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EFFECTS OF AIRCRAFT AND FLIGHT PARAMETERS ON ENERGY-EFFICIENT PROFILE DESCENTS IN TIME-BASED METERED TRAFFIC

by

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stops and Segment 2 begins. Still maintaining idle thrust and a clean configuration, the aircraft descends at constant CAS_d until the metering-fix altitude is reached. Segment 1 is a deceleration at constant altitude (h_{mf}) from CAS_d to the designated metering-fix calibrated airspeed (CAS_{mf}).

Section 4.1.1 in NASA CR-172338 describes the influence of the following parameters on the time, Δt_{TOT}, to fly from the entry fix to the metering fix: metering fix altitude (h_{mf}), descent Mach number (M_d), descent calibrated airspeed (CAS_d), cruise altitude (h_c), cruise Mach number (M_c), ground distance (ΔS_{TOT}), and aircraft weight (W). A nominal case for the B-737 was chosen and the separate effects of these parameters on Δt_{TOT} were calculated by changing each parameter by a prescribed amount while holding all the other parameters fixed at the values for the nominal case. A significant feature of the method used in those calculations was that the ground distance for Segment 4 (the constant speed segment) was adjusted in each case so that the aircraft would always arrive at the metering-fix position at the completion of the five segments of the profile descent. The aircraft would have the same airspeed and altitude as the nominal case, but the off-nominal cases would not arrive at the time predetermined for the nominal case. Thus, for the off-nominal cases, the uncertainty or error in each parameter investigated was known before the profile descent flight path was calculated so that the ground distance in Segment 4 could be adjusted to allow the aircraft to arrive at the metering fix position at the completion of the five segments of the profile descent.

NEW ANALYSIS

As a supplement to the information in NASA CR-172338, this addendum gives additional results on the influence of parameters on profile descents. In the present results additional parameters are considered and the method used to calculate the off-nominal cases was changed so that the ground distance in Segment 4 is not adjusted to allow the aircraft to arrive at the metering fix at the completion of the five segments of the profile descent. Instead, the time calculated for Segment 4 (Δt_4) in the nominal case is used for all off-nominal cases. This means that the aircraft may arrive at the metering-fix ground position before the profile descent is complete (early arrival), or it may complete the profile descent before the metering fix is reached (late arrival). The method used to calculate the time (Δt_i) and distance (ΔS_i) for each segment of the profile descent is the same as that described in NASA CR-172338 except for Segment 4 in the off-nominal cases. For the off-nominal cases, the time Δt_4 is the same as that for the nominal case, and since the airspeed and wind are constant in Segment 4, the distance ΔS_4 is obtained from eq. (27) in NASA CR-172338 as

$$\Delta S_4 = \Delta t_4 \, (V_4 + V_W \cos(\theta - \psi_W))$$

For late arrivals, the aircraft is flown at the prescribed metering fix altitude (h_{mf}) and airspeed (CAS_{mf}) from the position of completion of the profile descent to the metering fix ground position. This additional segment requires engine thrust above idle thrust in order to maintain constant altitude and airspeed. Consequently, the fuel flow rate is higher than that for idle thrust. When arriving at the metering fix the aircraft has the correct airspeed and altitude, but the time required is longer than that for the nominal case. The distance error is defined as the ground distance between the position where the profile descent was completed and the metering fix.

For early arrivals, the aircraft reaches the metering fix ground position before all of the profile descent segments have been completed. If the aircraft is still decelerating in Segment 1 when it arrives at the metering fix, it will have an error in its airspeed and time of arrival but its altitude is correct. If the aircraft is still in Segment 2 or 3 when it arrives at the metering fix, it will have errors in airspeed, altitude, and time of arrival. The distance error for early arrivals is defined as the ground distance from the metering fix to the position where the five segments of the profile descent would have been completed if the profile descent were continued beyond the metering fix position.

RESULTS AND DISCUSSION

The nominal case used here is the same B-737 profile descent used in Section 4.1.1 of NASA CR-172338. The prescribed parameters are:

W = 87,500 lb
h_c = 35,000 ft
M_c = 0.78
M_d = 0.67
CAS_d = 265 knots
h_{mf} = 19,500 ft
CAS_{mf} = 250 knots
ΔS_{TOT} = 75 n.mi
Δt_{REQ} = 699.54 sec
Standard day and no wind

Although the values of CAS_d and Δt_{REQ} differ slightly from those used to calculate Table 4-3 in NASA CR-172338, the values actually used for the nominal case in Section 4.1.1 were the same as those listed above. The calculated time and distance for each segment of the nominal case are:

	SEGMENT					
	1	2	3	4	5	TOTAL
ΔS_i(n.mi)	1.465	24.461	21.011	21.343	6.719	75.00
Δt_i(sec)	15.38	234.52	192.66	198.87	58.11	699.54

Metering fix crossing errors in ground distance, time, altitude, and calibrated airspeed have been calculated for off-nominal cases due to errors in the following parameters:

PARAMETER	ERROR RANGE
Weight, W	$\pm$ 40,000 lb
Cruise Altitude, h_c	$\pm$ 1,000 ft
Cruise Mach number, M_c	$\pm$ 0.08
Descent Mach number, M_d	$\pm$ 0.02
Descent Calibrated Airspeed, CAS_d	$\pm$ 10 knots
Wind Speed, V_W	$\pm$ 20 knots
Wind Speed Gradient, dV_W/dh	$\pm$ 0.008 knots/ft
Atmospheric Temperature Bias	$\pm$ 20°F

The wind-speed used in the wind-speed gradient cases was determined from the requirement that the average wind-speed between the cruise and metering fix altitudes was zero. Each off-nominal profile descent was calculated using the same input parameters as the nominal case, except for the specific off-nominal parameter considered. The results for the metering fix crossing errors due to errors in the eight parameters listed above are plotted in Figures A-1 through A-8. These figures show the altitude error, airspeed error, time error, and distance error when the aircraft crosses the metering fix ground position. Note that the distance error is the distance between the metering fix and the ground position when all segments of the profile descent are complete.

Table A-1 lists metering fix crossing errors in time, distance, and airspeed due to specfic variations in the eight parameters considered. An error in descent Mach number of only ±0.01 would produce a time error of ±6 sec at the metering fix, whereas an error of +5,000 lb in weight would cause only an error of +0.64 sec in time (a -5,000 lb weight error would cause a time error of -1.39 sec). Without wind and atmospheric temperature errors, the combined errors of the other 5 parameters could cause time errors between -11.20 sec and +9.97 sec for a nominal time of 700 sec, distance errors from -3.33 n.mi. to 2.73 n.mi. for a nominal value of 75 n.mi., and airspeed errors up to 23.63 knots for the nominal 250 knots at the metering fix. As expected, wind speed has a significant influence on the time. A variation of ±5 knots produced time errors from -10.14 sec to +10.65 sec. Wind-speed gradient and atmoshperic temperature errors produced much smaller time errors. Table A-1 shows that a combination of all the errors considered could produce errors in time from -27.78 sec to 26.78 sec, distance errors from -4.85 n.mi. to 4.25 n.mi., and airspeed errors up to 39.19 knots.

Table A-2 shows the change required in each parameter, separately, to produce an error of ±1 sec in the metering fix crossing time. In addition to the eight parameters considered previously, the effects of metering fix altitude and distance from entry fix to metering fix are shown also. Errors in descent Mach number from -0.0017 to 0.0018 can produce time errors of ±1 sec, and wind speed errors from -0.469 knots to 0.493 knots can produce errors of ±1 sec in time. On the other hand, a change of -3,603 lb to +7,829 lb in weight is required to change the time ±1 sec. In addition, Figure A-1 shows that a weight error of -20,000 lb produces a time error of -7 sec and an error of +20,000 lb causes only 1.6 sec error in time.

CONCLUSIONS

For a nominal profile descent of a B-737, it was found that errors in descent Mach number and wind speed produced large errors in the time required to cross the metering fix. Errors in weight were found to cause relatively smaller errors in time. However, these conclusions could change significantly for nominal profile descents different from the one considered here.

TABLE A-1

ERRORS IN CROSSING METERING FIX DUE TO VARIATION IN PARAMETERS

PARAMETER	VARIATION	TIME ERROR (sec)	DISTANCE ERROR (n.mi.)	AIRSPEED ERROR (knots)
Cruise Alt. (35,000 ft.)	250 ft -250 ft	+0.70 -0.84	-0.75 +0.75	7.65 0
Cruise Mach No. (0.78)	+0.01 -0.01	+1.27 -1.47	-0.47 +0.55	4.80 0
Descent Mach No. (0.67)	+0.01 -0.01	+6.00 -5.98	+0.10 -1.14	0 1.50
Descent CAS (265 knots)	+2.5 kts -2.5 kts	+1.36 -1.52	+0.27 -0.28	0 +2.89
Weight (87,500 lbs)	+5000 lb -5000 lb	+0.64 -1.39	-0.69 +1.06	6.79 0
WORST CASE(without wind and temp)		+9.97 -11.20	+2.73 -3.33	+22.63 -0
Wind Speed (0 knots)	+5 knots -5 knots	10.65 -10.14	-0.97 +0.97	+9.79 -0
Wind Speed Gradient (0 knots/ft)	+5kts/10^3ft -5kts/10^3ft	2.52 -2.71	-0.24 +0.24	+2.62 0
Atmospheric Temp. Bias (59°F at S.L.)	+5°F -5°F	+3.64 -3.73	-0.31 +0.31	+3.15 0
WORST CASE(including wind and temp)		+26.78 -27.78	+4.25 -4.85	+39.19 0

NOTE: For the parameters above, no altitude errors were found.

TABLE A-2

CHANGE IN PARAMETERS TO CHANGE TIME ±ONE SEC.

PARAMETER	PARAMETER CHANGE REQUIRED TO CHANGE TIME	
	+ONE SEC.	-ONE SEC.
Cruise Alt.	-299	+358 ft
Cruise Mach No.	-0.0068	+0.0079
Descent Mach No.	-0.0017	+0.0018
Descent Calibrated Airspeed	-1.65kts	+1.84kts
Metering Fix Altitude	+765 ft	-1372 ft
Distance from Entry Fix to Metering Fix	+0.093 n.mi	-0.093 n.mi
Weight	-3603 lb	+7829 lb
Atmospheric Temperature Bias	-1.34°F	+1.37°F
Wind Speed	-0.469kts	+0.493kts
Wind-Speed Gradient	$-0.199 kts/10^3 ft$	$+0.185 kts/10^3 ft$

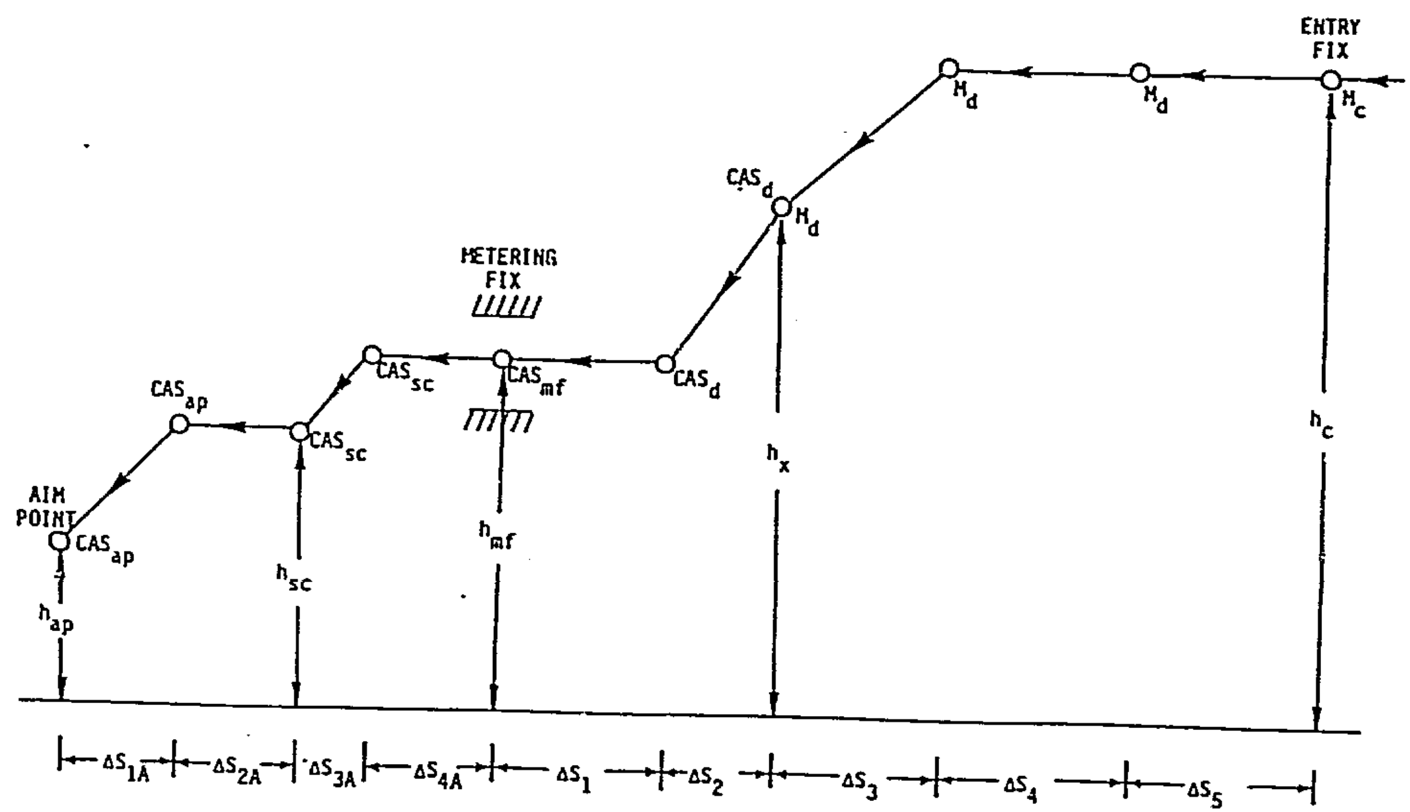

Figure 1-1. Geometry of flight-path segments.

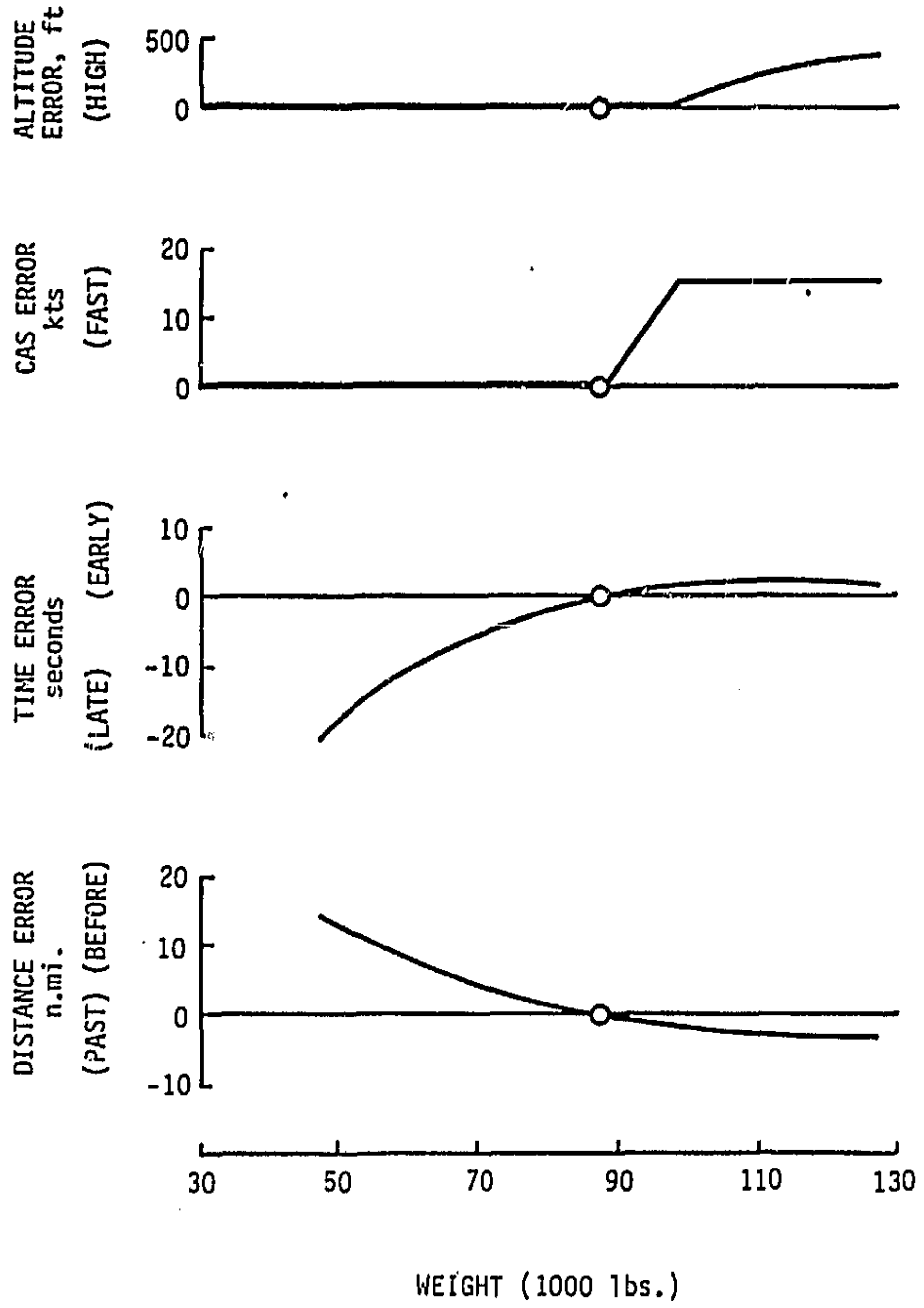

Figure A-1. Crossing Errors At Metering Fix Due To Weight Variation.

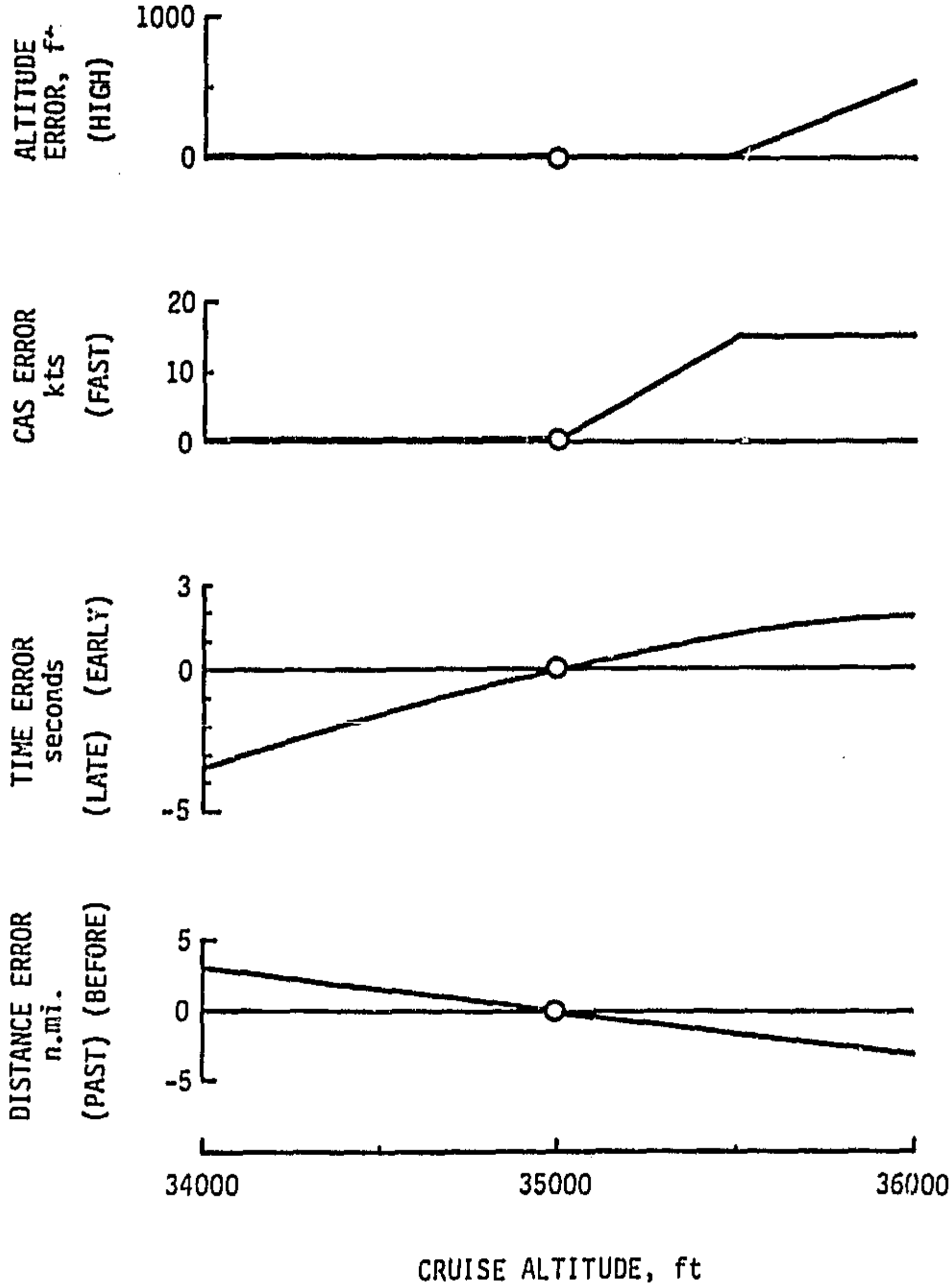

Figure A-2. Crossing Errors At Metering Fix Due To Cruise Altitude Variation.

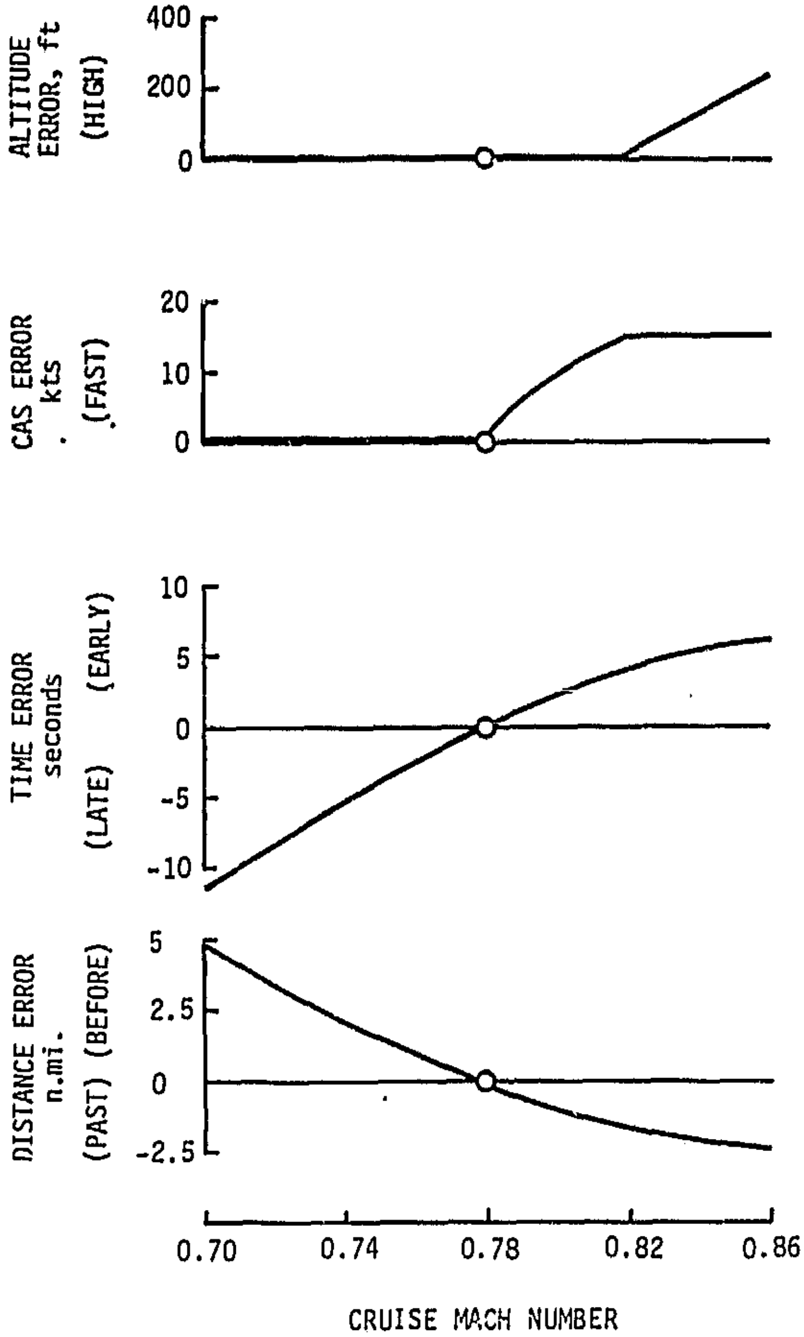

Figure A-3. Crossing Errors At Metering Fix Due To Cruise Mach Number Variation.

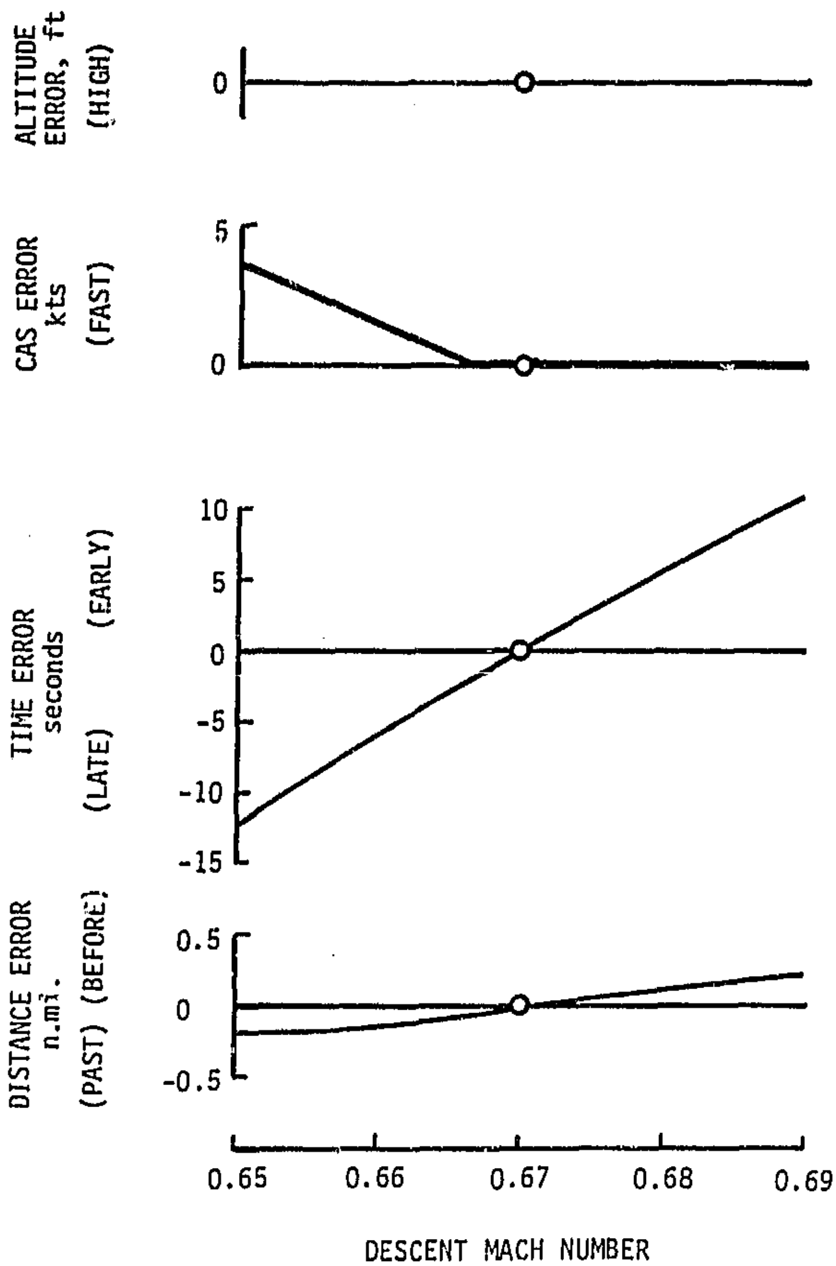

Figure A-4. Crossing Errors At Metering Fix Due To Descent Mach Number Variation.

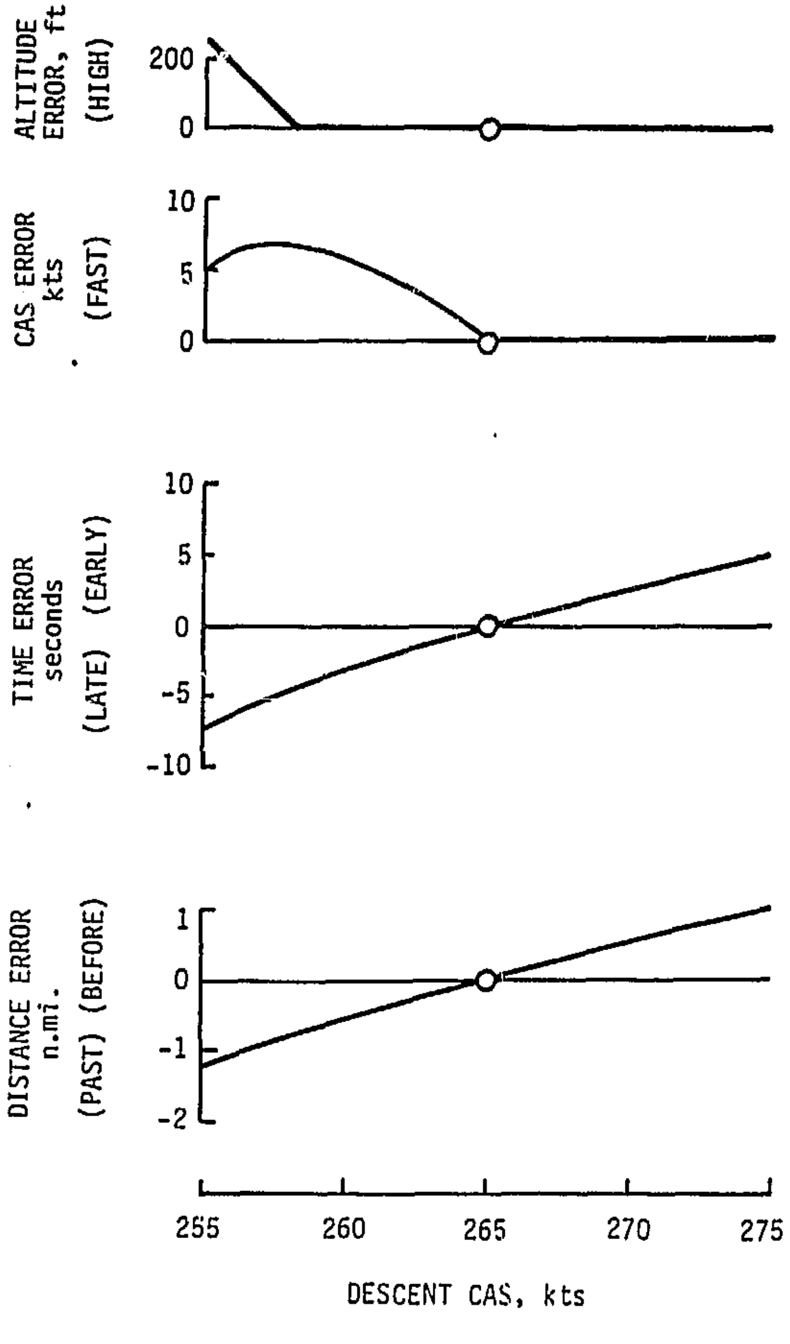

Figure A-5. Crossing Errors At Metering Fix Due To Descent Calibrated Airspeed Variation.

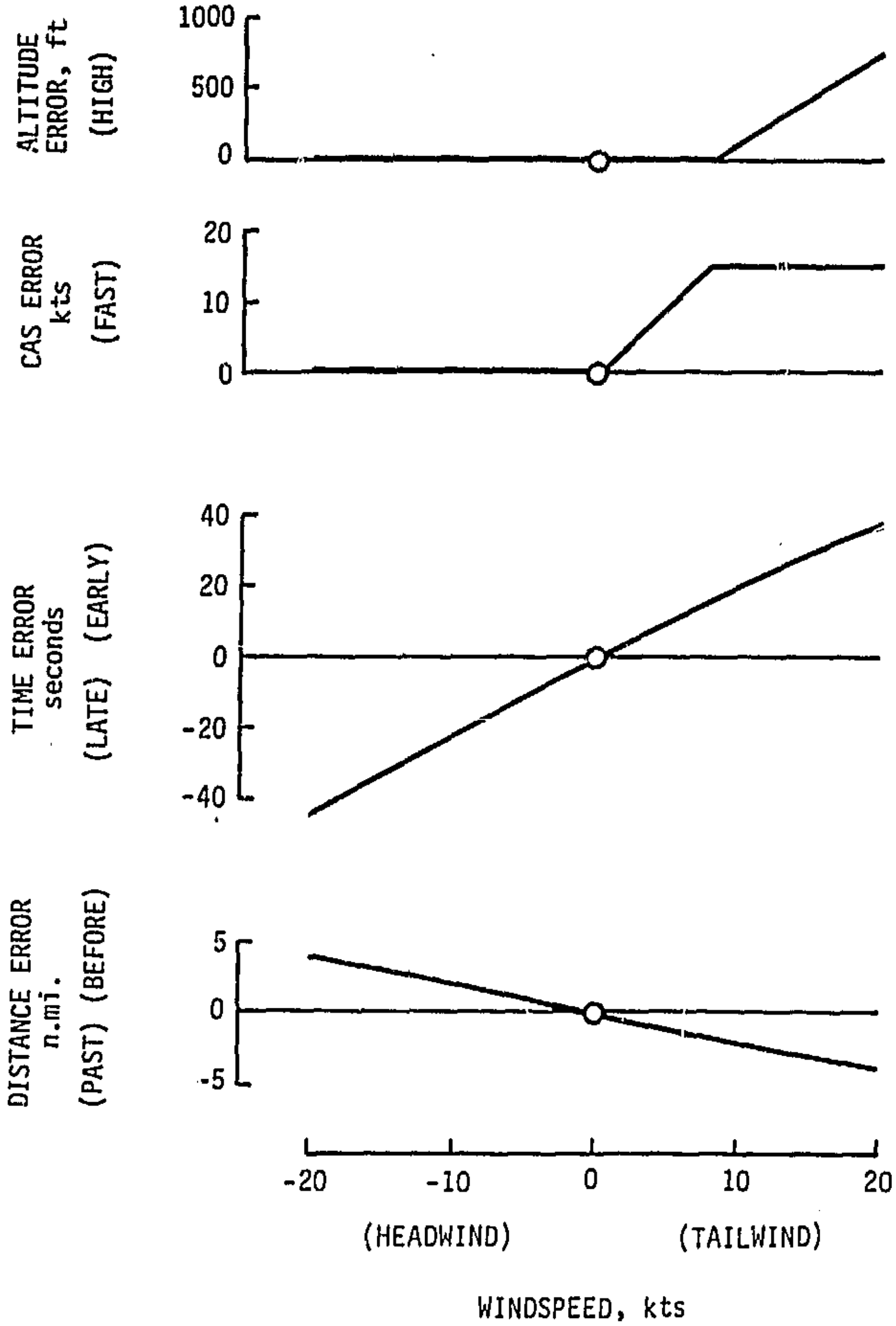

Figure A-6. Crossing Errors At Metering Fix Due To Wind Speed Variation.

SUMMARY

In NASA CR-172338 results were presented for the influence of several parameters on the time required to fly a nominal profile descent of a B-737 from an entry fix to a metering fix 75 n.mi. away. A significant feature of the method used in those calculations was that the ground distance for the constant speed segment was adjusted in each case so that the aircraft would always arrive at the metering-fix position at the completion of the five segments of the profile descent. This addendum gives the influence of eight parameters on the same nominal profile descent, but the method used for the off-nominal cases was changed. In the present results the ground distance in the constant speed segment is not adjusted as done previously. Instead, the time calculated for the constant speed segment in the nominal case is used for all off-nominal cases. This method allows the aircraft to arrive at the metering fix before (early arrival) or after (late arrival) the profile descent is complete. The results show that descent Mach number and wind speed have a large effect on the time error, whereas weight had a much smaller effect.

BACKGROUND

In the subject contractor report, NASA CR-172338, a computational algorithm is described for calculating the flight path information needed to fly from an entry fix through a profile descent to a metering fix and arrive there at a predetermined time, altitude, and airspeed. The five segments of the profile descent are illustrated in Figure 1-1 (repeated herein) as well as four additional segments for the flight path from the metering fix to the aim point. The segments are numbered in the reverse order from which they occur. Segment 5 starts at the entry fix with cruise altitude (h_c) and Mach number (M_c) and decelerates at constant altitude with idle thrust until the prescribed descent Mach number (M_d) is reached. Segment 4 is a constant speed and altitude path to the beginning of descent. In Segment 3 the aircraft descends with idle thrust and a clean (low drag) configuration at an attitude which maintains constant M_d. As the altitude decreases, the calibrated airspeed increases. When the calibrated airspeed reaches a prescribed value (CAS_d), Segment 3

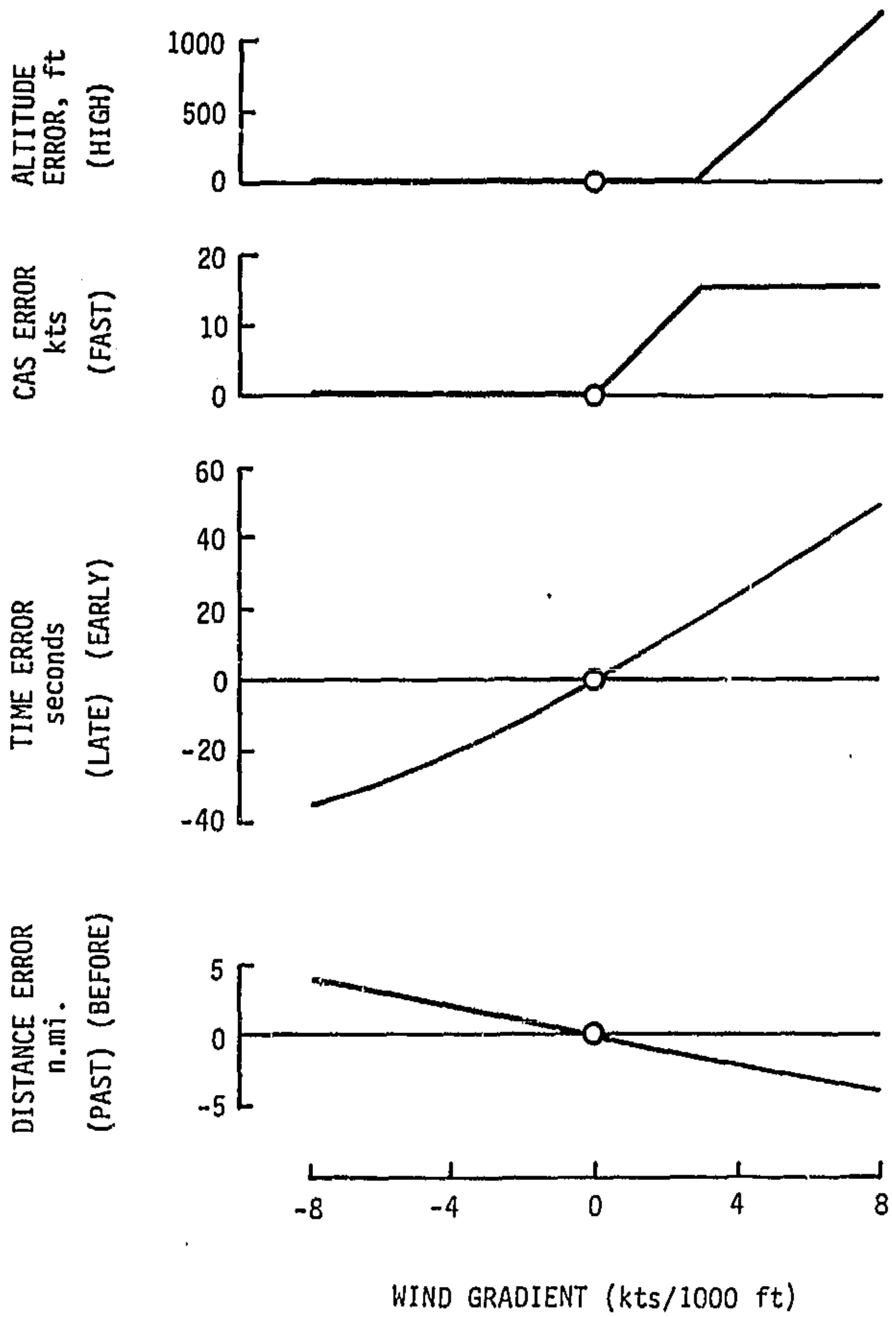

Figure A-7. Crossing Errors At Metering Fix Due To Wind Speed Gradient Variation.

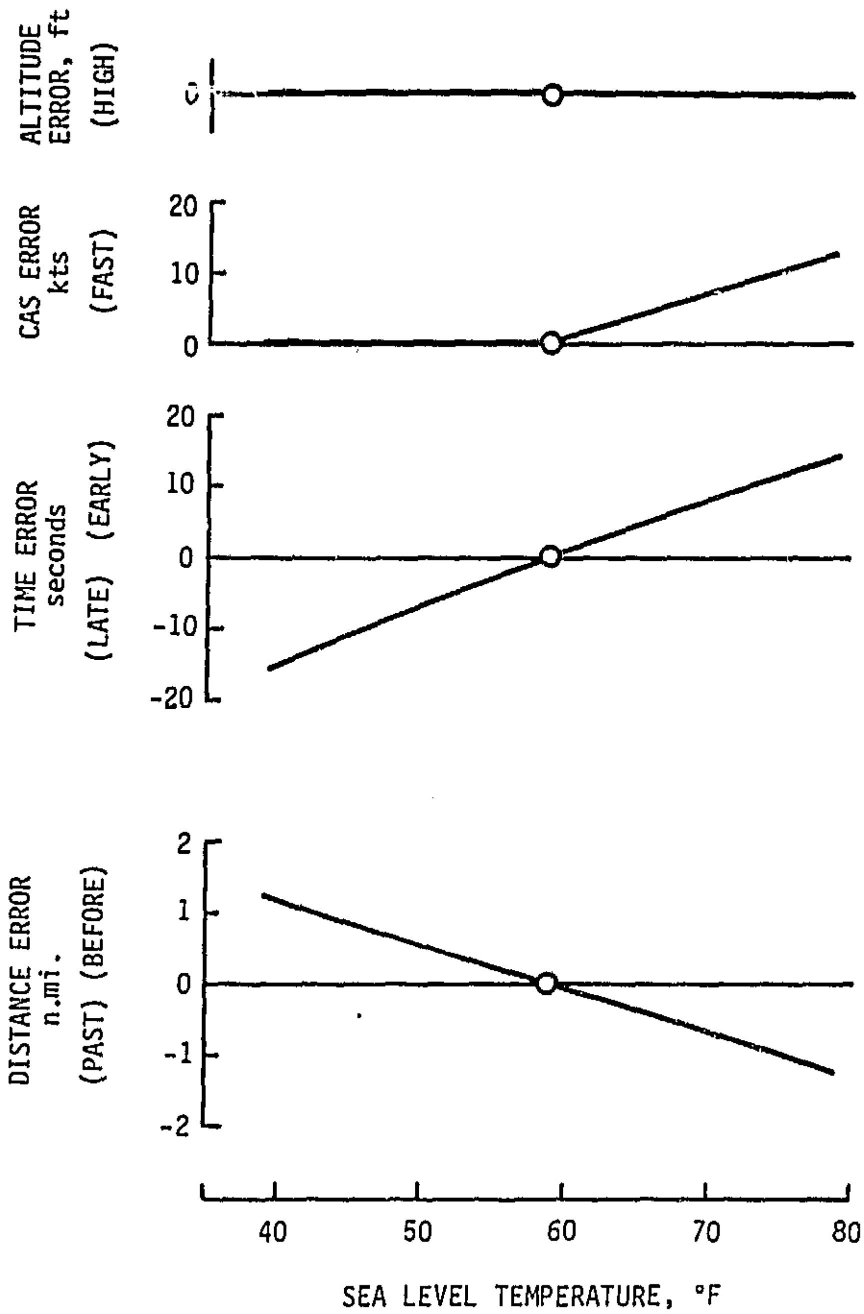

Figure A-8. Crossing Errors At Metering Fix Due To Temperature Bias Variation.

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16. Abstract

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