NASA-TM-86275 19840021802

NASA Technical Memorandum 86275

User's Manual for a Fuel-Conservative Descent Planning Algorithm Implemented on a Small Programmable Calculator

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August 1984

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SUMMARY

The Federal Aviation Administration (FAA) has implemented an automated, time-based metering form of air traffic control with profile descent procedures for arrivals into the terminal area. These concepts provide fuel savings by matching the airplane-arrival flow to the airport acceptance rate through time-control computations and by allowing the pilot to descend at his discretion from cruise altitude to a designated metering fix in an idle-thrust, clean-configuration (landing gear up, flaps zero, and speed brakes retracted). Substantial fuel savings have resulted from these procedures, but air traffic control (ATC) workload is high since the radar controller maintains time management for each airplane through either speed control or path stretching with radar vectors. Pilot workload is also high since the pilot must plan for an idle-thrust descent to the metering fix using various rules of thumb.

The National Aeronautics and Space Administration (NASA) has developed an airborne descent algorithm compatible with time-based metering procedures and profile descent procedures designed to improve the accuracy of delivering an airplane to a metering fix at a time designated by the ATC system. This algorithm provides open-loop guidance for an airplane to make an idle-thrust, clean-configured descent to arrive at the metering fix at a predetermined time, altitude, and airspeed. The algorithm may also be used for planning fuel-conservative descents when time is not a consideration.

The algorithm was programmed on a Hewlett Packard HP-41CV programmable calculator for use with a McDonnell Douglas DC-10 airplane. This report contains an explanation and examples of how the algorithm is used, as well as a detailed flow chart and listing of the algorithm.

INTRODUCTION

In an effort to improve the efficiency of terminal area operations, the Federal Aviation Administration (FAA) has implemented an automated time-based metering form of air traffic control with profile descent procedures. The time-based metering concept is based upon airplane arrivals crossing a metering fix (typically 30 to 40 n.mi. from the airport) at a specified altitude, airspeed, and time. The time metering derandomizes the arrivals at high altitudes prior to entering the terminal area resulting in a reduction of the low altitude, high fuel consumption flight normally used to sequence airplanes to a common final approach path. In addition, time-based metering allows the traffic to absorb delays at cruise altitudes or while on the ground prior to takeoff, resulting in even greater fuel savings. The proper sequencing and spacing of enroute traffic also allows for increased airport productivity (ref. 1 and 2). The profile descent procedure allows the pilot to plan and fly a descent which is fuel conservative for his particular airplane resulting in additional fuel savings.

With the current time-based metering/profile descent procedures, the air traffic controller is responsible for the time management of each aircraft. The controller can adjust the airplane's time of arrival at the metering fix by increasing the flight path length through heading changes or by requesting the pilot to change speed. The pilot is responsible for crossing the metering fix at the proper airspeed and altitude and must plan the descent carefully if fuel is to be conserved. The time management and the descent planning are both workload intensive and interdependent. Since limited or no guidance is available to either the controller or the pilot, their tasks must be accomplished independently through various rules of thumb and past experience. With this present operational concept, airplanes will typically cross the metering fix with a time accuracy between 1 and 2 minutes (ref. 3).

During the summer of 1979, the National Aeronautics and Space Administration (NASA) developed and flight tested in its Transport Systems Research Vehicle (TSRV, previously designated the Terminal Configured Vehicle B-737 research airplane) a flight-management descent algorithm designed to provide closed-loop guidance for a fuel conservative descent and to reduce the metering fix crossing time dispersion. The descent computations for the flight management algorithm were based on an idle-thrust, clean-configured descent (landing gear up, flaps and spoilers retracted) to arrive at the metering fix at the proper altitude, airspeed, and ATC-designated time. The results of the flight tests showed that the closed-loop guidance provided by the guidance and display system could reduce the crossing time dispersion to approximately 12 seconds (ref. 4).

This research was continued in June of 1981 with a T-39A (Sabreliner) airplane to determine if similar results could be obtained with open-loop guidance and a conventional complement of cockpit instrumentation (ref. 5). A version of the flight management descent algorithm was implemented on a small programmable calculator. Open-loop guidance was provided by the calculator in the form of, (1) the Mach number and airspeed at which the descent should be flown and, (2) the point at which the pilot was to reduce the thrust to flight idle and begin the descent. The descent was then flown with reference to the airplane Mach and airspeed indicators and by maintaining an altitude profile computed by the calculator as a function of distance to the metering fix. Flight tests using this open-loop guidance resulted in a time dispersion crossing the metering fix of approximately 20 seconds.

Having determined the viability of the open-loop descent guidance, additional research was conducted to evaluate the feasibility of using such a descent planning tool in an airline operational environment. This report contains an explanation and examples of how the descent calculator is used. A detailed flow chart and a listing of the algorithm are provided in Appendix A and B, respectively. A more detailed explanation of the algorithm and its development can be found in ref. 6.

The airplane performance model used in the algorithm is that of a McDonnell Douglas DC-10. The calculator in which the algorithm was programmed is a Hewlett-Packard HP-41CV. Use of company names or designations in this report does not constitute an official endorsement of such companies or products, either expressed or implied, by the National Aeronautics and Space Administration.

SYMBOLS AND ABBREVIATIONS

ATC	air traffic control
A_{gw}	coefficient for gross weight multiplication factor, lbs^{-1}
A_I	coefficient for constant IAS descent rate equation, ft/sec
A_M	coefficient for constant Mach descent rate equation, ft
B_{gw}	coefficient for gross weight multiplication factor
B_I	coefficient for constant IAS descent rate equation, $knots^{-1}$
B_M	coefficient for constant Mach descent rate equation, ft
CRS	Magnetic course, deg
C_I	coefficient for constant IAS descent rate equation, sec^{-1}
C_M	coefficient for constant Mach descent rate equation, sec^2/ft
c_1	constant in the model for $\dot{h}_{M_d}$, ft
DME	distance measuring equipment
D_w	magnetic wind direction, deg
$D_{w,h}$	magnetic wind direction evaluated at altitude h, deg
$D_{w,s}$	magnetic wind direction computed for sea-level altitude, deg
$\frac{dD_w}{dH}$	wind direction gradient with respect to altitude, deg/ft
$\frac{dS_w}{dH}$	wind speed gradient with respect to altitude, knots/ft
EF_{DME}	DME reading at the entry fix, n.mi.
GW	gross weight, lb

GSc	ground speed at cruise altitude, knots
GS_5	average ground speed on segment 5, knots
H	pressure altitude, ft
H_{avg}	average pressure altitude, ft
H_{bod}	pressure altitude at bottom of descent, ft
H_c	pressure altitude at cruise, ft
H_{MF}	pressure altitude of the metering fix, ft
H_{XO}	pressure altitude at transition from constant-Mach descent to constant-airspeed descent, ft
h	geopotential altitude, ft
h_c	geopotential cruise altitude, ft
h_{MF}	geopotential metering-fix altitude, ft
h_{XO}	geopotential altitude at transition from constant-Mach descent to constant-airspeed descent, ft
$\dot{h}_g$	rate of change of geopotential altitude due to wind gradient, ft/sec
IAS	indicated airspeed, knots
IAS_d	indicated airspeed used during descent, knots
$IAS_{d,initial}$	initial descent indicated airspeed for speed iteration computations, knots
$IAS_{d,i}$	descent indicated airspeed computed on ith iteration, knots
$IAS_{d,max}$	maximum operational descent indicated airspeed, knots
$IAS_{d,min}$	minimum operational descent indicated airspeed, knots
IAS_{MF}	indicated airspeed to cross metering fix, knots
IDL_{DME}	DME indication of the point where thrust should be reduced to flight idle, n.mi.

K	interpolation factor computed for speed iteration purposes
K_{gw}	gross-weight multiplication factor for altitude rate
K_g	coefficient in the rate of change of altitude due to wind gradient equation, ft/sec/knot/ft
$K_{\dot{h},XO}$	substitution variable in DME H routine
$K_{\dot{h},250}$	substitution variable in segment 2 computation
M	Mach number
M/IAS	Mach number and indicated airspeed
MF_{DME}	DME indication of the metering fix, n.mi.
MSL	mean sea level
M_c	cruise Mach number
M_d	descent Mach number
N	number of wind data points
N_{reg}	storage register number
N_{seg}	segment number
N_{sub}	subroutine number
OAT	outside air temperature, °C
S_w	wind speed, knots
$S_{w,s}$	wind speed computed for sea-level altitude, knots
TAS	true airspeed, knots
TAS_{avg}	average true airspeed, knots
TAS_f	final true airspeed of level flight segment, knots
TAS_i	initial true airspeed of level flight segment, knots
TRK	airplane magnetic track angle along ground, deg

TSRV	Transport Systems Research Vehicle
T_o	standard sea-level air temperature, ^oK
T'_o	nonstandard sea-level air temperature, ^oK
$T_{st,h}$	static air temperature at altitude h, ^oK
T_{trop}	static air temperature at tropopause, ^oK
t_E	time error for descent-speed convergence criteria, sec
$t_{E,initial}$	initial time error, sec
t_{EF}	time that entry fix was crossed, hr:min:sec
t_{IDL}	crossing time of point where the throttles are reduced to flight idle, hr:min:sec
t_{MF}	metering fix crossing time, hr:min:sec
VAR	magnetic variation, deg
VORTAC	very high frequency omnirange navigation radio
V_f	final speed of level flight segment, knots
V_i	initial speed of level flight segment, knots
W_c	difference between actual and computed ground speeds at cruise altitude, knots
$W_{H,c}$	head-wind component along airplane ground track in cruise, knots
$W_{H,h}$	head-wind component along airplane ground track evaluated at altitude h , knots
X	distance variable in DME H routine, n.mi.
X_{DME}	input DME reading used in the DME H routine, n.mi.
$\ddot{x}$	acceleration, knots/sec
Y_1,Y_2,Y_3	substitution variables used in DME H routine
$\Delta \ell$	distance increment, n.mi.

$\Delta \ell_j$	length of path segment j, n.mi.
Δt	time increment, sec
$\Delta t_{initial}$	time required to fly initial descent profile, sec
Δt_j	time required to fly on path segment j, sec
Δt_{req}	time required to fly between entry fix and metering fix, sec

DESCRIPTION OF GENERAL PROFILE

The flight management descent algorithm computes the parameters required to describe a seven-segment cruise and descent profile (fig. 1) between an arbitrarily located entry fix and an ATC-defined metering fix. The descent profile is computed based on empirical modeling of airplane performance for an idle-thrust, clean-configured descent. The descent Mach/airspeed schedule, airplane gross weight, wind, wind gradient, and nonstandard-temperature effects are also considered in these calculations.

Figure 1 shows the vertical-plane geometry of the path between the entry fix and the metering fix. Each path segment, starting at the metering fix, is numbered according to the order in which it is calculated by the algorithm. To be compatible with standard airline operating practices, the path is calculated based upon the descent being flown at a constant Mach number with transition to a constant indicated airspeed and all speed reductions made in level flight.

The first segment traversed on the profile is segment 7 which begins at the entry fix and is flown at constant cruise altitude and Mach number. Segment 6 is a relatively short, level-flight path segment in which the pilot transitions from the cruise Mach number to the descent Mach number. Segment 6 is eliminated if the descent and cruise Mach numbers are the same. Once the descent Mach number is attained, the constant Mach descent segment (segment 5) is started. As altitude is decreased along this path segment, the indicated airspeed will increase because of increasing air pressure. Segment 4 begins when the desired indicated airspeed is attained for descent. The descent is continued along this segment at the desired, constant indicated airspeed. When the metering fix altitude has been reached, the airplane is flown at a constant altitude along segment 3 and slowed from the descent airspeed to the designated airspeed over the metering fix.

If the metering-fix altitude is below 10 000 ft MSL and the descent airspeed is greater than 250 knots, segments 1 and 2 are computed for the pilot to comply with the ATC-imposed airspeed limit of 250 knots, or less, below 10 000 ft MSL. Segment 3 then becomes a level-flight segment at 10 000 ft MSL where the airspeed is reduced to 250 knots. The descent is then continued at 250 knots along segment 2. When the metering-fix altitude has been reached, the airplane is flown at a constant altitude along segment 1 and slowed from the descent airspeed to the designated airspeed over the metering fix. This path segment is eliminated if the descent and metering-fix airspeeds are the same.

DESCENT ALGORITHM OPERATING MODES

The flight management descent algorithm can be used in either of two modes. In the first mode the pilot can enter the desired M/IAS to be flown during descent. The descent profile is then computed based on this descent speed

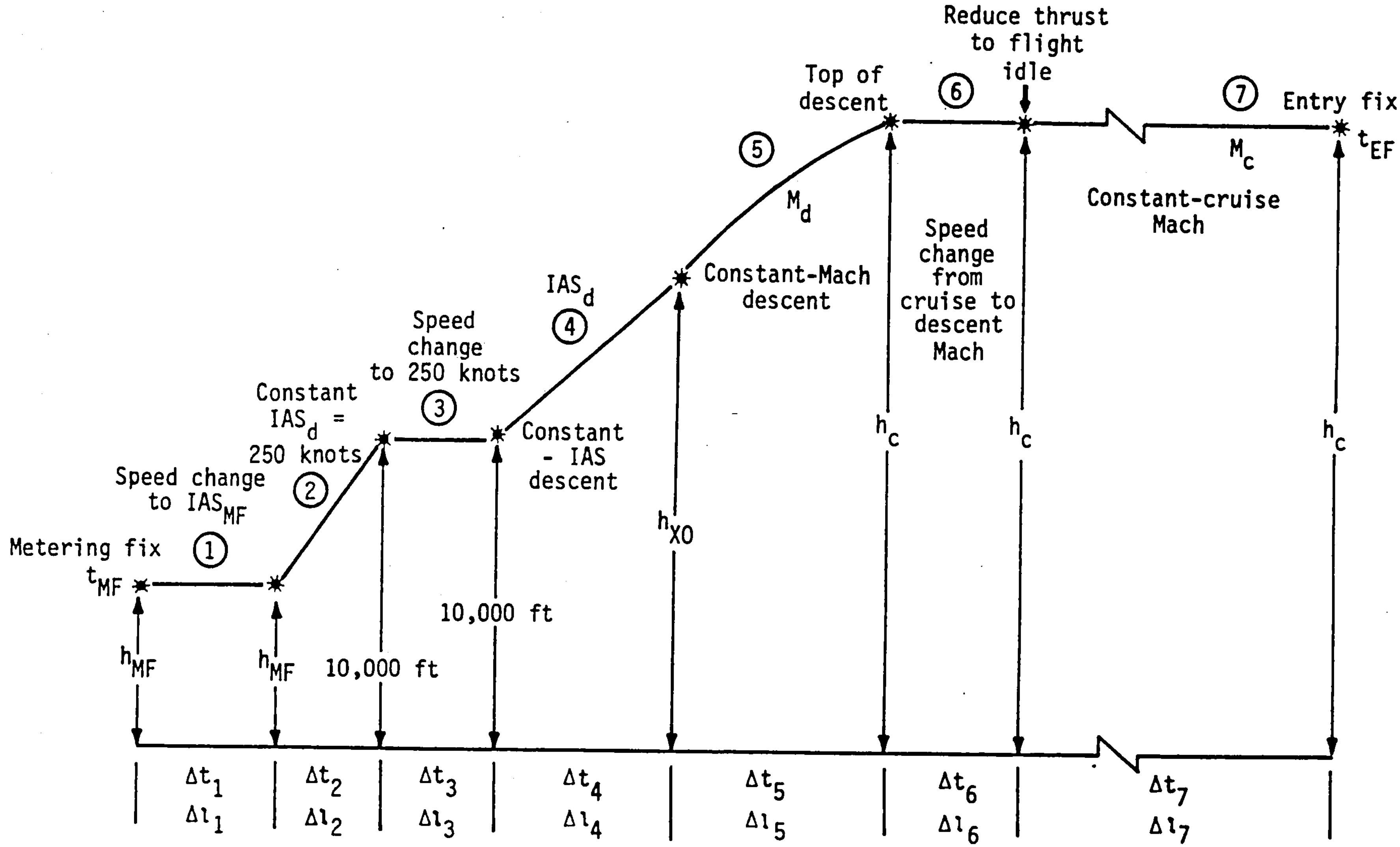


Figure 1. - Vertical plane geometry of computed descent path.

schedule without consideration of a constraint on metering-fix arrival time. This mode would be used when time-based metering is not being used.

The second mode was designed for time-metered operations. In this mode, instead of specifying the M/IAS descent schedule, the pilot enters the time that the entry fix was crossed and the metering-fix arrival time assigned by ATC. The descent profile is then calculated based on a M/IAS descent schedule, computed through an iterative process, that will closely satisfy the crossing time specified for the metering fix. The magnitude of the Mach number programmed for the descent is the same as that used for the cruise segment.

In the time-metered mode, a check is made within the profile computations to insure that the descent airspeed IAS_d is within the minimum and maximum speed limits for the particular airplane modeled. For the DC-10 airplane, these limits were

$$220 \leq IAS_d \leq 350 \qquad \text{[knots]}$$

There was an additional constraint that IAS_d would not be less than the airspeed at which the airplane was to cross the metering fix. This constraint eliminates the need for extra fuel to be used to accelerate the airplane to a higher airspeed. If the ATC-assigned metering-fix crossing time requires a descent airspeed less than the airplane's minimum descent airspeed limit, the profile is computed based on the minimum airspeed limit and a message is displayed to the pilot to "hold" (delay) for an appropriate amount of time. A similar "late" message is displayed with the time error if a descent airspeed schedule greater than the maximum allowed is required.

PROGRAM KEYS

The descent calculator is shown in figure 2. The program keys are color coded in accordance with their function. The white keys are data input keys, the blue keys are output keys, the gray keys define the algorithm operating mode, the gold key is for multi-function operations, the orange key is for entering new data, and the green key is for computing a new profile. A description of the program keys follows:

Key	Description
Profile *Wind	This green key is one of two multi-funtion keys. The first function of this key is to initiate the computation of the descent profile. This is accomplished by simply pushing the key. The other function of this key is the derivation of the wind model. This is accomplished by first pushing the gold (*) key and then this key (further description of the wind model derivation is discussed on page 15)
Mc/Hc *GSc	This white key is the other multi-function key. The first function of this key is to display and/or input the cruise Mach number and cruise altitude (ft). The other function of this key is to compute and/or input the ground speed (kts) at cruise. The ground speed function is initiated by first pushing the gold (*) key and then this key (further discussion of the ground speed computation is discussed on page 23)
Md/IASd	This gray key is used to display and/or input the Mach and indicated airspeed (kts) to be used during the descent. If a specific descent Mach/IAS is desired, the intended values must be entered here. If a metering fix arrival time is specified, the resultant descent Mach/IAS is computed and may be displayed by pushing this key.
Time MF/EF	This gray key is used to display and/or input the assigned metering fix arrival time (hr. min. sec) and the actual or estimated entry fix arrival time (hr. min. sec.). If a descent Mach/CAS has been specified, the resultant metering fix arrival time may be dispalyed by pushing this key.
GW/OAT	This white key is used to display and/or input the aircraft gross weight (lbs) at the top of the descent and the outside air temperature (^{o}F) at cruise altitude.
Metering Fix	This white key is used to display and/or input the metering fix altitude (ft), calibrated airspeed (kts) to be obtained at the metering fix, and the DME indication (n. mi.) that defines the metering fix.

Entry Fix — This white key is used to display and/or input the DME indication (n.mi.) that defines the entry fix, the magnetic course (deg) from entry fix to metering fix and the magnetic variation.

DME → H — This is one of three keys (the blue keys) used to display information about a descent profile after it has been computed. This one is used to display the altitude (ft) on the descent profile corresponding to any selected DME indication.

Early Late — This blue key is used to display the time error (hr. min. sec.) which the pilot will arrive at the metering fix if the assigned arrival time requires that the airplane be flown at speeds less than the minimum operational speed or faster than the maximum operational speed. A "HOLD" message and time error will be displayed to indicate the amount of required delay. A "LATE" message and time error will be displayed to indicate the arrival time error resulting when the airplane is flown at its maximum operational speeds.

Idle DME — This blue key is used to display the DME indication (n. mi.) where the thrust should be reduced to idle to begin the speed reduction for descent. This key is also used to display the estimated time at which the idle DME indication will be achieved.

***** — This is the gold key used to initiate the second function of the multi-function keys.

Negative — This white key is used to change the sign of an input variable.

Erase — This white key is used to delete the last input key stroke.

New Entry — This orange key is used to store the edited value of input data.

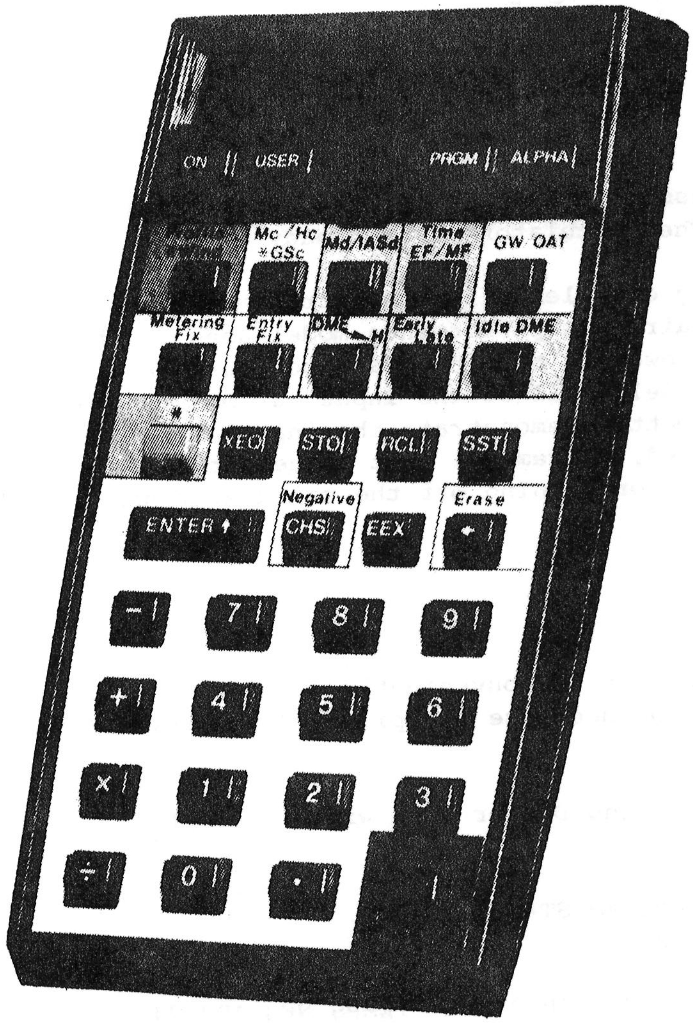


Figure 2.- Programmable Descent Calculator.

EXAMPLE CALCULATIONS

To begin, turn the calculator on. (It is assumed that the profile descent program has been loaded into the calculator. If this is not the case, do this now.) Check the display to see if the USER annunciator is on.

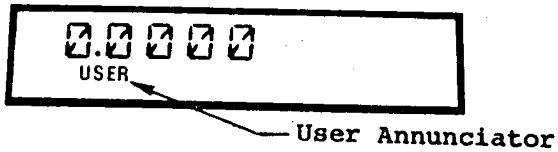


Figure 3.- Calculator display.

If it is not, press the USER Key. This activates all the programmed special function keys. The calculator is now ready for use.

The following examples will demonstrate the use of the Profile Descent Calculator. The aircraft performance model used in these examples is for a DC 10-10 airplane. However, the input and computation procedures are independent of the aircraft model. All of the input parameters have been intialized to zero in order to better demonstrate the input procedure. Once an input parameter is changed, it remains that value until a new value is input. Running the program or turning off the calculator has no effect on these values.

Wind Model

The wind model can be conveniently generated during the preflight planning. This helps decrease the pilot/calculator interaction during the flight.

Given the following Denver area wind forecast:

FD1 WESTERN UNITED STATES 291640
DATA BASED ON 291200Z

VALID 291800Z FOR USE 1700-2100Z TEMPS NEG ABV 24000

FT	3000	6000	9000	12000	18000	24000	30000	34000	39000
DEN			2814+08	2822+01	2631-14	2538-26	254642	245052	244961

The first wind data point in this forecast is for 9000 ft and is presented as 2814+08. This indicates that the wind is 280° at 14 knots and the temperature is 8°C.

There is no way to review or edit the wind data once it has been entered. Therefore, some care should be exercised in this operation. The wind information is inserted by the pilot as follows:

Keystrokes	Display	
[*] [Profile *Wind]	H = ? FT	This initiates the wind model program and queries for the first wind data point altitude
9000 [New Entry]	DIR.SPD ?	Asks for corresponding direction (deg) and speed (knots)
280.014 [New Entry]	H = ? FT	Queries for next data point. A minimum of two data points is required.

Note: The wind speed of 14 knots was input as .014 not .14 which would indicate 140 knots.

12000 [New Entry]	DIR.SPD ?	If you hit the wrong key, use the [Erase] key to correct
282.	282.	Oops!
[Erase] [Erase]	28	Erases last two key strokes. Input correct values
0.022 [New Entry]	H = ? FT • • • • • •	This data entry cycle continues until all of the wind data points have been entered.
39000 [New Entry]	DIR.SPD ?	
240.049 [New Entry]	H = ? FT	

1	Negative	New Entry	WIND IN	After the last wind data point has been entered, enter a negative altitude. This initiates the linear curve fit routine. When WIND IN is displayed, the wind model computation is finished

Time Mode Computation

As mentioned earlier, the profile descent can be flown in one of two modes. The first mode being that in which the metering fix arrival time is specified (Time Mode). When this is the case, the corresponding descent Mach/IAS schedule and the idle throttle DME reading are computed. The second mode is when the descent Mach/IAS is specified (Mach/IAS Mode). In this case, the idle throttle DME reading and the metering fix arrival time are computed.

The following is an example of a Time Mode computation. Suppose the aircraft is approaching Denver's Stapleton Airport from the northeast:

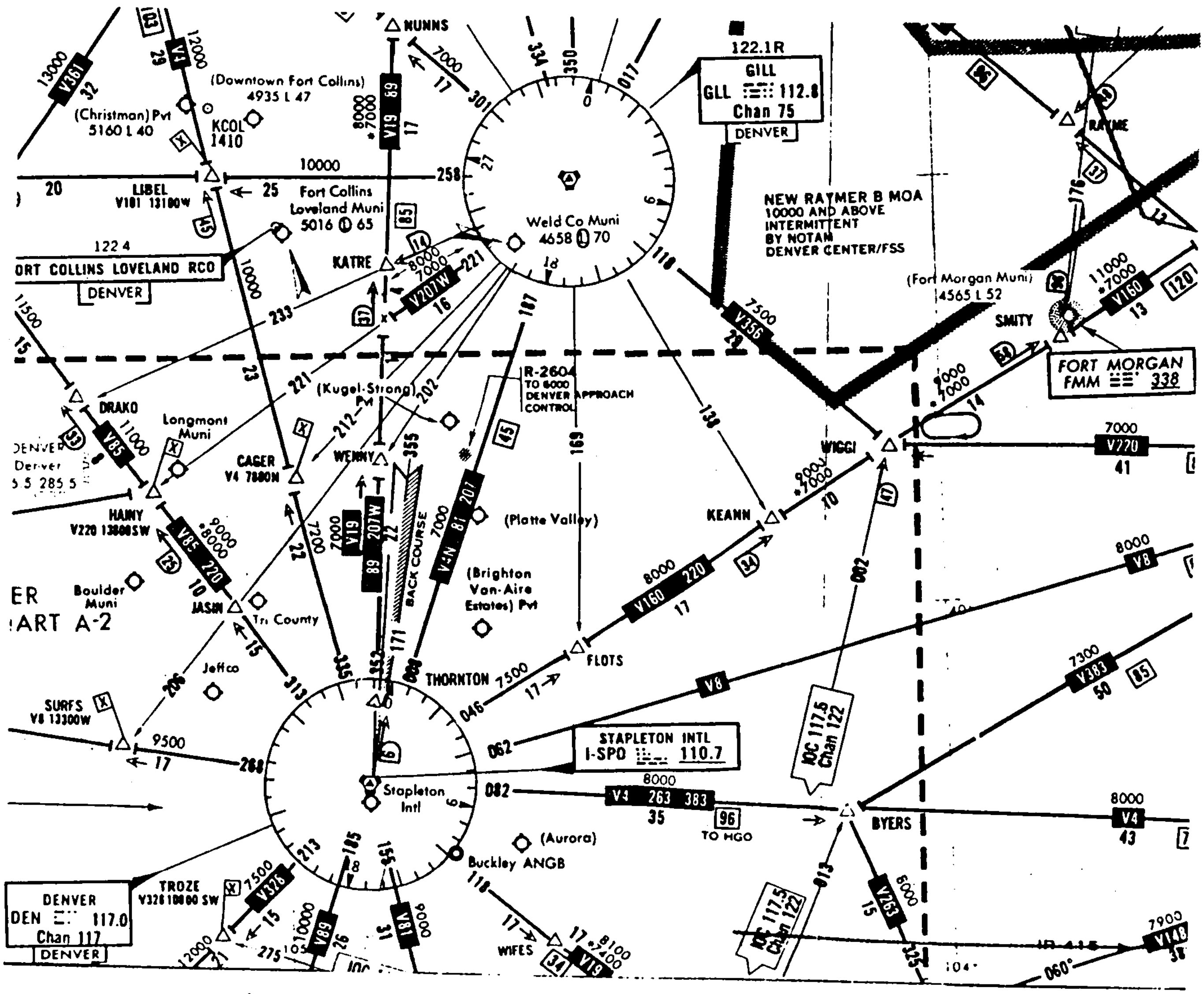


Figure 4.- Enroute low altitude chart of Denver area.

The airplane is cruising at 39000 ft, Mach 0.840; outside air temperature is -59 C^{o}; gross weight is 320000 lbs. Suppose the airplane crosses the point of the 120 n. mi. DME reading along the 046 radial at 19:57:08 GMT. The approach requires the airplane to cross KEANN at 17000 ft and 250 knots. Denver Center assigns the airplane a crossing time at KEANN of 20:11:00. We will assume that the wind data input earlier is current.

The calculator inputs for this problem are as follows:

> Note: The order in which the data is entered makes no difference. However, for simplicity and ease of understanding, the examples will progress from left to right across the keyboard.

Beginning with the cruise Mach and altitude inputs.

Keystrokes	Display	
[Mc/Hc *GSc]	Mc 0.000	Displays the value currently in storage
.84 [New Entry]	Hc 0.	
39000 [New Entry]	OK	This concludes the data entry for this key

The descent Mach/IAS schedule will be computed since this is a time mode computation, so no input is required for the [Md/IASd] key. The next input would therefore be the entry fix time and metering fix arrival time.

Keystrokes	Display	
[Time MF/EF]	MF TM 0.0000	The times are stored in terms of hr. min. sec. Therefore, 20:11:00 is input as 20.1100
20.11 [New Entry]	EF TM 0.0000	
19.5708 [New Entry]	DEL TM 832.0	After the entry fix time is entered, the calculator displays the time difference in seconds

The next inputs will be the gross weight and outside air temperature:

[GW/OAT]	GW 0.
320000 [New Entry]	OAT C 0.0
59 [Negative] [New Entry]	OK

Progressing to the metering fix inputs of crossing altitude, airspeed, and DME indication:

[Metering Fix]	H MF 0.
17000 [New Entry]	IAS MF 0.
250 [New Entry]	MF DME 0.0
34 [New Entry]	OK

The last inputs will be entry fix DME reading, the magnetic course from the entry fix to the metering fix, and the magnetic variation (East is negative; i.e. 3^{o}E = -3):

[Entry Fix]	EF DME 0.0
120 [New Entry]	MAGCRS 0.
226 [New Entry]	MAGVAR 0.
12 [Negative] [New Entry]	OK

All the data necessary for a time mode computation has now been entered. To initiate the computation, push the green [Profile] key, and in about one minute the idle throttle DME reading will be displayed.

[Profile * Wind]	IDL DME 94.2	The calculator displays the resultant idle throttle DME reading

Pushing the [Md/IASd] key will display the resultant descent Mach/indicated airspeed schedule.

[Md/IASd]	Md 0.840	Displays descent Mach number.
[Md/IASd]	IASd 263.	Displays descent indicated airspeed.

If one wishes to go back and review the idle DME reading, simply push the [Idle DME] key:

[Idle DME]	IDL DME 94.2	

A second push of the [Idle DME] key will display the estimated time at which the idle DME point will occur.

[Idle DME]	IDL TM 20.0047	The idle time message is in hr. min. sec. In this case the idle DME point should occur at 20:00:47 GMT

If one wishes to review any of the input data, simply push the corresponding key. For example, if you want to review the metering fix indicated airspeed, push the [Metering Fix] key:

[Metering Fix]	H MF 17,000.	Metering fix altitude
[Metering Fix]	IAS MF 250.	Metering fix indicated airspeed

Suppose a metering fix arrival time is specified which is impossible to meet. In such a case, the calculator will display the resultant time error. From the previous example, set the metering fix arrival time to 20:15:00 instead of 20:11:00. This will result in a time error situation.

[Time MF/EF]	MF TM 20.1100	
20.15 [New Entry]	EF TM 19.5708	

Now recompute the descent profile:

Profile *Wind	HOLD 0.0326	The time error message is in hr. min. sec. In this case, the error message indicates a early arrival by 3 min. and 26 sec.

Pushing the Md/IASd key will display the slowest possible idle descent Mach/IAS schedule:

Md/IASd	Md 0.840
Md/IASd	IASd 250.

Note: The descent Mach is equal to cruise Mach for the time-mode operation and the descent indicated airspeed is limited by the metering fix crossing speed.

Similar results are obtained for metering fix arrival times which require descents which are faster than possible. In this case, a "LATE" rather than a "HOLD" message would be displayed. If one wishes to review the time error, push the Early Late key:

Early Late	HOLD 0.0326

There is one other key which can be used to display the results of a computed descent profile. If one wishes to know the altitude at which the aircraft should be for a specific DME reading, simply key in the DME reading and push the DME→H key. For example, if you want to know the altitude corresponding to a DME indication of 60.0 n. mi. for the descent profile just computed, do the following:

60 DME→H	H = 26,404.

This feature allows the pilot to compute a series of check points along the profile.

Mach/IAS Mode Computation

The Mach/IAS mode is automatically activated by manually inputting the desired descent speed schedule. Suppose the aircraft is in the same situation as presented earlier. This time, assign a 0.83/280 kt. descent Mach/IAS schedule:

[Md/IASd]	Md 0.840
.83 [New Entry]	IASd 250.
280 [New Entry]	OK

Note the small zero flag annunicator next to the USER annunciator on the lower section of the display. When the zero flag annunciator is on, the calculator is in the Mach/IAS mode. When the zero flag is off, the calculator is in the time mode. To turn the zero flag off, one need only to assign a metering fix arrival time.

To compute the new profile, push the [Profile] key:

[Profile *Wind]	IDL DME 91.8

To display the metering fix arrival time, push the [Time EF/MF] key:

[Time EF/MF]	MF TM 20.1026	Arrival time is 20:10:26 GMT

Special Situations

Occasionally, the situation will arise where the forecasted winds are in error. This can be compensated for in the calculator through the [*GSc] key. This key is used to compute the ground speed at cruise based on the previously derived wind model. If this speed differs from the actual ground speed at cruise, the actual speed can be entered, and the wind model will be corrected accordingly. The head wind correction term, which is added to the wind model, diminishes to zero at sea level.

Suppose, from the previous example, the ground speed was observed to be 430 knots:

[*] [Mc/Hc *GSc]	GSc 425.	The computed ground speed at cruise is 425 knots.
430 [New Entry]	OK	The wind model is now corrected.

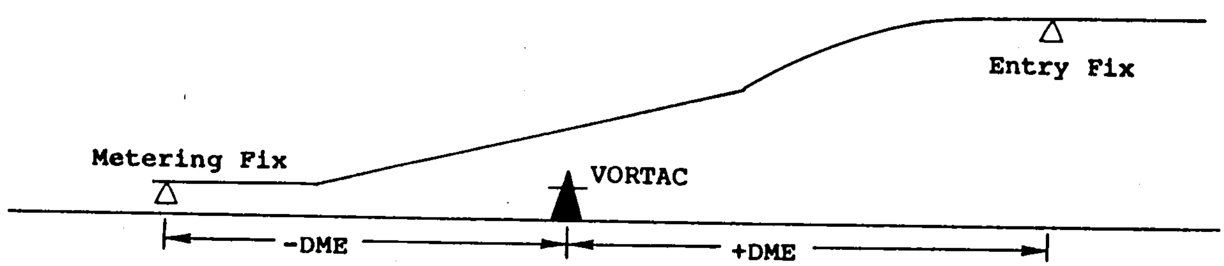
To check.

[*] [Mc/Hc *GSc]	GSc 430.	

Computing a new profile based on the updated wind model.

[Profile *Wind]	IDL DME 92.6	Need to start the descent 0.8 n.mi. sooner due to the 5 knot wind difference.

Another situation which may arise from time to time is having a metering fix which is located past the VORTAC being used for the DME readings. If this situation occurs, simply input the MF DME as a negative number.



The descent profile that the calculator computes is based on maintaining a constant heading from entry fix to metering fix. If a heading change is required in the descent, the winds used to compute the descent will be in error. To compensate for this, the average course or the course which is flown the longest should be used.

One other situation which may develop is if the distance between the metering fix and the entry fix is too short to accomplish the desired descent. If this is the case, a message will be displayed indicating that the entry fix distance is less than the required distance.

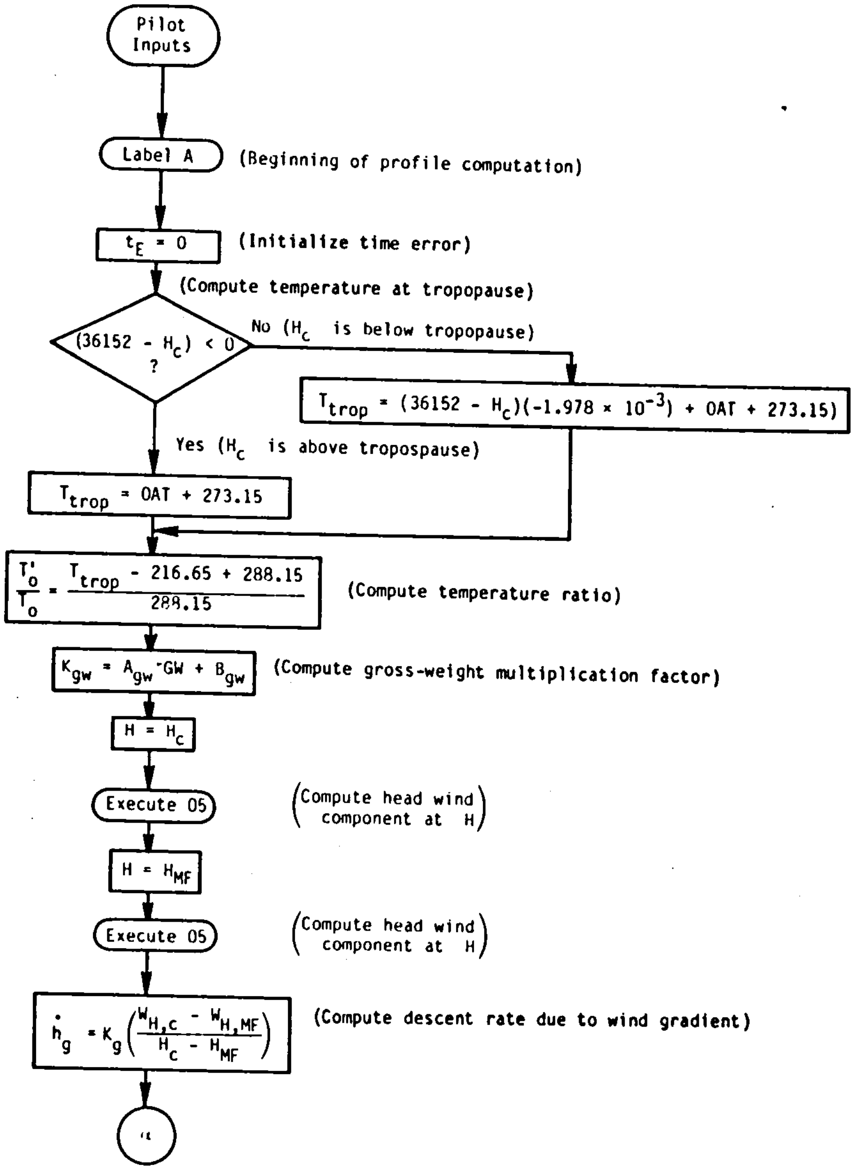
Example: Change the entry fix DME reading to 90 n.mi.

[Entry Fix]	EF DME 120.0	
90 [New Entry]	MAGCRS 226.	
[Profile *Wind]	EF < 92.6	An entry fix DME indication of 92.6 n.mi. is the minimum required to achieve the desired descent.

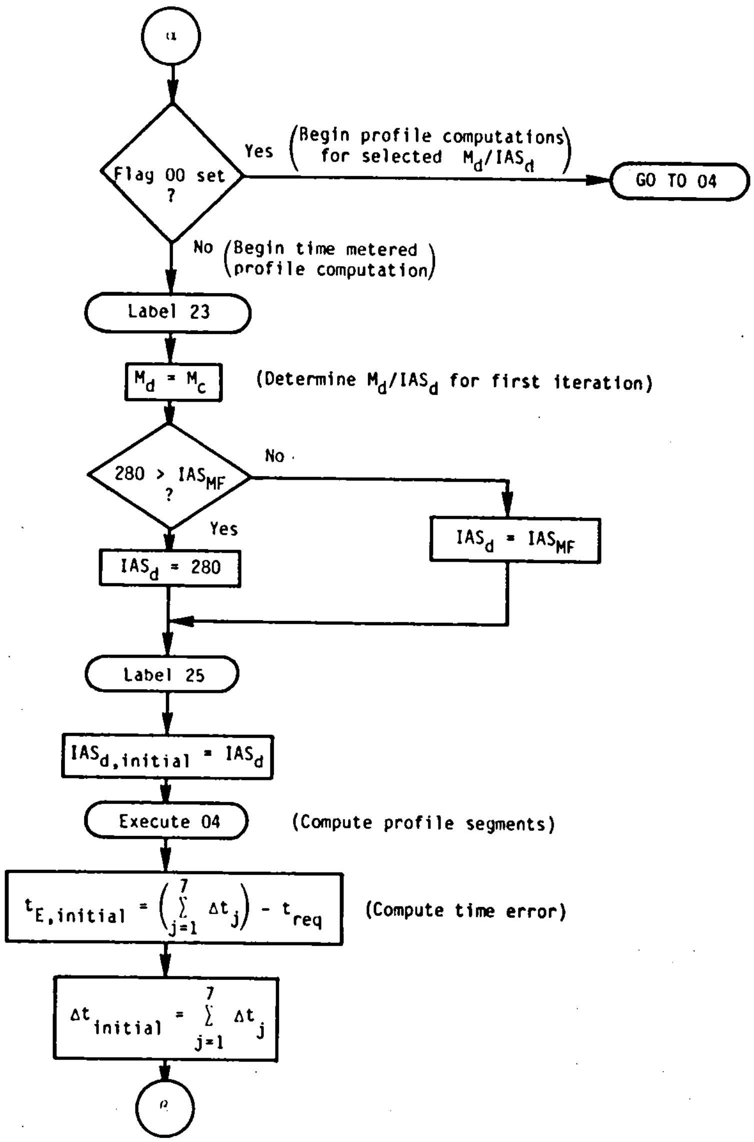
If the calculator is in the time mode and this situation arises, the message will not be displayed. The calculator just tries to satisfy the time criteria. If the required distance is too long it will become obvious when the idle DME reading is displayed.

APPENDIX A

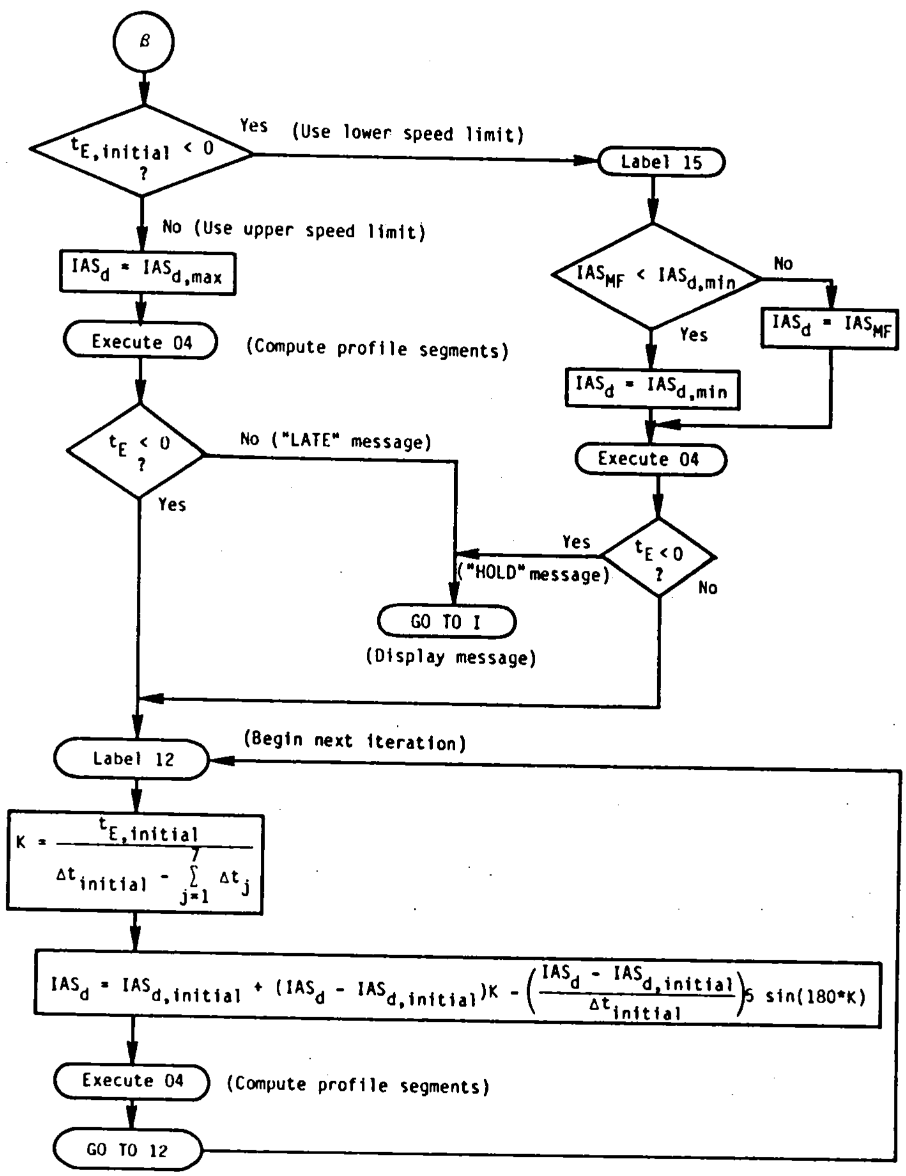
Program Flow Chart



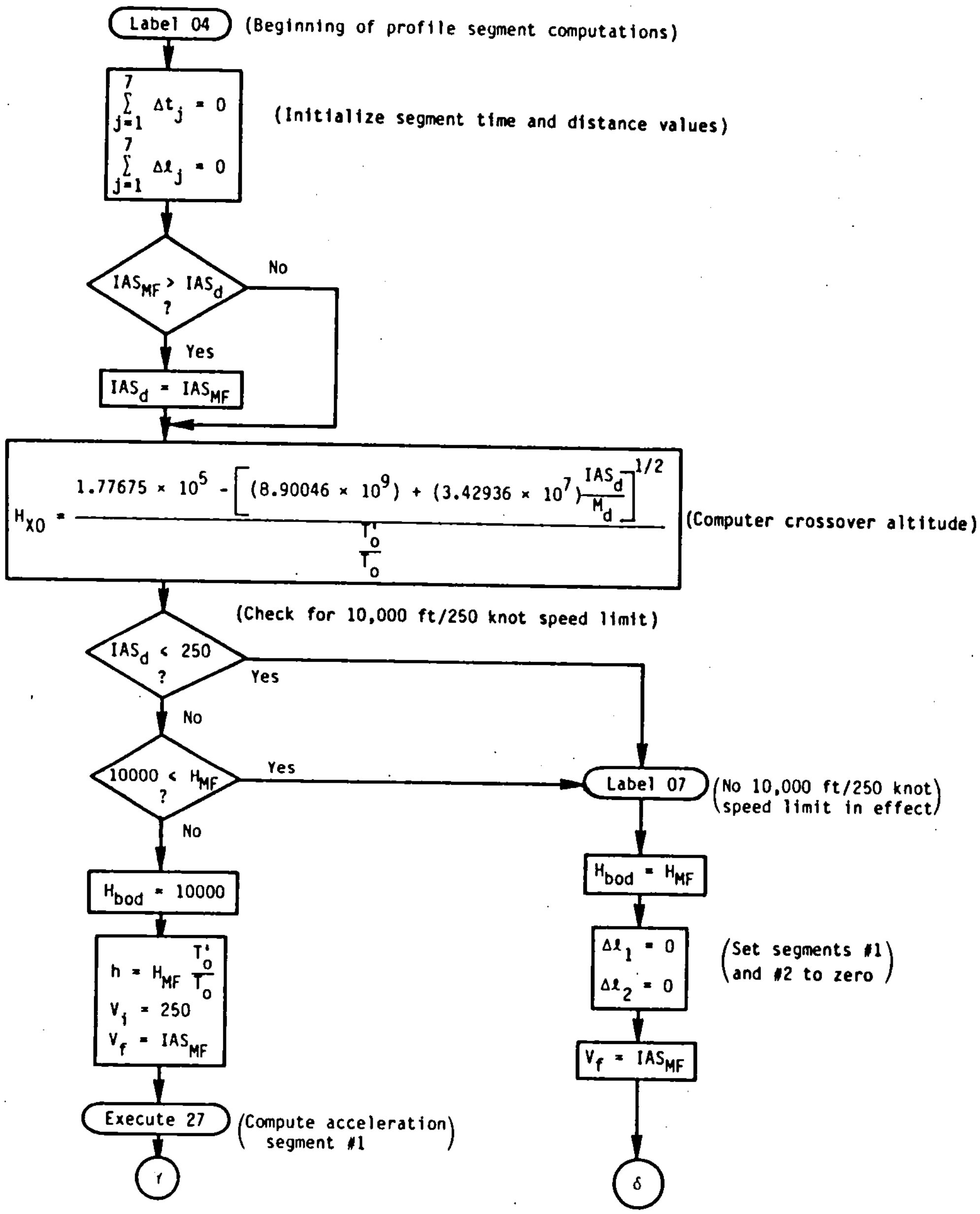
APPENDIX A



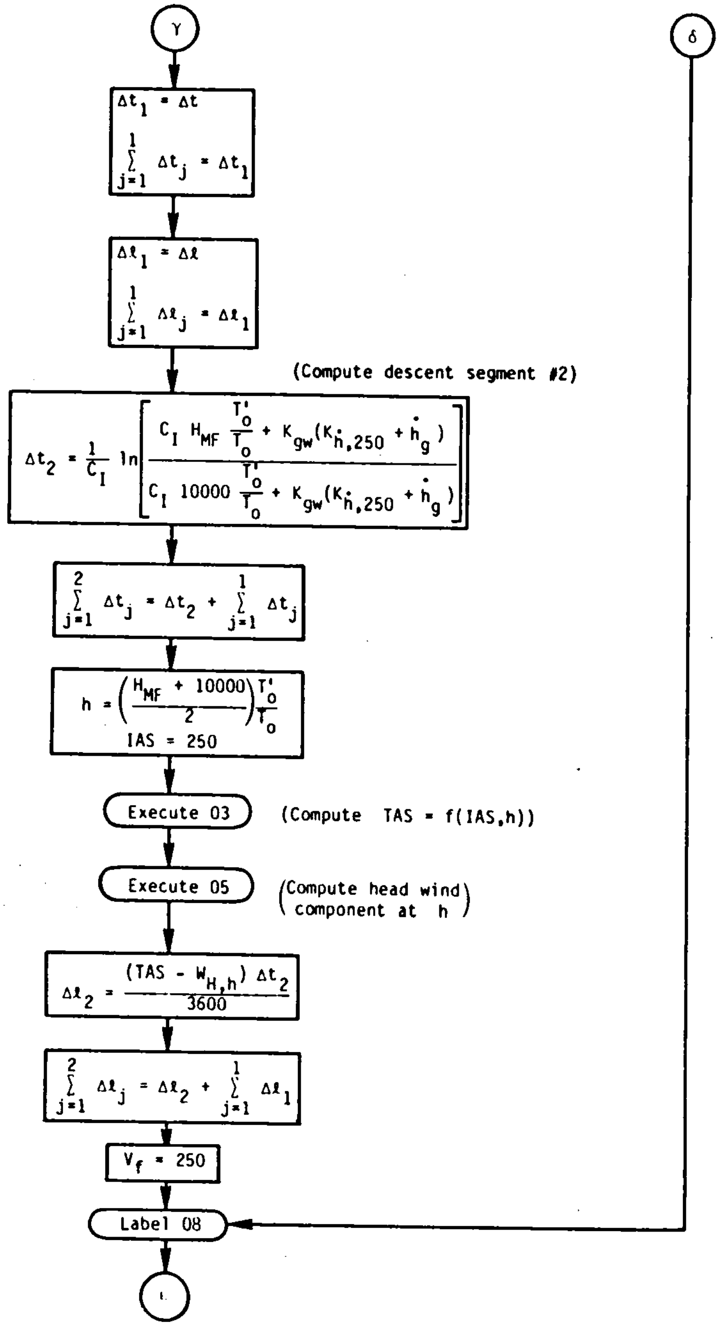
α
Flag 00 set ?
Yes
(Begin profile computations for selected M_d/IAS_d)
GO TO 04
No
(Begin time metered profile computation)
Label 23
M_d = M_c
(Determine M_d/IAS_d for first iteration)
280 > IAS_MF ?
No
Yes
IAS_d = 280
IAS_d = IAS_MF
Label 25
IAS_d,initial = IAS_d
Execute 04
(Compute profile segments)
t_E,initial = (Σ_{j=1}^{7} Δt_j) - t_req
(Compute time error)
Δt_initial = Σ_{j=1}^{7} Δt_j
β

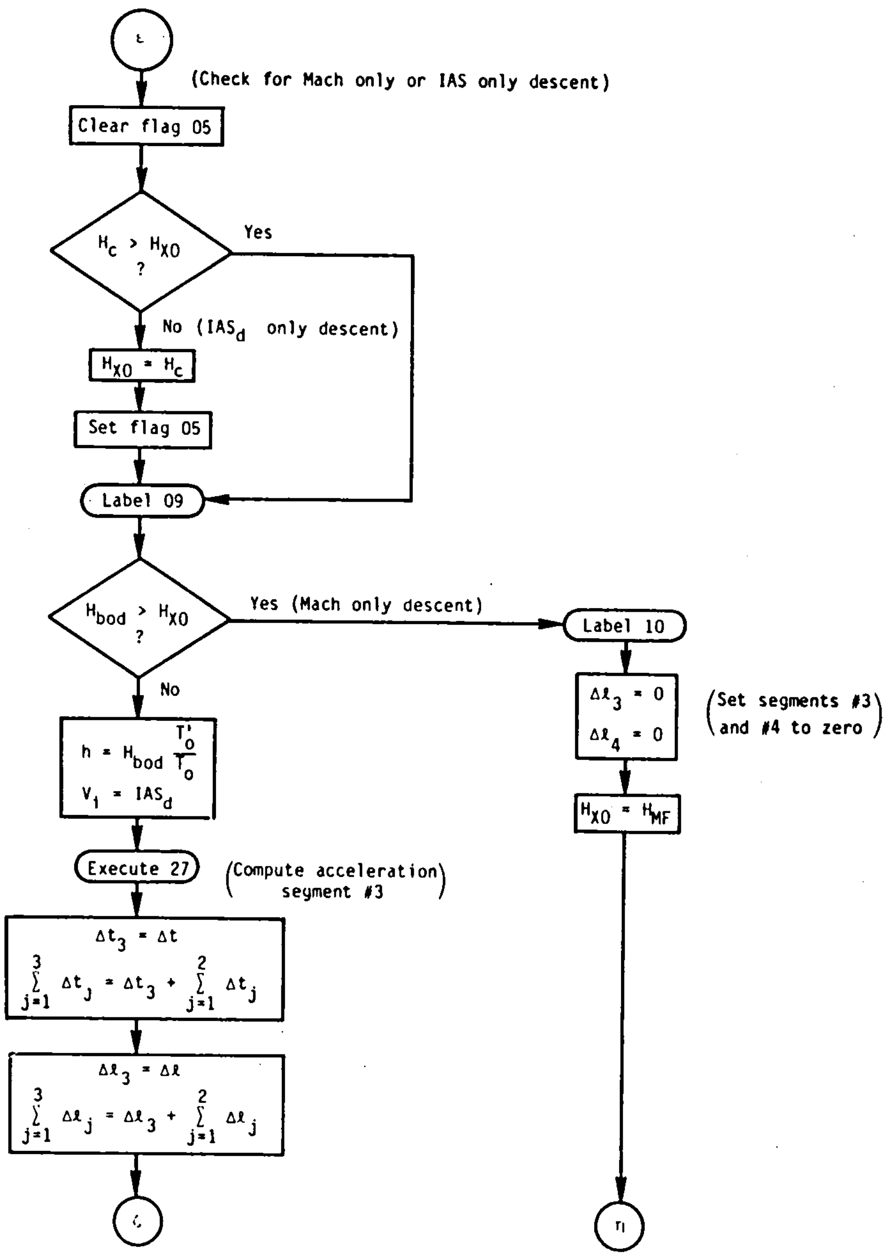


B
$t_{E,initial} < 0$?
Yes (Use lower speed limit)
Label 15
No (Use upper speed limit)
$IAS_d = IAS_{d,max}$
Execute 04
(Compute profile segments)
$IAS_{MF} < IAS_{d,min}$
No
Yes
$IAS_d = IAS_{MF}$
$IAS_d = IAS_{d,min}$
$t_E < 0$?
No ("LATE" message)
Yes
Execute 04
Yes
("HOLD" message)
$t_E < 0$?
No
GO TO I
(Display message)
Label 12
(Begin next iteration)
$K = \frac{t_{E,initial}}{\Delta t_{initial} - \sum_{j=1}^{7} \Delta t_j}$
$IAS_d = IAS_{d,initial} + (IAS_d - IAS_{d,initial})K - \left(\frac{IAS_d - IAS_{d,initial}}{\Delta t_{initial}}\right)5 \sin(180*K)$
Execute 04
(Compute profile segments)
GO TO 12

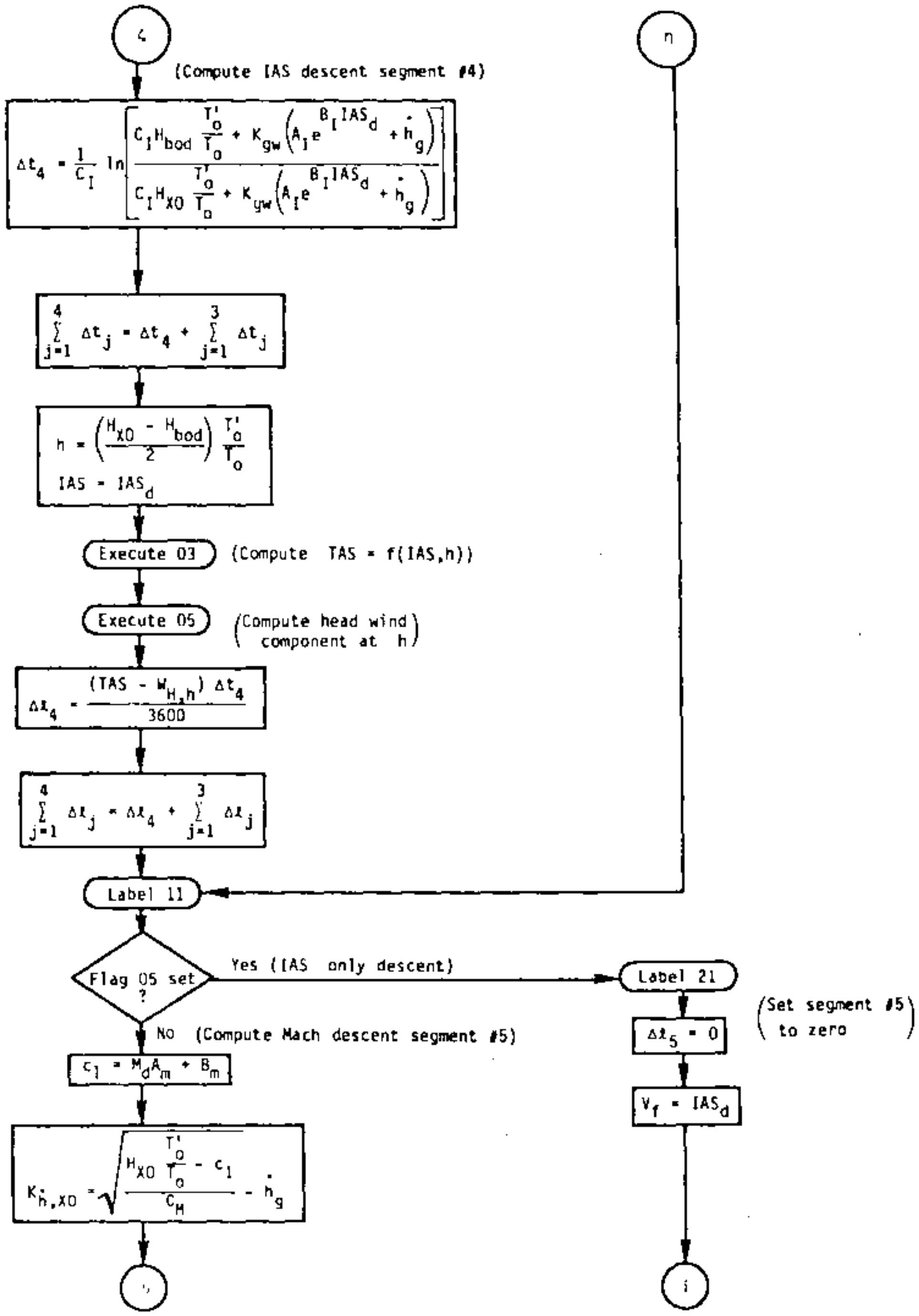


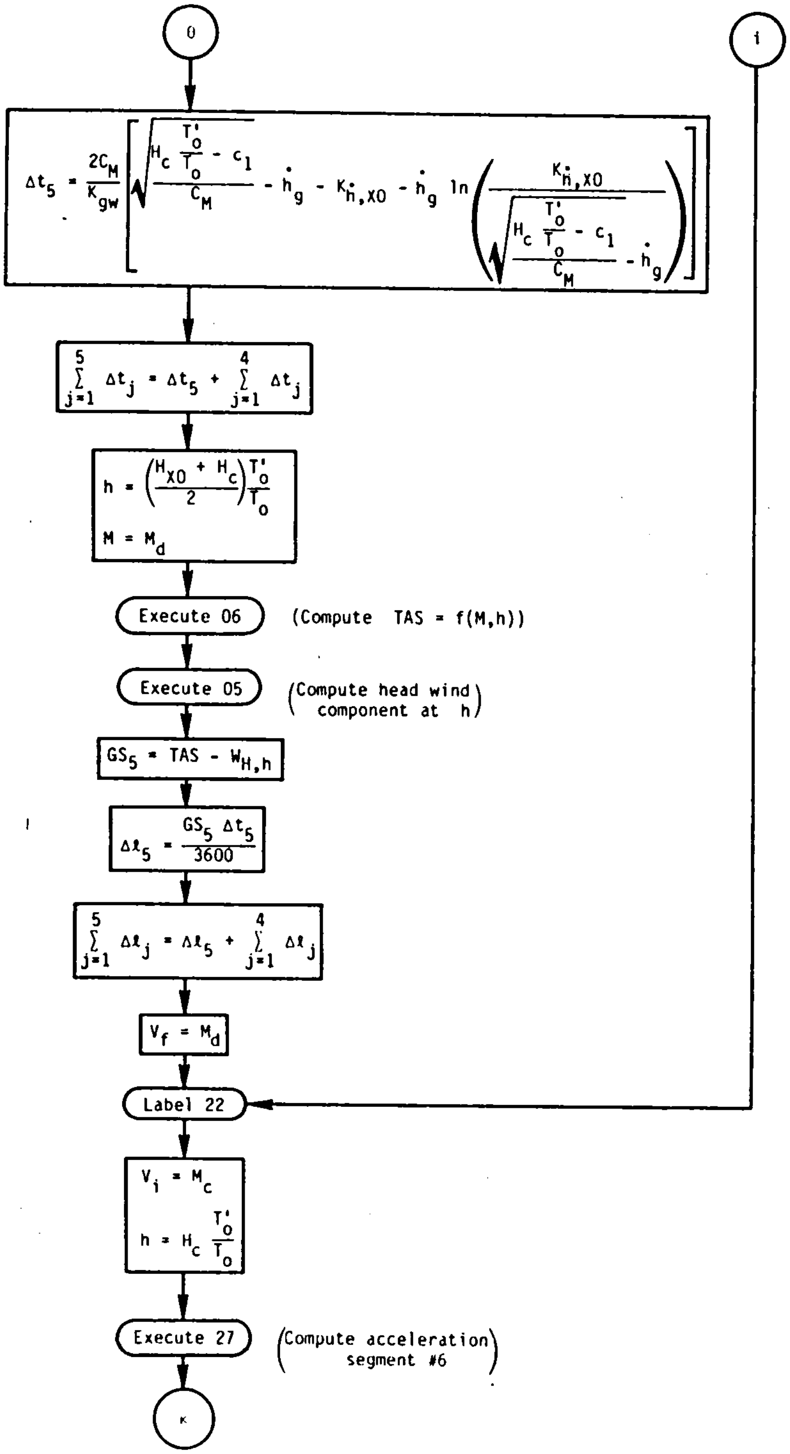
Label 04
(Beginning of profile segment computations)
$\sum_{j=1}^{7} \Delta t_j = 0$
$\sum_{j=1}^{7} \Delta \ell_j = 0$
(Initialize segment time and distance values)
$IAS_{MF} > IAS_d$?
No
Yes
$IAS_d = IAS_{MF}$
$H_{XO} = \dfrac{1.77675 \times 10^5 - \left[(8.90046 \times 10^9) + (3.42936 \times 10^7)\dfrac{IAS_d}{M_d}\right]^{1/2}}{\dfrac{T_o'}{T_o}}$
(Computer crossover altitude)
(Check for 10,000 ft/250 knot speed limit)
$IAS_d < 250$?
Yes
No
$10000 < H_{MF}$?
Yes
No
Label 07
(No 10,000 ft/250 knot speed limit in effect)
$H_{bod} = 10000$
$H_{bod} = H_{MF}$
$h = H_{MF} \dfrac{T_o'}{T_o}$
$V_i = 250$
$V_f = IAS_{MF}$
$\Delta \ell_1 = 0$
$\Delta \ell_2 = 0$
(Set segments #1 and #2 to zero)
$V_f = IAS_{MF}$
Execute 27
(Compute acceleration segment #1)
γ
δ

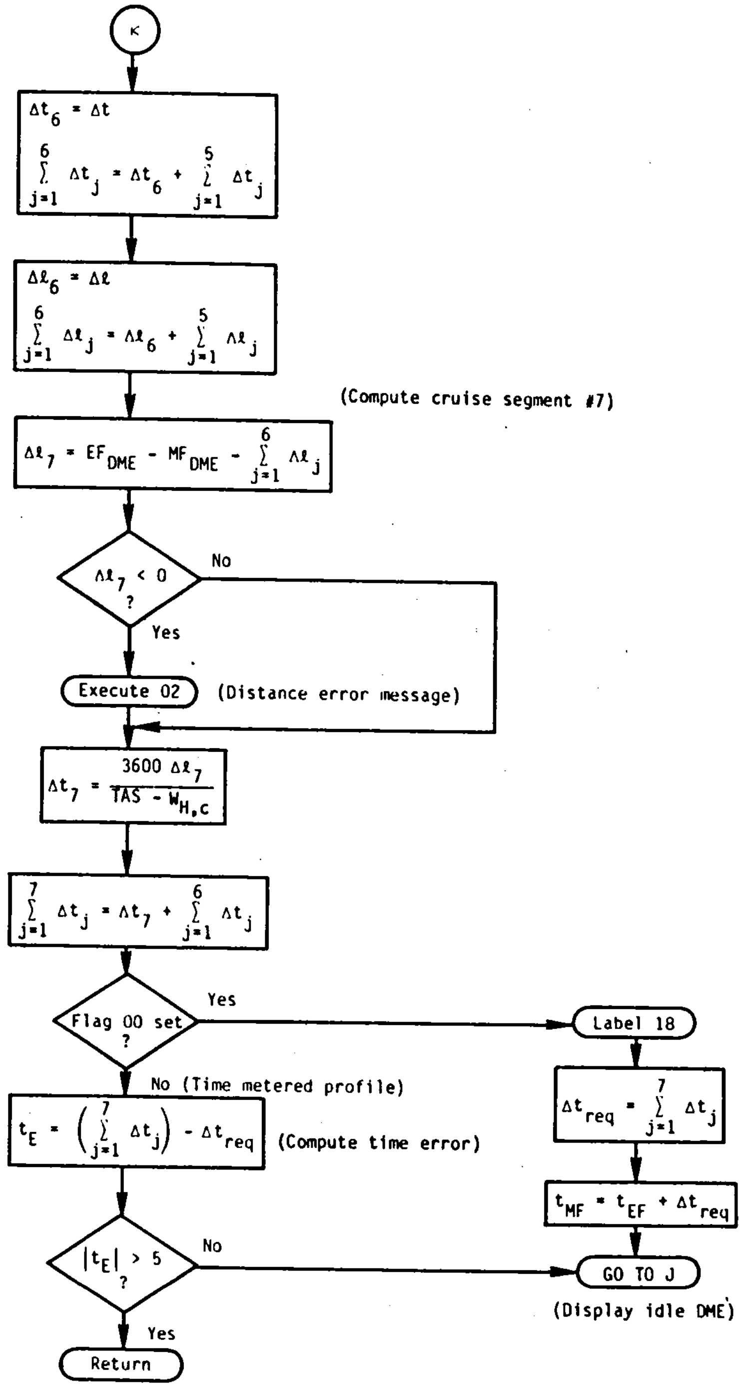

γ
δ
$\Delta t_1 = \Delta t$
$\sum_{j=1}^{1} \Delta t_j = \Delta t_1$
$\Delta \ell_1 = \Delta \ell$
$\sum_{j=1}^{1} \Delta \ell_j = \Delta \ell_1$
(Compute descent segment #2)
$\Delta t_2 = \frac{1}{C_I} \ln \left[\frac{C_I H_{MF} \frac{T_o'}{T_o} + K_{gw}(K_{\dot{h},250} + \dot{h}_g)}{C_I\ 10000 \frac{T_o'}{T_o} + K_{gw}(K_{\dot{h},250} + \dot{h}_g)} \right]$
$\sum_{j=1}^{2} \Delta t_j = \Delta t_2 + \sum_{j=1}^{1} \Delta t_j$
$h = \left(\frac{H_{MF} + 10000}{2}\right)\frac{T_o'}{T_o}$
IAS = 250
Execute 03
(Compute TAS = f(IAS,h))
Execute 05
(Compute head wind component at h)
$\Delta \ell_2 = \frac{(TAS - W_{H,h})\ \Delta t_2}{3600}$
$\sum_{j=1}^{2} \Delta \ell_j = \Delta \ell_2 + \sum_{j=1}^{1} \Delta \ell_1$
$V_f = 250$
Label 08
ι



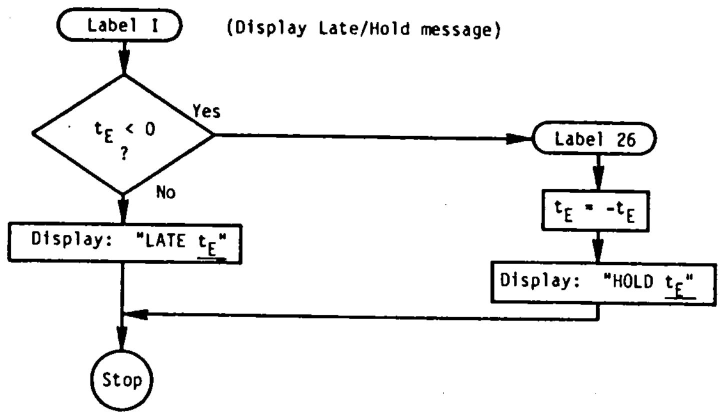
(Check for Mach only or IAS only descent)
Clear flag 05
$H_c > H_{XO}$?
Yes
No (IAS_d only descent)
$H_{XO} = H_c$
Set flag 05
Label 09
$H_{bod} > H_{XO}$?
Yes (Mach only descent)
No
$h = H_{bod} \frac{T_o'}{T_o}$
$V_i = IAS_d$
Execute 27
(Compute acceleration segment #3)
$\Delta t_3 = \Delta t$
$\sum_{j=1}^{3} \Delta t_j = \Delta t_3 + \sum_{j=1}^{2} \Delta t_j$
$\Delta \ell_3 = \Delta \ell$
$\sum_{j=1}^{3} \Delta \ell_j = \Delta \ell_3 + \sum_{j=1}^{2} \Delta \ell_j$
Label 10
$\Delta \ell_3 = 0$
$\Delta \ell_4 = 0$
(Set segments #3 and #4 to zero)
$H_{XO} = H_{MF}$


4
n
(Compute IAS descent segment #4)
$\Delta t_4 = \frac{1}{C_I} \ln \left[\frac{C_I H_{bod} \frac{T'_o}{T_o} + K_{gw}\left(A_I e^{B_I IAS_d} + \dot{h}_g\right)}{C_I H_{XO} \frac{T'_o}{T_o} + K_{gw}\left(A_I e^{B_I IAS_d} + \dot{h}_g\right)} \right]$
$\sum_{j=1}^{4} \Delta t_j = \Delta t_4 + \sum_{j=1}^{3} \Delta t_j$
$h = \left(\frac{H_{XO} - H_{bod}}{2}\right) \frac{T'_o}{T_o}$
$IAS = IAS_d$
Execute 03
(Compute TAS = f(IAS,h))
Execute 05
(Compute head wind component at h)
$\Delta \ell_4 = \frac{(TAS - W_{H,h})\,\Delta t_4}{3600}$
$\sum_{j=1}^{4} \Delta \ell_j = \Delta \ell_4 + \sum_{j=1}^{3} \Delta \ell_j$
Label 11
Flag 05 set ?
Yes (IAS only descent)
Label 21
(Set segment #5 to zero)
$\Delta \ell_5 = 0$
$V_f = IAS_d$
No (Compute Mach descent segment #5)
$c_1 = M_d A_m + B_m$
$K_{\dot{h},XO} = \sqrt{\frac{H_{XO} \frac{T'_o}{T_o} - c_1}{C_M} - \dot{h}_g}$
5
i

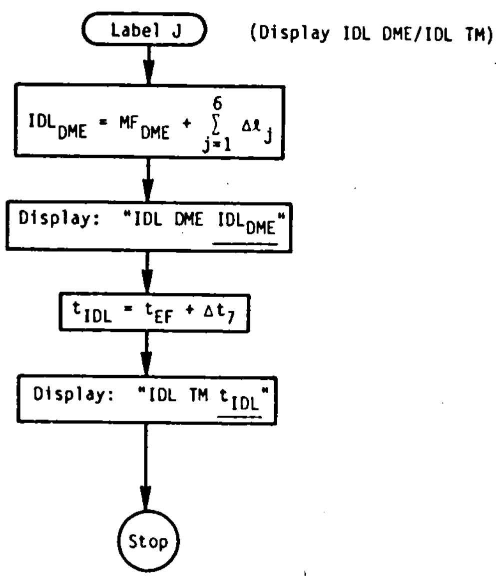

0
i
$\Delta t_5 = \frac{2C_M}{K_{gw}}\left[\sqrt{\frac{H_c \frac{T_o'}{T_o} - c_1}{C_M}} - \dot{h}_g - K_{\dot{h},XO} - \dot{h}_g \ln\left(\frac{K_{\dot{h},XO}}{\sqrt{\frac{H_c \frac{T_o'}{T_o} - c_1}{C_M}} - \dot{h}_g}\right)\right]$
$\sum_{j=1}^{5} \Delta t_j = \Delta t_5 + \sum_{j=1}^{4} \Delta t_j$
$h = \left(\frac{H_{XO} + H_c}{2}\right)\frac{T_o'}{T_o}$
$M = M_d$
Execute 06
(Compute TAS = f(M,h))
Execute 05
(Compute head wind component at h)
$GS_5 = TAS - W_{H,h}$
$\Delta \ell_5 = \frac{GS_5\, \Delta t_5}{3600}$
$\sum_{j=1}^{5} \Delta \ell_j = \Delta \ell_5 + \sum_{j=1}^{4} \Delta \ell_j$
$V_f = M_d$
Label 22
$V_i = M_c$
$h = H_c \frac{T_o'}{T_o}$
Execute 27
(Compute acceleration segment #6)
K


K
Δt6 = Δt
6
∑ Δtj = Δt6 + ∑ Δtj
j=1
5
j=1
Δℓ6 = Δℓ
6
∑ Δℓj = Δℓ6 + ∑ Δℓj
j=1
5
j=1
(Compute cruise segment #7)
Δℓ7 = EFDME - MFDME - ∑ Δℓj
6
j=1
Δℓ7 < 0
?
No
Yes
Execute 02
(Distance error message)
Δt7 = 3600 Δℓ7 / (TAS - WH,c)
7
∑ Δtj = Δt7 + ∑ Δtj
j=1
6
j=1
Flag 00 set
?
Yes
Label 18
No (Time metered profile)
tE = (∑ Δtj) - Δtreq
7
j=1
(Compute time error)
Δtreq = ∑ Δtj
7
j=1
tMF = tEF + Δtreq
|tE| > 5
?
No
GO TO J
(Display idle DME)
Yes
Return

APPENDIX A

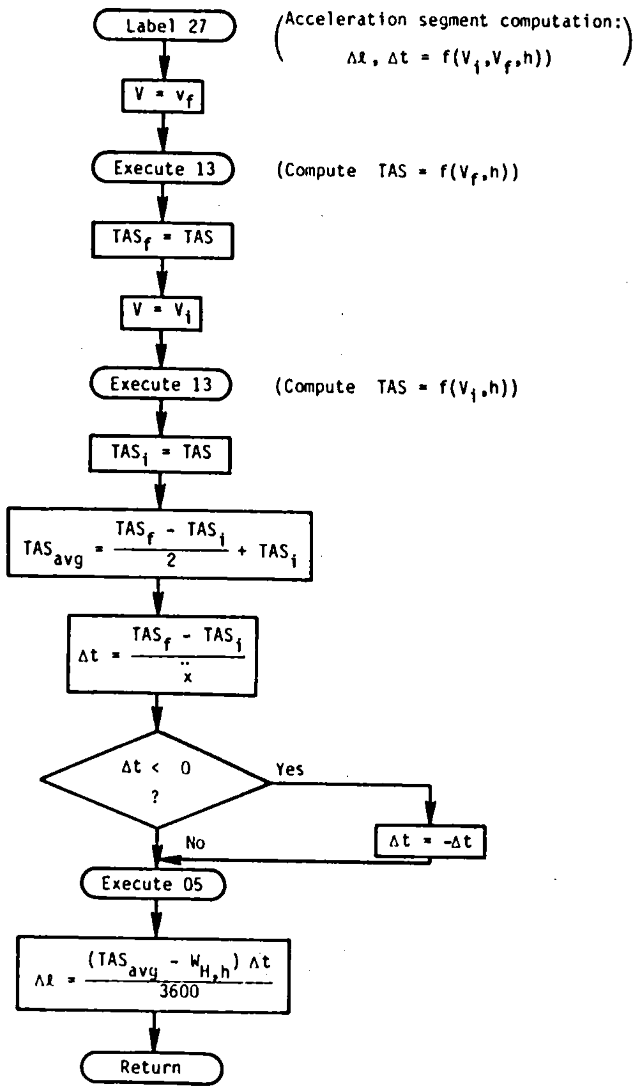


Label I
(Display Late/Hold message)
$t_E < 0$?
Yes
No
Label 26
$t_E = -t_E$
Display: "LATE $\underline{t_E}$"
Display: "HOLD $\underline{t_E}$"
Stop

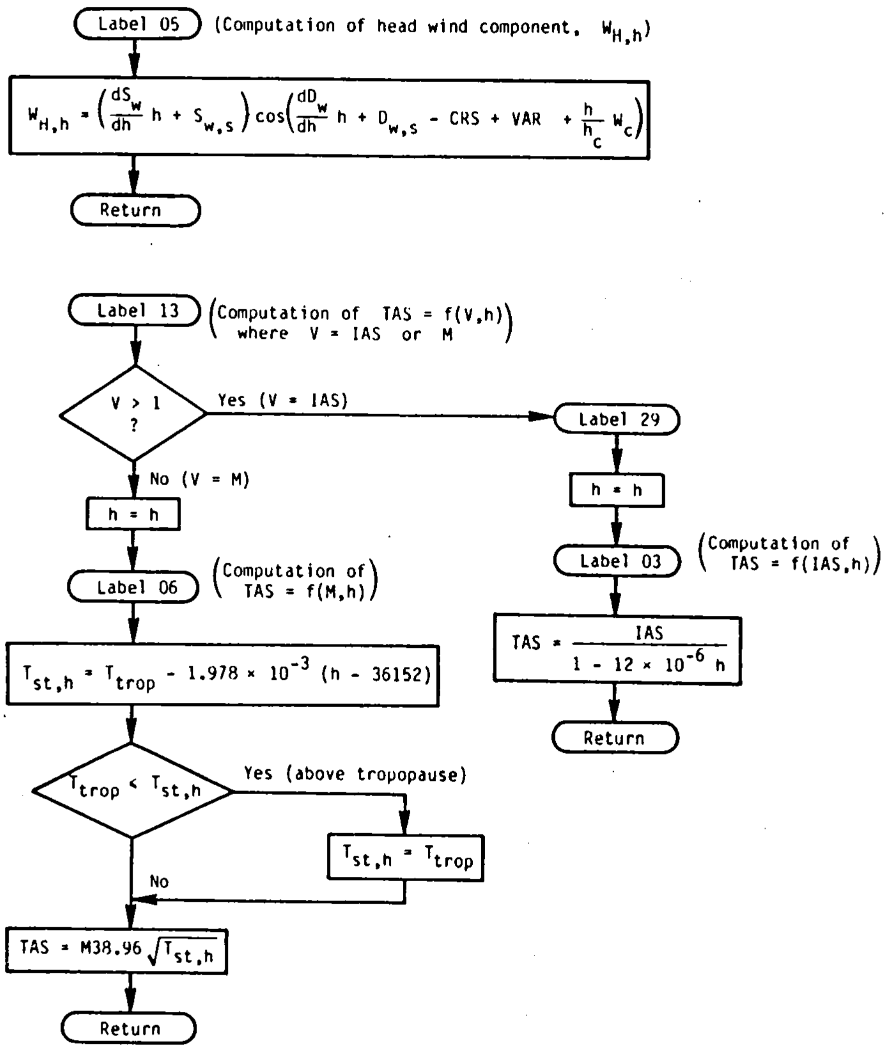


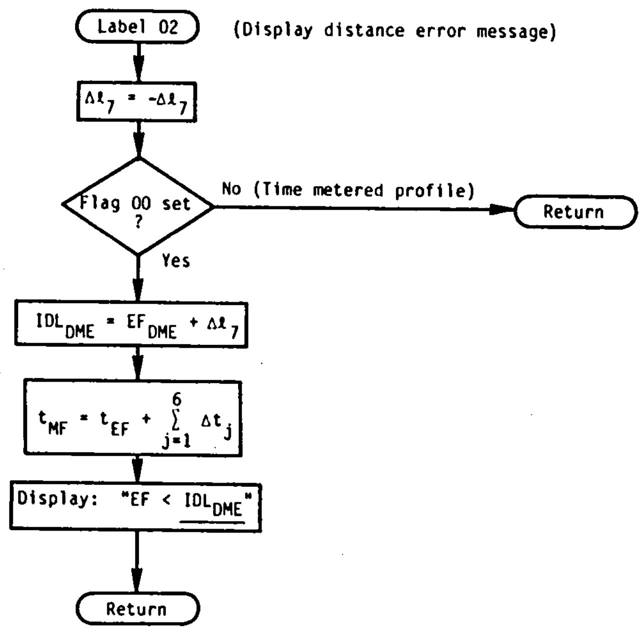
Label J
(Display IDL DME/IDL TM)
$IDL_{DME} = MF_{DME} + \sum_{j=1}^{6} \Delta\ell_j$
Display: "IDL DME $\underline{IDL_{DME}}$"
$t_{IDL} = t_{EF} + \Delta t_7$
Display: "IDL TM $\underline{t_{IDL}}$"
Stop

APPENDIX A

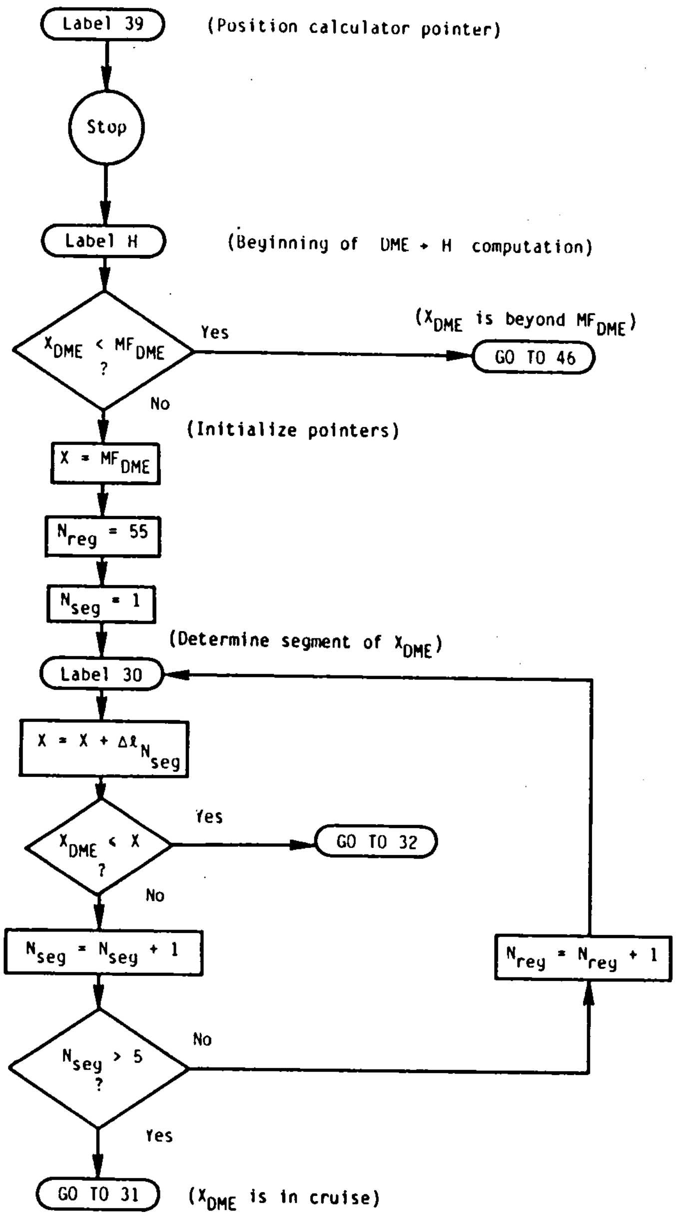


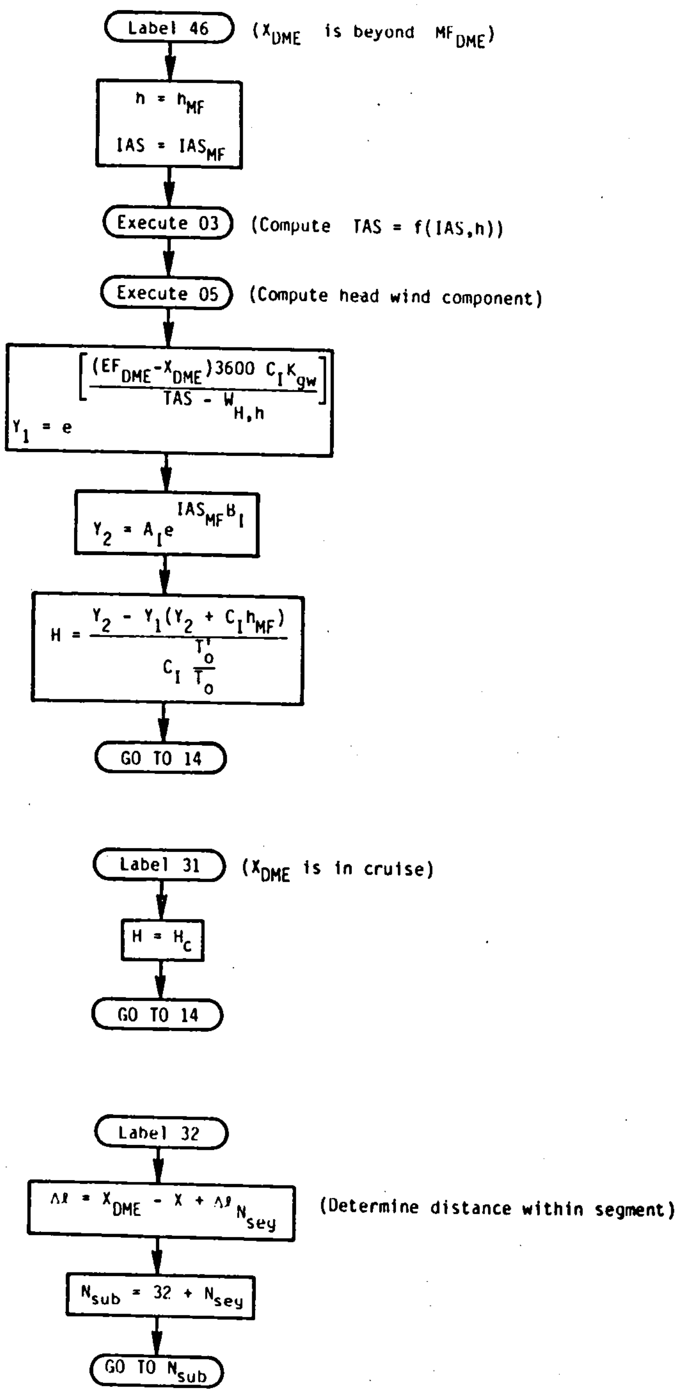
Label 27
(Acceleration segment computation:
Δℓ, Δt = f(V_i,V_f,h))
V = V_f
Execute 13
(Compute TAS = f(V_f,h))
TAS_f = TAS
V = V_i
Execute 13
(Compute TAS = f(V_i,h))
TAS_i = TAS
TAS_avg = (TAS_f - TAS_i)/2 + TAS_i
Δt = (TAS_f - TAS_i)/ẍ
Δt < 0
?
Yes
Δt = -Δt
No
Execute 05
Δℓ = (TAS_avg - W_H,h) Δt / 3600
Return


Label 05
(Computation of head wind component, W_H,h)
W_H,h = (dS_w/dh h + S_w,s) cos(dD_w/dh h + D_w,s - CRS + VAR + h/h_c W_c)
Return
Label 13
(Computation of TAS = f(V,h) where V = IAS or M)
V > 1 ?
Yes (V = IAS)
No (V = M)
h = h
Label 06
(Computation of TAS = f(M,h))
T_st,h = T_trop - 1.978 × 10^-3 (h - 36152)
T_trop < T_st,h
Yes (above tropopause)
T_st,h = T_trop
No
TAS = M38.96 √T_st,h
Return
Label 29
h = h
Label 03
(Computation of TAS = f(IAS,h))
TAS = IAS / (1 - 12 × 10^-6 h)
Return

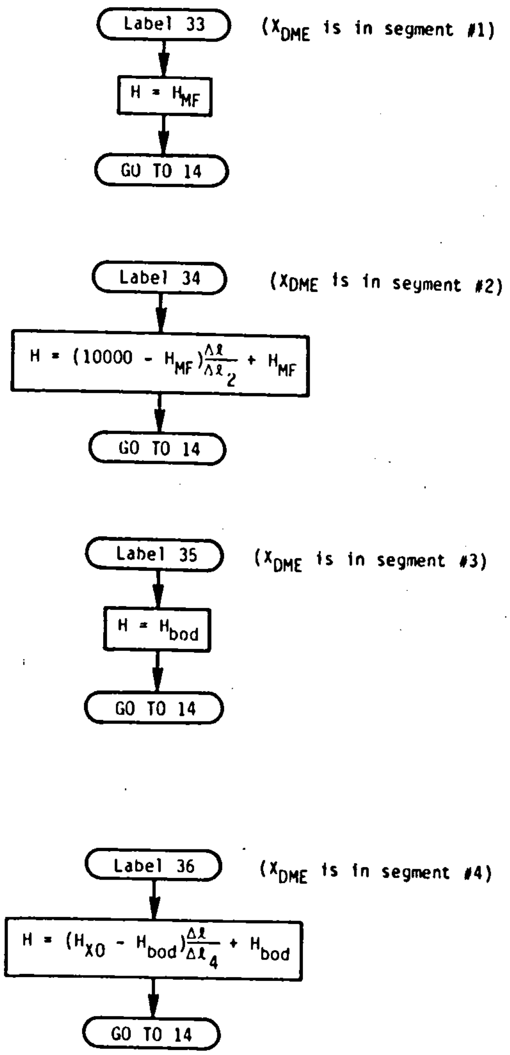


Label 02
(Display distance error message)
Δℓ7 = -Δℓ7
Flag 00 set ?
No (Time metered profile)
Return
Yes
IDL DME = EF DME + Δℓ7
t MF = t EF + Σ j=1 6 Δt j
Display: "EF < IDL DME"
Return

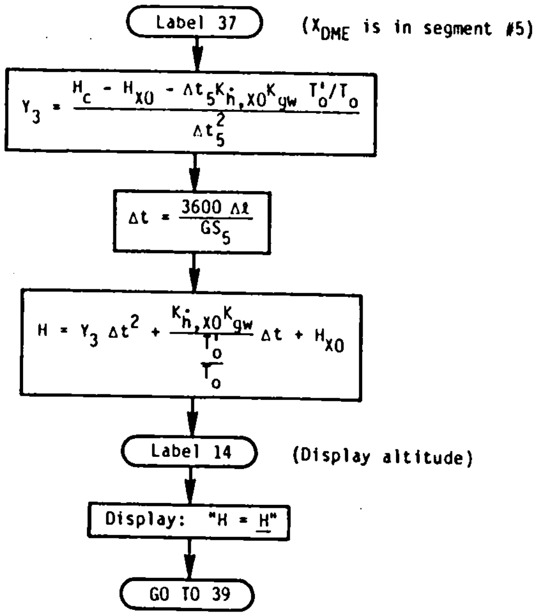

Label 39
(Position calculator pointer)
Stop
Label H
(Beginning of DME + H computation)
$X_{DME} < MF_{DME}$?
Yes
$(X_{DME}$ is beyond $MF_{DME})$
GO TO 46
No
(Initialize pointers)
$X = MF_{DME}$
$N_{reg} = 55$
$N_{seg} = 1$
(Determine segment of X_{DME})
Label 30
$X = X + \Delta \ell_{N_{seg}}$
$X_{DME} < X$?
Yes
GO TO 32
No
$N_{seg} = N_{seg} + 1$
$N_{reg} = N_{reg} + 1$
$N_{seg} > 5$?
No
Yes
GO TO 31
$(X_{DME}$ is in cruise)


Label 46
(X_{DME} is beyond MF_{DME})
$h = h_{MF}$
$IAS = IAS_{MF}$
Execute 03
(Compute $TAS = f(IAS,h)$)
Execute 05
(Compute head wind component)
$Y_1 = e^{\left[\frac{(EF_{DME}-X_{DME})3600\ C_I K_{gw}}{TAS - W_{H,h}}\right]}$
$Y_2 = A_I e^{IAS_{MF} B_I}$
$H = \frac{Y_2 - Y_1(Y_2 + C_I h_{MF})}{C_I \frac{T'_o}{T_o}}$
GO TO 14
Label 31
(X_{DME} is in cruise)
$H = H_c$
GO TO 14
Label 32
$\Delta\ell = X_{DME} - X + \Delta\ell_{N_{seg}}$
(Determine distance within segment)
$N_{sub} = 32 + N_{seg}$
GO TO N_{sub}

APPENDIX A

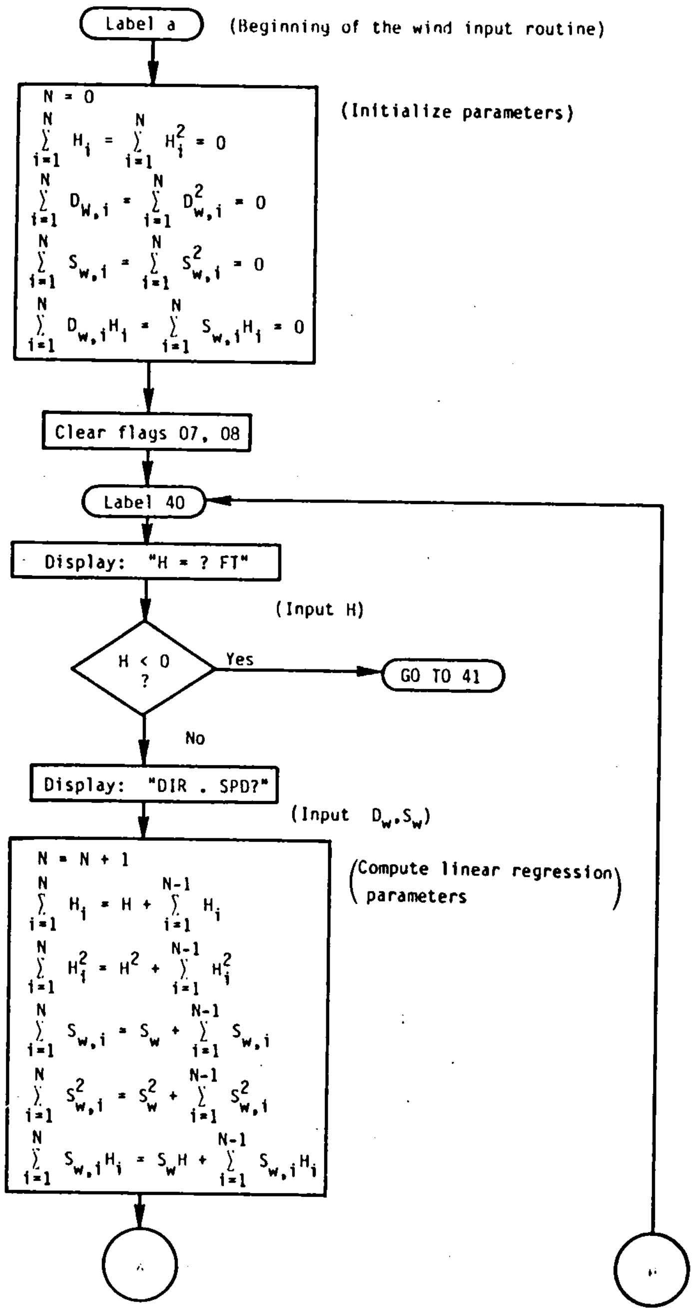

Label 33
(XDME is in segment #1)
H = HMF
GO TO 14
Label 34
(XDME is in segment #2)
H = (10000 - HMF)Δℓ/Δℓ2 + HMF
GO TO 14
Label 35
(XDME is in segment #3)
H = Hbod
GO TO 14
Label 36
(XDME is in segment #4)
H = (HXO - Hbod)Δℓ/Δℓ4 + Hbod
GO TO 14

APPENDIX A

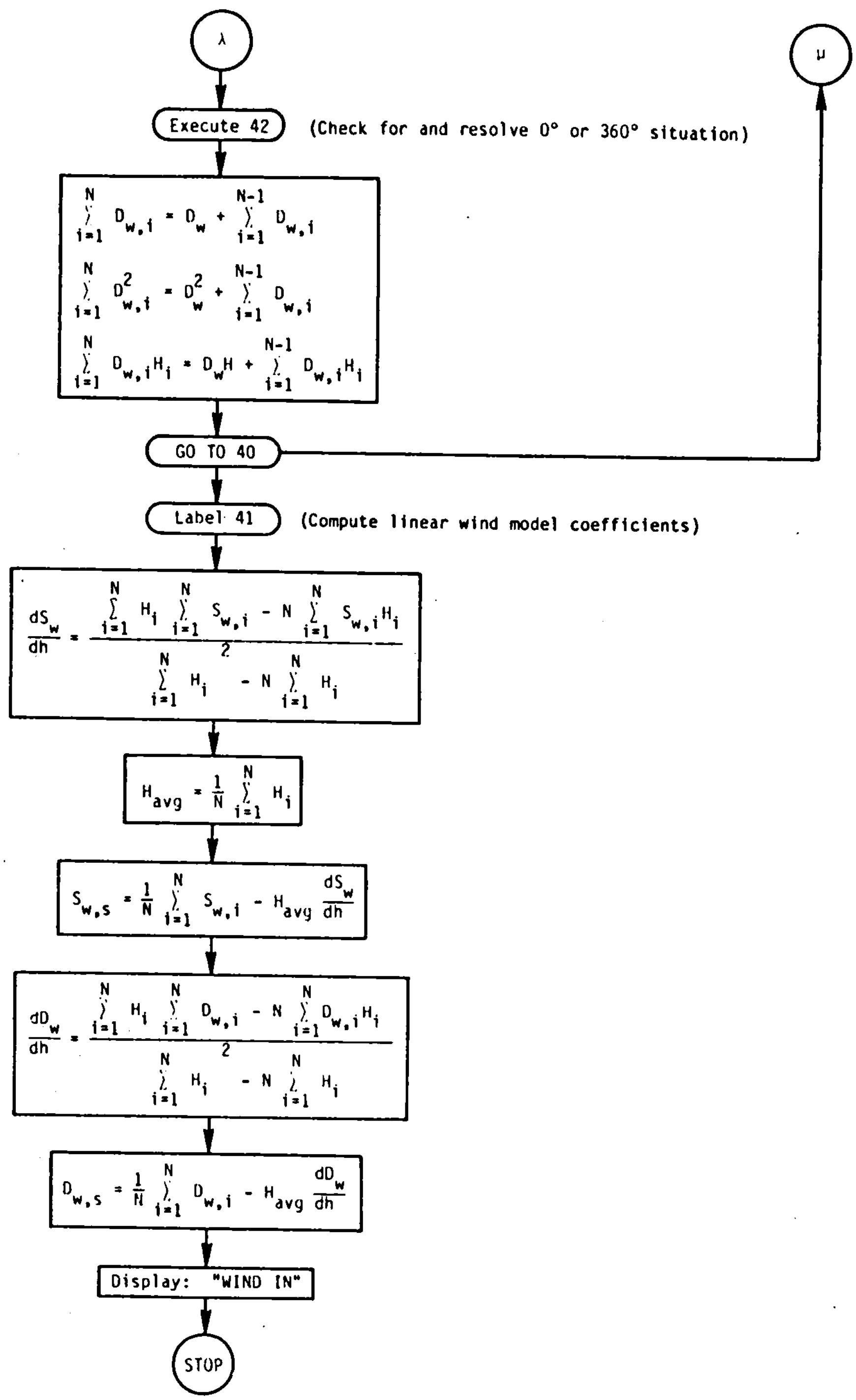


Label 37
(X_{DME} is in segment #5)
$Y_3 = \frac{H_c - H_{X0} - \Delta t_5 K_{\dot{h},X0} K_{gw} T_o'/T_o}{\Delta t_5^2}$
$\Delta t = \frac{3600\ \Delta \ell}{GS_5}$
$H = Y_3\ \Delta t^2 + \frac{K_{\dot{h},X0} K_{gw}}{\frac{T_o'}{T_o}}\ \Delta t + H_{X0}$
Label 14
(Display altitude)
Display: "H = H"
GO TO 39

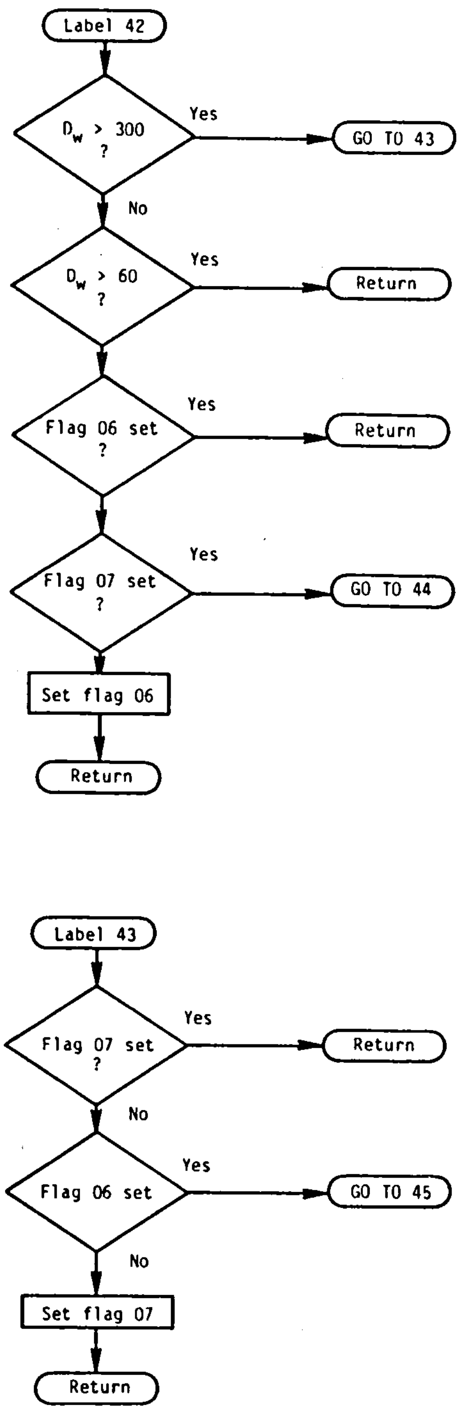
APPENDIX A


Label a
(Beginning of the wind input routine)
N = 0
$\sum_{i=1}^{N} H_i = \sum_{i=1}^{N} H_i^2 = 0$
$\sum_{i=1}^{N} D_{w,i} = \sum_{i=1}^{N} D_{w,i}^2 = 0$
$\sum_{i=1}^{N} S_{w,i} = \sum_{i=1}^{N} S_{w,i}^2 = 0$
$\sum_{i=1}^{N} D_{w,i}H_i = \sum_{i=1}^{N} S_{w,i}H_i = 0$
(Initialize parameters)
Clear flags 07, 08
Label 40
Display: "H = ? FT"
(Input H)
H < 0 ?
Yes
GO TO 41
No
Display: "DIR . SPD?"
(Input D_w,S_w)
N = N + 1
$\sum_{i=1}^{N} H_i = H + \sum_{i=1}^{N-1} H_i$
$\sum_{i=1}^{N} H_i^2 = H^2 + \sum_{i=1}^{N-1} H_i^2$
$\sum_{i=1}^{N} S_{w,i} = S_w + \sum_{i=1}^{N-1} S_{w,i}$
$\sum_{i=1}^{N} S_{w,i}^2 = S_w^2 + \sum_{i=1}^{N-1} S_{w,i}^2$
$\sum_{i=1}^{N} S_{w,i}H_i = S_wH + \sum_{i=1}^{N-1} S_{w,i}H_i$
(Compute linear regression parameters)

APPENDIX A

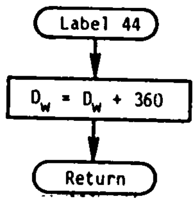

λ
μ
Execute 42
(Check for and resolve 0° or 360° situation)
$\sum_{i=1}^{N} D_{w,i} = D_w + \sum_{i=1}^{N-1} D_{w,i}$
$\sum_{i=1}^{N} D^2_{w,i} = D^2_w + \sum_{i=1}^{N-1} D_{w,i}$
$\sum_{i=1}^{N} D_{w,i}H_i = D_wH + \sum_{i=1}^{N-1} D_{w,i}H_i$
GO TO 40
Label 41
(Compute linear wind model coefficients)
$\frac{dS_w}{dh} = \frac{\sum_{i=1}^{N} H_i \sum_{i=1}^{N} S_{w,i} - N \sum_{i=1}^{N} S_{w,i}H_i}{\left(\sum_{i=1}^{N} H_i\right)^2 - N \sum_{i=1}^{N} H_i}$
$H_{avg} = \frac{1}{N} \sum_{i=1}^{N} H_i$
$S_{w,s} = \frac{1}{N} \sum_{i=1}^{N} S_{w,i} - H_{avg} \frac{dS_w}{dh}$
$\frac{dD_w}{dh} = \frac{\sum_{i=1}^{N} H_i \sum_{i=1}^{N} D_{w,i} - N \sum_{i=1}^{N} D_{w,i}H_i}{\left(\sum_{i=1}^{N} H_i\right)^2 - N \sum_{i=1}^{N} H_i}$
$D_{w,s} = \frac{1}{N} \sum_{i=1}^{N} D_{w,i} - H_{avg} \frac{dD_w}{dh}$
Display: "WIND IN"
STOP

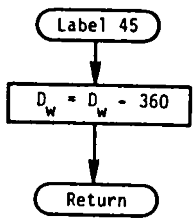
APPENDIX A



Label 42
D_w > 300 ?
Yes
GO TO 43
No
D_w > 60 ?
Yes
Return
Flag 06 set ?
Yes
Return
Flag 07 set ?
Yes
GO TO 44
Set flag 06
Return
Label 43
Flag 07 set ?
Yes
Return
No
Flag 06 set
Yes
GO TO 45
No
Set flag 07
Return

APPENDIX A





APPENDIX B

Program Listing and Storage Register Location of Descent Algorithm Variables (Numerical Values for DC10-10 Model)

Input Variables

17	M_c
18	H_c
08	M_d
10	IAS_d
21	t_{MF}
22	t_{EF}
23	GW
19	OAT
07	H_{MF}
26	IAS_{MF}
27	MF_{DME}
28	EF_{DME}
29	CRS
24	VAR

Computed Variables

00–04	Temporary
05	$\sum_{j=1}^{i} \Delta t_j$, i=1,7
06	$\sum_{j=1}^{i} \Delta \ell_j$, i=1,7
09	$\frac{T_o'}{T_o}$
11	H_{XO}
12	H_{bod}
13	K_{gw}
14	$t_{E,initial}$
15	t_E
16	$\Delta t_{initial}$
20	T_{trop}
25	Δt_{req}
55	$\Delta \ell_1$
56	$\Delta \ell_2$
57	$\Delta \ell_3$
58	$\Delta \ell_4$
59	$\Delta \ell_5$
60	Δt_5
61	GS_5
62	$K_{\dot{h},XO}$
63	$IAS_{d,i}$
64	GSc
65	$\dot{h}_g$
66	Δt_7

Wind Model Coefficients

50	$\frac{dD_w}{dH}$
51	$D_{w,s}$
52	$\frac{dS_w}{dH}$
53	$S_{w,s}$
54	$W_{H,c}$

Airplane Model Coefficients

30	$IAS_{d,min}$	(220)
31	$IAS_{d,max}$	(350)
32	A_M	(25 750)
33	B_M	(22 167)
34	C_M	(-1.85)
35	A_I	(-3.07783)

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```
160 *
161 RCL 19
162 273.15
163 +
164 +
165 STO 20
166 216.65
167 -
168 288.15
169 +
170 LASTX
171 /
172 STO 09
173 RCL 23
174 RCL 39
175 *
176 RCL 40
177 +
178 STO 13
179 RCL 18
180 XEQ 05
181 STO 01
182 RCL 07
183 XEQ 05
184 RCL 01
185 -
186 RCL 18
187 RCL 07
188 -
189 /
190 RCL 41
191 *
192 STO 65
193 FS? 00
194 GTO 04
195◆LBL 23
196 RCL 17
197 STO 03
198 RCL 26
199 280
200 X>Y?
201 GTO 25
202 X<>Y
203◆LBL 25
204 STO 63
205 STO 10
206 XEQ 04
207 LASTX
208 STO 14
209 RCL 05
210 STO 16
211 X<>Y
212 X<0?
213 GTO 15
214 RCL 31
215 STO 10
216 XEQ 04
217 LASTX
218 X<0?
219 GTO 12
220 GTO I
221◆LBL 15
222 RCL 30
223 RCL 26
224 X<Y?
225 X<>Y
226 STO 10
227 XEQ 04
228 LASTX
229 X<0?
230 GTO I
231◆LBL 12
232 RCL 14
233 RCL 16
234 RCL 05
235 -
236 /
237 STO 00
238 RCL 10
239 RCL 63
240 -
241 *
242 ENTER↑
243 ENTER↑
244 RCL 14
245 /
246 5
247 *
248 RCL 00
249 180
250 *
251 SIN
252 *
253 -
254 RCL 63
255 +
256 STO 10
257 XEQ 04
258 GTO 12
259◆LBL 04
260 0
261 STO 05
262 STO 06
263 RCL 10
264 RCL 26
265 X>Y?
266 STO 10
267 RCL 10
268 RCL 08
269 /
270 RCL 47
271 *
272 RCL 48
273 +
274 SQRT
275 CHS
276 RCL 49
277 +
278 RCL 09
279 /
280 STO 11
281 RCL 44
282 RCL 10
283 X<=Y?
284 GTO 07
285 RCL 07
286 RCL 43
287 X<=Y?
288 GTO 07
289 STO 12
290 RCL 07
291 RCL 09
292 *
293 STO 08
294 RCL 26
295 STO 01
296 RCL 44
297 STO 02
298 XEQ 27
299 RCL 01
300 STO 05
301 RCL 02
302 STO 06
303 STO 55
304 RCL 07
305 RCL 09
306 *
307 RCL 37
308 *
309 RCL 42
310 RCL 65
311 +
312 RCL 13
313 *
314 +
315 RCL 43
316 RCL 09
317 *
318 RCL 37
```

```
319 *
320 RCL 42
321 RCL 65
322 +
323 RCL 13
324 *
325 +
326 /
327 LN
328 RCL 37
329 /
330 STO 01
331 ST+ 05
332 RCL 07
333 RCL 43
334 +
335 2
336 /
337 RCL 09
338 *
339 STO 02
340 RCL 44
341 X<>Y
342 XEQ 03
343 RCL 02
344 XEQ 05
345 +
346 RCL 01
347 *
348 RCL 45
349 /
350 ST+ 06
351 STO 56
352 RCL 44
353 STO 01
354 GTO 08
355◆LBL 07
356 RCL 07
357 STO 12
358 0
359 STO 55
360 STO 56
361 RCL 26
362 STO 01
363◆LBL 08
364 CF 05
365 RCL 11
366 RCL 18
367 X>Y?
368 GTO 09
369 STO 11
370 SF 05
371◆LBL 09
372 RCL 11
373 RCL 12
374 X>Y?
375 GTO 10
376 RCL 09
377 *
378 STO 00
379 RCL 10
380 STO 02
381 XEQ 27
382 RCL 01
383 ST+ 05
384 RCL 02
385 STO 57
386 ST+ 06
387 RCL 10
388 RCL 36
389 *
390 E↑X
391 RCL 35
392 *
393 RCL 65
394 +
395 RCL 13
396 *
397 STO 01
398 RCL 12
399 RCL 09
400 *
401 RCL 37
402 *
403 +
404 RCL 11
405 RCL 09
406 *
407 RCL 37
408 *
409 RCL 01
410 +
411 /
412 LN
413 RCL 37
414 /
415 ST+ 05
416 STO 01
417 RCL 11
418 RCL 12
419 +
420 2
421 /
422 RCL 09
423 *
424 STO 02
425 RCL 10
426 X<>Y
427 XEQ 03
428 RCL 02
429 XEQ 05
430 +
431 RCL 01
432 *
433 RCL 45
434 /
435 ST+ 06
436 STO 58
437 GTO 11
438◆LBL 10
439 0
440 STO 57
441 STO 58
442 RCL 07
443 STO 11
444◆LBL 11
445 FS? 05
446 GTO 21
447 RCL 08
448 RCL 32
449 *
450 RCL 33
451 +
452 STO 01
453 RCL 18
454 RCL 09
455 *
456 -
457 CHS
458 RCL 34
459 /
460 SQRT
461 STO 02
462 RCL 11
463 RCL 09
464 *
465 RCL 01
466 -
467 RCL 34
468 /
469 SQRT
470 RCL 65
471 -
472 STO 62
473 RCL 02
474 RCL 65
475 -
476 /
477 LN
```

```
478 RCL 65
479 *
480 CHS
481 RCL 62
482 -
483 RCL 65
484 -
485 RCL 02
486 +
487 2
488 *
489 RCL 34
490 *
491 RCL 13
492 /
493 ST+ 05
494 STO 60
495 STO 01
496 RCL 11
497 RCL 18
498 +
499 2
500 /
501 RCL 09
502 *
503 STO 04
504 RCL 08
505 X<>Y
506 XEQ 06
507 RCL 04
508 XEQ 05
509 +
510 STO 61
511 RCL 01
512 *
513 RCL 45
514 /
515 ST+ 06
516 STO 59
517 RCL 06
518 STO 01
519 GTO 22
520♦LBL 21
521 0
522 STO 59
523 RCL 10
524 STO 01
525♦LBL 22
526 RCL 17
527 STO 02
528 RCL 18
529 RCL 09
530 *
531 STO 00
532 XEQ 27
533 RCL 01
534 ST+ 05
535 RCL 02
536 ST+ 06
537 RCL 28
538 RCL 27
539 -
540 RCL 06
541 -
542 X<0?
543 XEQ 02
544 RCL 45
545 *
546 RCL 03
547 RCL 04
548 +
549 /
550 STO 66
551 ST+ 05
552 FS? 00
553 GTO 18
554 5
555 RCL 05
556 RCL 25
557 -
558 STO 15
559 ABS
560 X>Y?
561 RTN
562 GTO J
563♦LBL 18
564 RCL 05
565 STO 25
566 RCL 45
567 /
568 HMS
569 RCL 22
570 HMS+
571 STO 21
572 GTO J
573♦LBL I
574 FIX 4
575 RCL 15
576 RCL 45
577 /
578 HMS
579 X<0?
580 GTO 26
581 "LATE "
582 ARCL X
583 PROMPT
584♦LBL 26
585 CHS
586 "HOLD "
587 ARCL X
588 PROMPT
589♦LBL J
590 RCL 27
591 RCL 06
592 +
593 FIX 1
594 "IDL DME "
595 ARCL X
596 PROMPT
597♦LBL J
598 RCL 66
599 RCL 45
600 /
601 HMS
602 RCL 22
603 HMS+
604 FIX 4
605 "IDL TM "
606 ARCL X
607 PROMPT
608♦LBL 27
609 RCL 01
610 XEQ 13
611 STO 01
612 RCL 02
613 XEQ 13
614 STO 02
615 STO 03
616 ST- 01
617 RCL 01
618 2
619 /
620 ST+ 02
621 RCL 01
622 RCL 38
623 /
624 X<0?
625 CHS
626 STO 01
627 RCL 00
628 XEQ 05
629 STO 04
630 RCL 02
631 +
632 *
633 RCL 45
634 /
635 STO 02
636 RTN
```

```
637♦LBL 05
638 STO 04
639 RCL 52
640 *
641 RCL 53
642 +
643 RCL 04
644 RCL 50
645 *
646 RCL 51
647 +
648 RCL 29
649 -
650 RCL 24
651 +
652 COS
653 *
654 CHS
655 RCL 04
656 RCL 54
657 *
658 RCL 18
659 /
660 -
661 RTN
662♦LBL 29
663 RCL 00
664♦LBL 03
665 -12 E-06
666 *
667 1
668 +
669 /
670 RTN
671♦LBL 13
672 1
673 X<>Y
674 X>Y?
675 GTO 29
676 RCL 00
677♦LBL 06
678 36152
679 -
680 RCL 46
681 *
682 RCL 20
683 +
684 RCL 20
685 X<=Y?
686 X<>Y
687 SQRT
688 RCL Z
689 *
690 38.96
691 *
692 RTN
693♦LBL 02
694 CHS
695 FC? 00
696 RTN
697 FIX 1
698 RCL 28
699 +
700 STO 00
701 RCL 05
702 RCL 45
703 /
704 HMS
705 RCL 22
706 HMS+
707 STO 21
708 RCL 00
709 "EF < "
710 ARCL X
711 PROMPT
712♦LBL 39
713 PROMPT
714♦LBL H
715 STO 00
716 RCL 27
717 X<>Y
718 X<Y?
719 GTO 46
720 RCL 27
721 STO 02
722 55
723 STO 03
724 1
725 STO 04
726♦LBL 30
727 RCL IND 03
728 ST+ 02
729 RCL 02
730 RCL 00
731 X<=Y?
732 GTO 32
733 1
734 ST+ 04
735 5
736 RCL 04
737 X>Y?
738 GTO 31
739 1
740 ST+ 03
741 GTO 30
742♦LBL 46
743 RCL 07
744 RCL 09
745 *
746 STO 03
747 RCL 26
748 X<>Y
749 XEQ 03
750 RCL 03
751 XEQ 05
752 +
753 RCL 27
754 RCL 00
755 -
756 /
757 1/X
758 RCL 45
759 *
760 RCL 37
761 *
762 RCL 13
763 *
764 E↑X
765 STO 01
766 RCL 26
767 RCL 36
768 *
769 E↑X
770 RCL 35
771 *
772 STO Y
773 RCL 37
774 RCL 03
775 *
776 +
777 RCL 01
778 *
779 -
780 RCL 37
781 /
782 RCL 09
783 /
784 CHS
785 GTO 14
786♦LBL 31
787 RCL 18
788 GTO 14
789♦LBL 32
790 RCL 00
791 RCL 02
792 -
793 RCL IND 03
794 +
795 STO 01
```

```
796 32
797 ST+ 04
798 GTO IND 04
799♦LBL 33
800 RCL 07
801 GTO 14
802♦LBL 34
803 RCL 43
804 RCL 07
805 -
806 RCL 01
807 *
808 RCL IND 03
809 /
810 RCL 07
811 +
812 GTO 14
813♦LBL 35
814 RCL 12
815 GTO 14
816♦LBL 36
817 RCL 11
818 RCL 12
819 -
820 RCL 01
821 *
822 RCL IND 63
823 /
824 RCL 12
825 +
826 GTO 14
827♦LBL 37
828 RCL 62
829 RCL 13
830 *
831 RCL 09
832 /
833 RCL 60
834 *
835 RCL 11
836 +
837 RCL 18
838 -
839 RCL 60
840 X↑2
841 /
842 CHS
843 STO 00
844 RCL 45
845 RCL 01
846 *
847 RCL 61
848 /
849 STO 01
850 X↑2
851 RCL 00
852 *
853 RCL 62
854 RCL 13
855 *
856 RCL 09
857 /
858 RCL 01
859 *
860 +
861 RCL 11
862 +
863♦LBL 14
864 FIX 0
865 "H = "
866 ARCL X
867 GTO 39
868♦LBL a
869 ΣREG 01
870 CLΣ
871 ΣREG 11
872 CLΣ
873 CF 07
874 CF 06
875♦LBL 40
876 "H=? FT"
877 PROMPT
878 X<0?
879 GTO 41
880 STO 00
881 "DIR . SPD ?"
882 PROMPT
883 STO 50
884 FRC
885 1000
886 *
887 RCL 00
888 X<>Y
889 Σ+
890 RCL 11
891 STO 01
892 RCL 12
893 STO 02
894 RCL 15
895 STO 03
896 RCL 00
897 LASTX
898 Σ-
899 RCL 04
900 STO 11
901 RCL 05
902 STO 12
903 RCL 06
904 STO 15
905 RCL 50
906 INT
907 XEQ 42
908 RCL 00
909 X<>Y
910 Σ+
911 RCL 11
912 STO 04
913 RCL 12
914 STO 05
915 RCL 15
916 STO 06
917 RCL 01
918 STO 11
919 RCL 02
920 STO 12
921 RCL 03
922 STO 15
923 GTO 40
924♦LBL 41
925 RCL 13
926 RCL 01
927 *
928 RCL 16
929 X=0?
930 XEQ a
931 /
932 RCL 03
933 -
934 RCL 13
935 X↑2
936 RCL 16
937 /
938 RCL 14
939 -
940 STO 11
941 /
942 STO 52
943 RCL 13
944 RCL 16
945 /
946 STO 12
947 *
948 CHS
949 RCL 01
950 RCL 16
951 /
952 +
953 STO 53
954 RCL 13
```

```
955 RCL 04
956 *
957 RCL 16
958 /
959 RCL 06
960 -
961 RCL 11
962 /
963 STO 50
964 RCL 12
965 *
966 CHS
967 RCL 04
968 RCL 16
969 /
970 +
971 STO 51
972 0
973 STO 54
974 "WIND IN"
975 PROMPT
976♦LBL 42
977 300
978 X<>Y
979 X>Y?
980 GTO 43
981 60
982 X<>Y
983 X>Y?
984 RTN
985 FS? 06
986 RTN
987 FS? 07
988 GTO 44
989 SF 06
990 RTN
991♦LBL 43
992 FS? 07
993 RTN
994 FS? 06
995 GTO 45
996 SF 07
997 RTN
998♦LBL 44
999 360
1000 +
1001 RTN
1002♦LBL 45
1003 360
1004 -
1005 RTN
1006 .END.
```

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-86275		

4. Title and Subtitle	5. Report Date
User's Manual for a Fuel Conservative Descent Planning Algorithm Implemented on a Small Programmable Calculator	August 1984
	6. Performing Organization Code 505-45-33-03
7. Author(s) Dan D. Vicroy	8. Performing Organization Report No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665	10. Work Unit No.
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546	13. Type of Report and Period Covered Technical Memorandum
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A simplified flight-management descent algorithm has been developed and programmed on a small programmable calculator. It was designed to aid the pilot in planning and executing a fuel-conservative descent to arrive at a metering fix at a time designated by the air traffic control system. The algorithm may also be used for planning fuel-conservative descents when time is not a consideration. The descent path was calculated for a constant Mach/airspeed schedule from linear approximations of airplane performance with considerations given for gross weight, wind, and nonstandard temperature effects. This report contains an explanation and examples of how the algorithm is used, as well as a detailed flow chart and listing of the algorithm.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
fuel conservation flight management systems airplanes airborne computer	Unclassified - Unlimited Subject Category 06

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	56	A04

N-305

For sale by the National Technical Information Service, Springfield, Virginia 22161