTIAL←0
[4]   INTYPE←⍎INPUT 'IS ''COMPLETE'' OR ''PARTIAL'' INPUT DESIRED? '
[5]   →(INTYPE=0)/PARTIN
[6]   W←⍎INPUT 'AIRPLANE WEIGHT (LBS) IS '
[7]   'S A E' ASSIGN⍎INPUT '(1) WING AREA (SQ.FT), (2) ASPECT RATIO, AND (3) SPAN EFFICIENCY ARE '
[8]   'CD0 OMEGA14' ASSIGN⍎INPUT '(1) ZERO-LIFT DRAG COEFFICIENT AND (2) 1/4 CHORD LINE SWEEP ANGLE (DEG.) AR
[9]   ALF0←⍎INPUT 'ZERO-LIFT ANGLE OF ATTACK (DEG.) IS '
[10]  ALF←⍎INPUT 'NOMINAL ANGLE(S) OF ATTACK (DEG.) ARE '
[11]  'NOFAN AJ1' ASSIGN⍎INPUT '(1) NUMBER OF FANS OPERATING AND (2) JET AREA PER FAN (SQ.FT.) ARE '
[12]  RHOJL←INPUT 'JET DENSITY IS EITHER ''RHO''(AMBIENT) OR THE FOLLOWING (SLUGS/CU.FT): '
[13]  ALT←VECTOR⍎INPUT 'FLIGHT ALTITUDE(S) (FT.) ARE '
[14]  ASPD←VECTOR⍎INPUT 'AIRSPEED(S) (N.MI/HR) ARE '
[15]  'GAM GAMD VDOT' ASSIGN⍎INPUT 'FLIGHT PATH (1) ANGLE (DEG), (2) ANG. RATE (DEG/SEC), AND (3) ACCELERATION (FPSPS) ARE '
[16]  →0
[17] PARTIN:'SPECIFY NEW INPUT AND THEN PUNCH ''→0'''
[18]  S∆FLYIN←INP
[19] INP:''
    ∇
      ∇RUNVALCRIT[⎕]∇
    ∇ RUNVALCRIT
[1]   'WT= ',(⍕W),' LB ;  FLIGHT PATH ANGLE= ',(⍕GAM),' DEG'
[2]   'FLIGHT PATH ANGLE RATE= ',(⍕GAMD),' DEG/SEC ;  ACC= ',(⍕VDOT),' FPSPS'
    ∇
```

Table A 4-5 Computer Program for Determination of VSTOL Performance (Cont'd)

```
        WHENCE
  THIS IS WORKSPACE VSTOL IN ACCOUNT NO. 10306
  IT IS 10:54 A.M. ON TUESDAY, NOVEMBER 11, 1975

        ∇DOVCRIT[□]∇
      ∇ DOVCRIT
[1]     →(SRCHTYPE=ARSPD)/DOALF
[2]     VCR←(K32+(((K32←W×GAMD×PI-32.2×180)*2)+2×K31×W×COS-GAM)*-2)-K31←RHO×S×K6
[3]     →0
[4]   DOALF:K6←((VCR×W×GAMD×PI-32.2×180)+W×COS-GAM)-0.5×RHO×S×VCR*2
[5]     ALF←ALFO+180×K6-PI×DCL
[6]     K4←CDO+(-PI×E×A)×K6*2
      ∇
        ∇DOMISCCRIT[□]∇
      ∇ DOMISCCRIT
[1]     MOMJ←FC←''
[2]     PWR←(-1100)×MJ×(VJ*2)-VCR*2
[3]     LP←MJ×K5×VJ+K2
[4]     DP←MJ×VCR-(VJ×1-K1)-K2×K1
[5]     PR←ALT[I]⊥COEFPR
[6]     TR←ALT[I]⊥COEFTR
[7]     MACH←VCR÷ALT[I]⊥COEFVS
[8]     THSCAL←(÷PR×NOFAN)×TH←((LP*2)+DP*2)*-2
[9]     II←0
[10]  TESTII:→((⍴PWR)<II←II+1)/DOVOUT
[11]    FC←FC,NOFAN×(TR*-2)×PR×(,(THSCAL[II]*0,⍳3)∘.×1,MACH[II])+.×COEFWSCAL
[12]    MOMJ←MOMJ,((1≥VR)∧0≤VR)×COEFMOMJ+.×⍉(VR←VCR[1I]-VJ[II])∘.*0,⍳4
[13]    →TESTII
[14]  DOVOUT:VOUT←ALF,(0.5925×VCR),MACH,MJ,VJ,MOMJ,PWR,(TH-PR),(FC-TH),FC,(VCR×0.5925-FC),(W-K3),60×VCR×SIN GAM
      ∇
        ∇FLYOUTCRIT[□]∇
      ∇ FLYOUTCRIT
[1]     'ALTITUDE IS ';ALT[I];' FT. '
[2]     ''
[3]     MATT←⍉(13,⍴ALF)⍴VOUT
[4]     FLD← 8 2 10 1 11 3 11 1 11 0 9 4 8 0 9 0 9 3 9 0 10 4 10 3 9 1
[5]     'ATTACK CRITICAL  FAN JET MASS ENGINE SCALED SFC, FUEL SPECIFIC  CLIMB  ' CENTER MATT
[6]     'ANGLE, AIRSPEED,  FLOW, VELOCITY, FLOW POWER, THRUST, LBM/HR/ RATE, RANGE, WEIGHT RATE,  ' CENTER MATT
[7]     'DEGREES N.MI./HR MACH SLUGS/SEC FPS RATIO I.G.HP. LB LBF LB/HR N.MI./LB COEF. FPM ' CENTER MATT
[8]     ''
[9]     FLD⍕MATT
[10]    ''
      ∇
        COEFRHU
¯1.667561117E¯14 2.735323504E¯9 ¯0.000226566253 7.652574995
        COEFPR
¯2.844375221E¯15 5.025133639E¯10 ¯3.591680244E¯5 0.9997492348
        COEFTR
1.856681712E¯15 ¯8.728952366E¯11 ¯5.862065147E¯6 0.9981874825
        COEFMOMJ
0.03564736884 6.363896005 ¯16.88032326 19.9242402 ¯9.444179612
        COEFVS
1.173801514E¯12 ¯6.306282581E¯8 ¯0.003183153124 1115.326511
        COEFWSCAL
  5.090909091E2
  1.370699301E3
  1.830555556E¯1
  5.564976690E¯1
  1.189393939E¯5
  4.434731935E¯6
 ¯1.199494949E¯10
 ¯1.529720280E¯10
```

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Auxiliary Functions

Table 4 A-6 on the following page lists several functions used to simplify program coding and input-output operations:

(1) SIN A computes the sine of angle A, where A is expressed in degrees.

(2) COS A computes the cosine of angle A, where A is expressed in degrees.

(3) VECTOR A converts the quantity A to a vector string if only a single element is specified in A. Otherwise, A would remain a scalar and could not be indexed.

(4) INPUT STATEMENT permits operator-supplied input to be requested without receiving the gratuitous carriage return and spacing otherwise associated with such operations, and thereby produces a less cluttered output record.

(5) LL ASSIGN NO permits assignments to be made to several variables in a single line operation. LL is a literal vector, containing names of variables separated by a single space and NO is a numerical vector containing as many elements as names in LL. The first number in NO is assigned to the first name in LL; the second to the second; etc.

(6) Y FIT X performs a regression analysis of order M, treating X as the independent variable and Y as dependent. X and Y must contain the same number of terms, and that number must be at least one greater than the value of M.

(7) HED CENTER MAT performs automatic centering of column headings above the individual columns of a two dimensional array of output. HED is a literal vector containing the column headings separated by single spaces, and contains as many names as columns in the array MAT. The variable FLD specifies the field and decimal characteristics of the desired output of MAT. Field widths should be at least two spaces greater than the respective column headings.

C-3

Table A 4-6 Auxiliary Computer Program for Determination of VSTOL Performance

```
      WHENCE
THIS IS WORKSPACE VSTOL IN ACCOUNT NO. 10306
IT IS 10:57 A.M. ON TUESDAY

      ∇SIN[⎕]∇
    ∇ Z←SIN A
[1]   Z←1○○A÷180
    ∇
      ∇COS[⎕]∇
    ∇ Z←COS A
[1]   Z←2○○A÷180
    ∇
      ∇VECTOR[⎕]∇
    ∇ Z←VECTOR A
[1]   →(1=⍴⍴A)/SKIP
[2]   Z←1⍴A
[3]   →0
[4]  SKIP:Z←A
    ∇
      ∇INPUT[⎕]∇
    ∇ Z←INPUT STATEMENT;A
[1]   Z←(⍴A)↓⍞,0⍴⍞←A←STATEMENT
[2]   ''
    ∇
      ∇ASSIGN[⎕]∇
    ∇ LL ASSIGN NO;N;NN
[1]   I←0
[2]   NL←⍕NO
[3]   LL←LL,' '
[4]  TESTI:→((1↑⍴NO)<I←I+1)/0
[5]   ⍎((N←LL⍳' ')↑LL),'←',(NN←NL⍳' ')↑NL
[6]   NL←NN↓NL
[7]   LL←N↓LL
[8]   →TESTI
    ∇
      ∇FIT[⎕]∇
    ∇ Z←Y FIT X
[1]   Z←Y⌹X∘.*0,⍳M
    ∇
      ∇CENTER[⎕]∇
    ∇ Z←HED CENTER MAT;HEADER;NOCOL;FLDMAT;WID;CENT;LFTEND;N;I;J
[1]   HED←HED,0↑HEADER←130⍴' '
[2]   NOCOL←(⍴MAT)[2]
[3]   WID←LFTEND←NOCOL⍴I←J←0
[4]   FLDMAT←⍉(NOCOL,2)⍴FLD←(2×NOCOL)⍴F
[5]  TESTI:→((1↑NOCOL)<I←I+1)/RESUME
[6]   WID[I]←(0⌈FLDMAT[2;I])+FLDMAT[2;I]+(0<X)×X←⌊/(¯1+×X)+⌊FZ÷10⍟(FZ←1E¯10)+|X←(⌊/X),⌈/X←,MAT[;I]
[7]   →TESTI
[8]  RESUME:CENT←(+\FLDMAT[1;J]) (WID÷1)÷2
[9]  TESTJ:→((1↑NOCOL)<J←J+1)/OUT
[10]  LFTEND[J]←⌊CENT[J]-0.5×⍴HEAD←(¯1+N←HED⍳' ')↑HED
[11]  HEADER[LFTEND[J]+⍳⍴HEAD]←HEAD
[12]  HED←N↓HED
[13]  →TESTJ
[14] OUT:(LFTEND[J-1]+⍴HEAD)↑HEADER
    ∇
```