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FINAL REPORT

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(NASA-CR-168973) [COST AND FUEL CONSUMPTION PER NAUTICAL MILE FOR TWO ENGINE JET TRANSPORTS USING OPTIM AND TRAGEN] Final Report (Hampton Inst.) 280 p HC A13/MF A01 CSCL 01C G3/05

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Principal Investigator

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April 30, 1982

PREFACE

In reading the following report, the reader will constantly see reference to the flags of the computer program OPTIM. There were three versions of OPTIM used in this report, each using different numbers of flags. The first draft which allowed the generation of optimal profiles for medium range two engine intermediate range jet aircraft had 11 flags. The next version used was released May, 1980 and had 12 flags. The final version used in this report used 10 flags and was released in October 1981. The company responsible for these revisions that were used in this report is Analytical Mechanics Associates, Inc. of Mountain View, California. The pertinent users guide for each revision would be useful in studying this report.

The principal investigator for this report would like to thank Mrs. Kathy Samms and Mr. R. E. Shanks of the NASA Langley Research Center and Mr. Octavio Winter of Computer Sciences Corporation for their valuable assistance in this research.

During the time period beginning June 1, 1980 and ending April 30, 1982, the principal investigator has been utilizing the computer programs OPTIM and TRAGEN at the NASA Langley Research Center. The information gained from fast-time simulation of these programs applies to a medium range two engine jet transport with take off weight equal to 4.45×10^5N (10^5lb.) and minimum (dry) weight 3.56×10^5N (8×10^4lb.). The output of OPTIM indicates that for trip lengths of between 300 and 1500 N.Mi., there is an increasing ordering of the cost/N.Mi. for the following types of optimal profiles:

1. Direct operating cost (with no 250 KIAS limit below 3048m. (10^4ft.) above sea level).
2. Direct operating cost (250 KIAS limit imposed below 3048m. (10^4ft.) above sea level).
3. Direct operating cost (with both 250 KIAS limit below 3048m. and a fixed cruise altitude of 1.04×10^4m. (34,000 ft.)).
4. Fuel optimal (with no 250 KIAS limit below 3048m. (10^4ft.)).
5. Fuel optimal (250 KIAS limit below 3048m. (10^4ft.).

This ordering is illustrated in Figure 1.

There is also an ordering (shown in Figure 2) of Fuel consumption in lb./N.Mi. for the above types of optimal profiles:

1. Fuel optimal (no 250 KIAS limit below 3048m. (10^4ft.)).
2. Fuel optimal (250 KIAS limit below 3048m. (10^4ft.)).
3. Direct operating cost (DOC) optimal (250 KIAS limit below 3048m. (10^4ft.)).
4. DOC optimal (no 250 KIAS limit below 3048m. (10^4ft.))
5. DOC optimal (250 KIAS limit below 3048m. (10^4ft.) and fixed cruise altitude of 1.04 X 10^4m. (34,000 ft.)).

The fuel efficiency decreases as the above list is read.

The fixed cruise altitude of 1.04 X 10^4m. (34,000 ft.) was chosen since it represented an "average cruise altitude" for variable cruise altitude optimal trajectories with ranges exceeding 300 N.Mi.

The cost per nautical mile and fuel consumption for a typical handbook standard profile (taken from the aircraft manufacturer's flight operations manual) are also shown in Figures 1 and 2, respectively. The reader can easily see the savings in fuel and direct operating costs per nautical mile for each of the different types of optimal trajectories over such a typical standard profile. These savings are pointed out as percentage

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savings and penalties in Table I. Figure 1 indicates that airlines can ideally save \$.40/N.Mi. for a 300 N.Mi. trip decreasing to a savings of \$.17/N.Mi. for a 1500 N.Mi. trip without removing the 250 knot indicated air speed limit restriction below 3048m. (10^4ft.) or the constant cruise altitude restriction. The penalties for the constant cruise altitude restriction can be seen from Figure 3 and the effects of the 250 knot indicated air speed limit below 3048m. (10^4ft.) can be assessed from Figure 4.

The cost and fuel consumption per N.Mi. for optimal profiles having fixed cruise altitudes are given as functions of the fixed cruise altitude in Figures 5 thru 8 for ranges of 200, 300, 500, and 750 N.Mi. These curves are useful in determining the "best cruise altitude" so that direct operating cost (DOC) is minimized. Also, the penalty of "fixed cruise altitude" can be easily assessed.

TABLE II - PENALTY DUE TO FIXED CRUISE ALTITUDE
(250 KIAS limit below 3048m.)

RANGE (N.Mi.)	APPROXIMATE "BEST" FIXED CRUISE ALT. (Ft.)	COST (\$/N.Mi.) UTILIZING "BEST" FIXED CRUISE ALT.	COST (\$/N.Mi.) VARIABLE CRUISE ALT.	PENALTY (\$/N.Mi.)
300	33,000	3.79	3.74	.05
500	33,000	3.51	3.48	.03
750	33,000	3.36	3.33	.03

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The best fixed cruise altitude choice for optimizing fuel consumption by flying a DOC optimal profile can also be approximated by use of these figures.

TABLE III - FUEL PENALTY DUE TO FIXED CRUISE ALTITUDE
(250 KIAS limit below 3048m.)

RANGE (N.Mi.)	"BEST" FIXED CRUISE ALT FOR FUEL ECONOMY (Ft.)	FUEL CONSUMPTION AT "BEST CRUISE ALT" (LB./N.Mi.)	FUEL CONSUMPTION WITH VARIABLE CRUISE ALT (LB./N.Mi.)	PENALTY (LB./M.Mi.)
300	28,000	14.7	14.4	.3
500	34,000	13.4	13.1	.3
750	34,000	12.6	12.4	.2

The cost, fuel, and time penalties associated with a fixed 1.04 X 10^4m. (34,000 ft.) cruise as functions of range are contained in the graphs of Figure 3. Similar penalties for DOC versus fuel optimal paths are shown in Figure 9.

Figures 10 thru 12 were generated from data gathered from a large number of computer runs. These graphs give the time of flight (min.), fuel used (lb.), initial and final cruise altitudes (ft.), and cost ($/N.Mi.) as functions of fuel cost ($/lb/) for trip lengths of 400, 750, and 1,000 N.Mi. Each run used was DOC optimal with the usual 250 KIAS limit below 3048m. (10^4ft.).

Both the fuel consumption and time of flight curves have been smoothed (the original data contained small perturbations due to the approximations inherent to the optimization technique used and the aerodynamic aircraft and engine data input to OPTIM).

Figures 13 and 14 give initial and final cruise mach numbers as functions of fuel cost. Note that the two curves coincide in Figure 13.

Figures 1 and 2 show orderings of cost per nautical mile and fuel consumption per nautical mile for several different types of optimal trajectories at ranges of 200 N.Mi. through 1,500 N.Mi. and their savings over a standard handbook profile. We then elaborate on the particular data points on four of these curves at the specific ranges of 200 and 1,000 N.Mi.. Specifically, this is accomplished with figures 15a and 15b which illustrate the vertical distance-altitude profile for ascent-descent at 200 N.Mi.. Figures 16.1 - 19.6 yield specific information for climb and descent concerning airspeed, mach, time, flight path angle, engine exhaust pressure ratio and fuel burned versus altitude. Hopefully, this information would be useful and sufficient for pilots of the twin engine jet transport aircraft modelled to minimize fuel consumption or direct operating costs. Figures 20a and 20b along with 21.1 - 24.6 contain similar information for the 1,000 N.Mi. range.

Information on cost and fuel consumption for fuel optimal trajectories at 1,000 N.Mi. range with fixed cruise altitude is contained in Figure 25. An analysis of this figure shows that the fixed altitude HCRUZ = 31,000 ft. should be chosen over all other altitudes to minimize fuel consumption to 11.77 lb./N.Mi.. However, any fixed altitude between 29,500 and 35,000 ft. would result in a fuel consumption of less than 11.9 lb. per N.Mi.. It can also be seen that the best value of HCRUZ is 34,000 ft. if one also wishes to minimize costs with a fixed altitude fuel-optimal trajectory. One should note the fact that these curves have two different minima. One should also note the large penalties paid if cruise altitude is below 29,000 ft.. Similar information can be obtained from OPTIM for other trip lengths.

The next research phase involved utilization of the fixed time of arrival (ITOA = 1) capability of OPTIM. The input ranges used were 400, 500 and 750 N.Mi.. At the 750 N.Mi. range altitude was plotted against range, fuel burned, EPR setting, mach number, flight path angle, true airspeed and time so that comparisons of two fixed time (6,800 sec. and 7,500 sec.) flights with the free time of flight (7,118 sec.) could be made. These comparisons are made in figures 26, 27, 28 and Table 6. Figures 29a - 29d yield direct operating costs and fuel consumption for each time of arrival in an interval containing the free time of arrival fuel optimal case for the 400, 500 and the 750 N.Mi. ranges. Figures 29b and 29c compare these functions as changes are made in the MFGR flags of OPTIM as well as DEW (which determines the altitudes at which the cruise tables are formed). Direct operating cost (DOC) and fuel consumption penalties due to changes in time of arrival can be easily figured from these graphs.

The possibility that an airplane may be directed to change its destination while in flight makes the study of cruise-descent (two part) profiles useful. Data was collected from OPTIM and Figures 30 - 31 show fuel efficiency and cost for both fuel and DOC optimal trajectories at ranges of 300 - 750 N.Mi. The penalty of optimization using only one control variable (airspeed) as opposed to two controls (airspeed and thrust) is evident from figures 30a and 30b. The penalties due to fixed Time of Arrival (TOA) are evident from Figures 31a, b, and c. These could be useful in assigning arrival times to aircraft so that penalties in fuel consumption and/or DOC are kept below a certain amount. Due to the small change in fuel efficiency or DOC in graphs 30a and b, it was decided that one control would be used in the fixed time of arrival study referred to here. Figures 32 - 33 illustrate the very small differences between using 1 or 2 controls as far as cost or fuel efficiency is concerned for the three part trajectories. These results, together with those of the two part trajectories, indicate that optima utilizing one control variable only should be used due to their relative simplicity and the smaller computer execution time required.

A series of computer runs with OPTIM utilizing the one control option was made showing the variation of the vertical flight profile shape, mach number, true airspeed, flight path angle, fuel burned, EPR setting and time elapsed, all as functions of altitude for time costs/hr. (other than fuel) of $200, $600 and $1,000. These results are contained in Figures 34. Figures 35 show the dependence of these same relations on fuel cost/lb.. Three specific values ($.10/lb., $.15/lb. and $.25/lb.) are used in these graphs. Both series of graphs vary continuously; the former series with time cost and the latter series with fuel cost.

An atmospheric effect study was completed, the results indicating a substantial effect of changes in atmosphere on the trajectories, power available, mach, and other variables. These results are contained in graphs 36.1 - 36.5 for climb only. Descent changes in the variables were minimal. The test atmospheres varied from the Standard Day (15^o Centigrade) by temperature variations DTEMPK = -20 C^o, -10 C^o, 0 C^o, 10 C^o and 20 C^o. The cooler atmosphere was beneficial for fuel economy. This is illustrated for ranges of 300 and 1,000 N.Mi. in figures 37.1 and 37.2. However, direct operating costs depend on the range as well as the atmosphere in this respect. The cooler atmosphere saving at 300 N. Mi. and the warmer at 1,000 N.Mi.. These runs were DOC optimals with the usual $.15/$600 fuel and time costs.

Figure 38 gives the wind envelope at ranges between 300 and 1,500 N.Mi. and DOC optimal costs will remain inside these extremes for other winds having magnitudes at all altitudes less than or equal to the wind modelled regardless of the direction of the wind at any altitude. The wind model used in OPTIM is shown in Figure 39.

A series of runs utilizing flags 00004001'032 and costs $.15/ $600 were simulated at trip lengths of 300, 500 and 750 N.Mi. with DEW, W and WN on Card 4 of OPTIM taking on the values in Table 7 which in effect cause the creation of different numbers of cruise tables. The larger DEW becomes the fewer cruise tables created and the CP seconds execution time decreases. At 300 and 500 N.Mi. several runs resulted in no results and this problem is currently being investigated. At 750 N.Mi. the results are very consistent and stable, no matter what viable DEW was used and even the large DEW = 20,000 lb. (which caused the creation of only two cruise tables) is accurate and should be used due to the savings of over 200 CP seconds execution time over the DEW = 1,000 lb. case.

In the currently revised OPTIM (Revision 5, dated October 1981) there is an option for a three part fixed cruise altitude trajectory with step climb. This option assumes a 4,000 ft. climb at maximum thrust after attainment of the fixed cruise altitude. The optimum distance into cruise at which the step climb starts is solved for along with the other optimization variables.

Table 9 compares this step climb option with the variable altitude for .15/$600 fuel-time costs at weights of 85,000 lb. upward to 110,000 lb.. This allows a direct comparison of the two types of trajectories as well as the weight penalties involved. Figure 41 shows the effect of take off weight on the 750 mile DOC optimal profile (flags 0030001130) fuel consumption, cost/n.mi., and initial and final cruise altitudes. The actual physical profiles and related characteristics are compared in Figures 42.1 - 42.18. Figure 43 allows a visual comparison of cost and fuel consumption as functions of take-off weight between the step-climb option and the free cruise altitude option for direct operating cost (DOC) optimal profiles. Figures 44.1 - 44.18 physically compare the step-climb DOC optimals at weights of 90,000, 100,000 and 110,000 lb.

In Figures 45.1 - 45.18 we have profile comparisons for four types of optimal profiles at 750 N.MI. (fuel optimals with one and two controls and direct operating cost optimals with one and two controls). In particular we note the transition between the pairs of fuel optimals and DOC optimals so that the controls become more dominant in determining the profile shape above 24,000 ft. altitude. The two control DOC and fuel optimal trajectories have ascent ranges of 160 N.MI. while the single control ascent ones have greater flight path angle avove 24,000 ft. and are well into their cruise phase by the time the two control optimals enter their cruise phase. The exhaust pressure-altitude portion of Figure 45 shows why this transition takes place at 24,000 ft; the two control options have reduced EPR settings above 24,000 ft. Table 10 contains a summary table for the DOC optimal RUNDB which has fuel/time cost .15/600, FLAGS 0020001130, and an initial weight of 100,000 lb. This particular direct operating costs optimal , having one control only, a necessity required for any input trajectory for TRAGEN, is used to verify TRAGEN's usefulness as a trajectory generator.

Table 11 shows the effect of an inaccuracy in take off weight on the trajectory generated. An error of 10,000 lb. yields $0.23 - $0.44 penalty per N.MI. between 90,000 and 110,000 lb. take off weight on the ascent segment. These values are from comparison with the "suboptimal" trajectory simulated by TRAGEN in generating the OPTIM result RUNDB with RUNDB itself. The totals for the entire trip (ascent, cruise and descent combined) show a penalty of $0.08 - $0.19 per N.MI. for a 10,000 lb. inaccuracy in take off weight. Also, the suboptimal trajectory with W_o = 100,000 lb. generated by TRAGEN agrees in cost per N.MI. with RUNDB.

Figure 46 shows climb portion of the TRAGEN simulations of the optimal RUNDB (which had W_o = 100,000 lb) with take off weights of 90,000, 100,000 and 110,000 lb.. The effect of initial weight inaccuracies on the physical profiles is evident.

Table 12 illustrates the effect of an error in initial weight estimation on the cost of TRAGEN generated suboptimal profiles (using RUNDB OPTIM output data). Note that the TRAGEN output costs at 100,000 lb. agrees closely with the RUNDB OPTIM output costs in all segments of the profile as well as overall. Moreover, the effect of weight on the profile generated is significant.

If ITRAJ = 2, a reference trajectory is computed by TRAGEN. The variables VIAP1, VIAP2 and RMP3 (referring to Card 7, TRAGEN input data) used for the runs of Table 13 were 250 KIAS in climbing to (or descending from) 10,000 ft. altitude, 340 KIAS in climbing from (or descending to) 10,000 ft. altitude up to the intersection with Mach number RMP3, which was set at .78, being the desired Mach number in climbing from (or descending to) VIAP2 up to the intersection with the cruise altitude.

Tragen verifies these self-generated trajectories at all three initial weights used to within one cent per nautical mile. This is certainly acceptable accuracy.

CONCLUSIONS AND RECOMMENDATIONS

The principal investigator recommends that the project of mounting the hardware on board the TCV to utilize the results from OPTIM should proceed. The program (through Revision 5) gives valid results and has been extensively tested by fast-time simulation by the writer of this report and others. The final test is in how well it can be adapted to the TCV and finally to commercial aircraft.

TABLE I - COST, FUEL, AND TIME SAVINGS OR PENALTIES FOR FUEL AND DOC OPTIMAL FLIGHT PATHS AS COMPARED WITH STANDARD PROFILES

DOC OPTIMAL (250 KIAS); FLAGS (00102001103)

RANGE (N.Mi.)	FUEL (LB.) CONSUMED	% FUEL SAVINGS	TIME OF FLIGHT (HR, MIN, SEC)	TIME SAVINGS (MIN, SEC)	DIRECT OPERATING COSTS ($)	%COST SAVINGS	$/N.Mi.
300	4307	16.7	47:39	2:48	1122.67	12.3	3.74
400	5433	14.8	1:01:38	3:08	1431.34	10.8	3.58
500	6544	13.8	1:15:43	3:22	1738.77	9.9	3.48
750	9280	12.6	1:50:51	4:02	2500.58	8.8	3.33
1000	11953	12.4	2:25:57	4:44	3252.54	8.5	3.25
1250	14555	12.7	3:01:17	5:12	3996.14	8.5	3.20
1500	17107	13.1	3:36:37	5:40	4732.30	8.6	3.15

MOST GENERAL DOC OPTIMAL; FLAGS (00102000103)

RANGE (N.Mi.)	FUEL (LB.) CONSUMED	% FUEL SAVINGS	TIME OF FLIGHT (HR, MIN, SEC)	TIME SAVINGS (MIN, SEC)	DIRECT OPERATING COSTS ($)	%COST SAVINGS	$/N.Mi.
300	4340	16.0	44:27	6:00	1095.54	14.4	3.65
400	5548	13.0	58:30	6:16	1417.18	11.7	3.54
500	6668	12.1	1:12:31	6:34	1725.47	10.6	3.45
750	9302	12.4	1:47:37	7:16	2471.63	9.8	3.30
1000	11975	12.2	2:22:47	7:54	3224.21	9.3	3.22
1250	14586	12.5	2:58:03	8:26	3968.44	9.1	3.17
1500	17161	12.9	3:31:19	10:58	4707.38	9.1	3.14

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TABLE I (Continued)

FUEL OPTIMAL (250 KIAS); FLAGS (00102001103)

RANGE (N.Mi.)	FUEL (LB.) CONSUMED	% FUEL SAVINGS	TIME OF FLIGHT (HR, MIN, SEC)	TIME PENALTY (MIN, SEC)	DIRECT OPERATING COSTS($)	%COST SAVINGS	$/N.Mi.
300	4193	18.9	53:09	2:42	1160.45	9.4	3.87
400	5297	17.0	1:08:42	3:56	1481.55	7.7	3.70
500	6390	15.8	1:24:11	5:06	1800.33	6.7	3.60
750	9074	14.5	2:03:00	8:07	2591.10	5.5	3.45
1000	11694	14.3	2:42:09	11:28	3375.60	5.0	3.33
1250	14257	14.5	3:21:24	14:55	4152.55	4.9	3.32
1500	16762	14.9	4:00:31	18:14	4919.47	5.0	3.28
MOST GENERAL FUEL OPTIMAL; FLAGS (00102000103)							
300	4151	19.7	52:07	1:40	1143.82	10.6	3.81
400	5256	17.6	1:07:40	2:54	1465.07	8.7	3.66
500	6349	16.4	1:23:07	4:02	1783.52	7.6	3.57
750	9037	14.9	2:01:50	6:57	2573.88	6.1	3.43
1000	11661	14.5	2:40:51	10:10	3357.65	5.5	3.36
1250	14227	14.7	3:19:58	13:29	4133.72	5.3	3.31
1500	16736	15.0	3:58:55	16:38	4899.57	5.4	3.27

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TABLE I (Continued)

DOC OPTIMAL (250 KIAS; = 34000); FLAGS (00102011103)

RANGE (N.Mi.)	FUEL (LB.) CONSUMED	% FUEL SAVINGS	TIME OF FLIGHT (HR, MIN, SEC)	TIME SAVINGS (MIN, SEC)	DIRECT OPERATING COSTS ($)	%COST SAVINGS	$/N.Mi.
300	4418	14.5	47:30	2:57	1137.74	11.1	3.79
400	5553	13.0	1:01:29	3:17	1447.87	9.8	3.62
500	6667	12.2	1:15:28	3:37	1756.36	9.0	3.51
750	9443	11.1	1:50:26	4:27	2520.81	8.1	3.36
1000	12154	10.9	2:25:17	5:24	3276.08	7.8	3.28
1250	14799	11.2	3:00:16	6:13	4022.67	7.9	3.22
1500	17381	11.8	3:35:21	6:56	4760.60	8.1	3.17
STANDARD PROFILE							
300	5169		50:27		1279.83		4.27
400	6380		1:04:46		1604.64		4.01
500	7591		1:19:05		1929.51		3.86
750	10618		1:54:53		2741.52		3.66
1000	13646		2:30:41		3553.74		3.55
1250	16673		3:06:29		4365.81		3.49
1500	19701		3:42:17		5177.97		3.45

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TABLE 4 (RUN 201)

FLAGS (00102001103); .15/0; FUEL OPTIMAL TRAJECTORY; VARIABLE CRUISE ALTITUDE; 250 KIAS BELOW 3,048m. (10,000 ft.)

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97891.	97891.	TAS	373.	373.
COST ($/NM)	1.758	1.758	IAS	254.81	254.81
ENERGY (FT)	32717.	32717.	GR SP KN	372.83	372.83
ALTITUDE	26568.	26568.	MACH NO	.62346	.62346

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2108.82	62.69	0:11: 6	316.32	5.05
DESCEND	937.83	132.60	0:25:53	140.68	1.06
CRUISE	0.00	0.00	0: 0: 0	0.00	0.00
TOTAL	3046.66	195.30	0:37: 0	457.00	2.34

LANDING WEIGHT = 96953.

CRUISE AND OVERALL EFFICIENCY 0.000 15.600 LB/NM

COST (% OVER LAMBDA) = 3.41 NO OF ITERATIONS = 5

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TABLE 4 (RUN 202)

FLAGS (00102000103); .15/0; FUEL OPTIMAL TRAJECTORY; VARIABLE CRUISE ALTITUDE; NO KIAS LIMIT BELOW 3,048m. (10,000 ft.)

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97930.	97930.	TAS	372.	372.
COST ($/NM)	1.761	1.761	IAS	254.73	254.73
ENERGY (FT)	32563.	32563.	GR SP KN	371.98	371.98
ALTITUDE	26442.	26442.	MACH NO	.62171	.62171

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2070.40	63.73	0:10:39	310.56	4.87
DESCEND	940.62	132.27	0:25:36	141.09	1.07
CRUISE	0.00	0.00	0: 0: 0	0.00	0.00
TOTAL	3011.02	196.00	0:36:15	451.65	2.30

LANDING WEIGHT = 96989.

CRUISE AND OVERALL EFFICIENCY 0.000 15.363 LB/NM

COST (% OVER LAMBDA) = 3.54 NO OF ITERATIONS = 5

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TABLE 4 (RUN 204)

FLAGS (00102001103); .15/600; DIRECT OPERATING COSTS OPTIMAL; VARIABLE CRUISE ALTITUDE; 250 KIAS BELOW 3,048m. (10,000 ft.)

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97640.	97640.	TAS	438.	438.
COST ($/NM)	3.245	3.245	IAS	304.91	304.91
ENERGY (FT)	34984.	34984.	GR SP KN	437.75	437.75
ALTITUDE	26508.	26508.	MACH NO	.73182	.73182

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2359.71	74.97	0:12:26	473.30	6.38
DESCEND	895.10	126.28	0:21:31	349.55	2.77
CRUISE	0.00	0.00	0: 0: 0	0.00	0.00
TOTAL	3254.81	201.24	0:33:57	827.86	4.11

LANDING WEIGHT = 96745.

CRUISE AND OVERALL EFFICIENCY 0.000 16.173 LB/NM

COST (% OVER LAMBDA) = 3.70 NO OF ITERATIONS = 3

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TABLE 4 (RUN 203)

FLAGS (00102000103); .15/600; DIRECT OPERATING COSTS OPTIMAL; VARIABLE CRUISE ALTITUDE; NO KIAS LIMIT BELOW 3,048m. (10,000 ft.)

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97391.	97391.	TAS	434.	434.
COST ($/NM)	3.157	3.157	IAS	278.85	278.85
ENERGY (FT)	39319.	39319.	GR SP KN	433.80	433.80
ALTITUDE	30995.	30995	MACH NO	.73926	.73926

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2608.92	92.46	0:14: 6	532.44	5.76
DESCEND	709.75	112.30	0:17:11	278.37	2.48
CRUISE	0.00	0.00	0: 0: 0	0.00	0.00
TOTAL	3318.67	204.76	0:31:18	810.82	3.96

LANDING WEIGHT = 96681.

CRUISE AND OVERALL EFFICIENCY 0.000 16.207 LB/NM

COST (% OVER LAMBDA) = 1.00 NO OF ITERATIONS = 0

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TABLE 5 (RUN F1)

FLAGS (00102001103); .15/0; FUEL OPTIMAL TRAJECTORY; VARIABLE CRUISE ALTITUDE; 250 KIAS BELOW 3,048m. (10,000 ft.)

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97703.	89101.	TAS	389.	384.
COST ($/NM)	1.697	1.553	IAS	252.48	240.31
ENERGY (FT)	36343.	382[illegible]7.	GR SP KN	388.56	384.13
ALTITUDE	29664.	31700.	MACH NO	.65837	.65664

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2296.58	72.33	0:12:34	344.49	4.76
DESCEND	795.15	135.20	0:26:34	119.27	.88
CRUISE	8602.55	792.48	2: 2:59	1290.38	1.63
TOTAL	11694.28	1000.00	2:42: 9	1754.14	1.75

LANDING WEIGHT = 88306.

CRUISE AND OVERALL EFFICIENCY 10.855 11.694 LB/NM

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = 0

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TABLE 5 (RUN F2)

FLAGS (00102000103); .15/0; FUEL OPTIMAL TRAJECTORY; VARIABLE CRUISE ALTITUDE; NO KIAS LIMIT BELOW 3,048m. (10,000 ft.)

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97729.	89112.	TAS	389.	384.
COST ($/NM)	1.698	1.553	IAS	252.52	240.33
ENERGY (FT)	36337.	38225.	GR SP KN	388.59	384.14
ALTITUDE	29658.	31697.	MACH NO	.65839	.65665

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2270.62	74.10	0:12:13	340.59	4.60
DESCEND	772.50	132.20	0:25:27	115.88	.88
CRUISE	8617.42	793.70	2: 3:11	1292.61	1.63
TOTAL	11660.55	1000.00	2:40:51	1749.08	1.75

LANDING WEIGHT = 88339.

CRUISE AND OVERALL EFFICIENCY 10.857 11.661 LB/NM

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = 0

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TABLE 5 (RUN C1)

FLAGS (00102001103); .15/600; DIRECT OPERATING COSTS OPTIMAL; VARIABLE CRUISE ALTITUDE;
250 KIAS BELOW 3,048m. (10,000 ft.)

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97231.	89239.	TAS	428.	425.
COST ($/NM)	3.123	2.997	IAS	259.43	248.60
ENERGY (FT)	42266.	43965.	GR SP KN	428.22	424.93
ALTITUDE	34155.	35978.	MACH NO	.74000	.74037

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2769.47	98.97	0:15:42	572.42	5.78
DESCEND	1192.20	176.36	0:28:16	461.55	2.62
CRUISE	7991.70	724.66	1:41:58	2218.57	3.06
TOTAL	11953.37	1000.00	2:25:57	3252.54	3.25

LANDING WEIGHT = 88047.

CRUISE AND OVERALL EFFICIENCY 11.028 11.953 LB/NM

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = 0

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TABLE 5 (RUN C2)

FLAGS (00102000103); .15/600; DIRECT OPERATING COSTS OPTIMAL; VARIABLE CRUISE ALTITUDE; NO KIAS LIMIT BELOW 3,048m. (10,000 ft.)

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97243.	89092.	TAS	428.	425.
COST ($/NM)	3.123	2.995	IAS	259.46	248.37
ENERGY (FT)	42263.	44007.	GR SP KN	428.22	424.88
ALTITUDE	34152.	36022.	MACH NO	.74000	.74045

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2756.68	101.46	0:15:19	566.72	5.59
DESCEND	1084.19	158.91	0:23:21	396.16	2.49
CRUISE	8151.68	739.63	1:44: 5	2263.69	3.06
TOTAL	11992.56	1000.00	2:22:46	3226.57	3.23

LANDING WEIGHT = 88007.

CRUISE AND OVERALL EFFICIENCY 11.021 11.993 LB/NM

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = 0

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TABLE 6 (R7T1)

FLAGS (000030011132); .15/0; ITOA = 1 (6800 sec TOF); $W_o = 10^5$; $W_{min} = 8 \times 10^4$; $\Delta W = 4000$

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97103.	91287.	TAS	419.	418.
COST ($/NM)	2.651	2.560	IAS	252.09	245.21
ENERGY (FT)	42197.	43392.	GR SP KN	419.29	417.69
ALTITUDE	34420.	35675.	MACH NO	.72543	.72676

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2896.58	105.36	0:16:53	550.41	5.22
DESCEND	436.77	106.80	0:19:27	199.04	1.86
CRUISE	5816.18	537.84	1:17: 6	1401.51	2.61
TOTAL	9149.53	750.00	1:53:27	2150.96	2.87

LANDING WEIGHT = 90850.

CRUISE AND OVERALL EFFICIENCY 10.814 12.199 LB/NM

ON PASS NO. 3 FLIGHT TIME IS 6807.07 SEC. FOR THE COST OF TIME SET AT 411.736 $/HR

RUN CONVERGED

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = *****

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TABLE 6 (R7T5)

FLAGS (000030011132); .15/0; ITOA = 1 (7500 sec TOA); W_c = 10^5; W_{min} = 8 X 10^4; ΔW = 4000

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97422.	91369.	TAS	388.	384.
COST ($/NM)	.948	.842	IAS	239.02	231.52
ENERGY (FT)	39315.	40315.	GR SP KN	388.27	384.32
ALTITUDE	32646.	33778.	MACH NO	.66648	.66320

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2578.16	85.24	0:14:58	315.31	3.70
DESCEND	518.09	110.37	0:23:58	-36.61	-.33
CRUISE	6052.96	554.38	1:26: 7	497.15	.90
TOTAL	9149.21	750.00	2: 5: 3	775.85	1.03

LANDING WEIGHT = 90851.

CRUISE AND OVERALL EFFICIENCY 10.918 12.199 LB/NM

ON PASS NO. 8 FLIGHT TIME IS 7503.97 SEC. FOR THE COST OF TIME SET AT -286.182 $/HR

RUN CONVERGED

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = *****

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TABLE 6 (R7T7)

FLAGS (000030011032); .15/0; ONE CONTROL (V)

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT	97173.	91451.	TAS	408.	406.
COST ($/NM)	1.658	1.564	IAS	143.97	237.26
ENERGY (FT)	41870.	42934.	GR SP KN	407.86	405.53
ALTITUDE	34511.	35660.	MACH NO	.70595	.70557

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2826.77	100.83	0:16:46	424.02	4.21
DESCEND	500.94	116.60	0:23:19	75.14	.64
CRUISE	5722.00	532.57	1:18:33	858.30	1.61
TOTAL	9049.71	750.00	1:58:38	1357.46	1.81

LANDING WEIGHT = 90950.

CRUISE AND OVERALL EFFICIENCY 10.744 12.066 LB/NM

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = 0

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TABLE 7

ONE CONTROL - NEW CRUISE TABLES

FLAGS (000040011032); .15/600; W_0 = 100,000 LB.; 300 N. Mi.

ΔW (LB)	COST/ N. MI.	FUEL (LB/NM) CONSUMPTION	CP SEC EXECUTION	TIME OF FLIGHT (SEC)
1,000	$3.76	14.48	399.7	2858
2,000	3.77	14.52	273.3	2824
2,500	3.77	14.53	357.6	2821
4,000	3.76	14.48	292.3	2856
5,000	3.77	14.52	274.2	2836
10,000	3.77	14.50	201.6	2850
20,000	3.78	14.58	211.6	2811

TWO CONTROLS - NEW CRUISE TABLES

FLAGS (101040011032); .15/600; W_0 = 100,000 LB.; 300 N. Mi.

1,000	$3.73	14.34	369.0	2937
2,000				
2,500	3.74	14.38	369.6	2917
4,000	3.73	14.32	369.1	2952
5,000	3.73	14.33	375.1	2943
10,000	3.73	14.33	365.5	2944
20,000	3.79*	14.61	361.3	2675

*RANGES WERE NOT ACCEPTABLE

ΔW = 1,000 (10 CRUISE TABLES)
= 2,000 (6 " ")
= 2,500 (9 " ")
= 4,000 (6 " ")
= 5,000 (5 " ")
= 10,000 (2 " ")
= 20,000 (2 " ")

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TABLE 7 (Continued)

ONE CONTROL - NEW CRUISE TABLES

FLAGS (000040011032); .15/600; W_0 = 100,000 LB.; 500 N. Mi.

ΔW (LB)	COST/ N. MI.	FUEL (LB/NM) CONSUMPTION	CP SEC EXECUTION	TIME OF FLIGHT (SEC)
1,000	$3.48	12.99	295.8	4589
2,000	3.48	12.99	185.4	4588
2,500	3.48	12.98	269.6	4588
4,000	3.48	12.98	189.4	4588
5,000	3.48	13.07	209.0	4538
10,000				
20,000	3.48	13.06	181.6	4533

TWO CONTROLS - OLD CRUISE TABLES

FLAGS (101040011032); .15/600; W_0 = 100,000 LB.; 500 N. Mi.

ΔW (LB)	COST/ N. MI.	FUEL (LB/NM) CONSUMPTION	CP SEC EXECUTION	TIME OF FLIGHT (SEC)
1,000	$3.47	12.99	50.6	4568
2,000	3.47	12.99	48.9	4567
2,500	3.47	12.98	49.5	4568
4,000	3.47	12.99	49.5	4567
5,000	3.47	12.99	50.1	4568
10,000				
20,000	3.47	12.98	48.5	4564

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TABLE 7 (Continued)

ONE CONTROL - NEW CRUISE TABLES

FLAGS (000040011032); .15/600; W_0 = 100,000 LB.; 750 N. Mi.

ΔW (LB)	COST/ N. MI.	FUEL (LB/NM) CONSUMPTION	CP SEC EXECUTION	TIME OF FLIGHT (SEC)
1,000	$3.32	12.18	296.9	6734
2,000	3.32	12.18	185.4	6733
2,500	3.32	12.18	269.5	6735
4,000	3.32	12.17	186.4	6735
5,000	3.32	12.17	160.3	6734
10,000	3.32	12.17	80.8	6735
20,000	3.32	12.14	80.1	6732

TWO CONTROLS - OLD CRUISE TABLES

FLAGS (101040011032); .15/600; W_0 = 100,000 LB.; 750 N. Mi.

1,000	$3.32	12.18	50.5	6713
2,000	3.32	12.18	48.2	6712
2,500	3.32	12.17	50.3	6714
4,000	3.32	12.18	49.5	6714
5,000	3.32	12.18	51.2	6714
10,000	3.32	12.18	48.7	6717
20,000	3.32	12.17	49.3	6711

TABLE 8 DEPENDENCE OF COSTS AND FUEL CONSUMPTION ON ΔE FLAGS (100040011032)

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RANGE (N. Mi.)	ΔE (FT)	FUEL CONSUMPTION (LB./N. Mi.)	DIRECT OPERATING COSTS ($/N.Mi.)	CP SEC EXECUTION TIME (SEC.)
100	250	19.29	4.82	92.0
	500	19.29	4.82	52.6
	1000	19.33	4.84	28.5
	2000	19.40	4.89	16.6
200	250	16.15	4.11	214.8
	500	16.14	4.11	119.7
	1000	16.15	4.12	63.4
	2000	16.14	4.12	34.4
300	250	14.49	3.76	240.5
	500	14.48	3.76	128.6
	1000	14.48	3.77	65.8
	2000	14.49	3.77	34.7
500	250	12.98	3.48	41.6
	500	12.98	3.48	22.2
	1000	12.97	3.48	12.4
	2000	12.98	3.48	7.5
750	250	12.17	3.32	41.0
	500	12.17	3.32	23.0
	1000	12.16	3.32	12.9
	2000	12.16	3.33	7.5

TAPE 8 = TE1K3
W = 100,000
WN = 91,000
DEW = 1,000

TAPE 8 = TE4K7
W = 100,000
WN = 80,000
DEW = 4,000

TABLE 9

FLAGS (0030001130); .15/600; WTO = 85,000 LB.; TAPE 11 = CL7085

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	82458.	77430.	TAS	418.	418.
COST ($/NM)	2.856	2.773	IAS	229.06	222.60
ENERGY (FT)	45698.	47000.	GR SP KN	417.55	418.03
ALTITUDE	37986.	39270.	MACH NO	.72798	.72882

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2541.91	99.80	0:15:42	538.29	5.39
CRUISE	5028.54	547.39	1:18:36	1540.38	2.81
DESCEND	402.30	102.81	0:17:43	237.62	2.31
TOTAL	7972.75	750.00	1:52: 2	2316.28	3.09

LANDING WEIGHT = 77027.

CRUISE AND OVERALL EFFICIENCY 9.186 10.630 LB/NM

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = 0

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TABLE 9 (Continued)

FLAGS (0030001130); .15/600; WTO = 90,000 LB.; TAPE 11 = CL7090

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	87363.	82060.	TAS	418.	418.
COST ($/NM)	2.935	2.849	IAS	236.80	228.57
ENERGY (FT)	44298.	45798.	GR SP KN	417.74	417.59
ALTITUDE	36579.	38084.	MACH NO	.72832	.72805

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2636.69	100.25	0:15:48	553.54	5.52
CRUISE	5303.32	547.11	1:18:39	1582.14	2.89
DESCEND	406.58	102.64	0:17:49	239.22	2.33
TOTAL	8346.60	750.00	1:52:17	2374.90	3.17

LANDING WEIGHT = 81653.

CRUISE AND OVERALL EFFICIENCY 9.693 11.129 LB/NM

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = 0

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TABLE 9 (Continued)

FLAGS (0030001130); .15/600; WTO = 100,000 LB.; TAPE 11 = CL7100

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97123.	91273.	TAS	420.	419.
COST ($/NM)	3.085	2.997	IAS	249.26	242.83
ENERGY (FT)	42033.	43192.	GR SP KN	420.25	418.64
ALTITUDE	34221.	35440.	MACH NO	.72633	.72753

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2876.57	104.64	0:16:34	597.23	5.71
CRUISE	5850.18	544.96	1:17:56	1656.90	3.04
DESCEND	408.29	100.39	0:17:41	238.21	2.37
TOTAL	9135.05	750.00	1:52:12	2492.34	3.32

LANDING WEIGHT = 90865.

CRUISE AND OVERALL EFFICIENCY 10.735 12.180 LB/NM

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = 0

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TABLE 9 (Continued)

FLAGS (0030001130); .15/600; WTO = 110,000 LB.; TAPE 11 = CL7110

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	106852.	100512.	TAS	423.	421.
COST ($/NM)	3.232	3.136	IAS	259.46	252.85
ENERGY (FT)	40185.	41373.	GR SP KN	422.55	421.05
ALTITUDE	32287.	33531.	MACH NO	.72406	.72547

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	3147.72	110.72	0:17:36	648.17	5.85
CRUISE	6340.29	540.06	1:16:49	1719.35	3.18
DESCEND	411.54	99.22	0:17:40	238.40	2.40
TOTAL	9899.55	750.00	1:52: 5	2605.92	3.47

LANDING WEIGHT = 100100.

CRUISE AND OVERALL EFFICIENCY 11.740 13.199 LB/NM

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = 0

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TABLE 9 (Continued)

STEP CLIMB OPTION; FLAGS (0030021130); .15/600; WTO = 85,000 LB.; TAPE 11 = SCX085; HCRUZ = 36000

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	81111.	77341.	TAS	416.	417.
COST ($/NM)	2.860	2.781	IAS	217.85	218.21
ENERGY (FT)	47666.	47689.	GR SP KN	416.30	416.92
ALTITUDE	40000.	40000.	MACH NO	.72580	.72689

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2383.42	88.81	0:14: 6	498.65	5.62
PRECRUISE	1157.35	120.85	0:17:18	346.72	2.87
STEP	348.39	25.12	0: 3:36	88.40	3.52
CRUISE	3770.03	410.18	0:59: 5	1156.36	2.82
DESCEND	407.98	105.04	0:18: 1	241.53	2.30
TOTAL	8067.17	750.00	1:52: 9	2331.66	3.11

LANDING WEIGHT = 76933.

CRUISE AND OVERALL EFFICIENCY 9.191 10.76 LB/NM

	WITHOUT STEP	WITH STEP
FINAL WEIGHT	76914.5	76932.8
FINAL COST	2330.	2332.

STEP CLIMB COSTS MORE THAN CONSTANT ALTITUDE CRUISE 2330. 2332.

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TABLE 9 (Continued)

STEP CLIMB OPTION; FLAGS (0030021130); .15/600; WTO = 85,000 LB.; TAPE 11 = SCW085; HCRUZ = 37000

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	77734.	77355.	TAS	416.	416.
COST ($/NM)	2.806	2.737	IAS	212.76	212.79
ENERGY (FT)	48661.	48663.	GR SP KN	416.17	416.22
ALTITUDE	41000.	41000.	MACH NO	.72558	.72567

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2464.68	94.37	0:14:54	518.78	5.50
PRECRUISE	4461.39	479.45	1: 8:43	1356.53	2.83
STEP	339.88	25.61	0: 3:41	87.84	3.43
CRUISE	379.26	41.90	0: 6: 2	117.30	2.80
DESCEND	418.00	108.67	0:18:35	248.65	2.29
TOTAL	8063.20	750.00	1:51:57	2329.09	3.11

LANDING WEIGHT = 76937.

CRUISE AND OVERALL EFFICIENCY 9.052 10.75 LB/NM

	WITHOUT STEP	WITH STEP
FINAL WEIGHT	76965.2	76936.8
FINAL COST	2324.	2329.

STEP CLIMB COSTS MORE THAN CONSTANT ALTITUDE CRUISE 2324. 2329.

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TABLE 9 (Continued)

STEP CLIMB OPTION; FLAGS (0030021130); .15/600; WTO = 90,000 LB.; TAPE 11 = SCL090

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	82528.	81990.	TAS	416.	416.
COST ($/NM)	2.918	2.904	IAS	212.75	212.80
ENERGY (FT)	48661.	48664.	GR SP KN	416.15	416.24
ALTITUDE	41000.	41000.	MACH NO	.72555	.72570

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2687.76	103.78	0:16:18	566.31	5.46
PRECRUISE	4351.41	445.70	1: 4: 4	1293.52	2.90
STEP	432.77	32.69	0: 4:42	111.99	3.43
CRUISE	537.98	55.00	0: 7:55	159.98	2.91
DESCEND	433.67	112.82	0:19:24	259.07	2.30
TOTAL	8443.59	750.00	1:52:25	2390.86	3.19

LANDING WEIGHT = 81556.

CRUISE AND OVERALL EFFICIENCY 9.781 11.26 LB/NM

	WITHOUT STEP	WITH STEP
FINAL WEIGHT	81601.6	81556.4
FINAL COST	2381.	2391.

STEP CLIMB COSTS MORE THAN CONSTANT ALTITUDE CRUISE 2381. 2391.

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TABLE 9 (Continued)

STEP CLIMB OPTION; FLAGS (0030021130); .15/600; WTO = 100,000 LB.; TAPE 11 = SCL100

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	91692.	91222.	TAS	415.	415.
COST ($/NM)	3.047	3.036	IAS	227.46	227.50
ENERGY (FT)	45618.	45621.	GR SP KN	415.00	415.06
ALTITUDE	38000.	38000.	MACH NO	.72354	.72365

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2861.80	103.76	0:16:26	593.74	5.72
PRECRUISE	5037.68	466.21	1: 6:30	1420.80	3.05
STEP	408.03	27.04	0: 3:53	100.19	3.71
CRUISE	470.32	44.26	0: 6:23	134.54	3.04
DESCEND	432.05	108.74	0:19: 1	255.08	2.35
TOTAL	9209.87	750.00	1:52:17	2504.33	3.34

LANDING WEIGHT = 90790.

CRUISE AND OVERALL EFFICIENCY 10.626 12.28 LB/NM

	WITHOUT STEP	WITH STEP
FINAL WEIGHT	90817.6	90790.1
FINAL COST	2497.	2504.

STEP CLIMB COSTS MORE THAN CONSTANT ALTITUDE CRUISE 2497. 2504.

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TABLE 9 (Continued)

STEP CLIMB OPTION; FLAGS (0030021130); .15/600; WTO = 110,000 LB.; TAPE 11 = SCL110

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	100969.	100441.	TAS	414.	414.
COST ($/NM)	3.198	3.187	IAS	237.54	237.56
ENERGY (FT)	43586.	43587.	GR SP KN	414.11	414.14
ALTITUDE	36000.	36000.	MACH NO	.72149	.72154

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	3127.01	109.59	0:17:25	643.37	5.87
PRECRUISE	5462.43	461.46	1: 5:23	1473.24	3.19
STEP	441.86	27.06	0: 3:53	105.13	3.88
CRUISE	527.61	45.44	0: 6:34	144.97	3.19
DESCEND	430.74	106.45	0:18:49	252.84	2.38
TOTAL	9989.65	750.00	1:52: 6	2619.54	3.49

LANDING WEIGHT = 100010.

CRUISE AND OVERALL EFFICIENCY 11.612 13.32 LB/NM

	WITHOUT STEP	WITH STEP
FINAL WEIGHT	100039.3	100010.4
FINAL COST	2612.	2620.

STEP CLIMB COSTS MORE THAN CONSTANT ALTITUDE CRUISE 2612. 2620.

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TABLE 10

FLAGS (0020001130); .15/600; WTO = 100,000 LB.; TAPE 11 = RUNDB

	INITIAL CRUISE	FINAL CRUISE		INITIAL CRUISE	FINAL CRUISE
WEIGHT (LB)	97121.	91279.	TAS	420.	419.
COST ($/NM)	3.085	2.997	IAS	249.01	242.36
ENERGY (FT)	42053.	43281.	GR SP KN	420.07	418.54
ALTITUDE	34248.	35533.	MACH NO	.72610	.72765

	FUEL USED (LB)	DISTANCE (N M)	HR:MIN:SEC	COST($)	$/NM
CLIMB	2878.55	104.76	0:16:35	597.70	5.71
CRUISE	5842.62	544.54	1:17:55	1655.63	3.04
DESCEND	409.11	100.70	0:17:44	238.86	2.37
TOTAL	9130.28	750.00	1:52:15	2492.18	3.32

LANDING WEIGHT = 90870.

CRUISE AND OVERALL EFFICIENCY 10.729 12.174 LB/NM

COST (% OVER LAMBDA) = 0.00 NO OF ITERATIONS = 0

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TABLE 11 - EFFECT OF INITIAL WEIGHT (W_o) ON SIMULATION OF OPTIMAL FLIGHT PROFILE RUNDB

	TIME (SEC)	RANGE (N.MI.)	FINAL ALT. (FT.)	FUEL USED (LB.)	FUEL ECON. (FT/N.MI.)	DOC ($)	COST ($/N.MI.)
			CLIMB				
OPTIM RUNDB	995	104.8	34248	2879	27.47	597.68	5.70
			TRAGEN SIMULATION				
$W_o=90\times10^3$ LB	915	101.9	34003	2677	26.27	554.05	5.44
$W_o=10^5$ LB	992	105.5	33997	2888	27.37	598.53	5.67
$W_o=11\times10^4$ LB	1009	101.1	32380	2998	29.65	617.87	6.11
			CRUISE				
OPTIM RUNDB	4675	544.5	35533	5843	10.73	1655.62	3.04
			TRAGEN SIMULATION				
W_o=90,000 LB	4518	544.	35533	5752	10.57	1615.80	2.97
W_o=100,000 LB	4633	545.	35533	5899	10.82	1657.02	3.04
W_o=110,000 LB	4842	545.	35533	6441	11.82	1773.15	3.25
			DESCENT				
OPTIM RUNDB	1064	100.7	0	409	4.06	238.68	2.37
			TRAGEN SIMULATION				
W_o=90,000 LB	1065	97.4	509	396	4.07	236.90	2.43
W_o=100,000 LB	1067	100.8	-21	409	4.06	239.18	2.37
W_o=110,000 LB	1026	100.8	388	398	3.95	230.70	2.29
			TOTALS FOR ENTIRE TRIP				
OPTIM RUNDB	6734	750.		9131	12.17	2491.98	3.32
$W_o=90\times10^3$	6498	743.3		8825	11.87	2406.75	3.24
$W_o=10^5$	6692	751/3		9196	12.24	2494.73	3.32
$W_o=1.1\times10^5$	6877	746.9		9837	13.17	2621.72	3.51

OPTIM PARAMETERS FOR RUNDB

FLAGS - 0020001130

OTHER INPUT CARDS

.15	600	.00	90.00	
100K	80K	4K		
100K	750.	500.	34000.	.0
0.	210.	0.	210.0	

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Table 12 - Take off weight error effect on Suboptimal trajectory generation by TRAGEN.

SIMULATION	TAKE OFF WEIGHT (LB)	COST ($)	COST/N.MI. ($/N.MI.)
	CLIMB		
TRAGEN (RUNDB INPUT)	90,000	553.88	5.44
" " "	100,000	598.39	5.67
" " "	110,000	617.72	6.11
OPTIM (RUNDB)	100,000	597.70	5.71
	CRUISE		
TRAGEN (RUNDB INPUT)	90,000	1615.80	2.96
" " "	100,000	1657.05	3.04
" " "	110,000	1773.15	3.25
OPTIM (RUNDB)	100,000	1655.63	3.04
	DESCENT		
TRAGEN (RUNDB INPUT)	90,000	236.58	2.35
" " "	100,000	238.85	2.37
" " "	110,000	237.20	2.35
OPTIM (RUNDB)	100,000	238.86	2.37
	OVERALL		
TRAGEN (RUNDB INPUT)	90,000	2406.26	3.21
" " "	100,000	2494.29	3.33
" " "	110,000	2628.07	3.50
OPTIM (RUNDB)	100,000	2492.18	3.32

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TABLE 13

	INITIAL WEIGHT	TOTAL COST	COST/N.MI.
*TRAGEN COMPUTED INPUT REFERENCE TRAJECTORY 1	90,000	2462.44	3.34
TRAGEN GENERATED OUTPUT FROM TRAJECTORY 1	90,000	2458.18	3.33
*TRAGEN COMPUTED INPUT REFERENCE TRAJECTORY 2	100,000	2600.17	3.50
TRAGEN GENERATED OUTPUT FROM TRAJECTORY 2	100,000	2591.18	3.49
*TRAGEN COMPUTED INPUT REFERENCE TRAJECTORY 3	110,000	2745.99	3.68
TRAGEN GENERATED OUTPUT FROM TRAJECTORY 3	110,000	2734.49	3.67
HANDBOOK PROFILE		2741.52	3.66

*Reference trajectories computed to follow a sequence of fixed Mach Number and indicated airspeed segments.

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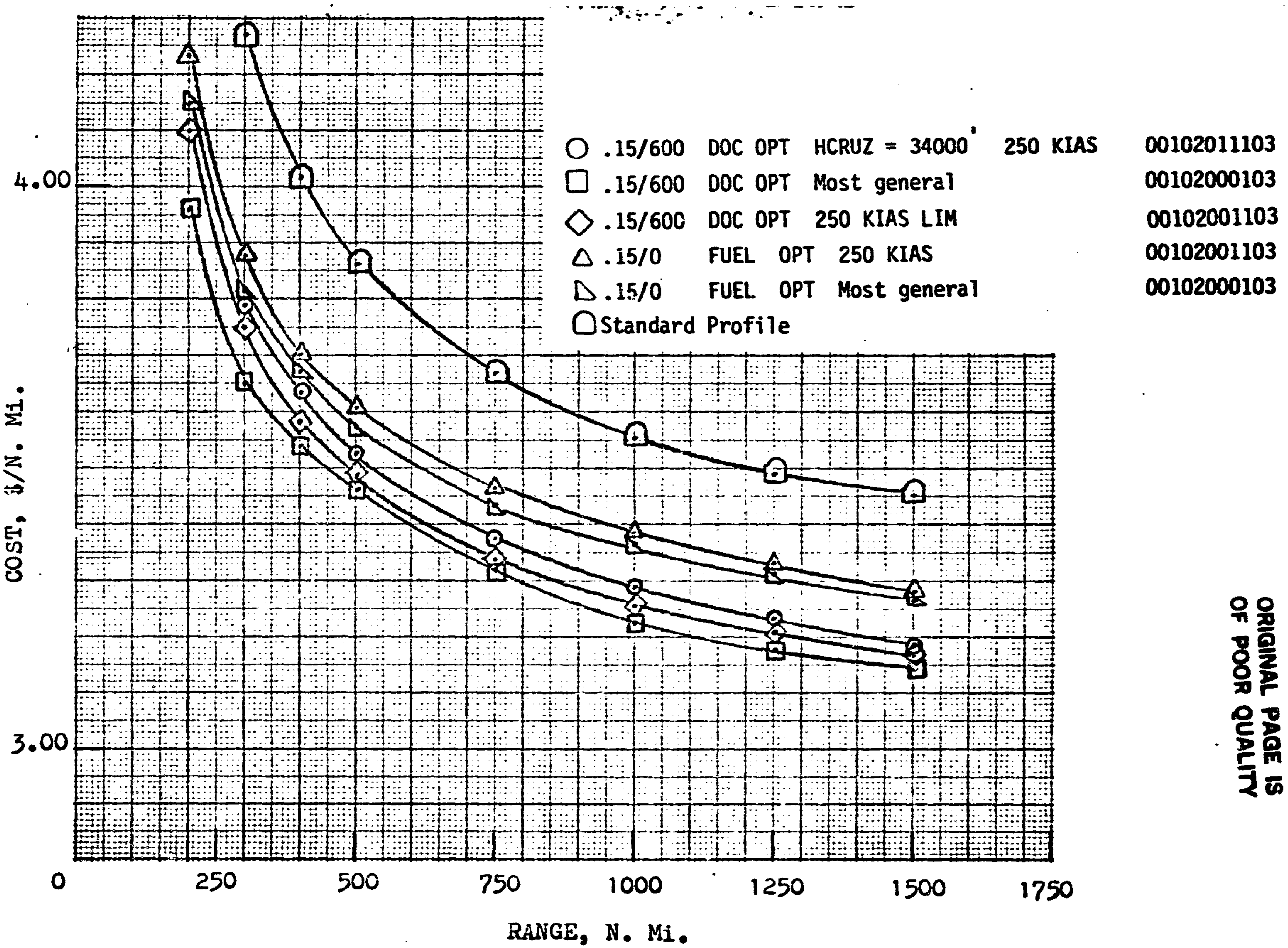

Figure 1. - Comparisons of cost savings of several types of optimal flight profiles over standard profile.

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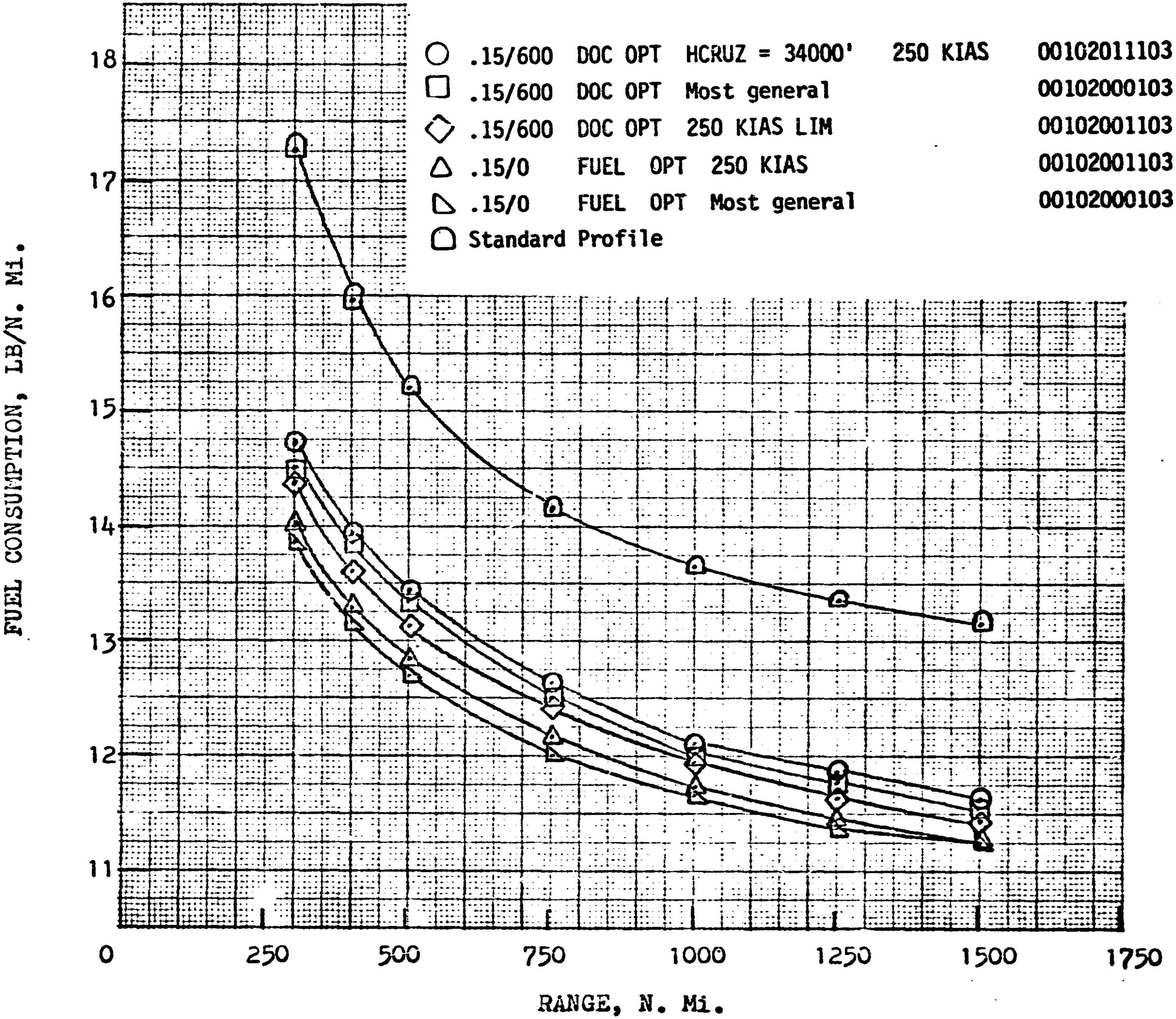

Figure 2. - Comparisons of fuel savings of several types of optimal flight profiles over standard profile.

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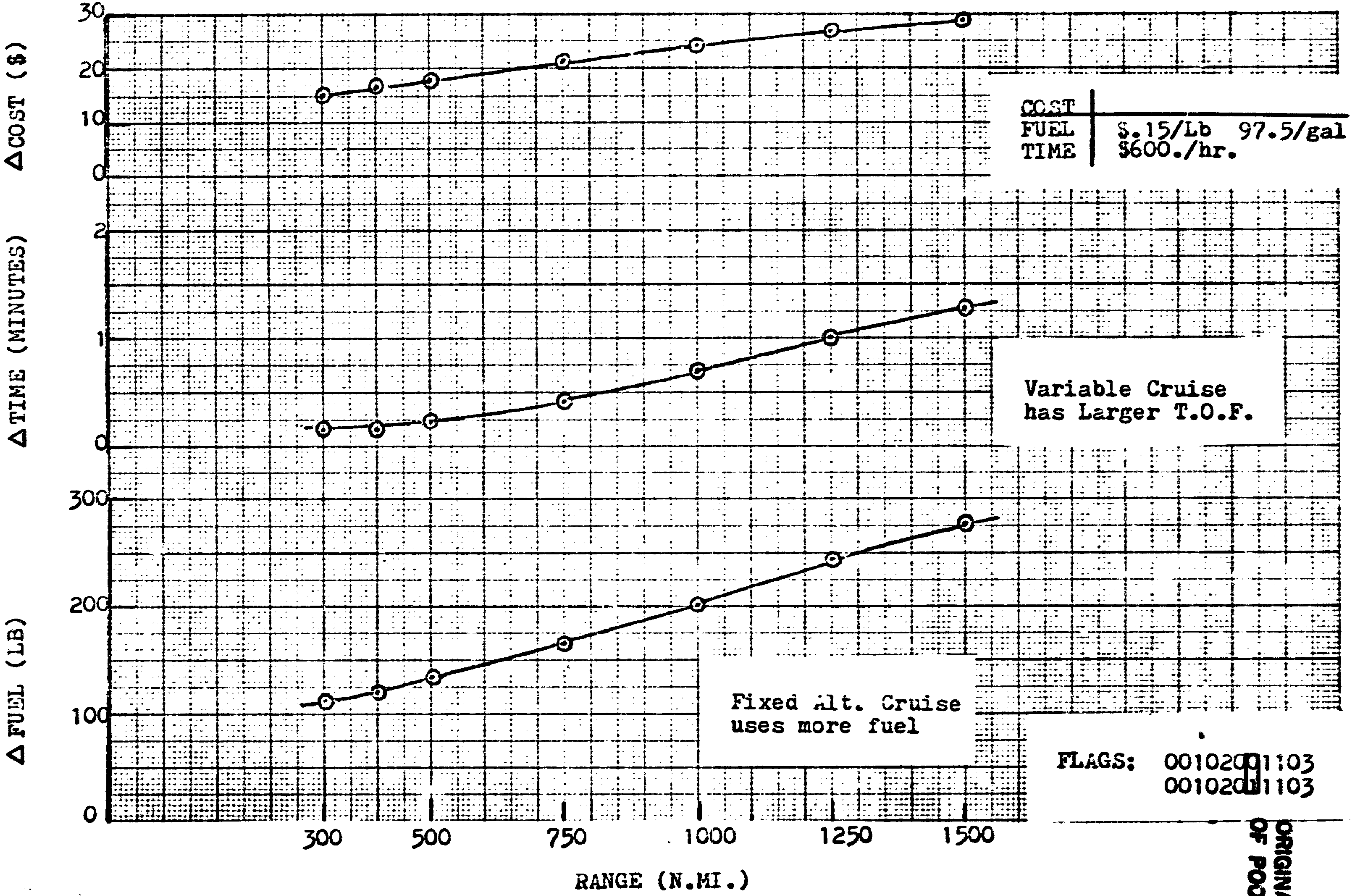
COMPARISON OF FIXED ALT. (34000 ft.) WITH UNRESTRAINED ALT.



FLAGS: 00102001103
00102001103

Figure 3. - Penalty in cost, fuel and time associated with the restriction of fixed cruise altitude.

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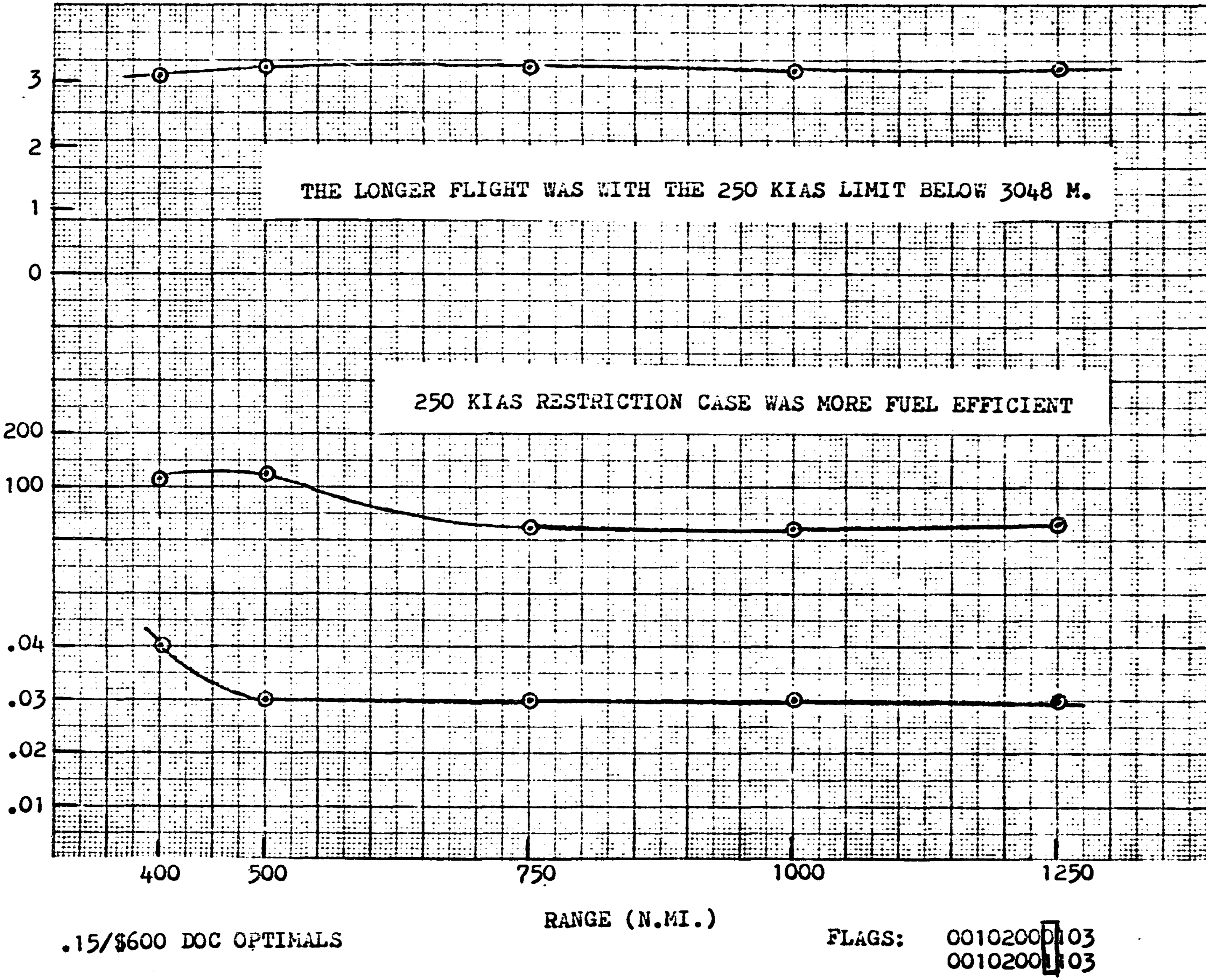

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Figure 4. - Cost, fuel, and time penalties due to a
250 knot IAS limit below 10,000 ft.

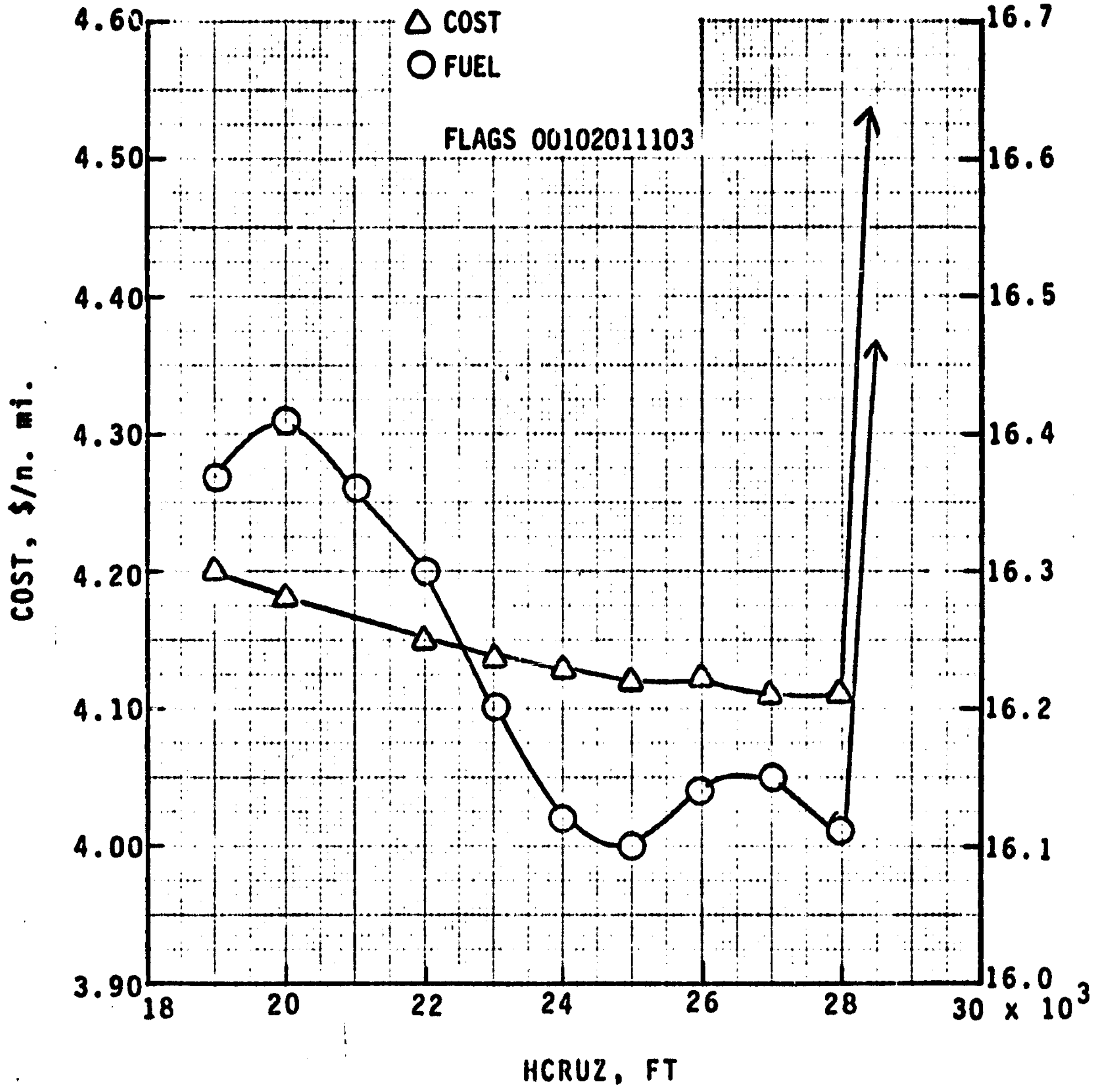

Figure 5.- Cost and fuel consumption per nautical mile as functions of fixed cruise altitude for 200 n. mi. range.

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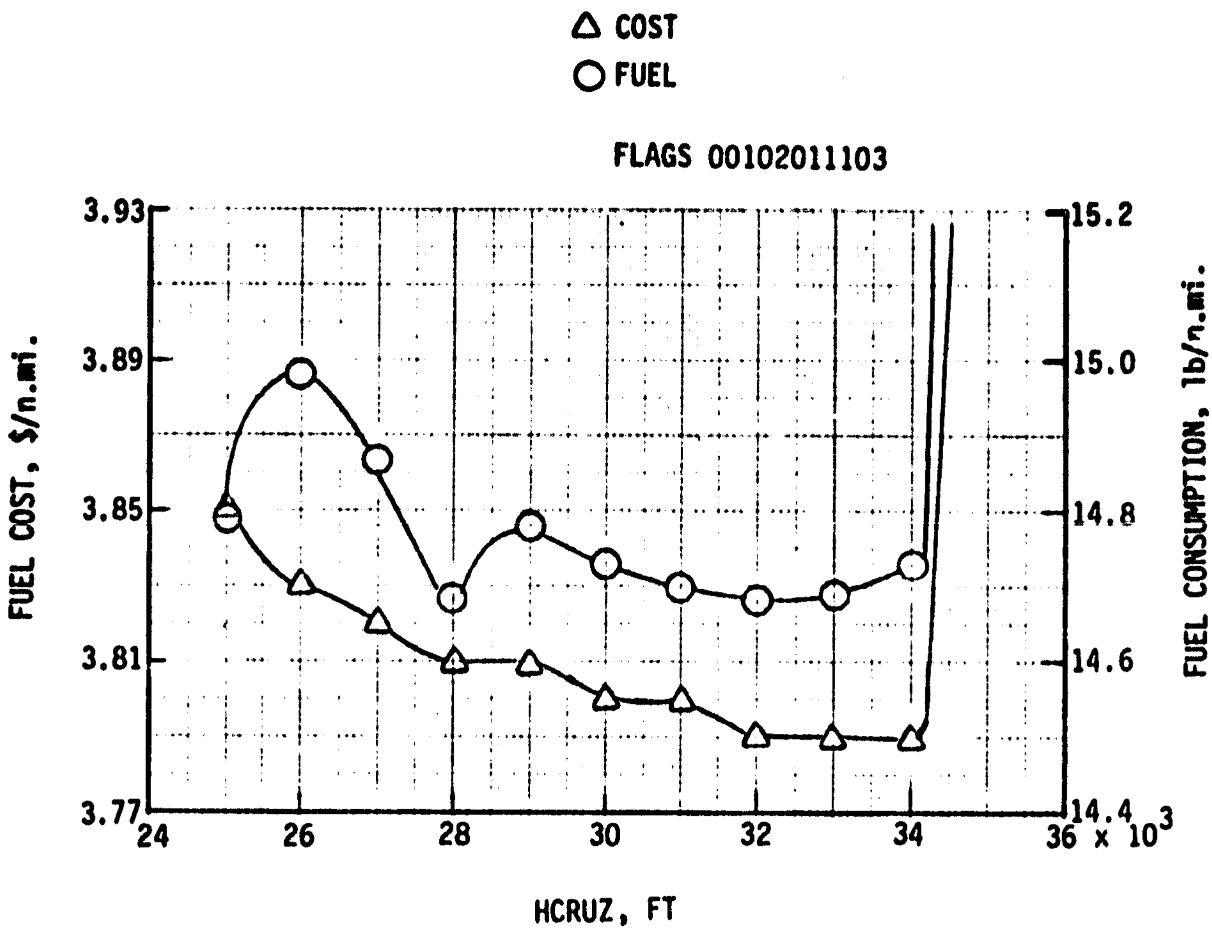

Figure 6.- Cost and fuel consumption per nautical mile as functions of fixed cruise altitude for 300 n. mi. range.

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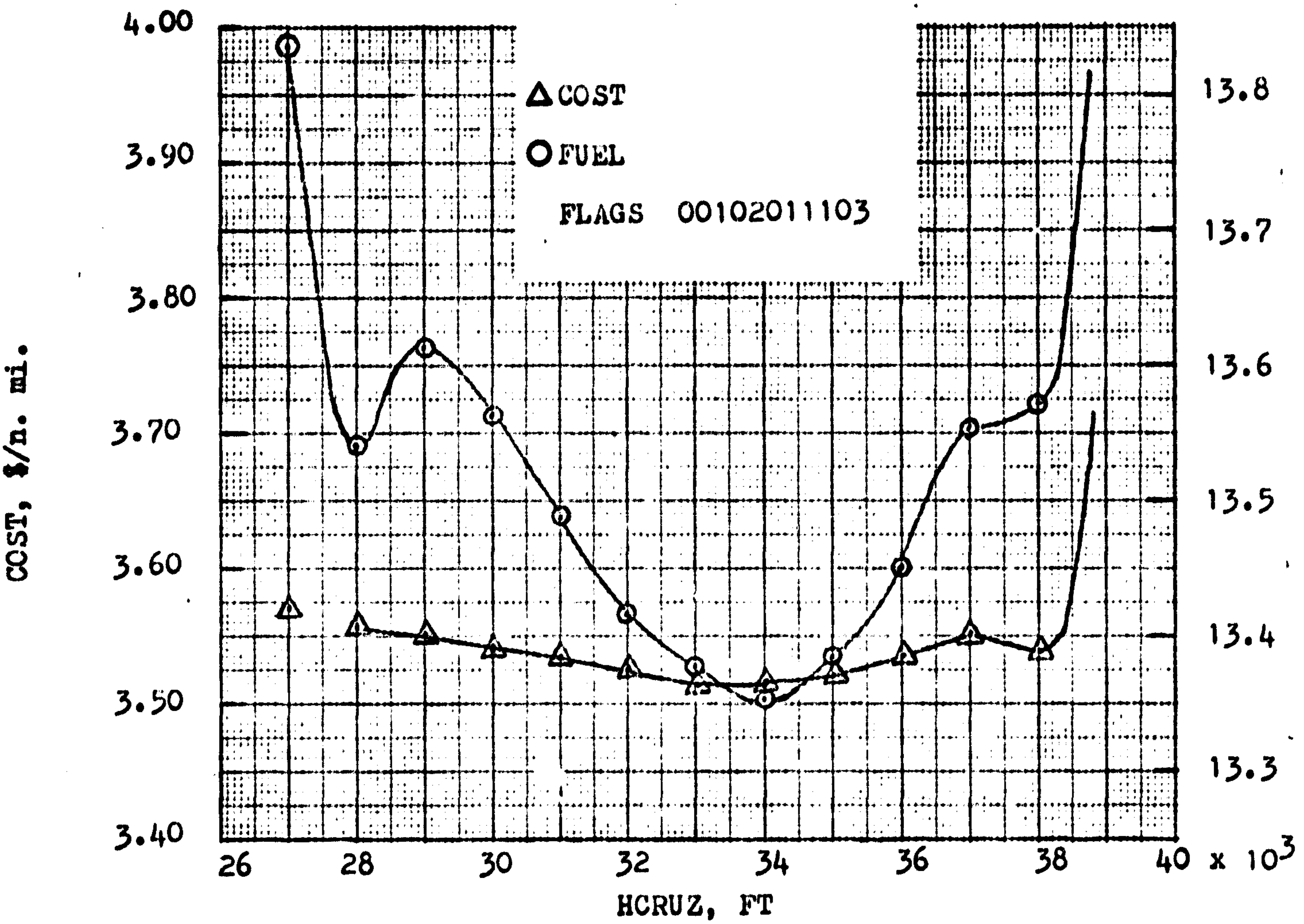

Figure 7. - Cost and fuel consumption per nautical mile as functions of fixed cruise altitude for 500 n. mi. range.

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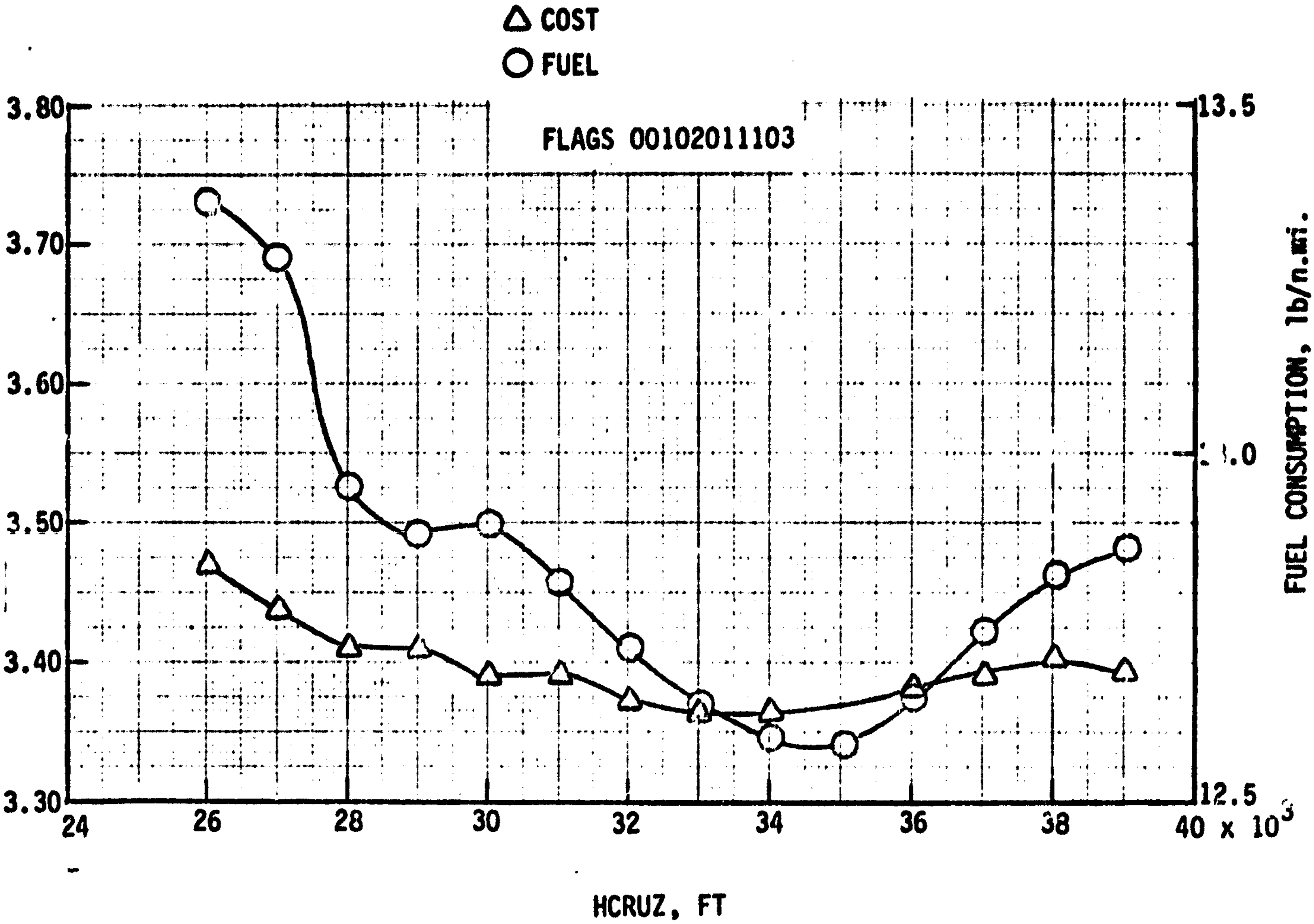

Figure 8.- Cost and fuel consumption per nautical mile as functions of fixed cruise altitude for 750 n. mi. range.

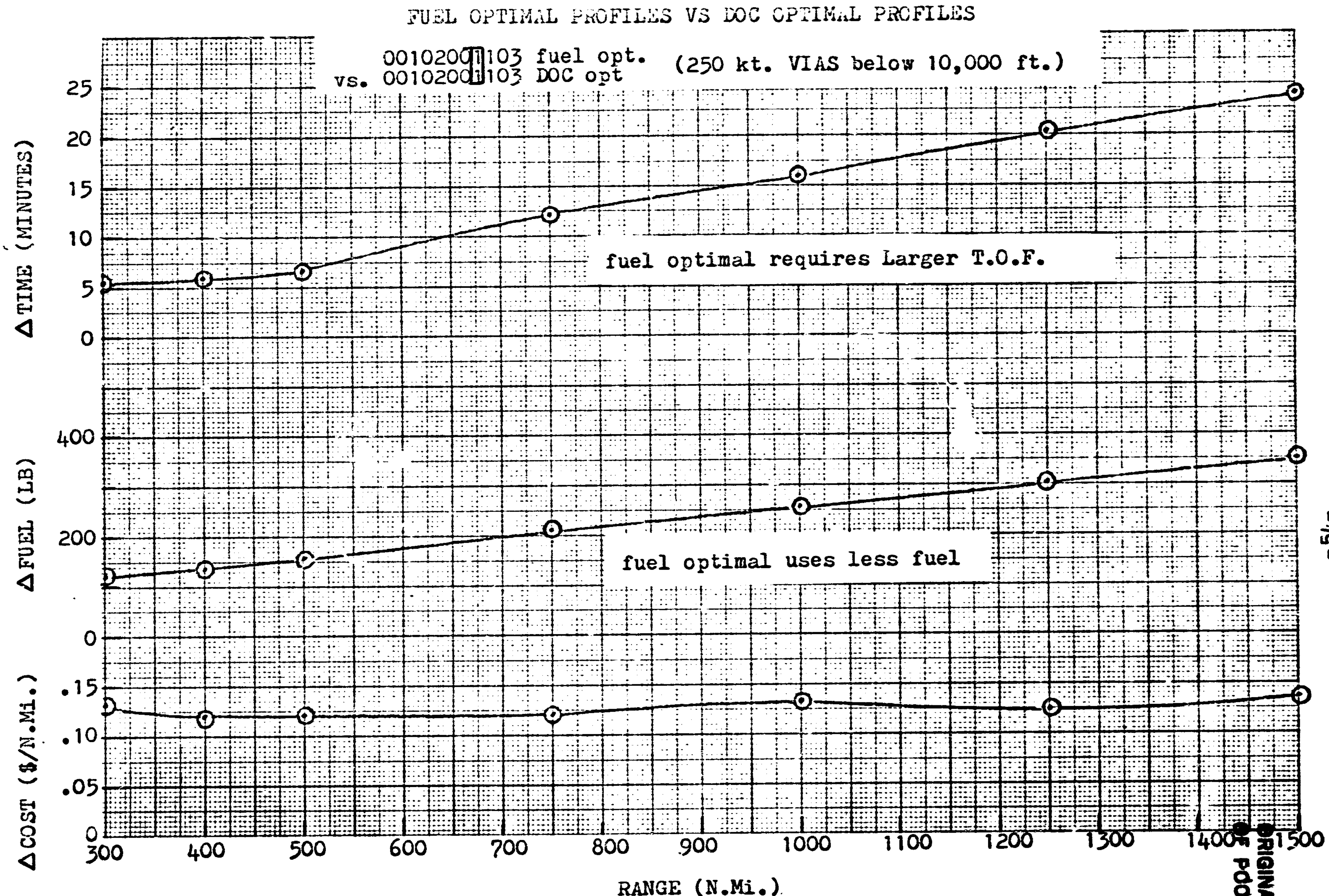

Figure 9. - Cost, fuel, and time penalties between DOC optimal and fuel optimal flight profiles.

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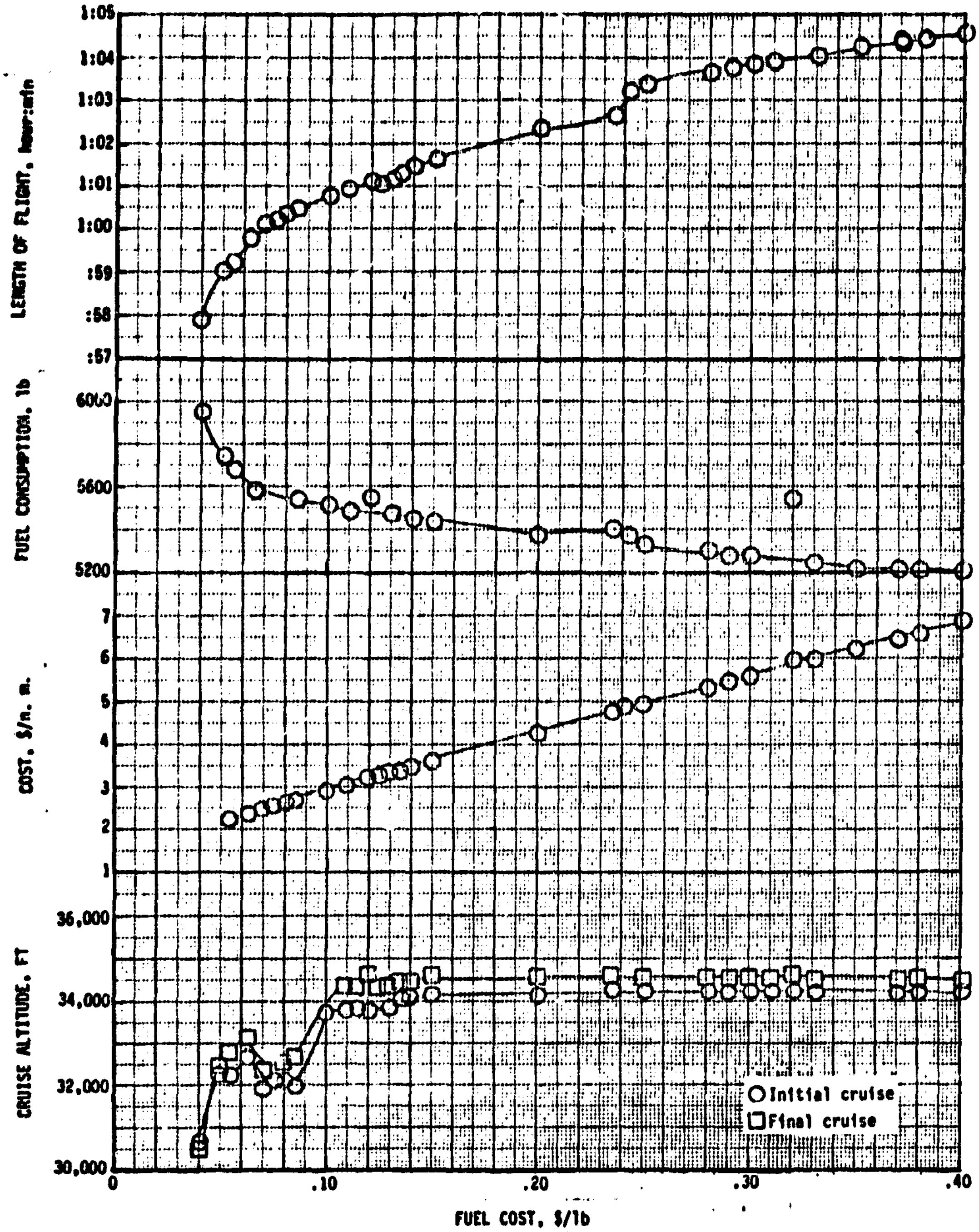

Figure 10.- Effects of fuel cost on time of flight, direct operating cost, fuel consumed, and initial and final cruise altitudes for 400 n. mi. range.

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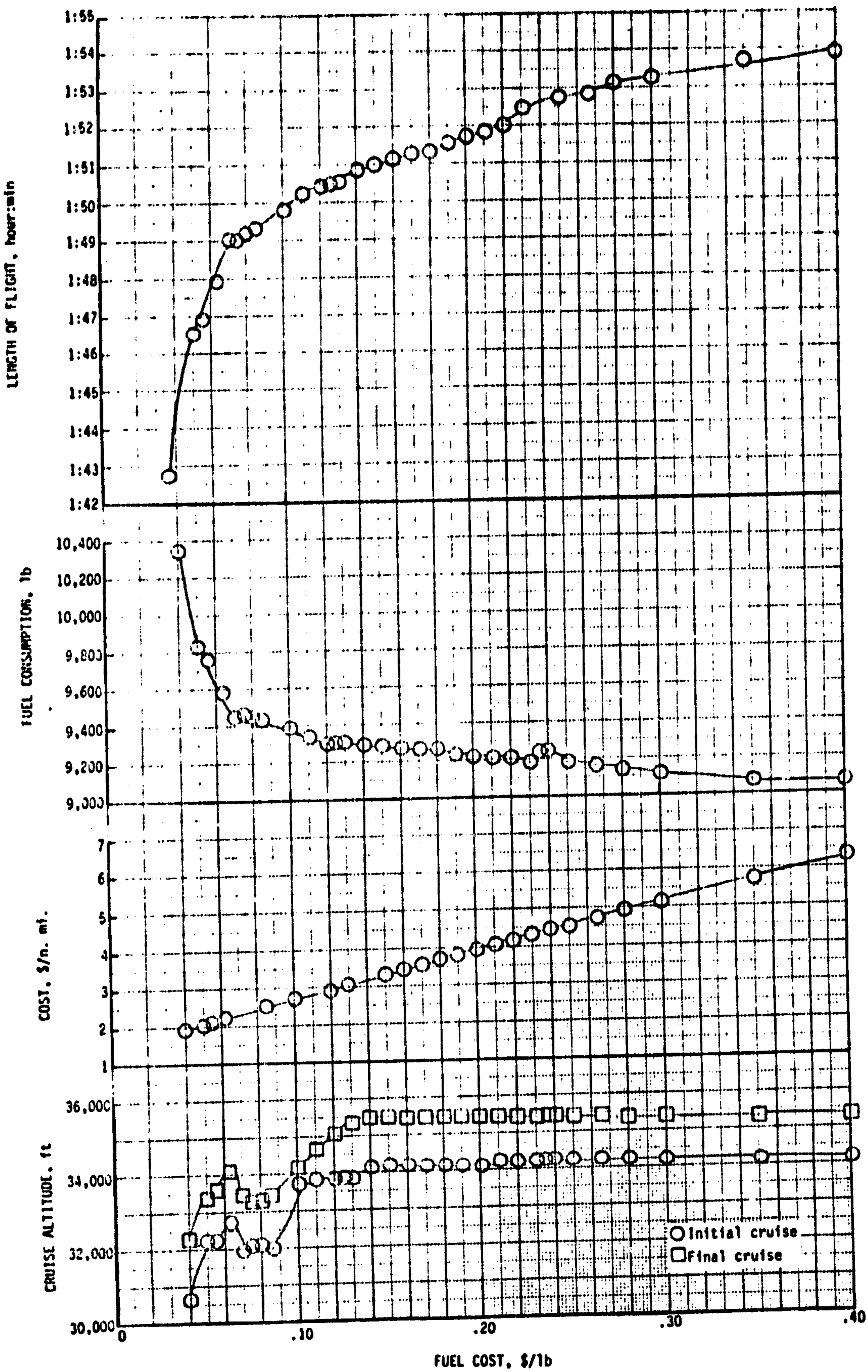

Figure 11.- Effects of fuel cost on time of flight, direct operating cost, fuel consumed, and initial and final cruise altitudes for 750 n. mi. range

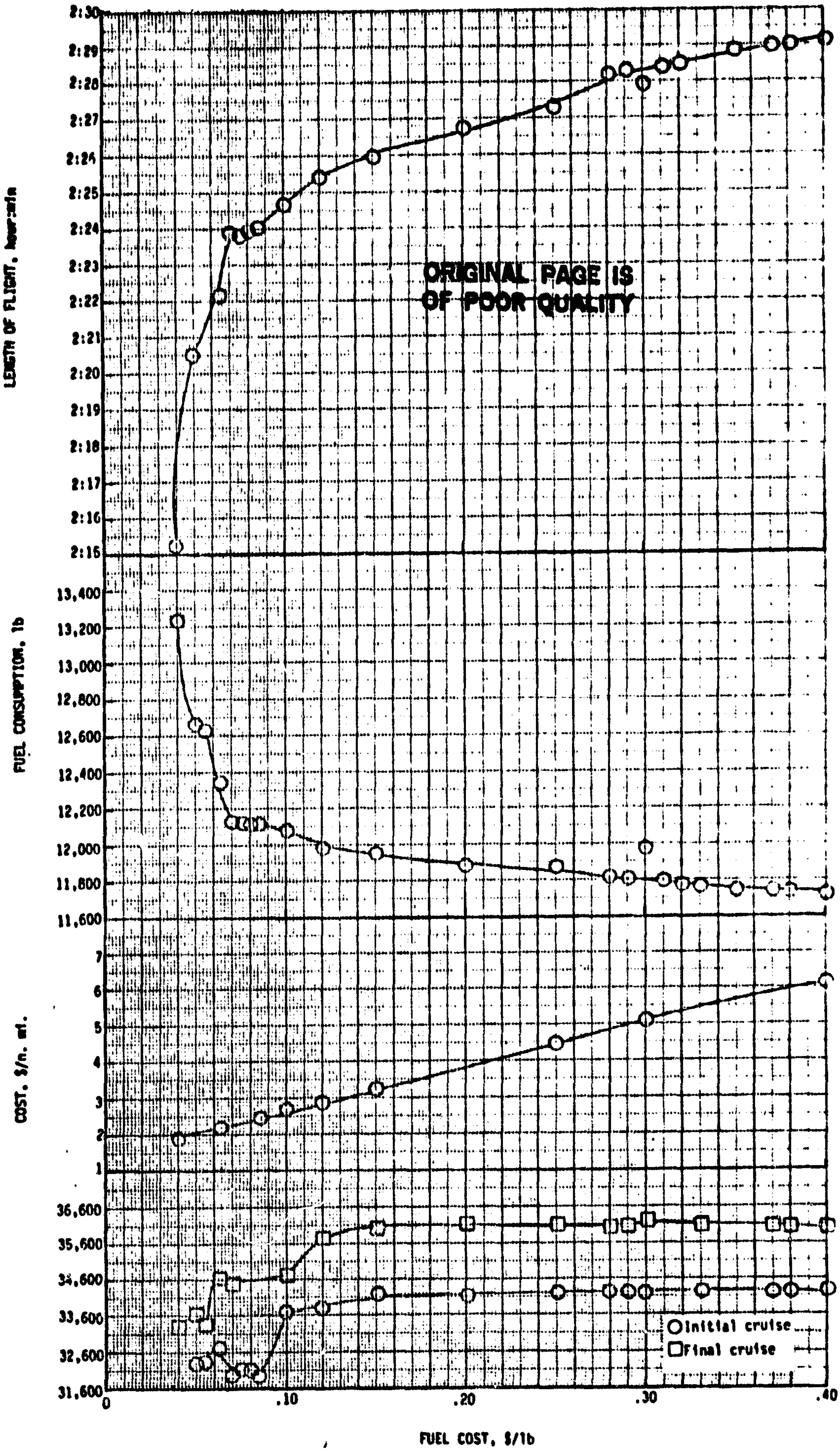

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Figure 12.- Effects of fuel cost on time of flight, direct operating cost, fuel consumed, and initial and final cruise altitudes for 1000 n. mi. range.

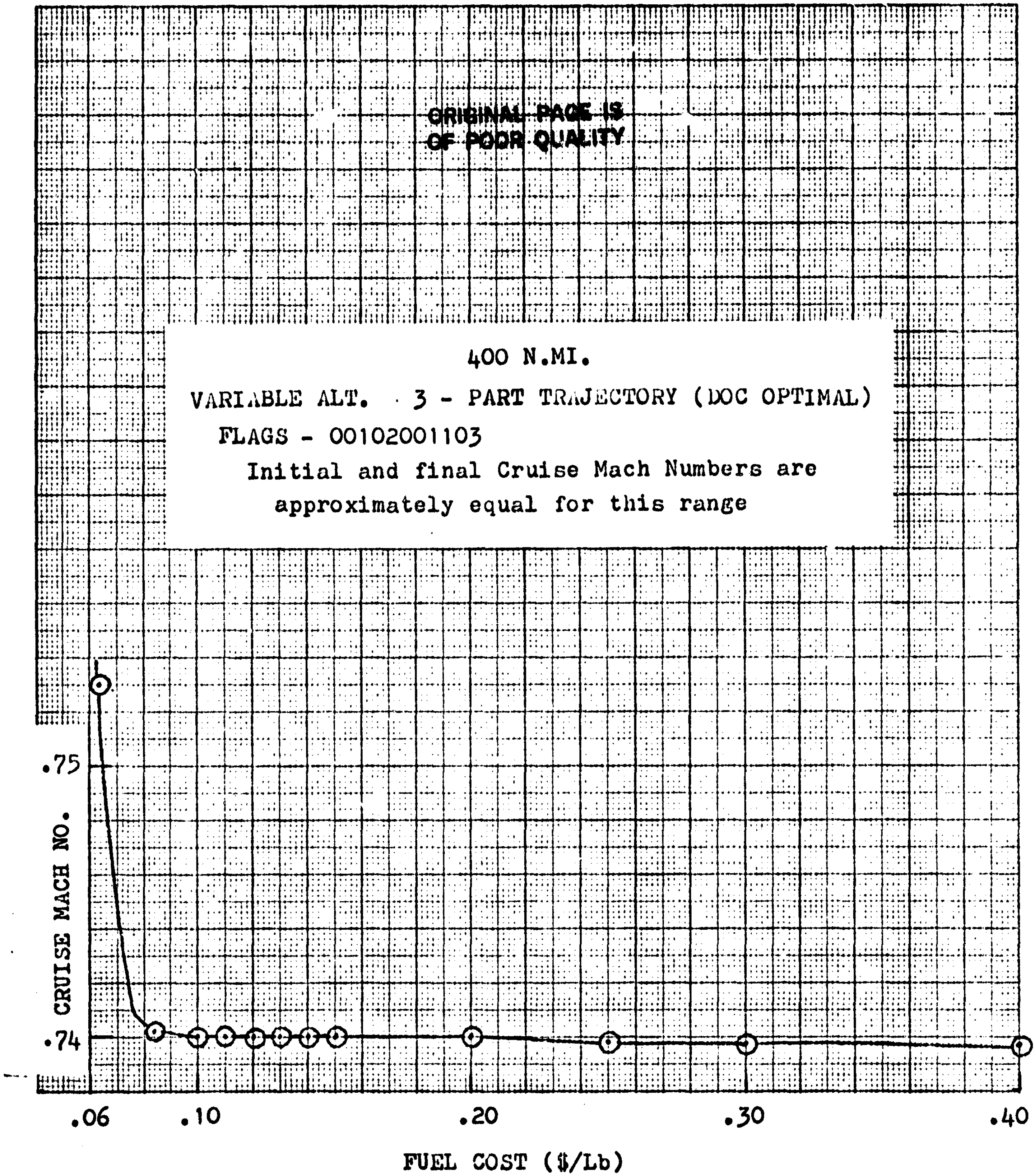

Figure 13. - Cruise mach as a function of fuel cost for 400 n. mi. trip.

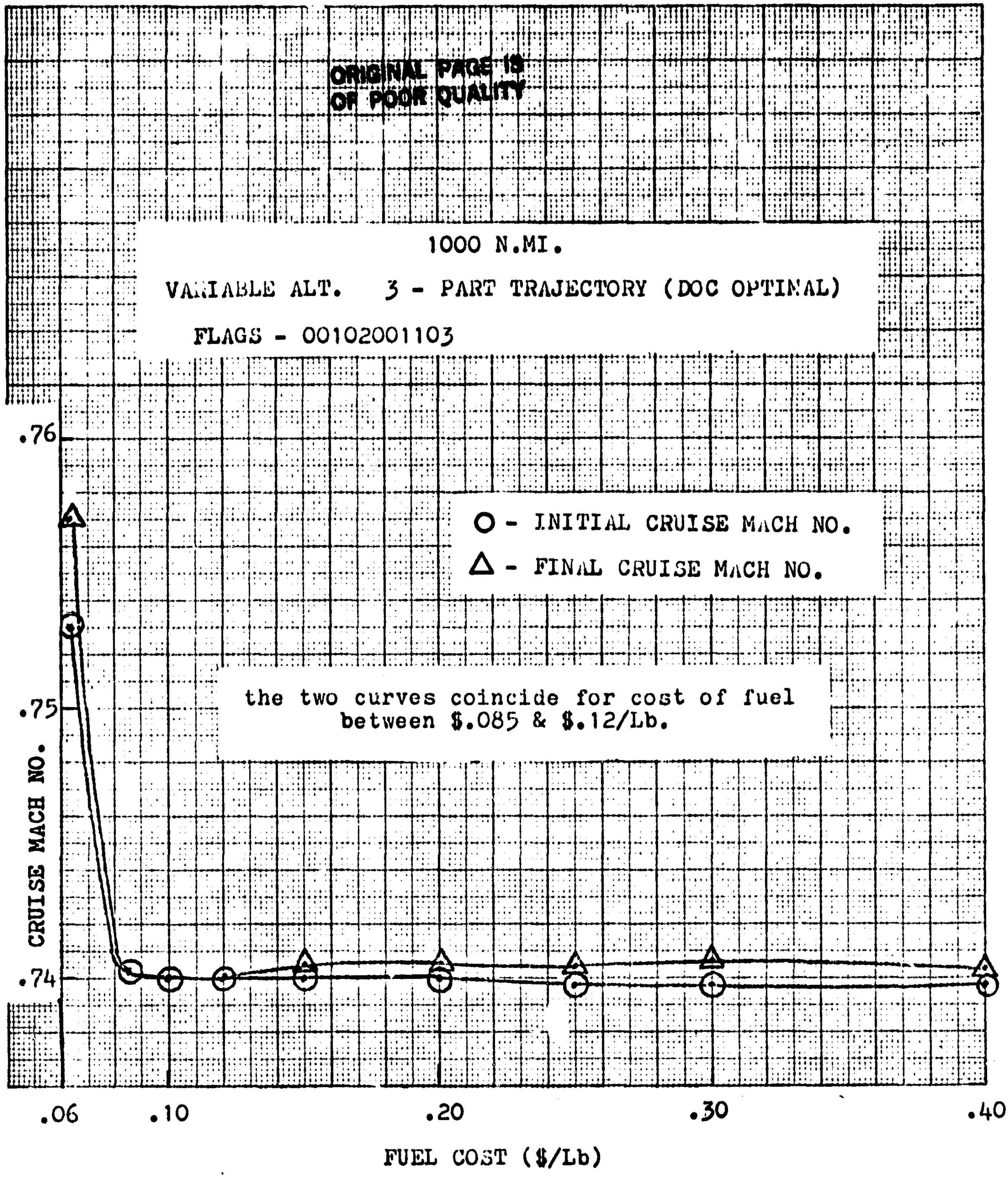

Figure 14. - Initial and final cruise mach numbers as functions of fuel cost for 1000 n. mi. trip.

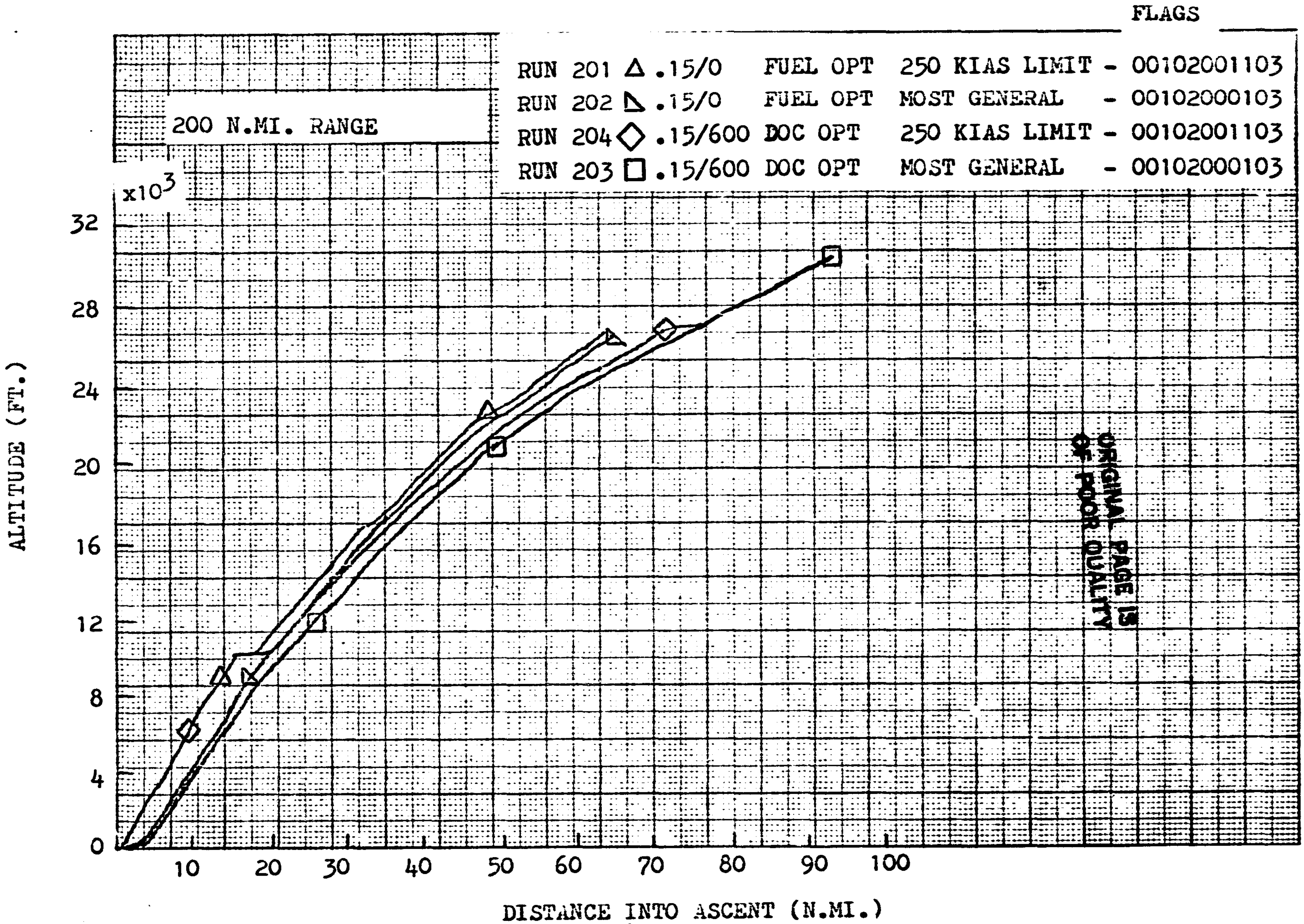

Figure 15a. - Comparisons of the vertical flight (Distance-Altitude) Profiles (Ascent) at 200 N.Mi. range. See figure 15b for Descent.

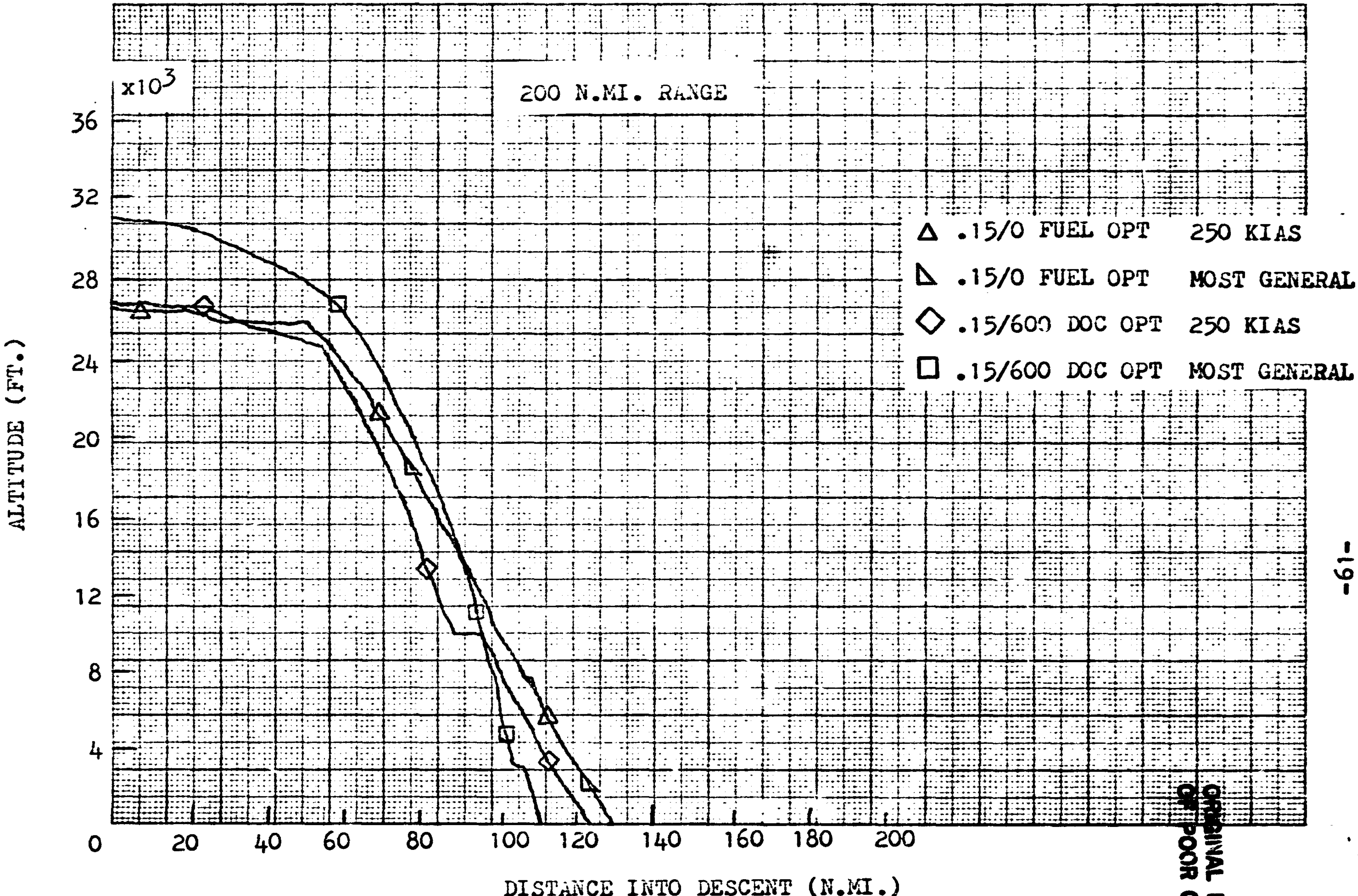

Figure 15b. - Descent portions of vertical flight profiles at 200 N.Mi. range.

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CLIMB-DESCENT

RUN201 FUEL OPTIMAL - 250 KIAS LIMIT

200 N.MI.

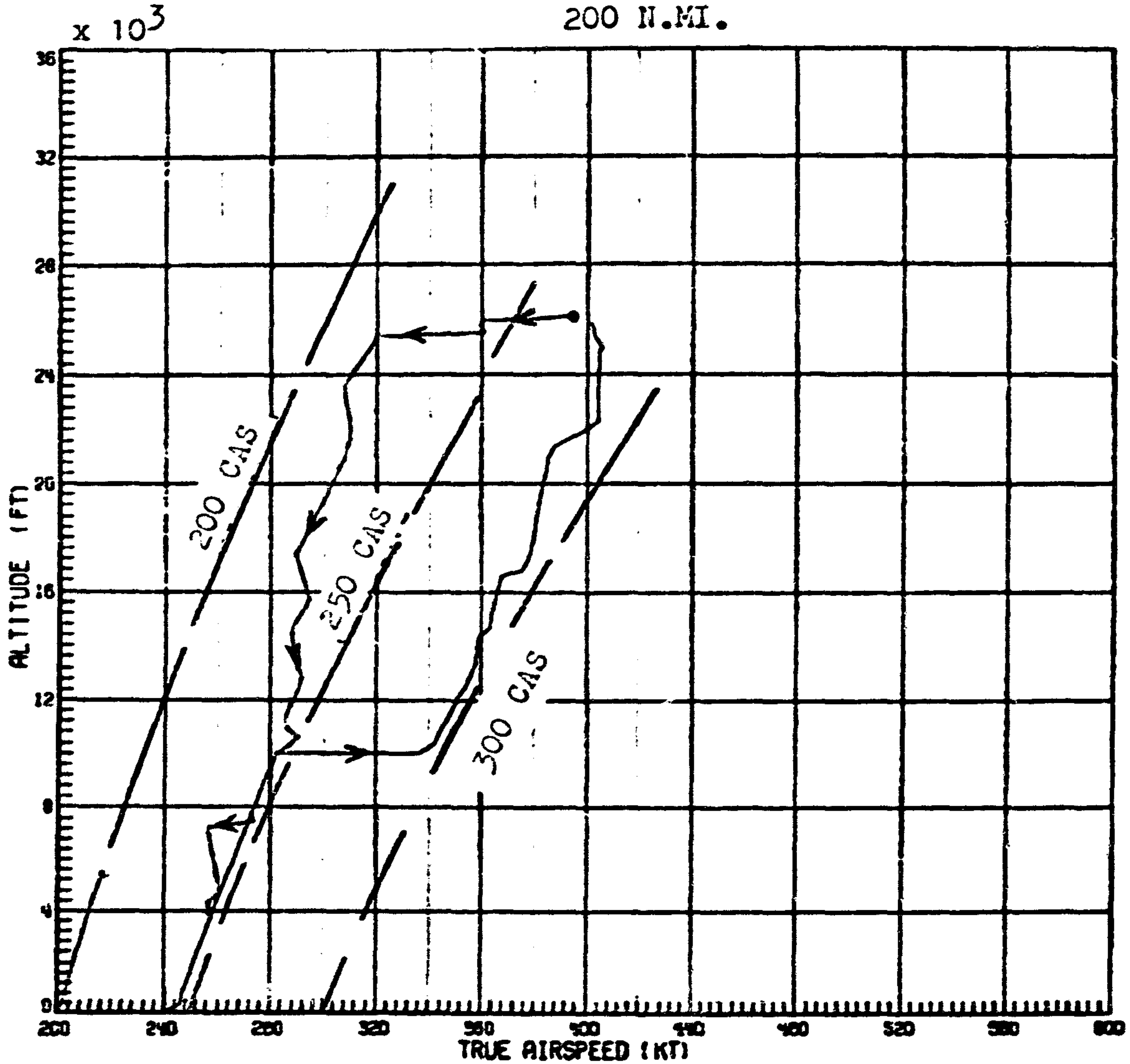

Figure 16.1 - AIRSPEED-ALTITUDE RELATIONSHIP FOR RUN 201

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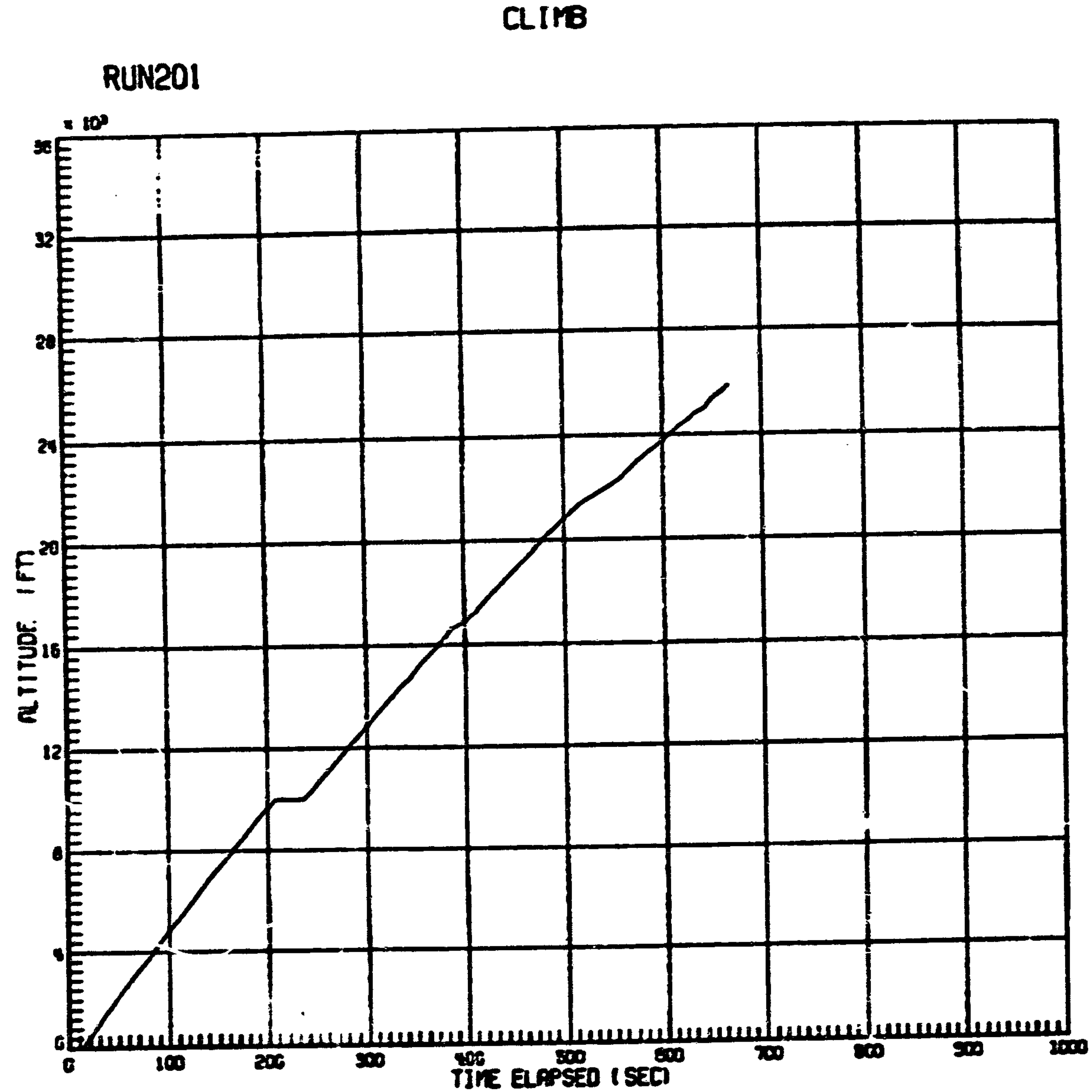

Figure 16.2 - TIME-ALTITUDE RELATION FOR RUN 201

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DESCENT

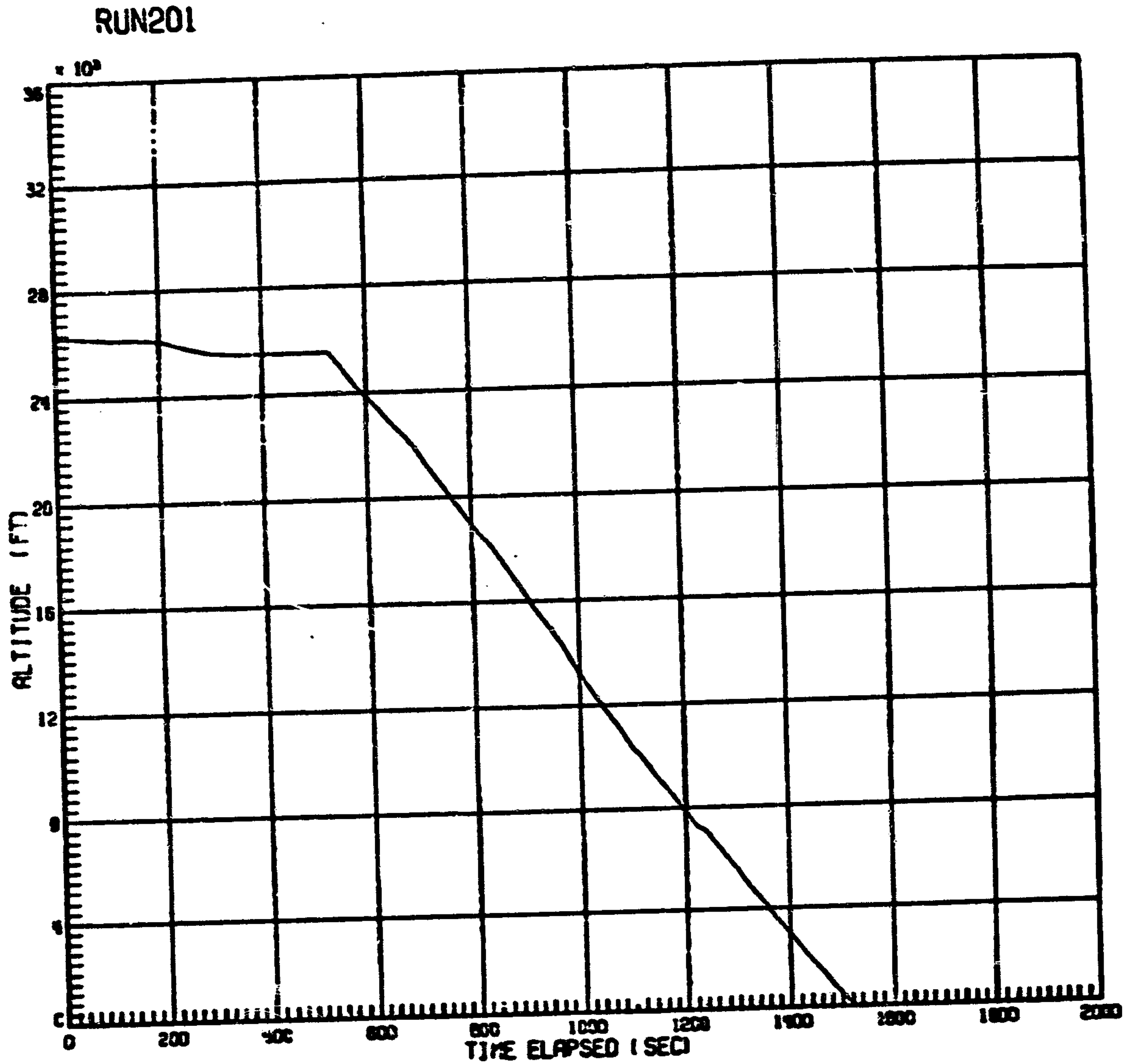

Figure 16.2 (DESCENT)

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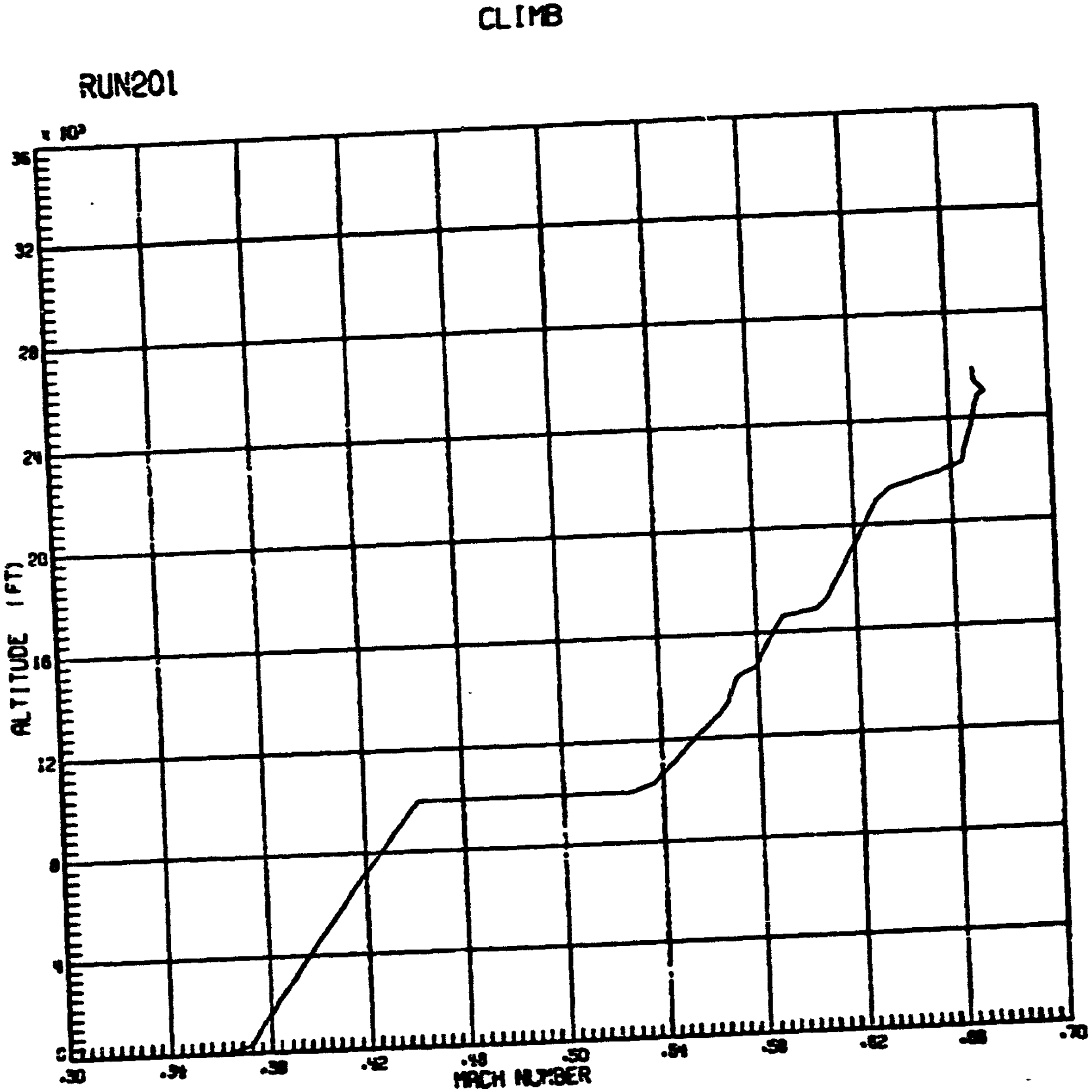

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Figure 16.3 - MACH-ALTITUDE RELATION FOR RUN 201

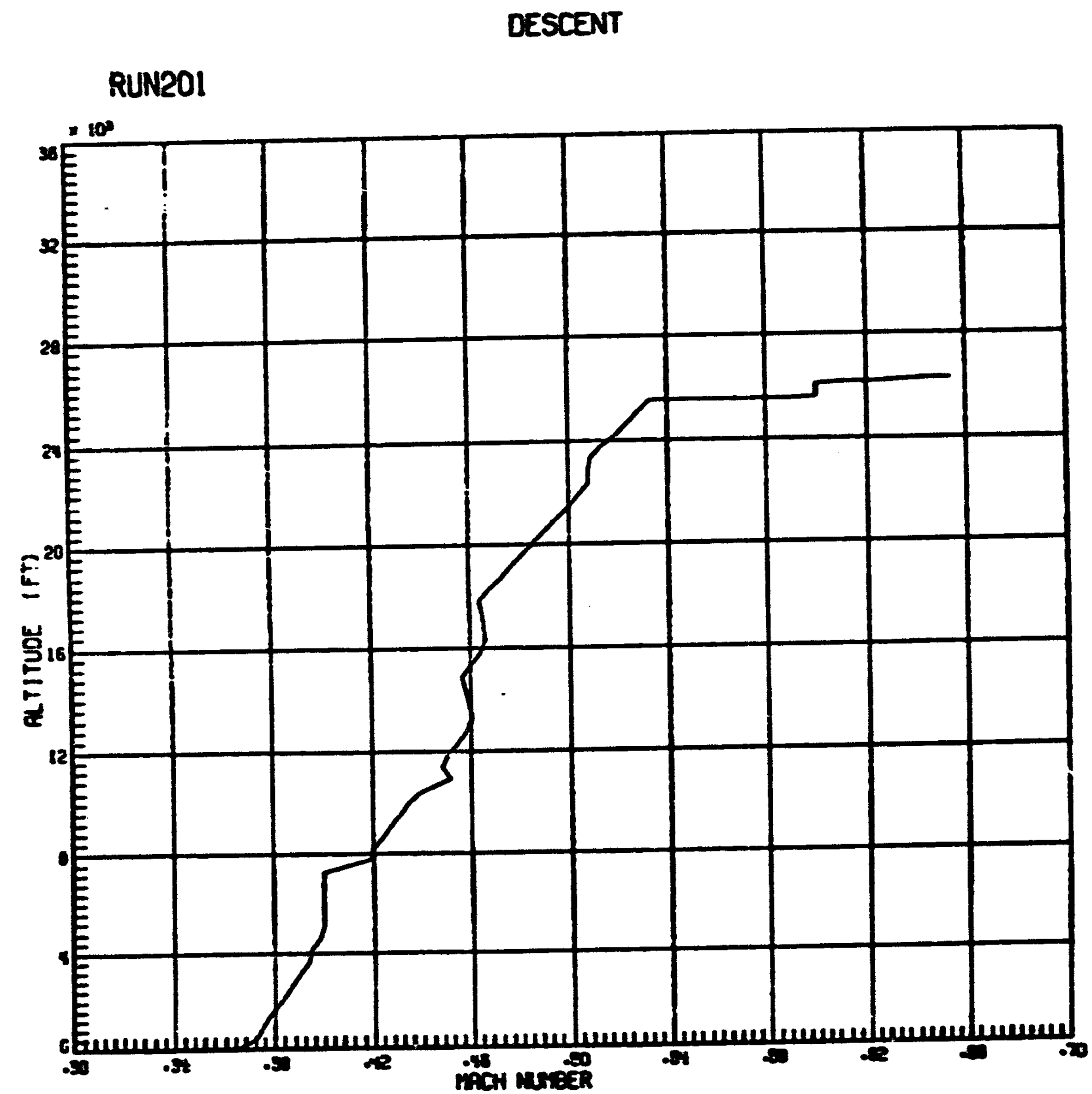

Figure 16.3 (DESCENT)

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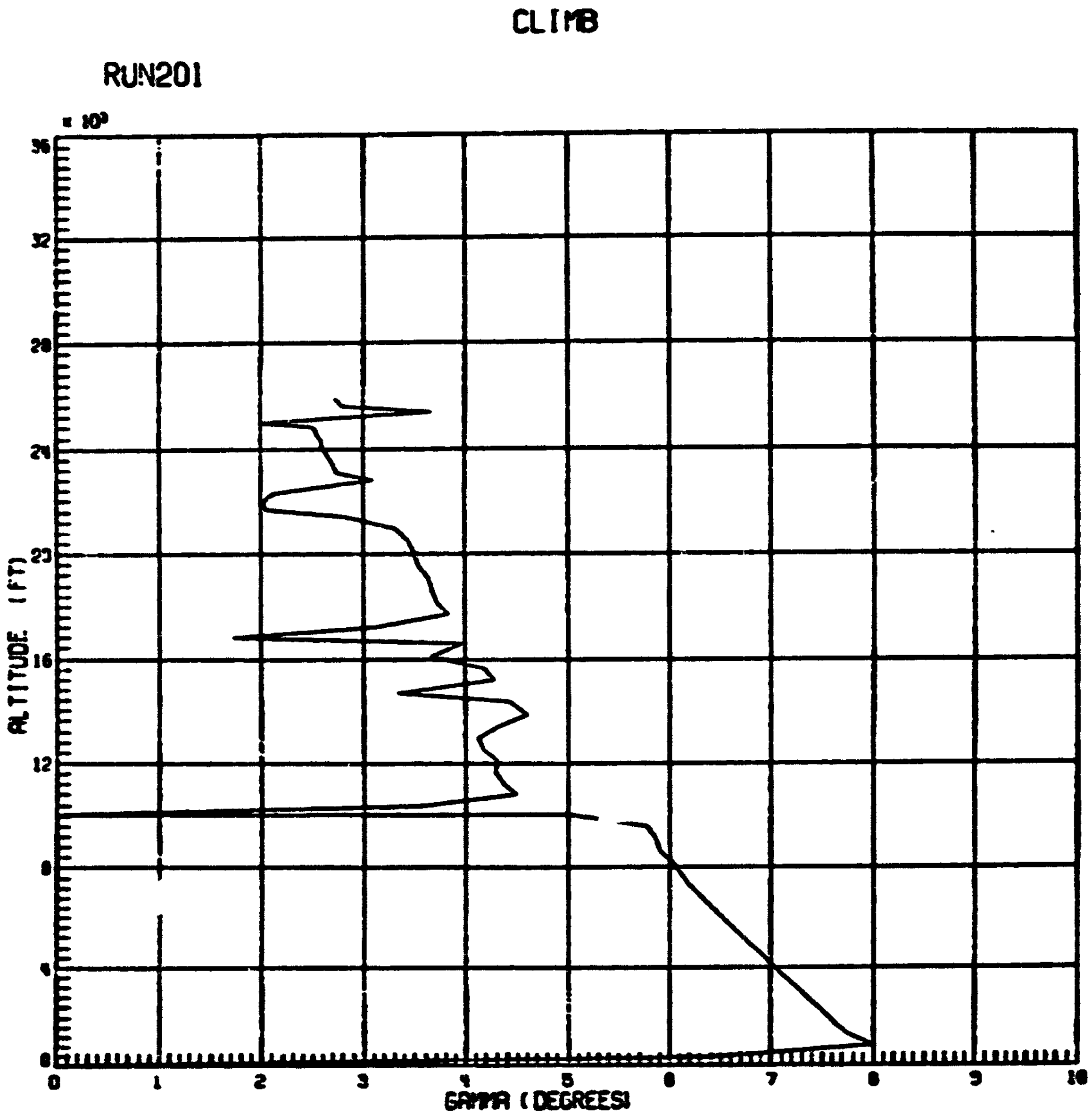

Figure 16.4 - FLIGHT PATH ANGLE-ALTITUDE FOR RUN 201

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RUN201 FUEL OPTIMAL 250 KIAS<10000 FT.

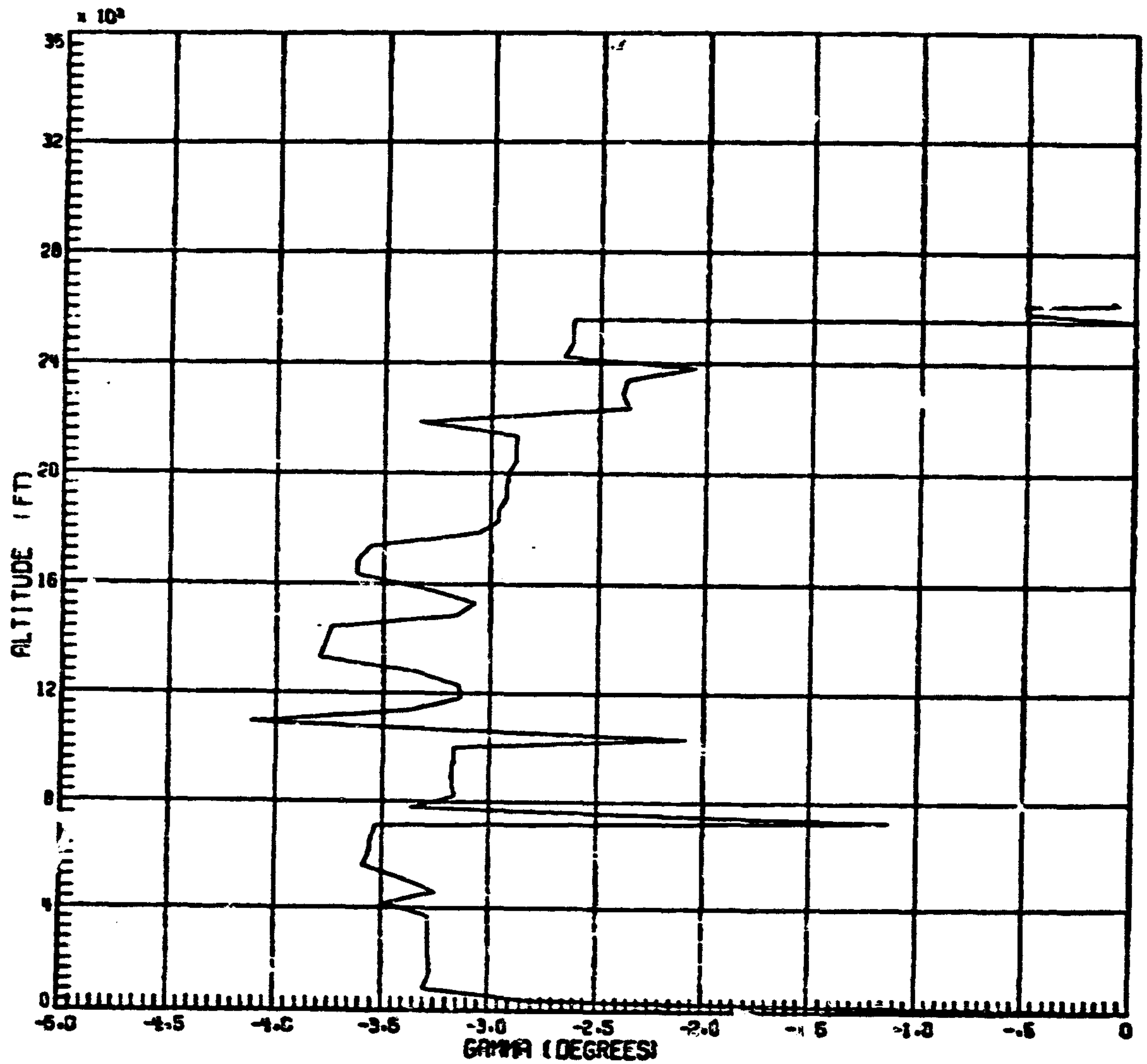

Figure 16.4 (DESCENT)

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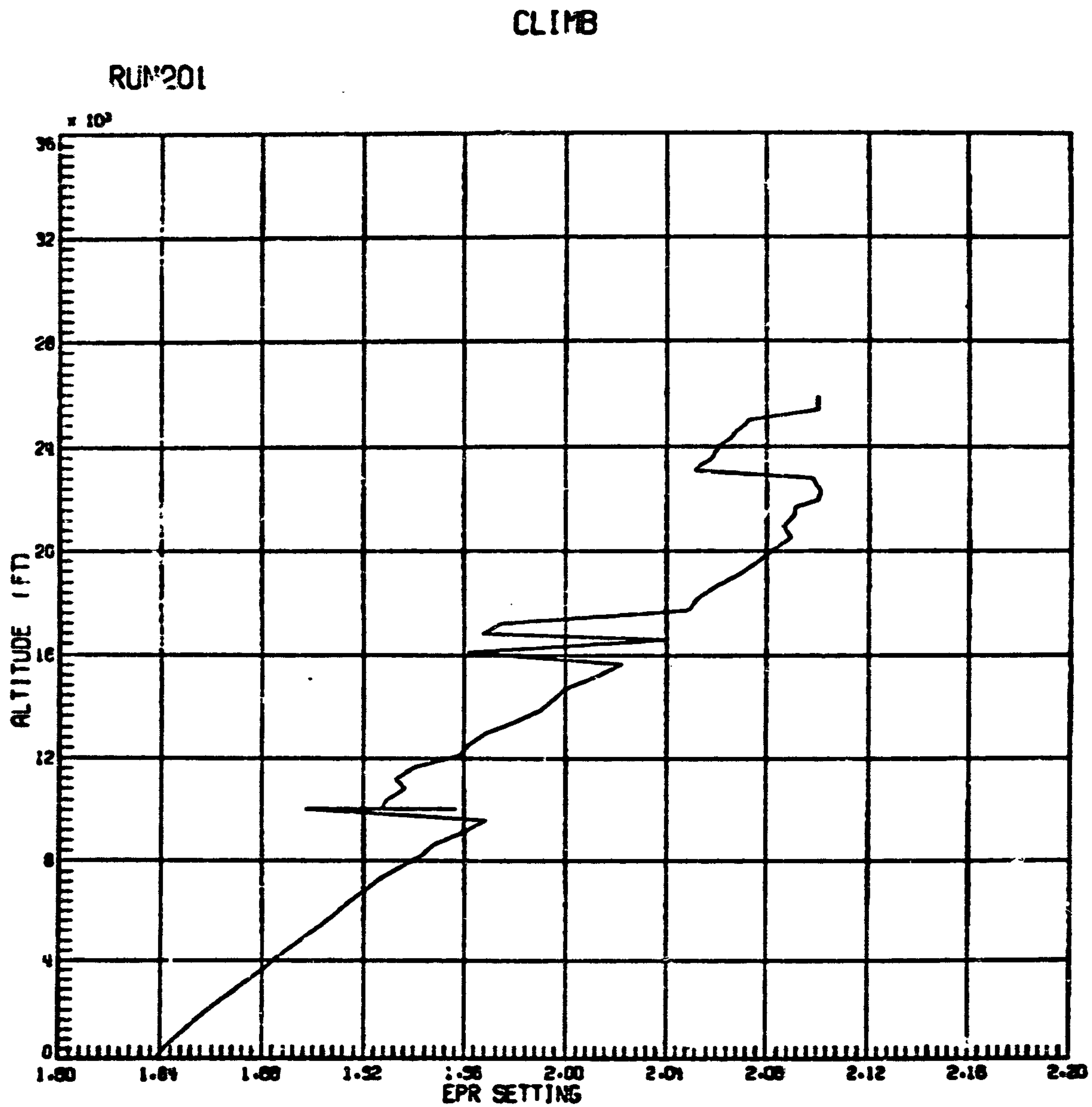

Figure 16.5 - EXHAUST PRESSURE RATIO - ALTITUDE RELATION FOR RUN 201

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RUN20! FUEL OPTIMAL 250 KIAS<10000 FT.

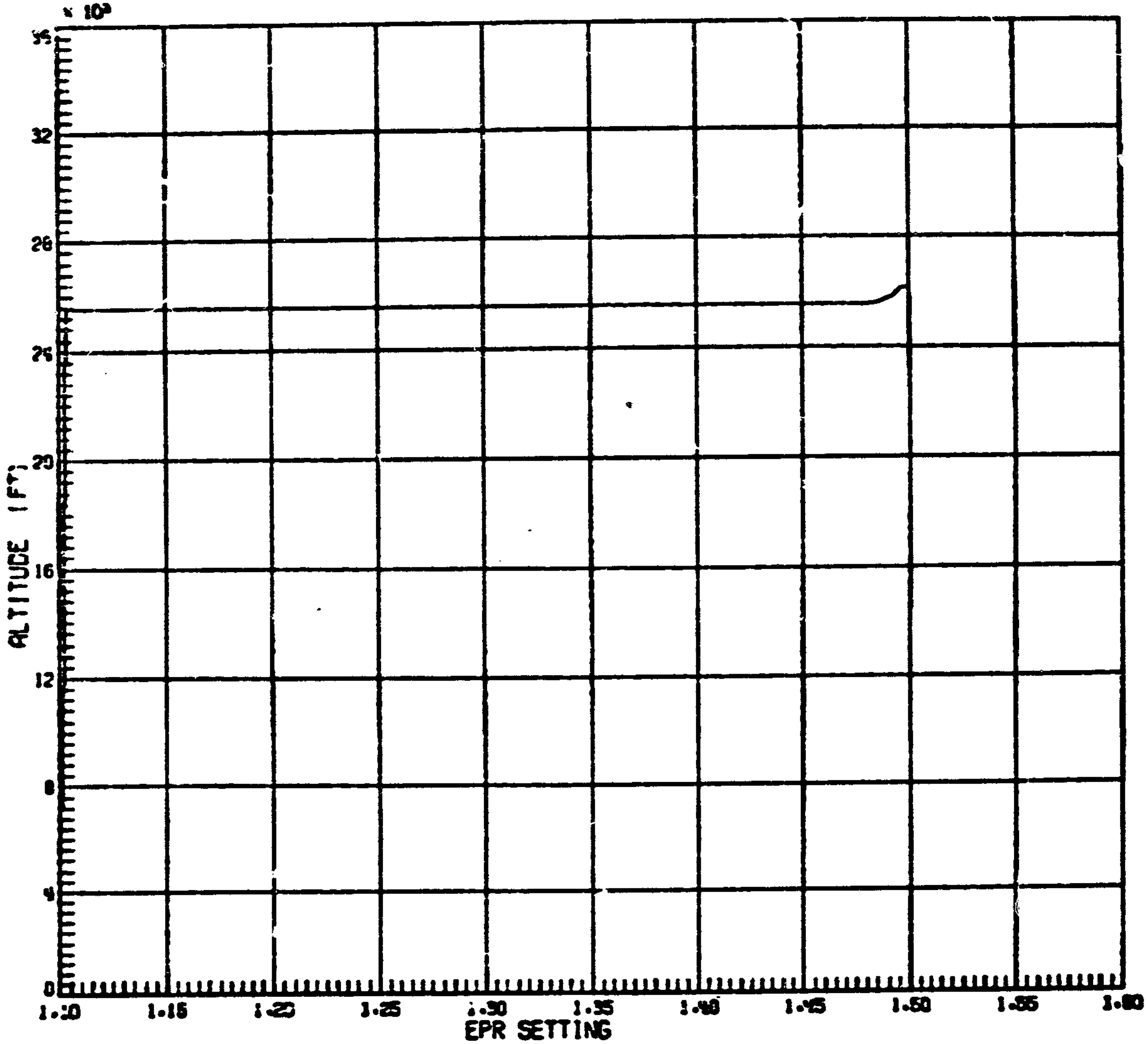

Figure 16.5 (DESCENT)

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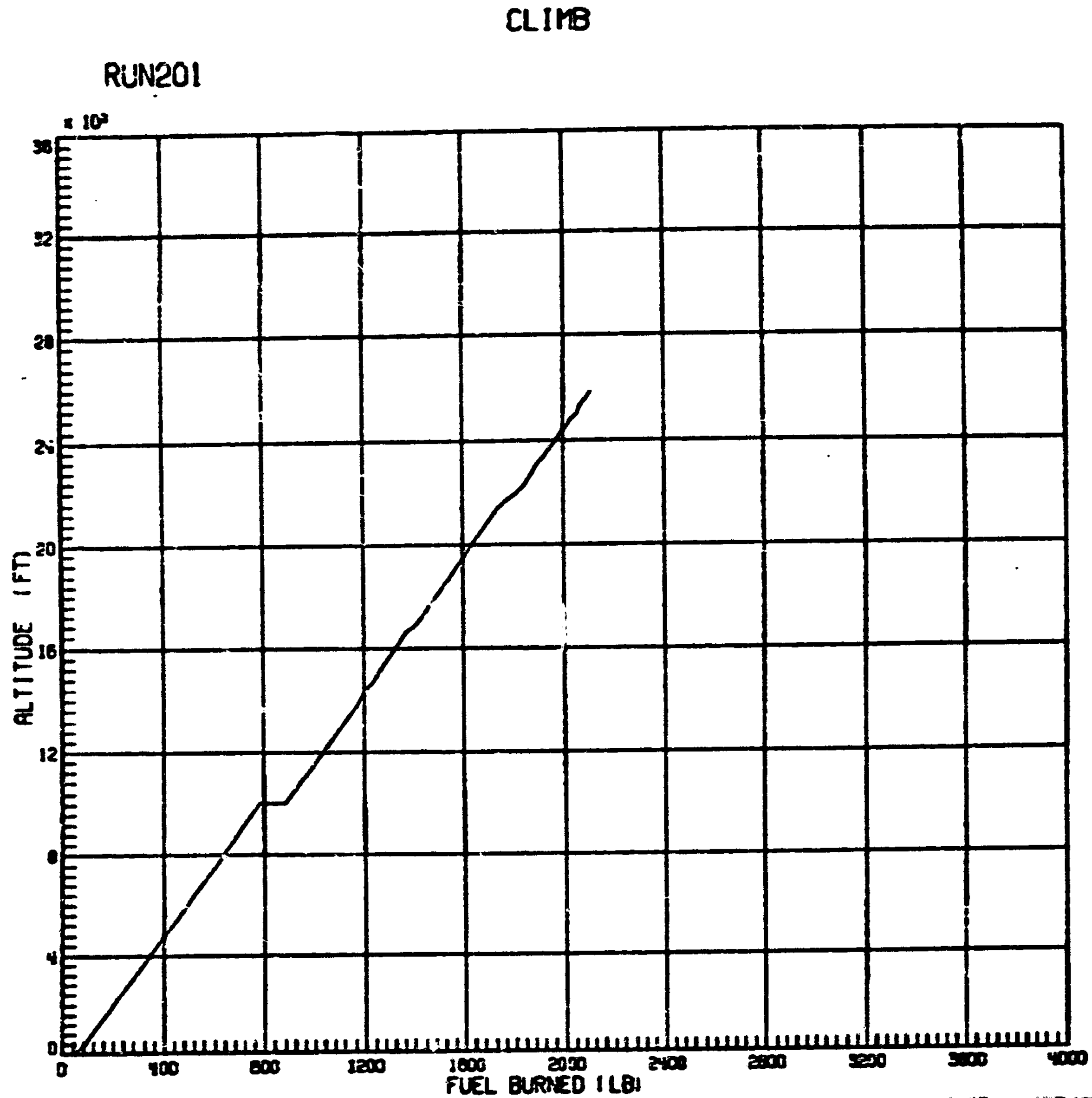

Figure 16.6 - FUEL BURNED - ALTITUDE RELATION
FOR RUN 201

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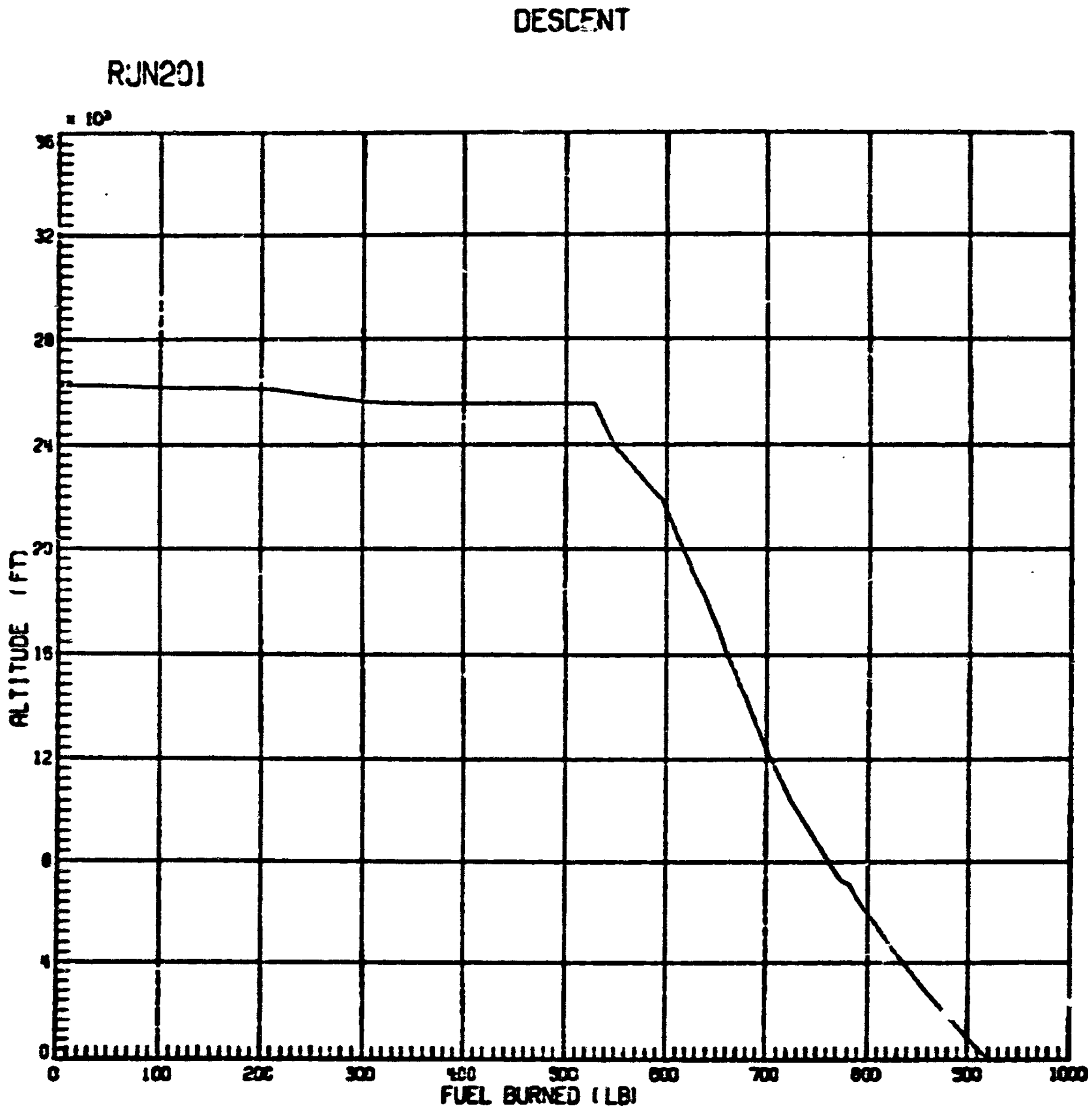

Figure 16.6 (DESCENT)

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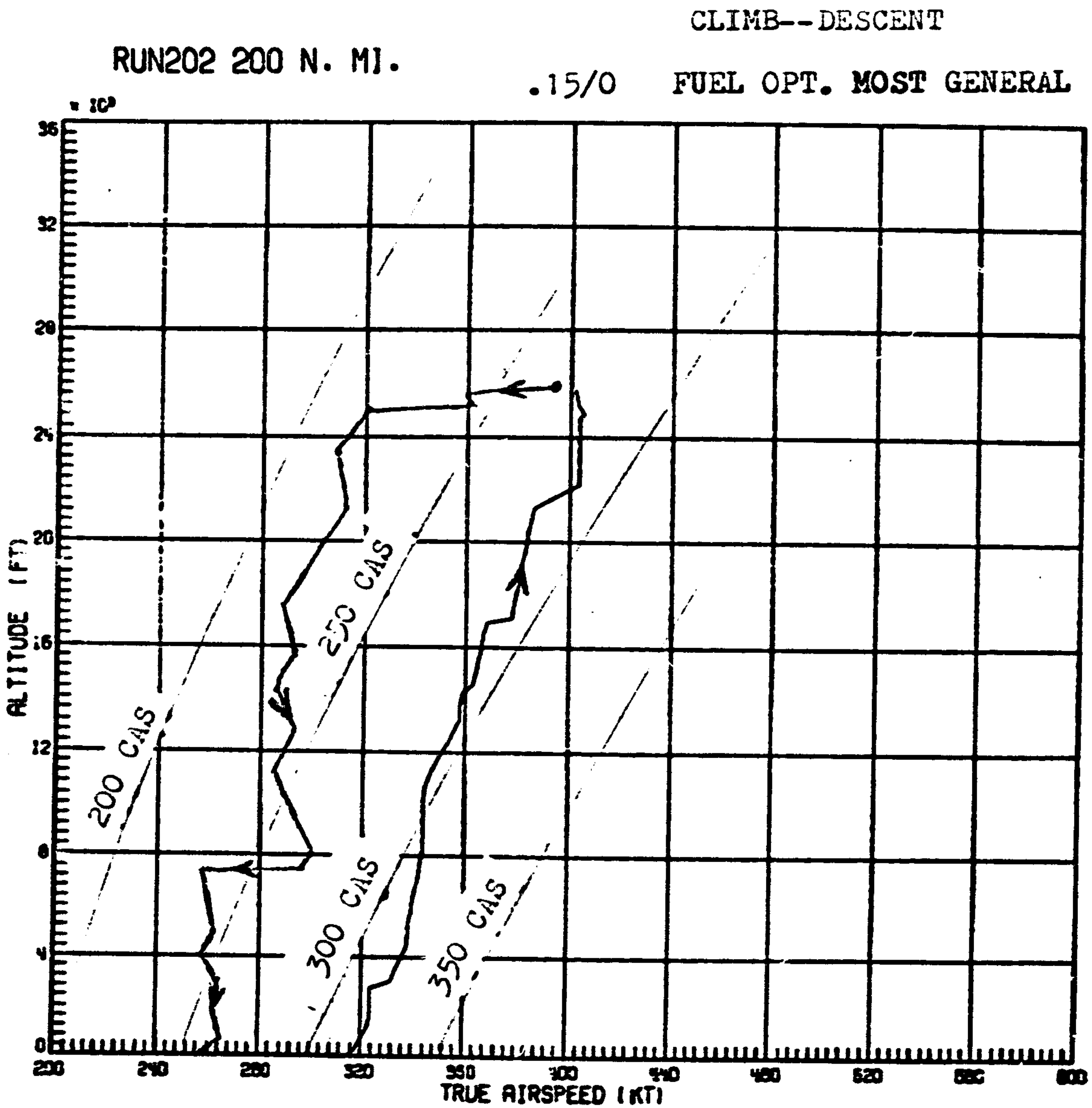

Figure 17.1 - AIRSPEED - ALTITUDE FOR RUN 202

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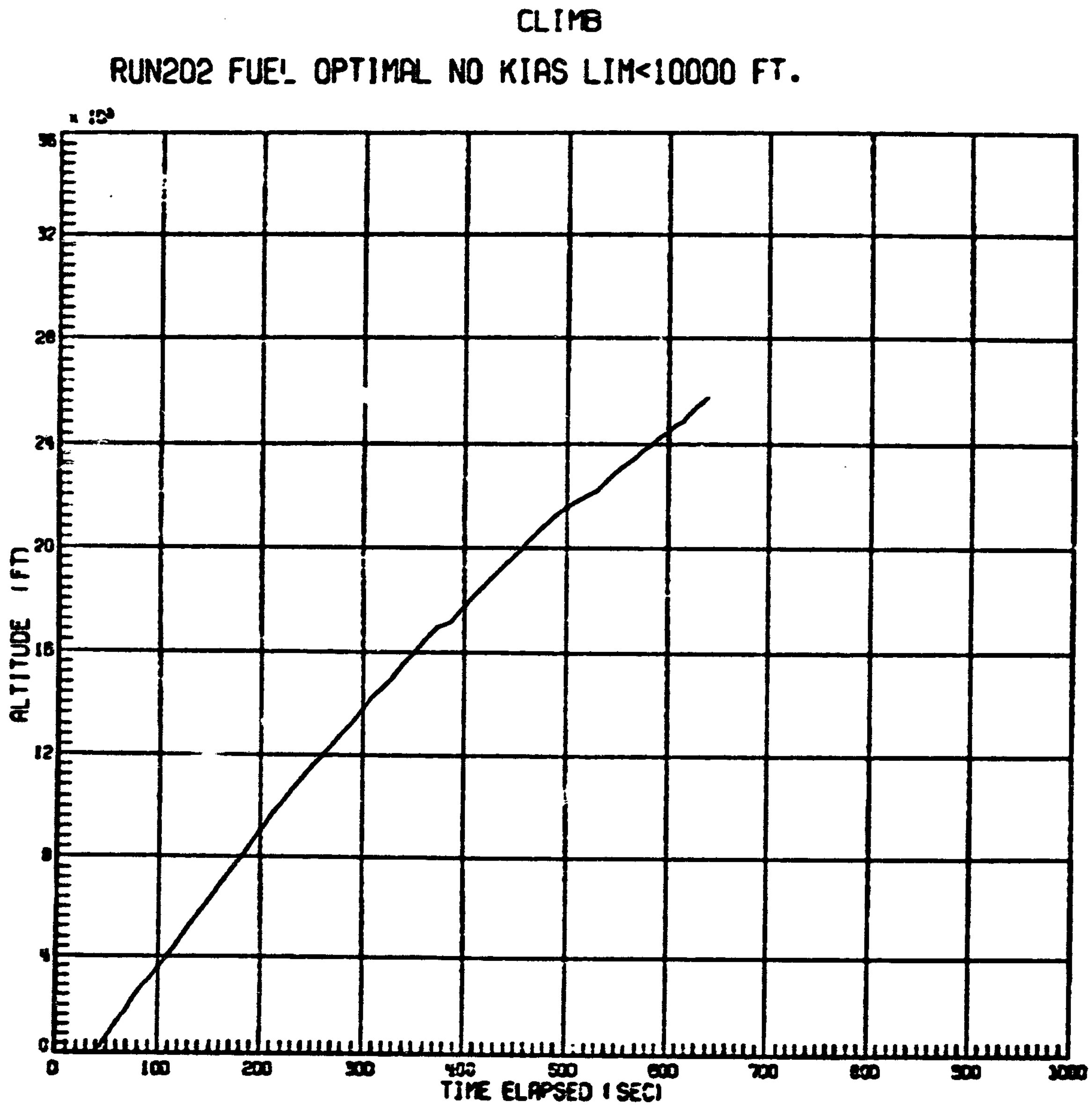

Figure 17.2 - TIME-ALTITUDE FOR RUN 202

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DESCENT

RUN202 FUEL OPTIMAL NO KIAS LIM

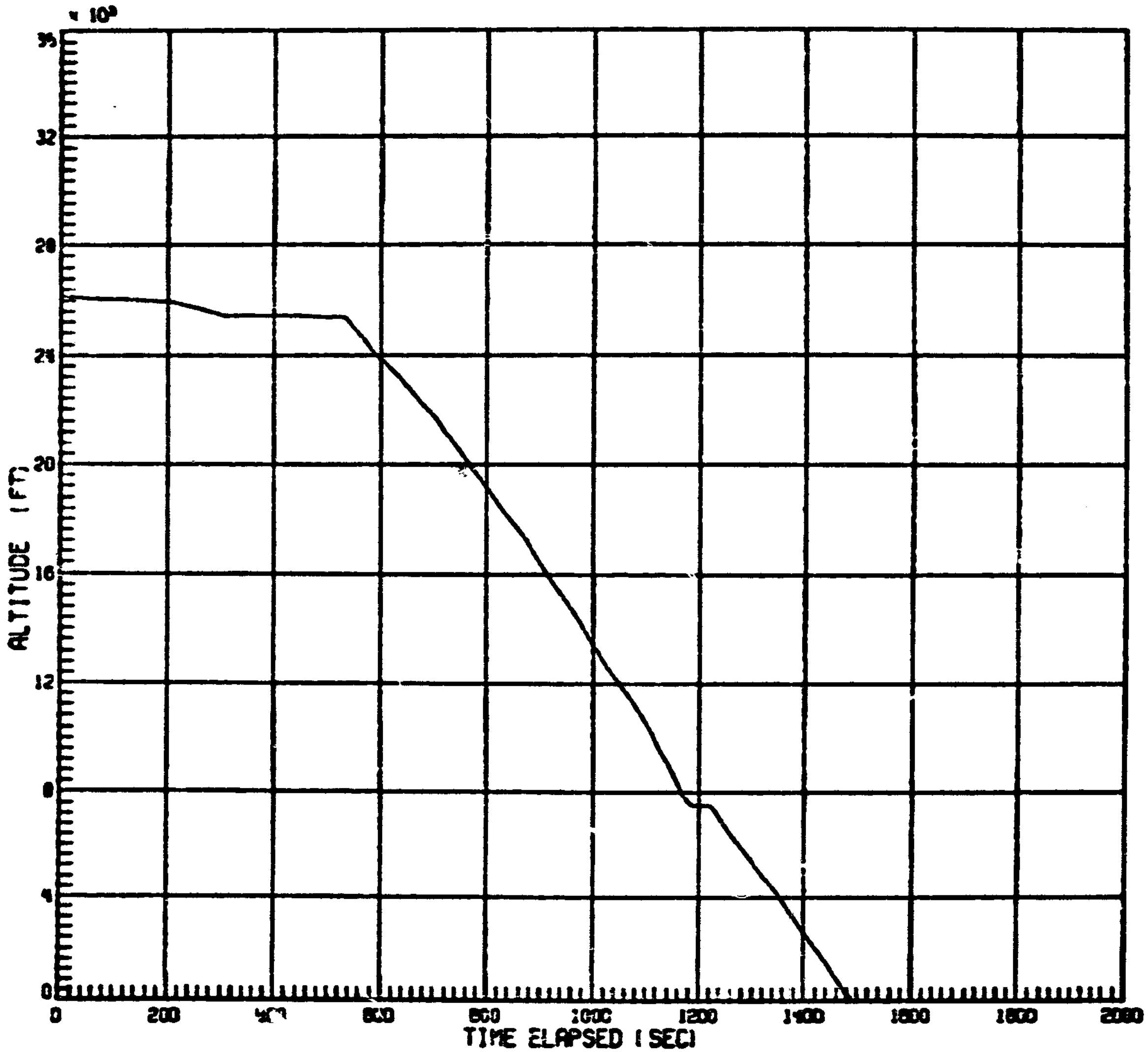

Figure 17.2 (DESCENT)

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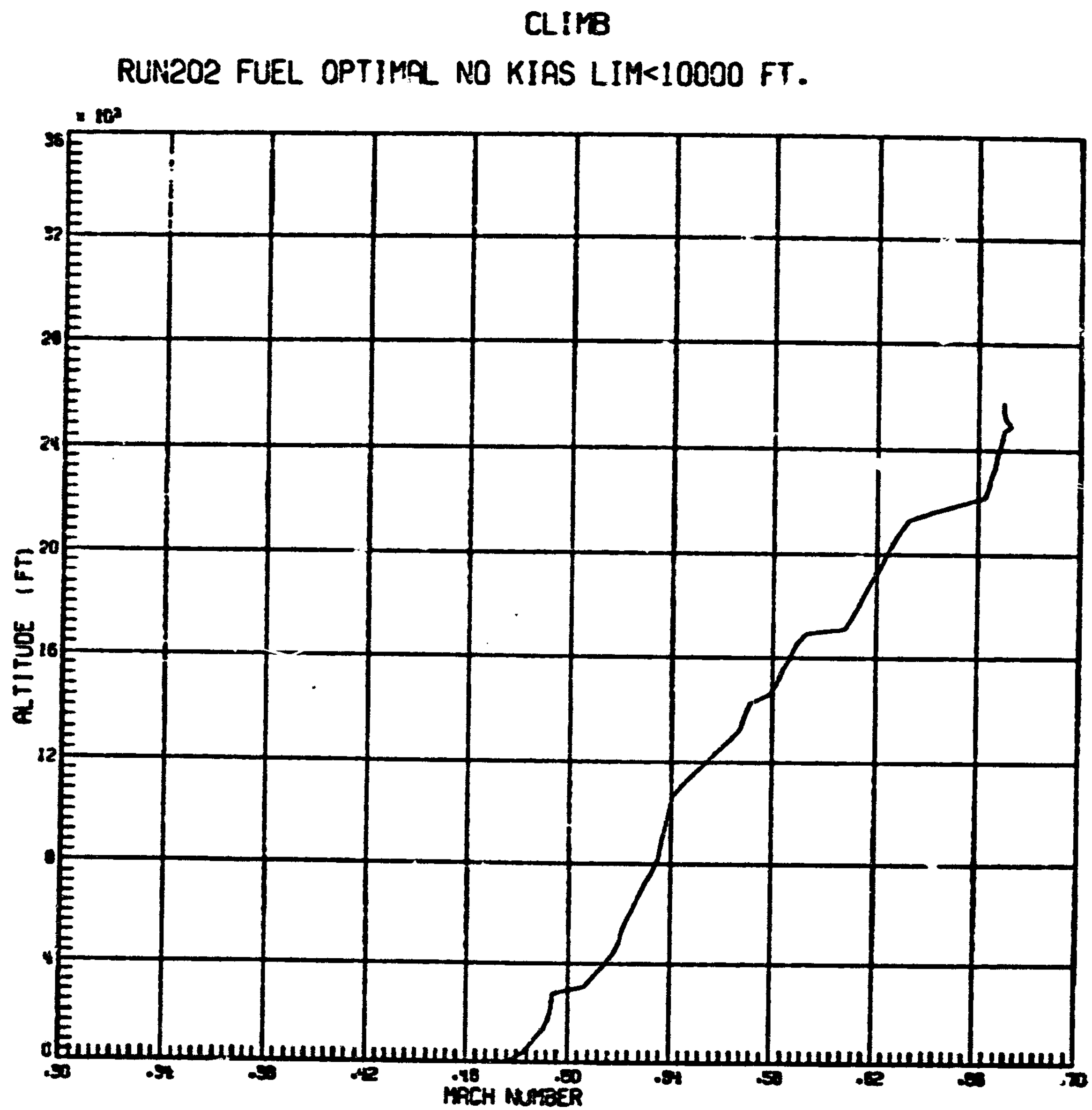

Figure 17.3 - MACH-ALTITUDE RELATION FOR RUN 202

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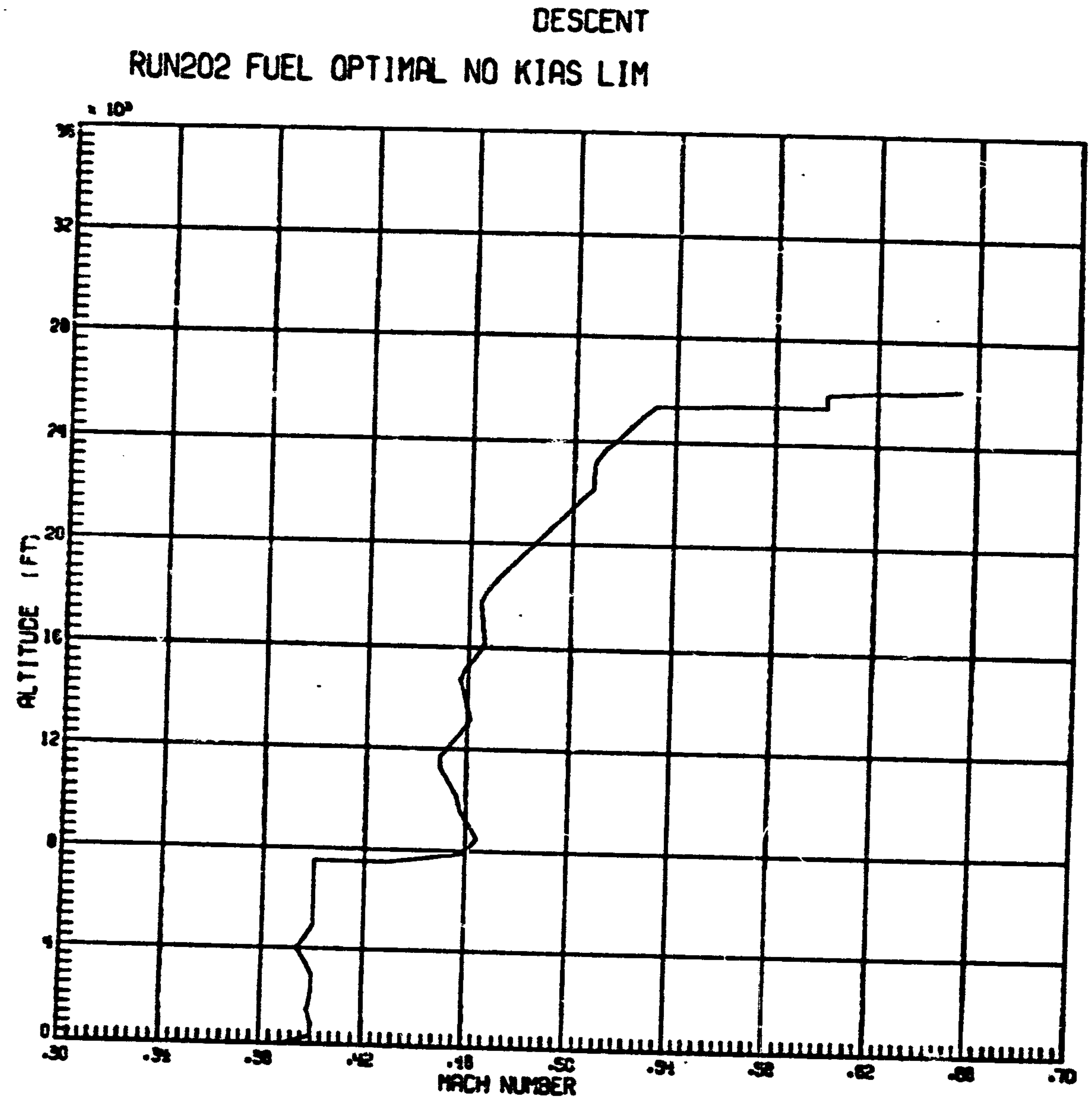

Figure 17.3 (DESCENT)

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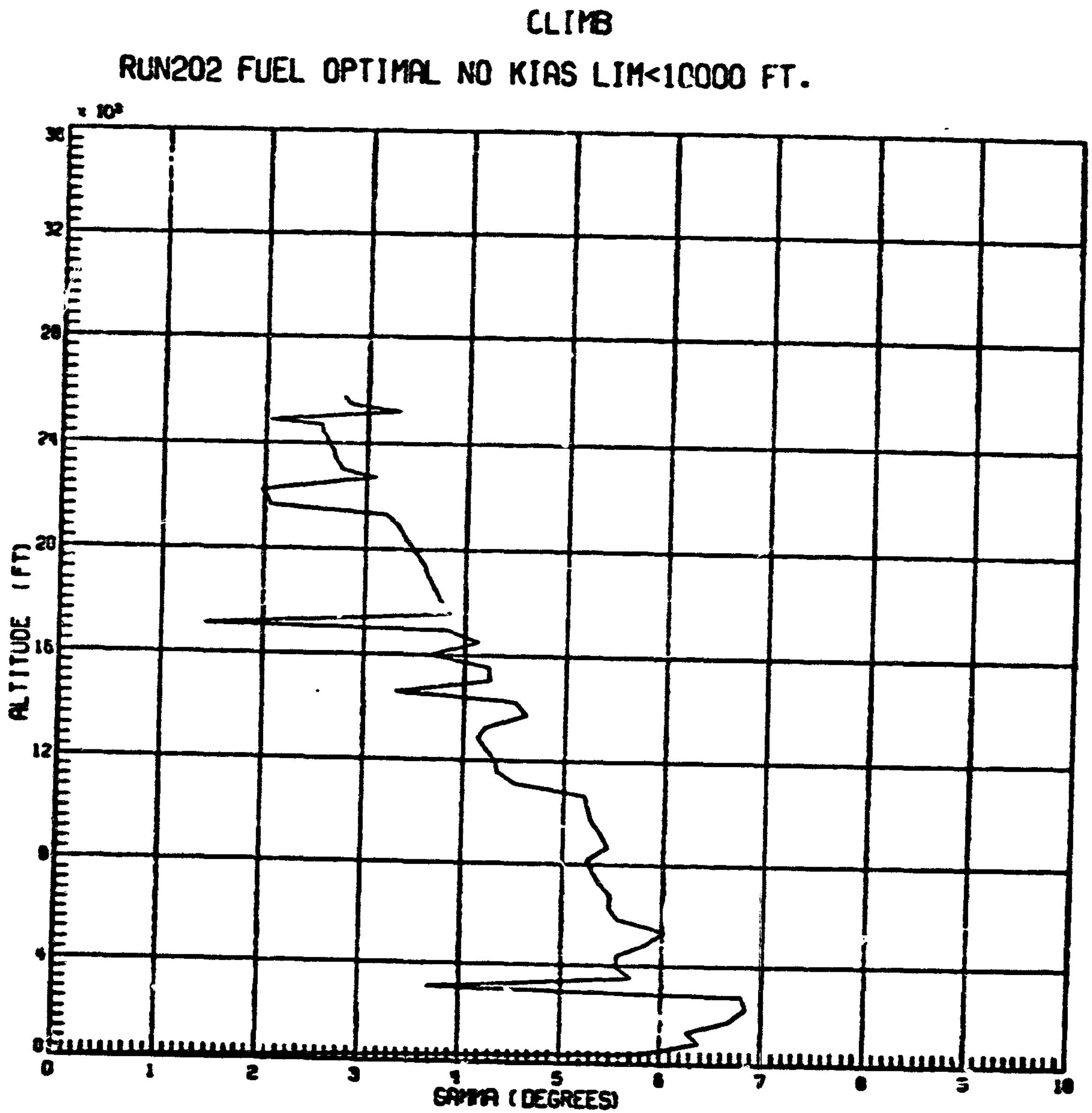

Figure 17.4 - GAMMA-ALTITUDE RELATION FOR RUN 202

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DESCENT

RUN202 FUEL OPTIMAL NO KIAS LIM

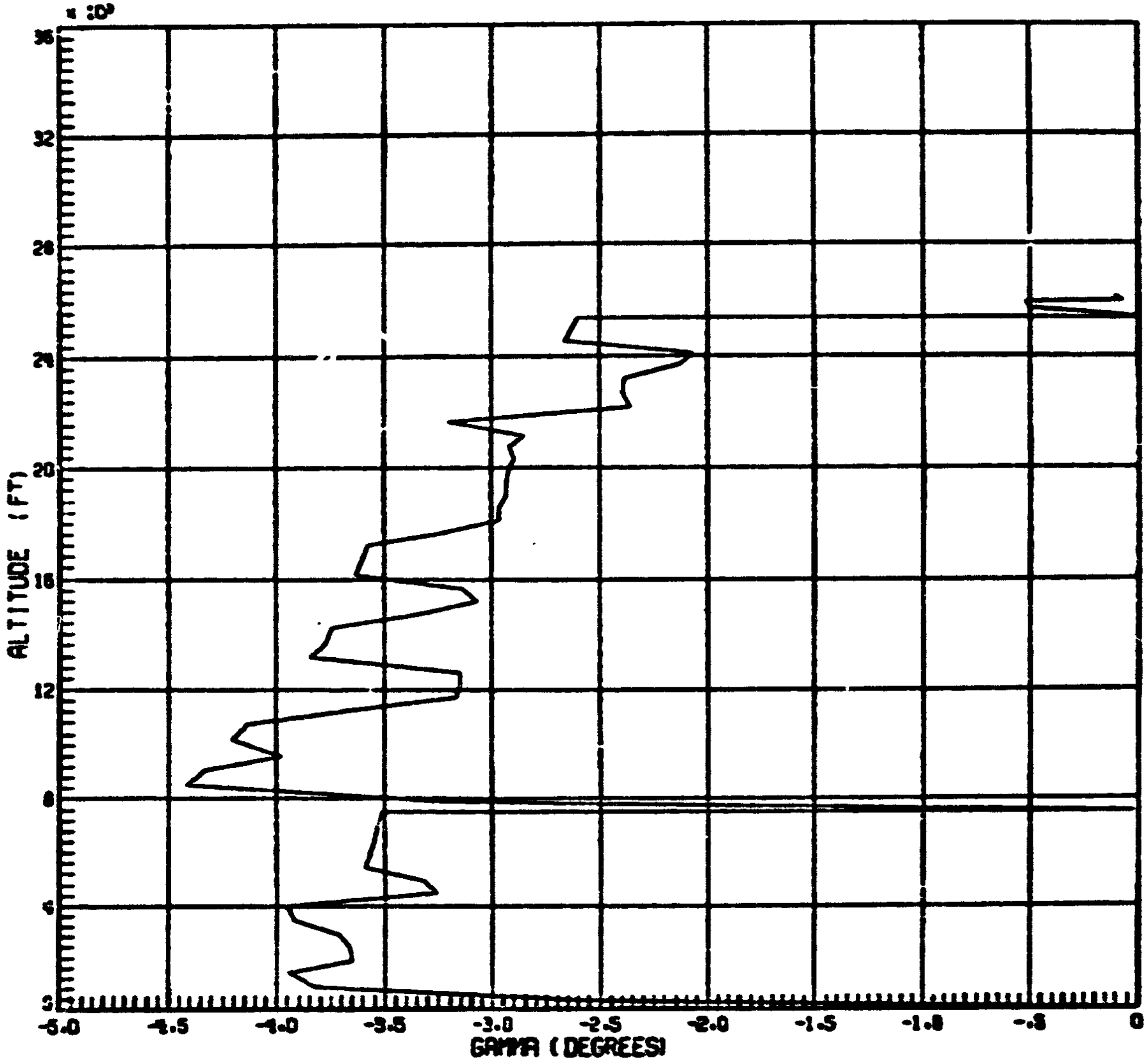

Figure 17.4 (DESCENT)

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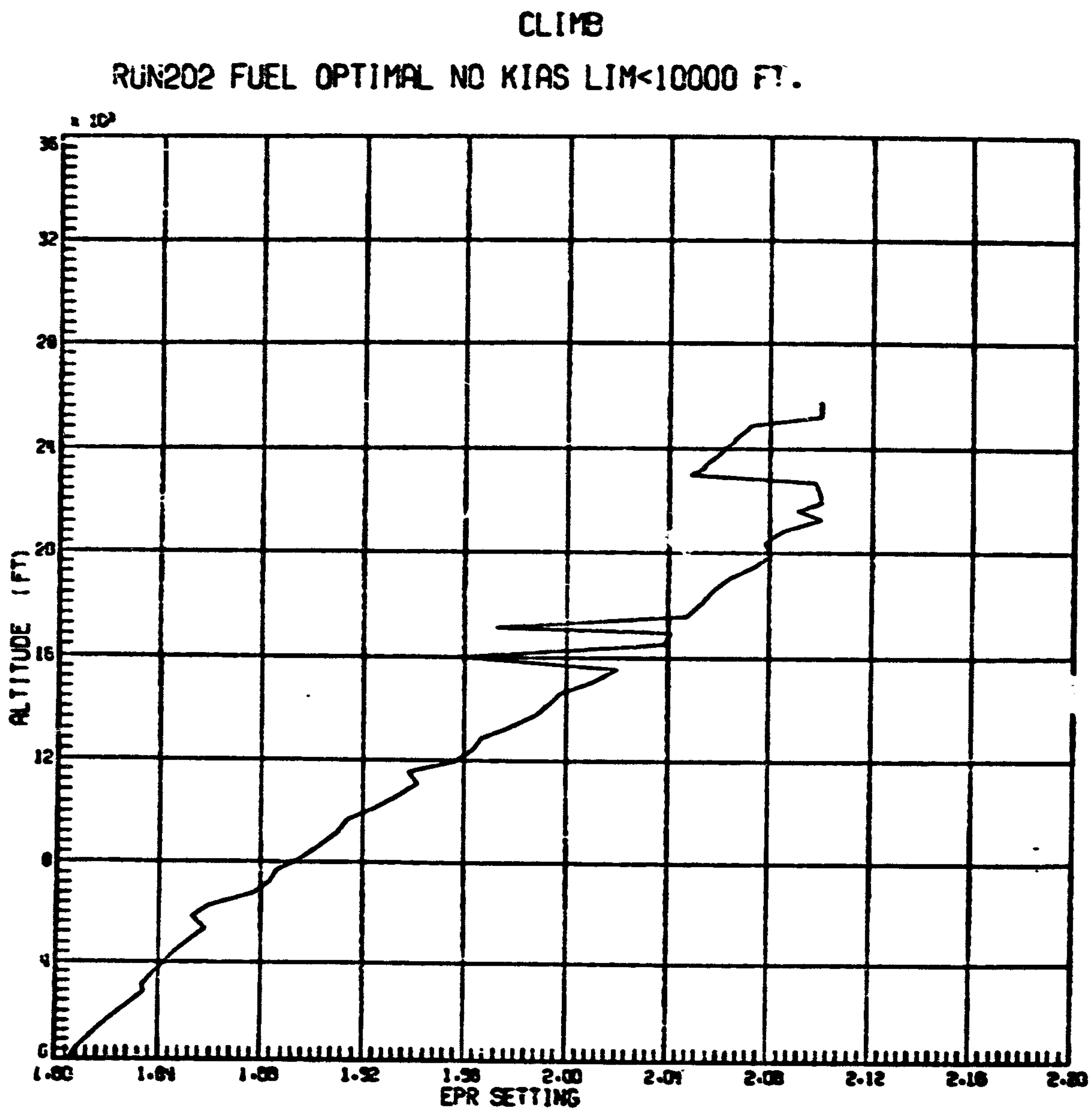

Figure 17.5 - EPR-ALTITUDE RELATION FOR RUN 202

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DESCENT

RUN202 FUEL OPTIMAL NO KIAS LIM

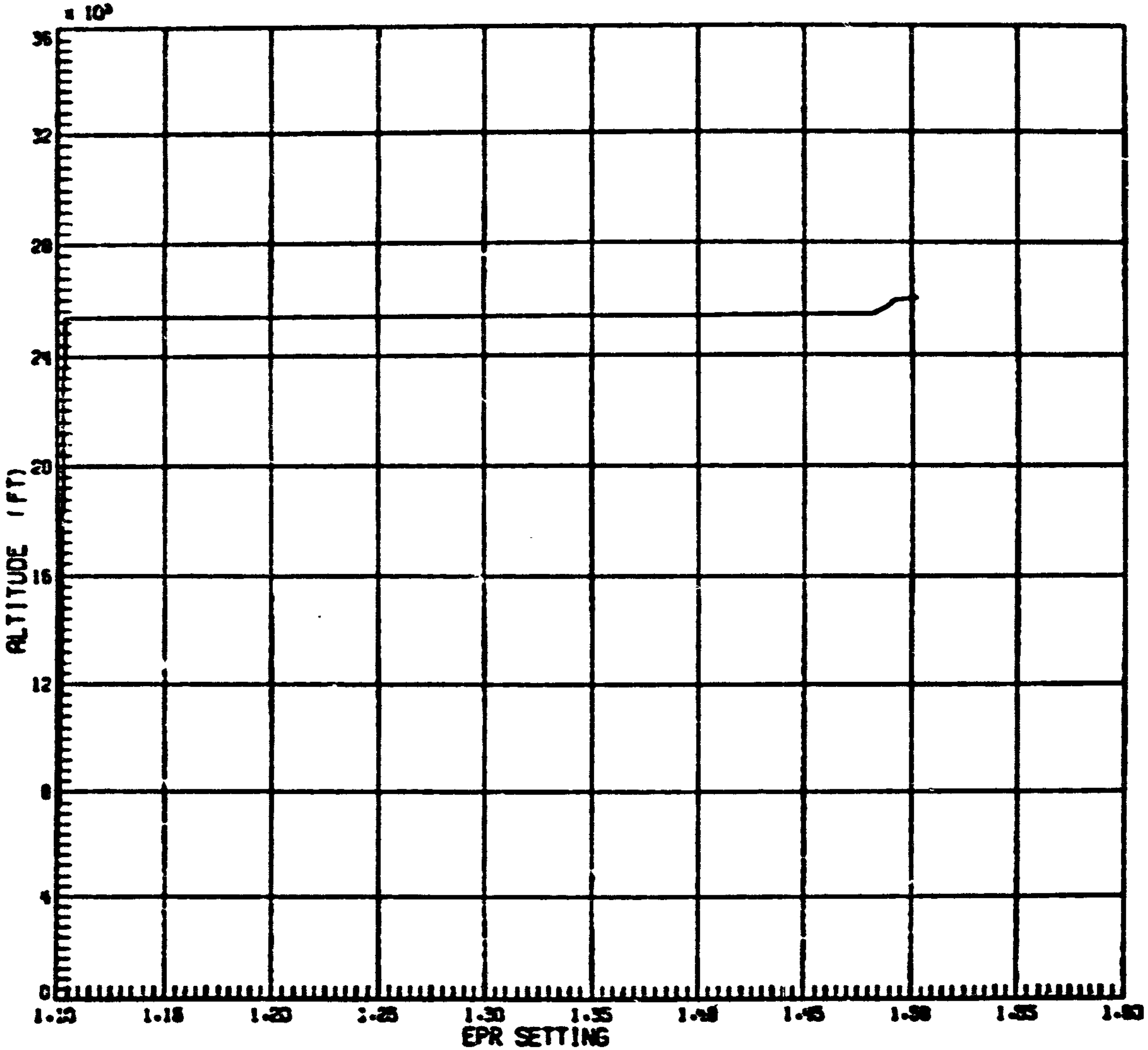

Figure 17.5 (DESCENT)

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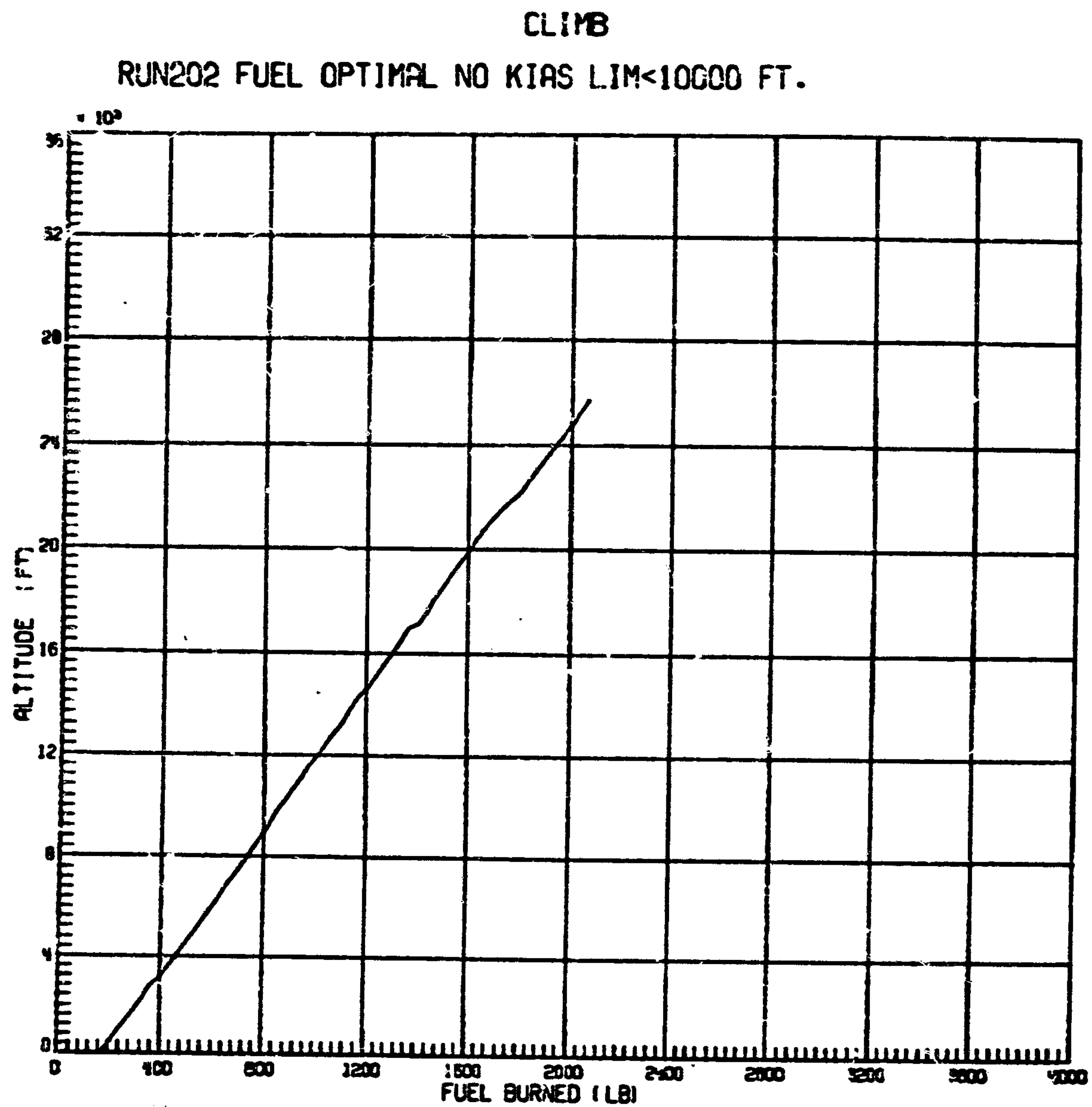

Figure 17.6 - FUEL BURNED-ALTITUDE RELATION FOR RUN 202

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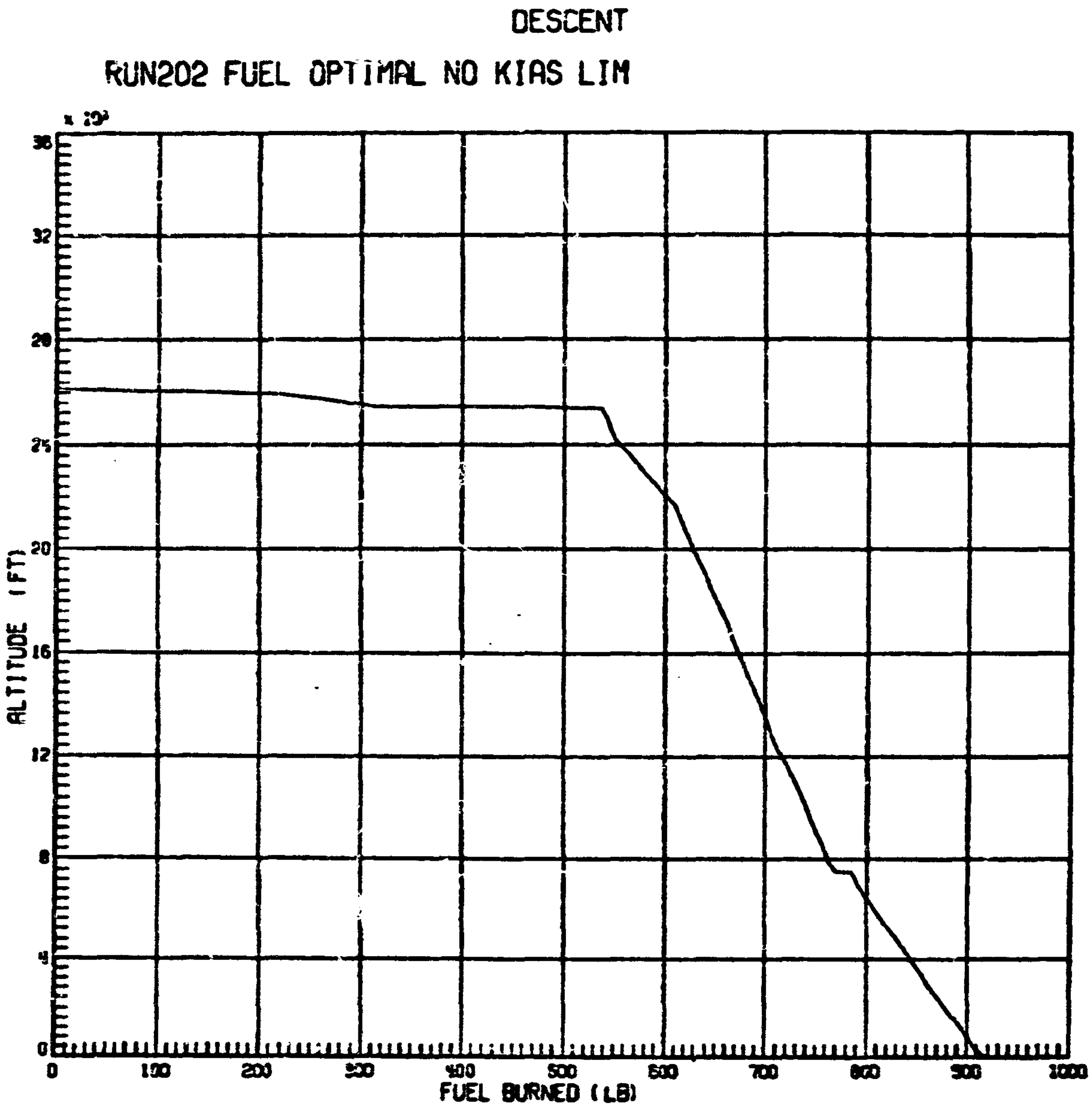

Figure 17.6 (DESCENT)

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CLIMB - DESCENT

RUN203 200 N. MI. .15/600 DOC OPTIMAL MOST GENERAL

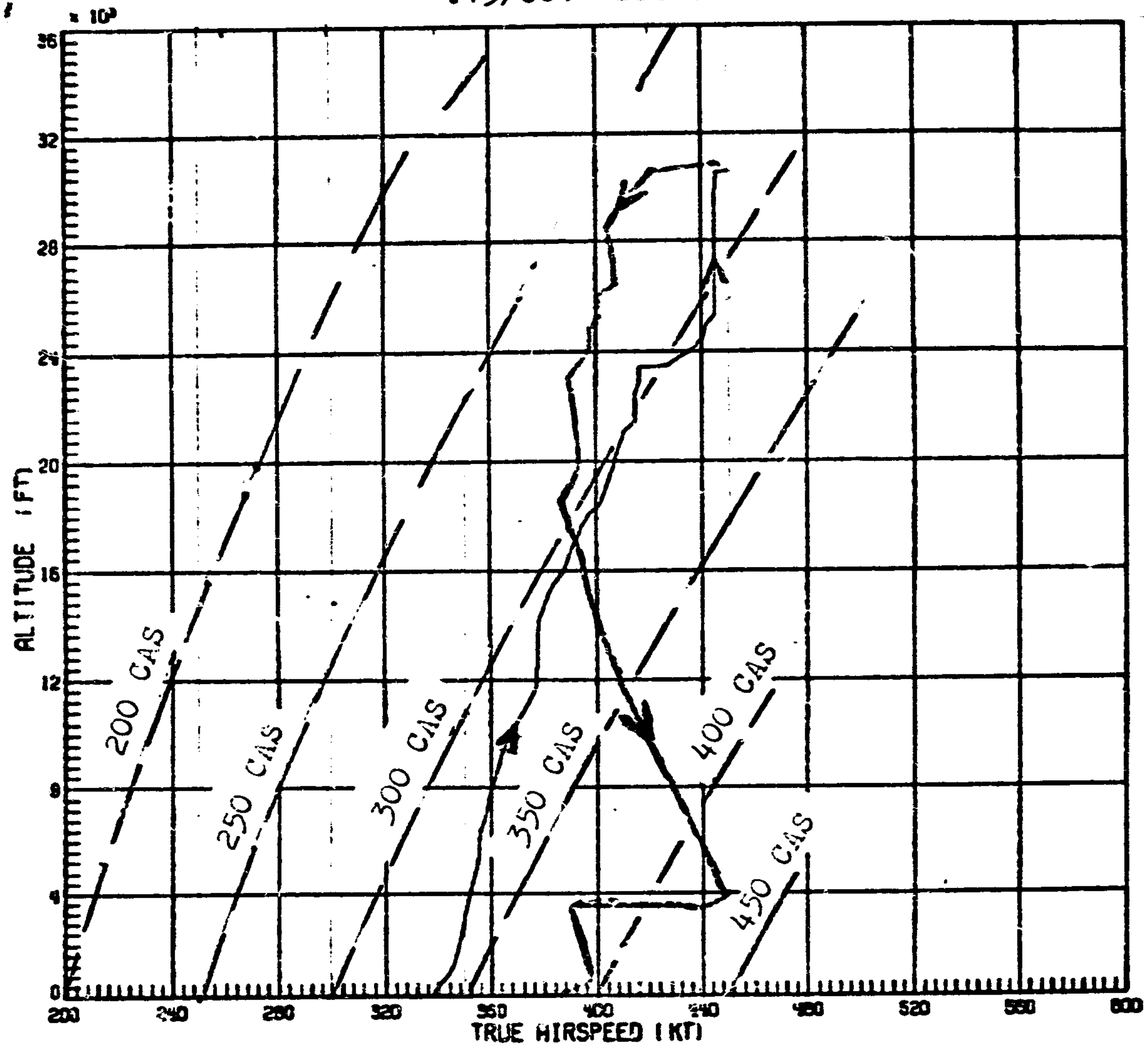

Figure 18.1 - AIRSPEED-ALTITUDE RELATION FOR RUN 203

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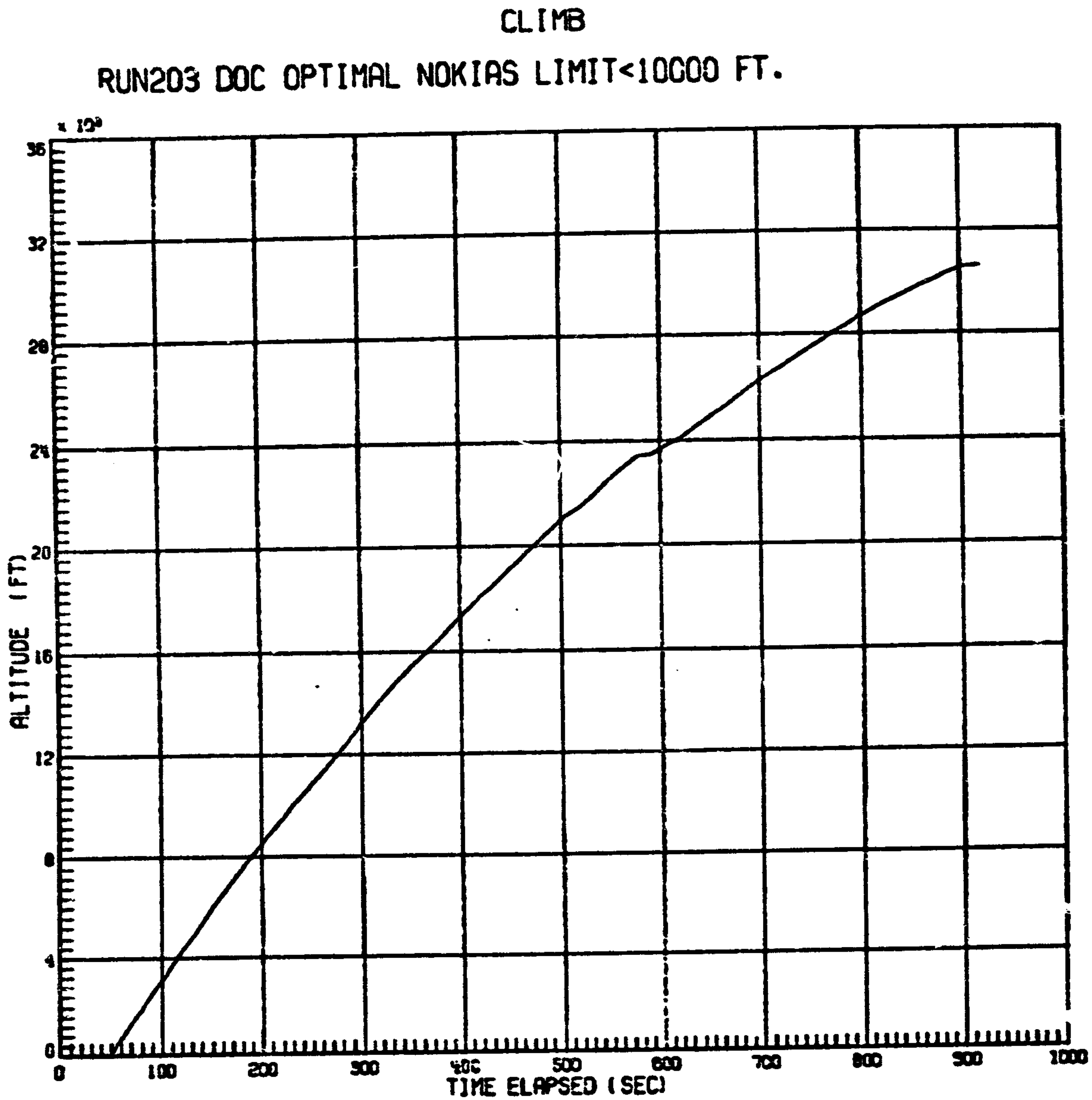

Figure 18.2 - TIME-ALTITUDE RELATION FOR RUN 203

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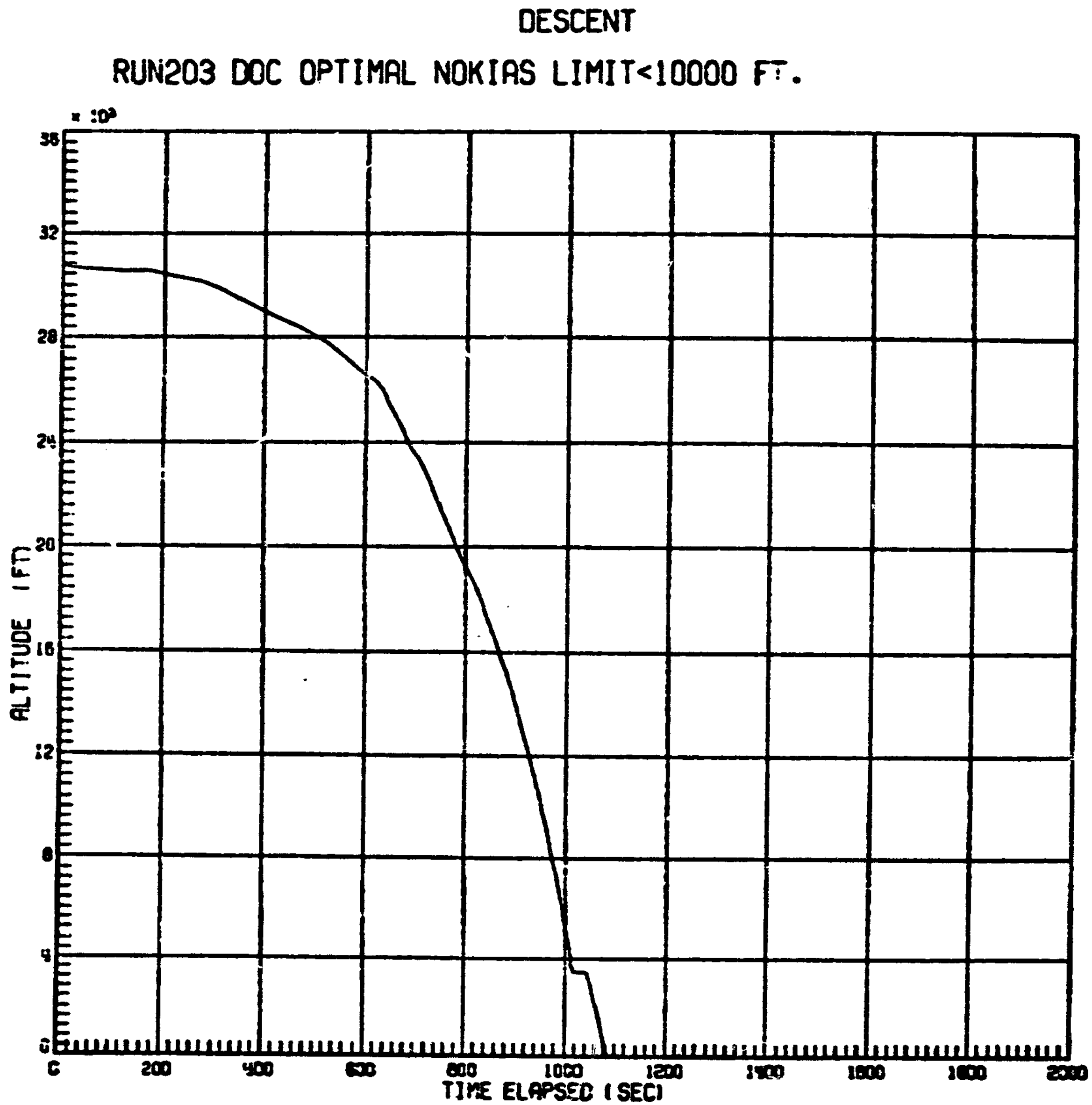

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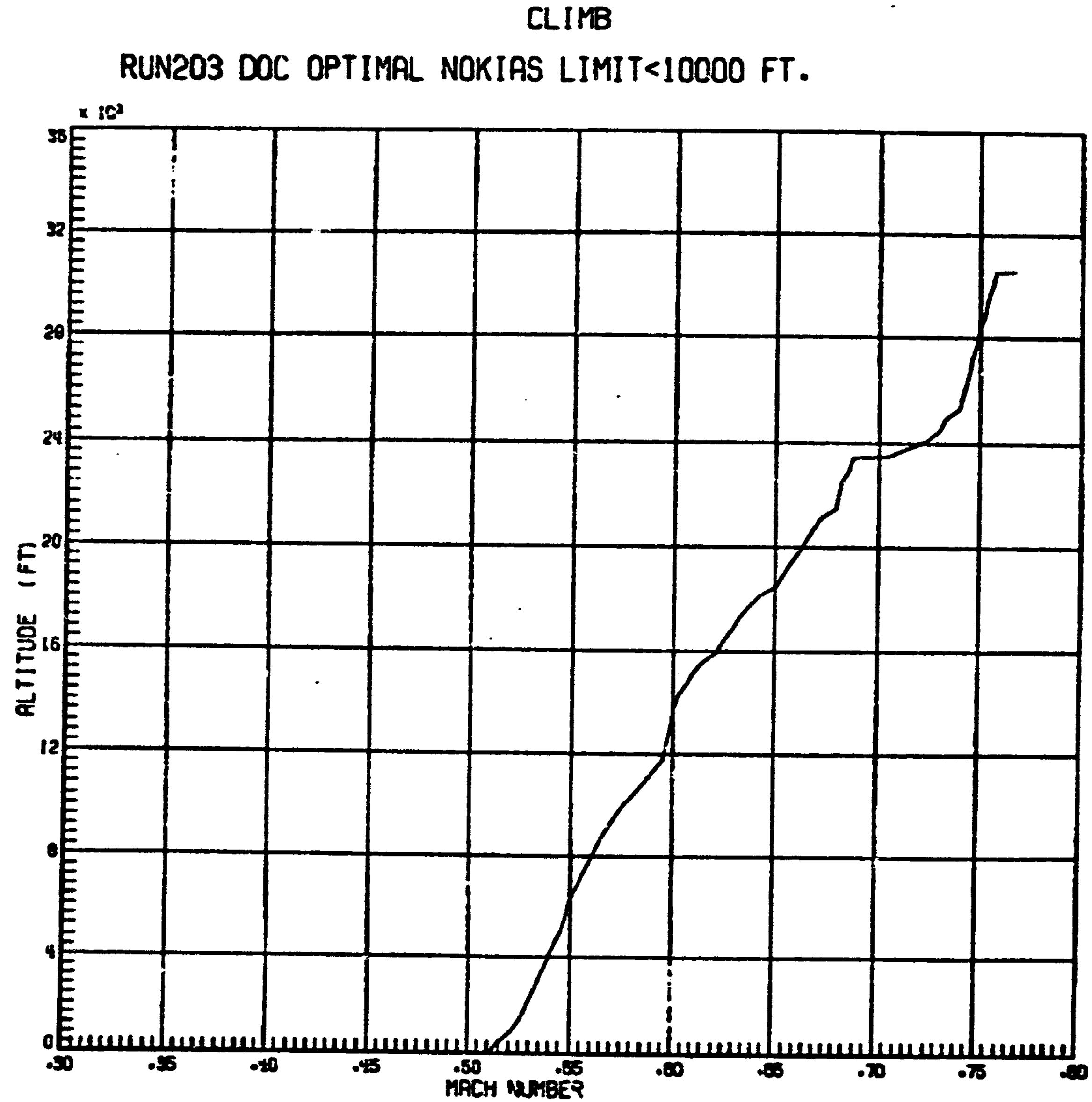

Figure 18.3 - MACH-ALTITUDE RELATION FOR RUN 203

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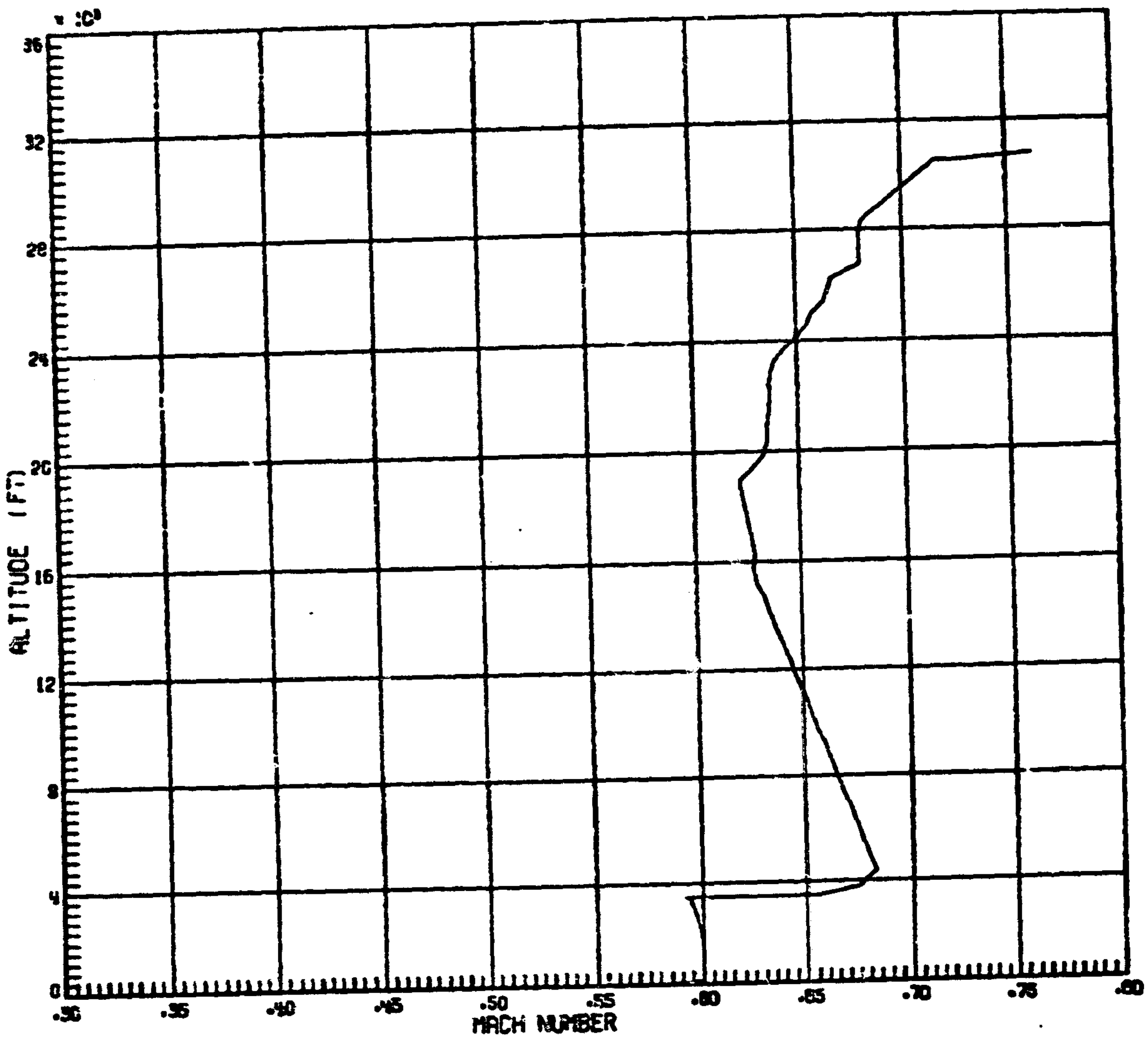

Figure 18.3 (DESCENT)

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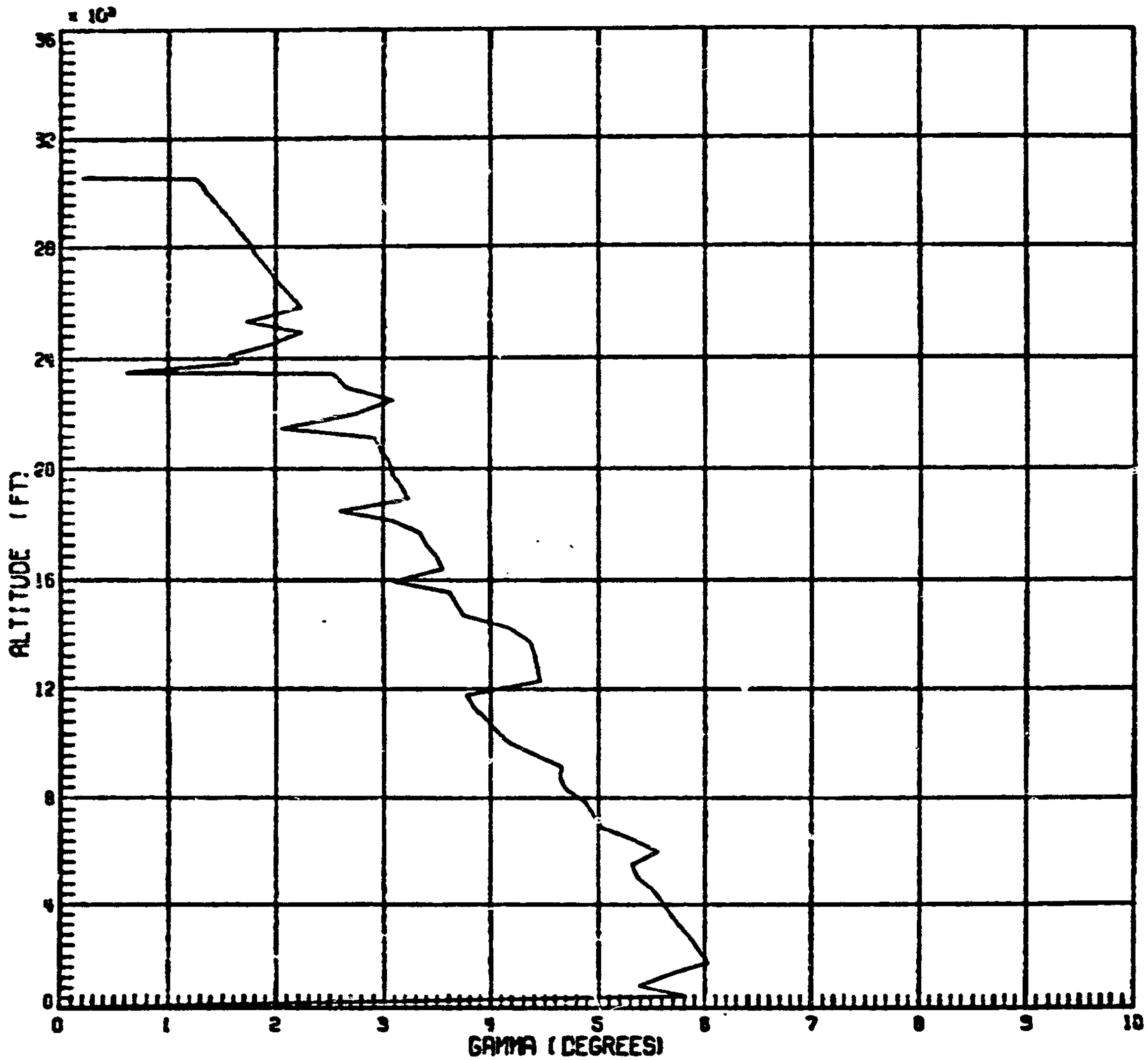

Figure 18.4 - GAMMA-ALTITUDE RELATION FOR RUN 203

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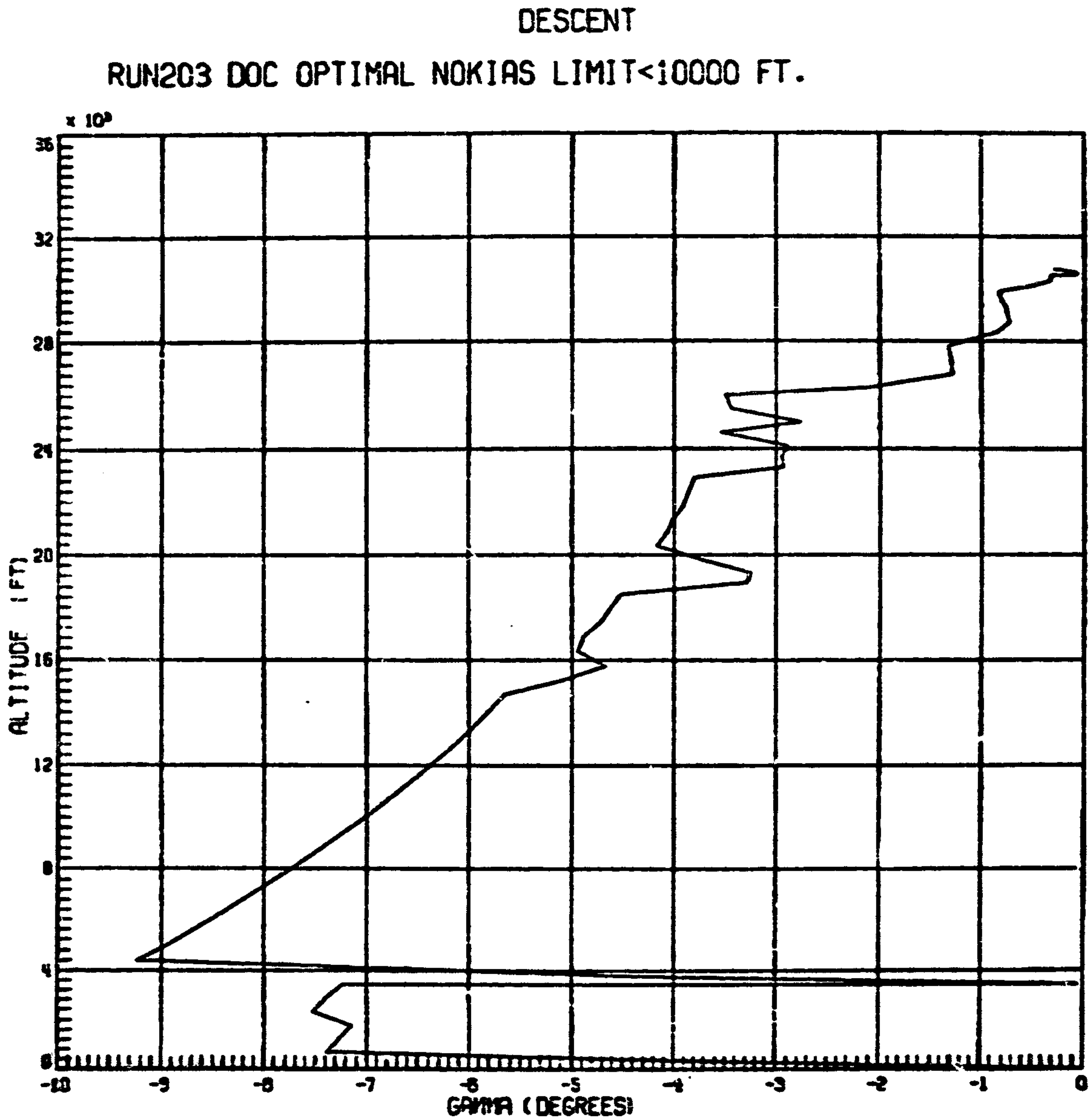

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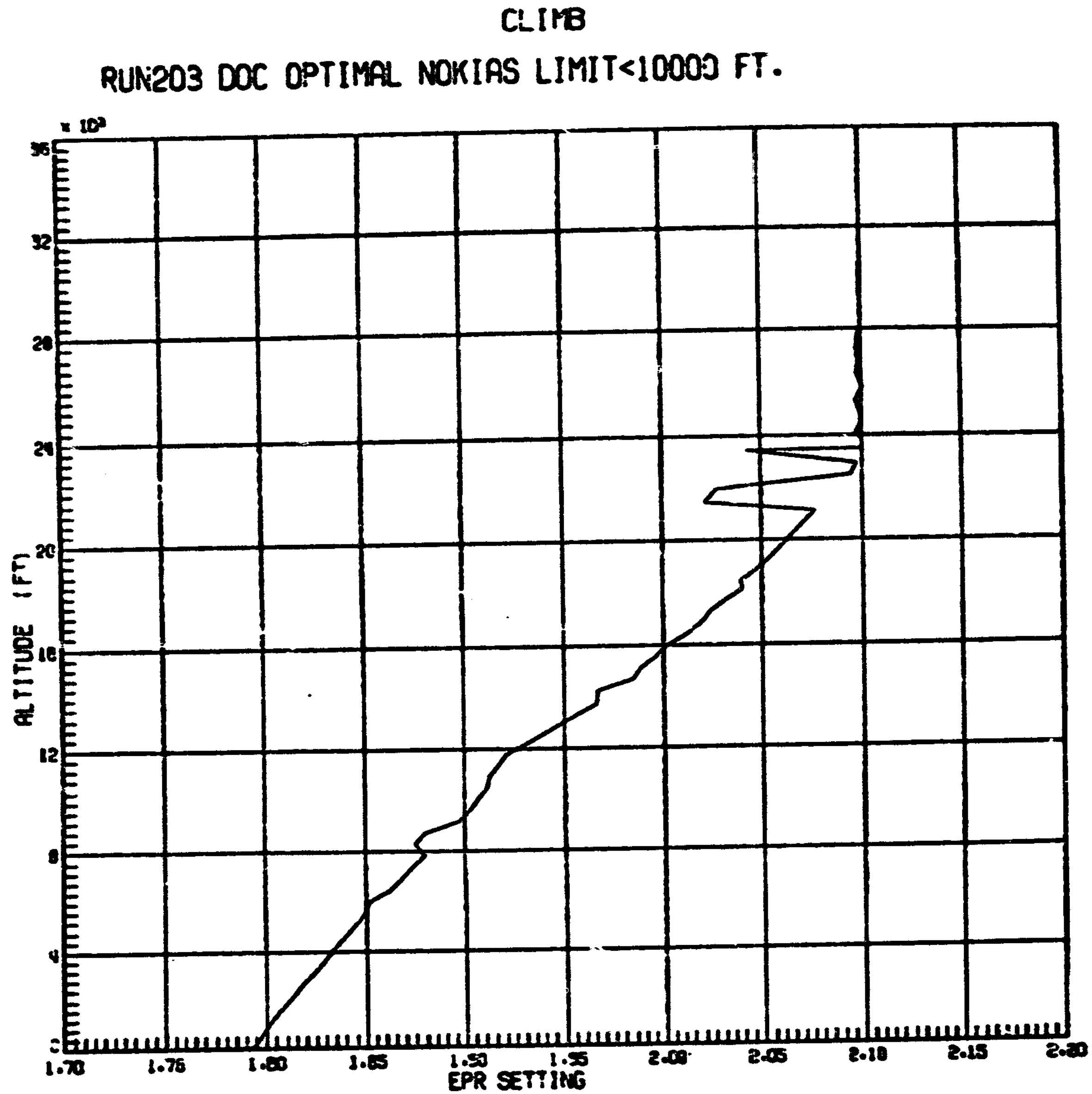

Figure 18.5 - EPR-ALTITUDE RELATION FOR RUN 203

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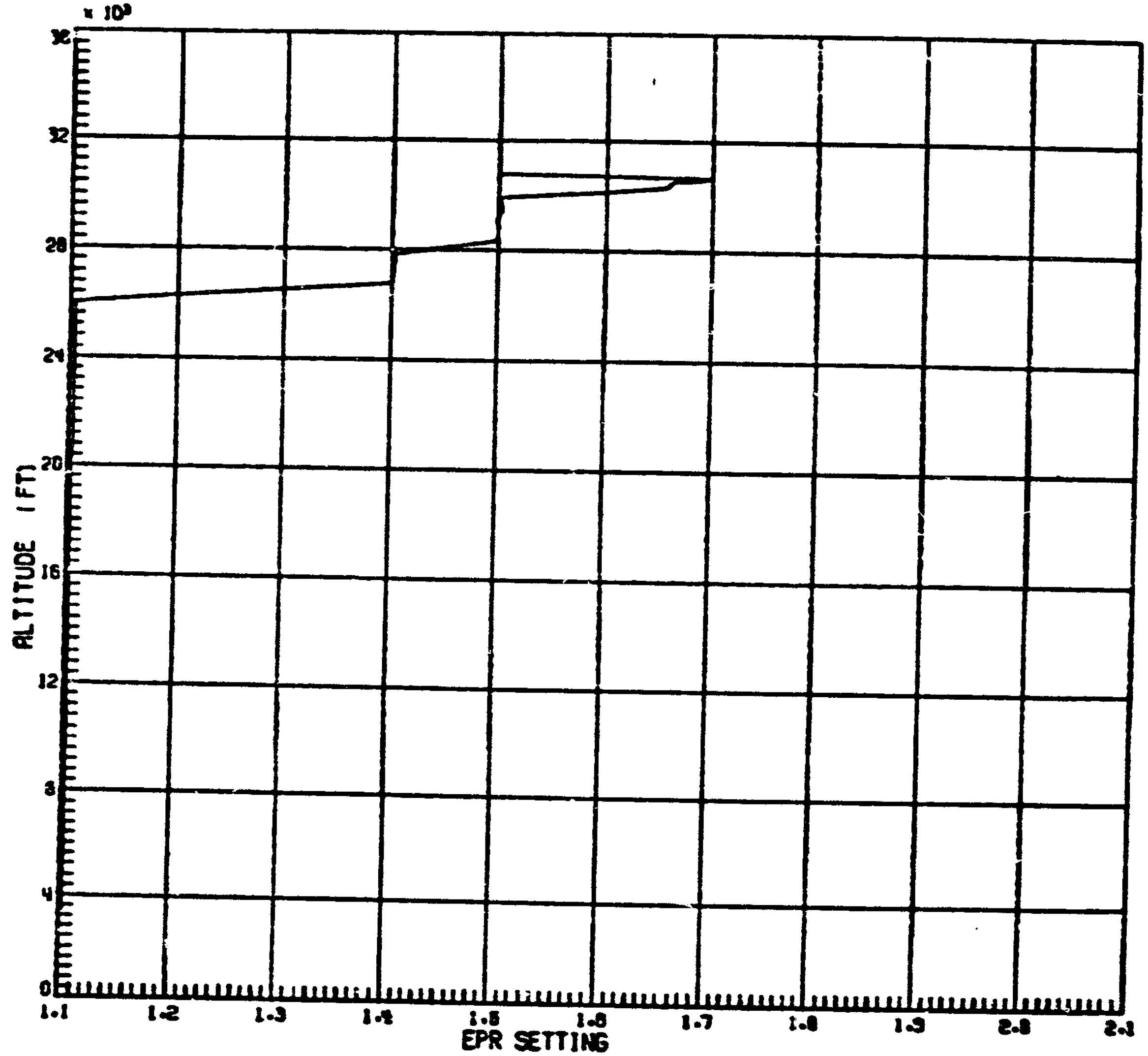

Figure 18.5 (DESCENT)

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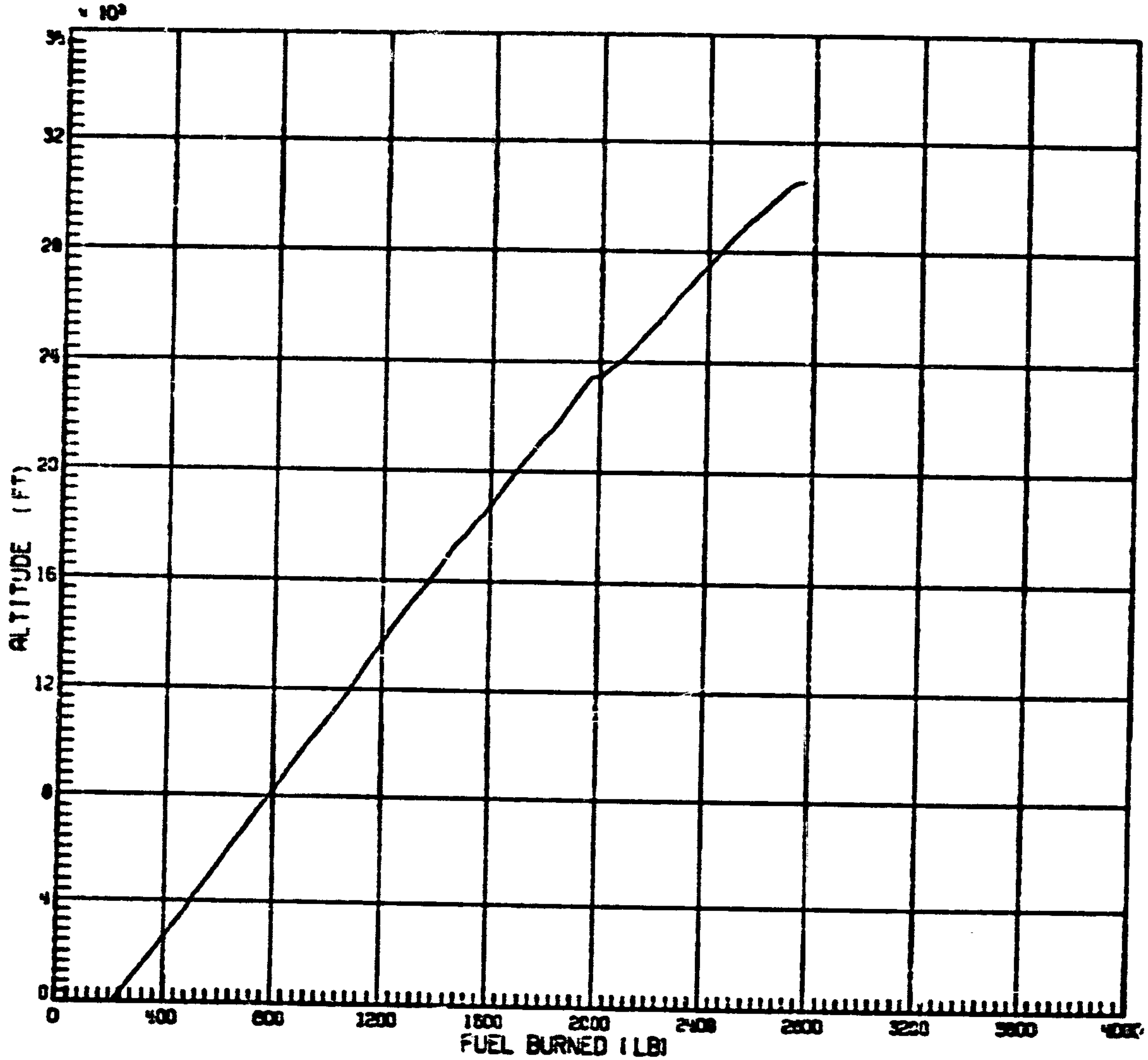

Figure 18.6 - FUEL BURNED-ALTITUDE RELATION FOR RUN 203

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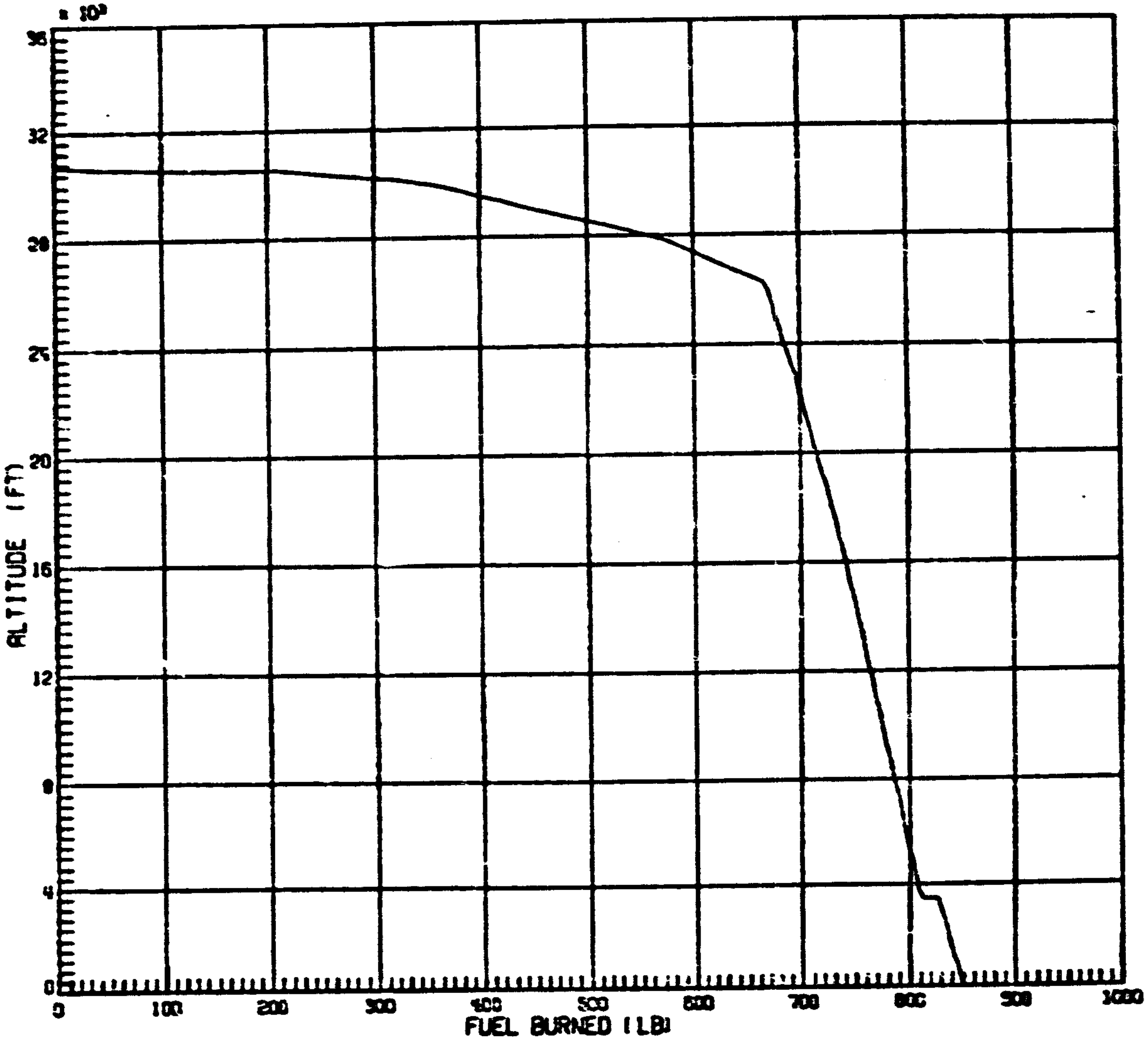

Figure 18.6 (DESCENT)

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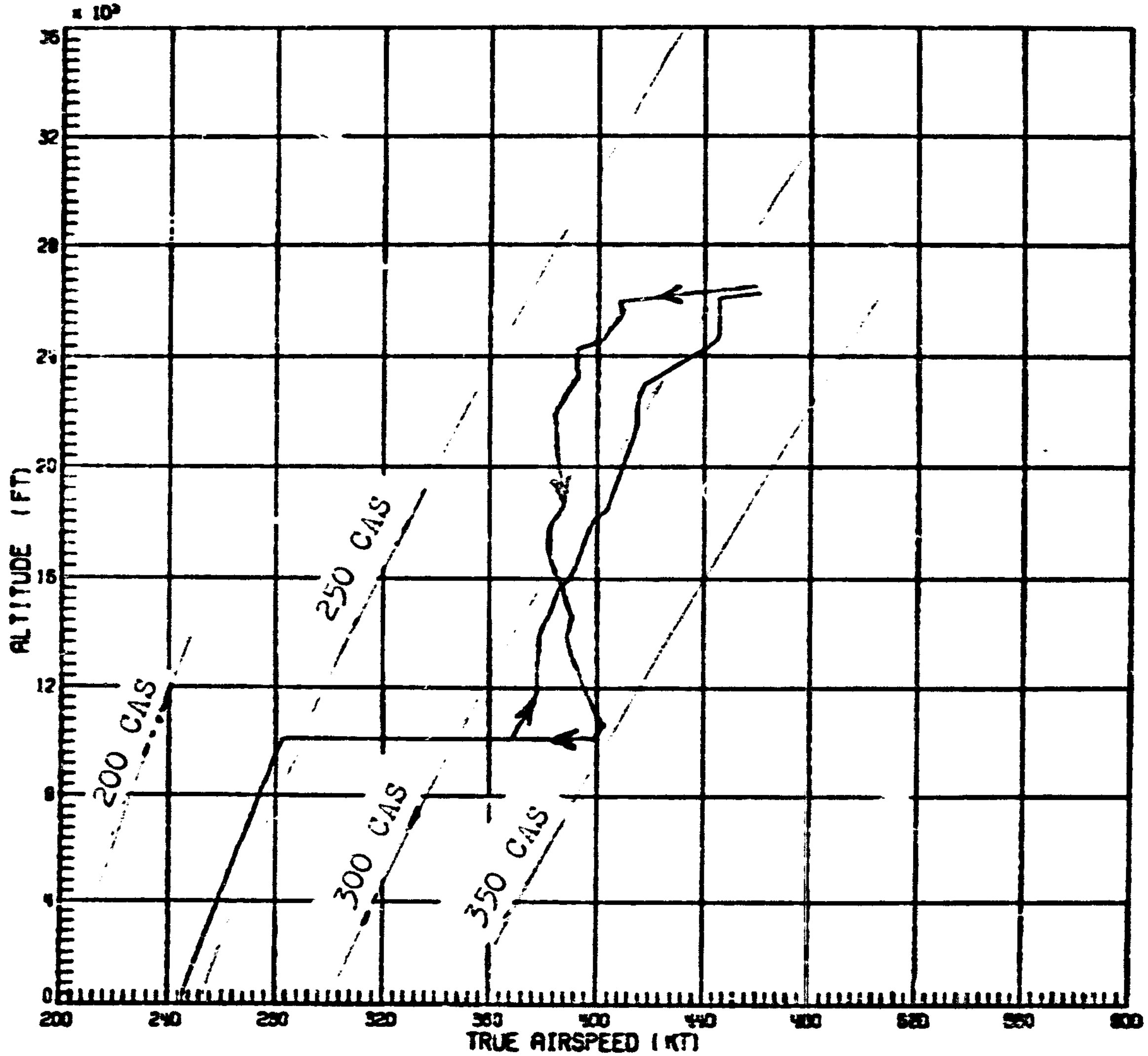
RUN 204 200 N. MI.

DOC OPT. 250 KIAS LIMIT



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CRUISE TABLE INFO. 100K 80K

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Figure 19.1 - AIRSPEED-ALTITUDE RELATION FOR RUN 204

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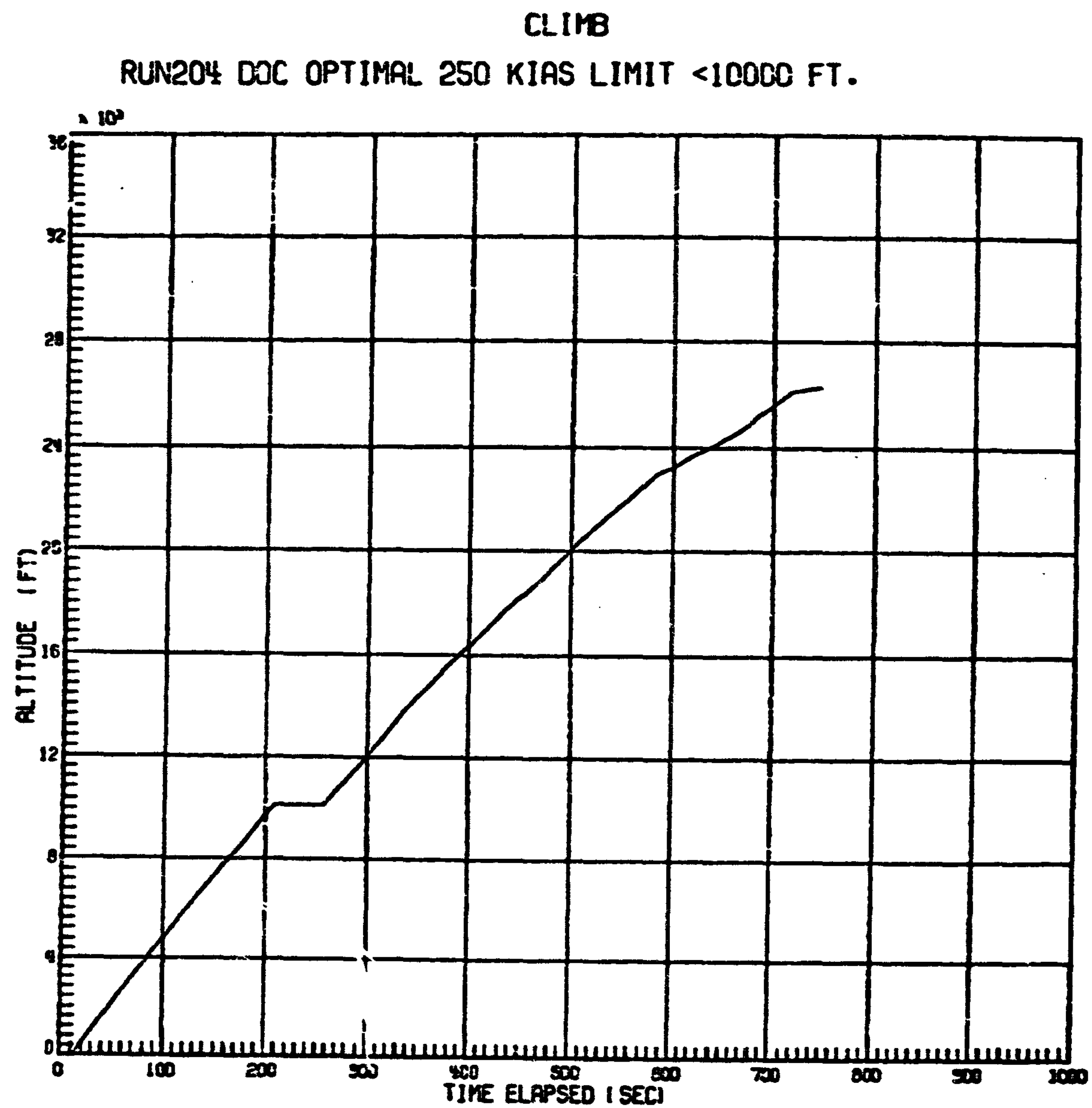

Figure 19.2 - TIME-ALTITUDE RELATION FOR RUN 204

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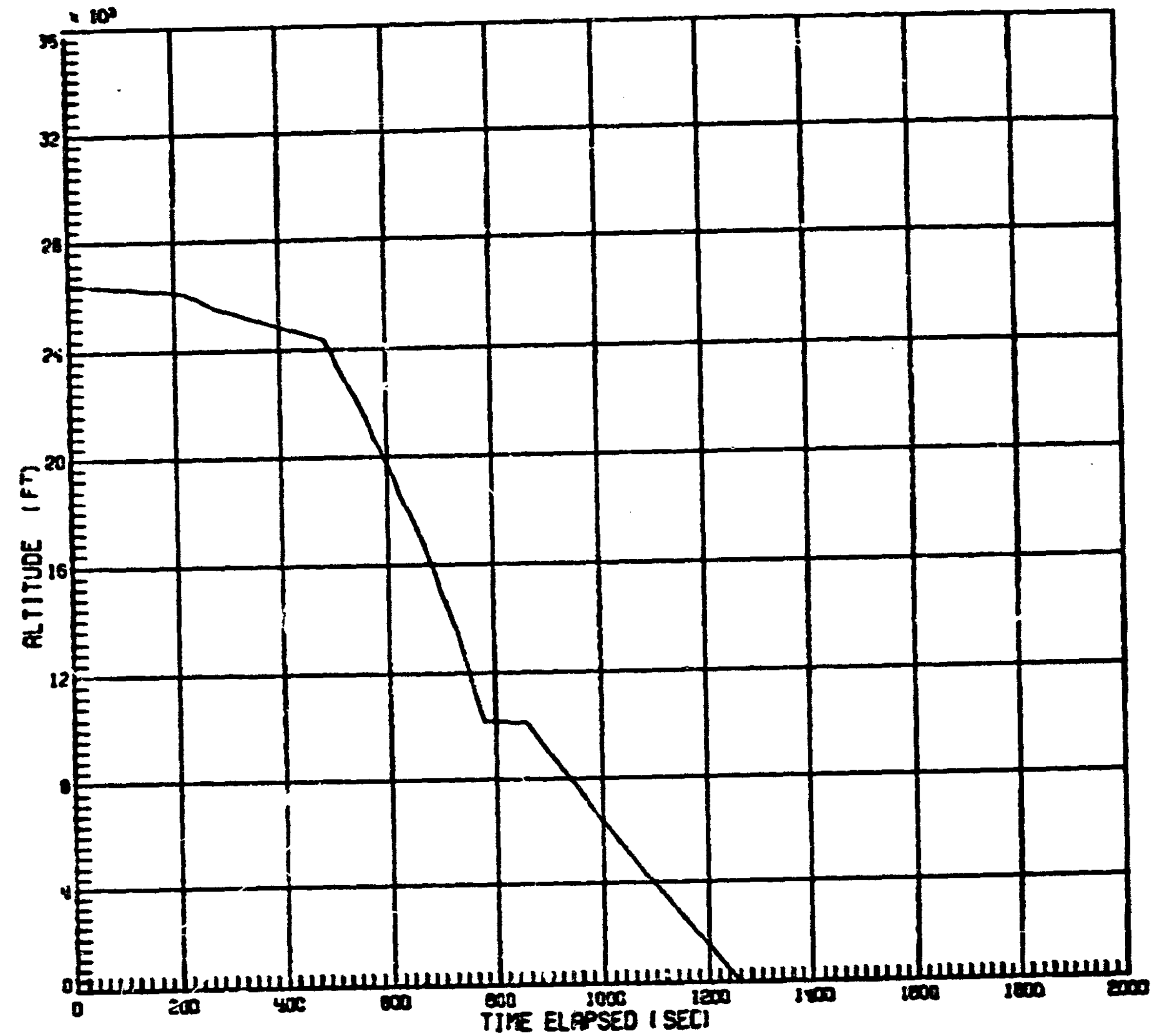

Figure 19.2 (DESCENT)

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RUN204 DOC OPTIMAL 250 KIAS LIMIT < 10000 FT.

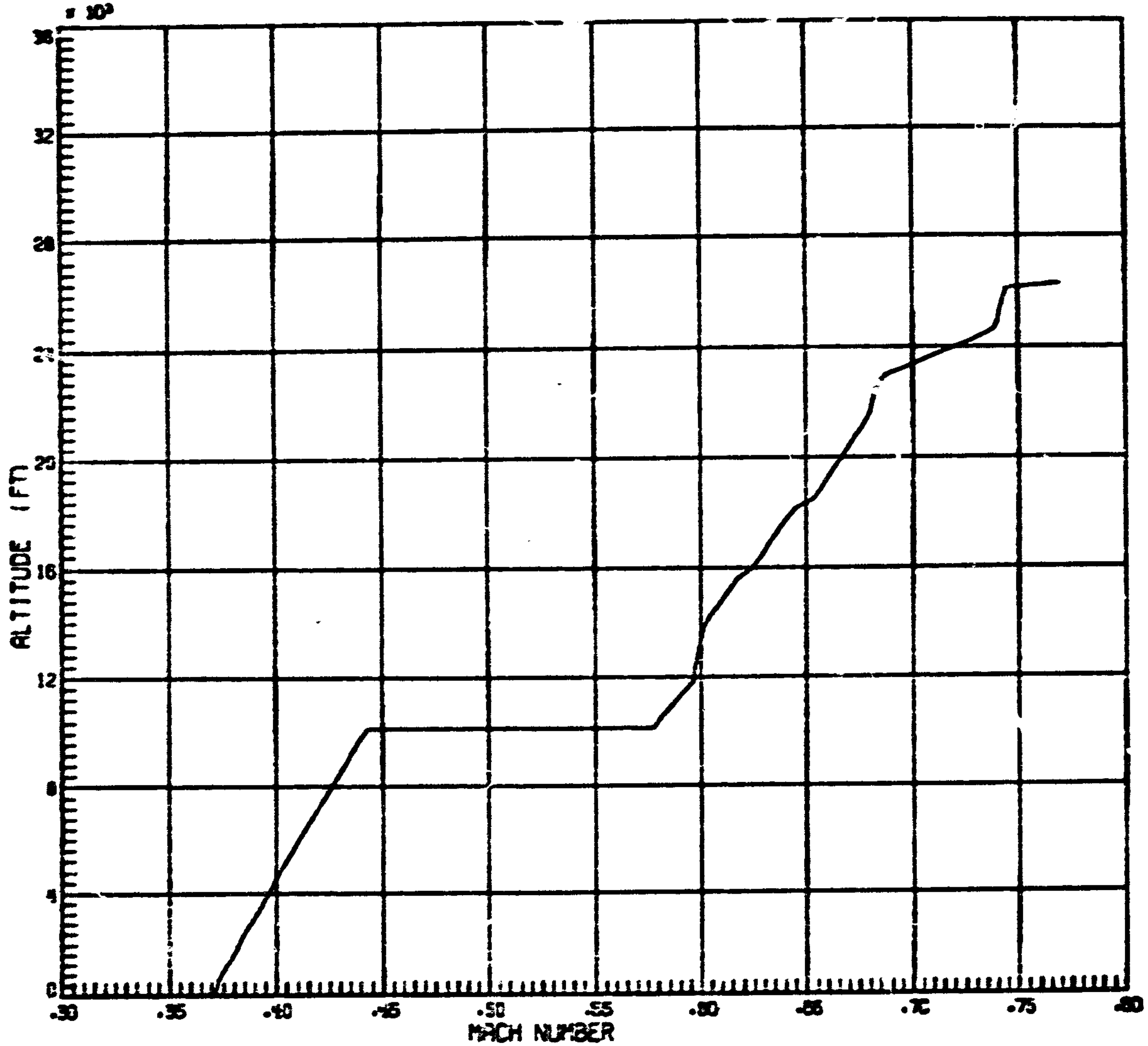

Figure 19.3 - MACH-ALTITUDE RELATION FOR RUN 204

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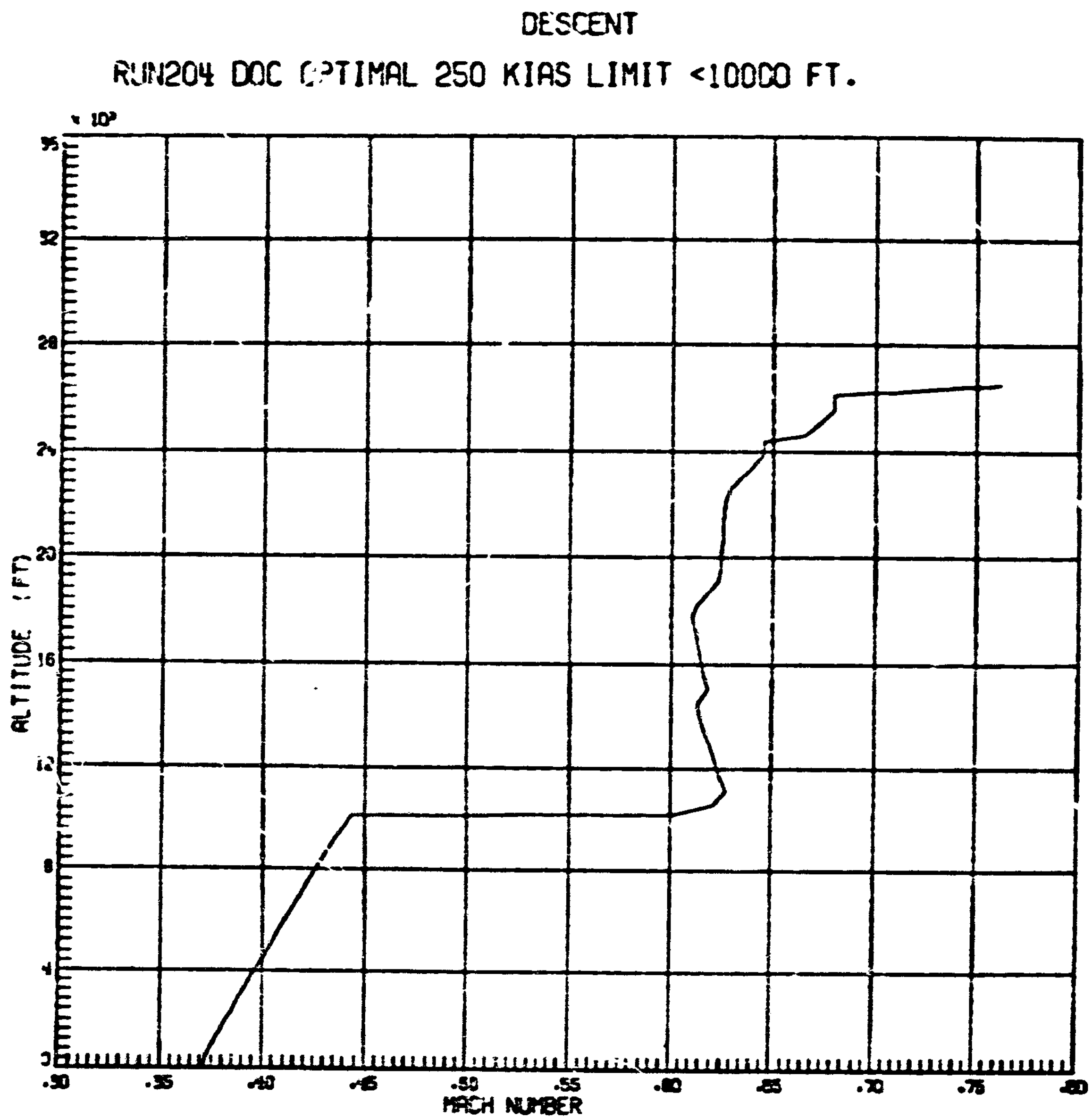

Figure 19.3 (DESCENT)

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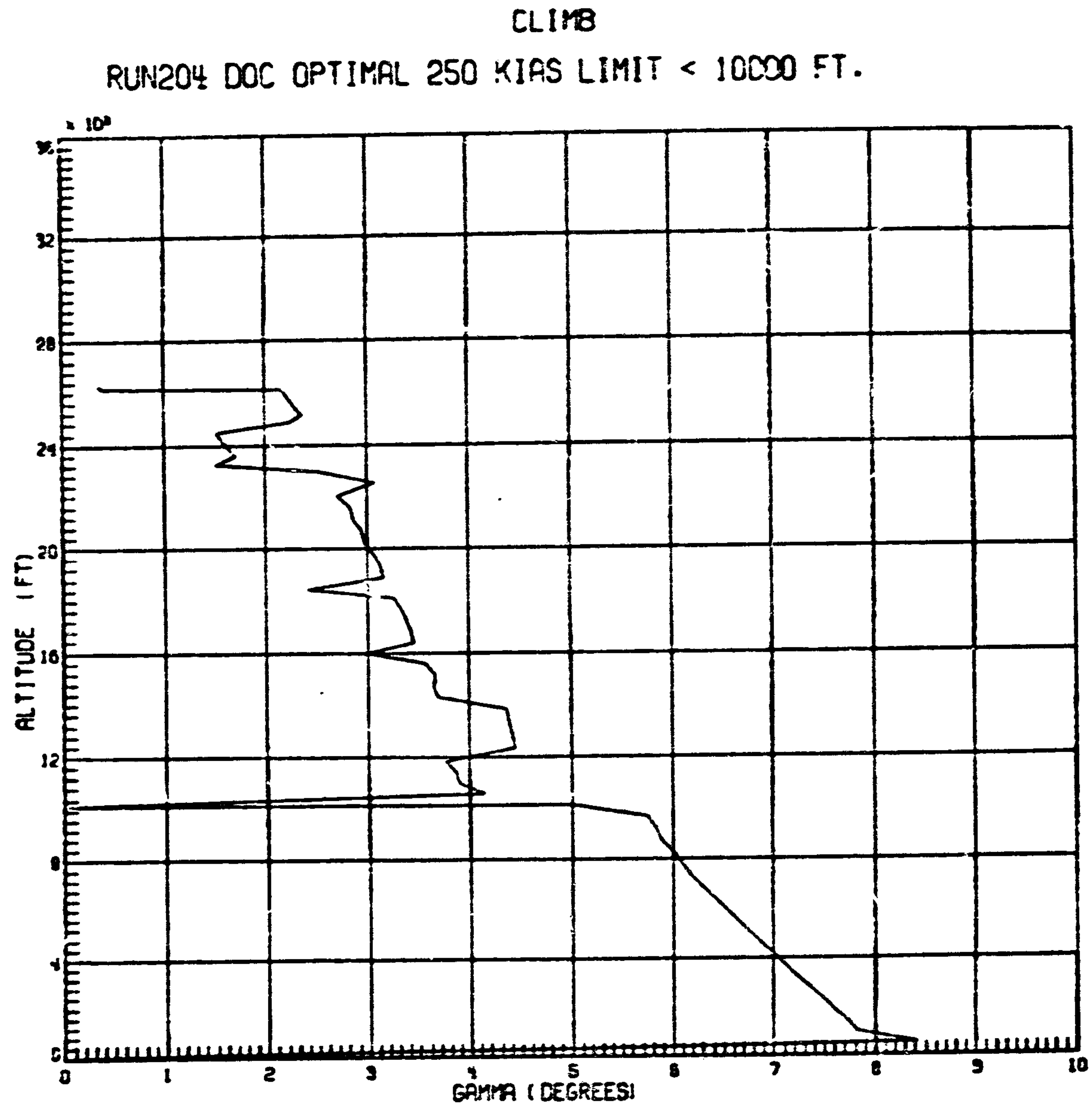

Figure 19.4 - GAMMA-ALTITUDE RELATION FOR RUN 204

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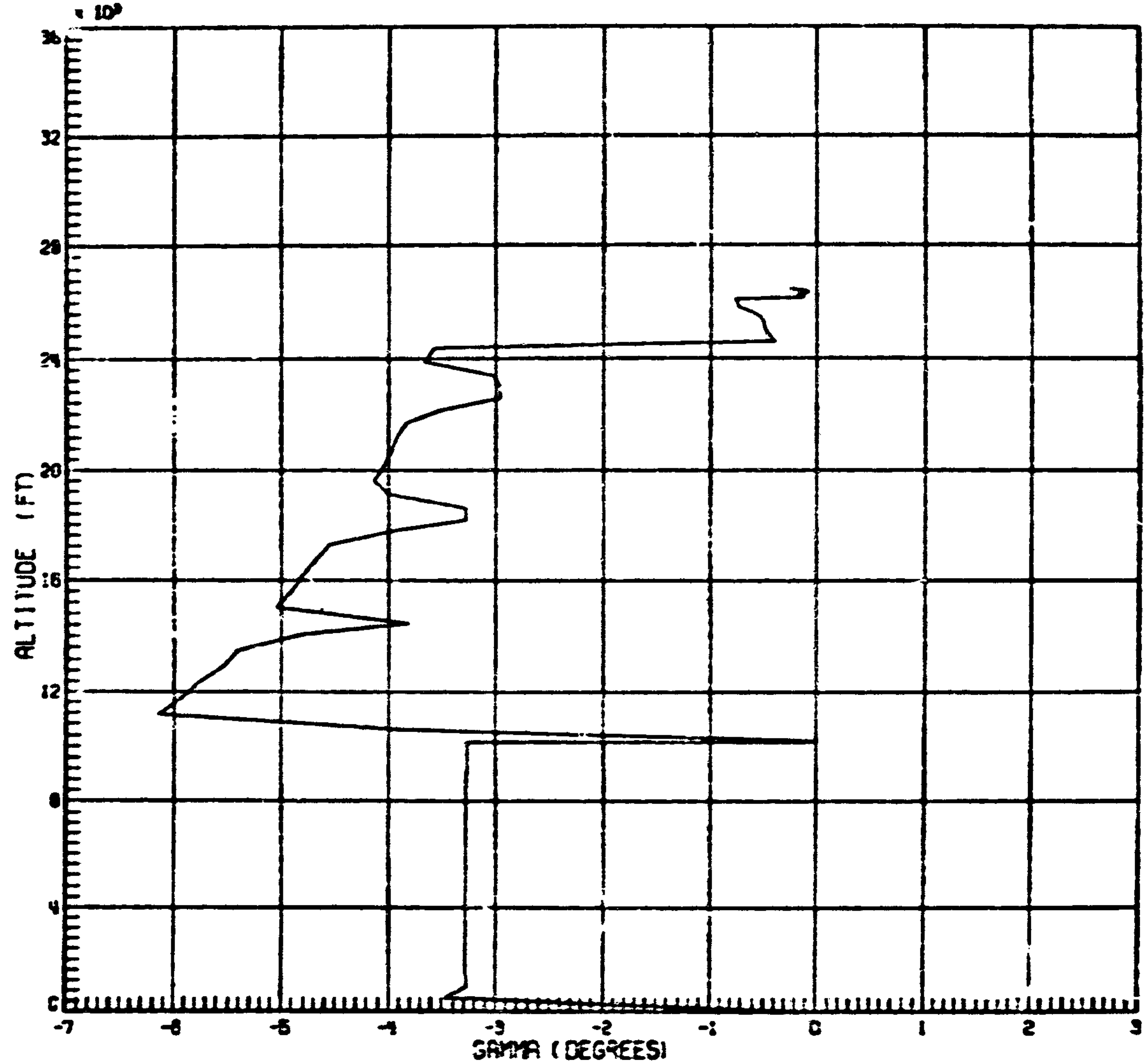

Figure 19.4 (DESCENT)

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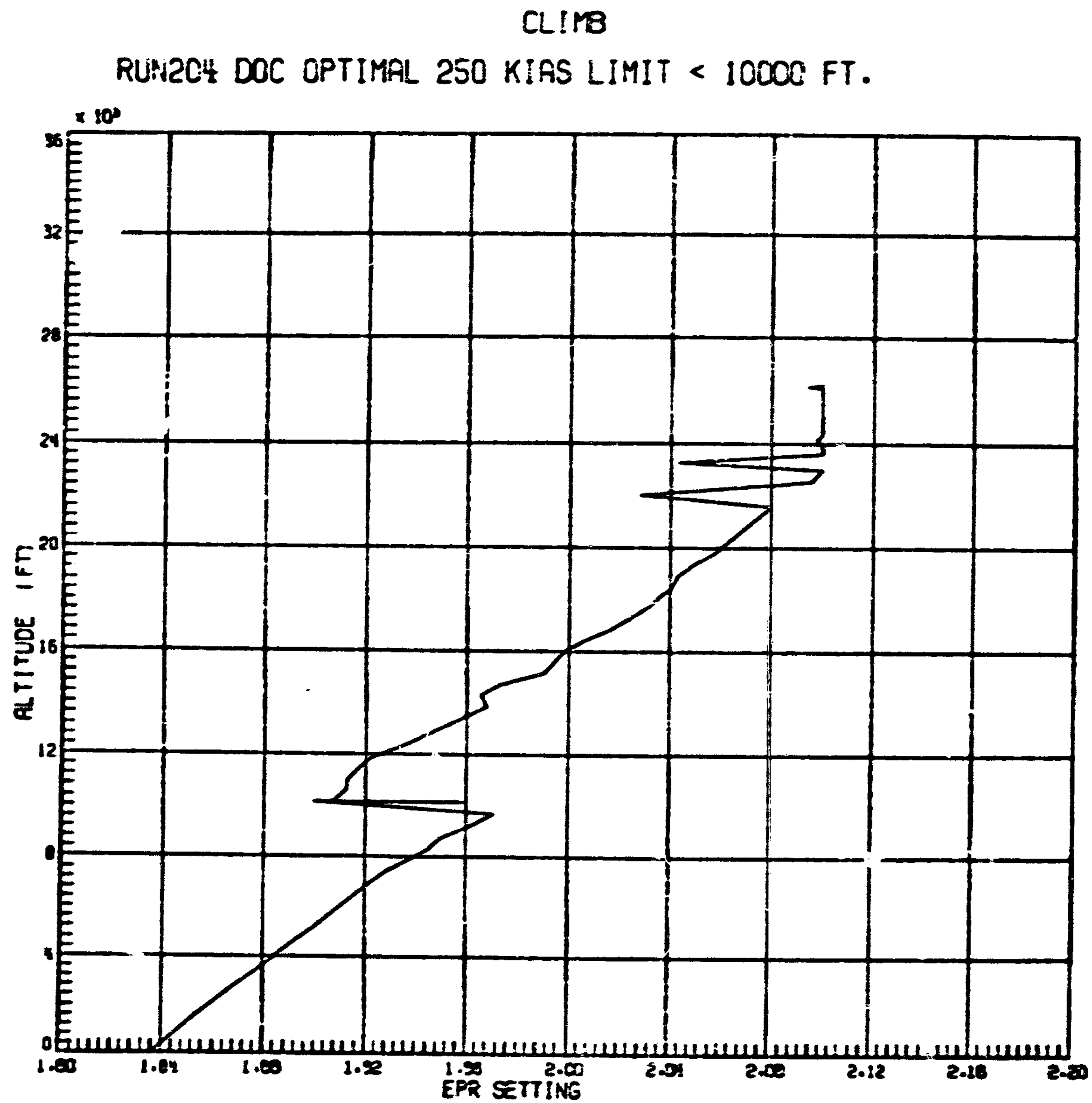

Figure 19.5 - EPR-ALTITUDE RELATION FOR RUN 204

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RUN204 DOC OPTIMAL 250 KIAS LIMIT <10000 FT.

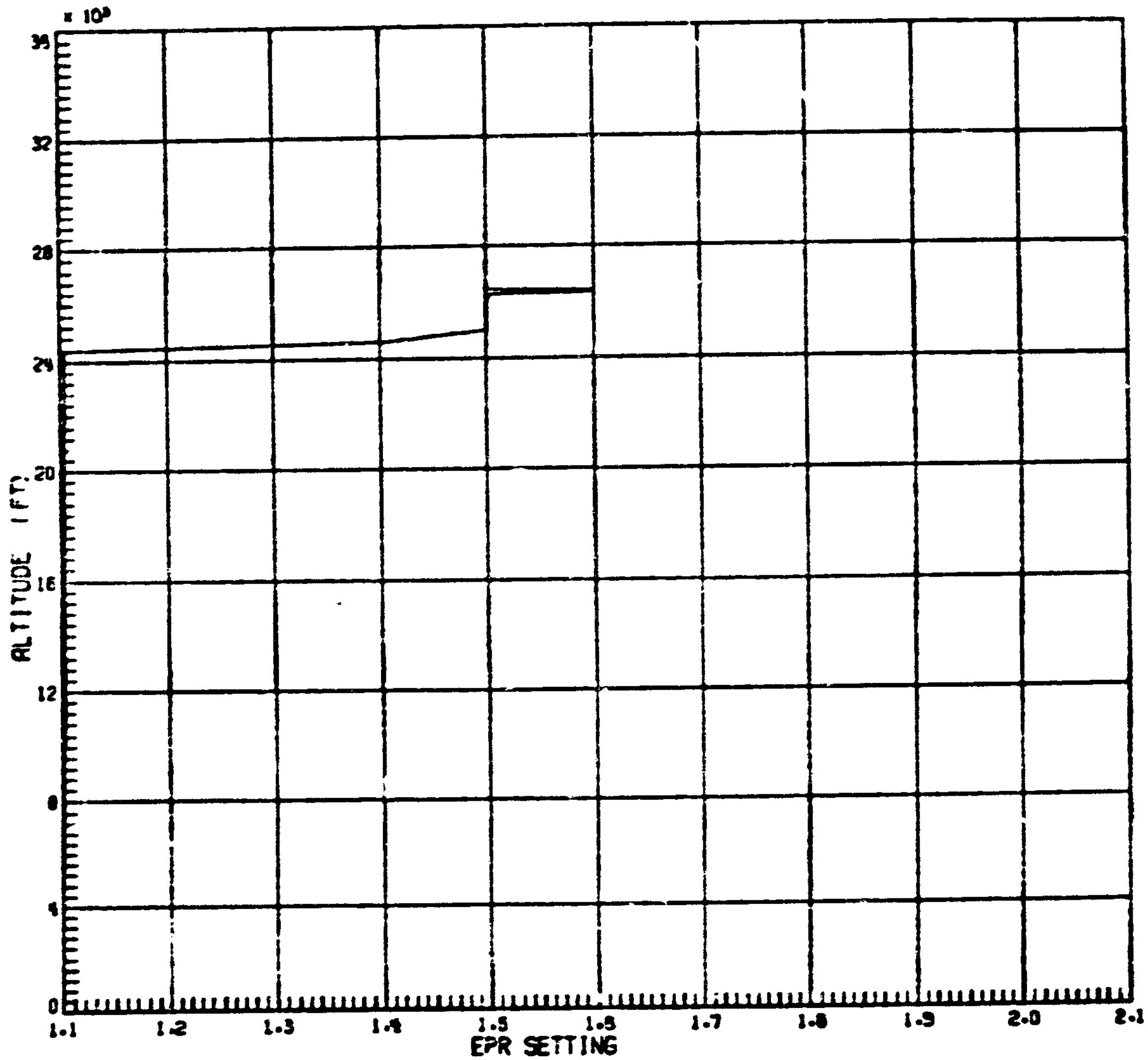

Figure 19.5 (DESCENT)

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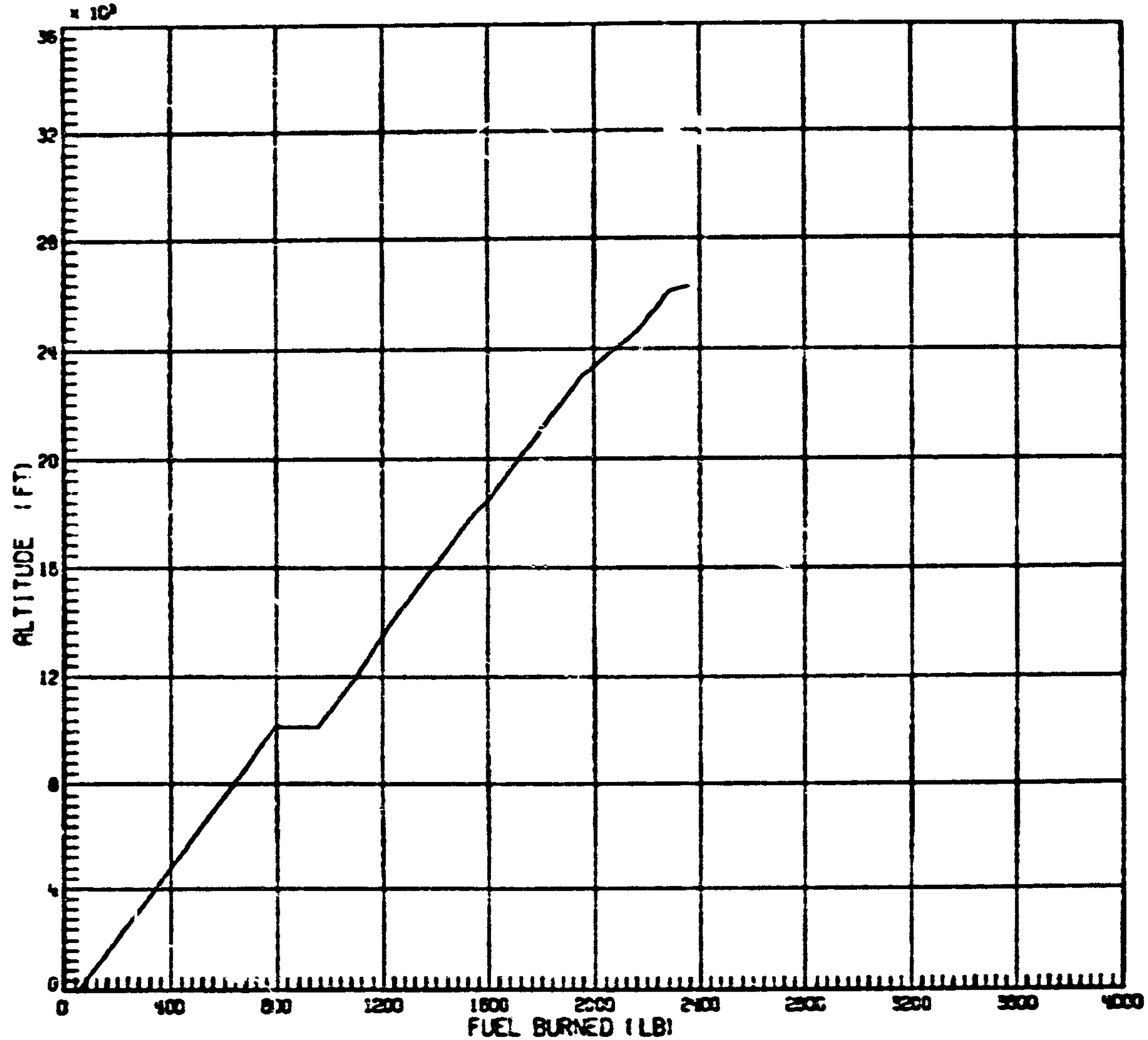

Figure 19.6 - FUEL BURNED-ALTITUDE RELATION FOR RUN 204

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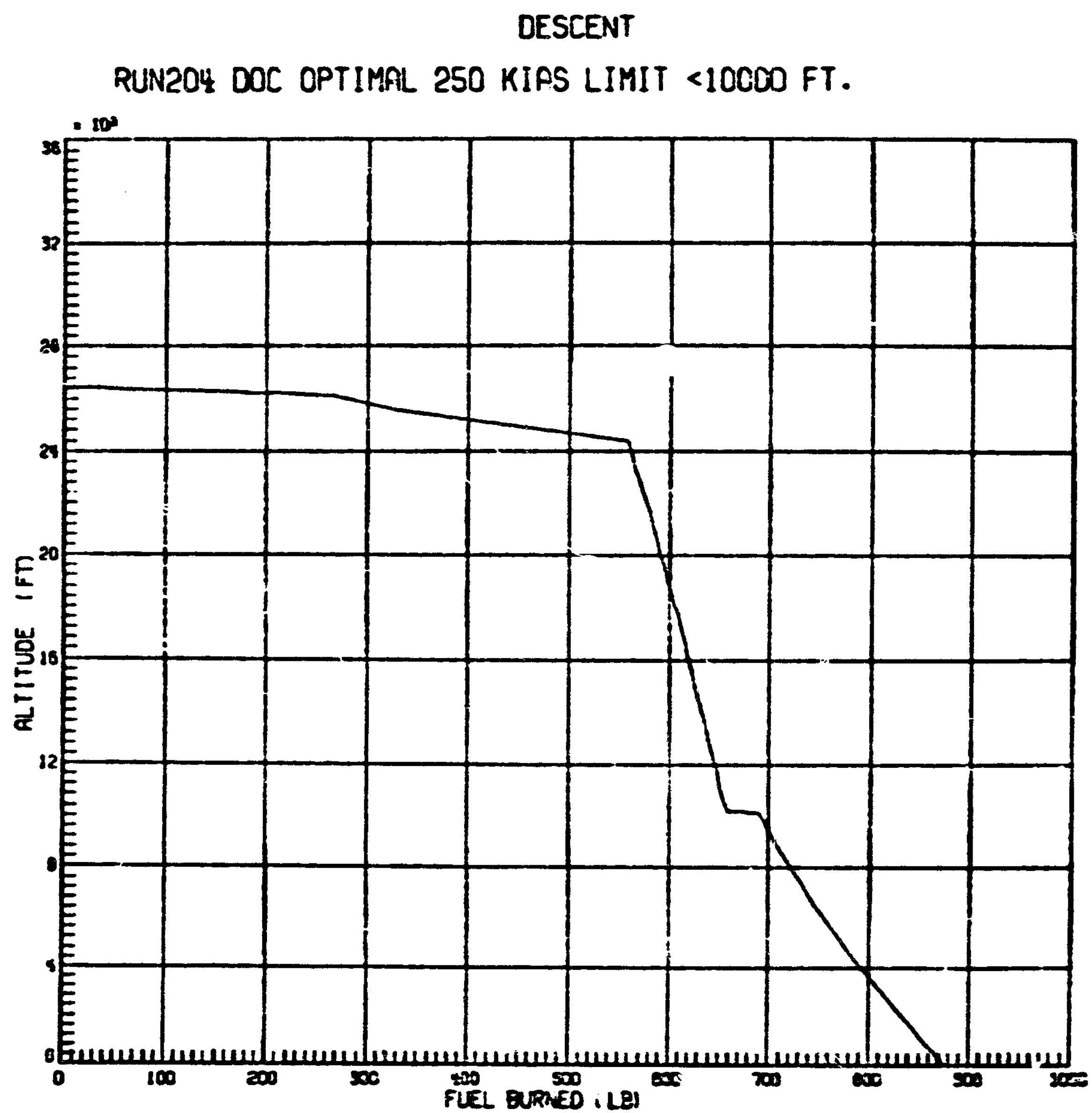

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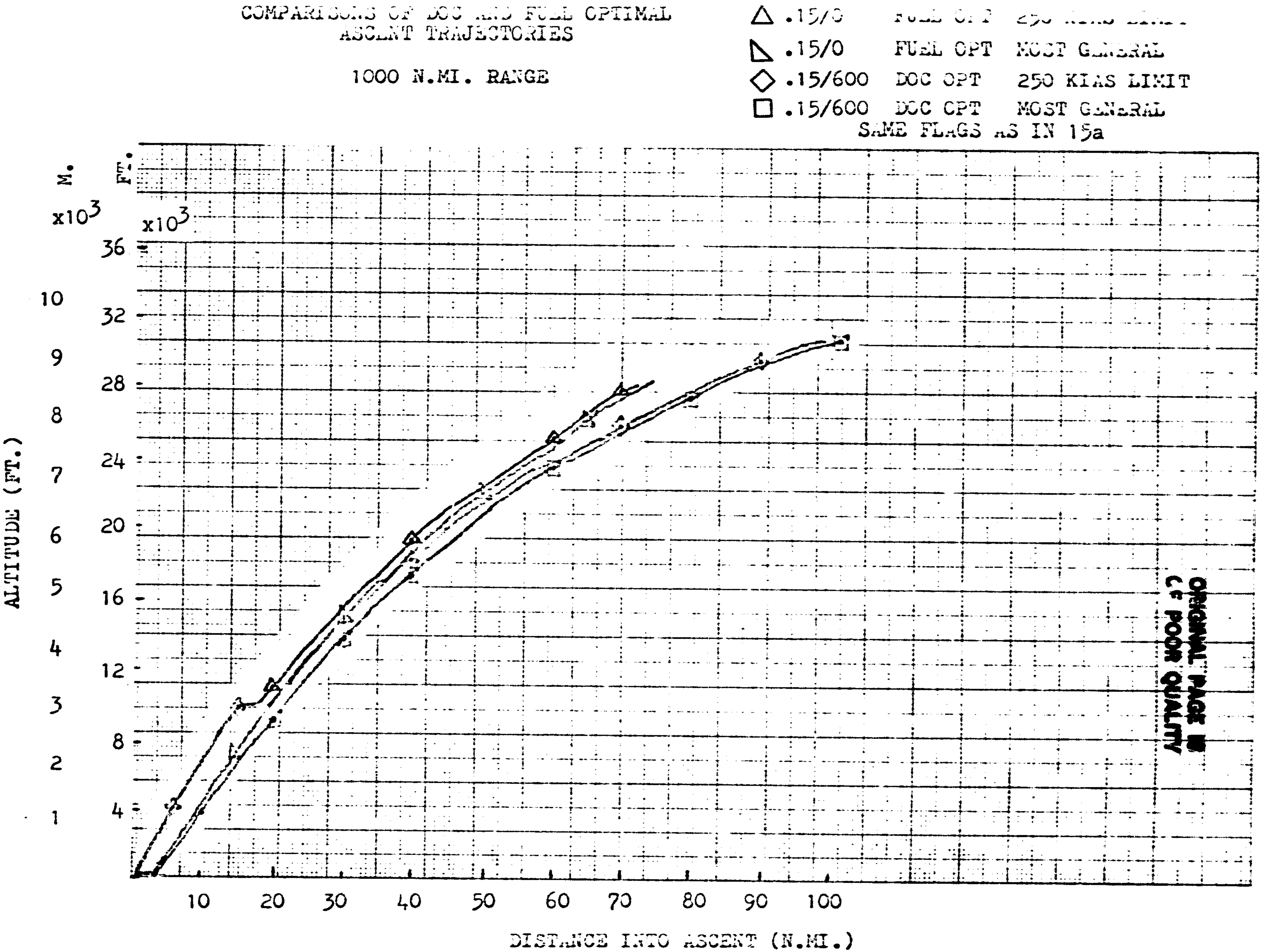

Figure 20a. - Comparisons of vertical flight profiles at 1,000 N.Mi.

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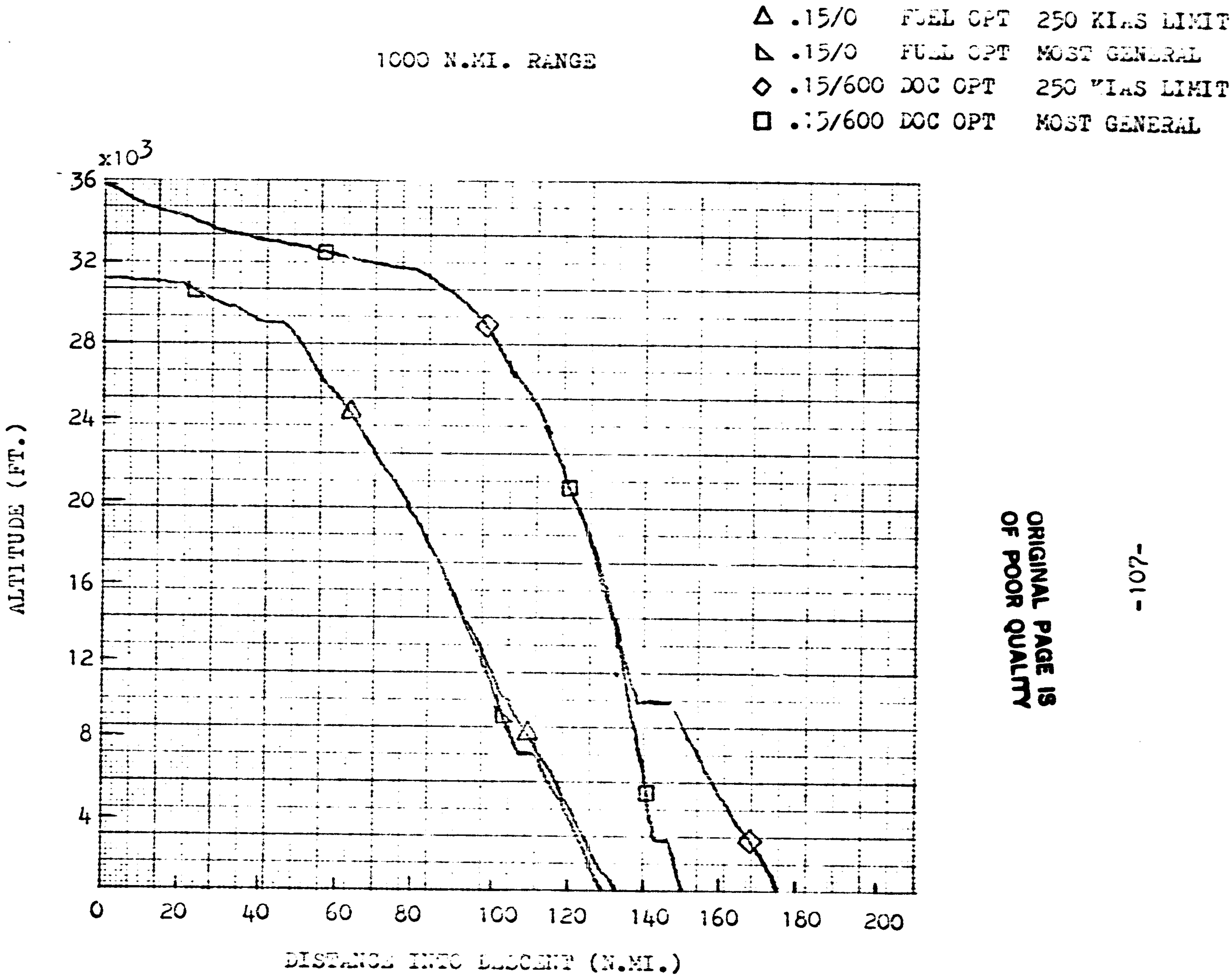

Figure 20b. - Descent portions of vertical profiles at 1,000 N.Mi.

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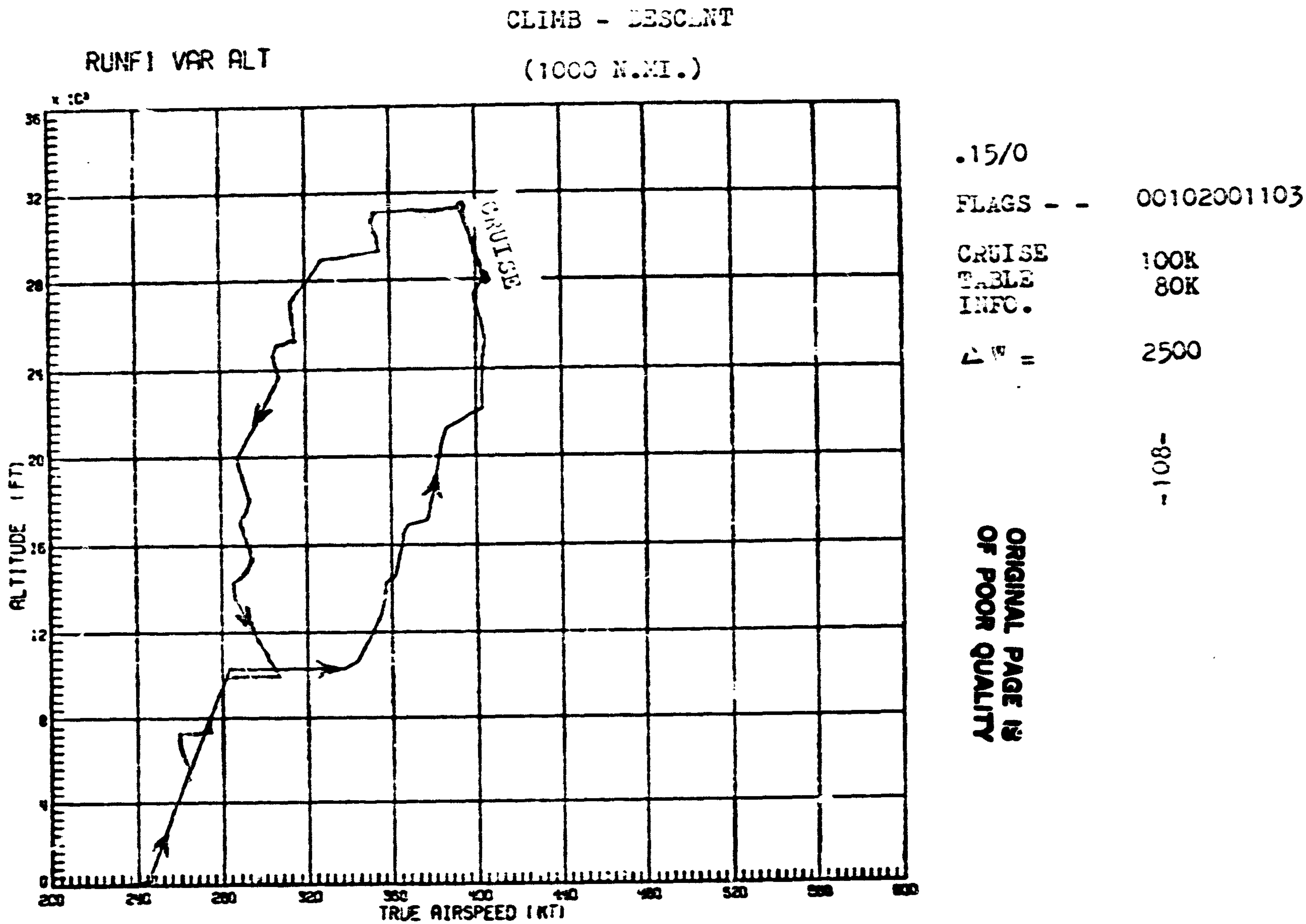

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Figure 21.1 - AIRSPEED-ALTITUDE RELATION FOR RUN F1

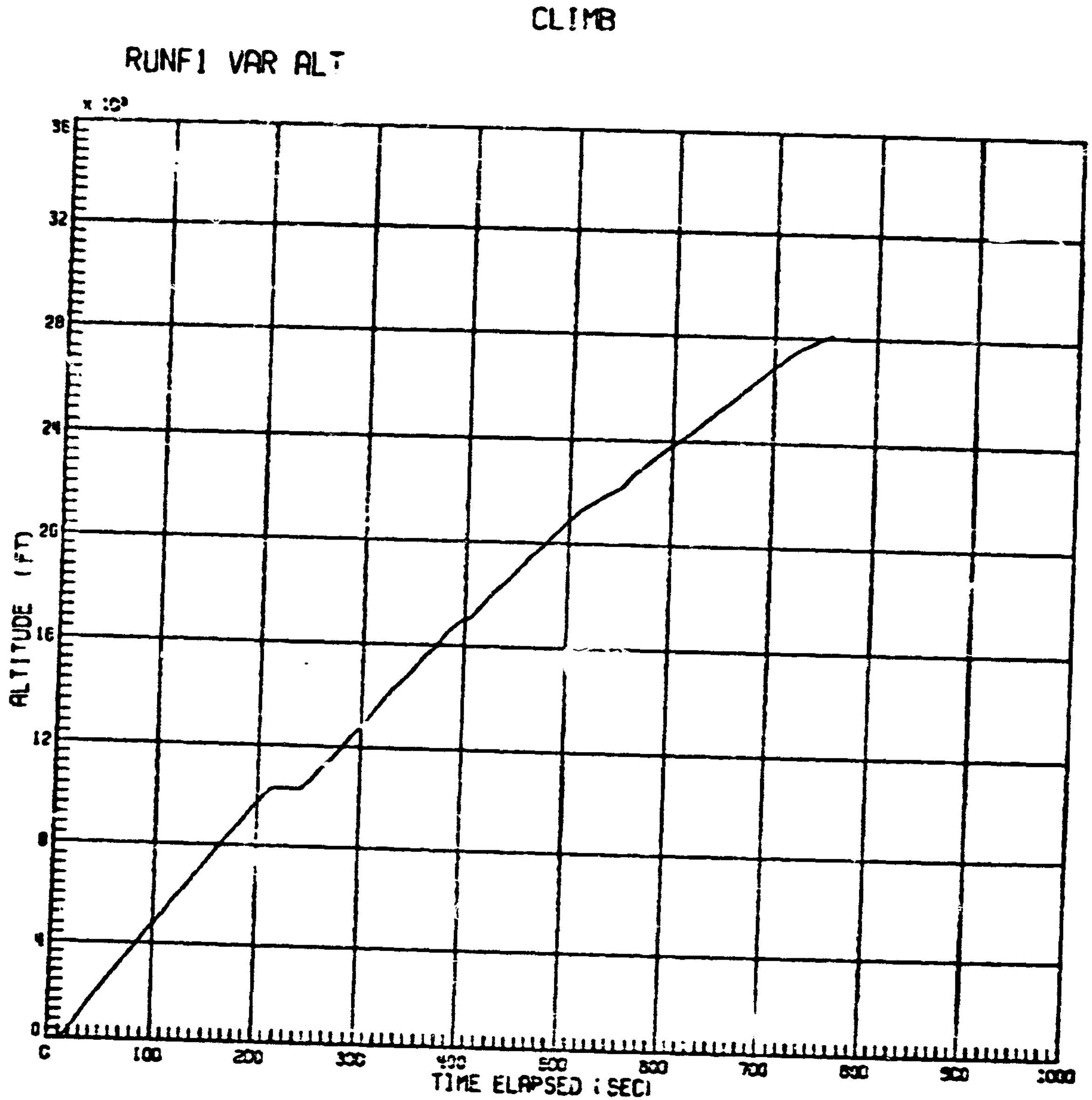

Figure 21.2 - TIME-ALTITUDE RELATION FOR RUN F1

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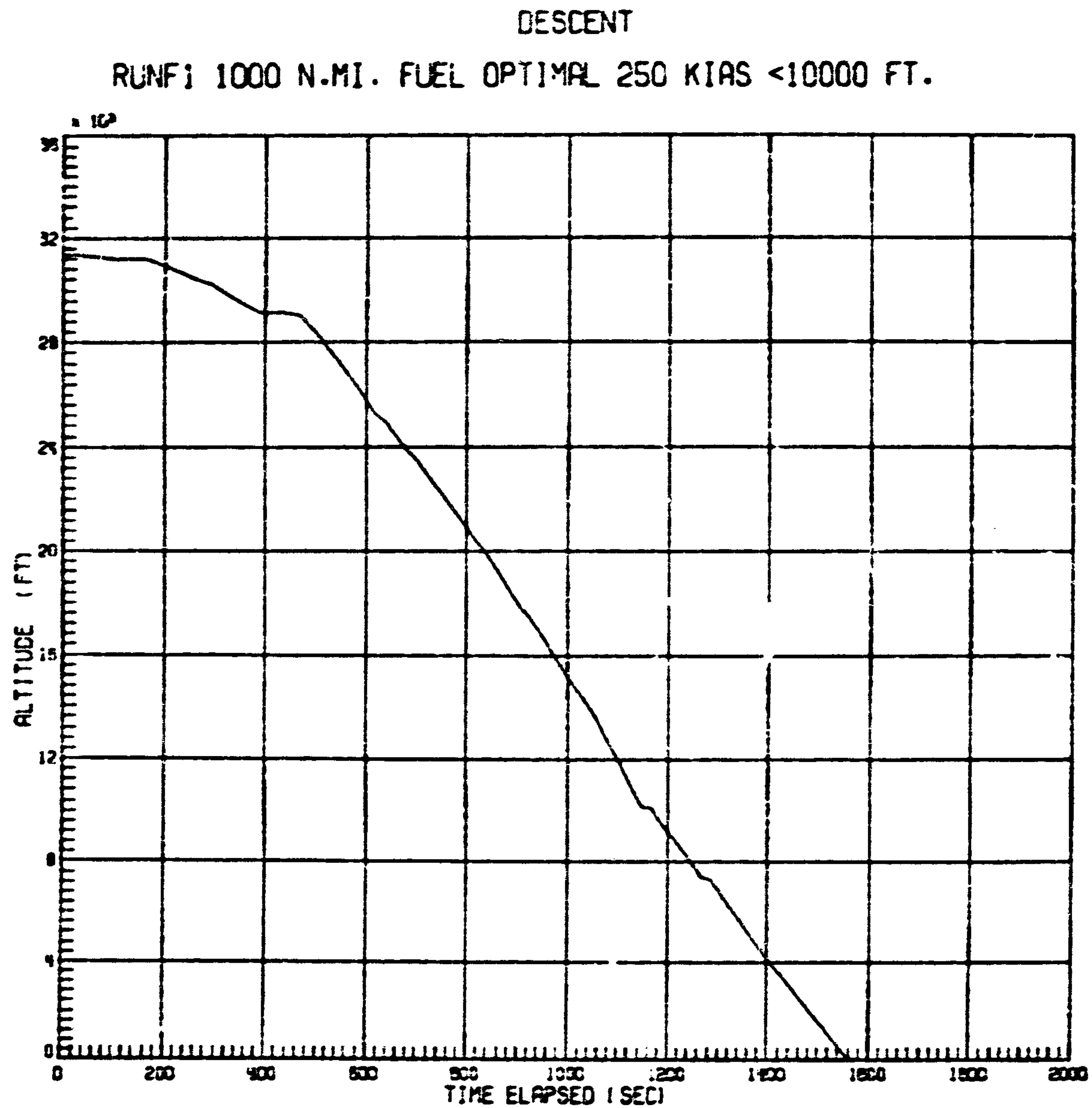

Figure 21.2 (DESCENT)

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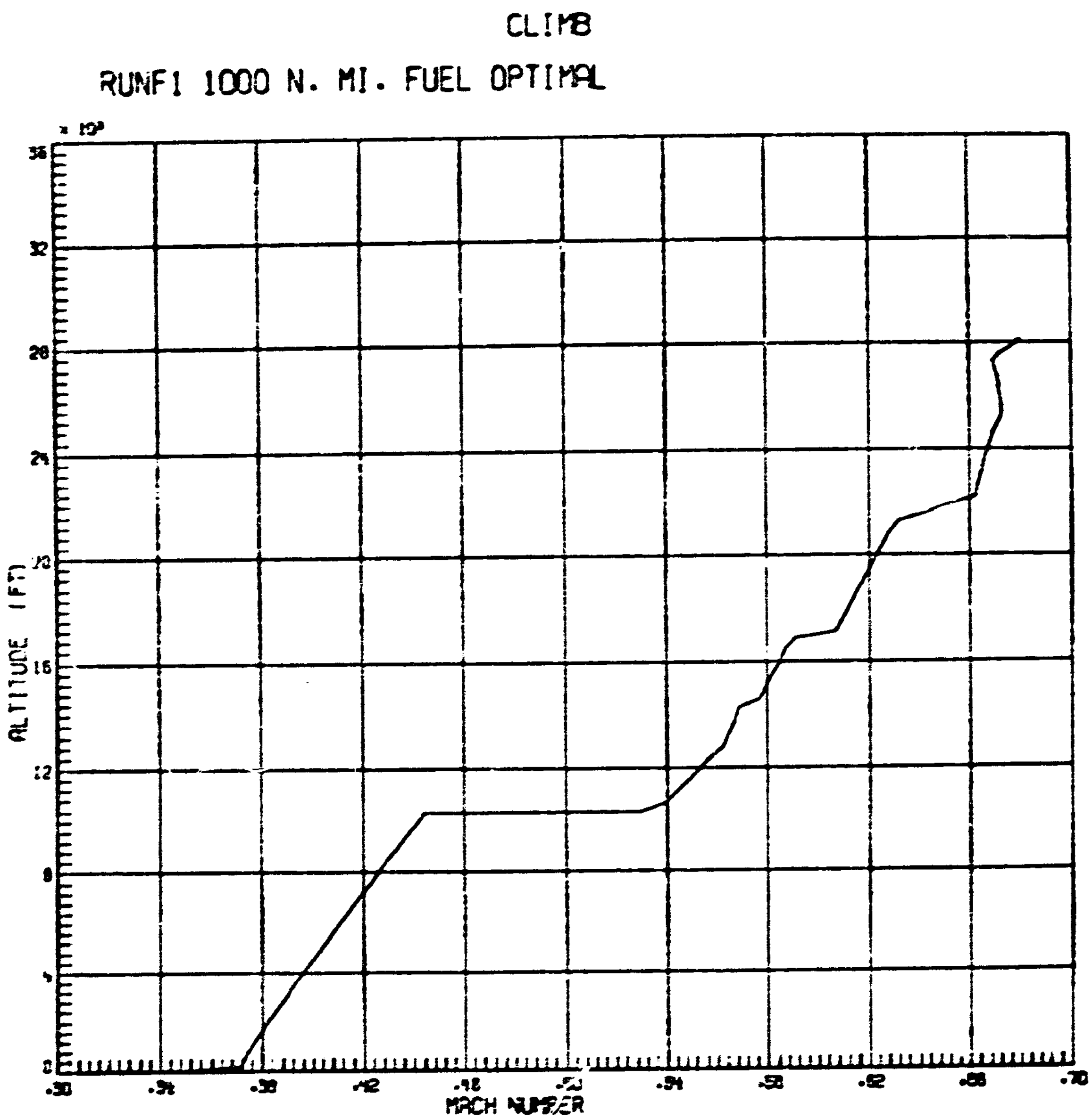

Figure 21.3 - MACH-ALTITUDE RELATION FOR RUN F1

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RUNF1 1000 N.MI. FUEL OPTIMAL 250 KIAS <10000 FT.

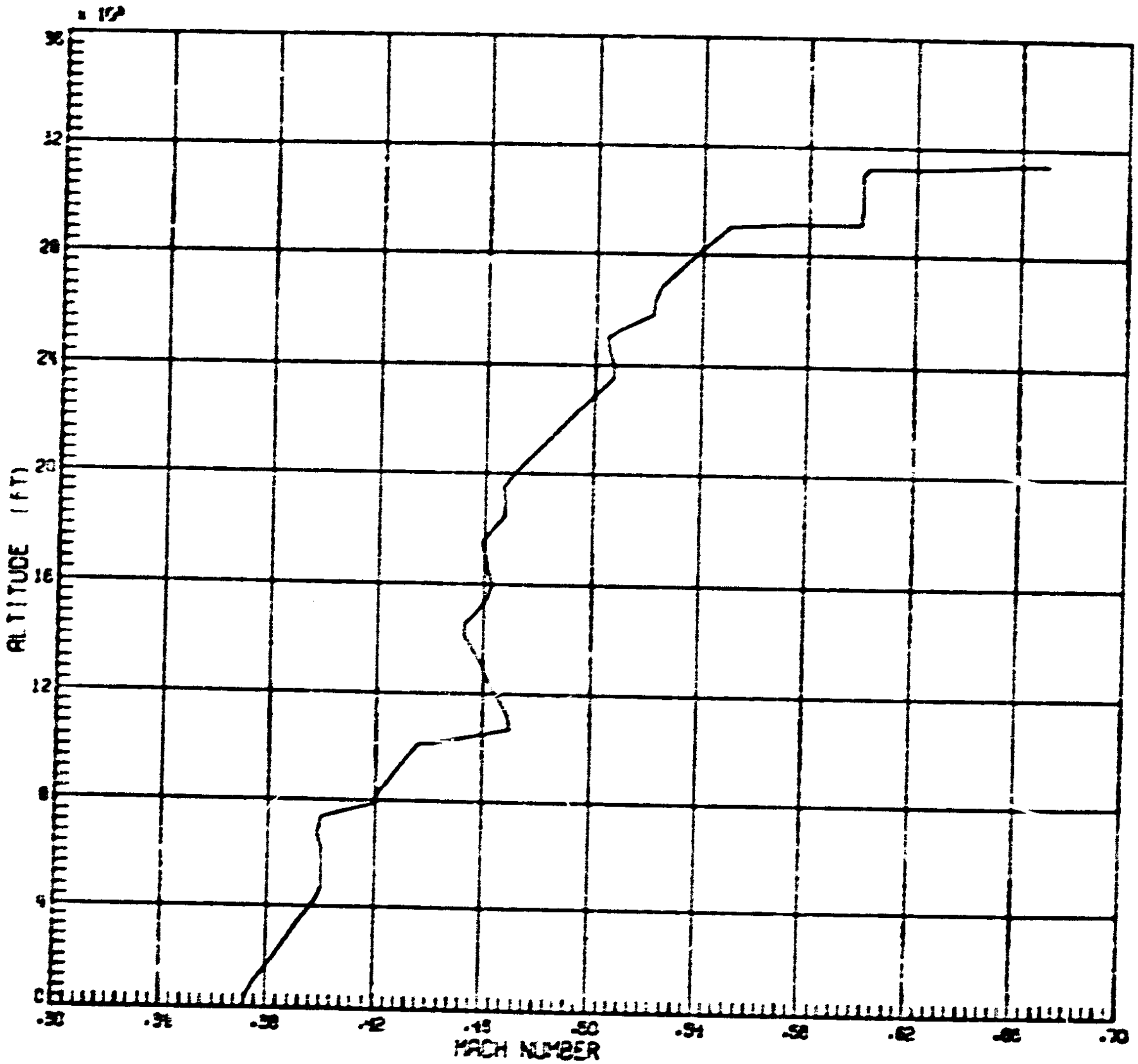

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Figure 21.3 (DESCENT)

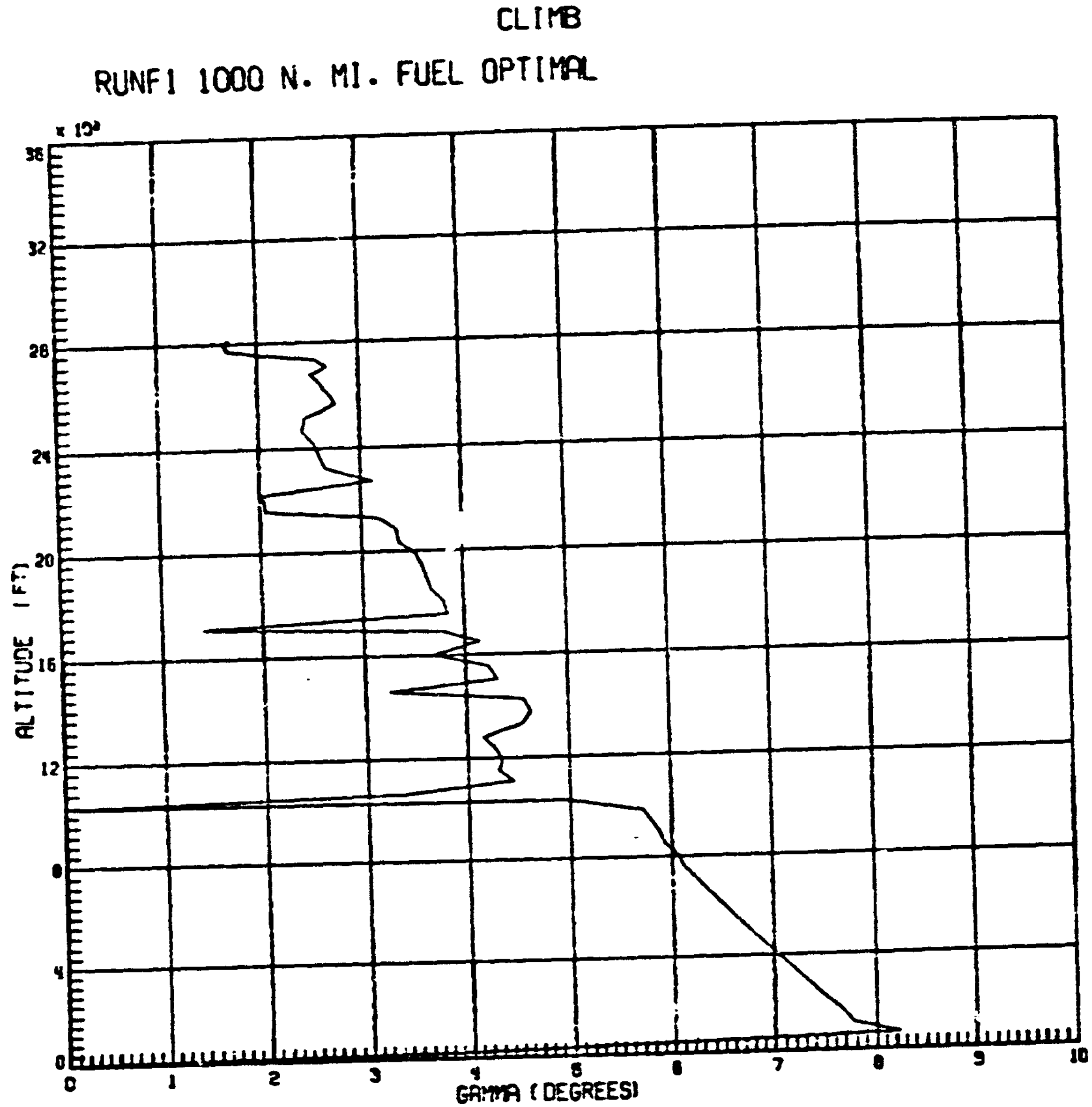

Figure 21.4 - FLIGHT PATH ANGLE-ALTITUDE FOR RUN F1

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RUNF1 1000 N.MI. FUEL OPTIMAL 250 KIAS <10000 FT.

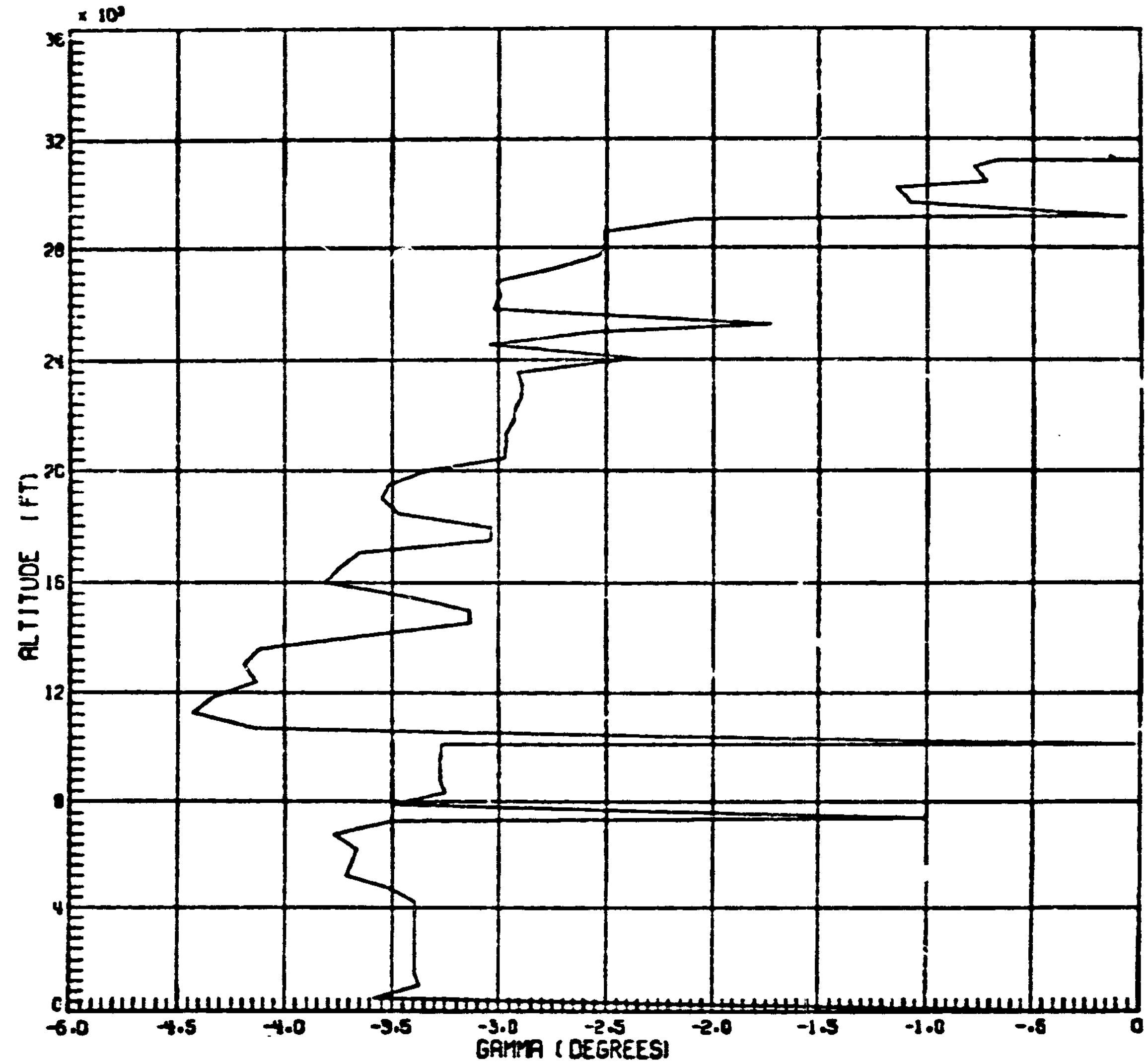

Figure 21.4 (DESCENT)

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RUNF1 1000 N. MI. FUEL OPTIMAL

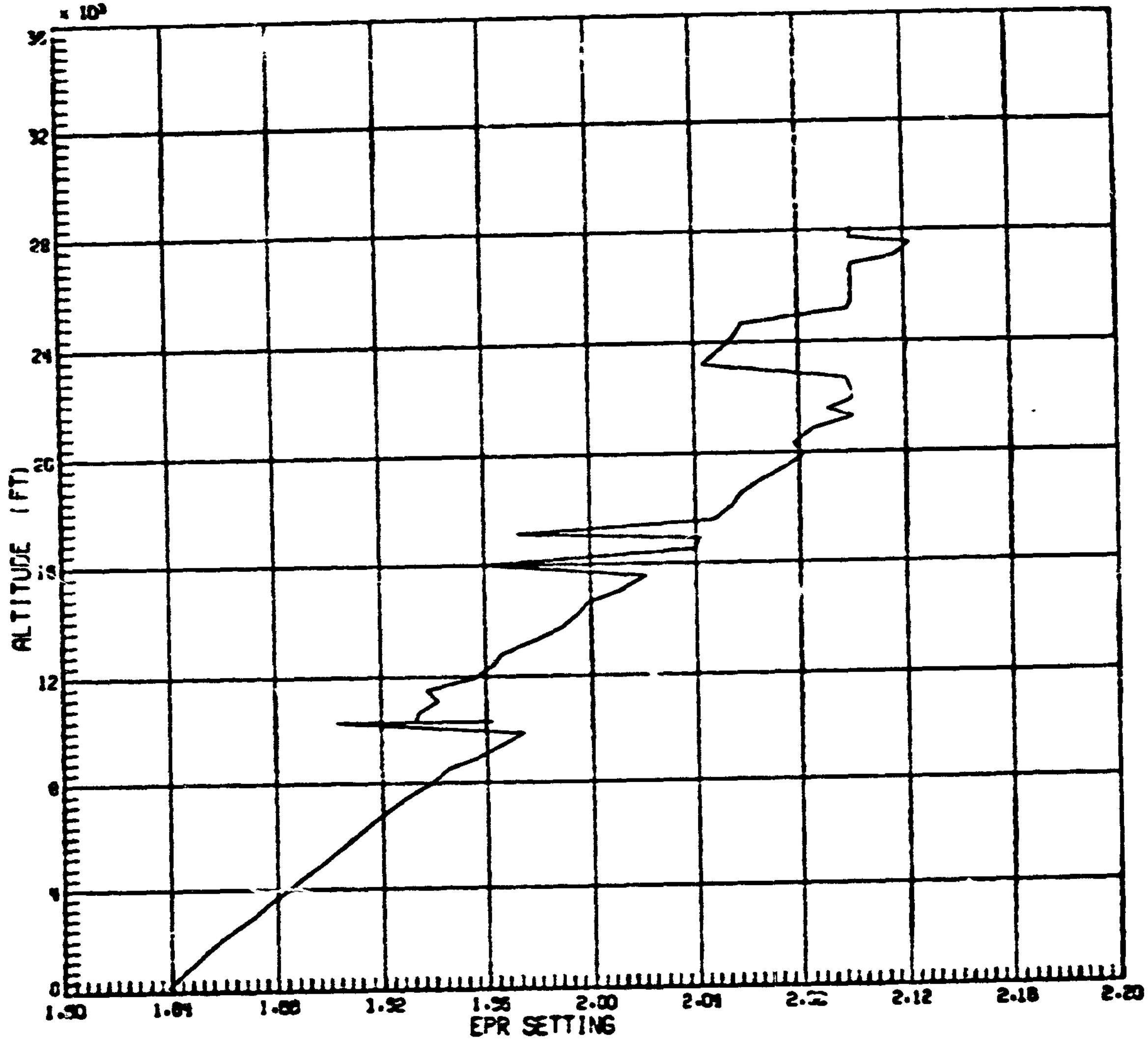

Figure 21.5 - ENGINE EXHAUST PRESSURE RATIO -ALTITUDE FOR RUN F1

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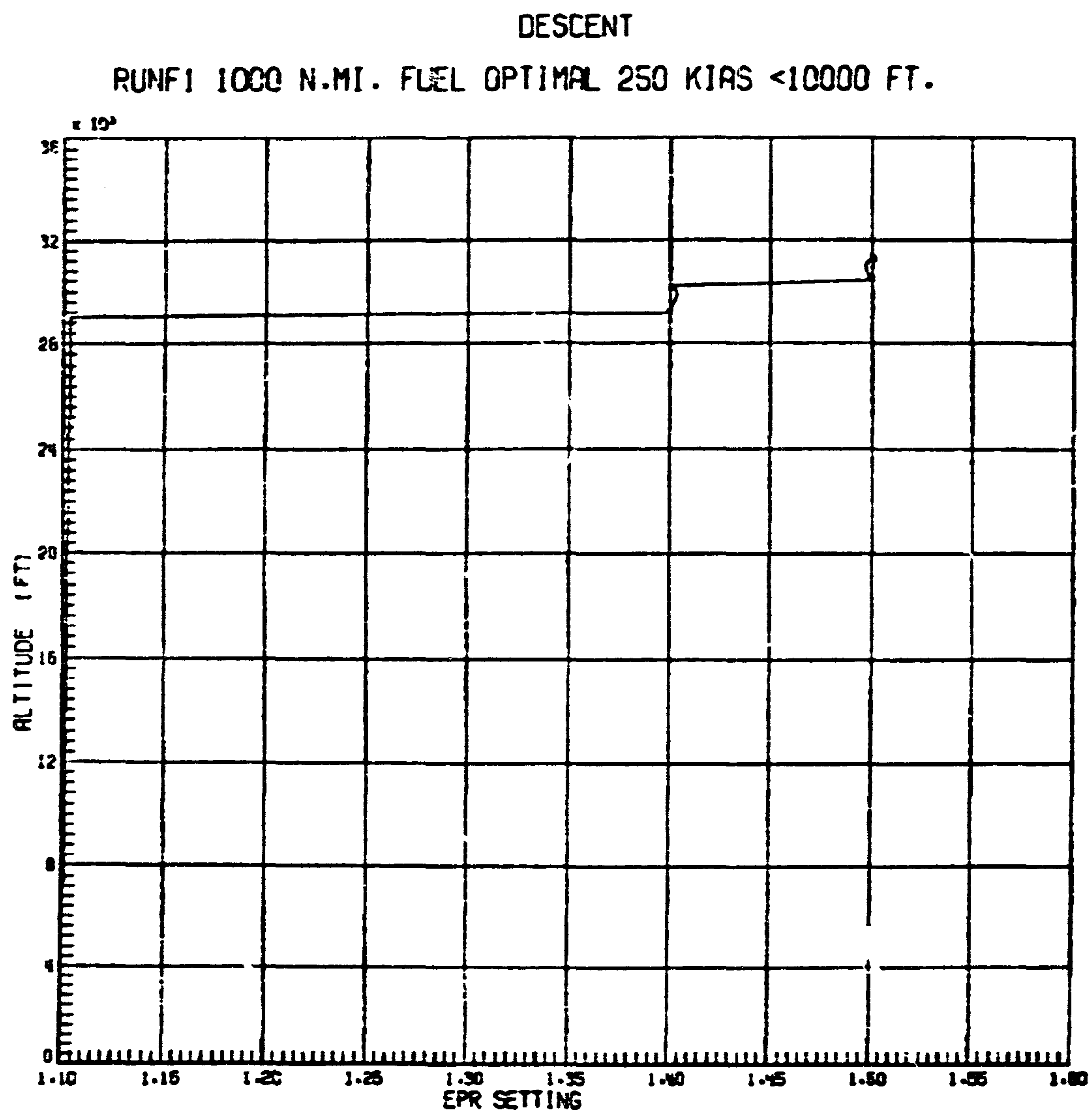

Figure 21.5 (DESCENT)

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RUNF1 1000 N. MI. FUEL OPTIMAL

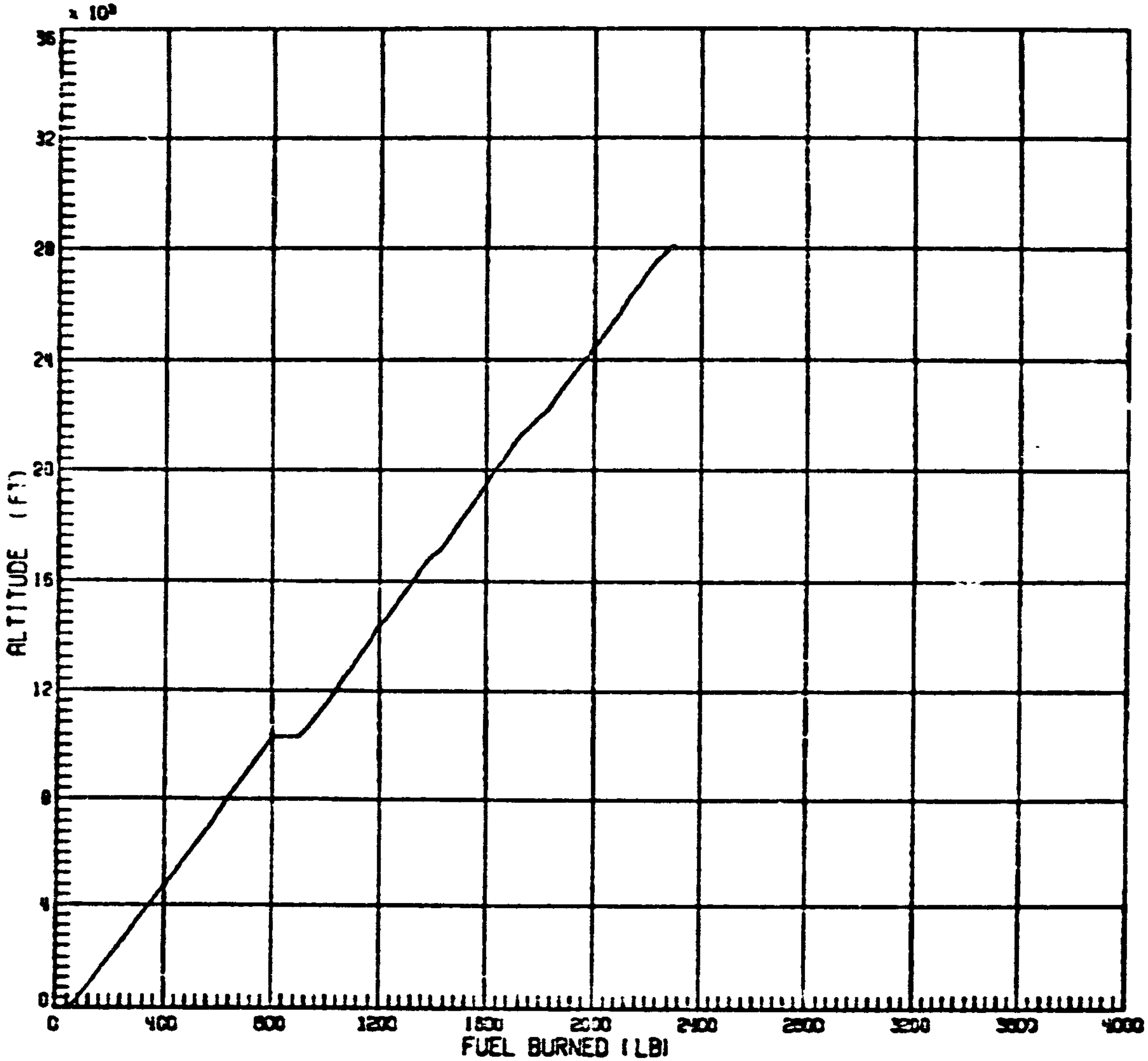

Figure 21.6 - FUEL BURNED-ALTITUDE FOR RUN F1

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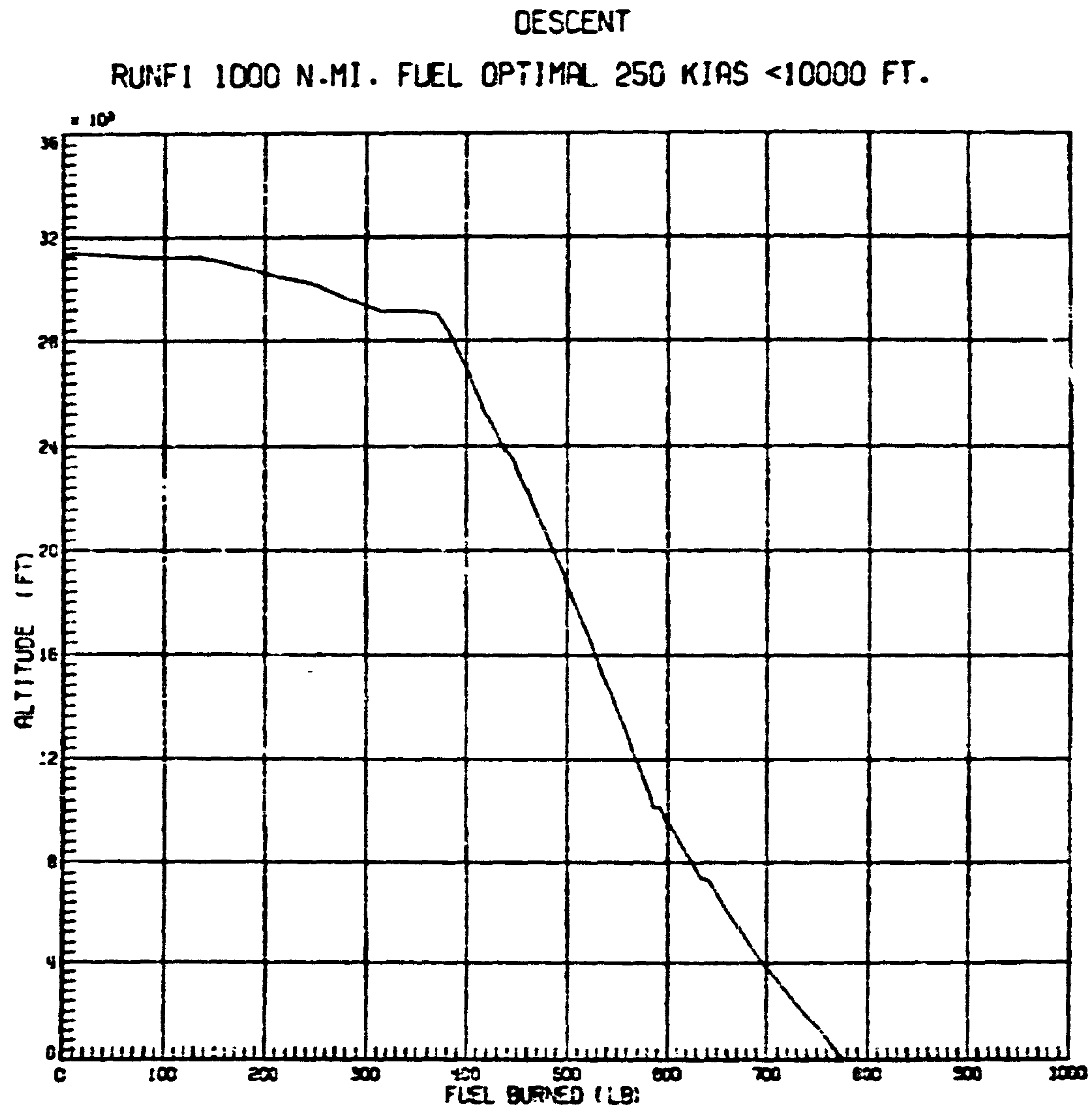

Figure 21.6 (DESCENT)

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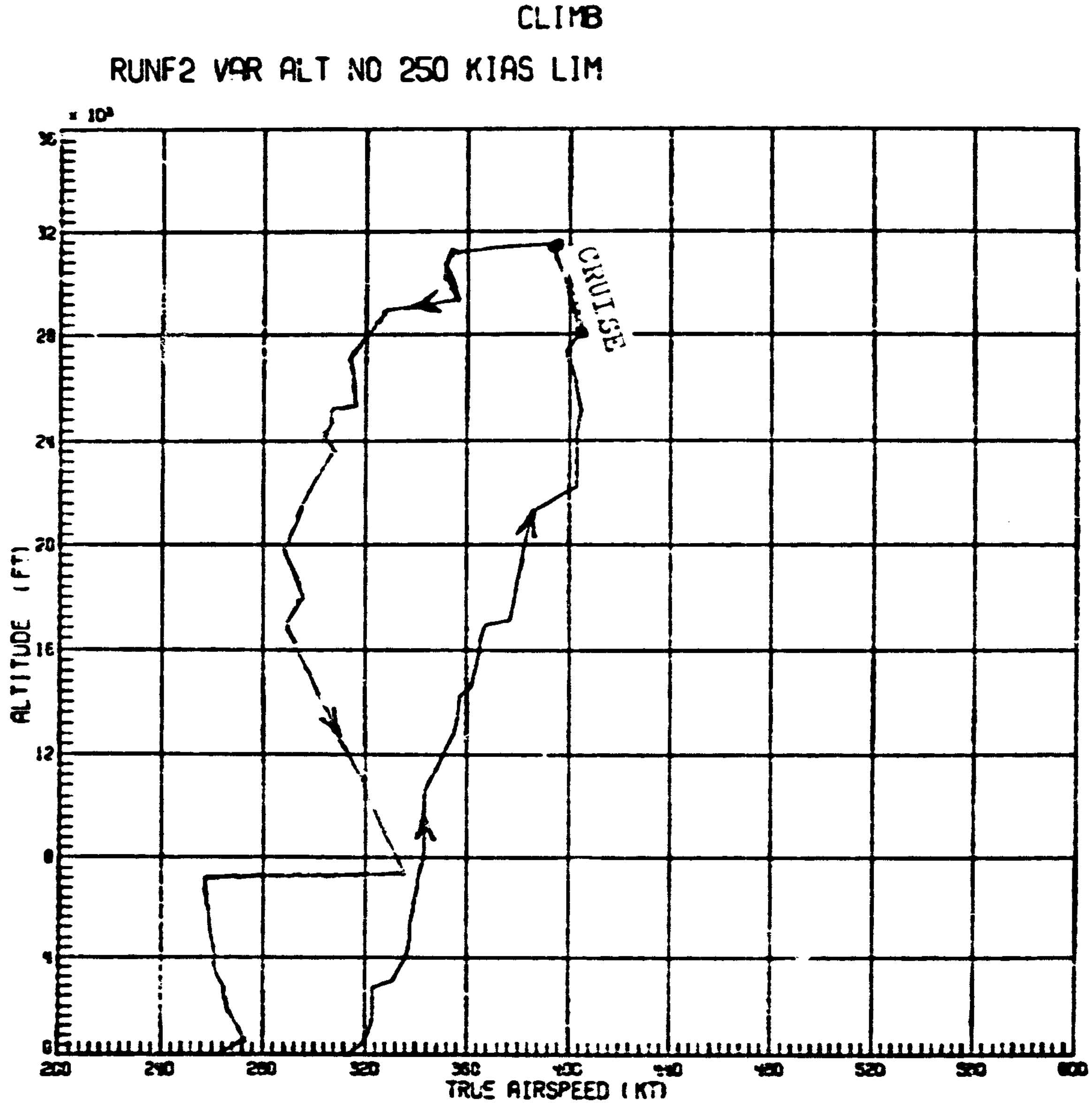

Figure 22.1 - TRUE AIRSPEED-ALTITUDE FOR RUN F2

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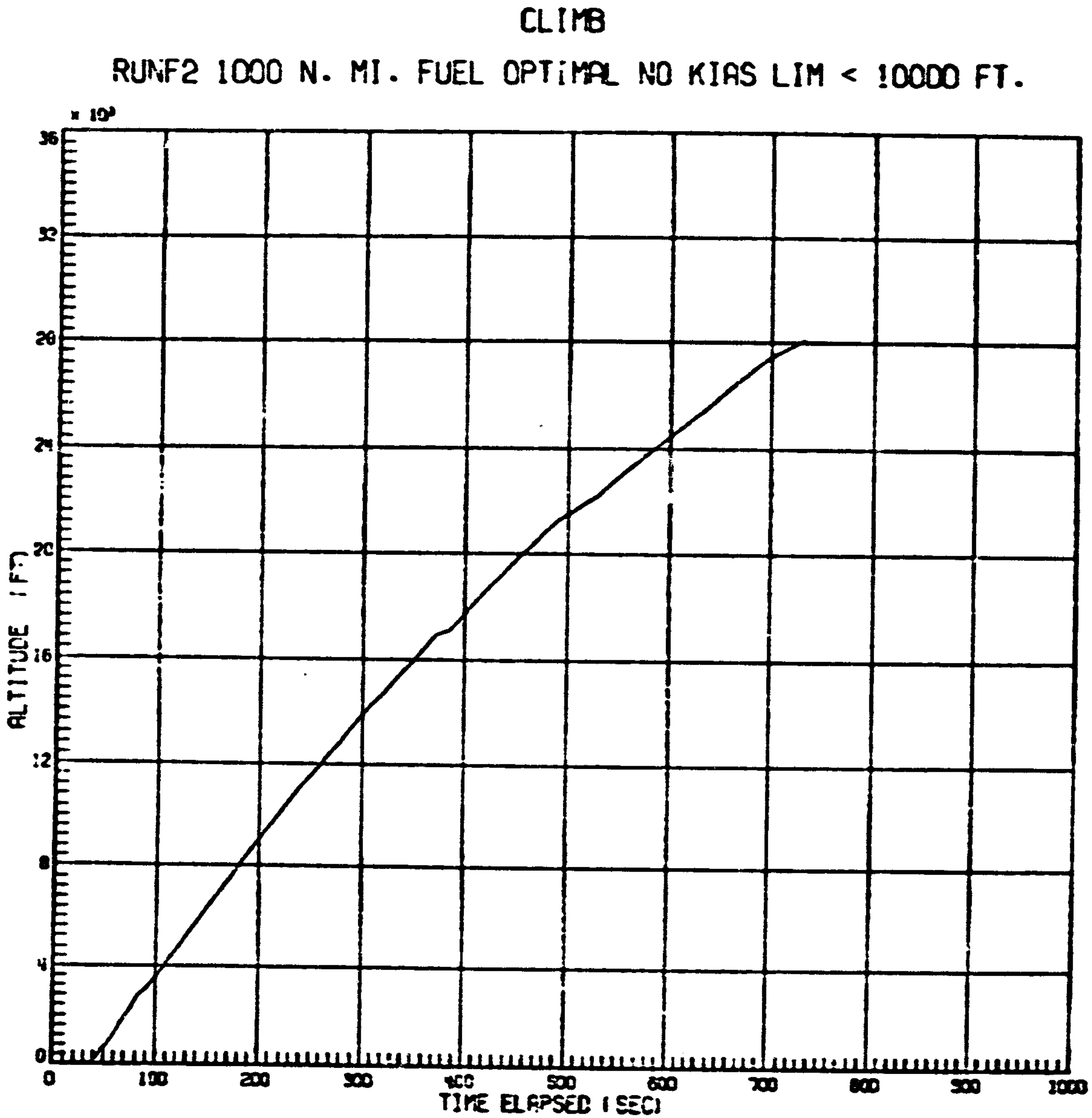

Figure 22.2 - TIME ELAPSED-ALTITUDE FOR RUN F2

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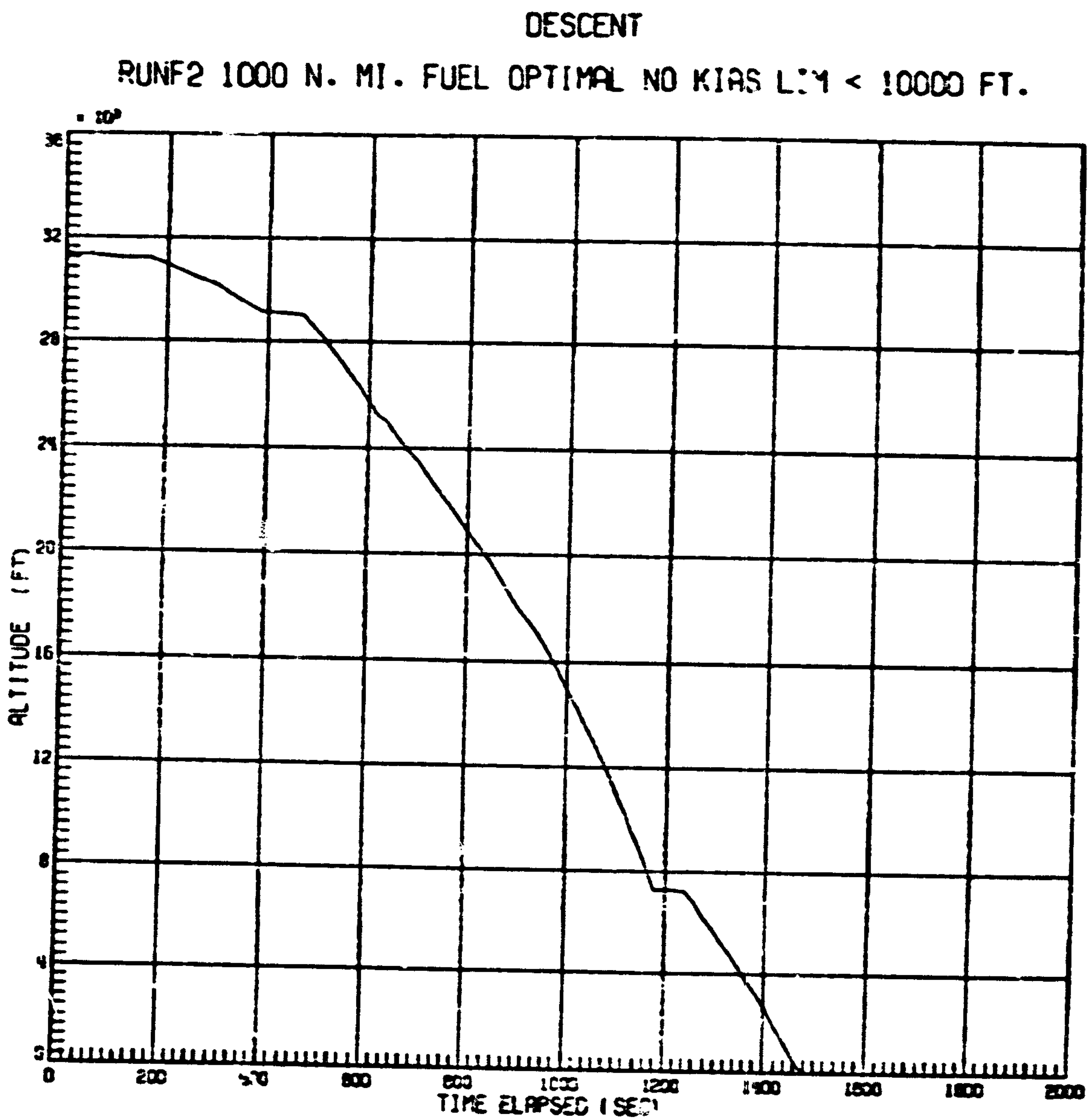

Figure 22.2 - DESCENT GRAPH (TIME-ALTITUDE) FOR RUN F2

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RUNF2 1000 N. MI. FUEL OPTIMAL NO KIAS LIM < 10000 FT.

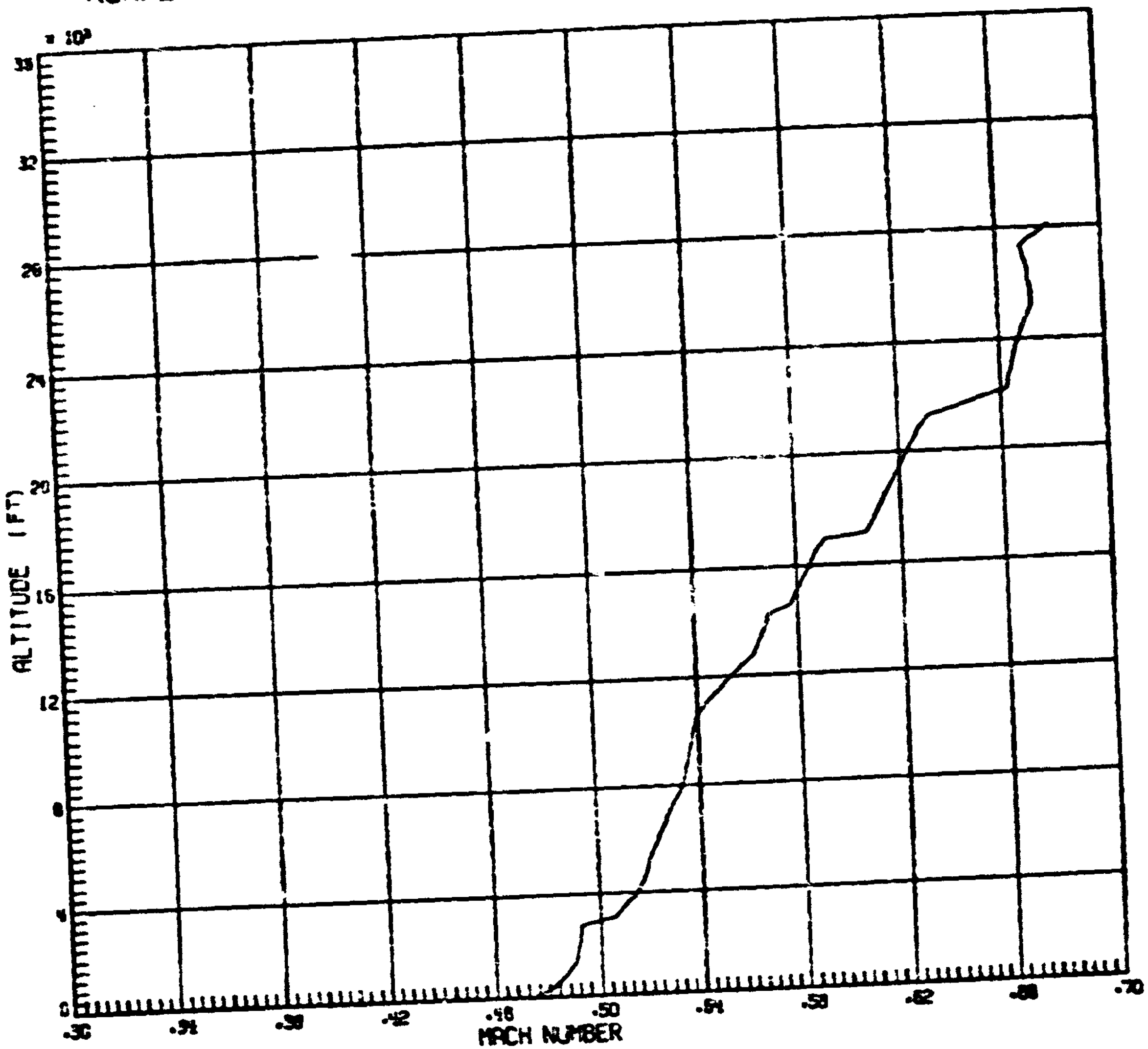

Figure 22.3 - MACH-ALTITUDE FOR RUN F2

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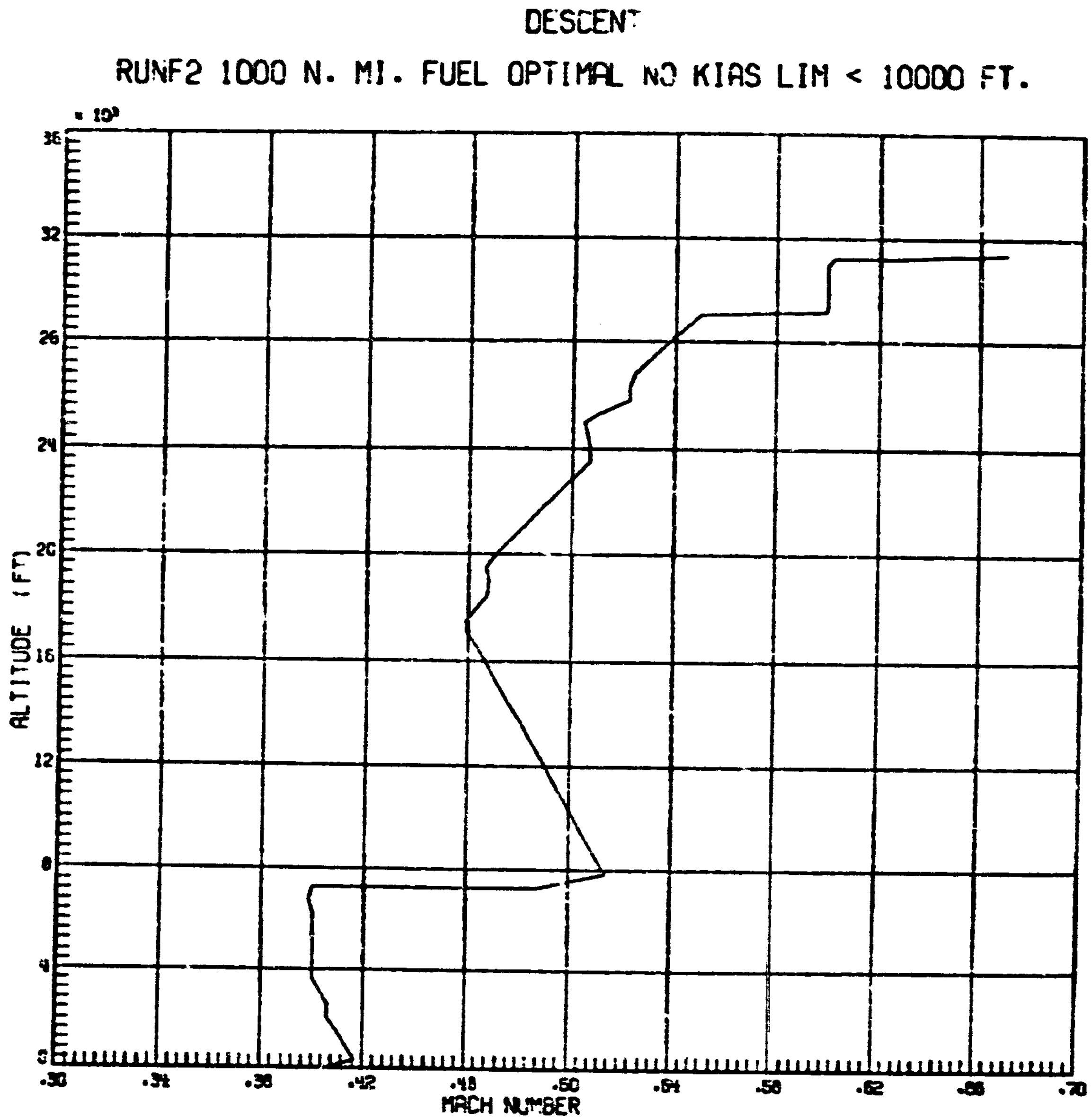

Figure 22.3 - MACH-ALTITUDE (DESCENT) FOR RUN F2

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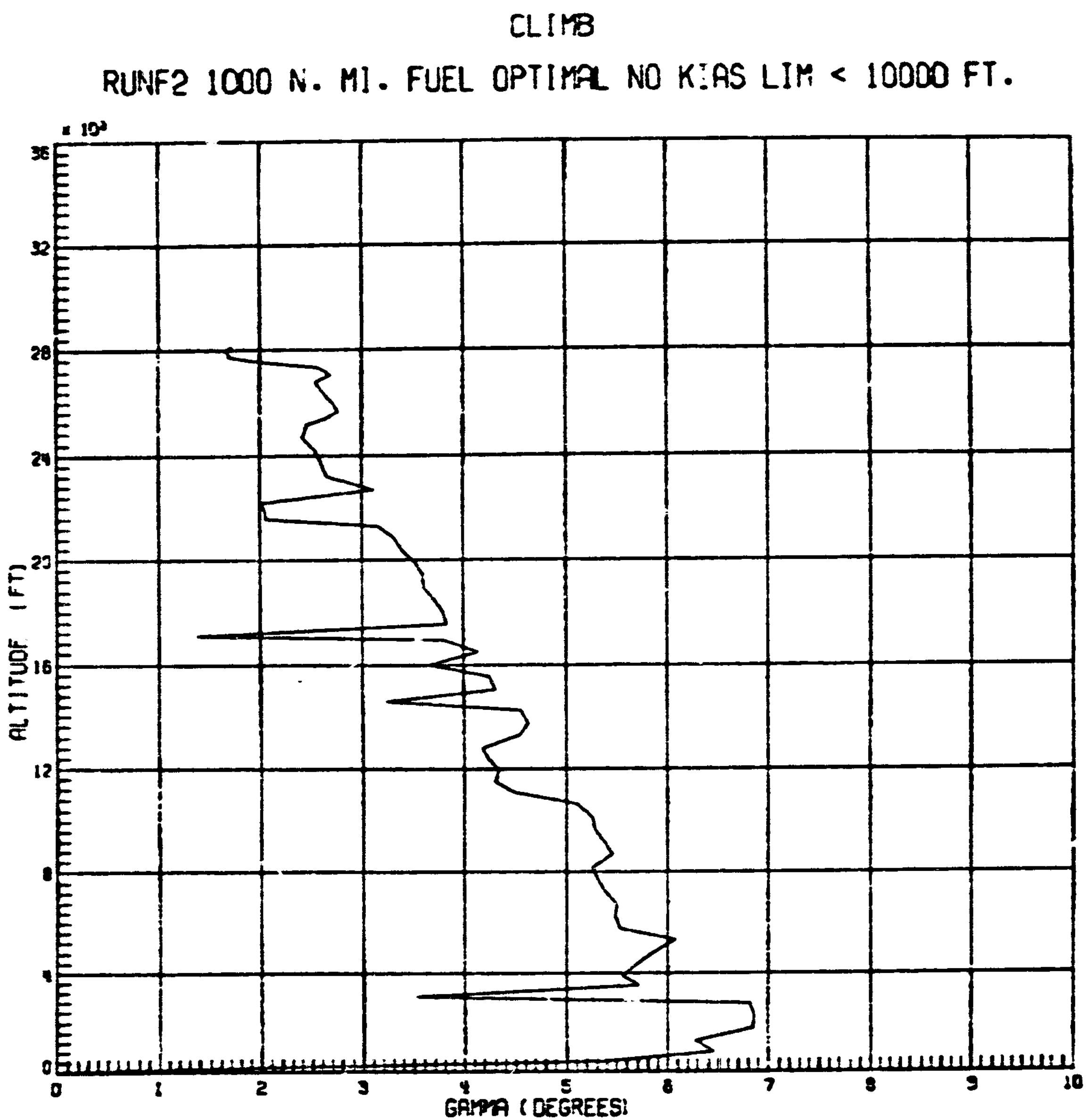

Figure 22.4 - FLIGHT PATH ANGLE-ALTITUDE FOR RUN F2

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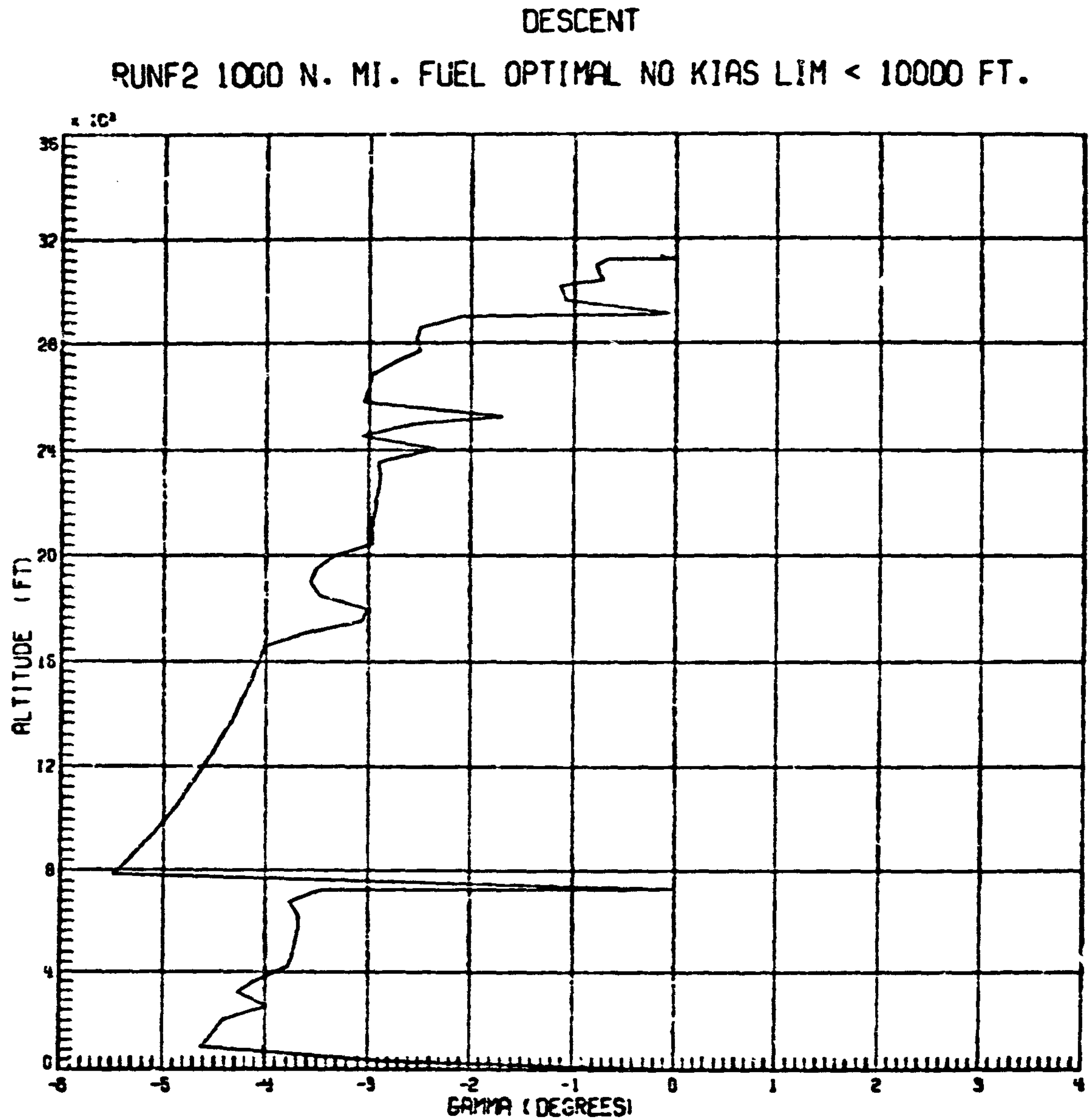

Figure 22.4 - FLIGHT PATH ANGLE-ALTITUDE (DESCENT) FOR RUN F2

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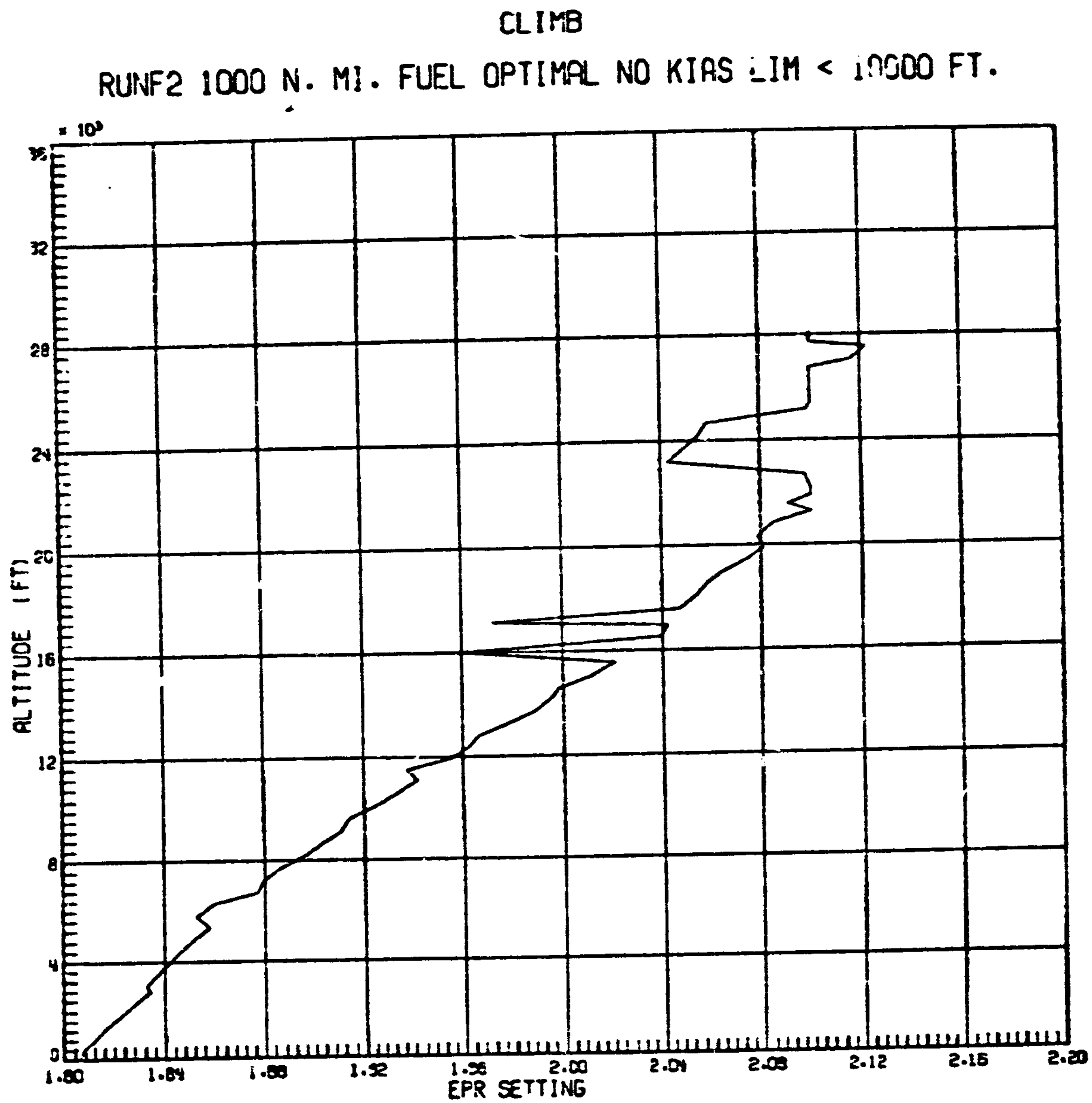

Figure 22.5 - EXHAUST PRESSURE RATIO-ALTITUDE FOR RUN F2

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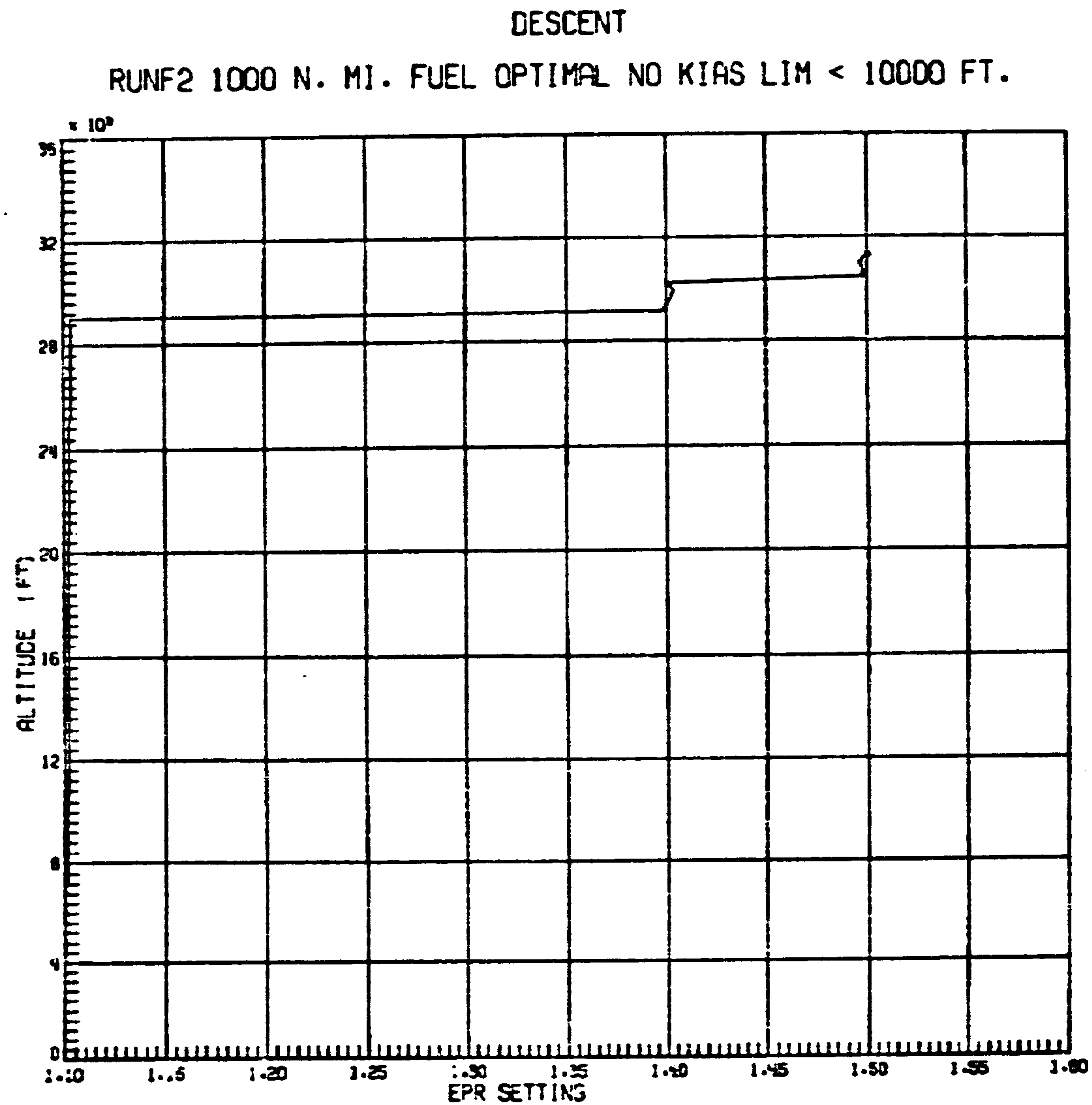

Figure 22.5 - EPR-ALTITUDE FOR RUN F2 (DESCENT)

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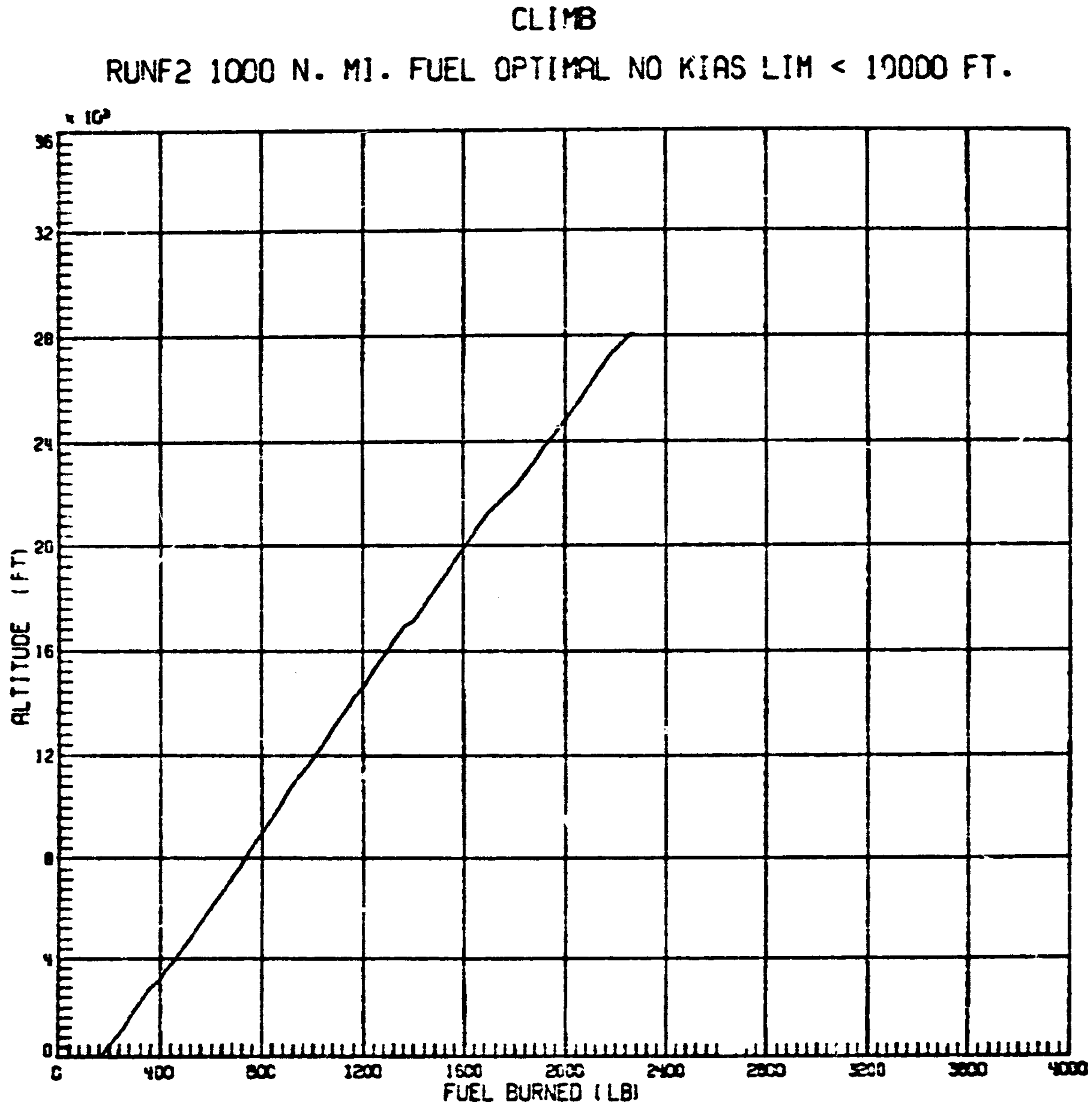

Figure 22.6 - FUEL BURNED-ALTITUDE FOR RUN F2

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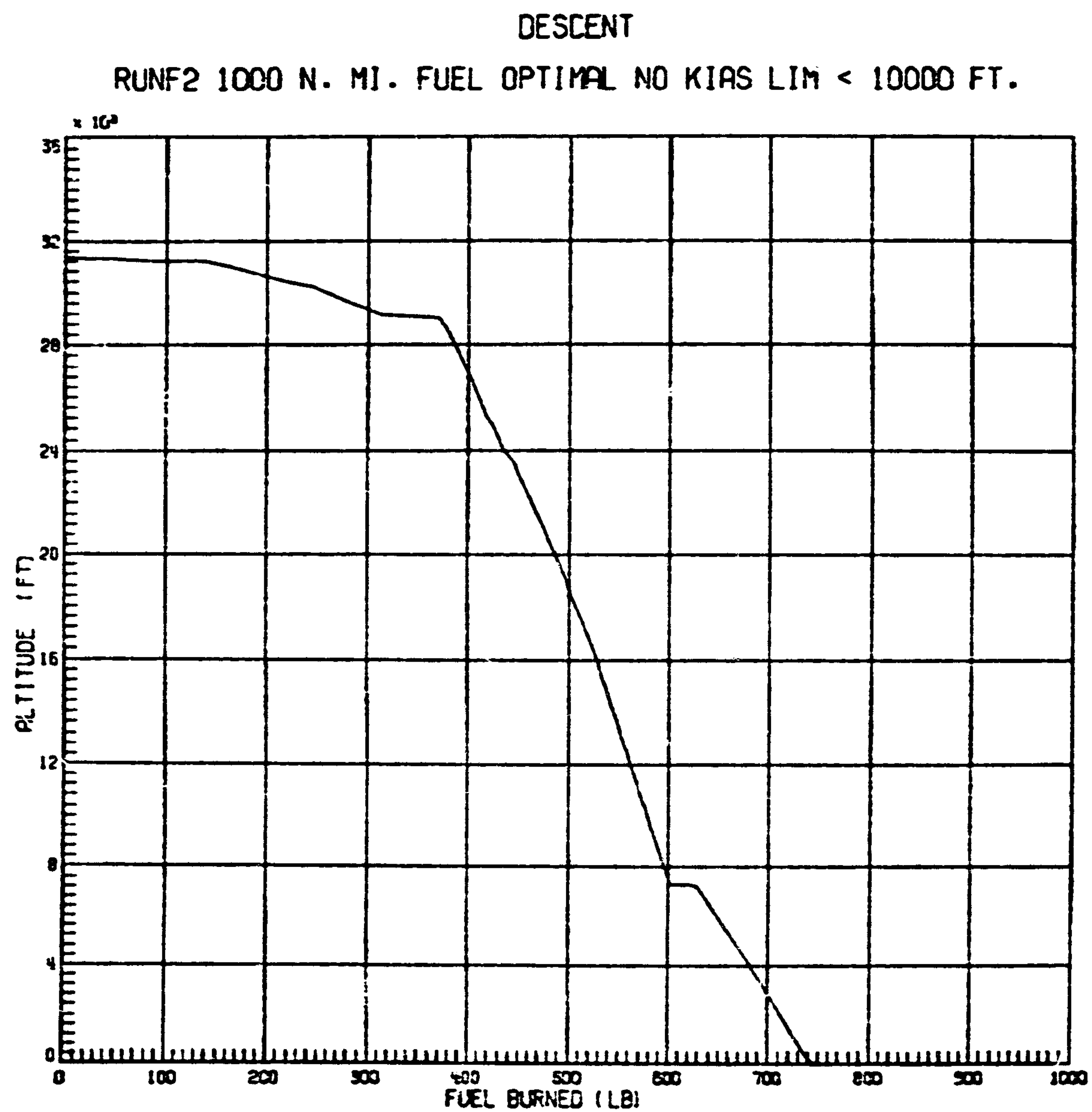

Figure 22.6 - FUEL BURNED-ALTITUDE FOR RUN F2 (DESCENT)

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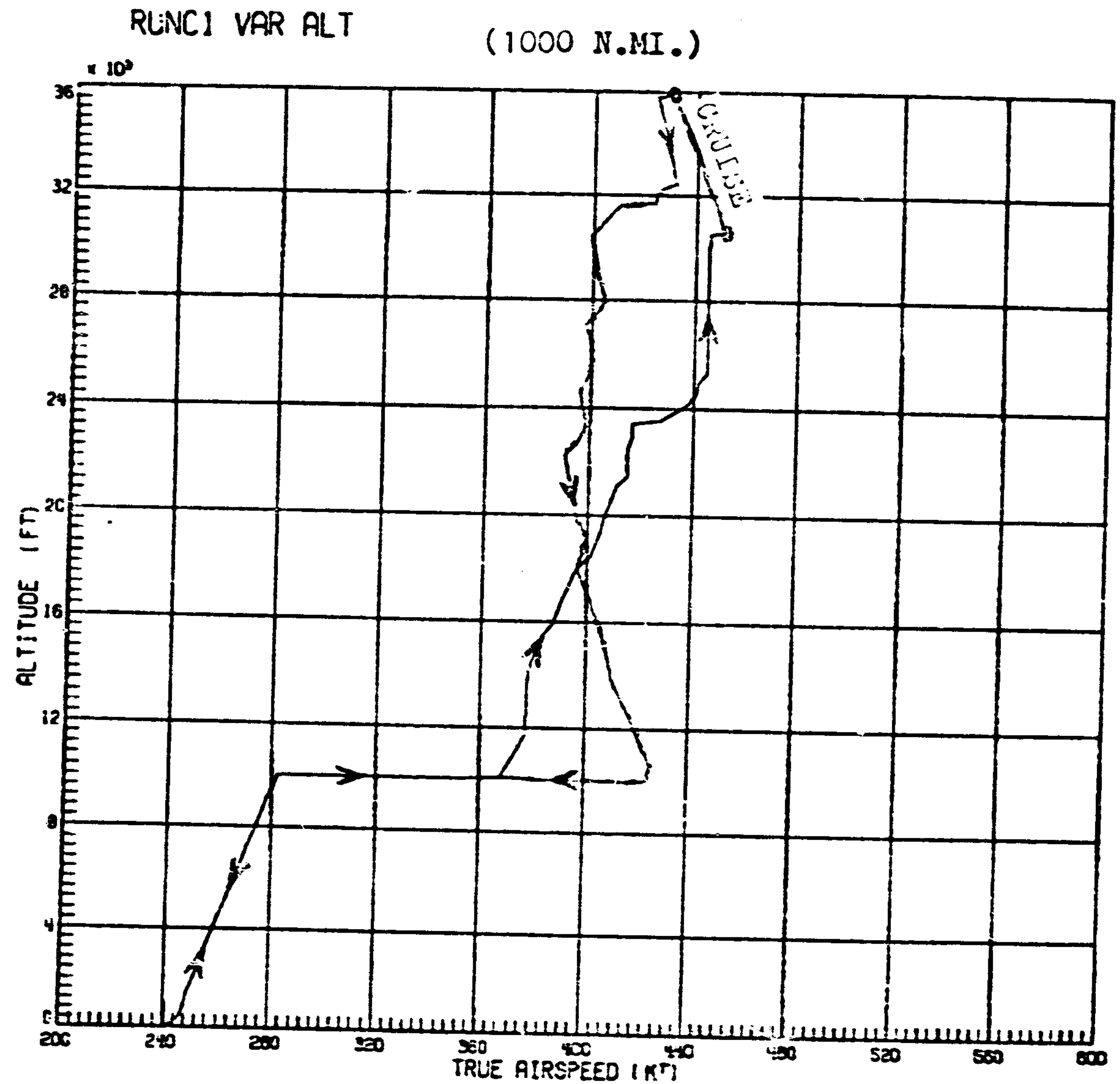

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CRUISE TABLE INFO 100K 80K

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Figure 23.1 - TRUE AIRSPEED-ALTITUDE FOR RUN C1

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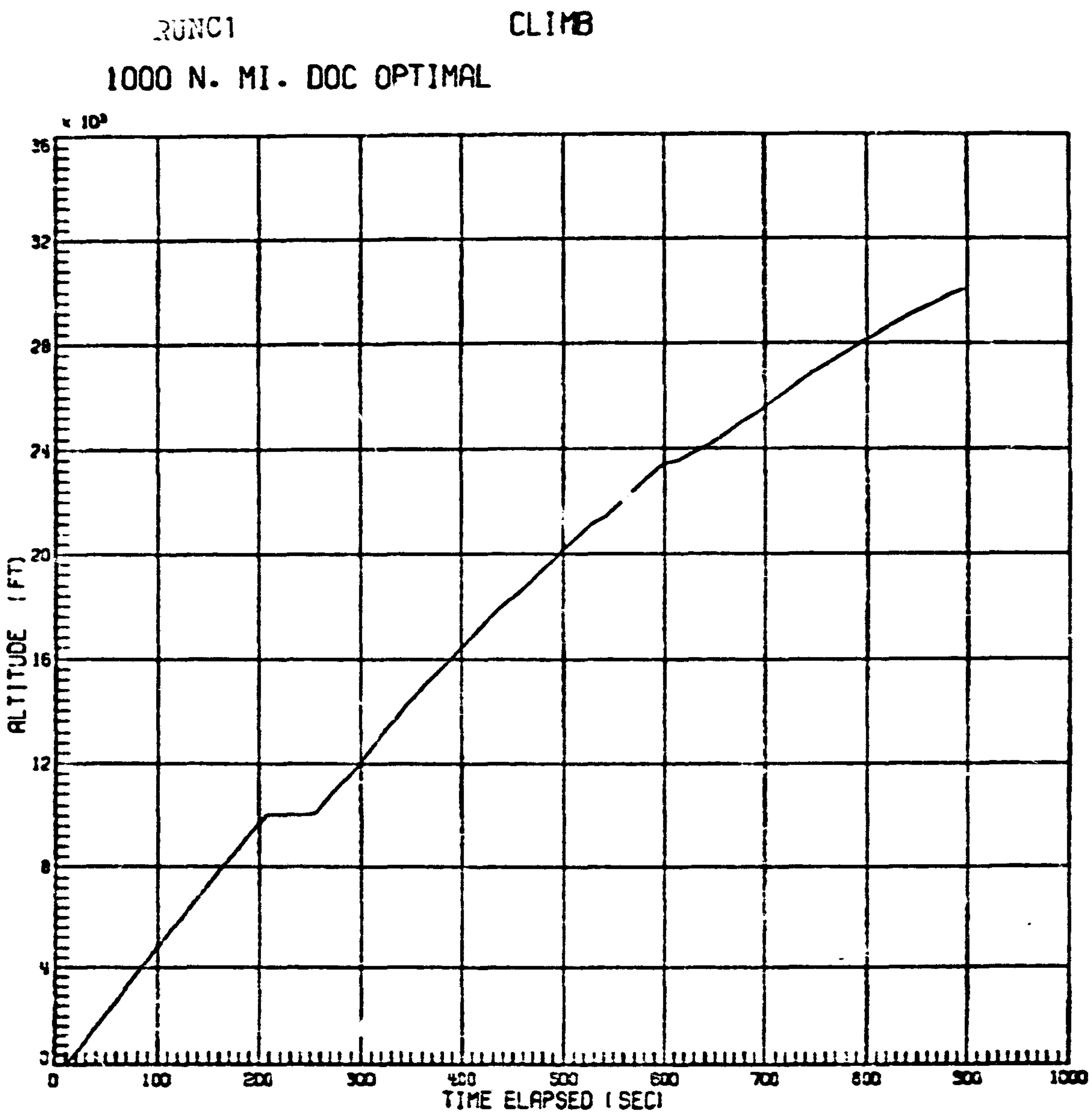

Figure 23.2 - TIME ELAPSED-ALTITUDE FOR RUN C1

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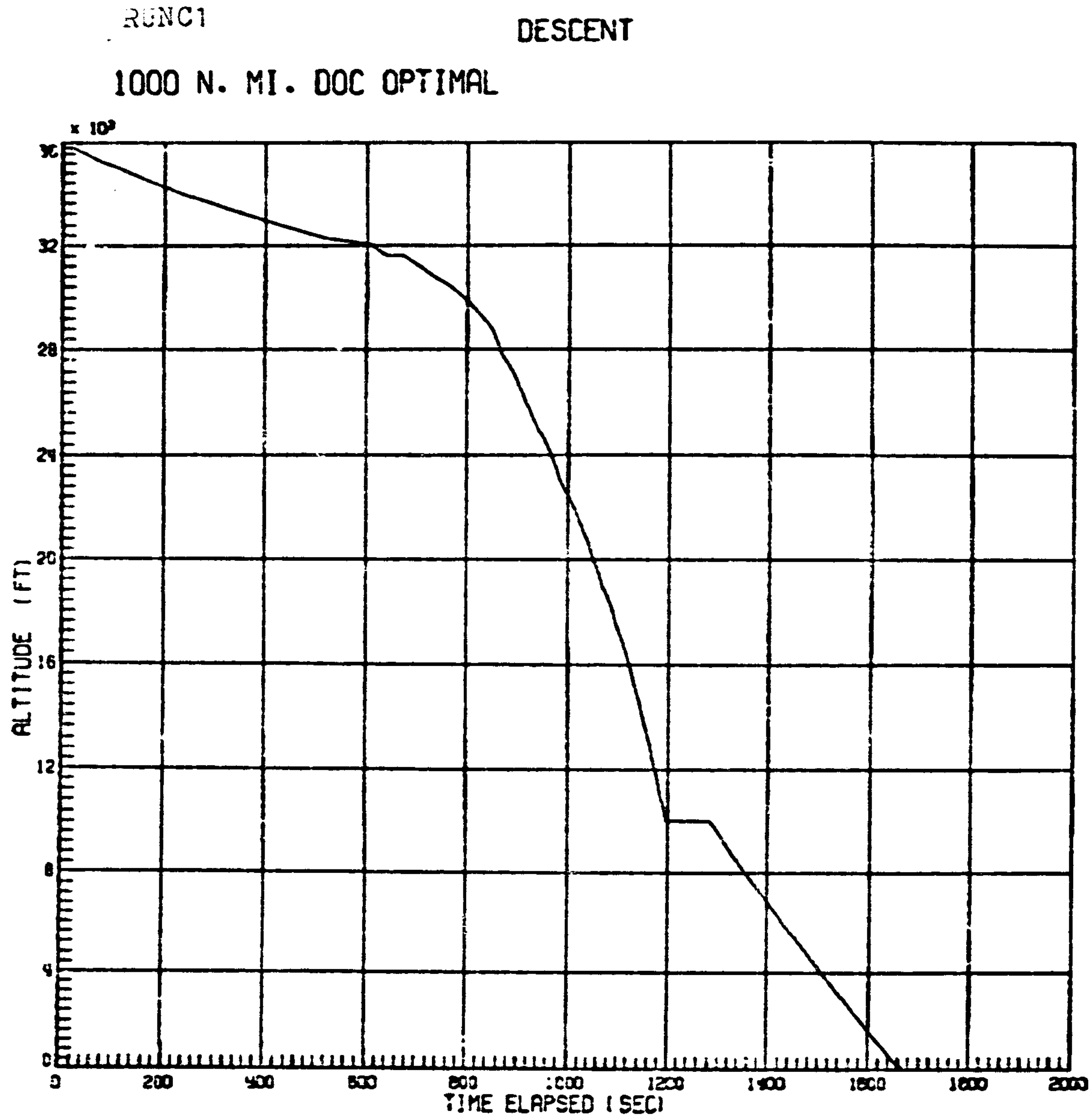

Figure 23.2 - TIME ELAPSED-ALTITUDE FOR RUN C1 (DESCENT)

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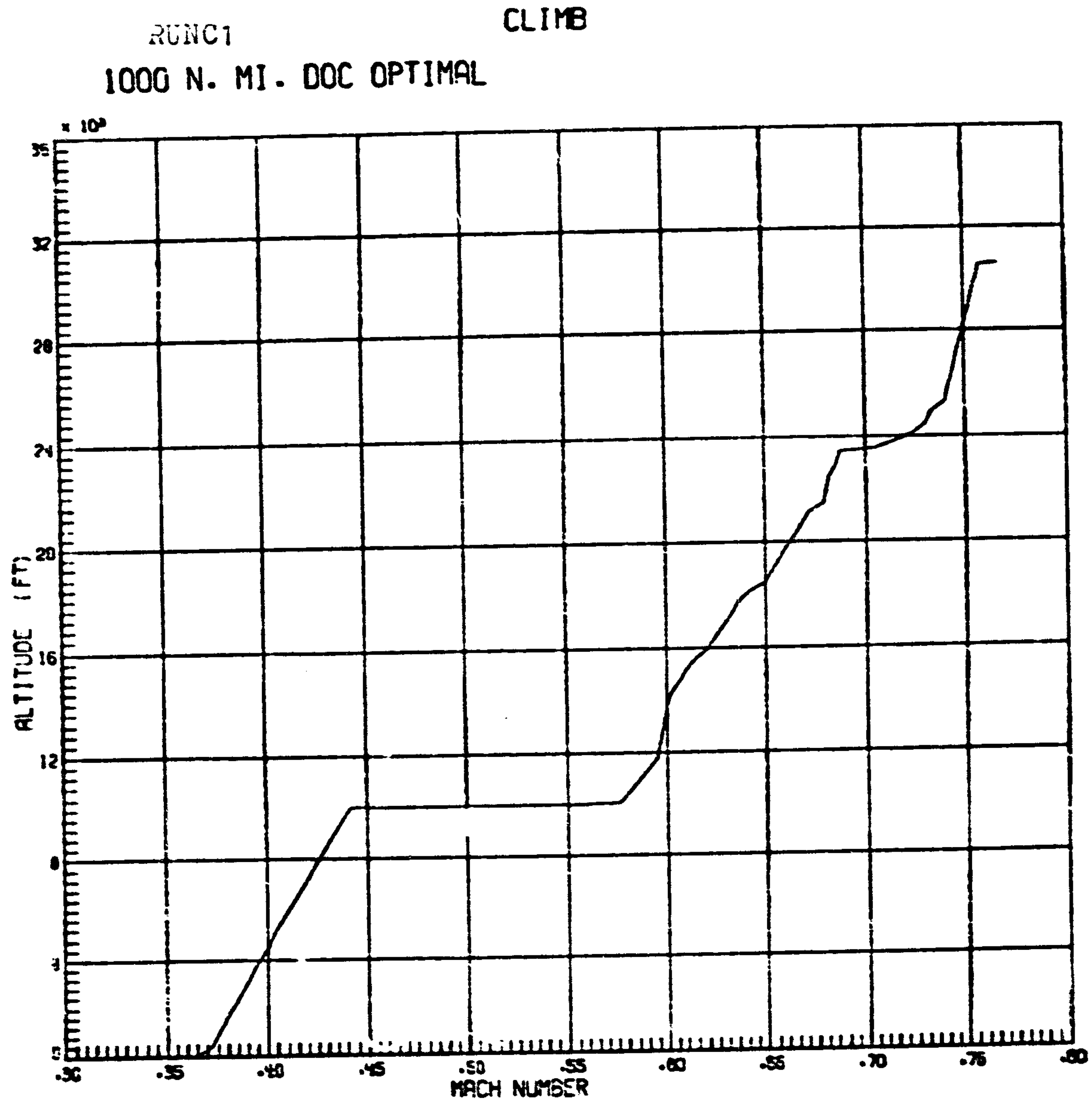

Figure 23.3 - MACH-ALTITUDE FOR RUN C1

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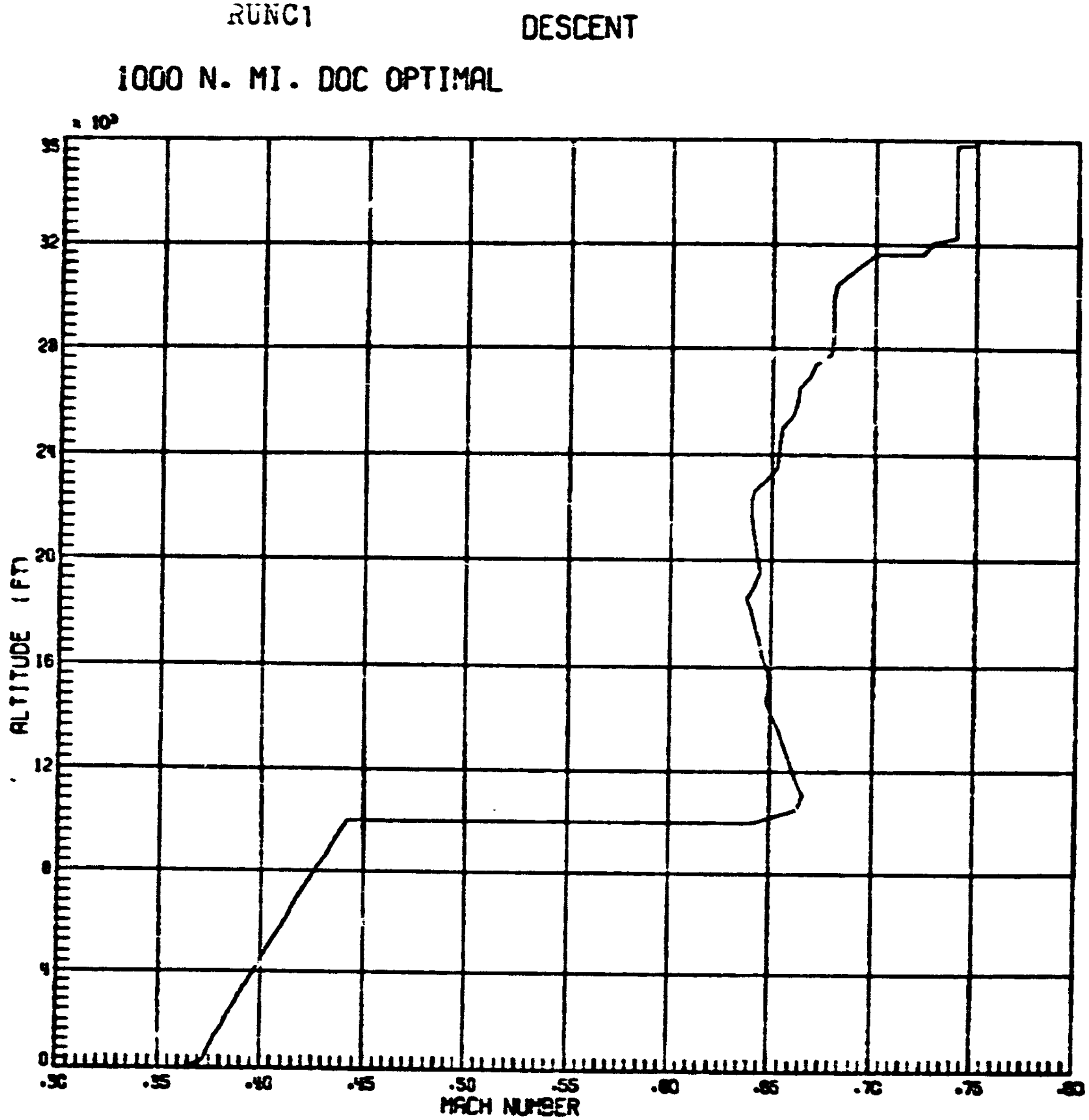

Figure 23.3 - MACH-ALTITUDE FOR RUN C1 (DESCENT)

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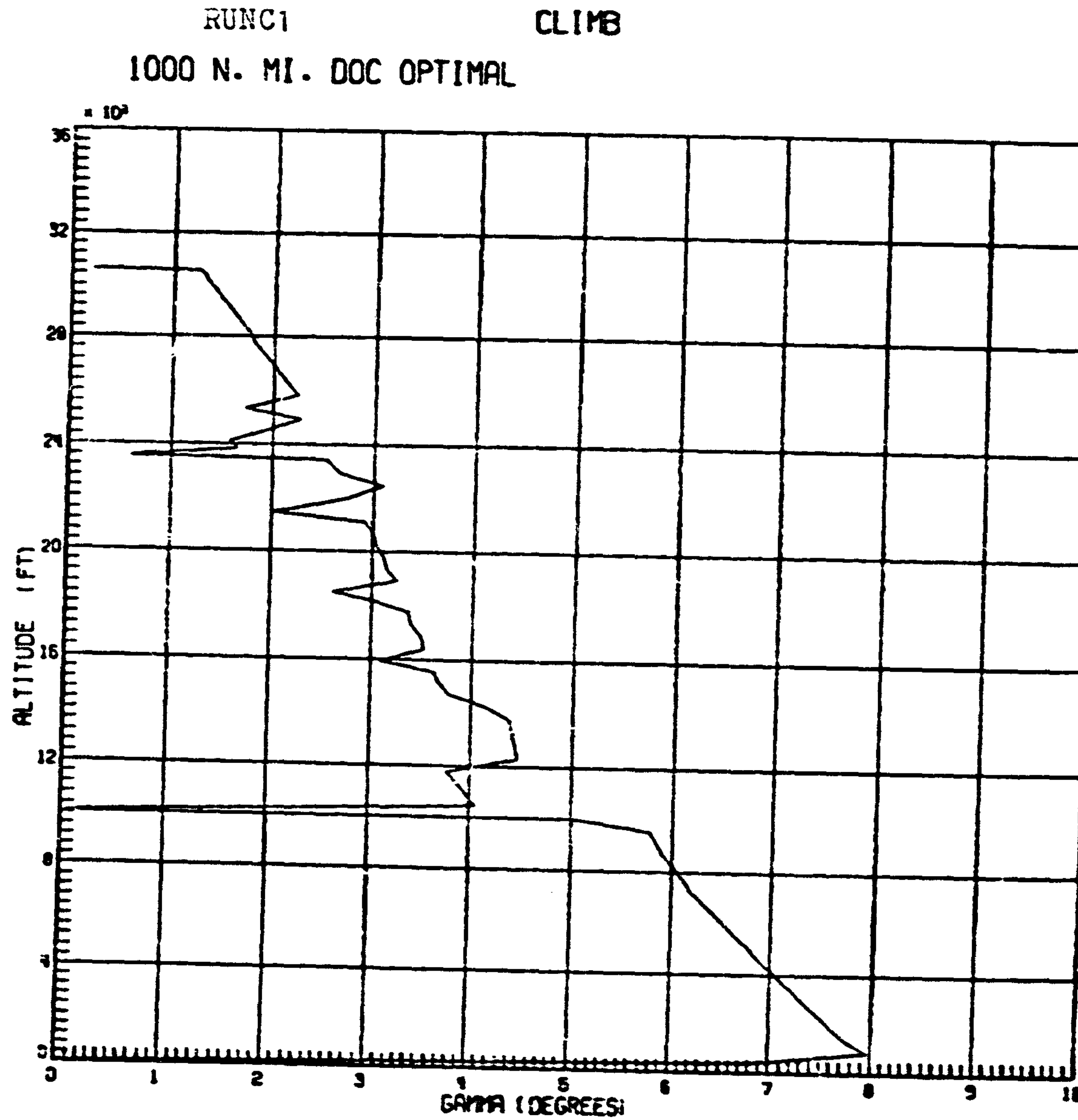

Figure 23.4 - FLIGHT PATH ANGLE-ALTITUDE FOR RUN C1

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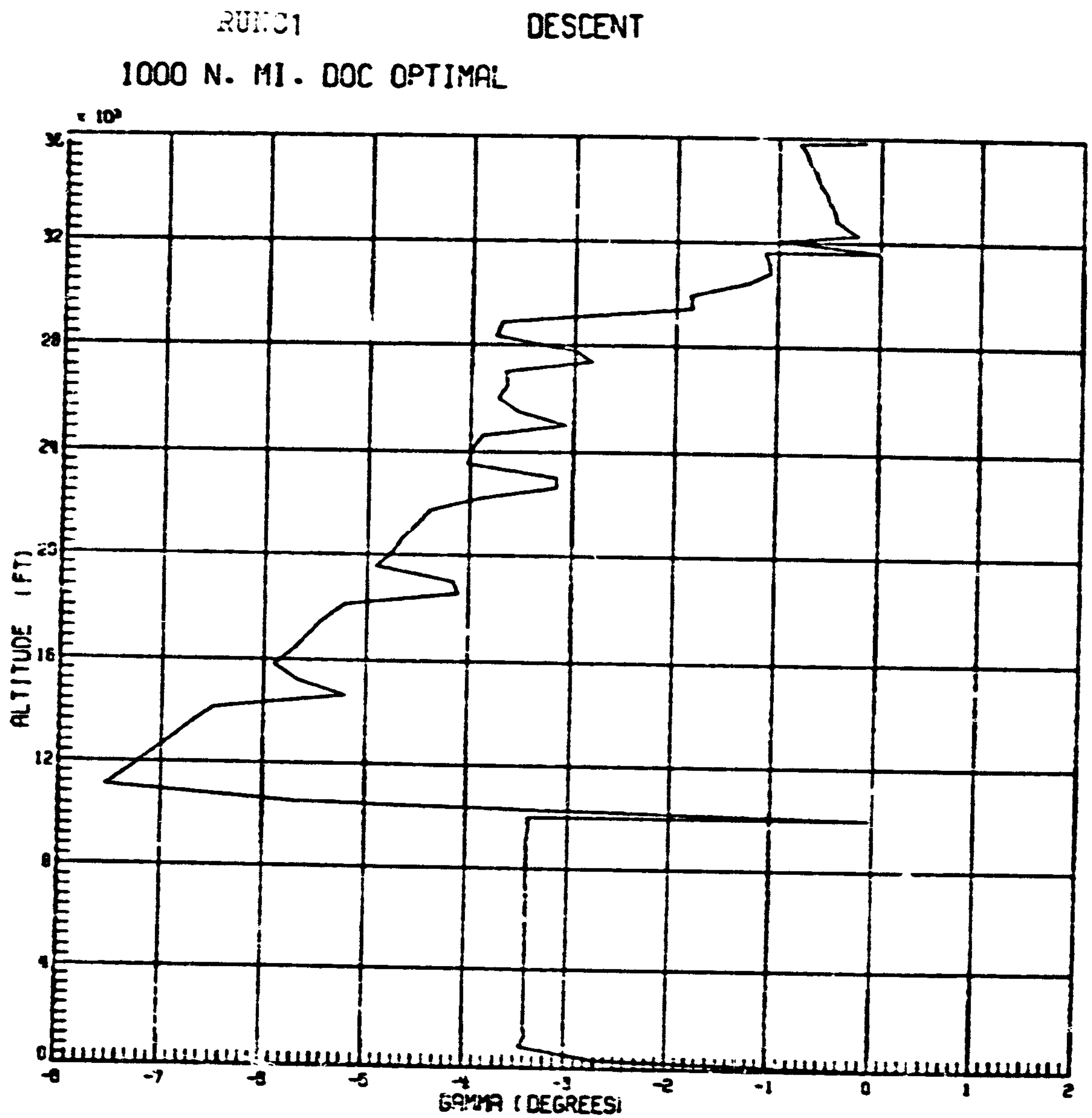

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Figure 23.4 - FLIGHT PATH ANGLE-ALTITUDE FOR RUN C1 (DESCENT)

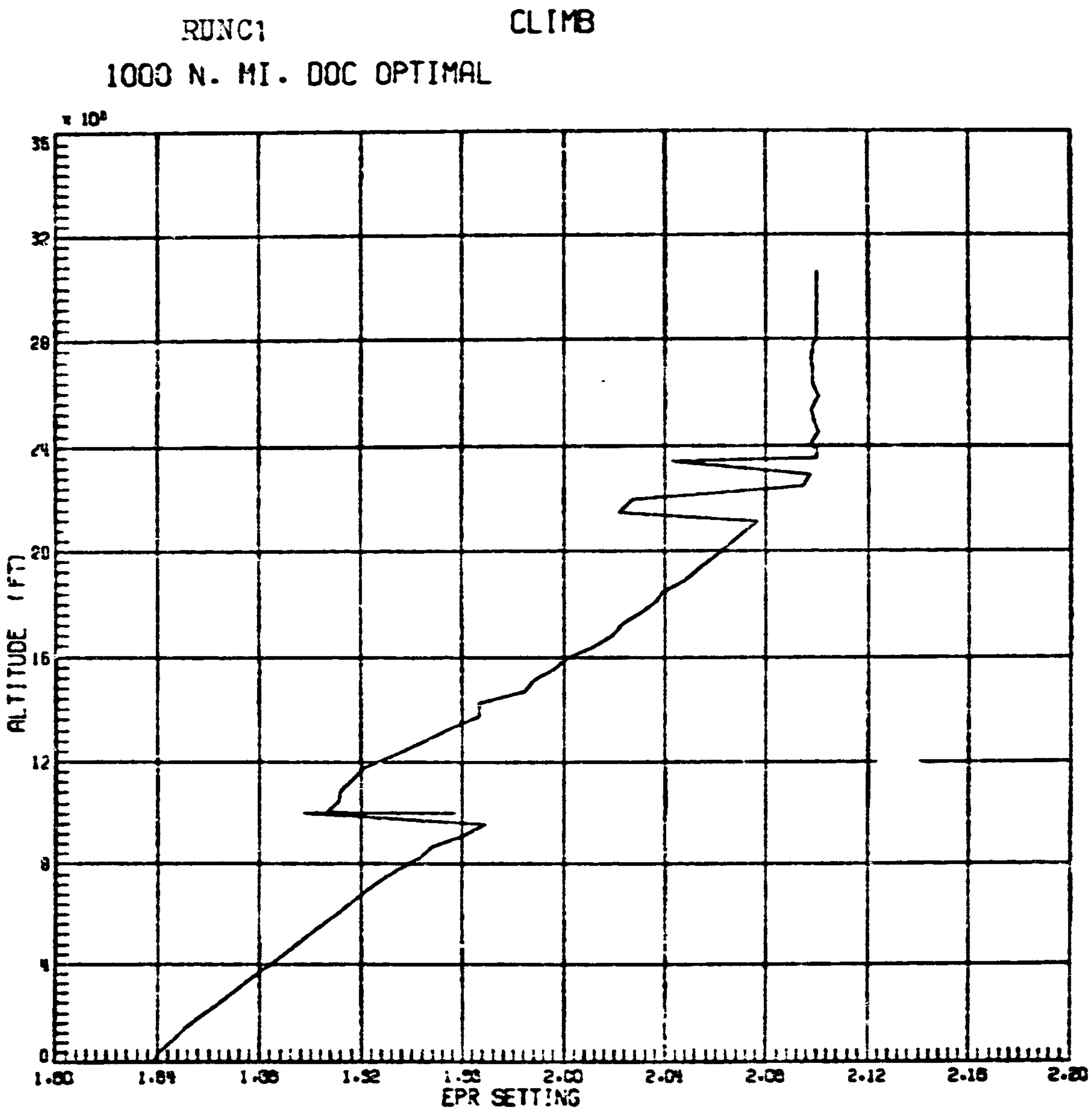

Figure 23.5 - EXHAUST PRESSURE RATIO-ALTITUDE FOR RUN C1

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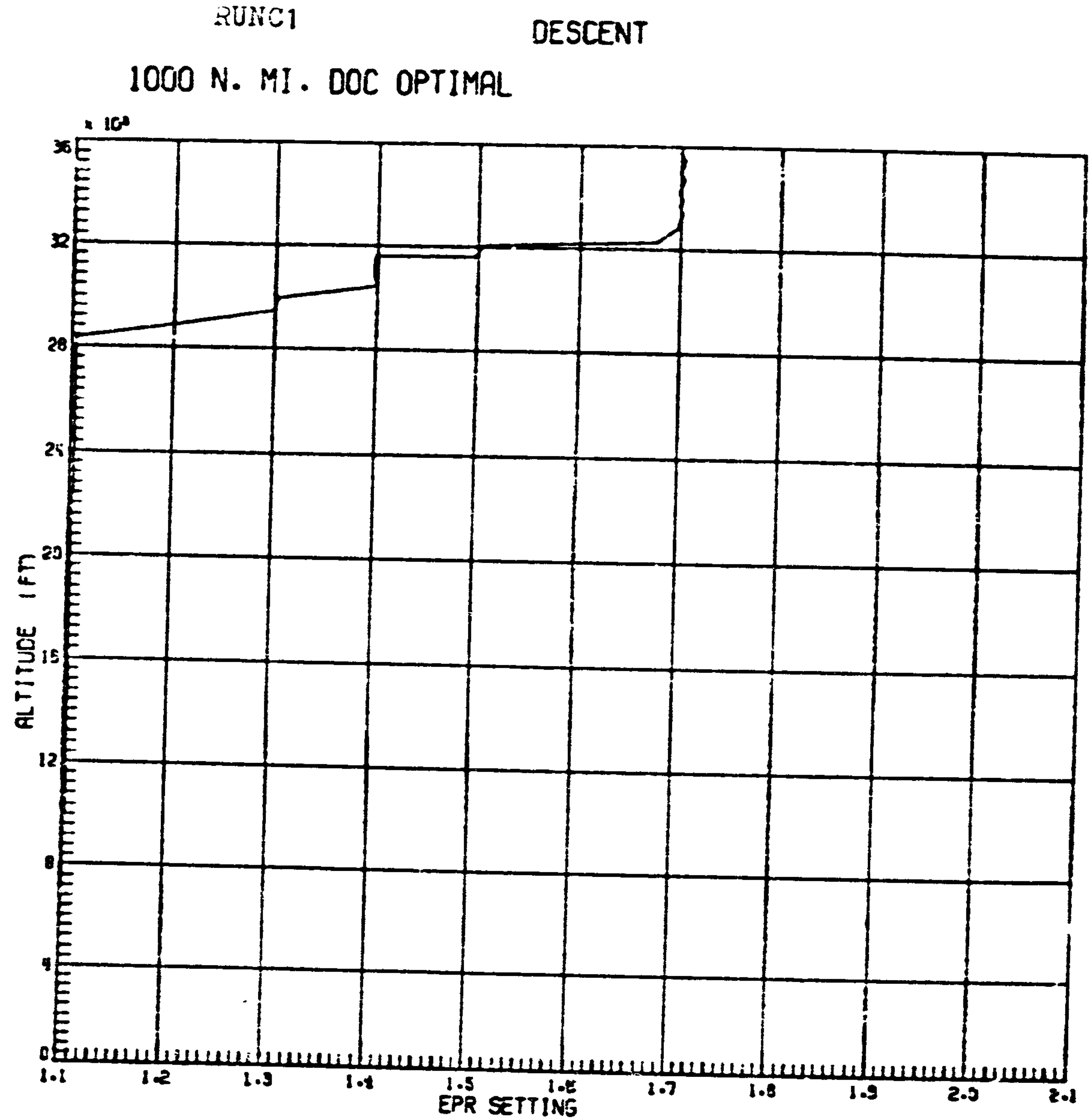

Figure 23.5 - EXHAUST PRESSURE RATIO-ALTITUDE FOR RUN C1 (DESCENT)

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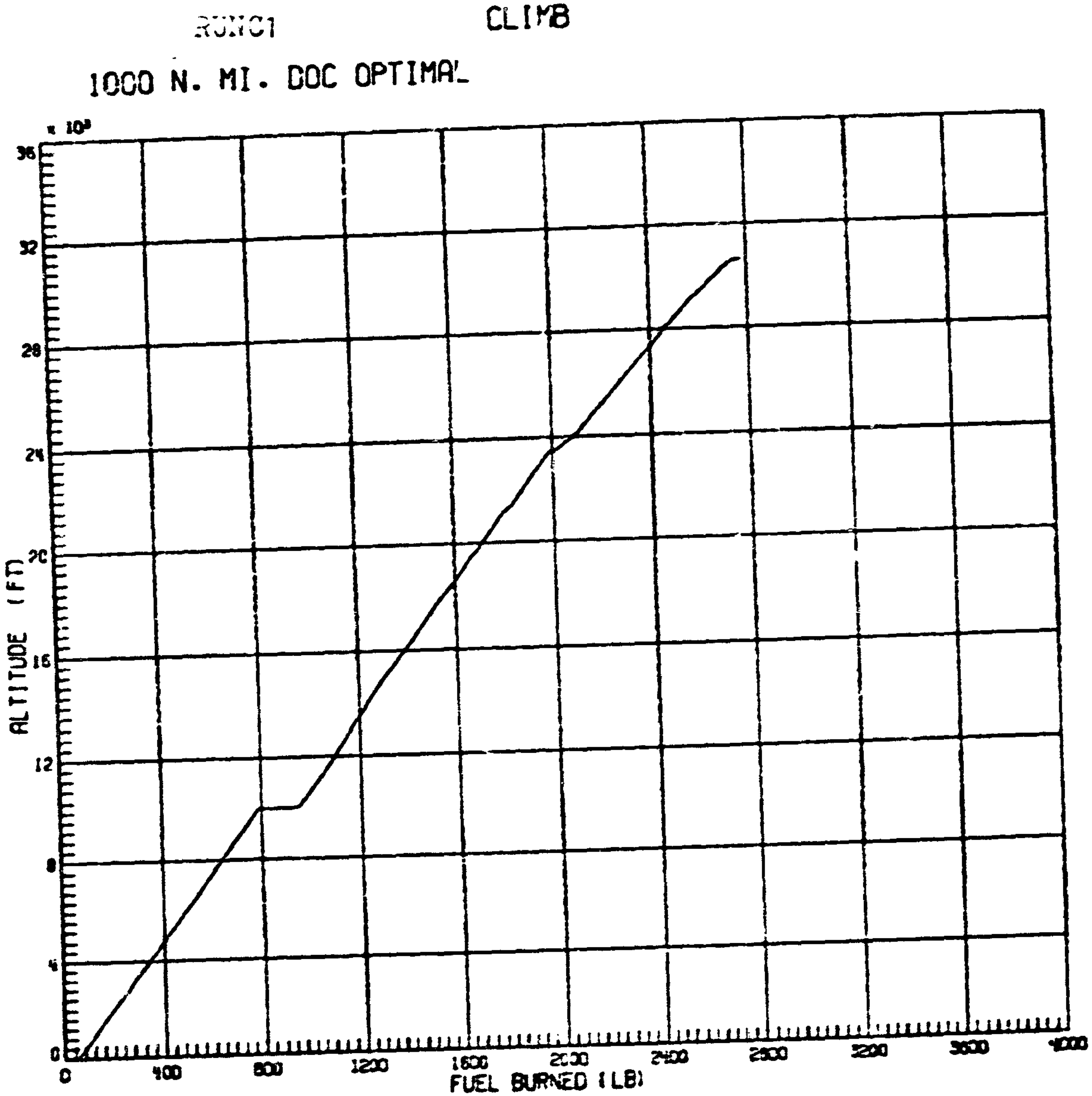

Figure 23.6 - FUEL BURNED-ALTITUDE FOR RUN C1

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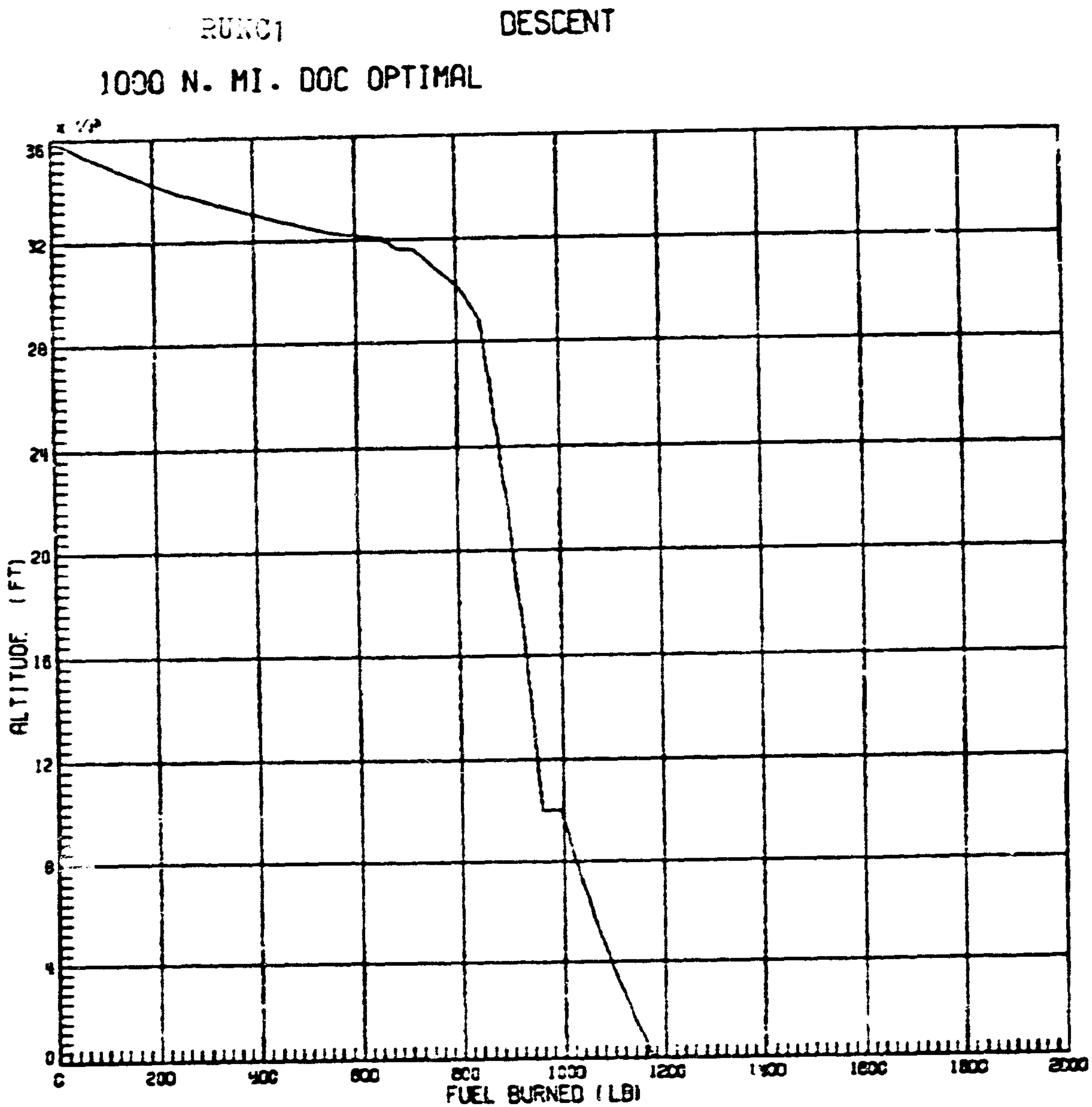

Figure 23.6 - FUEL BURNED-ALTITUDE FOR RUN C1 (DESCENT)

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RUNC2 (1000 N.MI.)

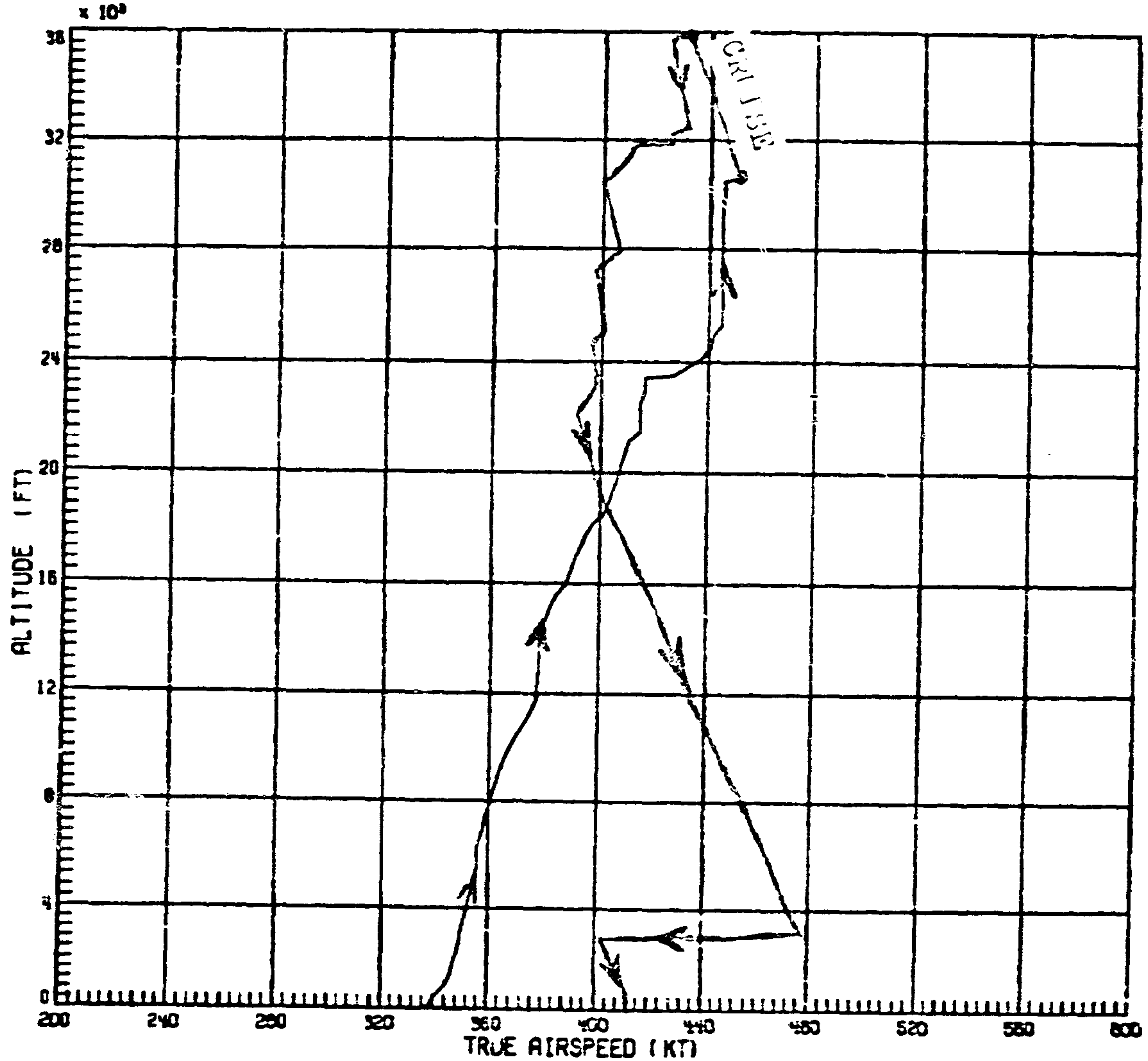

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Figure 24.1 - TRUE AIRSPEED-ALTITUDE FOR RUN C2

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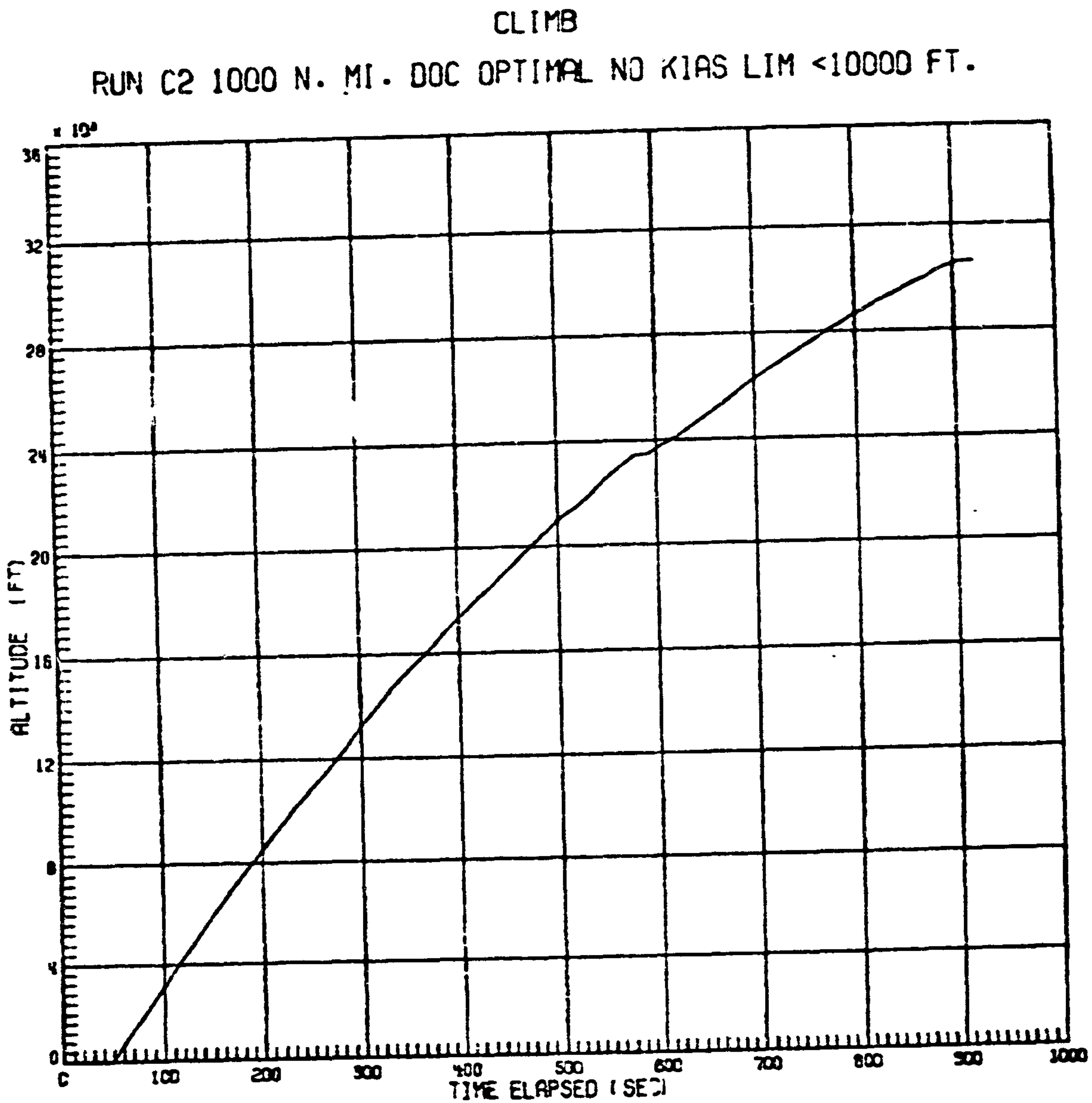

Figure 24.2 - TIME ELAPSED-ALTITUDE FOR RUN C2

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DESCENT

RUN C2 1000 N. MI. DOC OPTIMAL NO KIAS LIM <10000 FT.

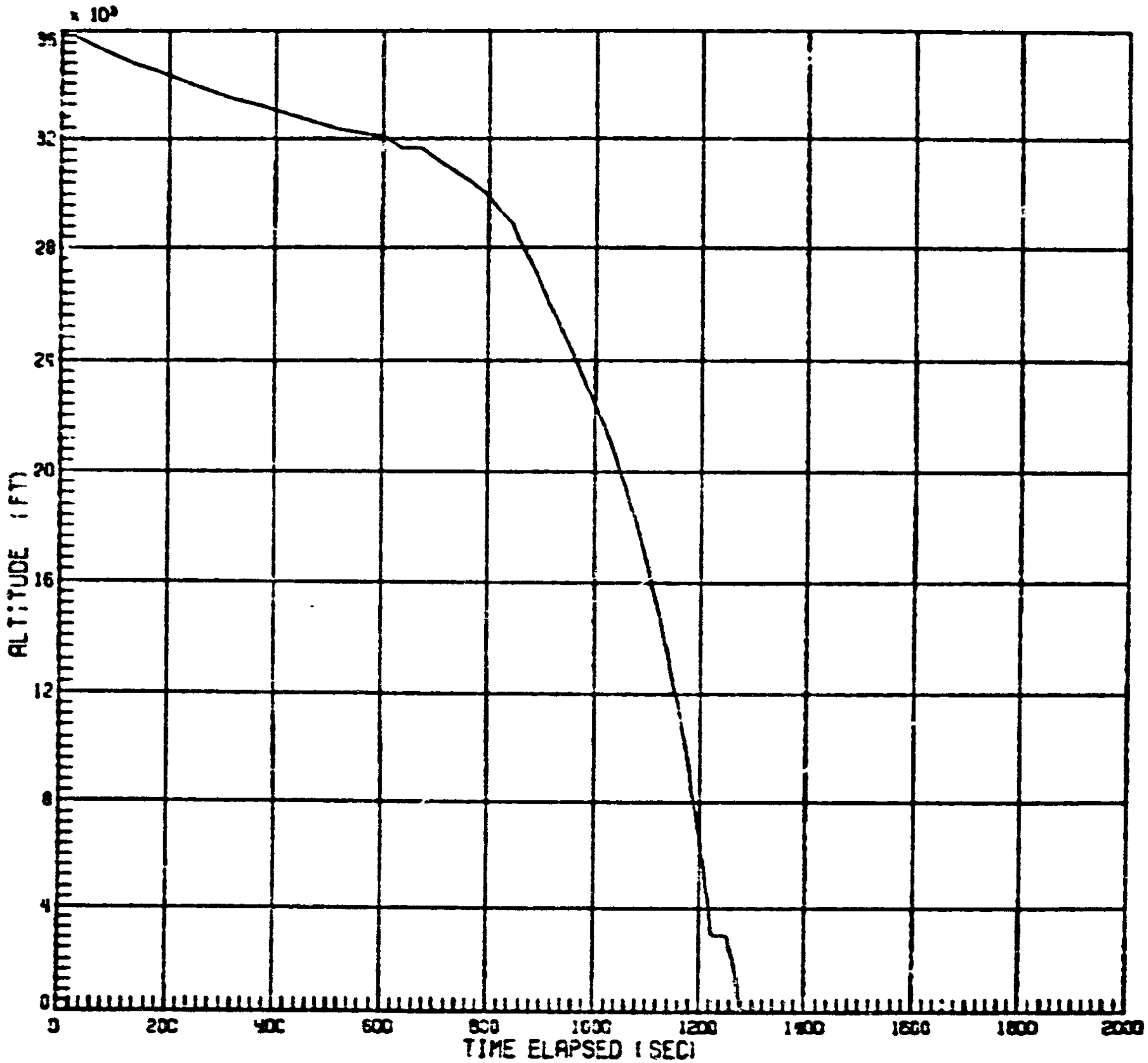

Figure 24.2 - TIME ELAPSED-ALTITUDE FOR RUN C2 (DESCENT)

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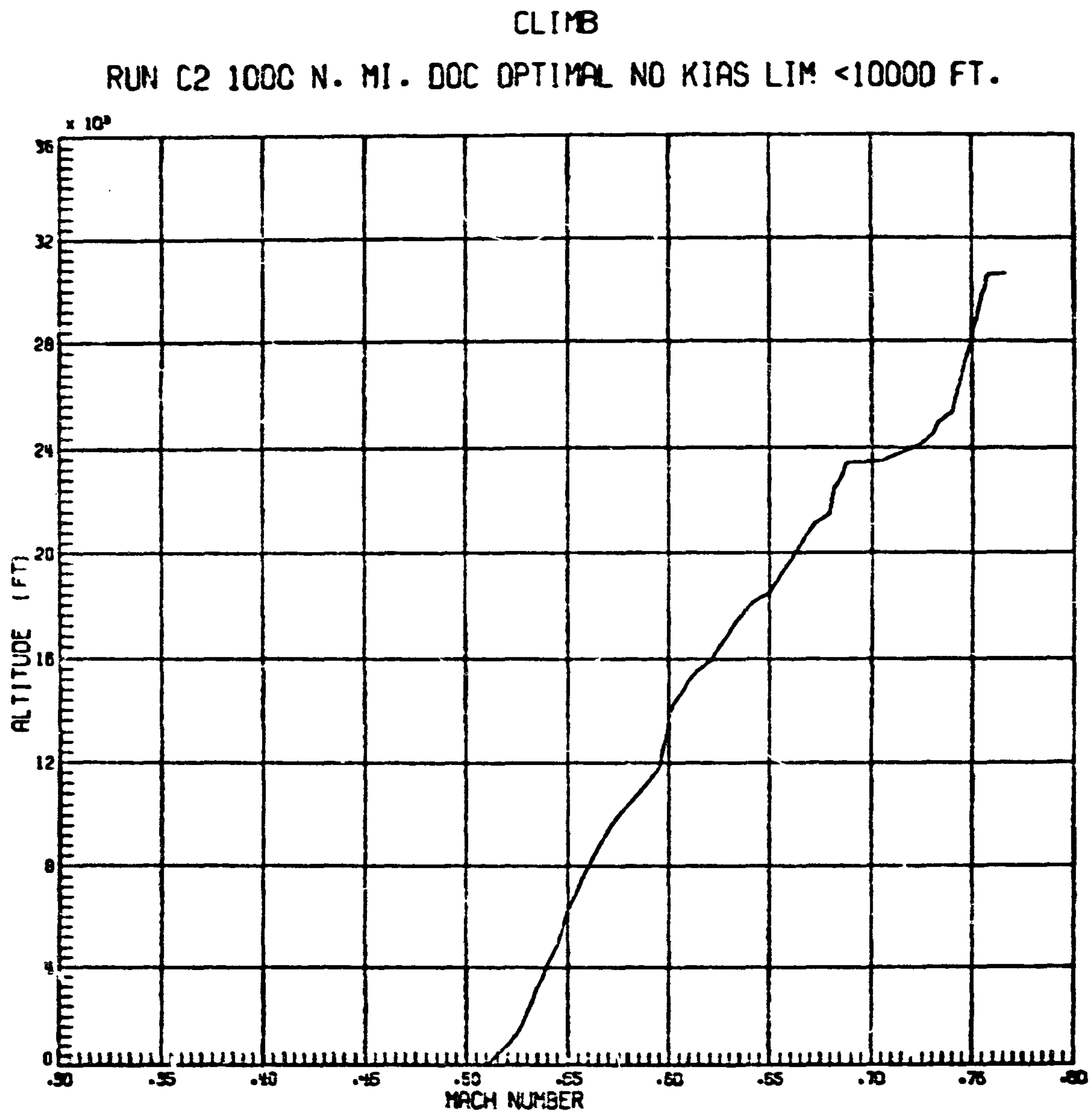

Figure 24.3 - MACH-ALTITUDE FOR RUN C2

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DESCENT

RUN C2 1000 N. MI. DOC OPTIMAL NO KIAS LIM <10000 FT.

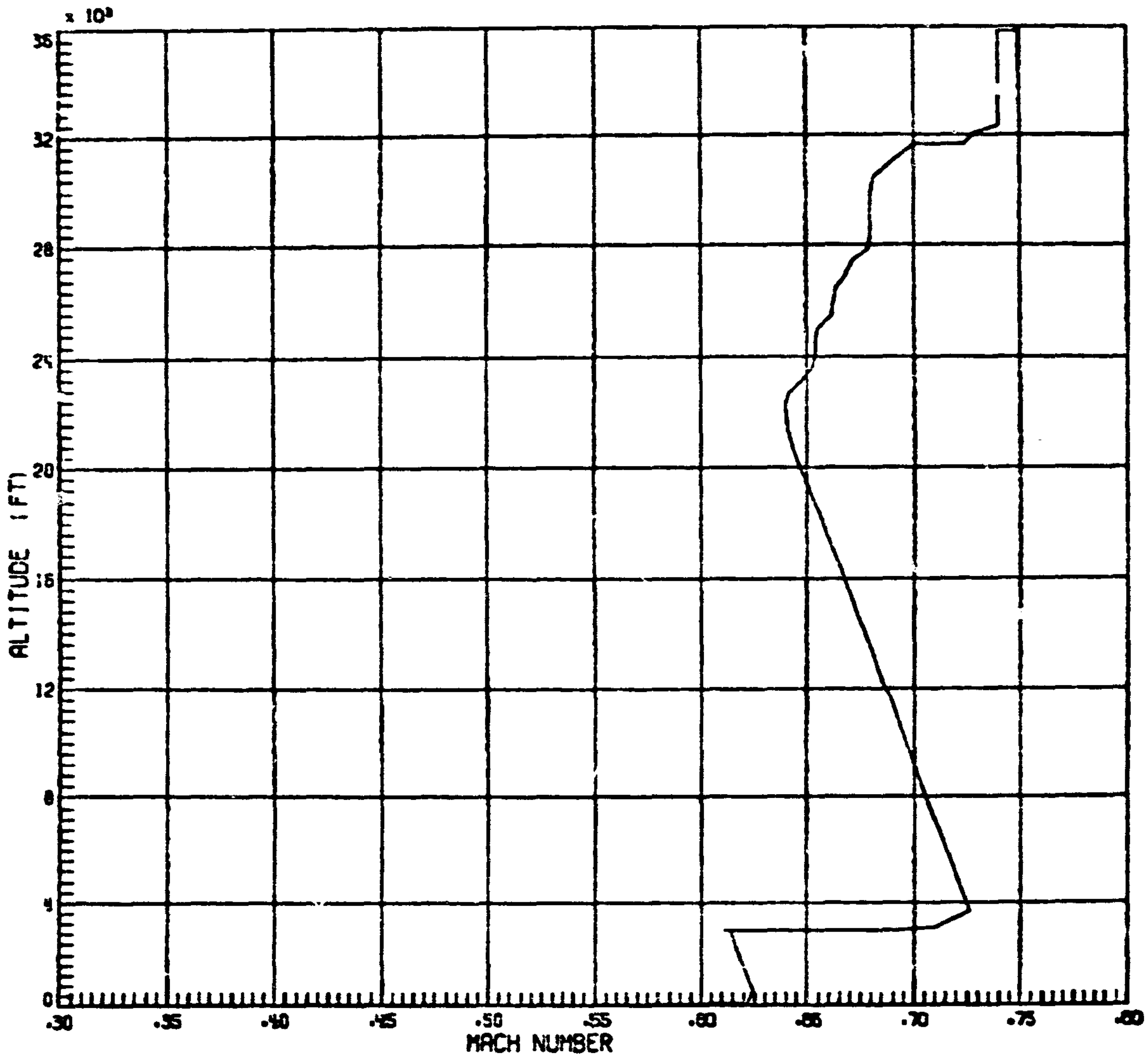

Figure 24.3 - MACH-ALTITUDE FOR RUN C2 (DESCENT)

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RUN C2 1000 N. MI. DOC OPTIMAL NO KIAS LIM <10000 FT.

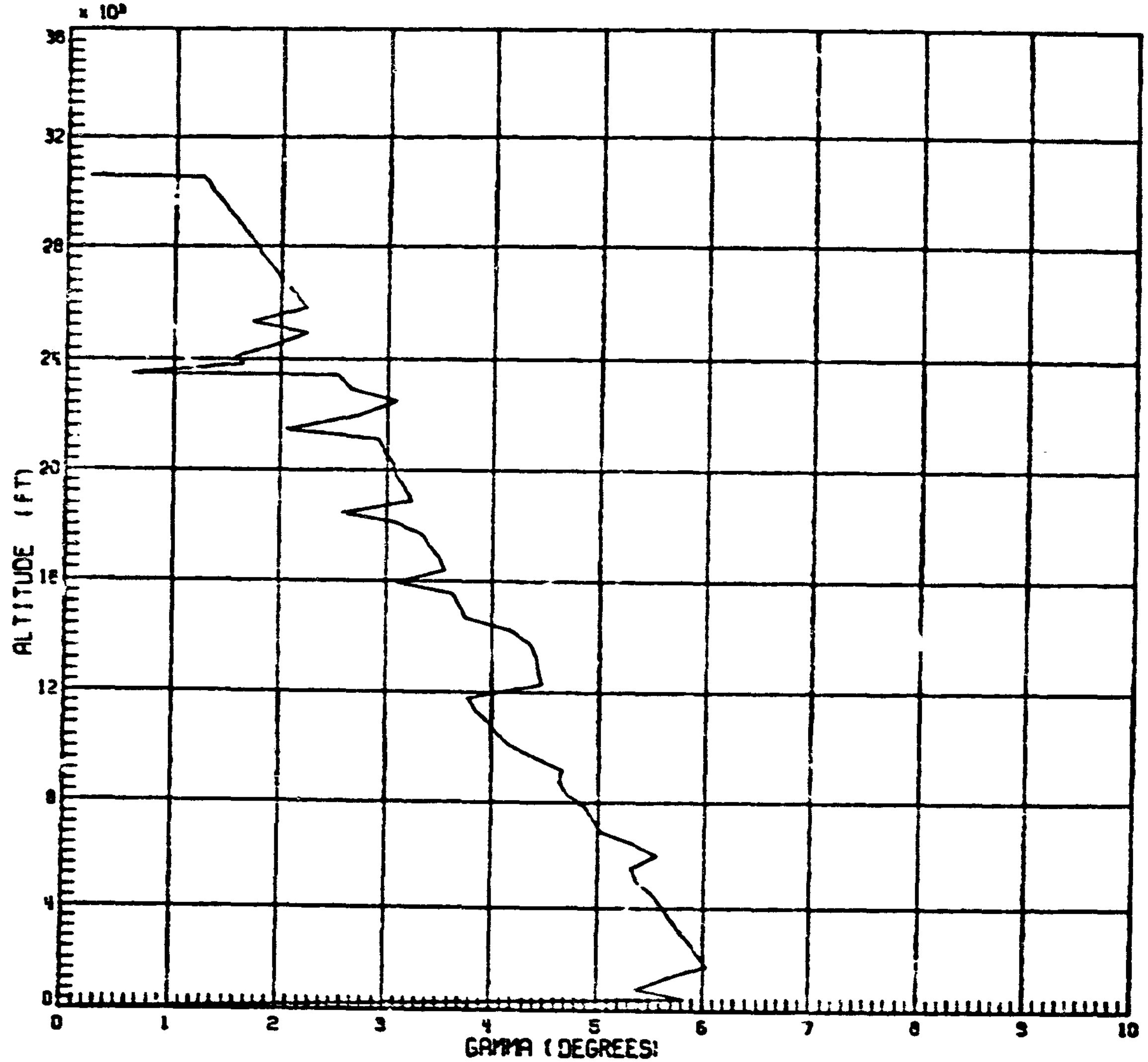

Figure 24.4 - FLIGHT PATH ANGLE-ALTITUDE FOR RUN C2

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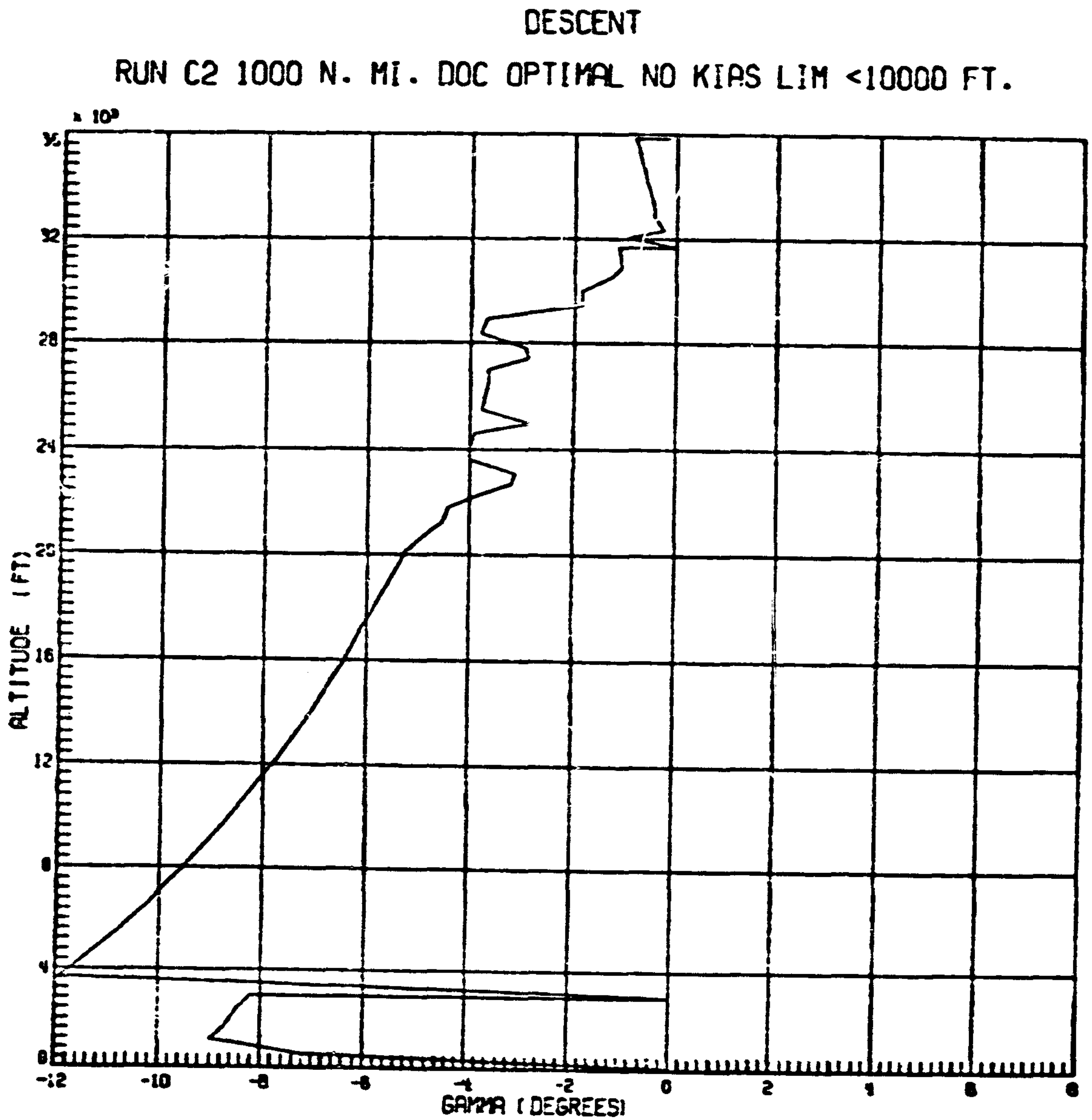

Figure 24.4 - FLIGHT PATH ANGLE-ALTITUDE FOR RUN C2 (DESCENT)

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RUN C2 1000 N. MI. DOC OPTIMAL NO KIAS LIM <10000 FT.

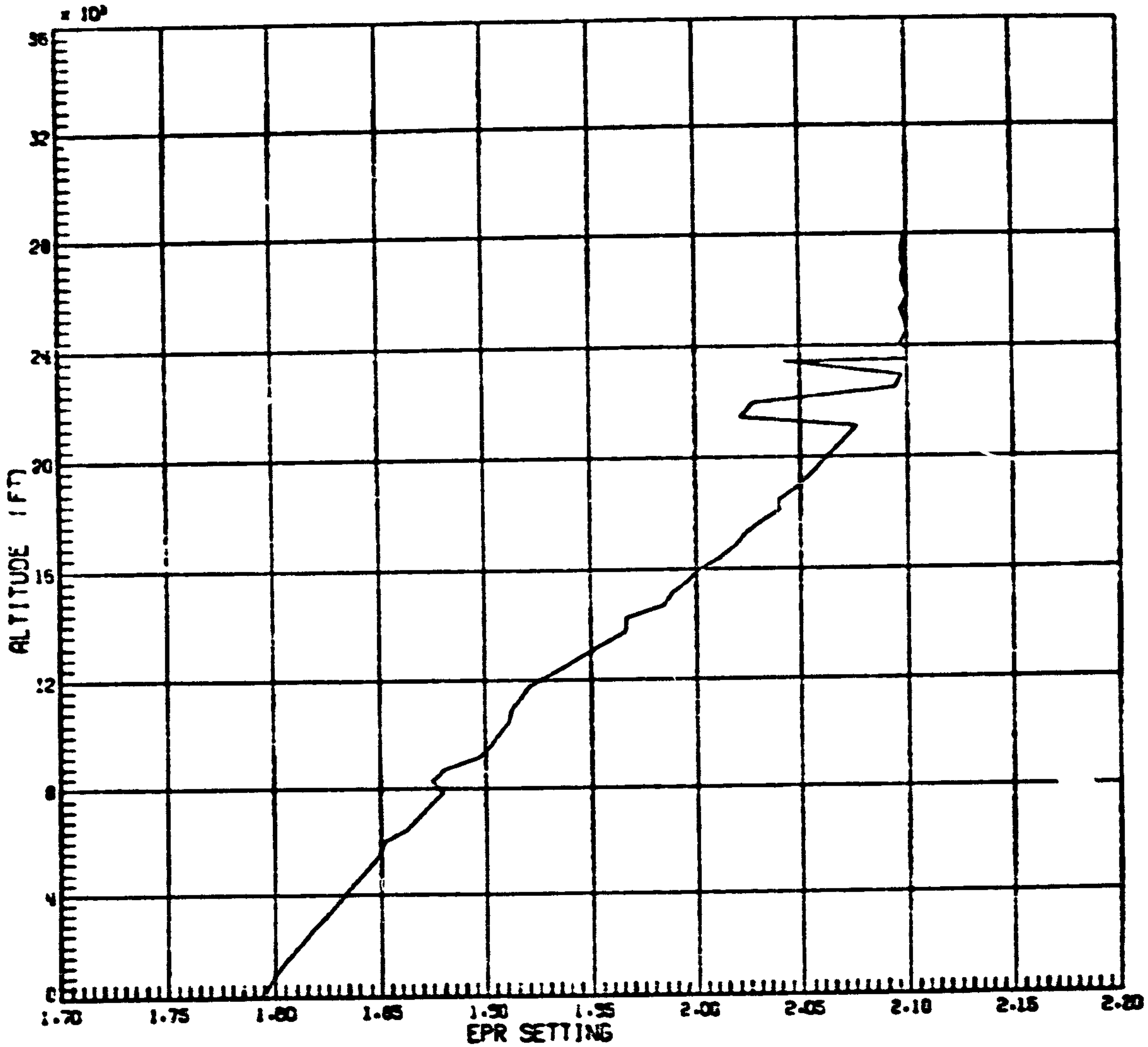

Figure 24.5 - EXHAUST PRESSURE RATIO-ALTITUDE FOR RUN C2

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DESCENT

RUN C2 1000 N. MI. DOC OPTIMAL NO KIAS LIM <10000 FT.

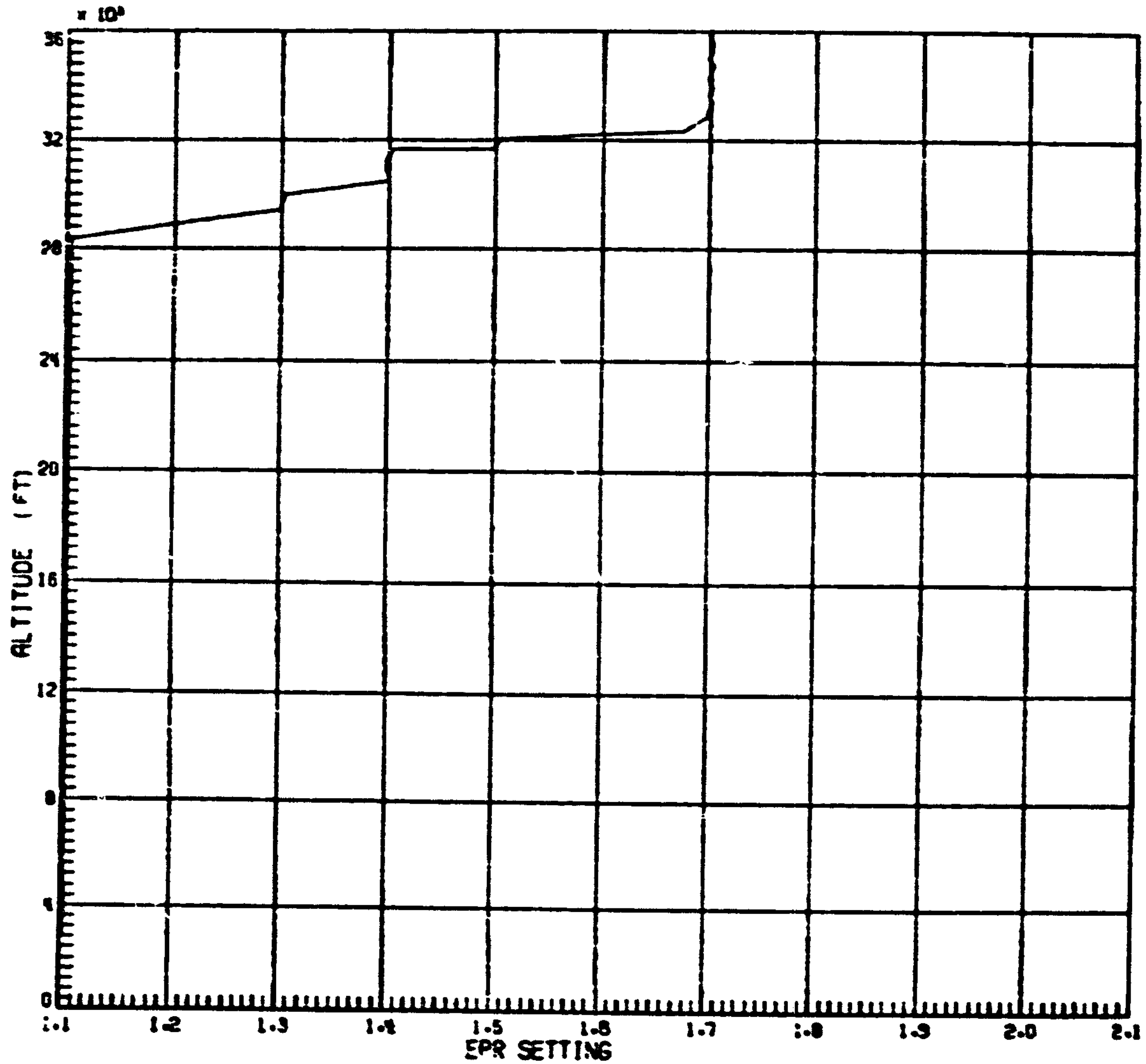

Figure 24.5 - EPR-ALTITUDE FOR RUN C2 (DESCENT)

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RUN C2 1000 N. MI. DOC OPTIMAL NO KIAS LIM <10000 FT.

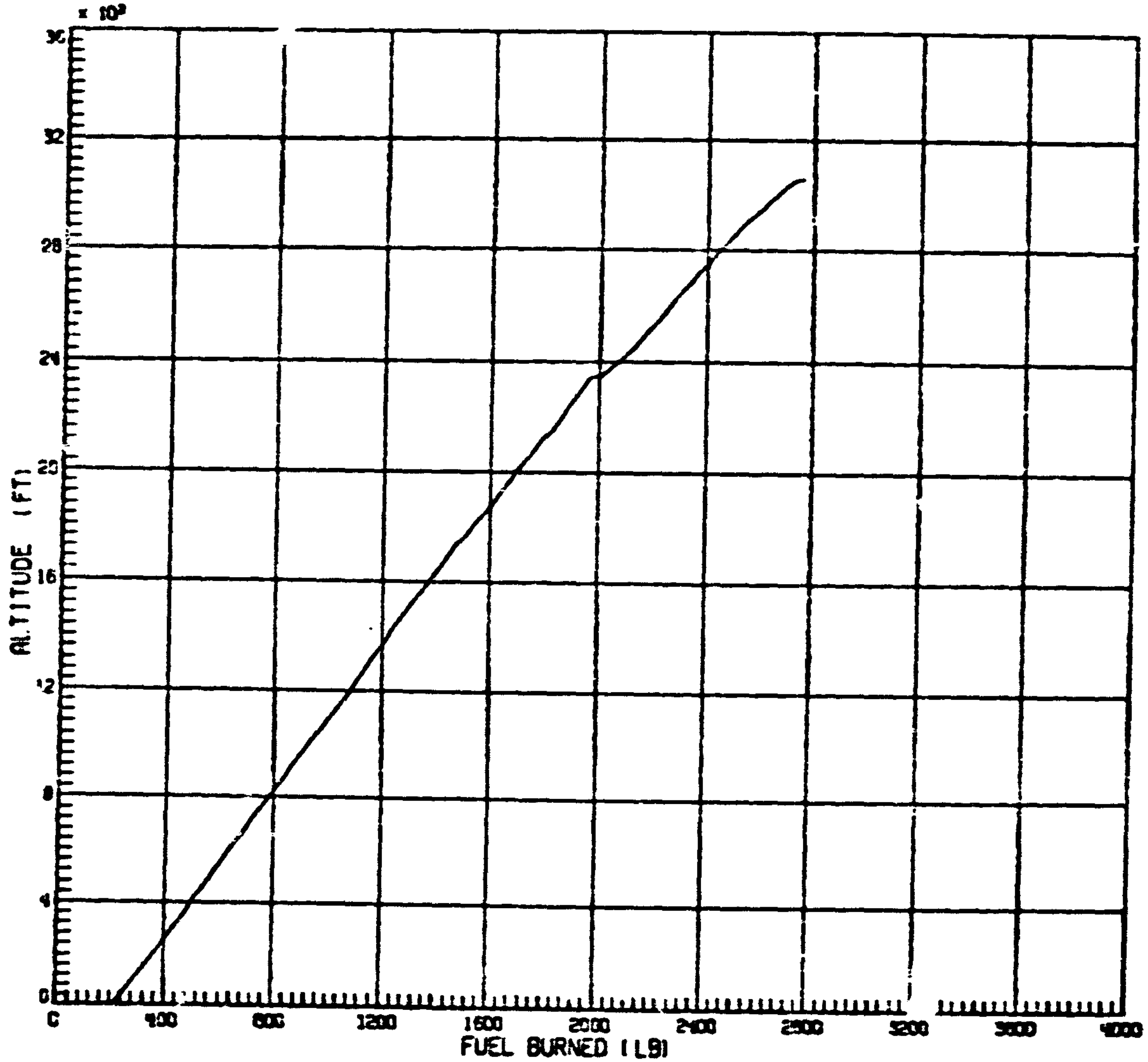

Figure 24.6 - FUEL BURNED-ALTITUDE FOR RUN C2

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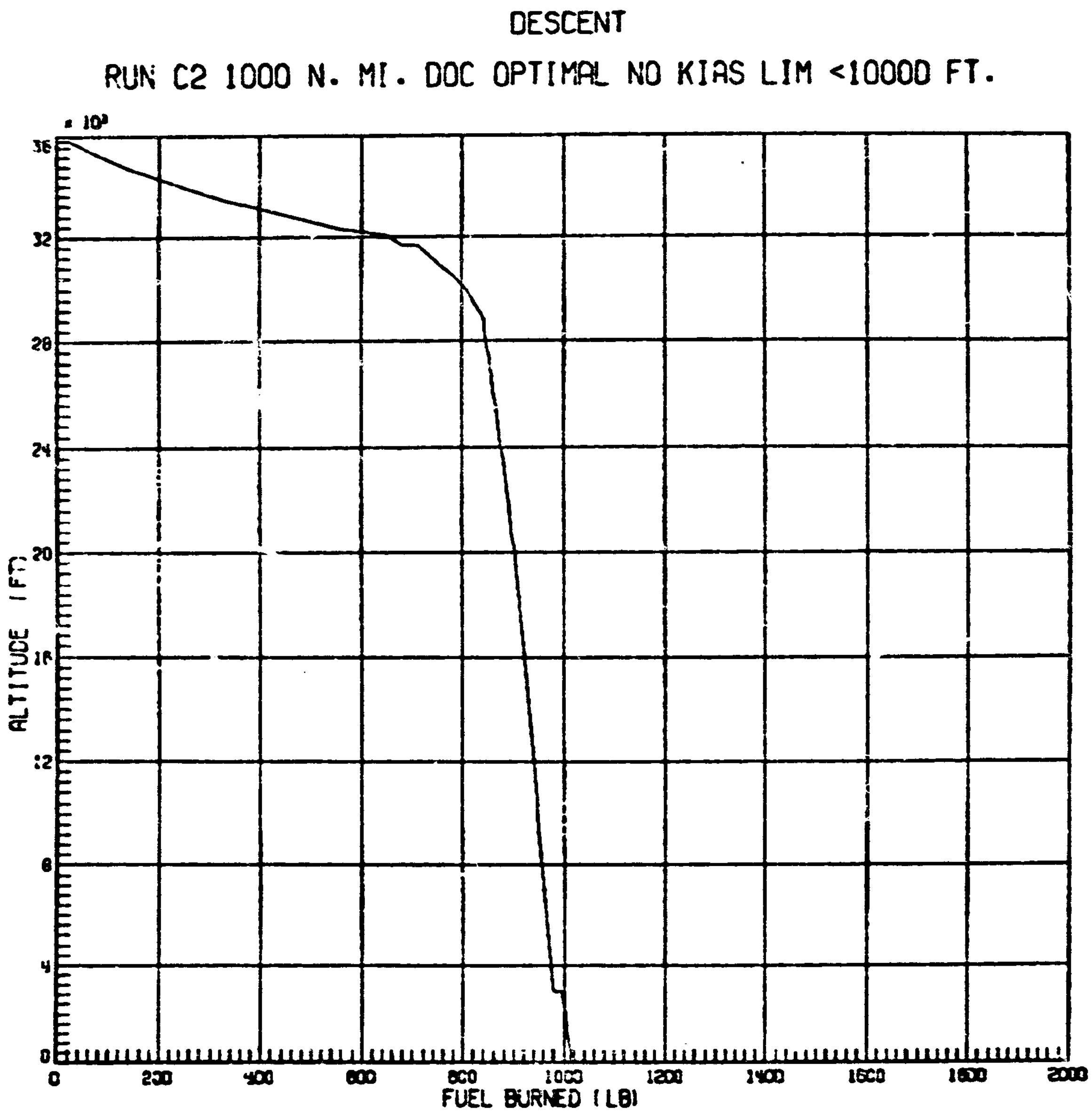

Figure 24.6 - FUEL BURNED-ALTITUDE FOR RUN C2 (D[illegible]ENT)

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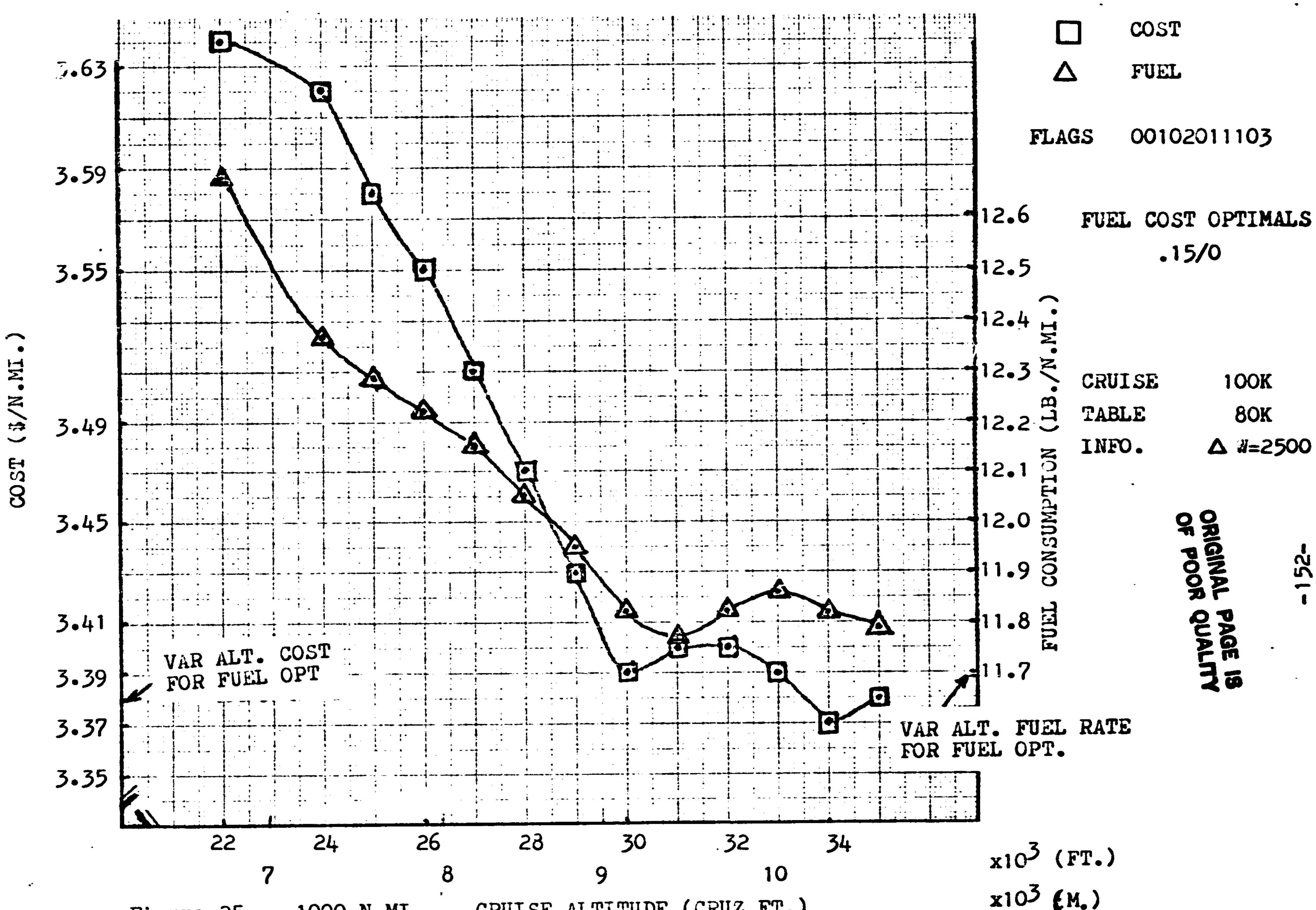

Figure 25 1000 N.MI. CRUISE ALTITUDE (CRUZ,FT.)

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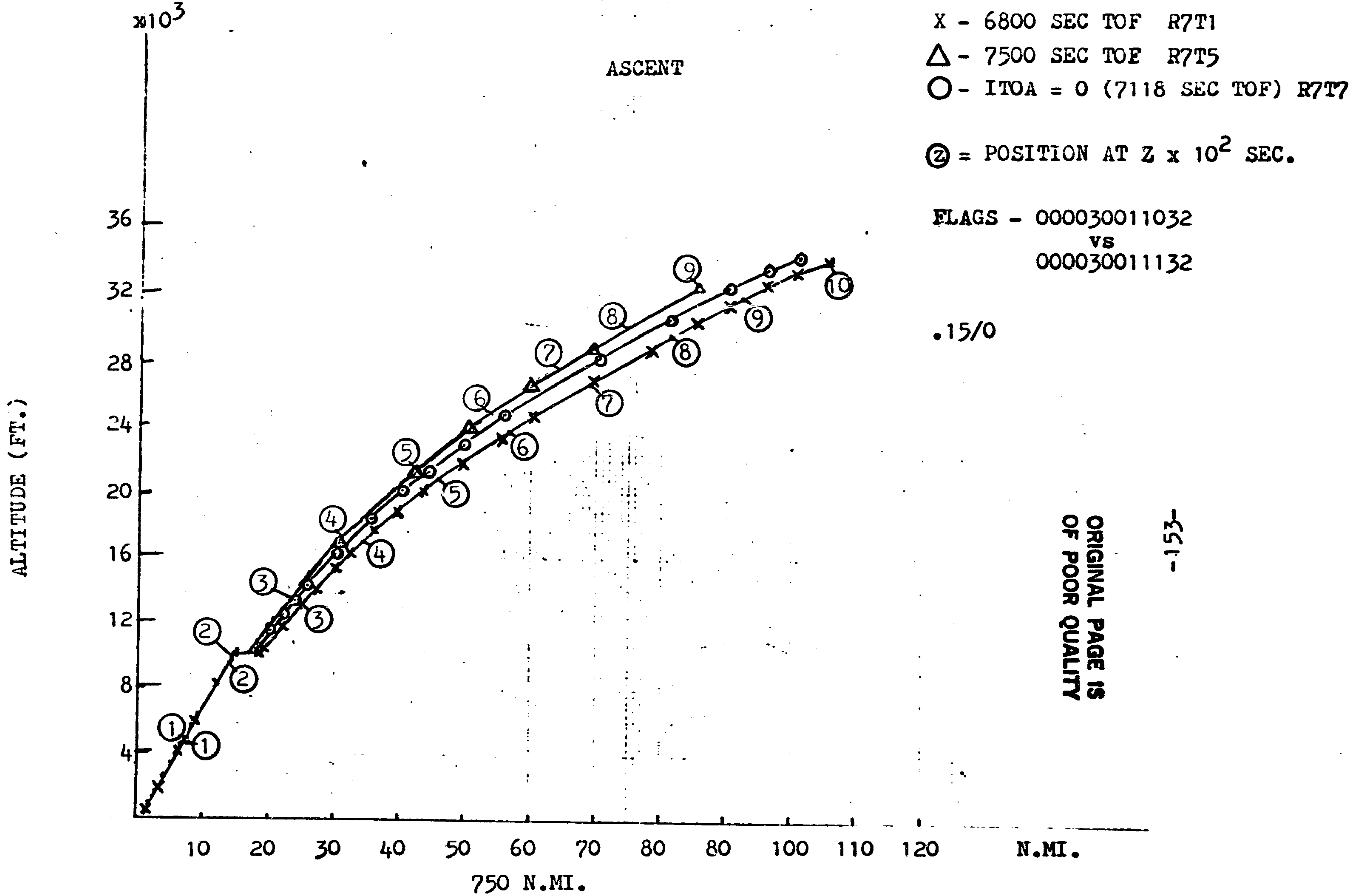

Figure 26.1(a) - Comparisons of ascent portions of several fixed time of arrival trajectories with free time of arrival trajectory.

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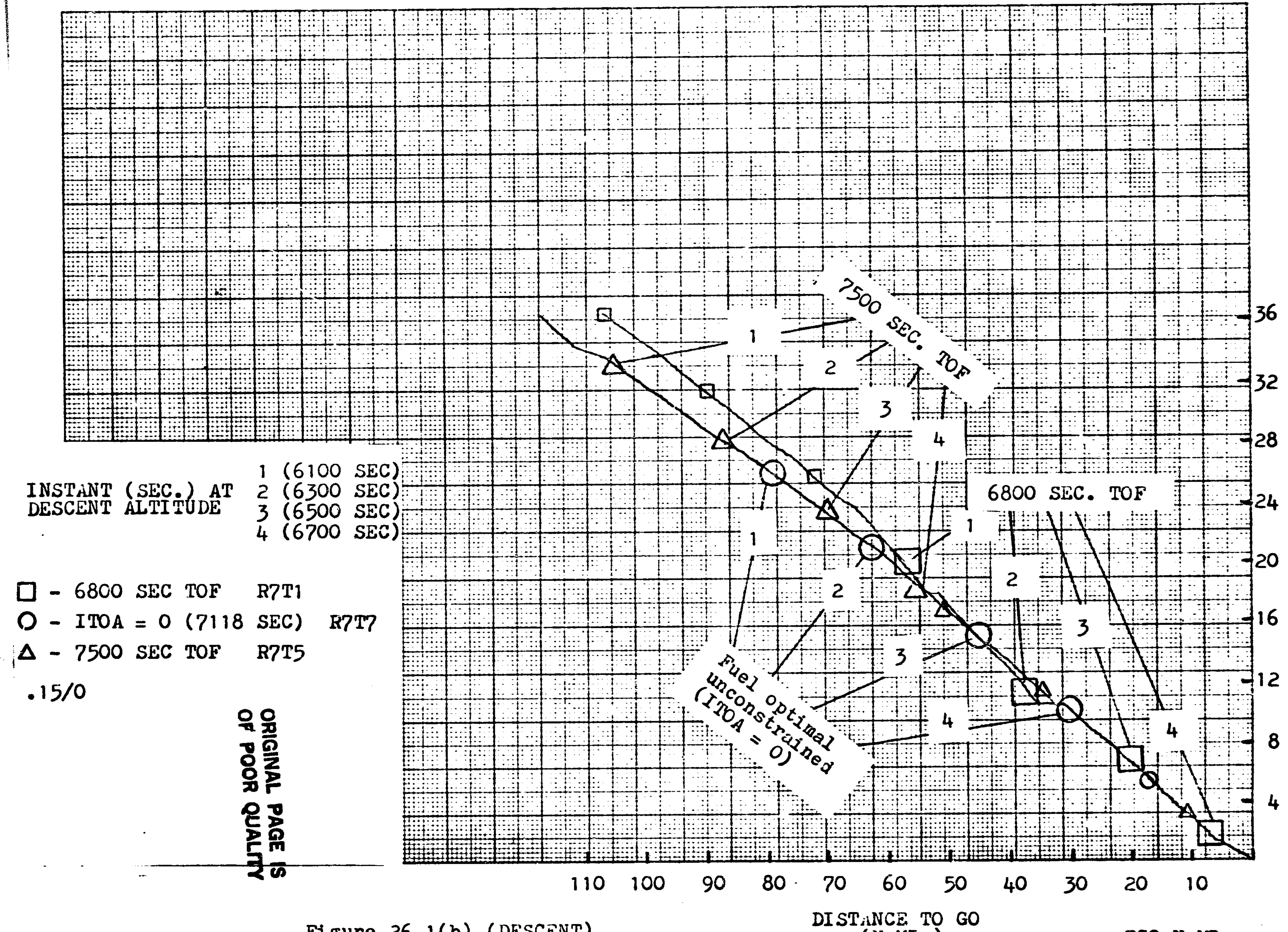

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Figure 26.1(b) (DESCENT)

CLIMB, CRUISE AND DESCENT
.15/0 000030011032 750 N.MI.
000030011132

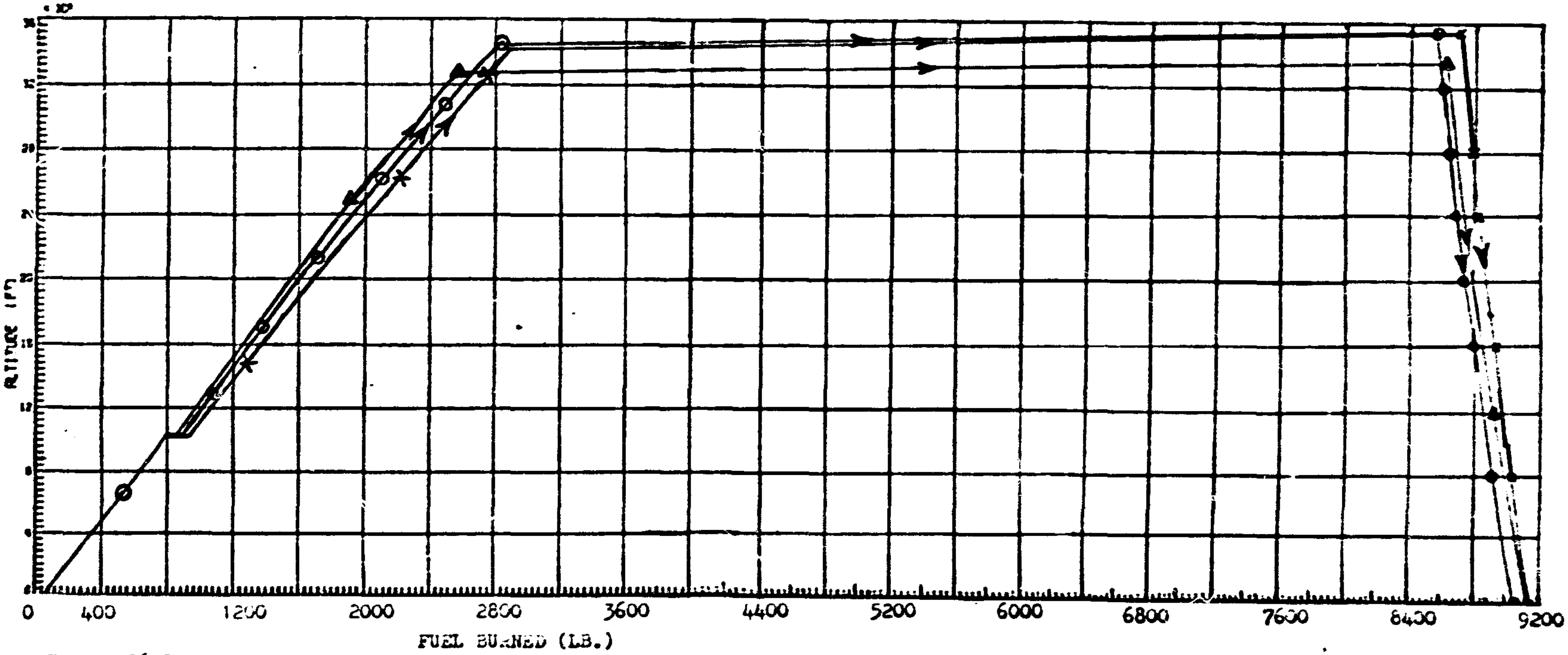

Figure 26.2

X - ITOA = 1 6800 SEC TOF R7T1
Δ - ITOA = 1 7500 SEC TOF R7T5
O - ITOA = 0 7118 SEC TOF R7T7

-155-

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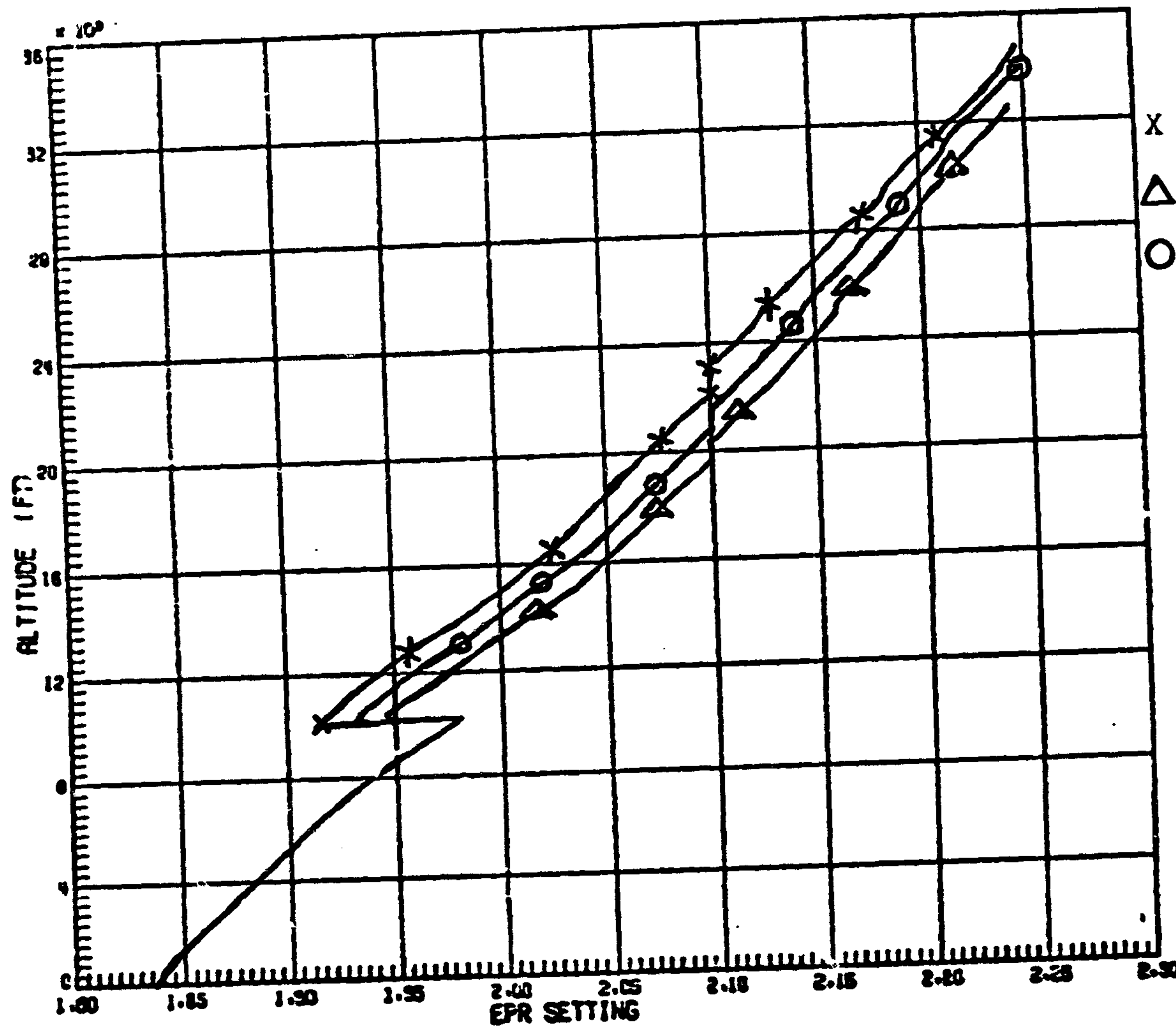
CLIMB

000030011032 .15/0
000030011132



FILE NO.

X - ITOA = 1 6800 SEC TOF R7T1

△ - ITOA = 1 7500 SEC TOF R7T5

O - ITOA = 0 7118 SEC TOF R7T7

DESCENT EPR = 1.10

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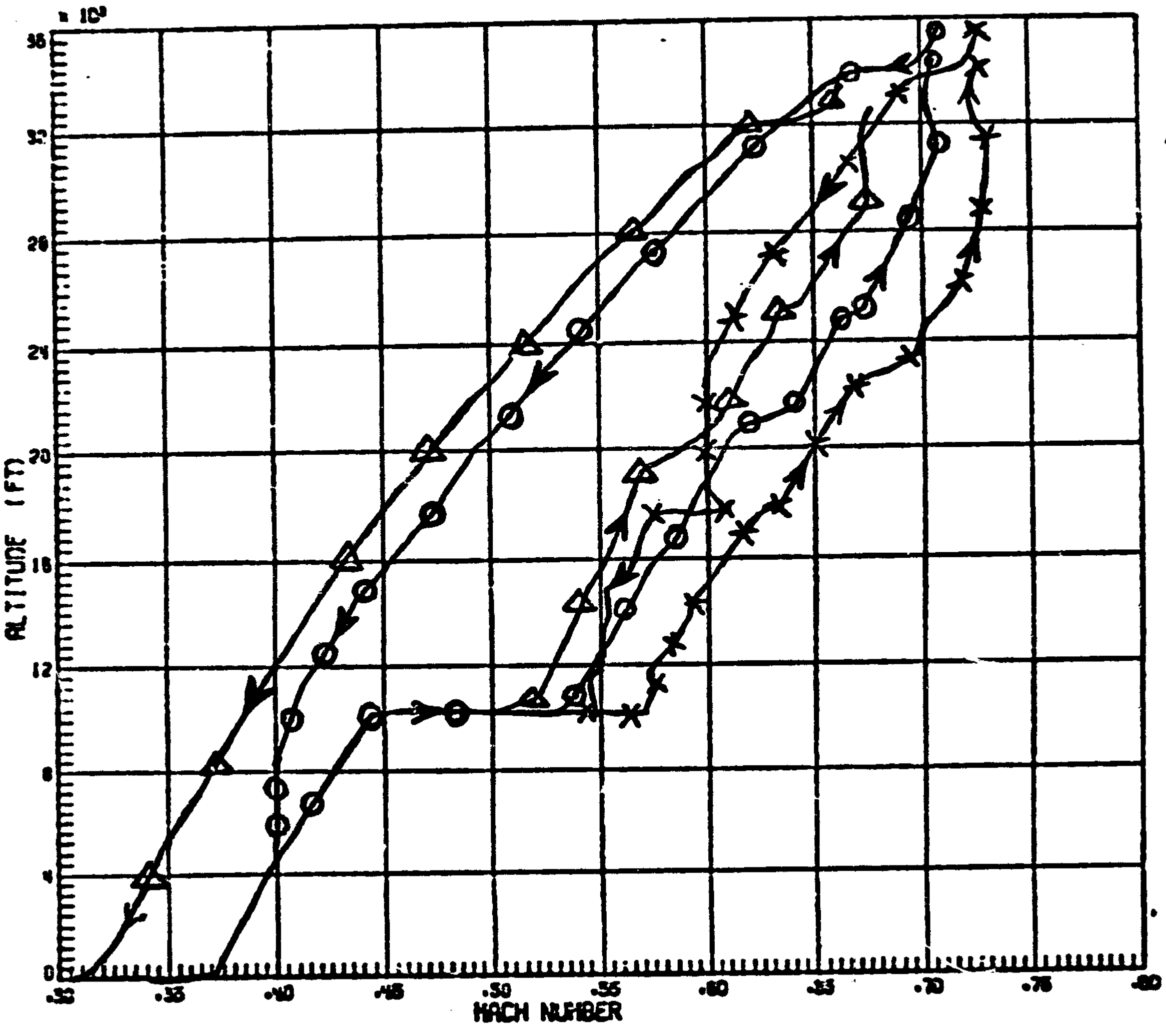
Figure 26.3

CLIMB AND DESCENT

.15/0 000030011032 750 N.MI.
000030011132

FILE
NO.



X - 6800 SEC TOF R7T1

△ - 7500 SEC TOF R7T5

ITOA = 1

○ - 7118 SEC TOF R7T7 ITOA = 0

Figure 26.4

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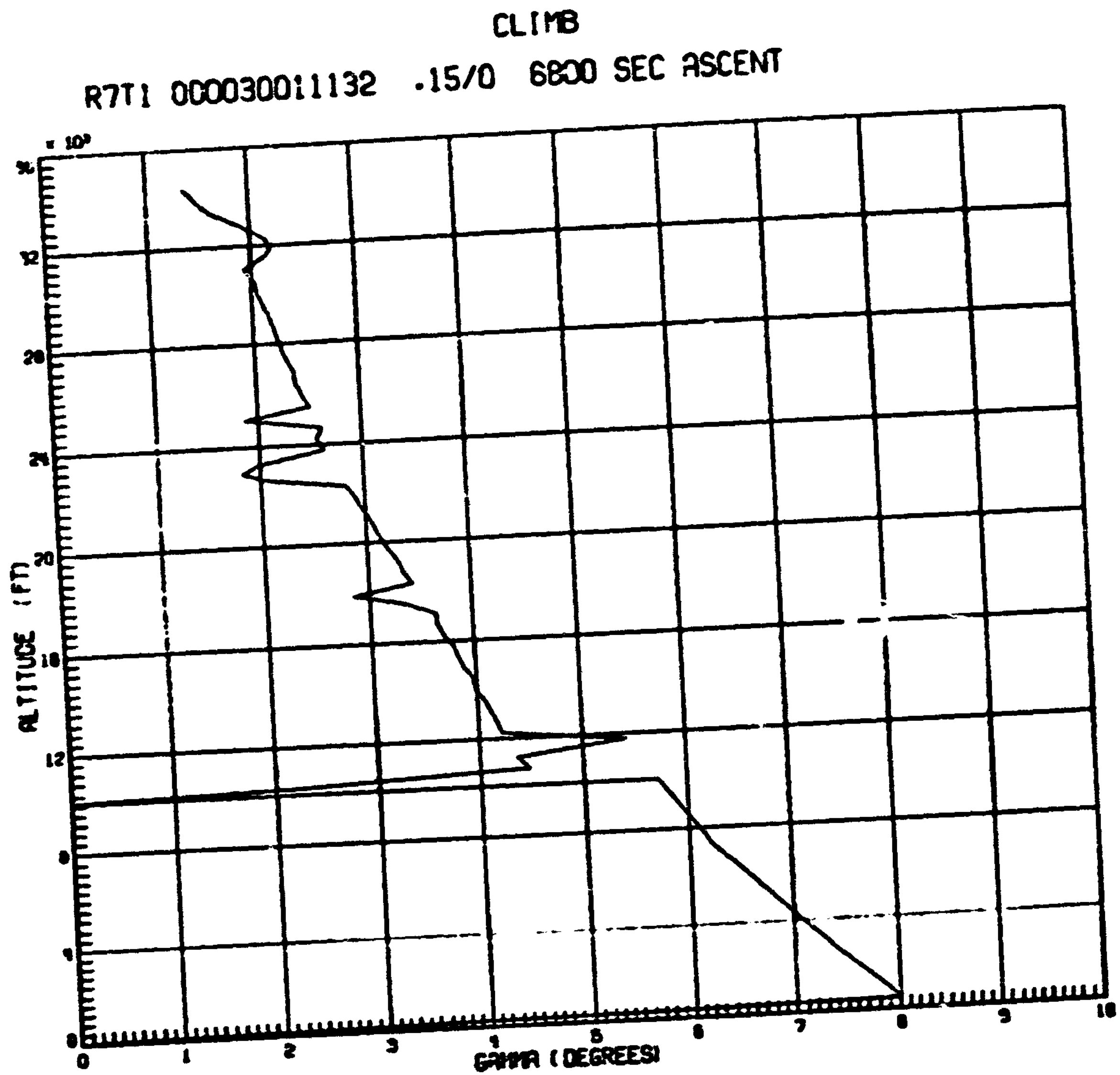

Figure 26.5 - GAMMA-ALTITUDE RELATION FOR RUN R7T1

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DESCENT

R7T1 000030011132 .15/0 6800 SEC ASCENT

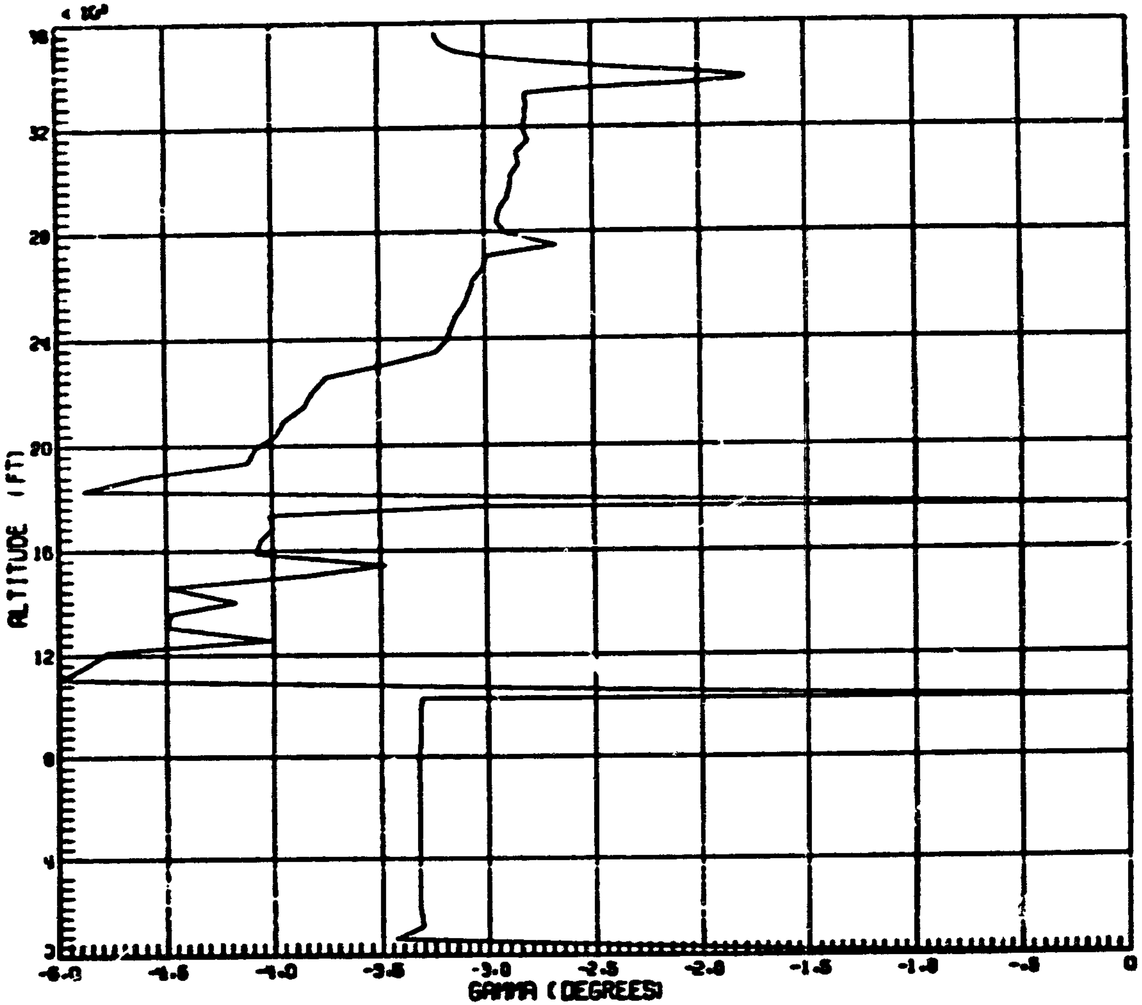

Figure 26.5 (DESCENT)

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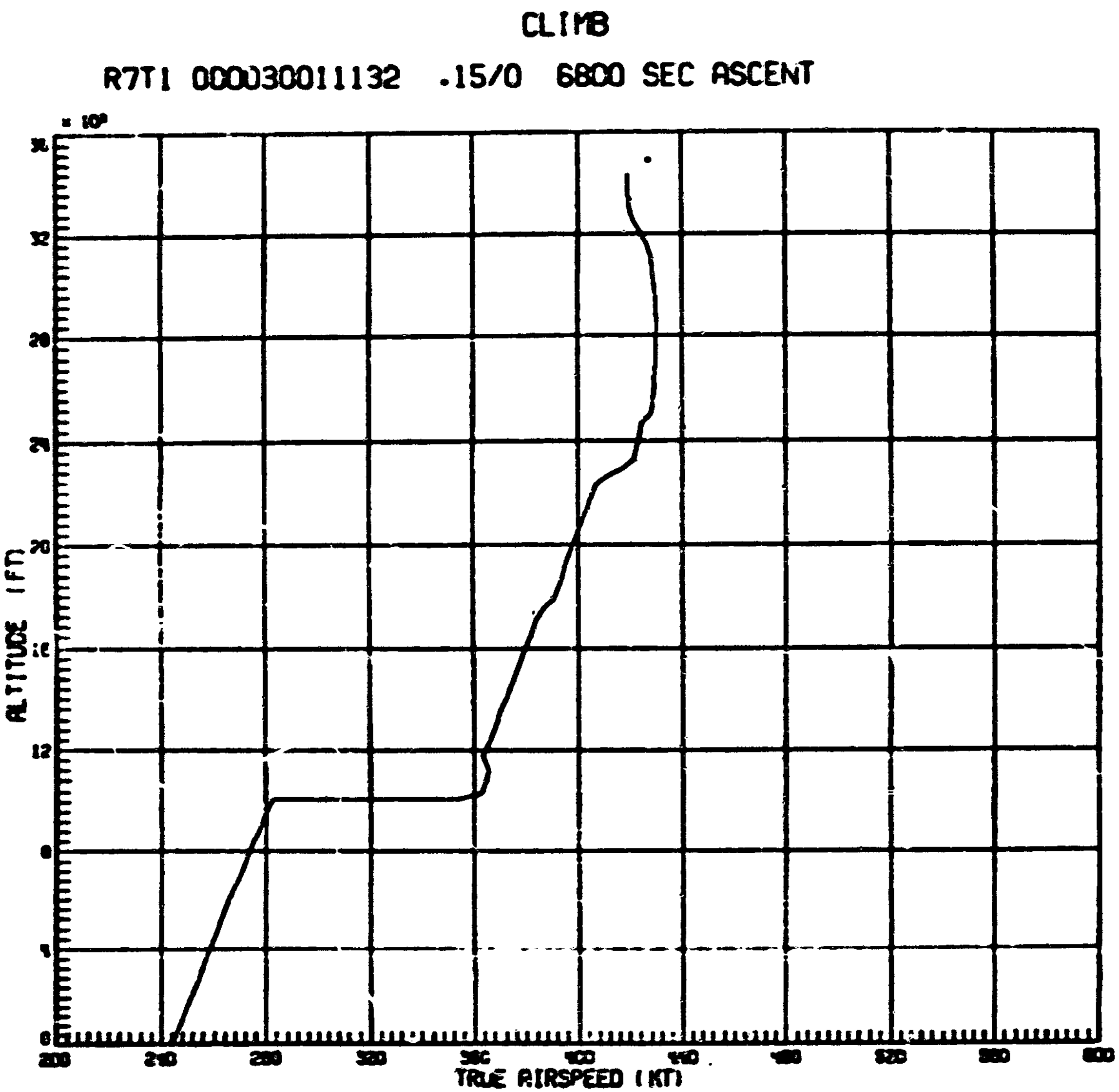

Figure 26.6 - TRUE AIRSPEED-ALTITUDE FOR RUN R7T1

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DESCENT

R7T1 000030011132 .15/0 6800 SEC ASCENT

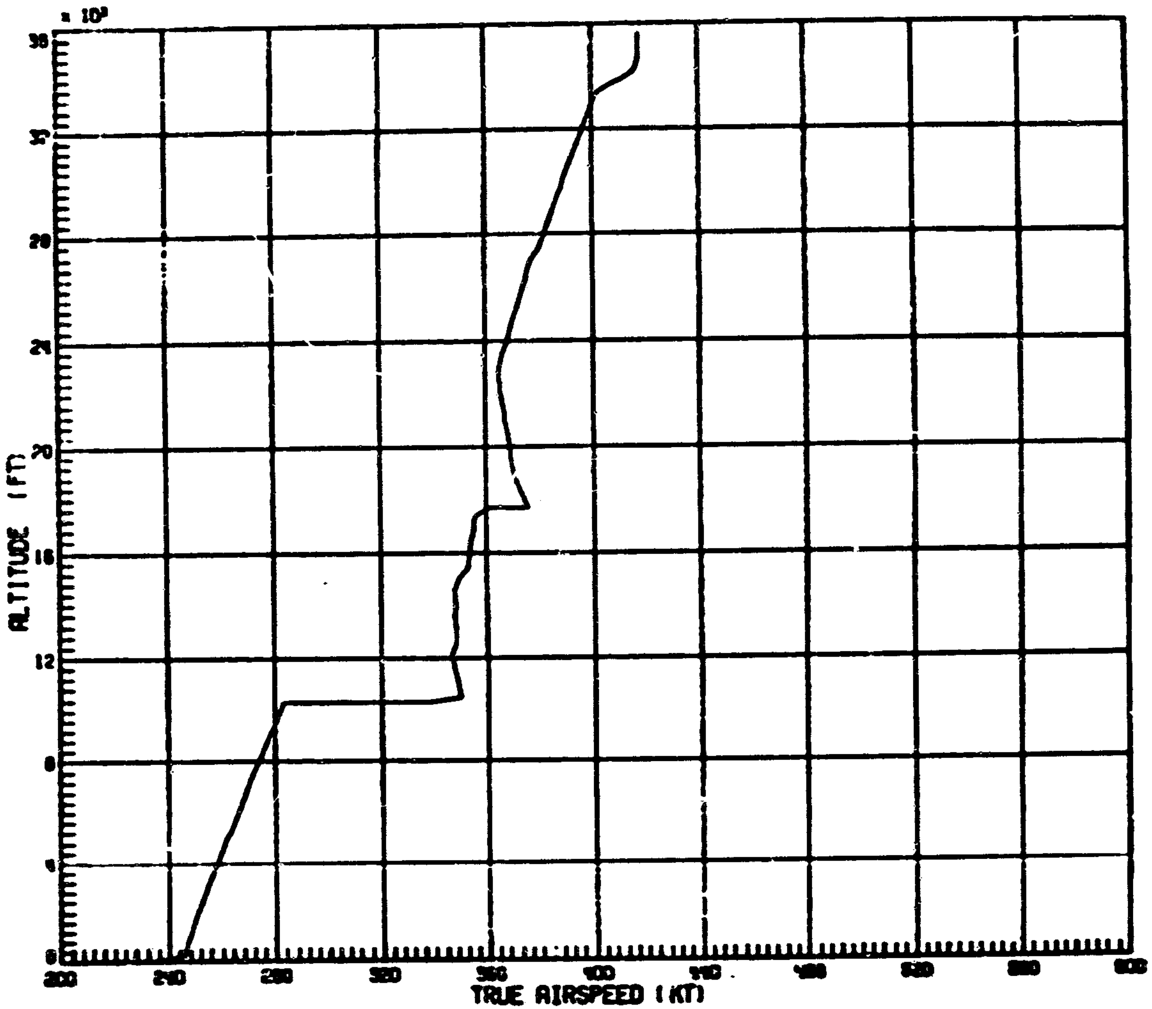

Figure 26.6 (DESCENT)

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CLIMB

R7T1 000030011132 .15/0 6800 SEC ASCENT

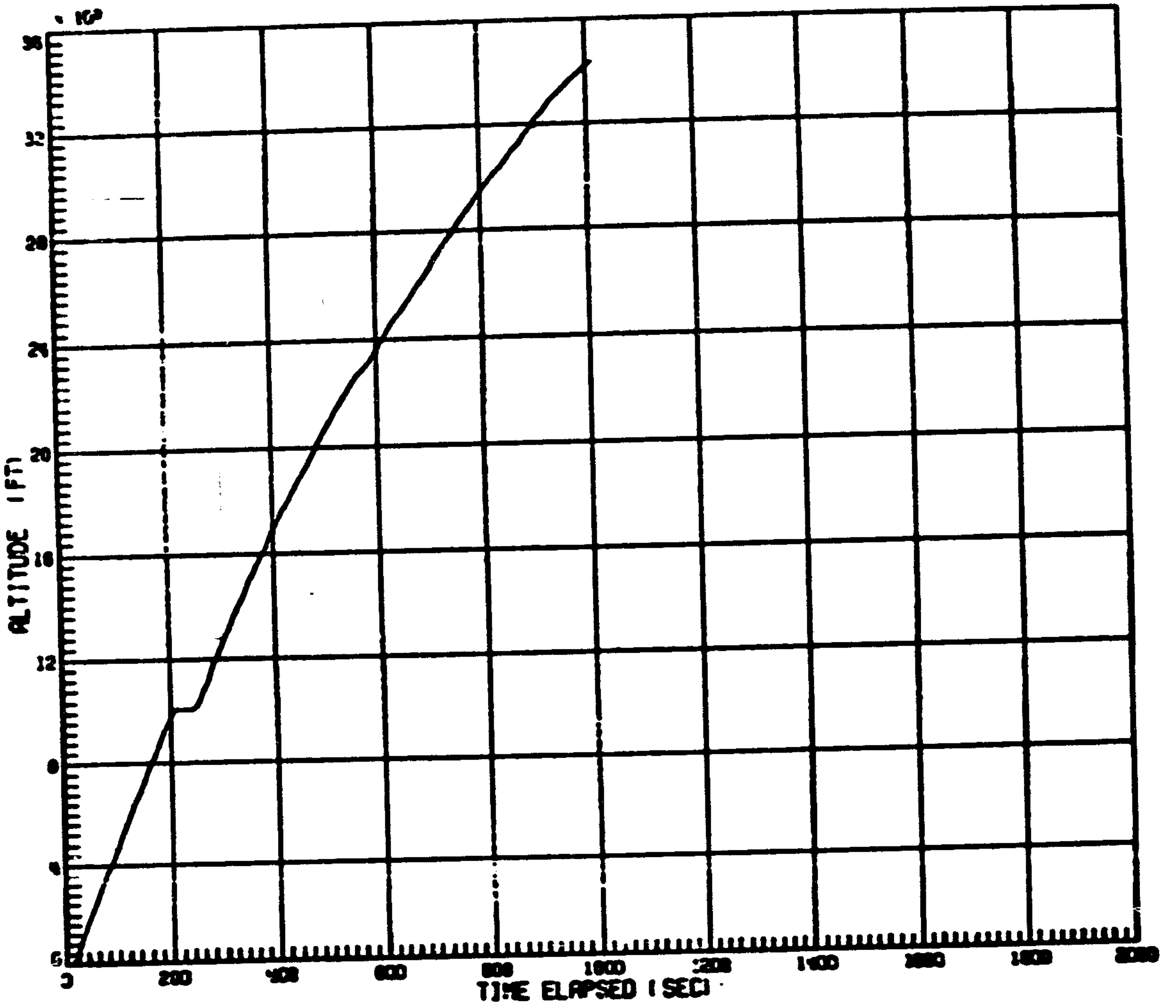

Figure 26.7 - TIME ELAPSED-ALTITUDE FOR RUN R7T1

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DESCENT

R7T1 000030011132 6800 SEC ASCENT

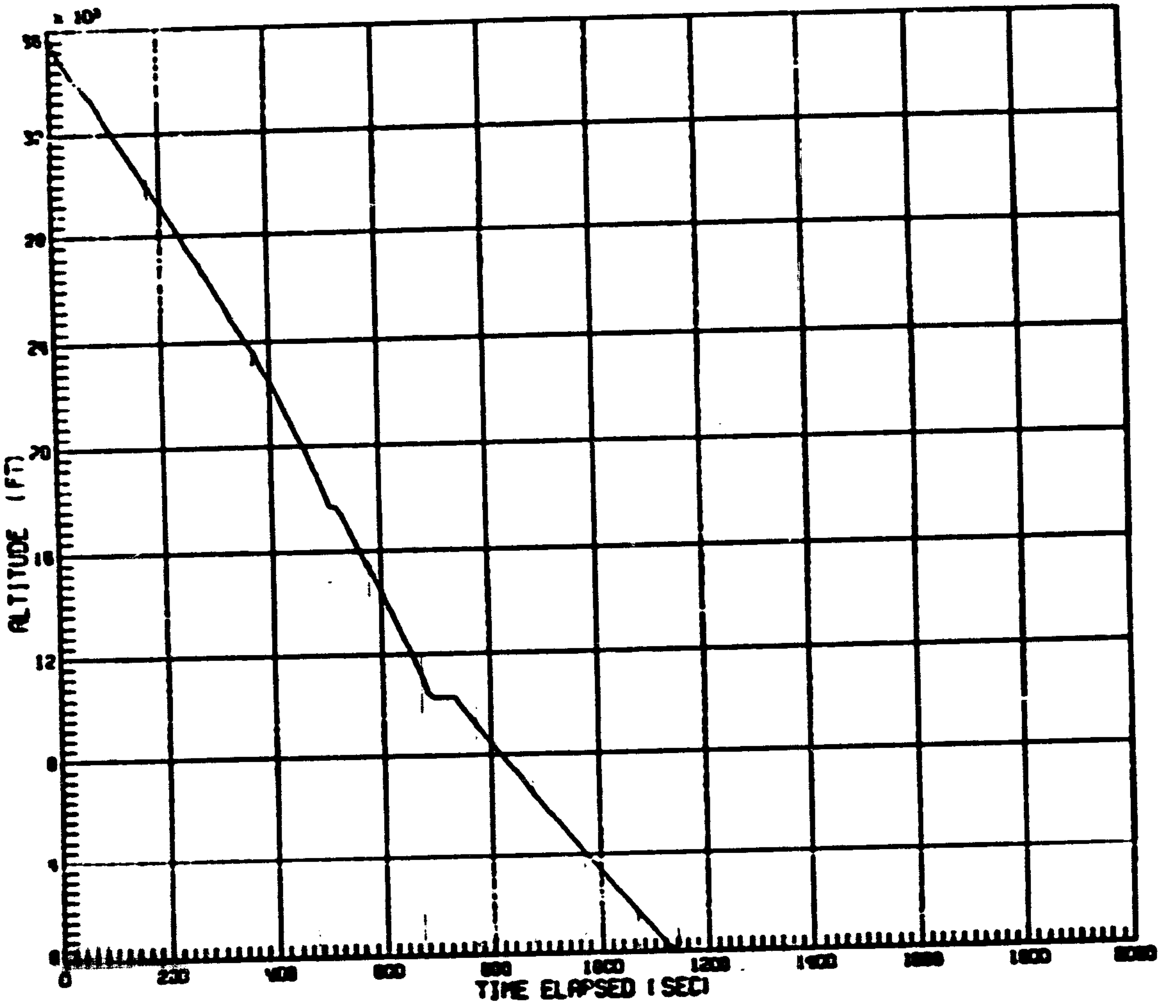

Figure 26.7 (DESCENT)

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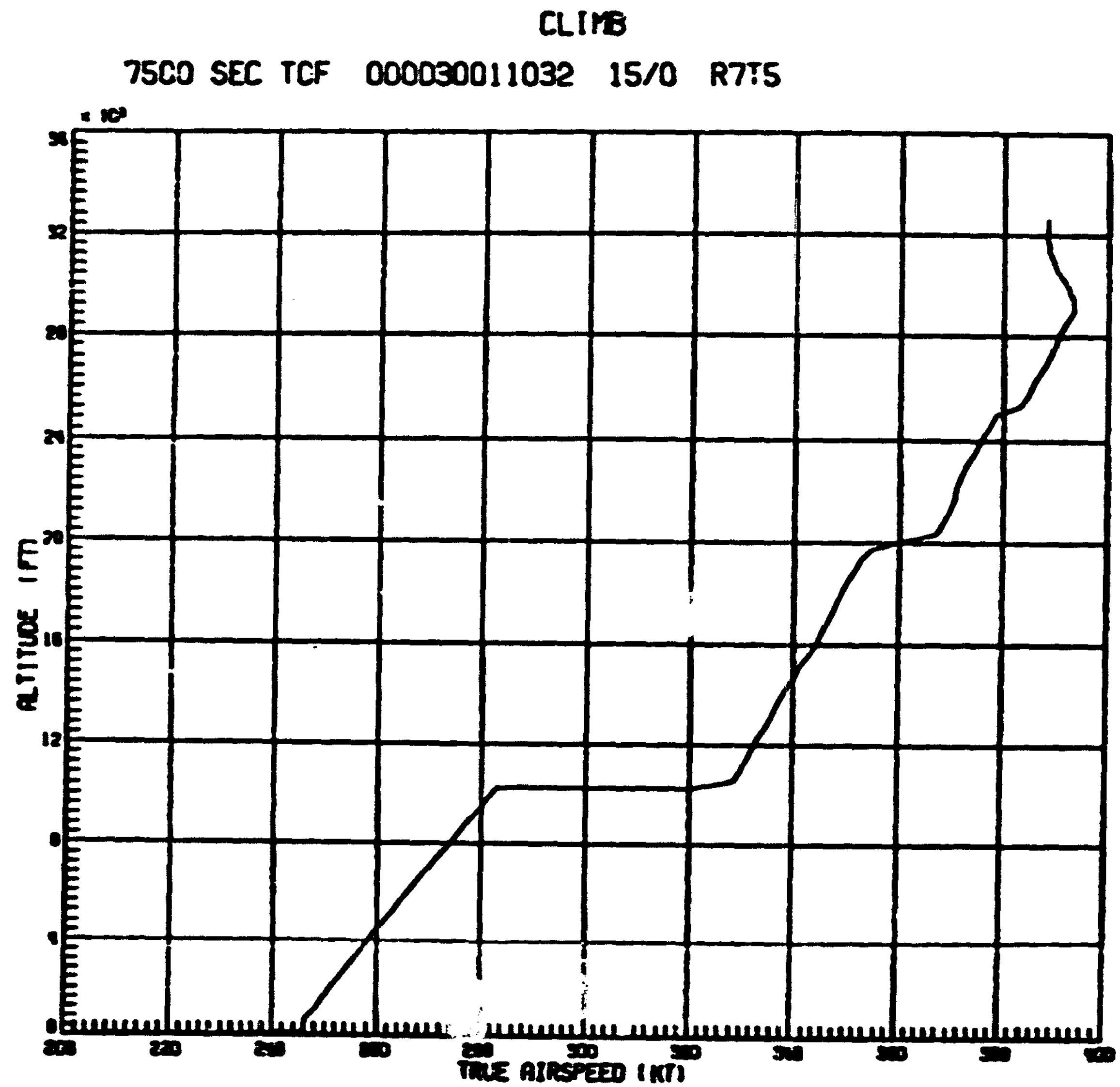

Figure 27.1 - TRUE AIRSPEED-ALTITUDE FOR RUN R7T5

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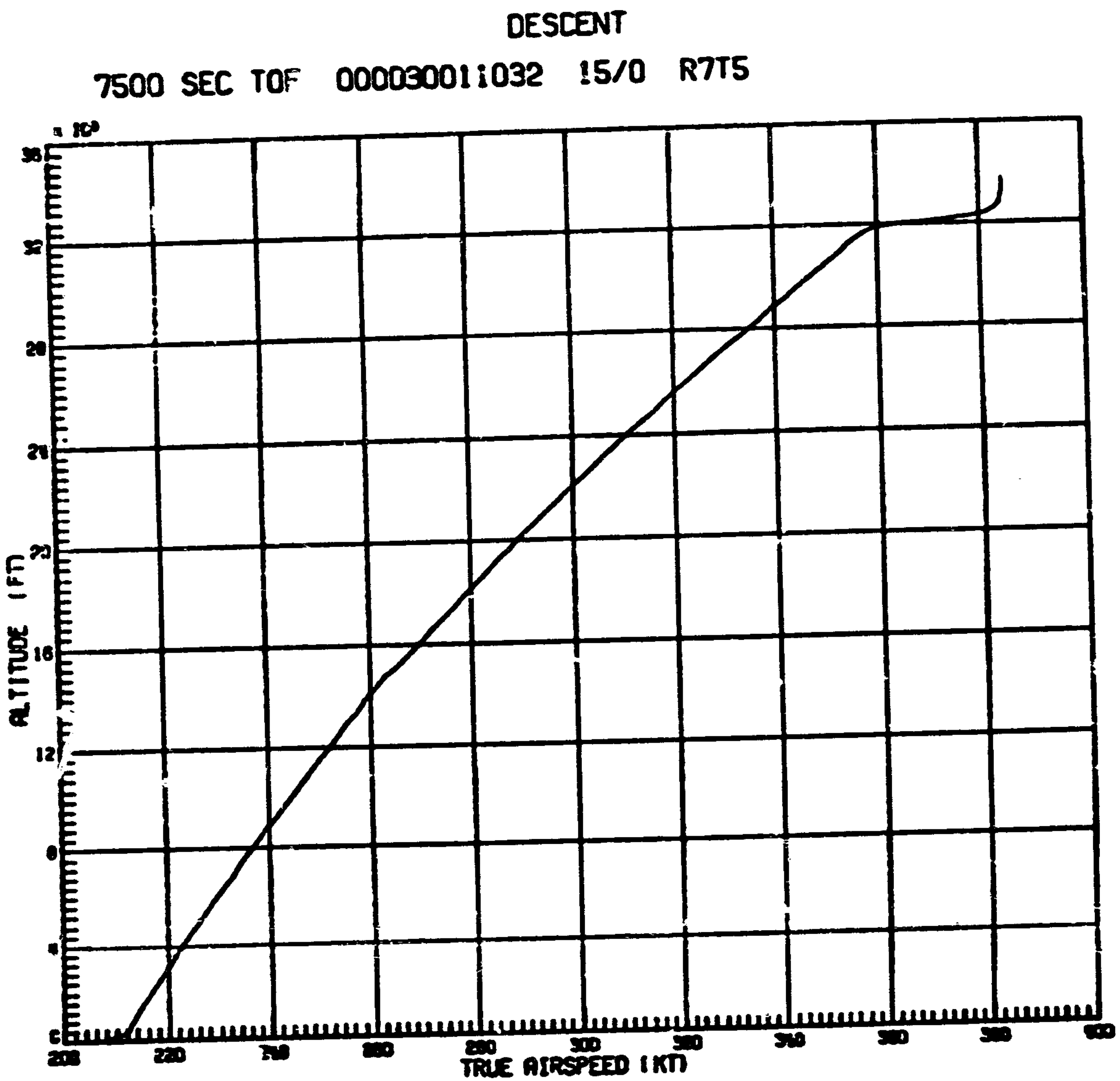

Figure 27.1 (DESCENT)

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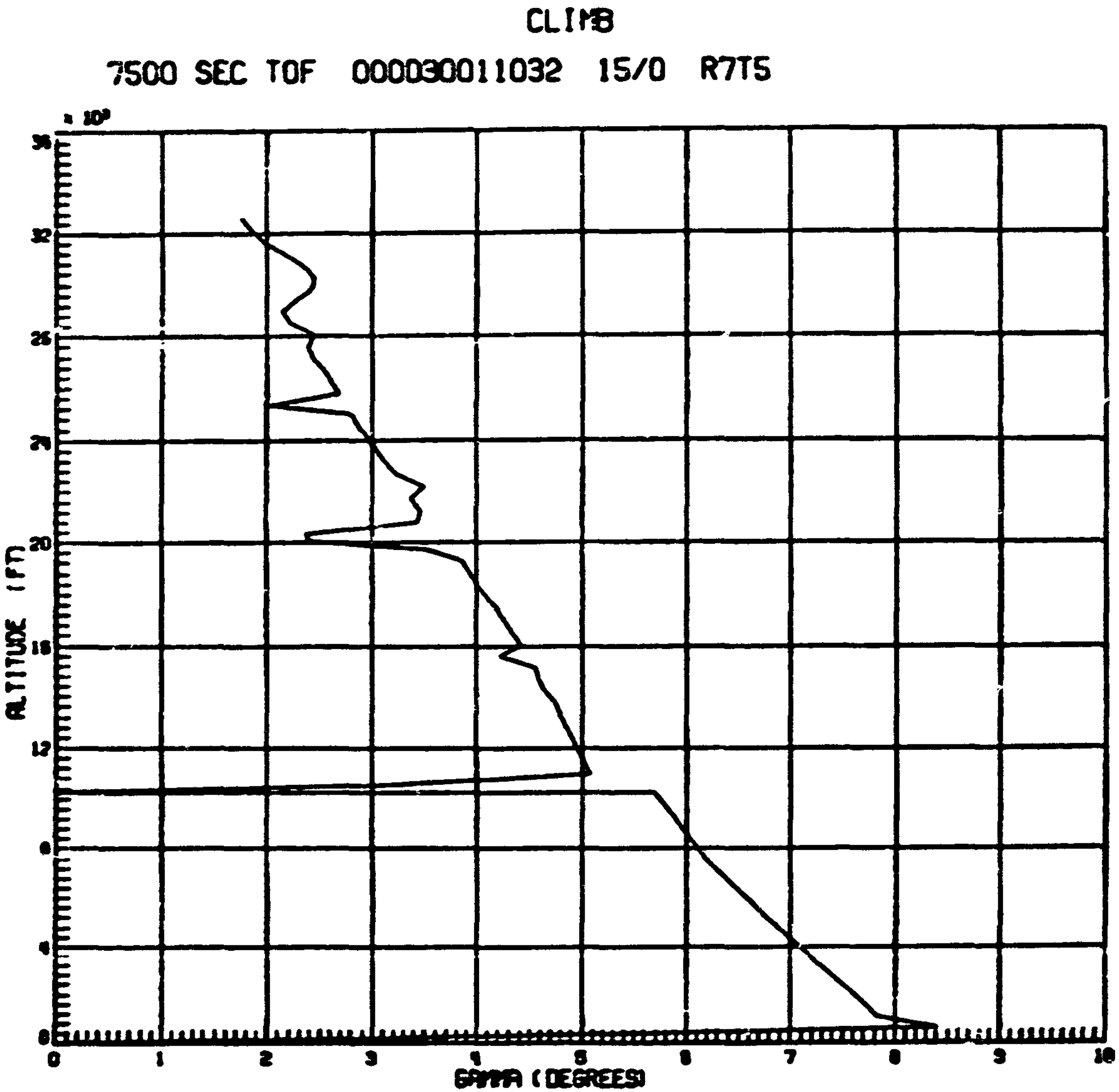

Figure 27.2 - GAMMA-ALTITUDE FOR RUN R7T5

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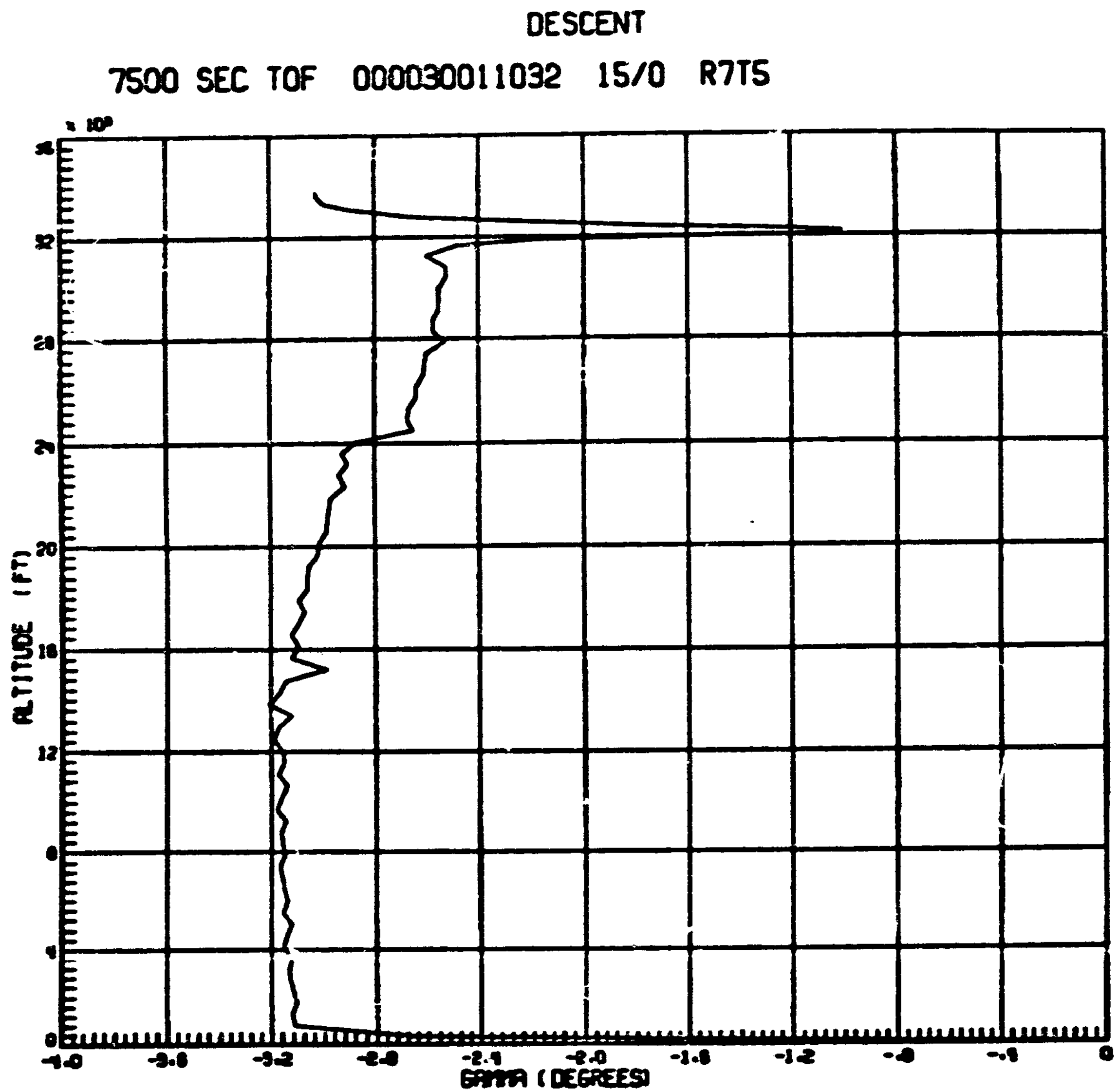

Figure 27.2 (DESCENT)

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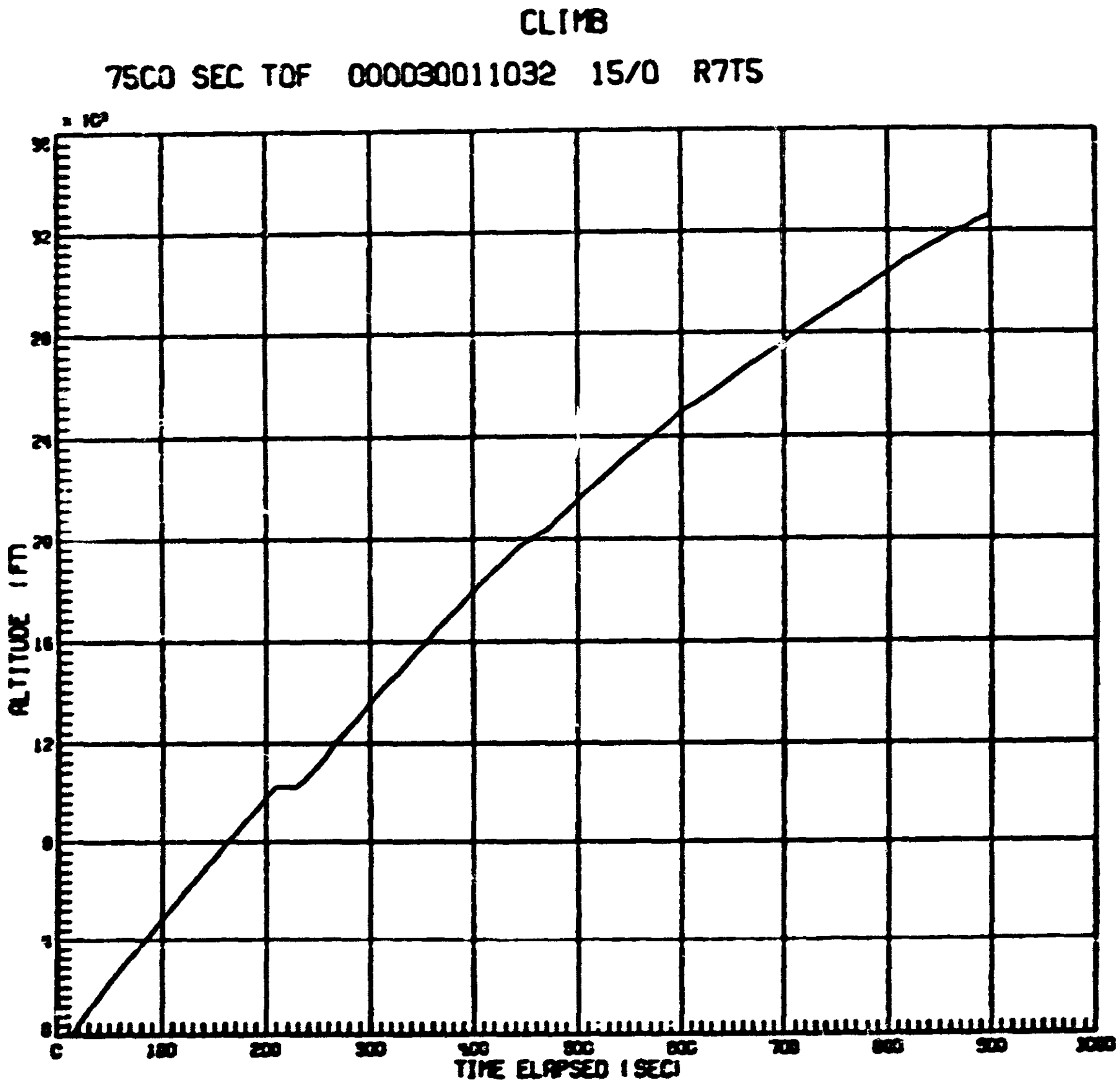

Figure 27.3 - TIME ELAPSED-ALTITUDE FOR RUN R7T5

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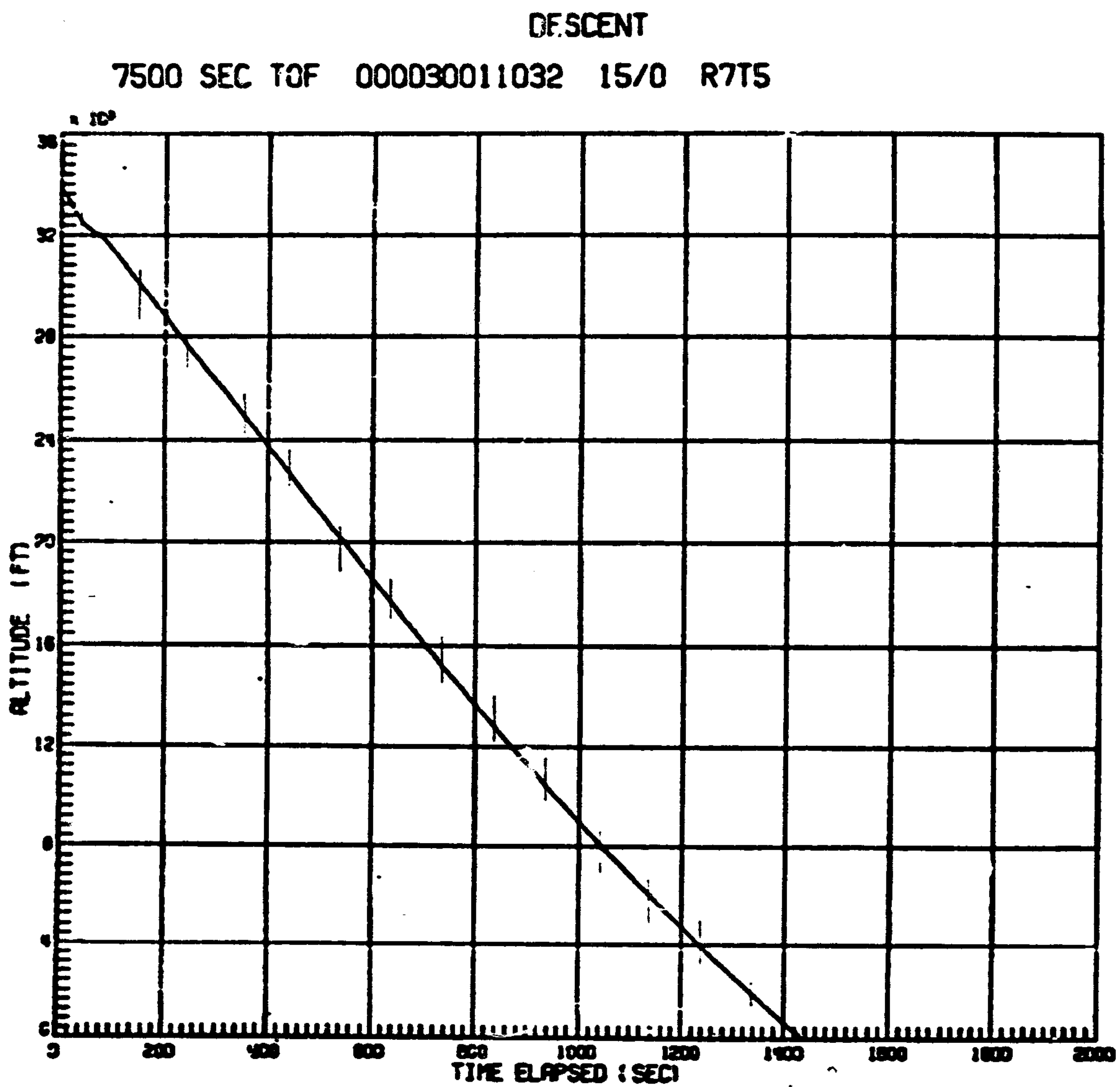

Figure 27.3 (DESCENT)

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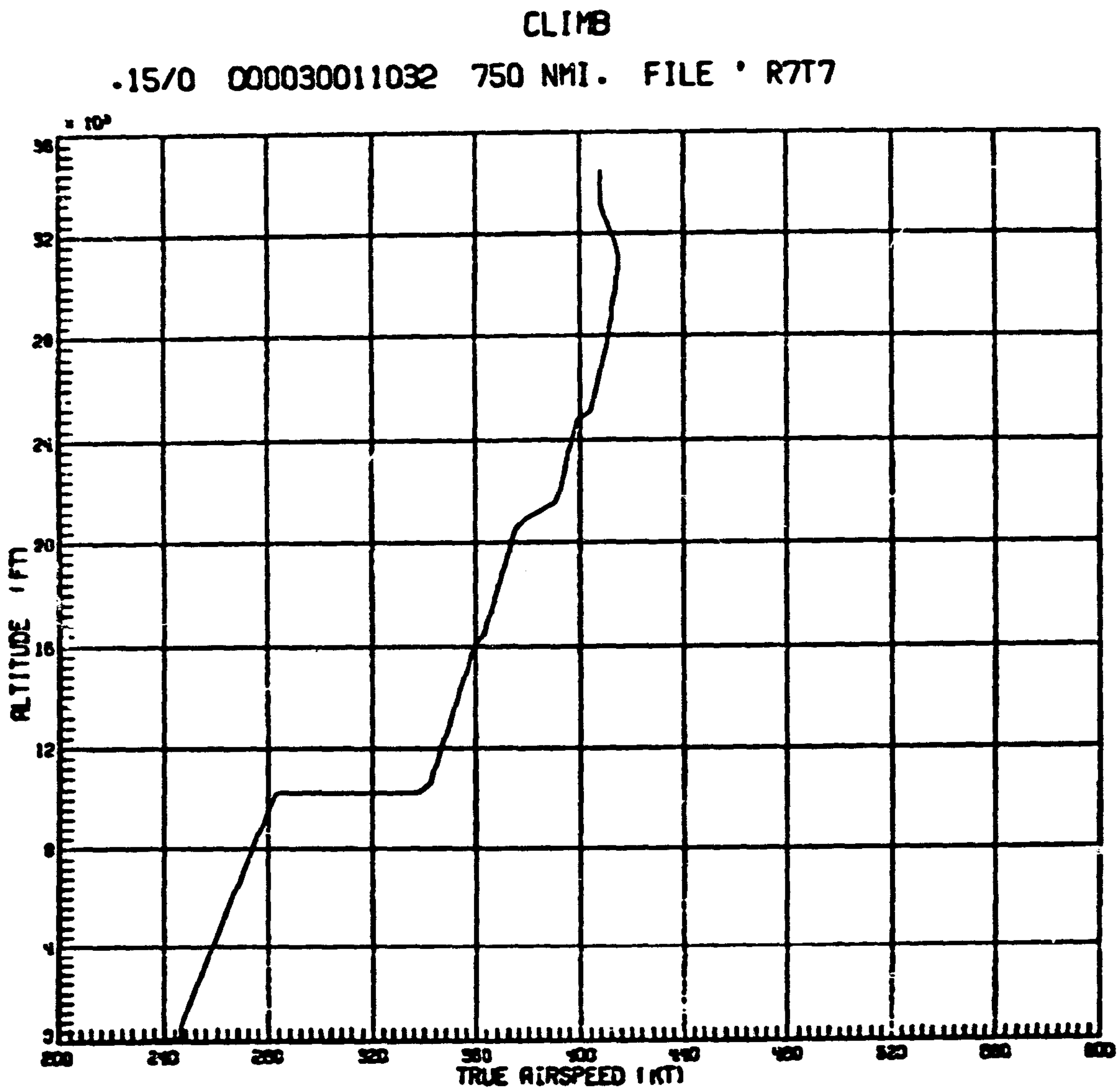

Figure 28.1 - TRUE AIRSPEED-ALTITUDE FOR RUN R7T7

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DESCENT

.15/0 000030011032 750 NMI. FILE ' R7T7

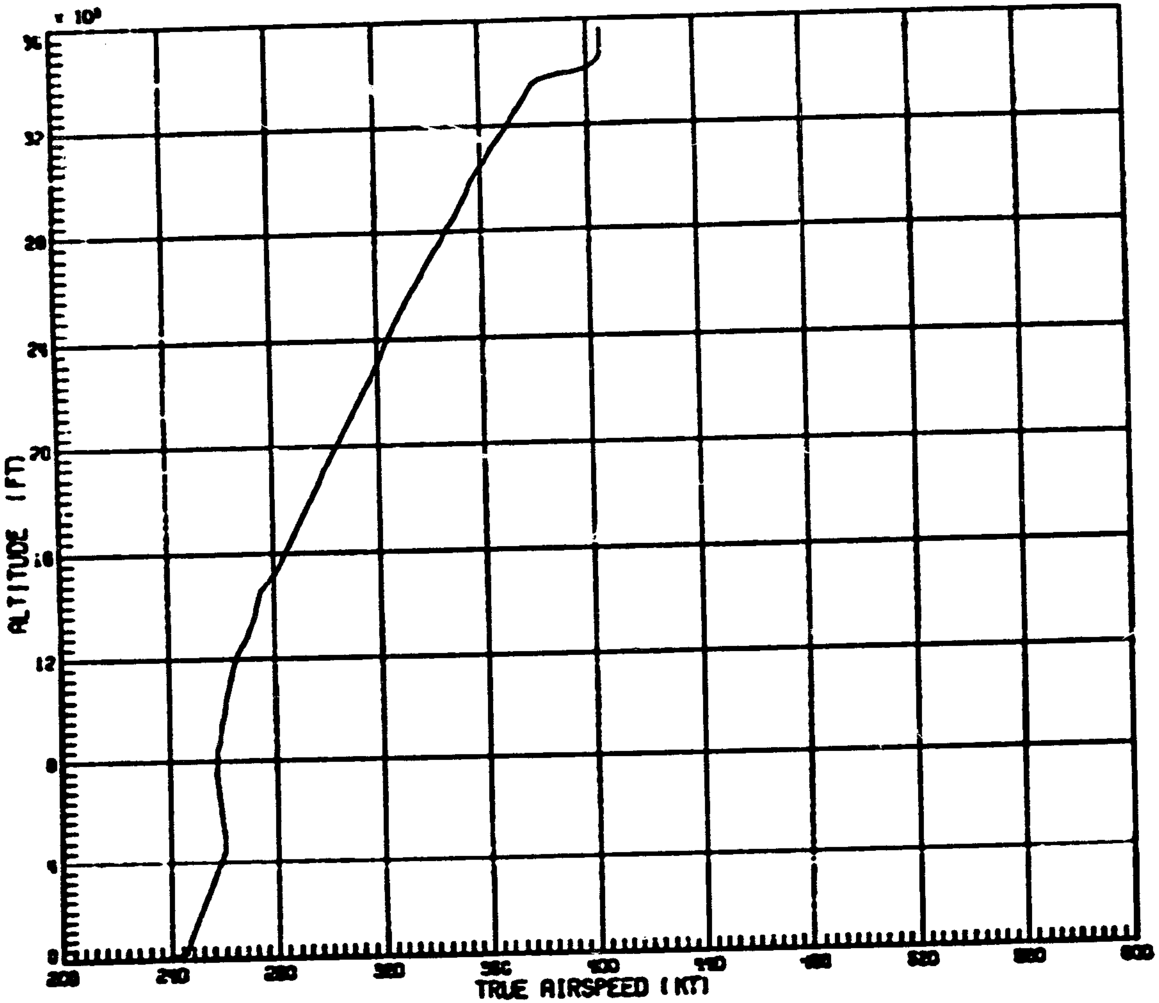

Figure 28.1 (DESCENT)

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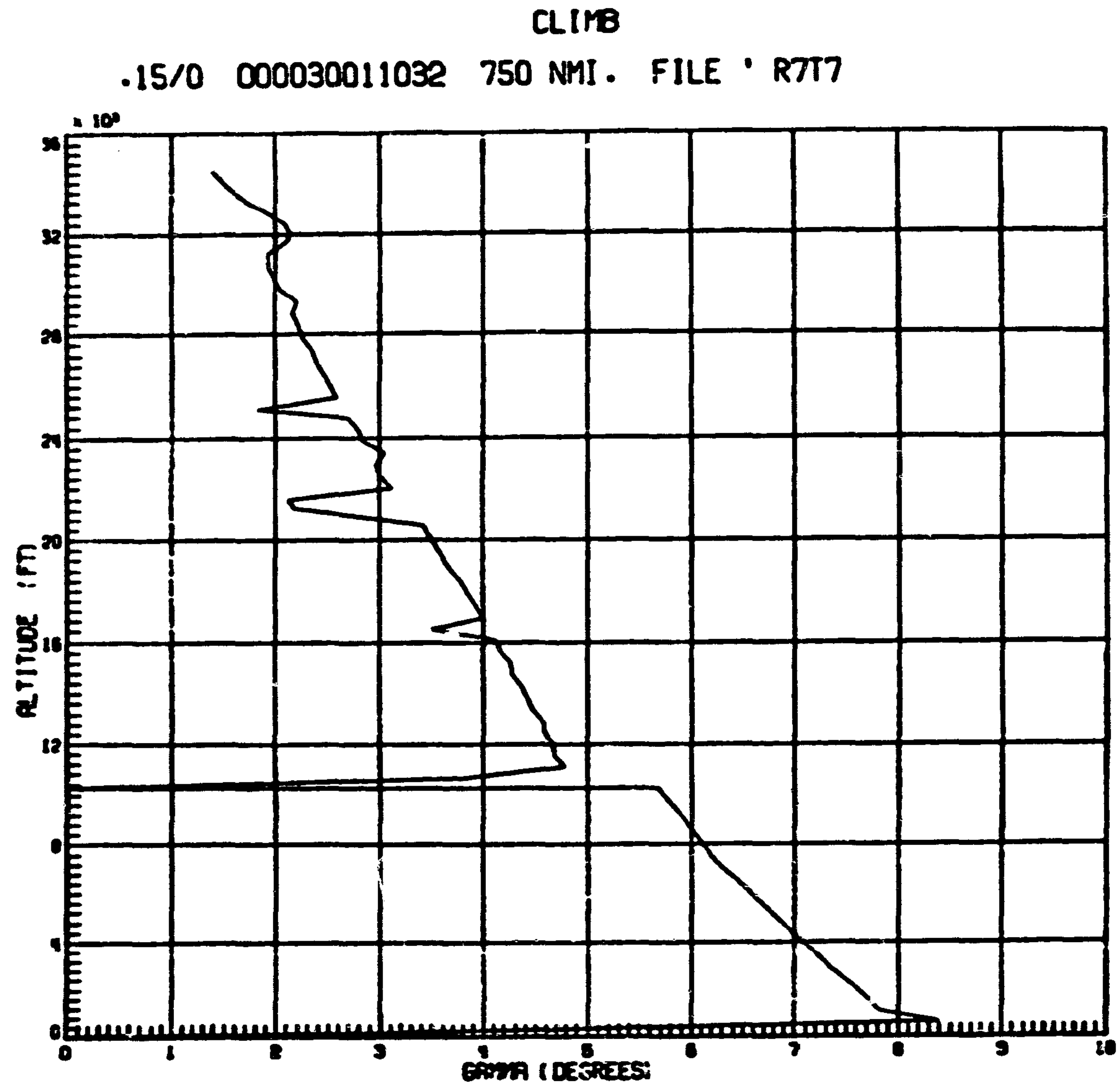

Figure 28.2 - GAMMA-ALTITUDE FOR RUN R7T7

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DESCENT

.15/0 000030011032 750 NMI. FILE ' R7T7

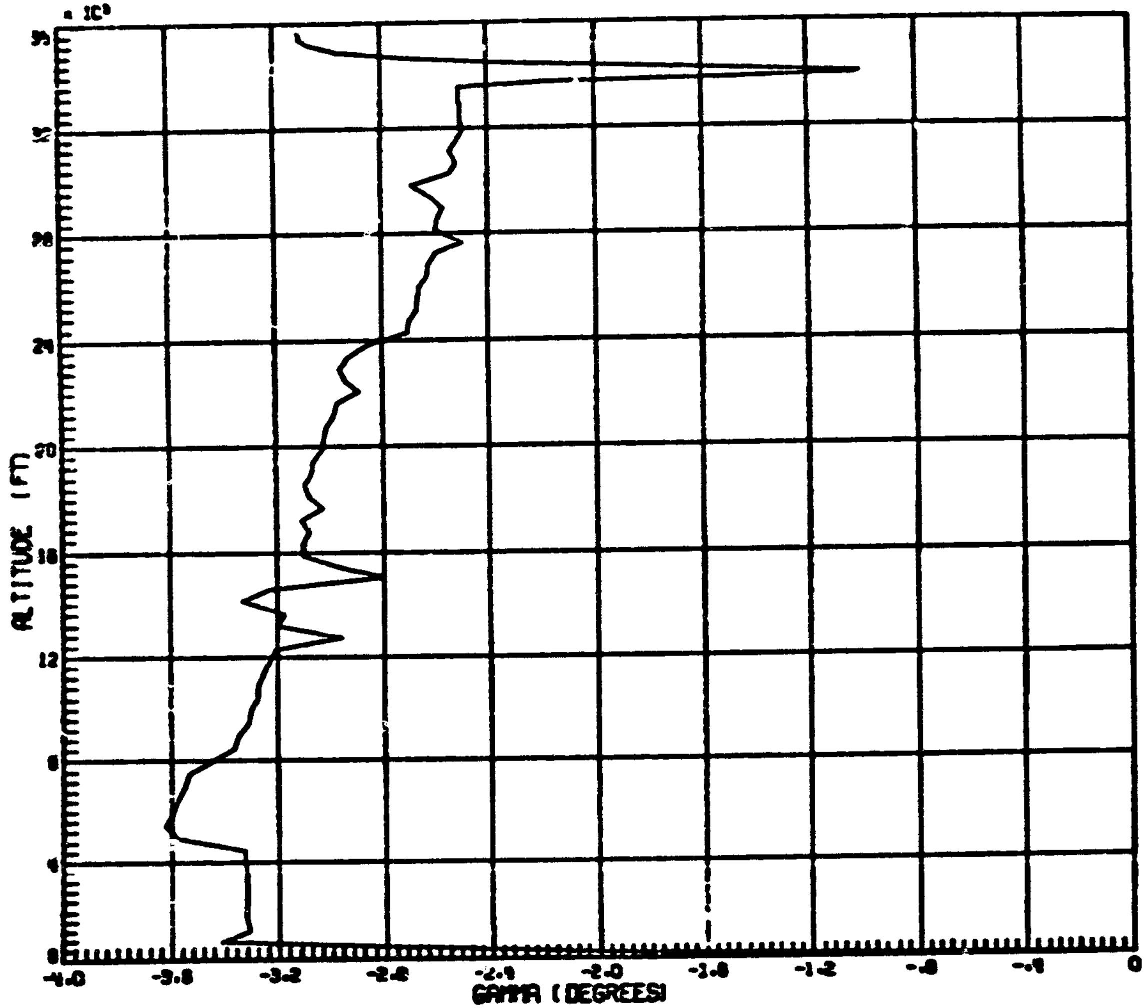

Figure 28.2 (DESCENT)

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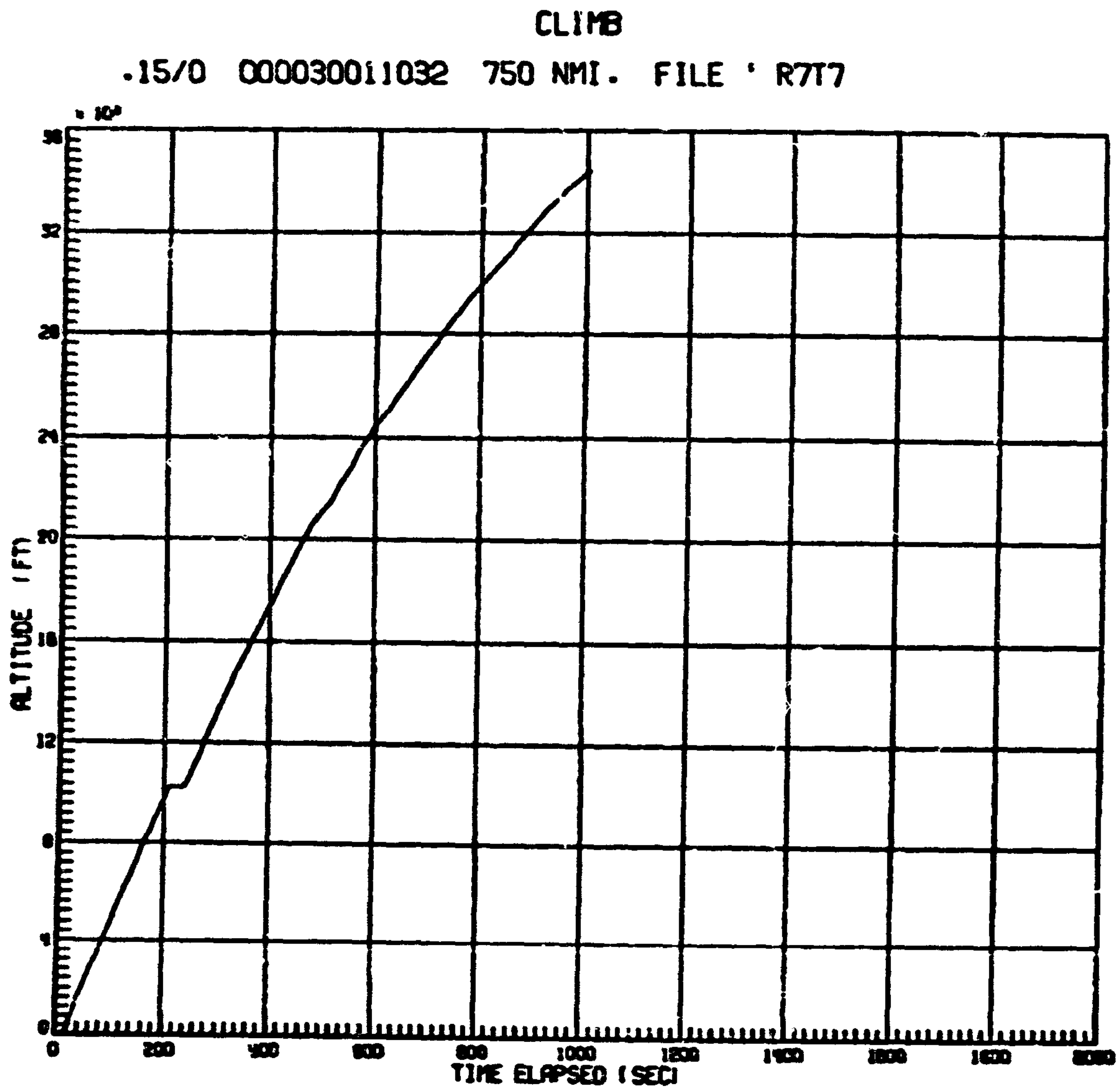

Figure 28.3 - TIME ELAPSED-ALTITUDE FOR RUN R7T7

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DESCENT

.15/0 000030011032 750 NMI. FILE ' R7T7

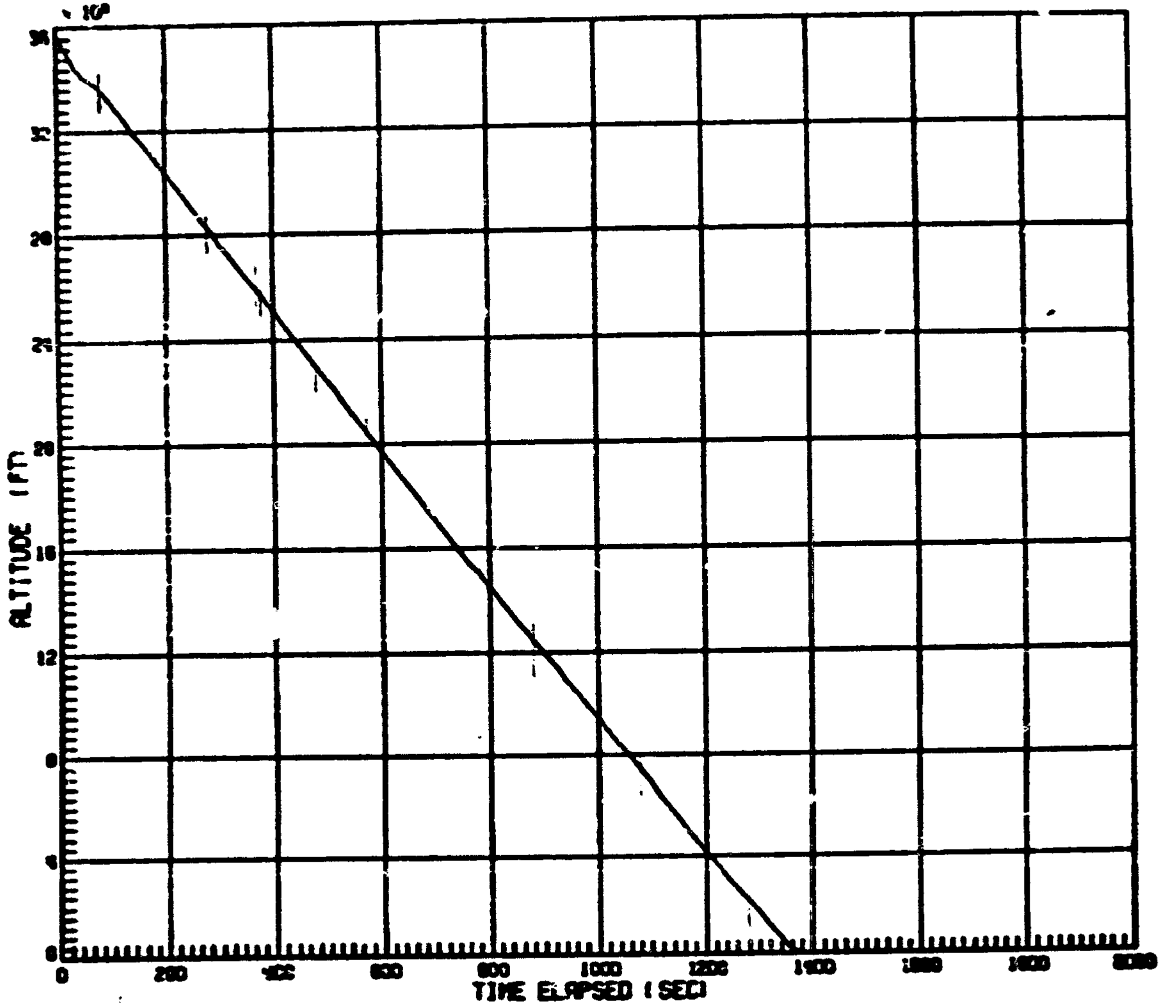

Figure 28.3 (DESCENT)

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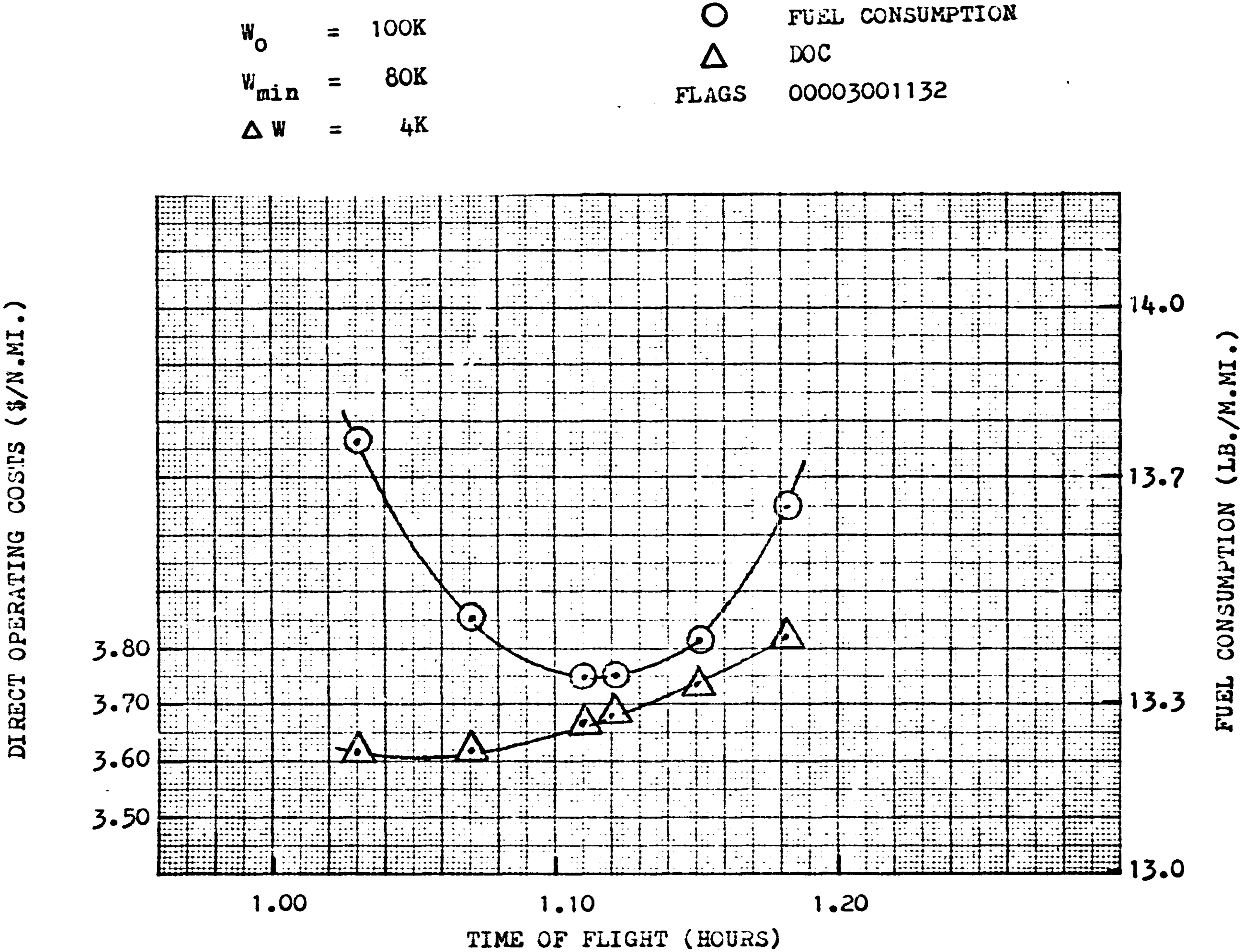

Figure 29a. - Fuel and DOC penalties due to constrained time of flight for 400 N.Mi.

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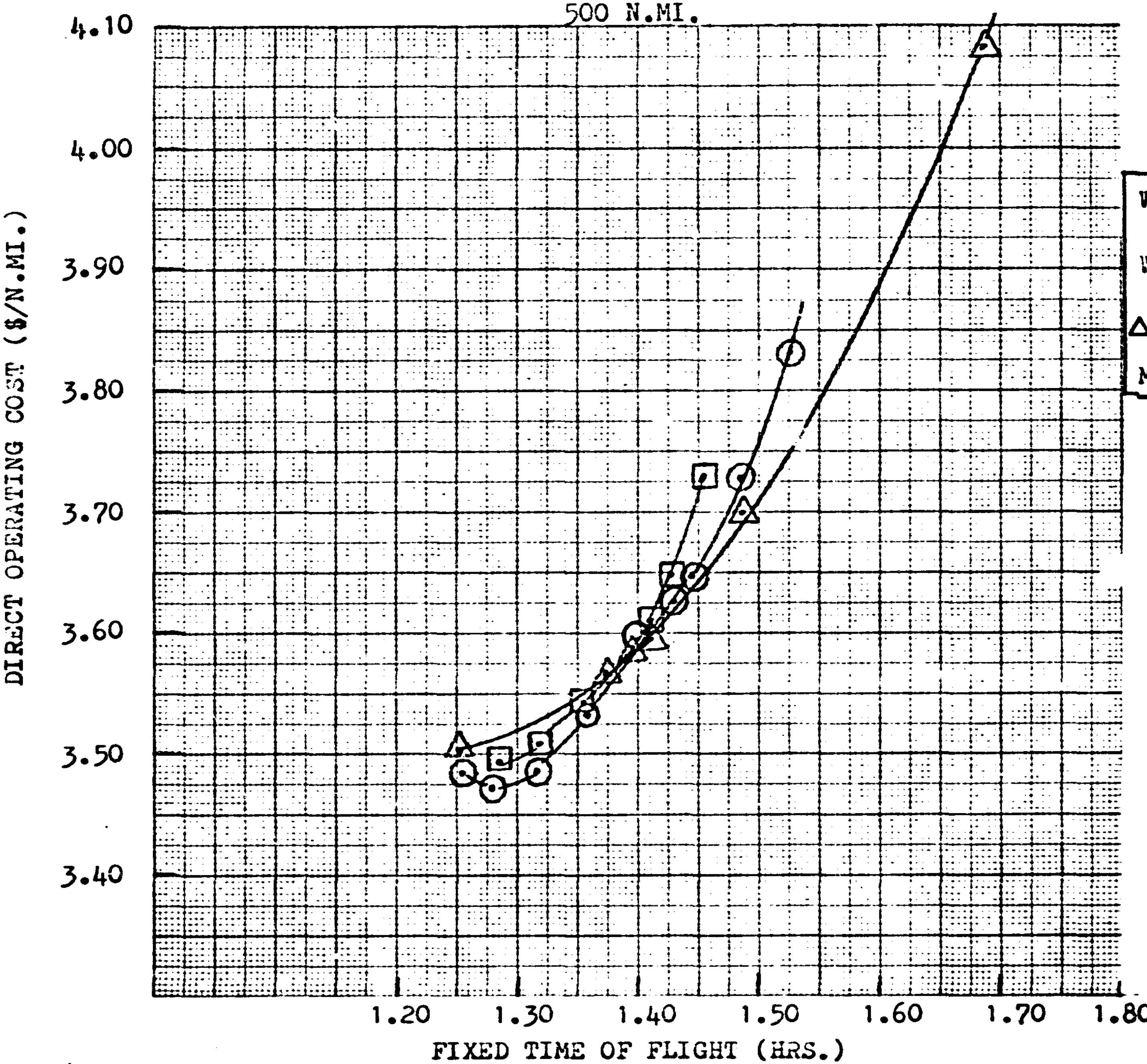

	△	○	○	□
W_o	10×10^4	10^5	10^5	10^5
W_{min}	8×10^4	7×10^4	7×10^4	80K
ΔW	2500	10^4	10^4	4K
MFGR	2	3	4	3
FLAGS	00102001132	00103001132	00104001132	00003001132

These gave the same graphs.

Figure 29b. - Time of arrival penalty at 500 N.Mi.

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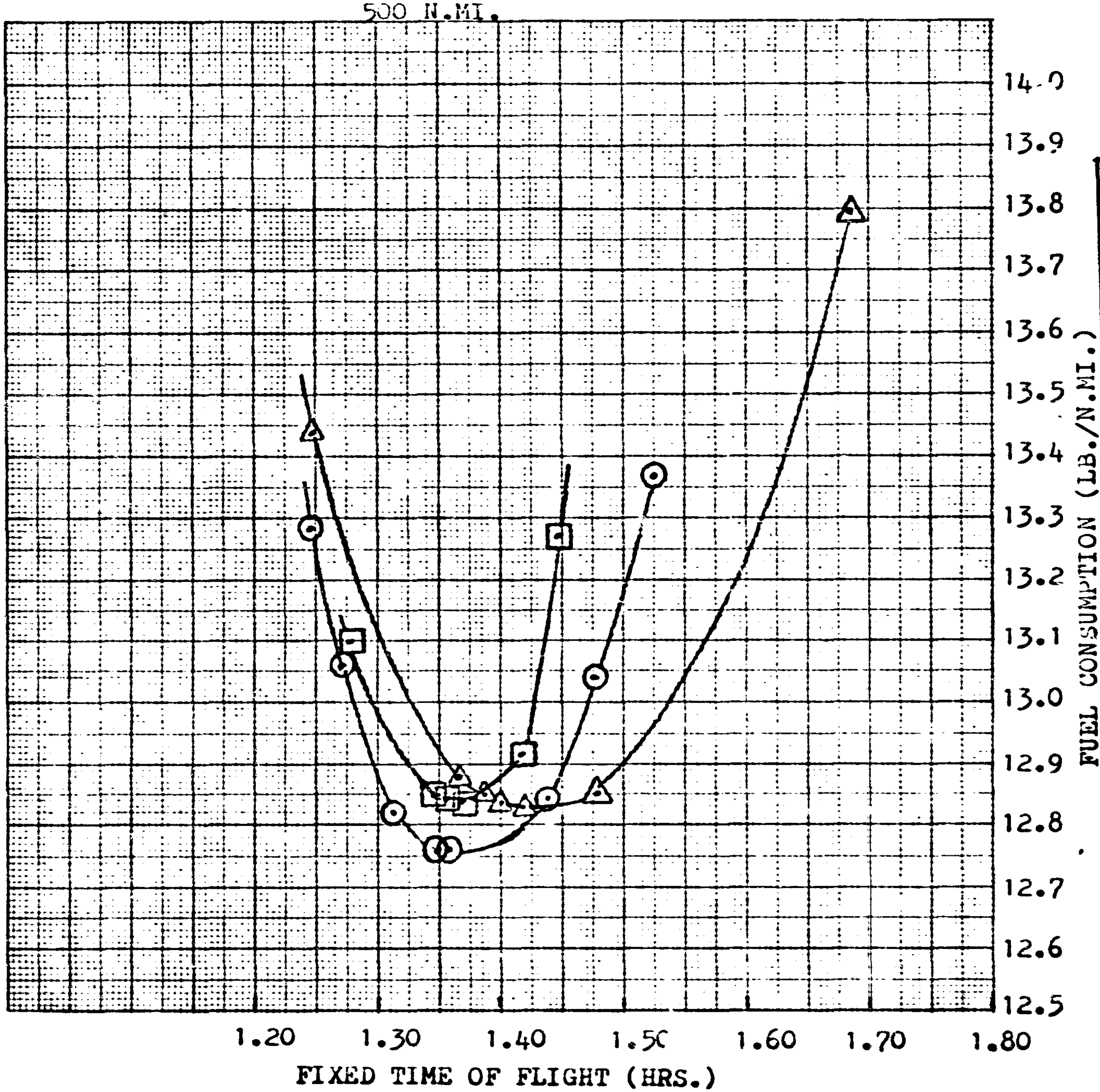

	△	○	○	□
W_o	$10x10^4$	10^5	10^5	10^5
W_{min}	$8x10^4$	$7x10^4$	$7x10^4$	80K
ΔW	2500	10^4	10^4	4K
MFGR	2	3	4	3
		These gave the same graphs.		
FLAGS	001020011132	001030011132	001040011132	000030011132

Figure 29c. - Time of arrival penalty at 500 N.Mi.

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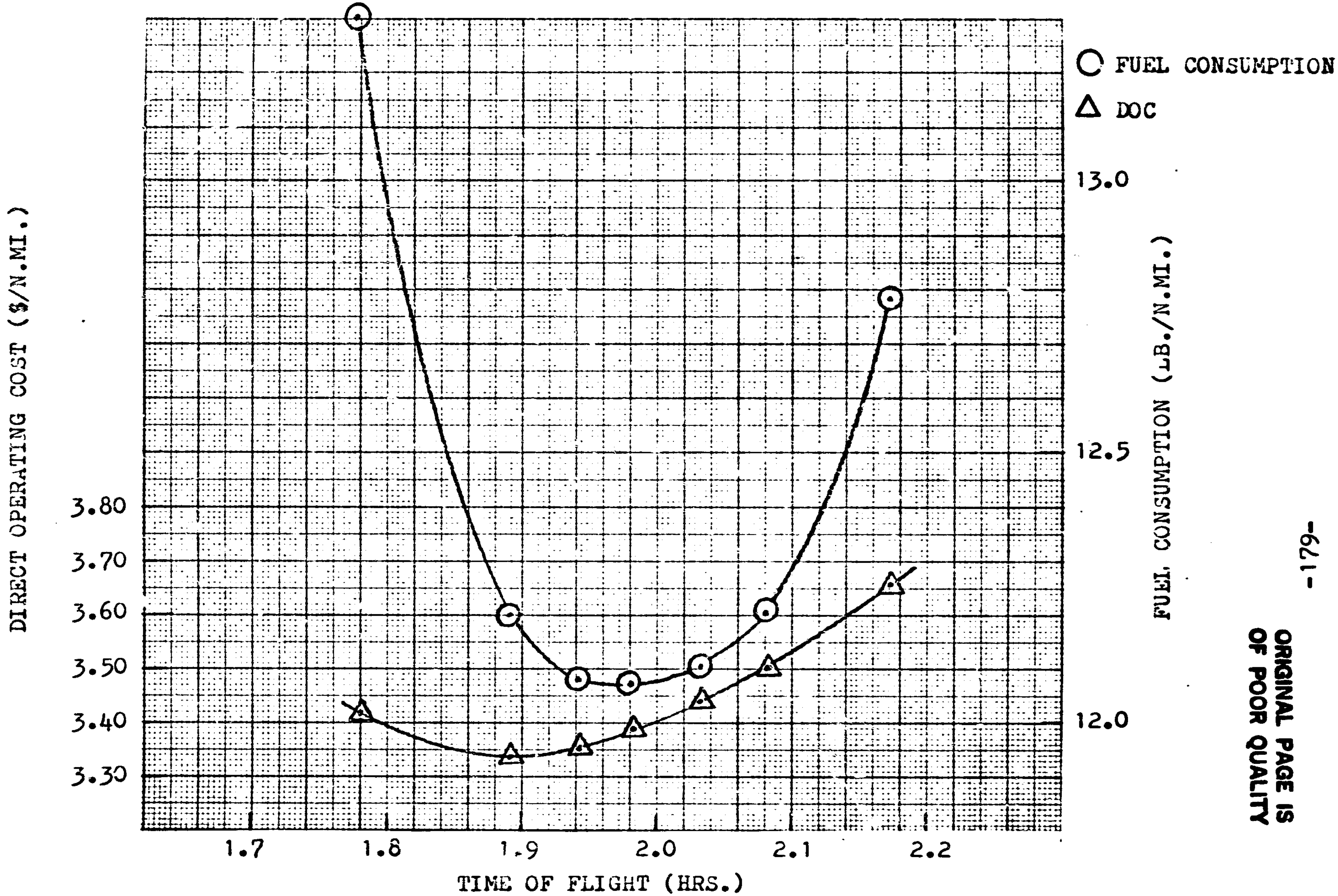

Figure 29d. - Fuel and DOC penalties due to constrained time of flight for 750 N.Mi.

FLAGS - 000030011132

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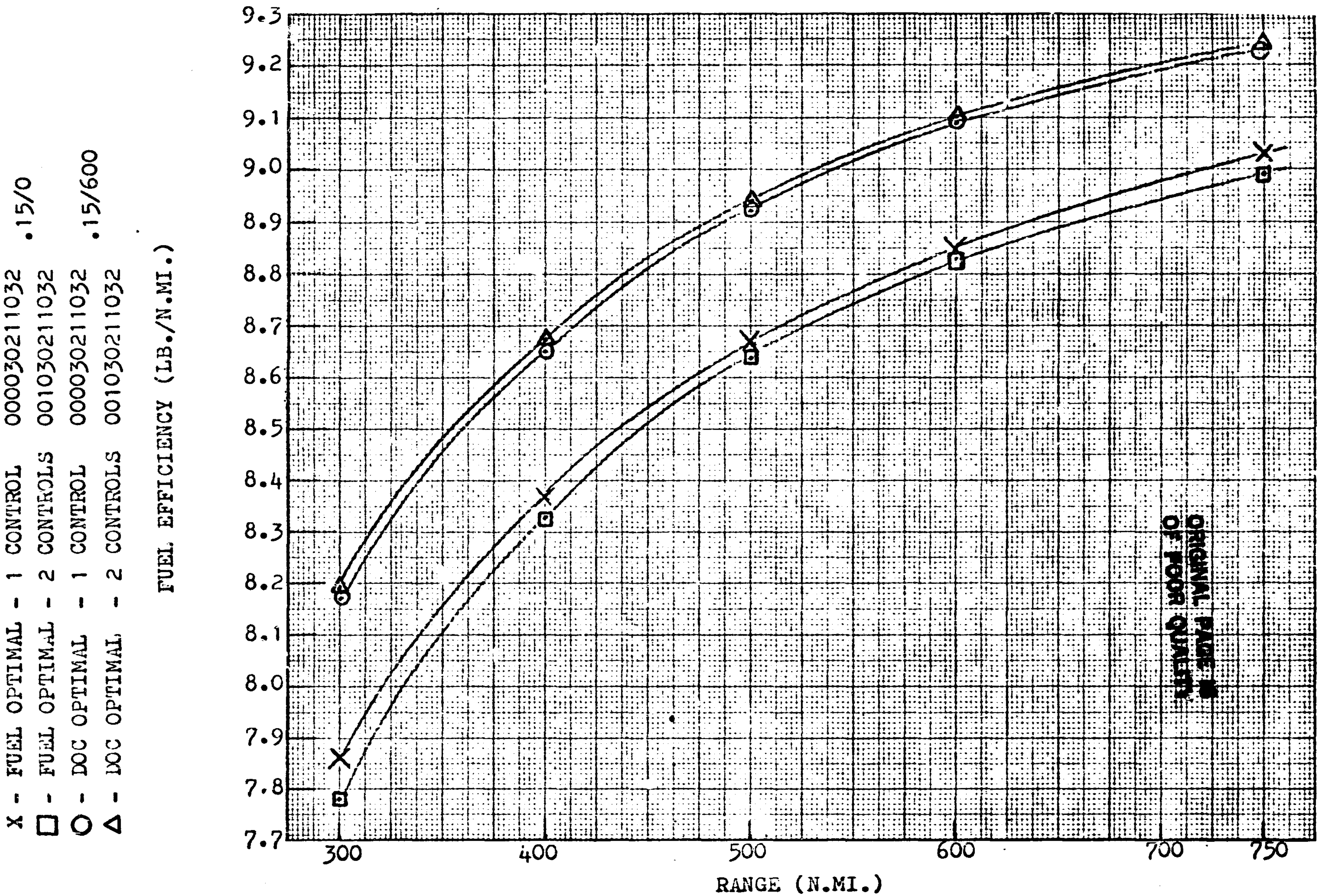


Figure 30a. - Fuel efficiency for two part (Cruise-Descent) profiles as function range.

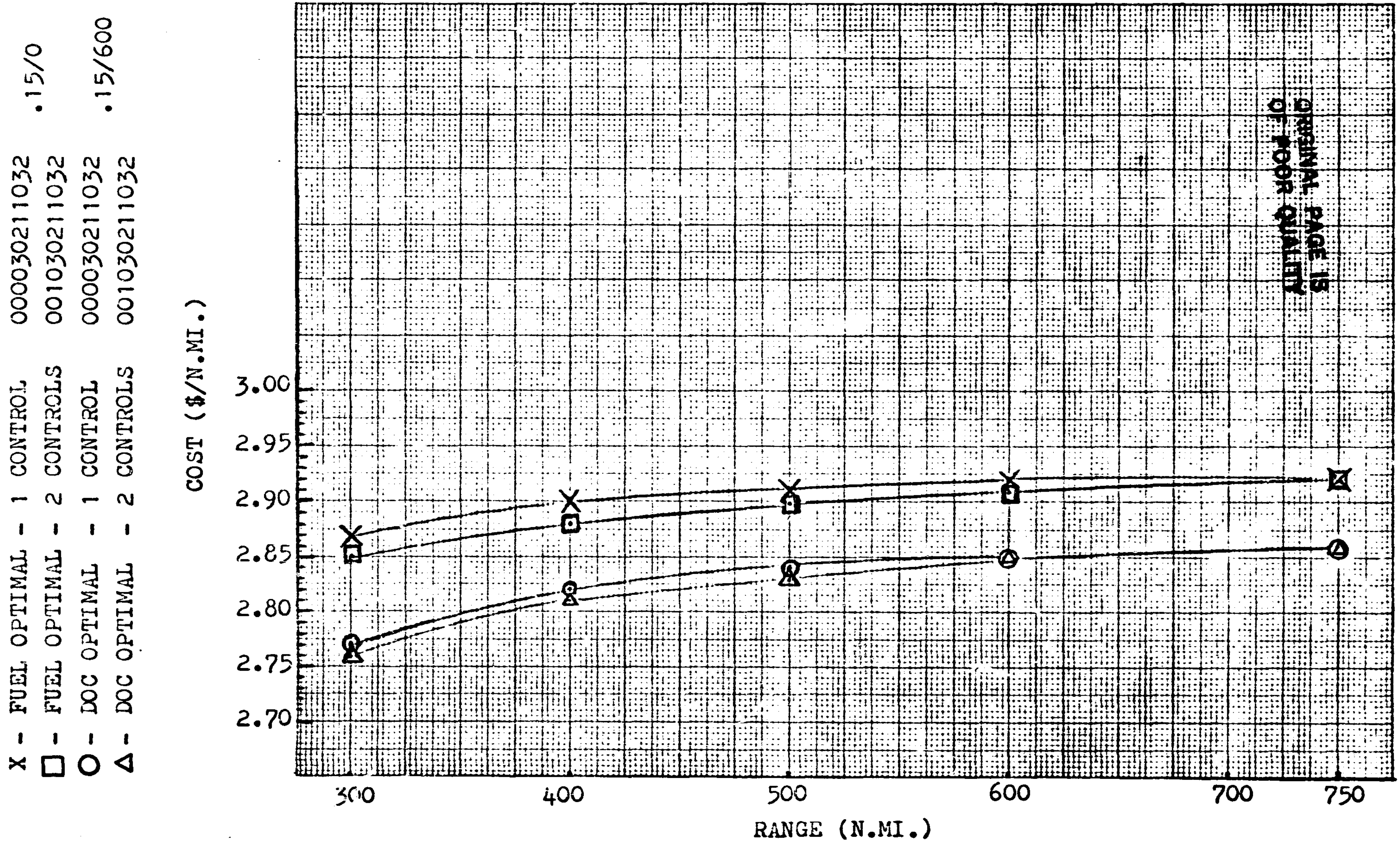
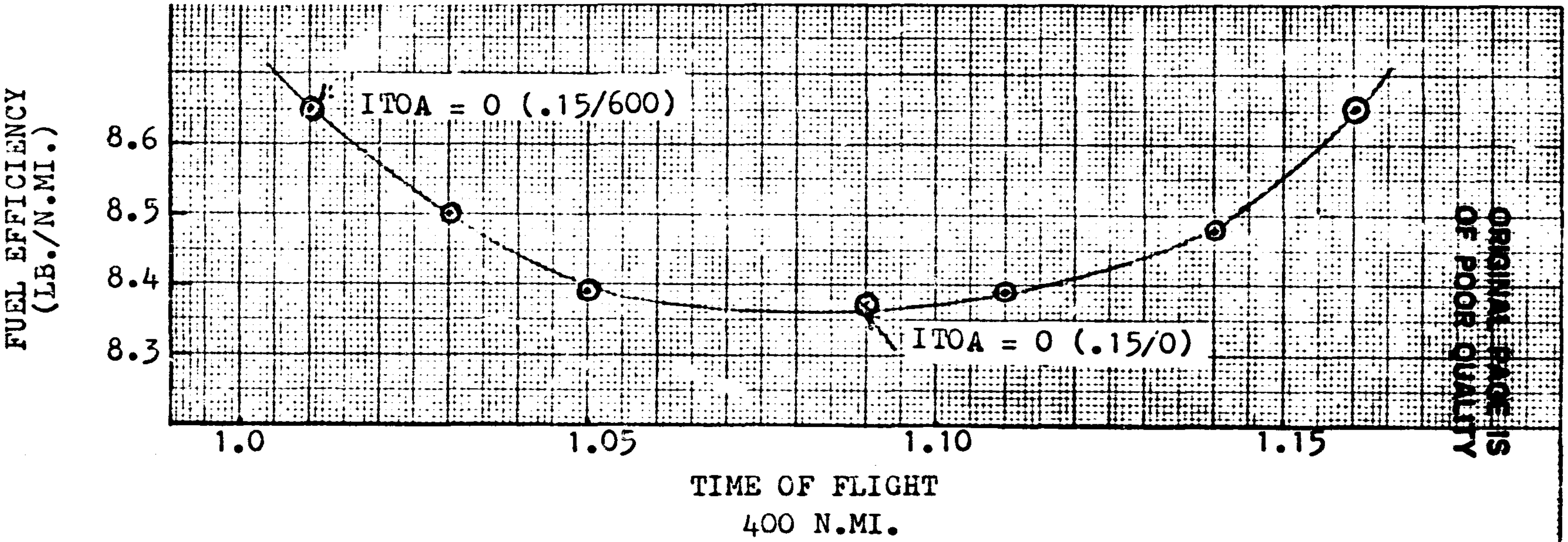


Figure 30b. - Cost/N.Mi. for two part (Cruise-Descent) profiles as function of range.

ONE CONTROL



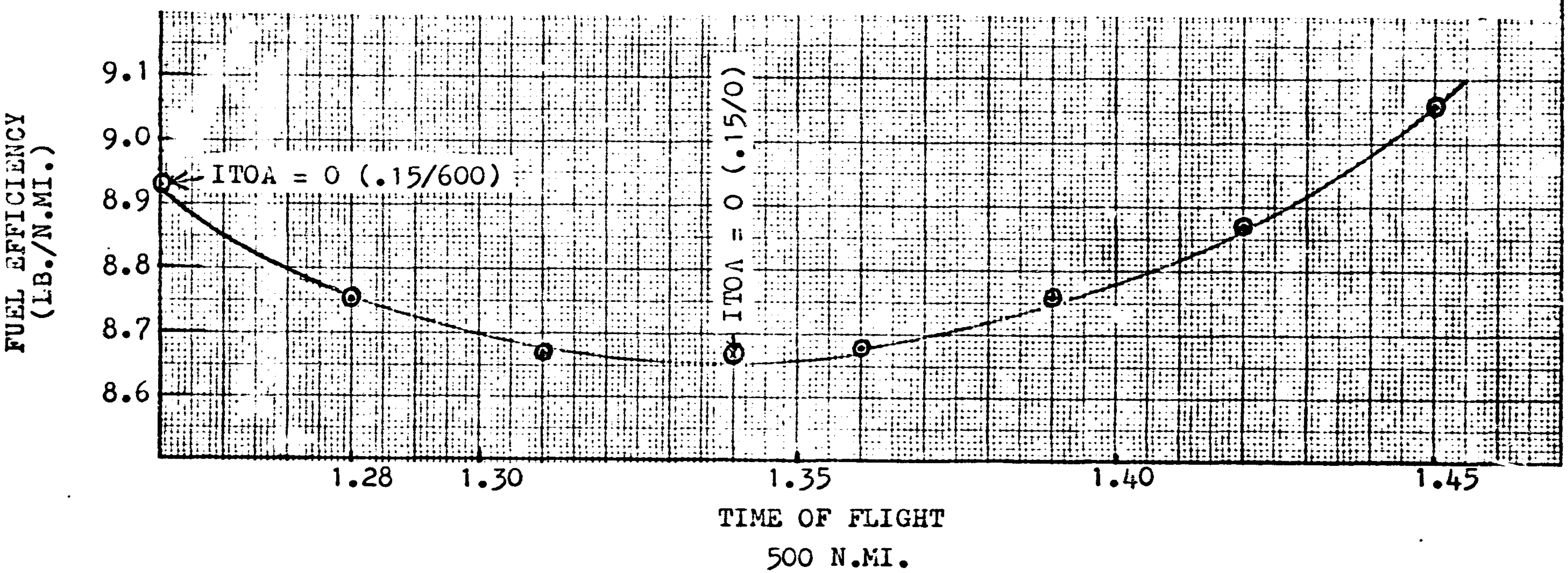


Figure 31a. - Fuel efficiency as function of TEND for 400 & 500 N.Mi. Cruise-Descent optimal fixed TOF paths.

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ONE CONTROL

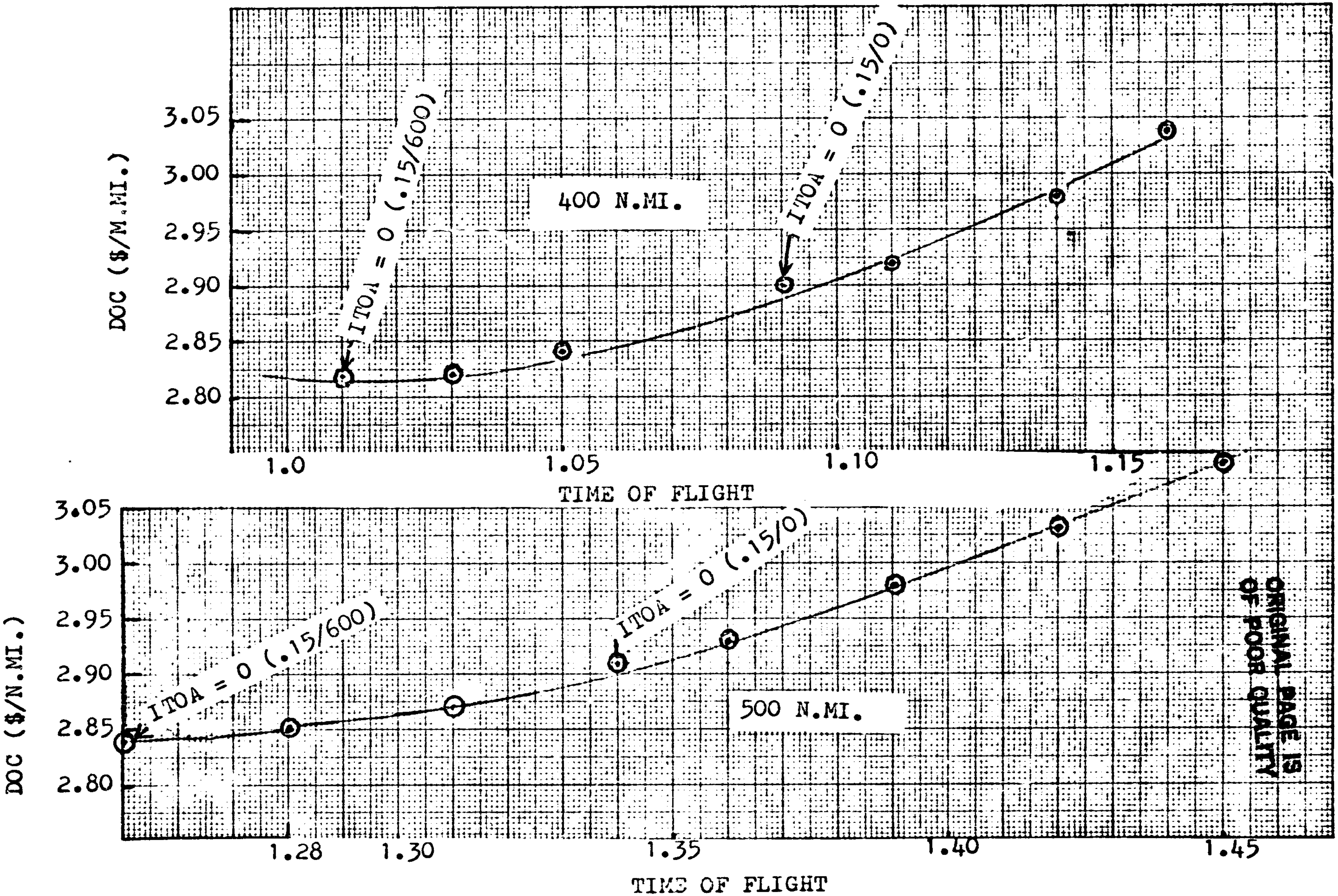

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Figure 31b. - Direct operating costs as functions of TEND for 400 & 500 N.Mi.
Cruise-Descent optimal fixed TOF paths.

ONE CONTROL

750 N.MI.

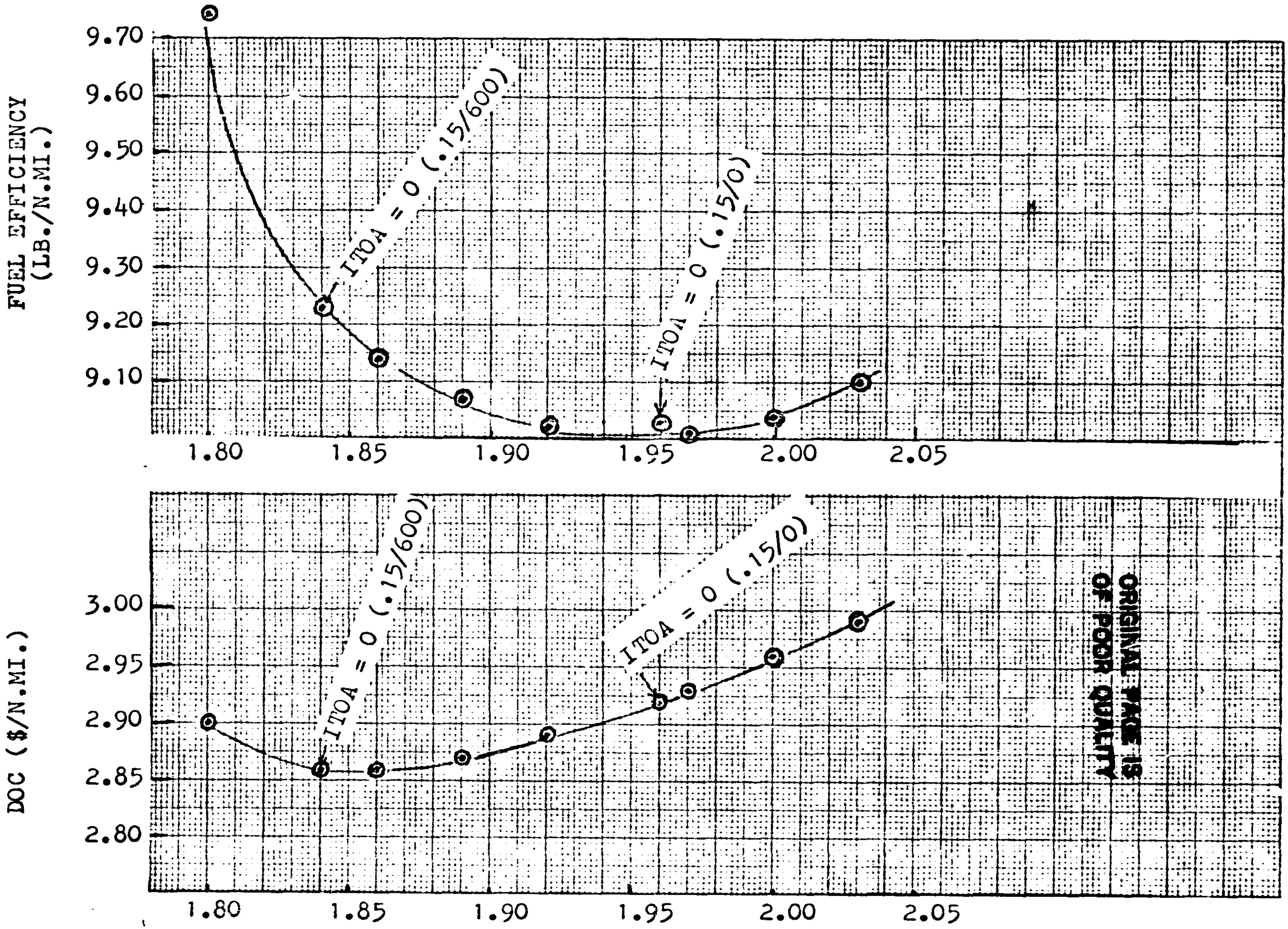

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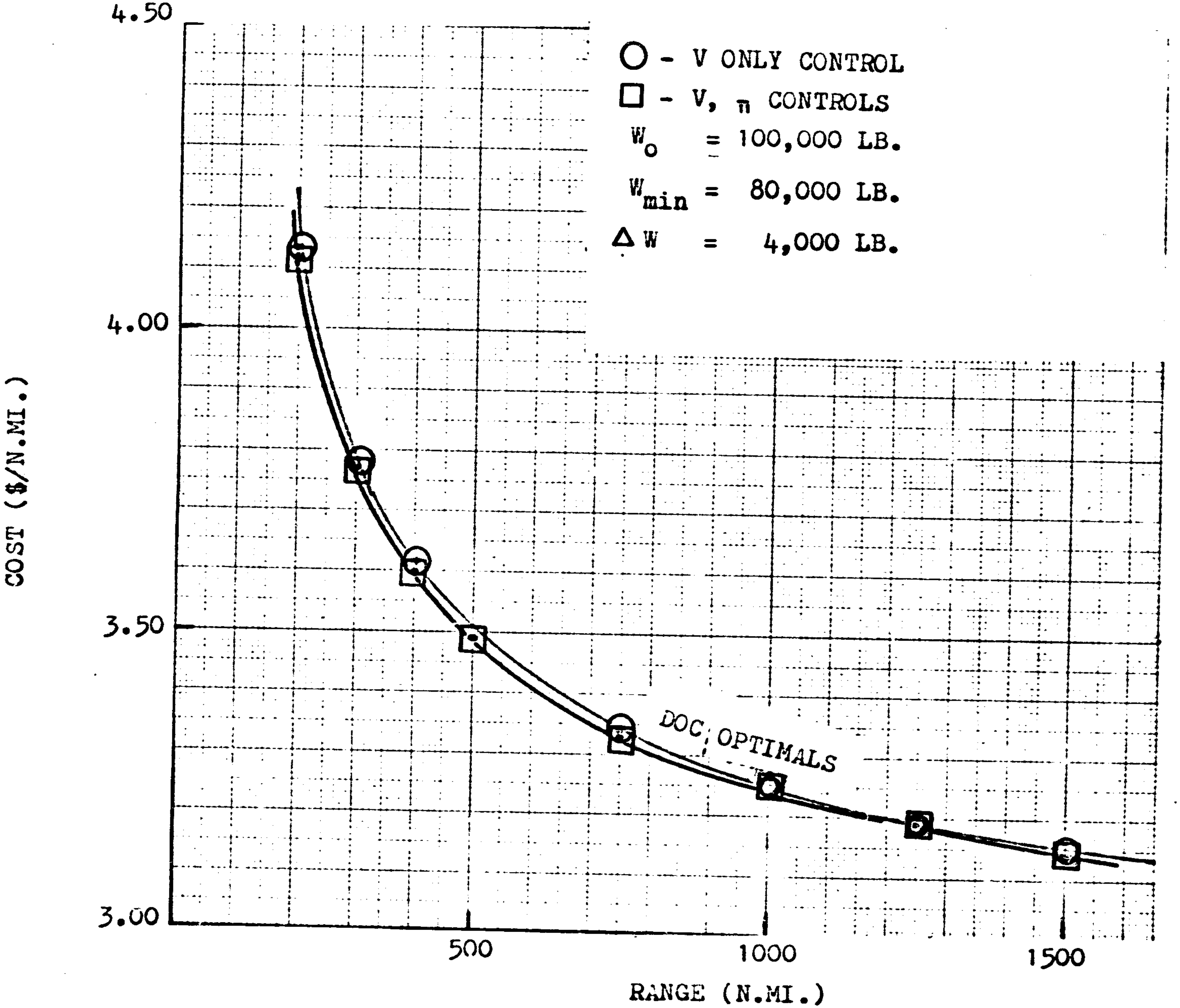
Figure 31c. - Fuel efficiency and direct operating costs as functions of TEND for 750 N.Mi., Cruise-Descent optimal fixed TOF paths.



FLAGS
001030011032
000030011032

.15/600

Figure 32.1 - Cost as function of range for DOC optimal trajectories, comparing one vs. two controls.

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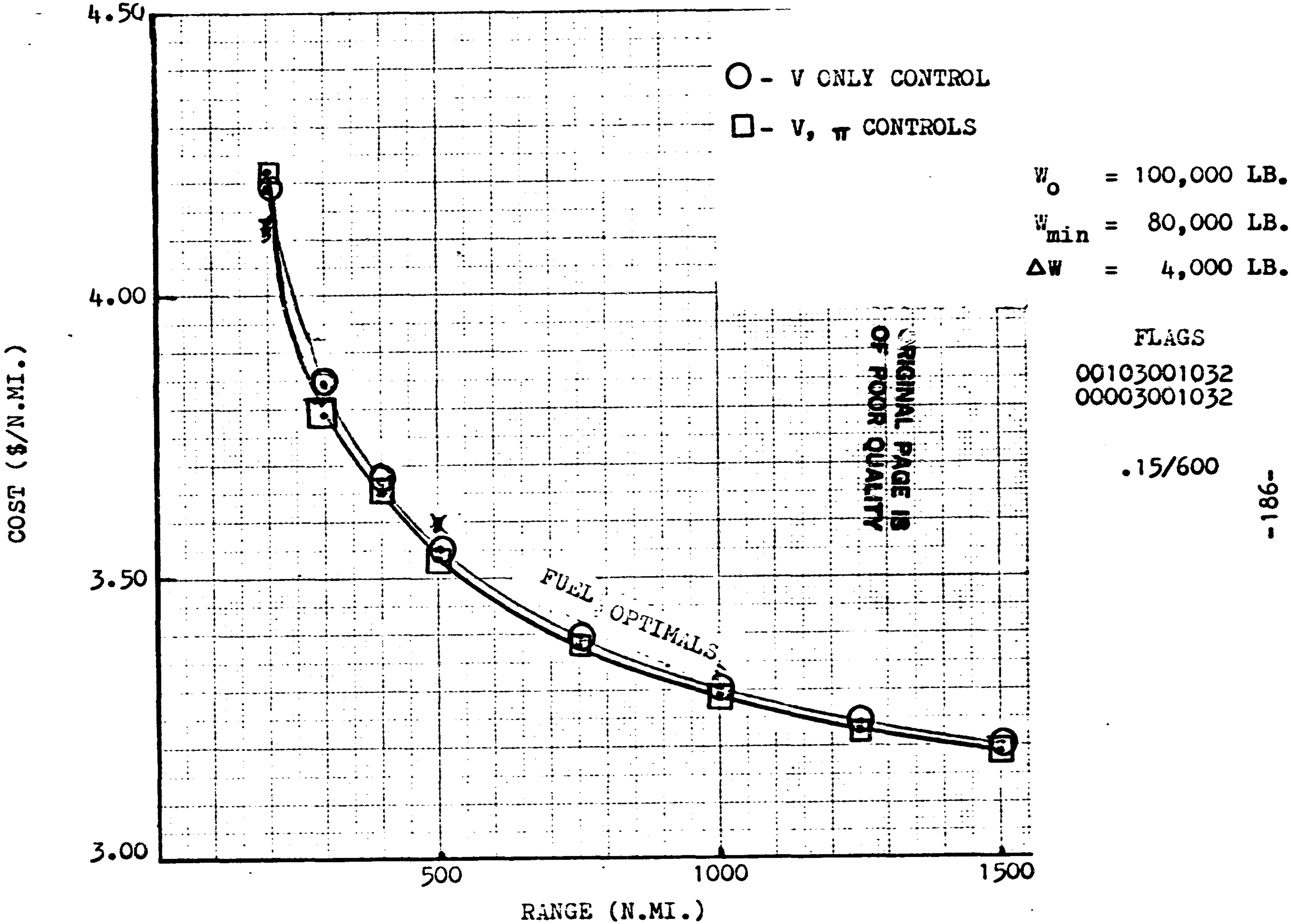

Figure 32.2 - Comparison of costs for one control (V) compared to two controls for fuel optimals, as function of range.

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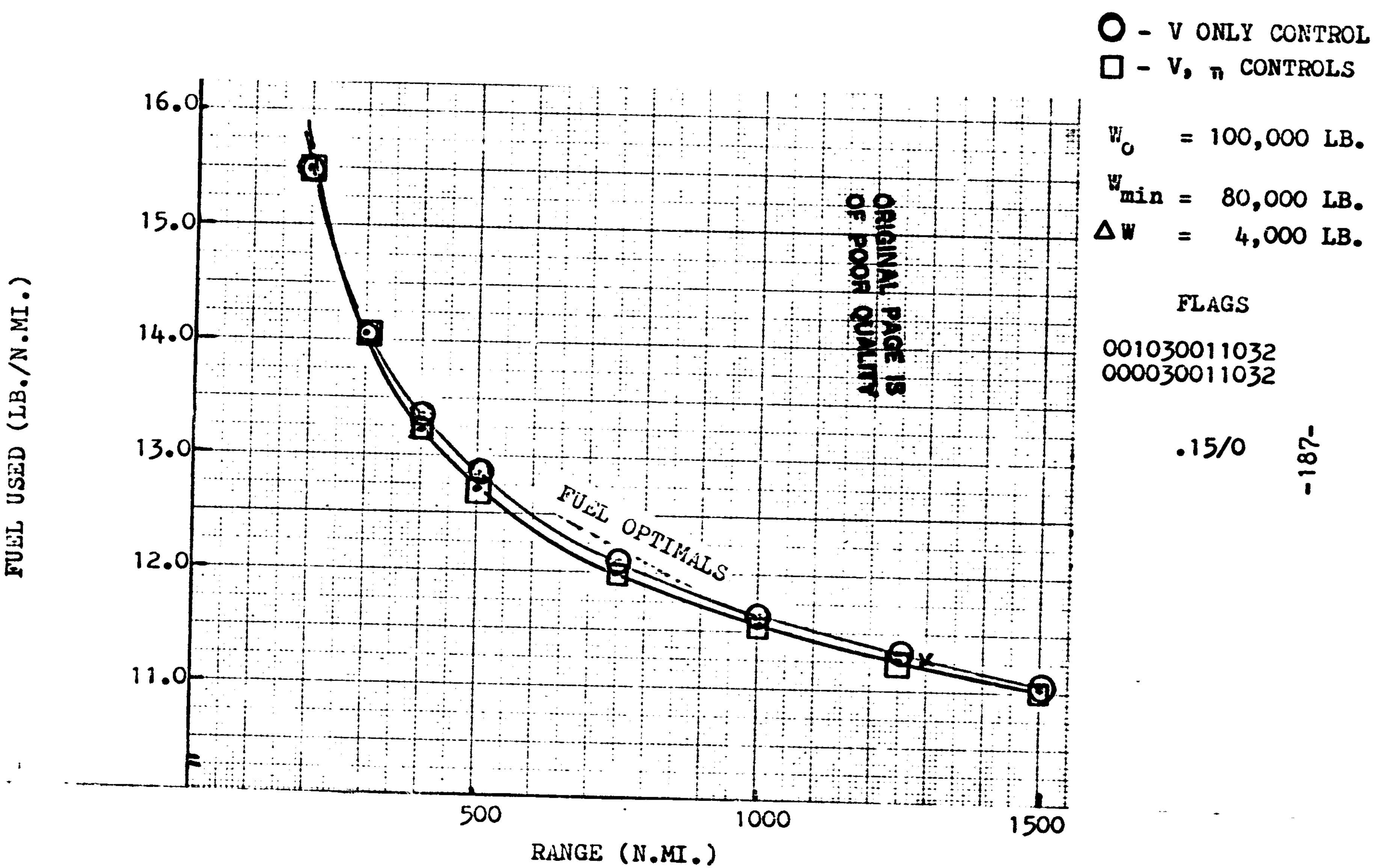

Figure 33.1 - Fuel consumption as function of range for fuel optimal trajectories. Comparison of one vs. two controls.

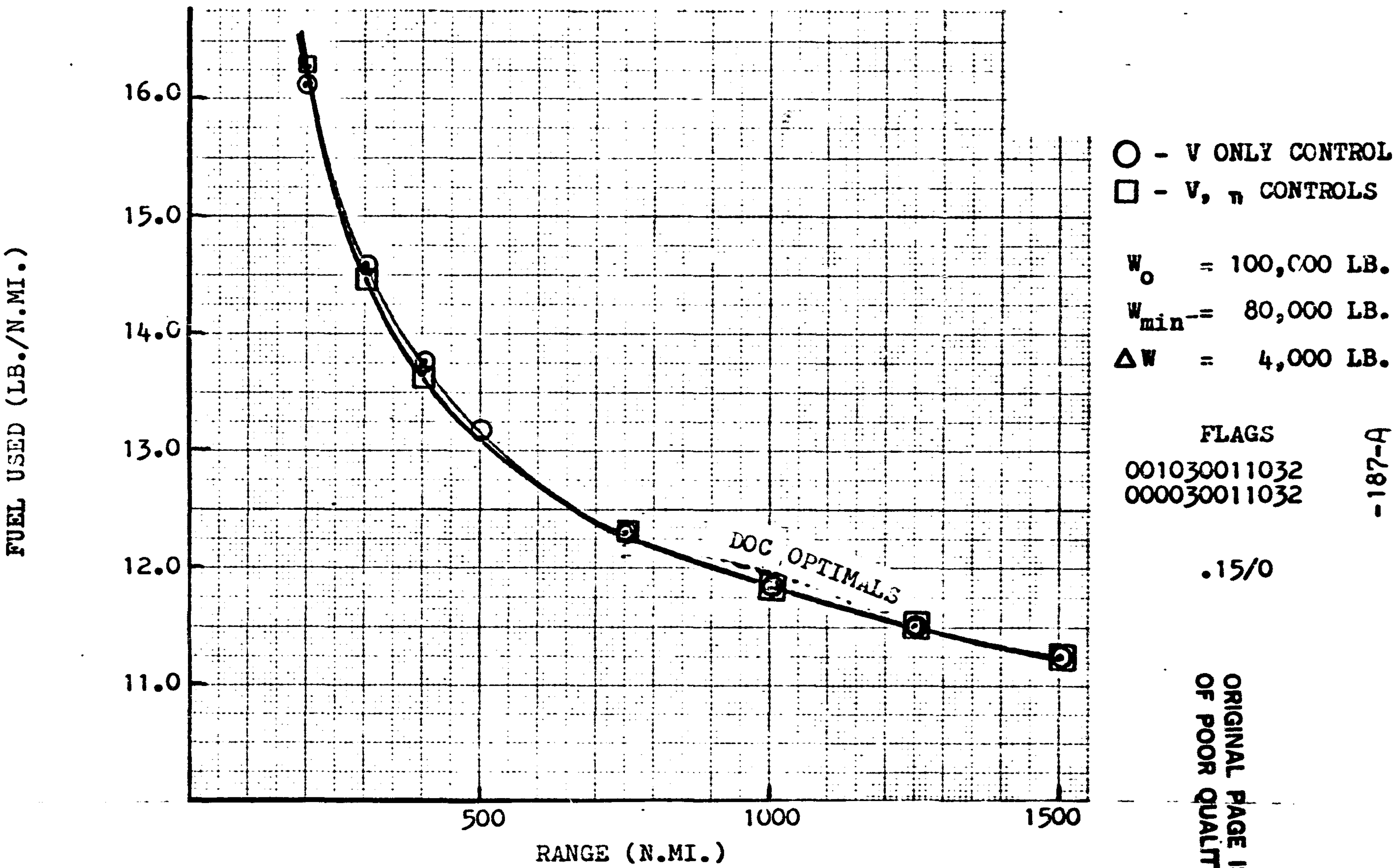

Figure 33.2 - Fuel consumption as function of range for DOC optimal trajectories. Comparison of one vs. two controls.

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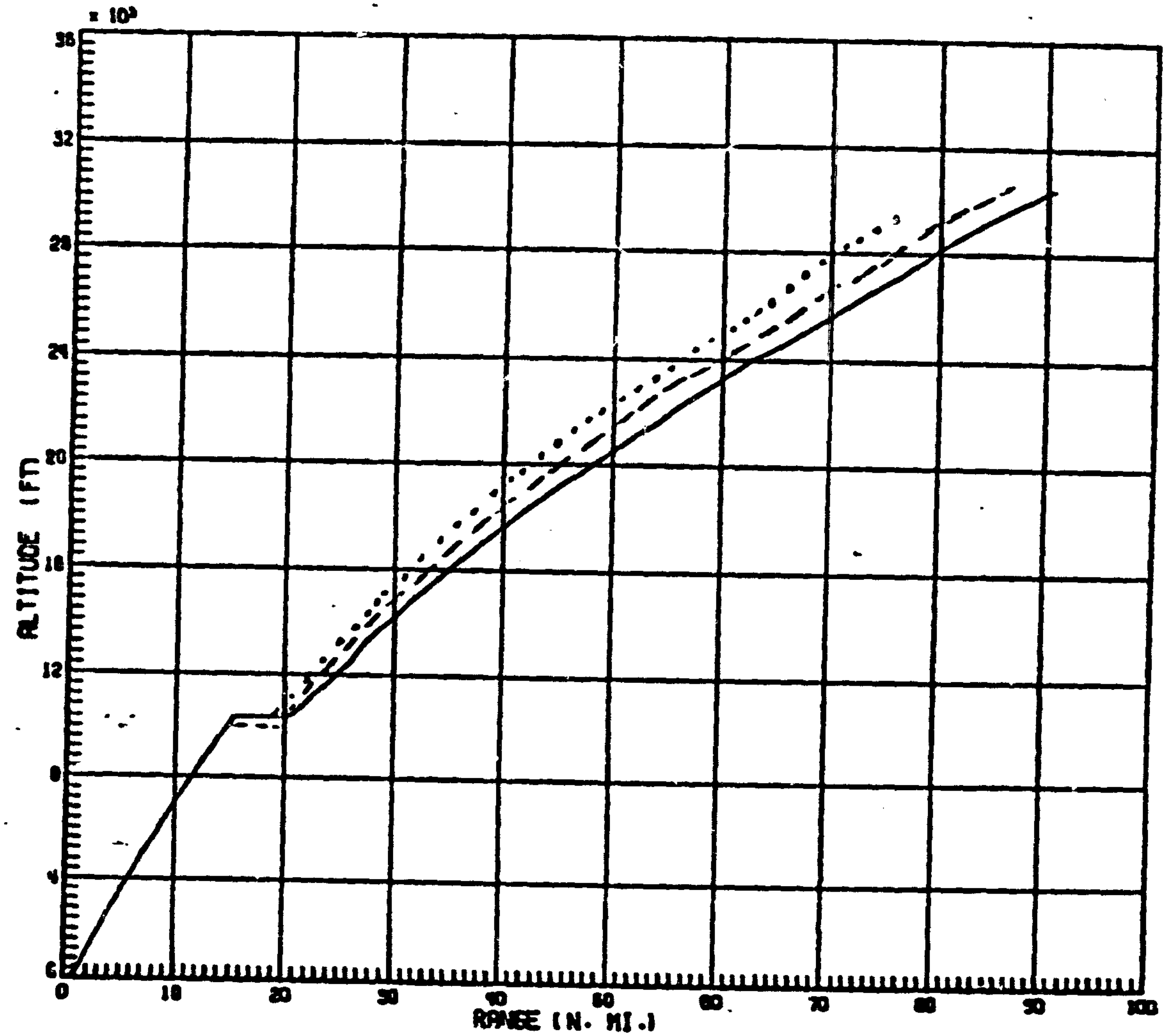

KEY FOR FIGURES 34

FILE NAME EVPDC05 .... .15/200

EVPFC15 ---- .15/600

EVPDC10 —— .15/100C

RANGE = 300 N.MI.

FLAGS - - 000030011032

CRUISE 100K
TABLE 80K
INFO. 4K

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Figure 34.1 - Vertical profiles as functionals of time cost.

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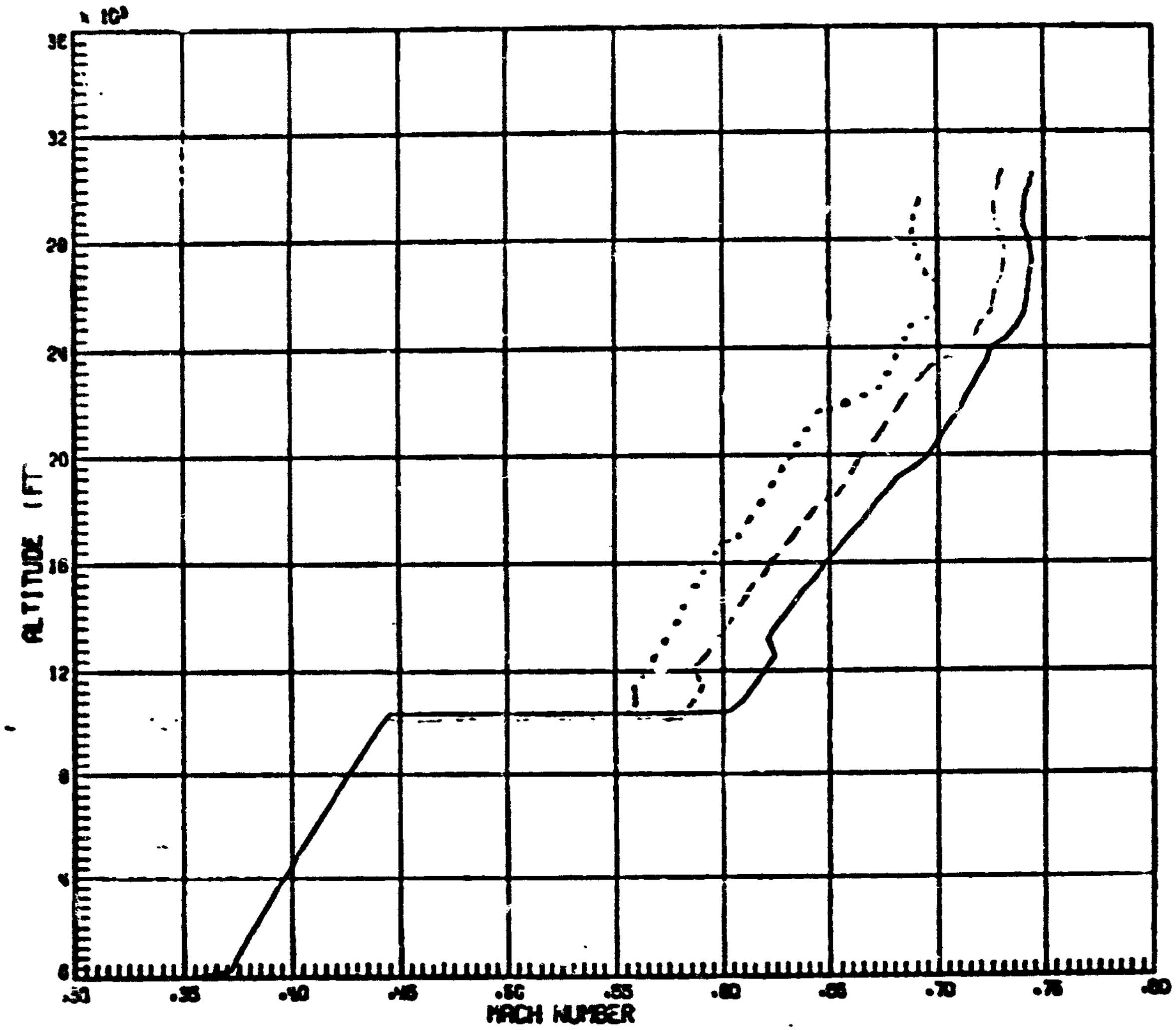

Figure 34.2

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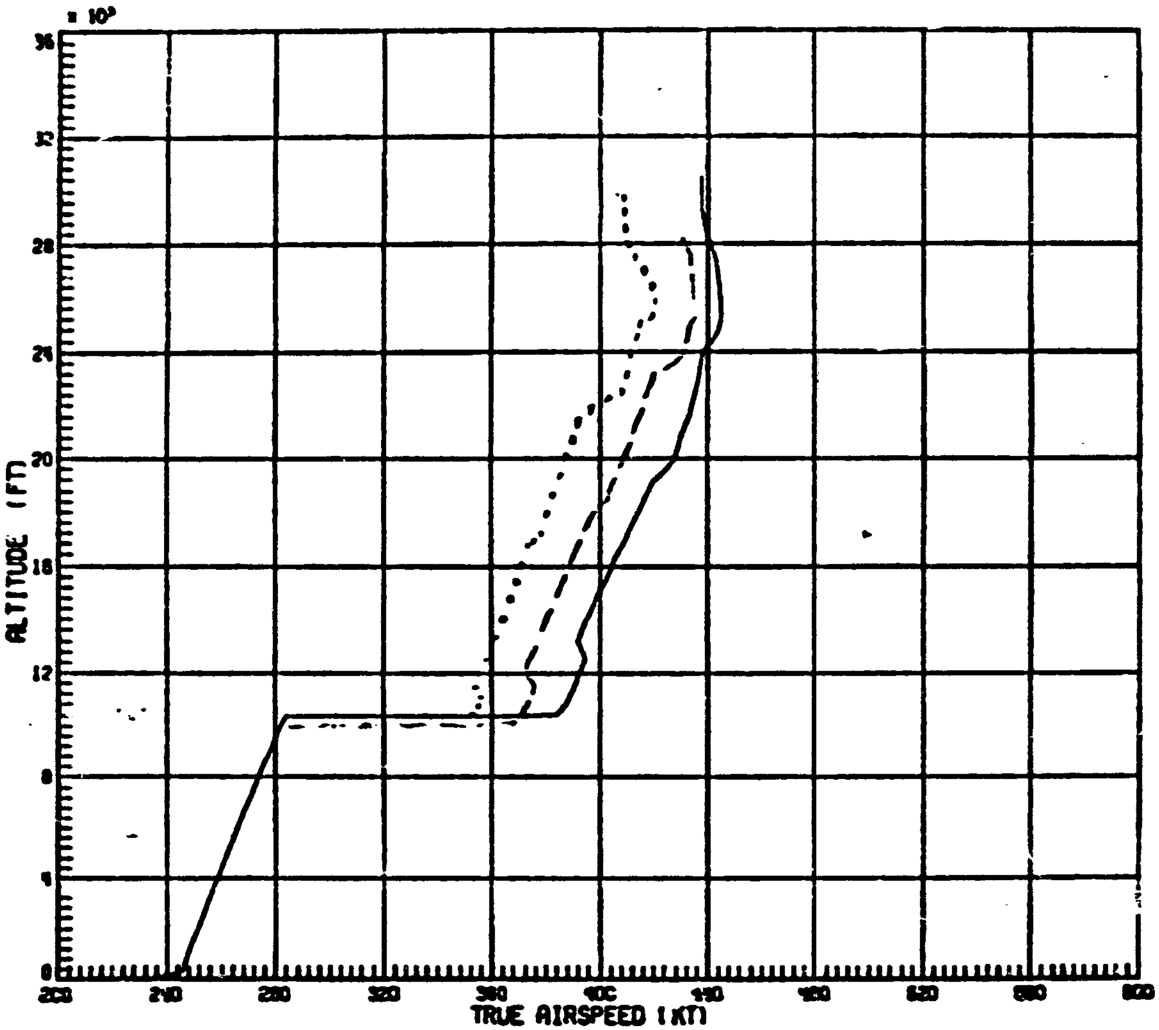

Figure 34.3

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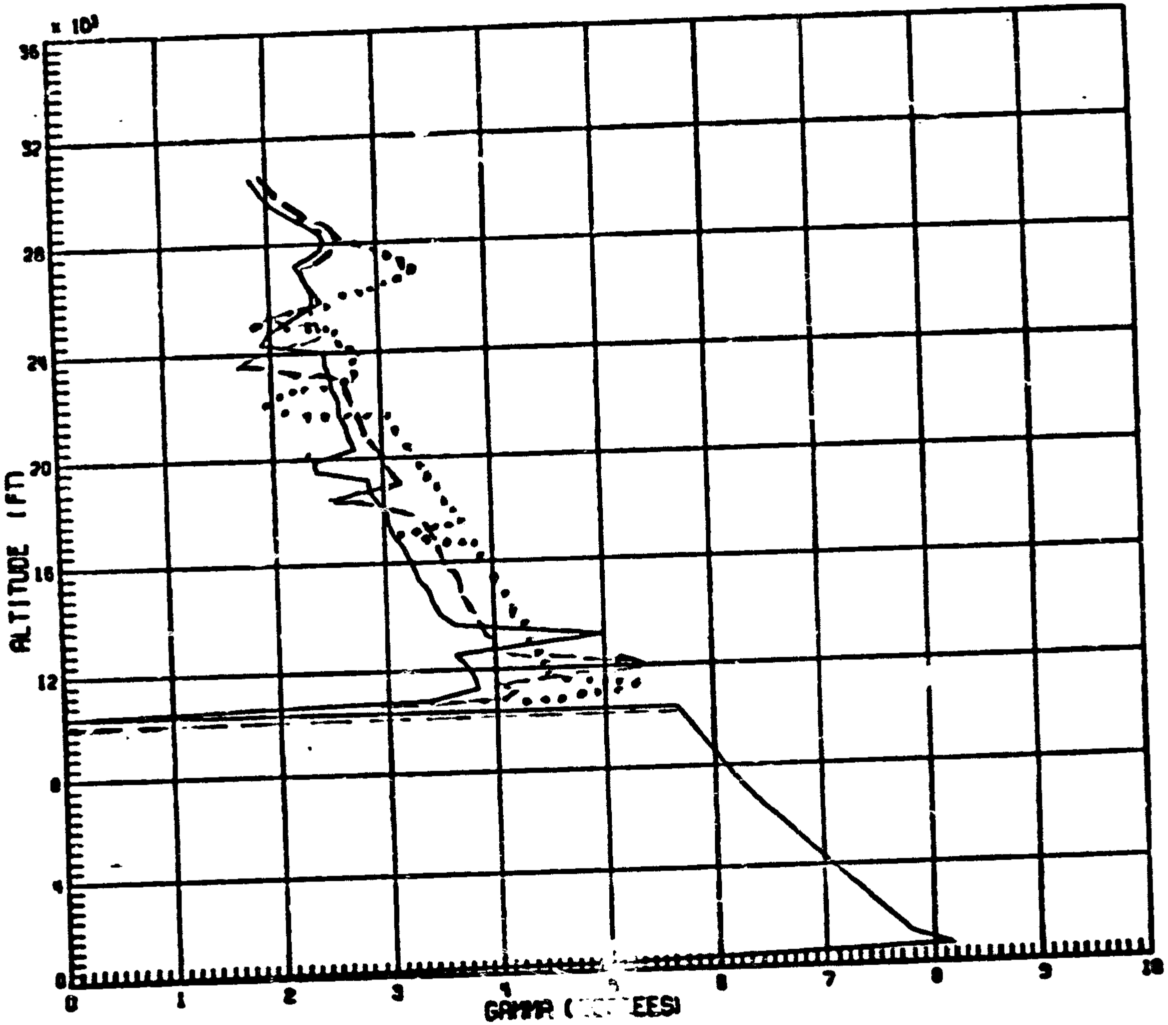

Figure 34.4

C-3

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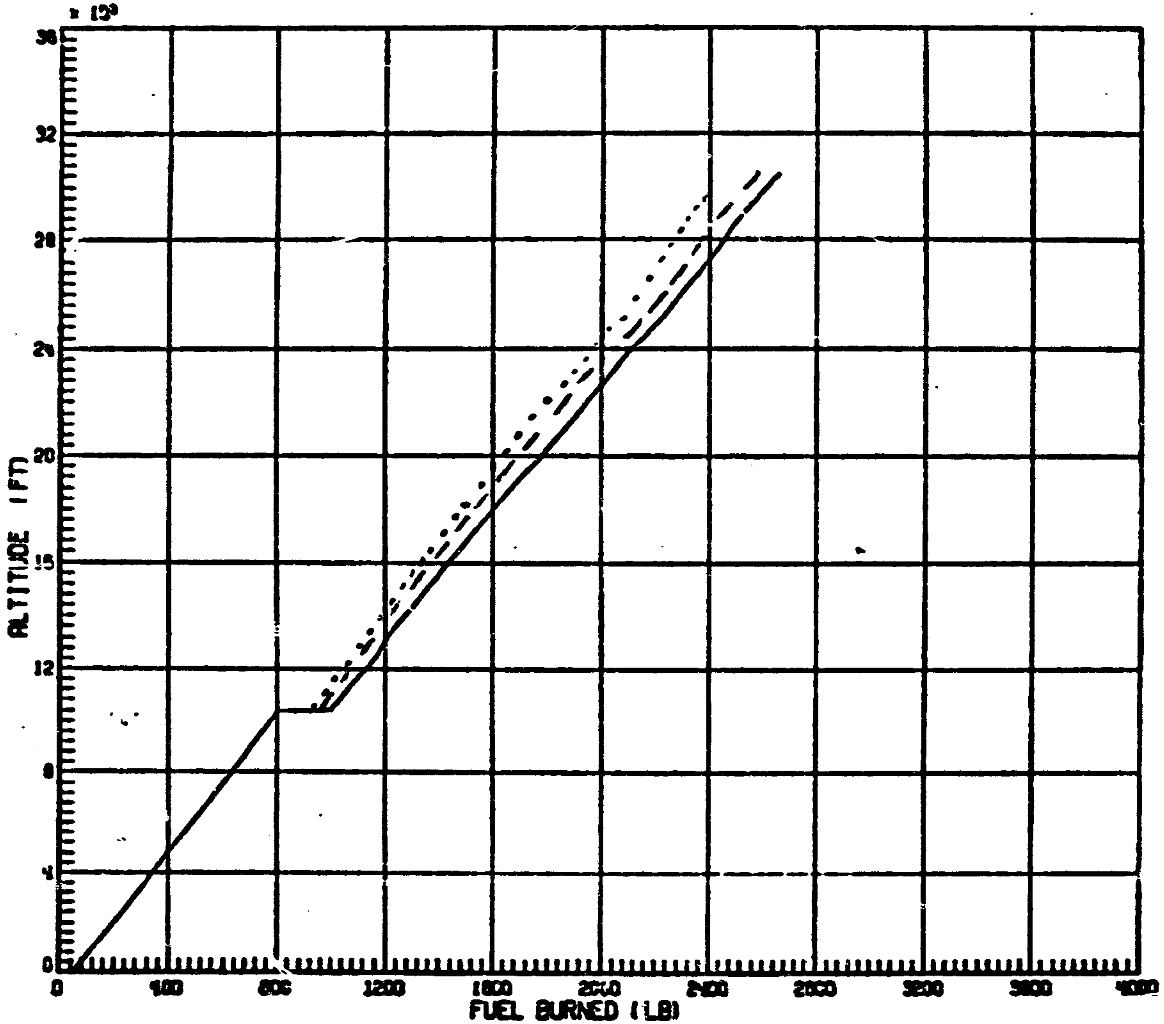

Figure 34.5

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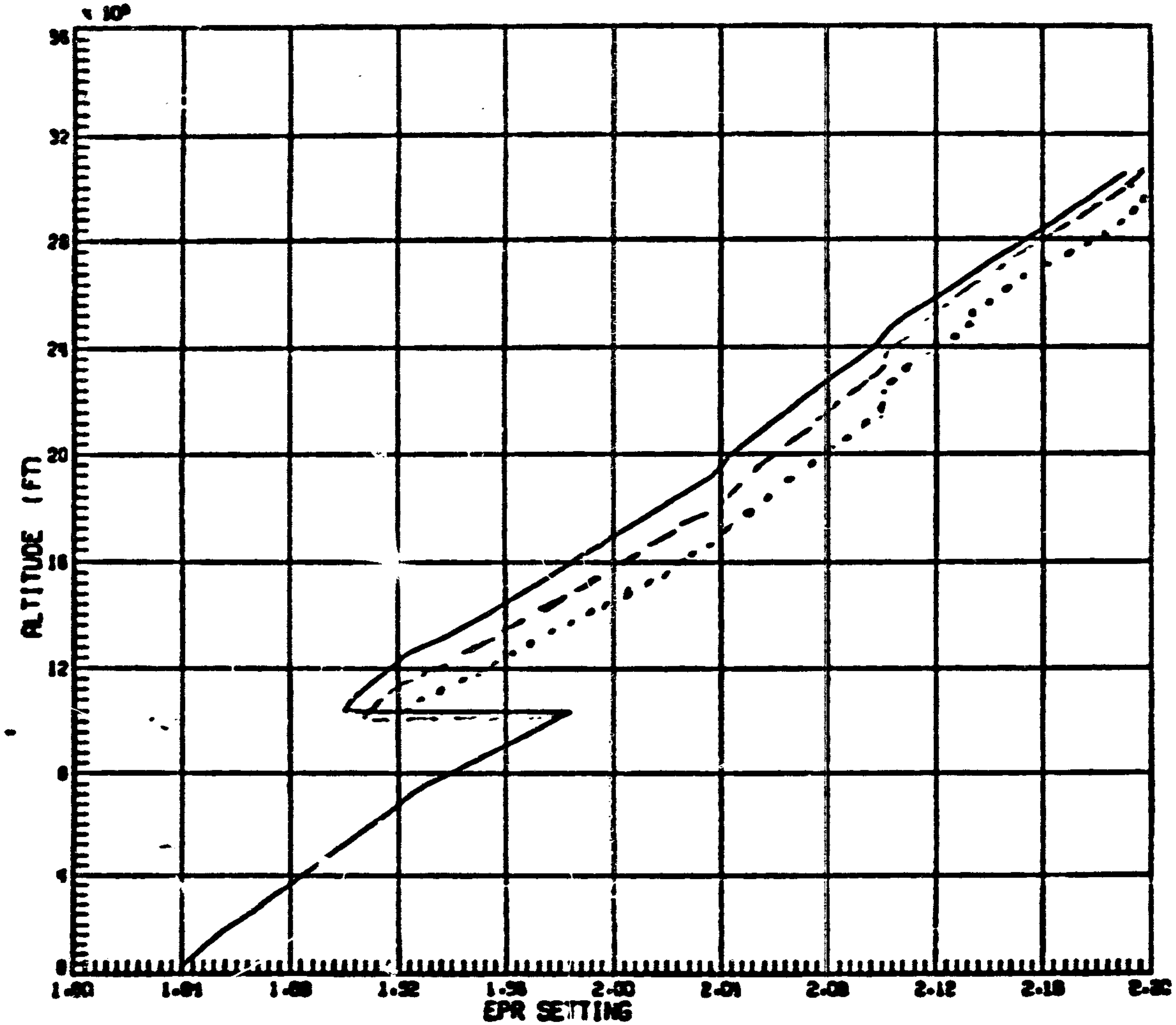

Figure 34.6

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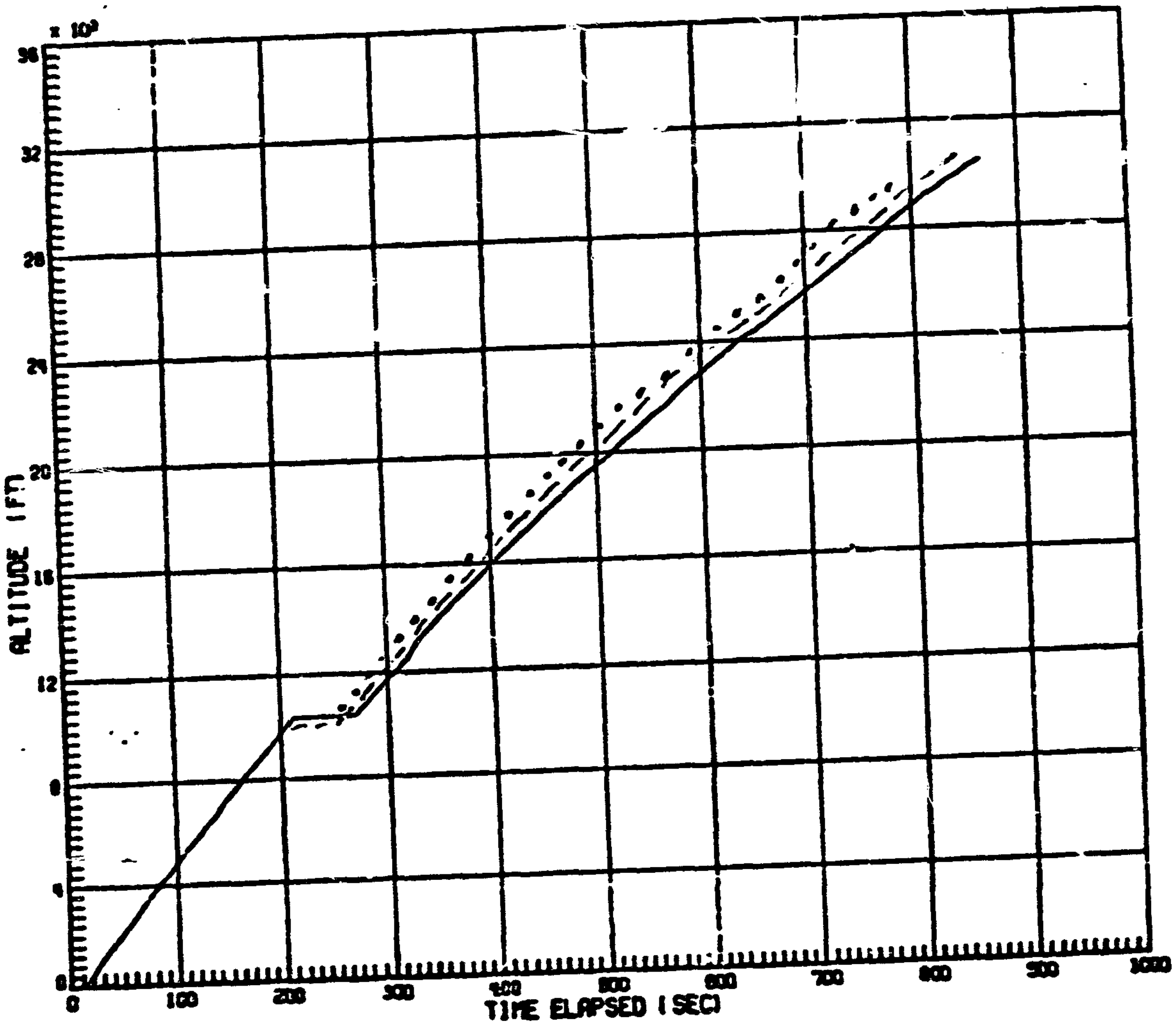

Figure 34.7

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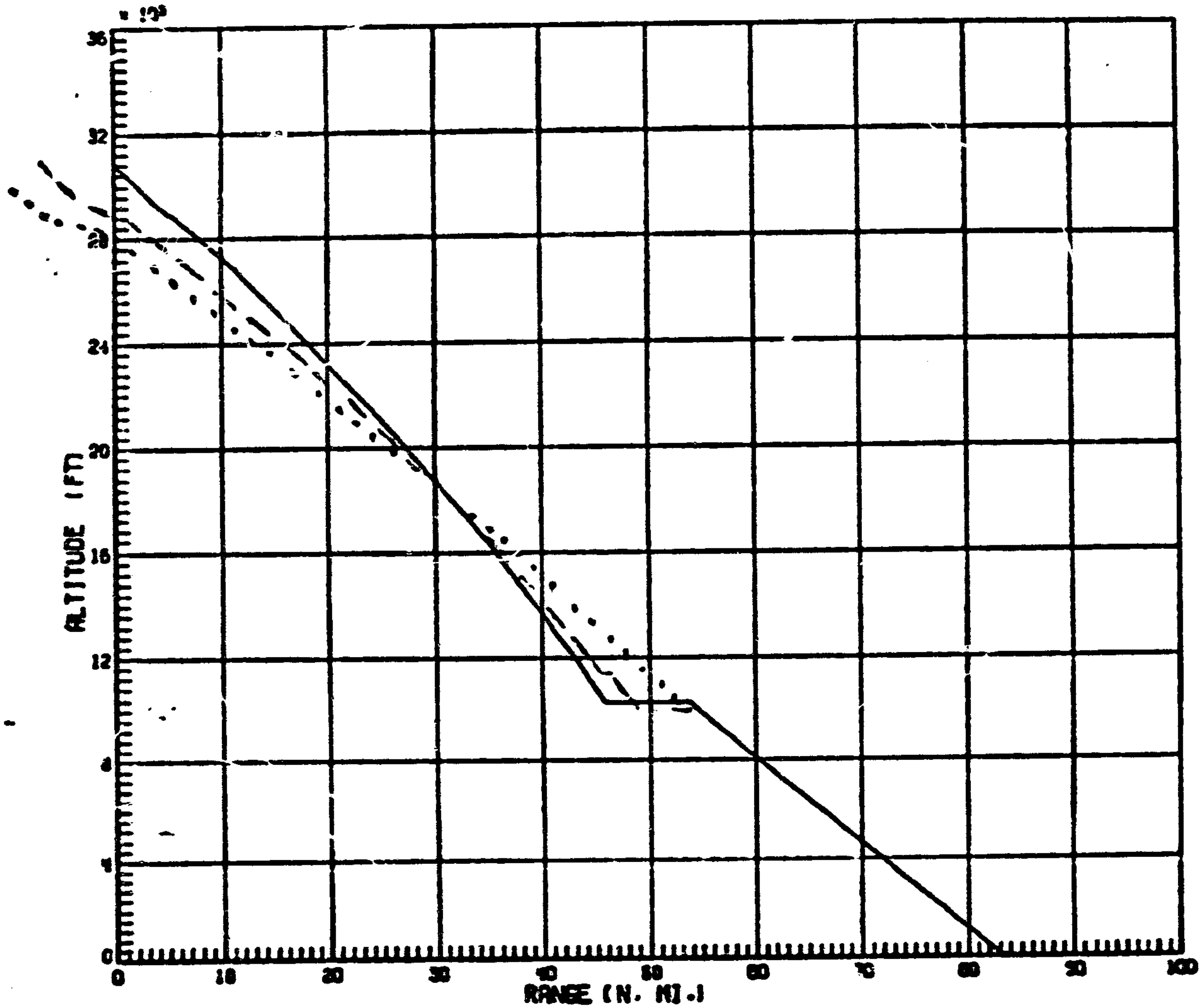

Figure 34.8

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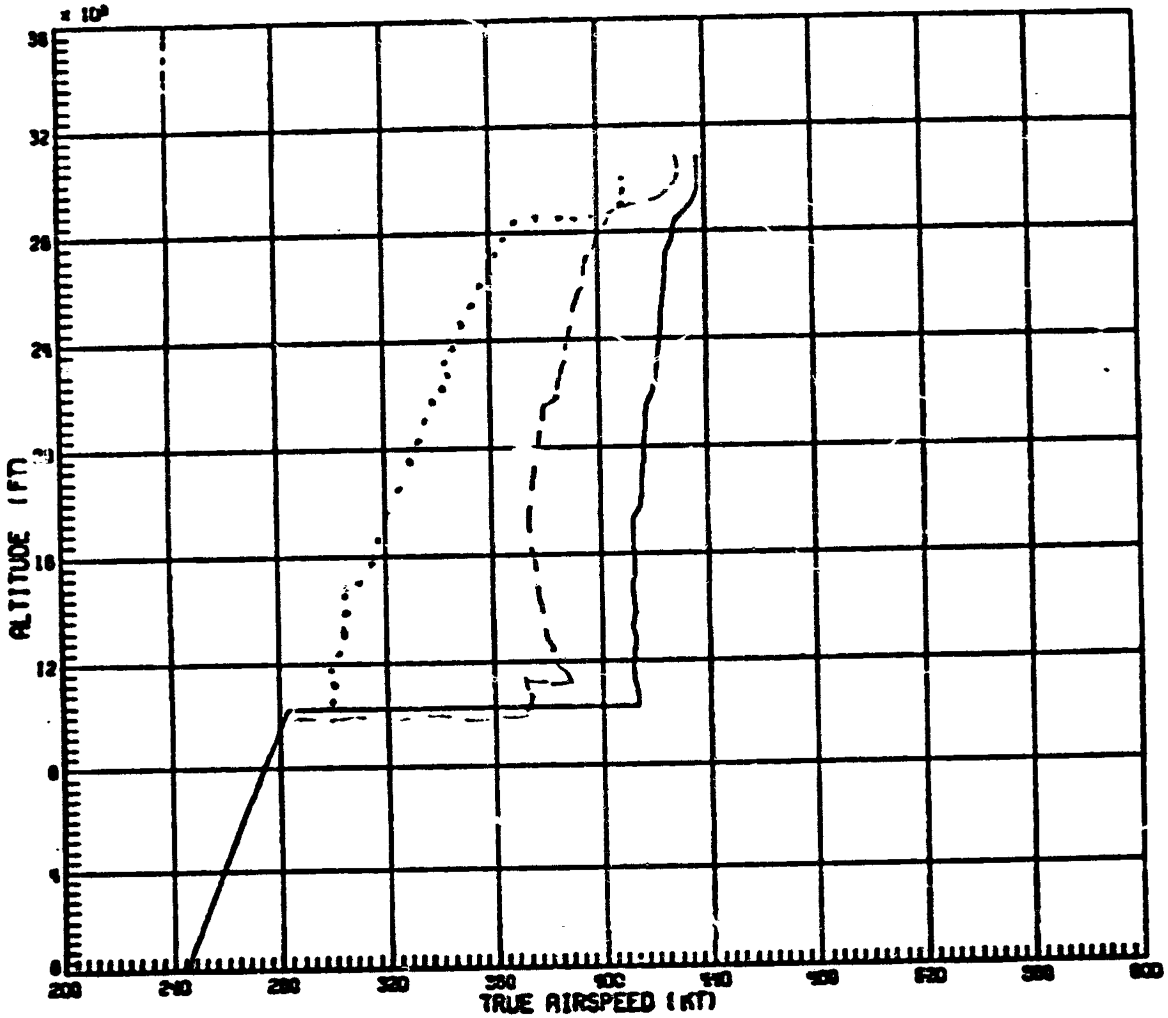

Figure 34.9

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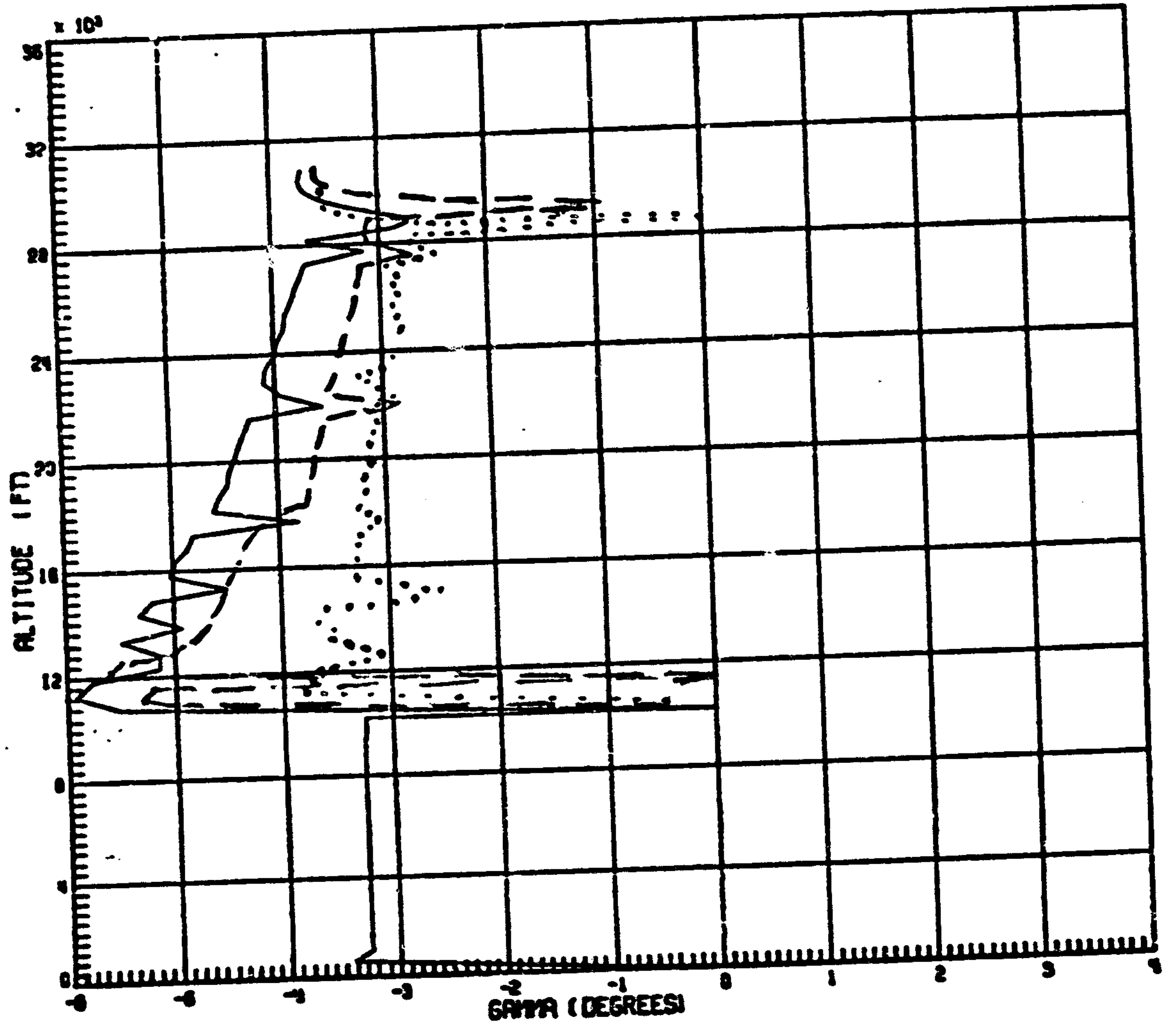

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Figure 34.10

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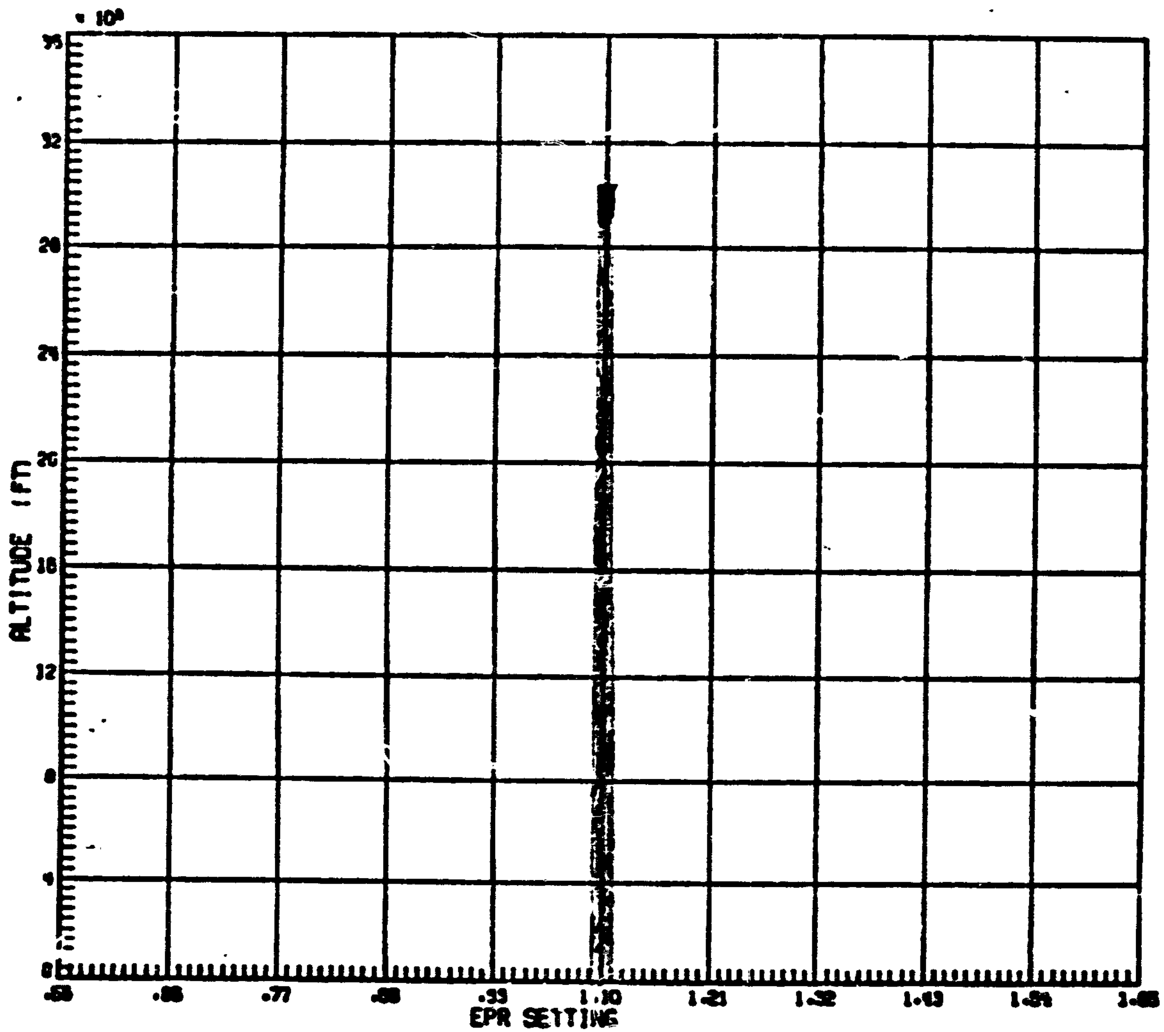

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Figure 34.11

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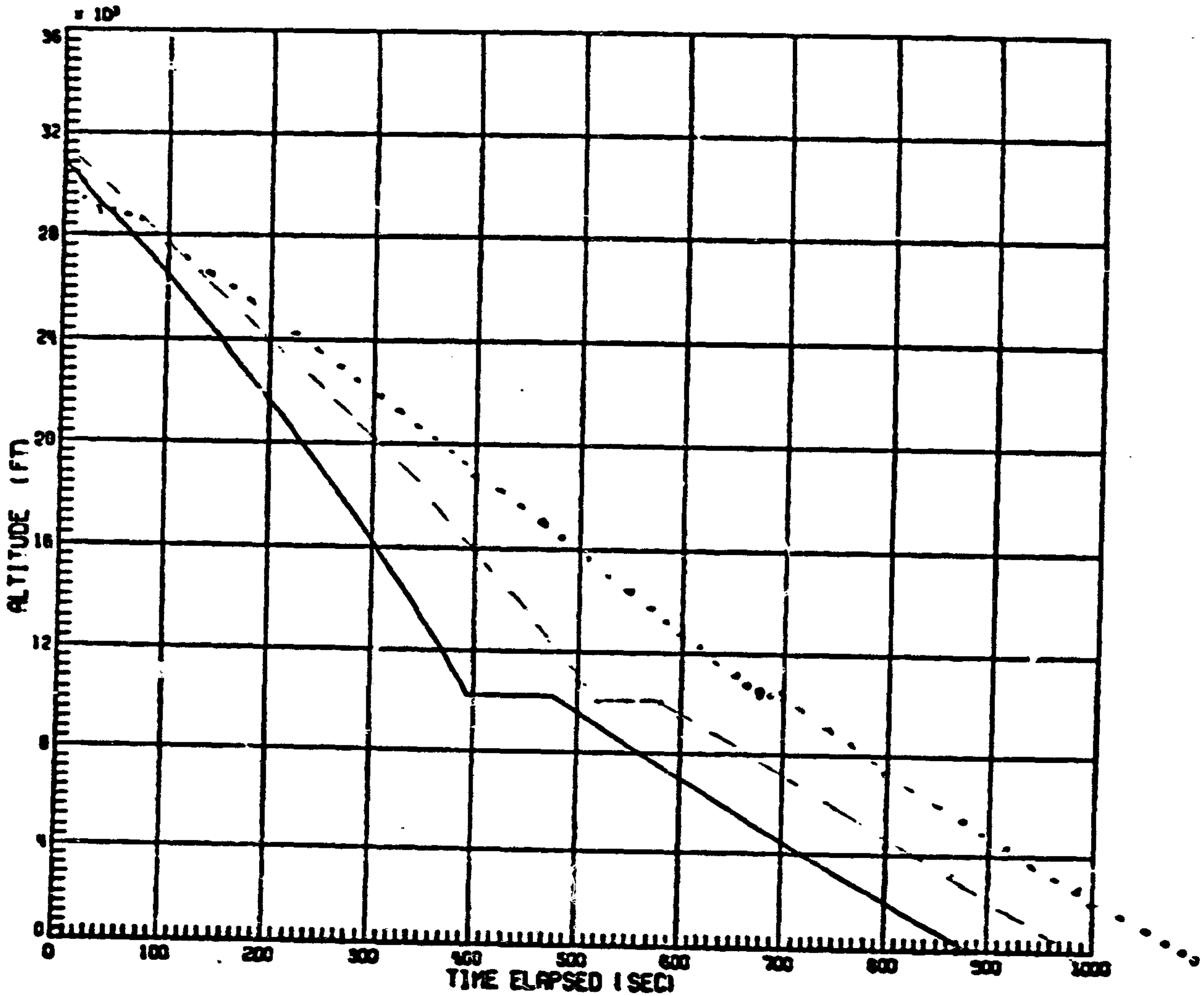

Figure 34.12

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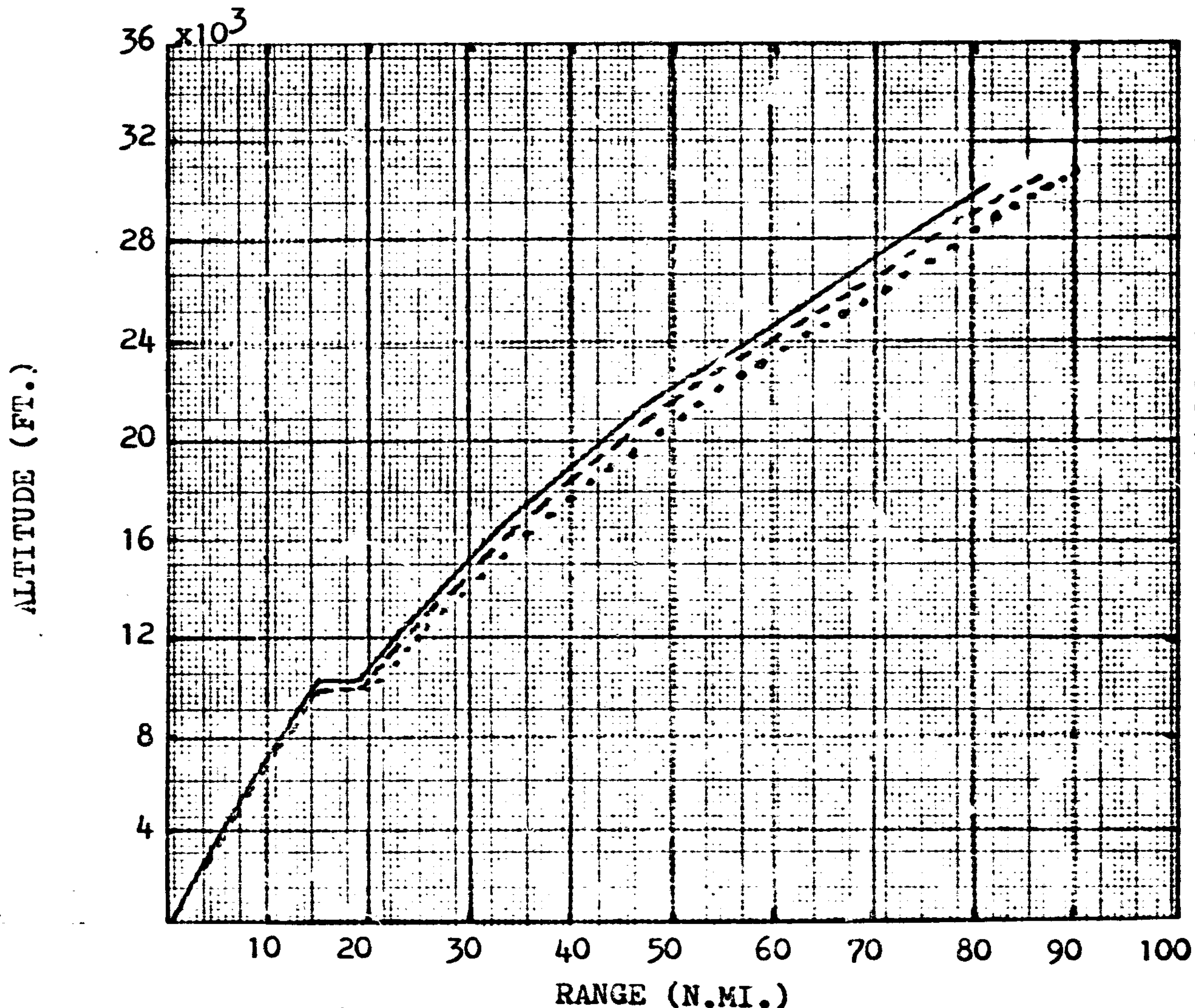

KEY FOR FIGURES 35

FILE NAME EVPFC10 .... .10/600

EVPFC15 ---- .15/600

EVPFC25 ——— .25/600

RANGE = 300 N.MI.

FLAGS - - 000030011032

CRUISE 100K
TABLE 80K
INFO. 4K

Figure 35.1(a) - Vertical profiles as functionals of fuel cost

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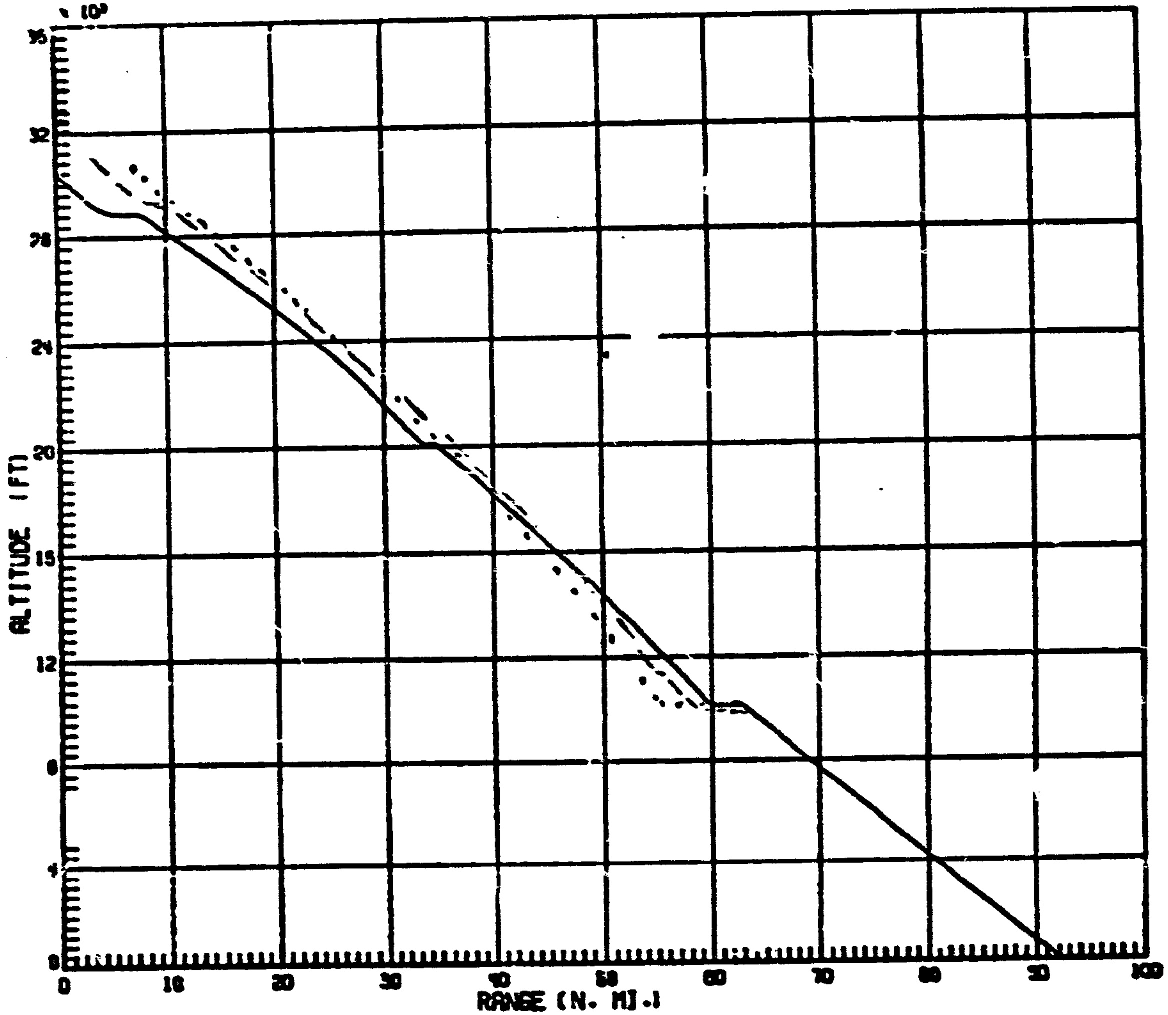

Figure 35.1 (b)

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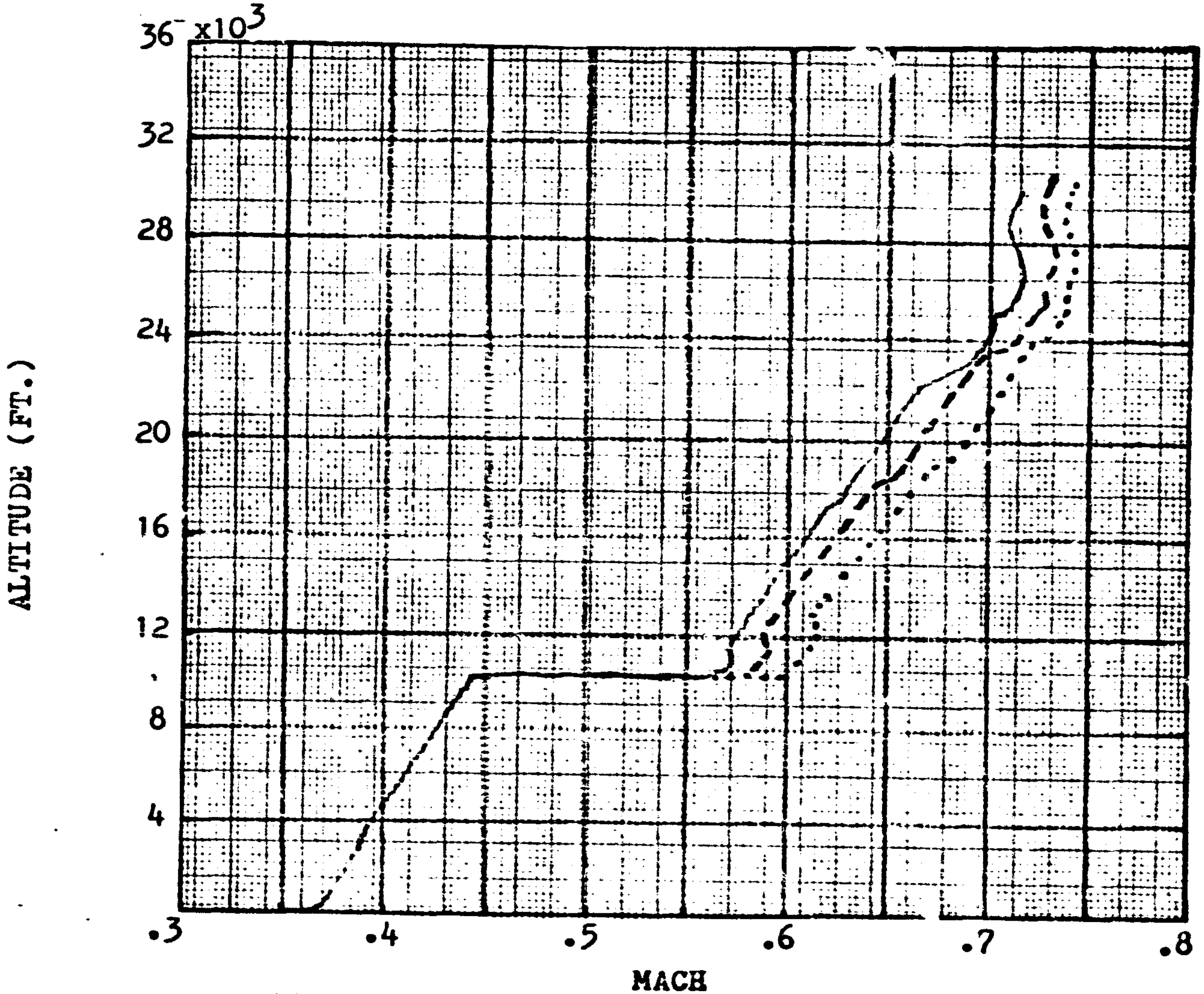

Figure 35.2

...... - .10/600

------ - .15/600

FLAGS - 000030011032

CRUISE 100K
TABLE 80K
INFO. 4K

RANGE = 300 N.MI.

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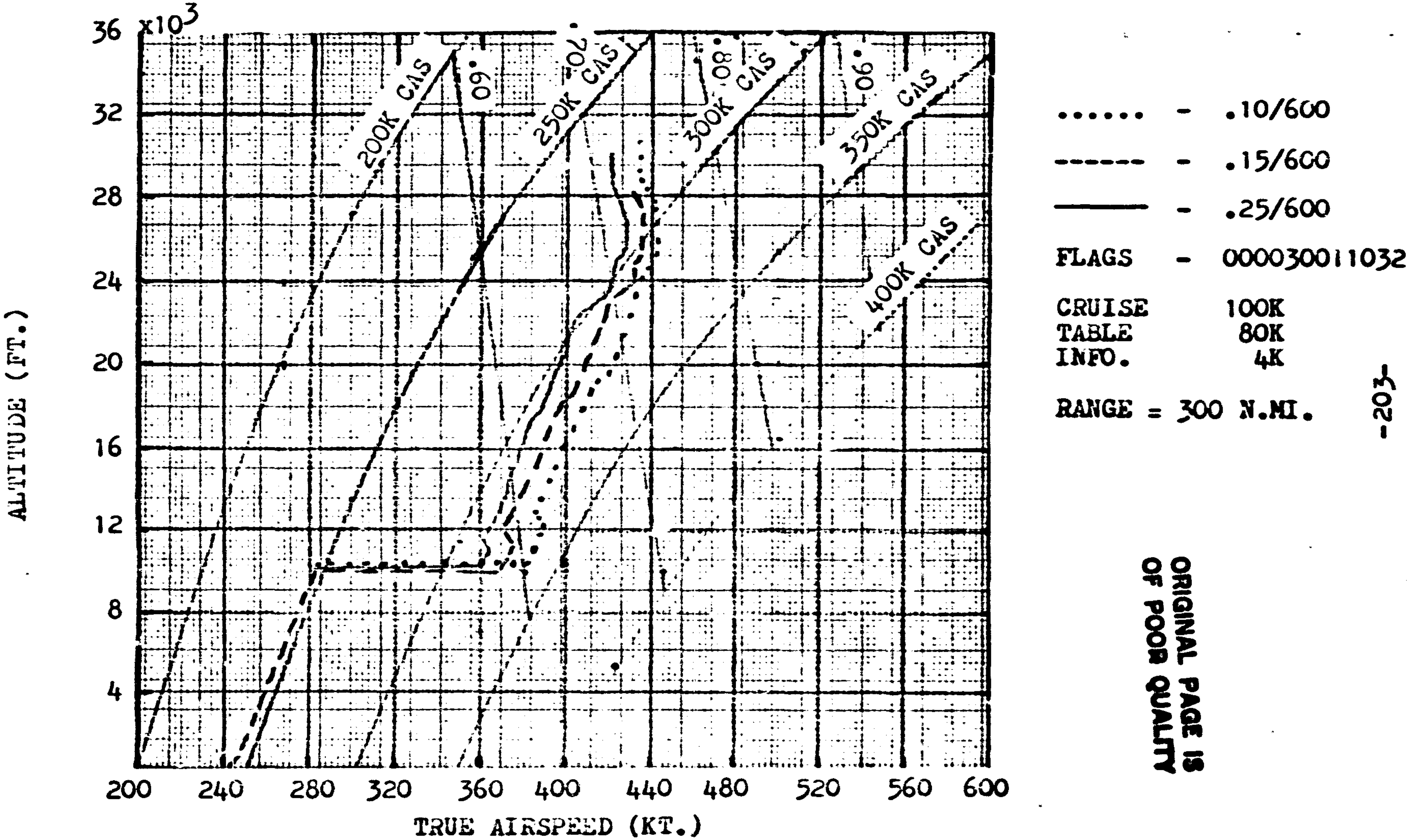

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Figure 35.3(a) - Altitude as a function of true airspeed for direct operating cost optimal flight paths having differing fuel costs/lb.

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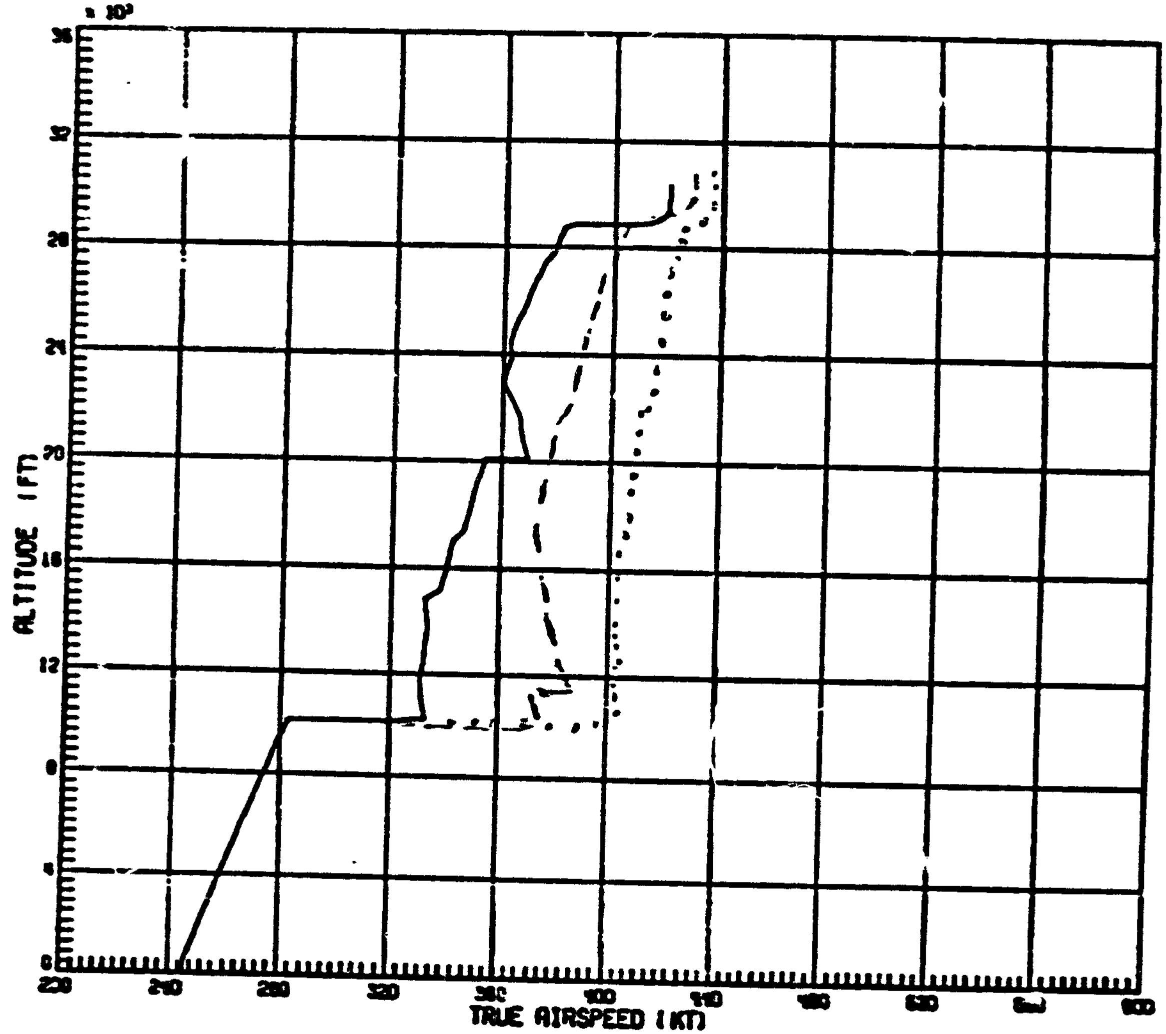

Figure 35.3 (b)

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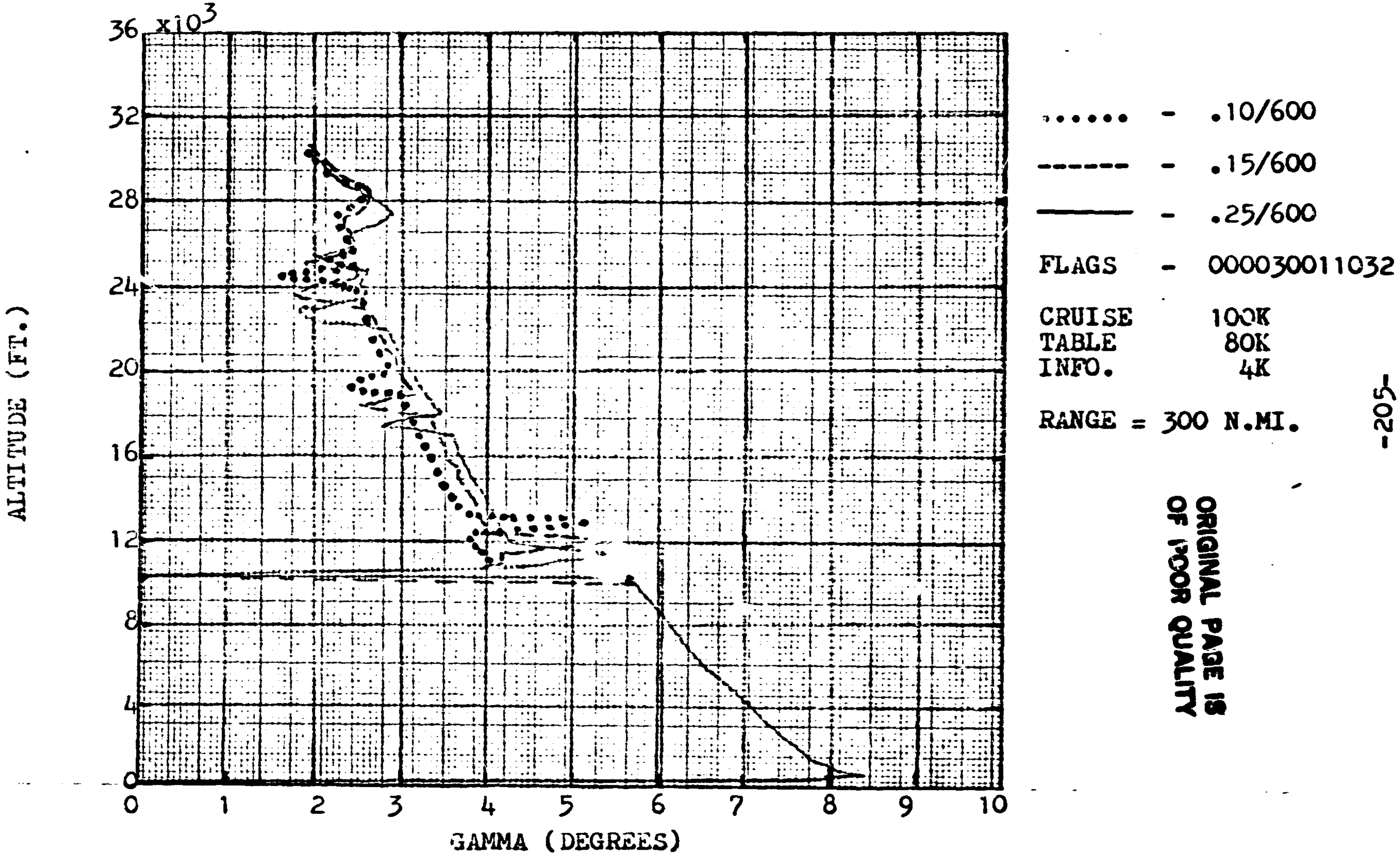

Figure 35.4(a)

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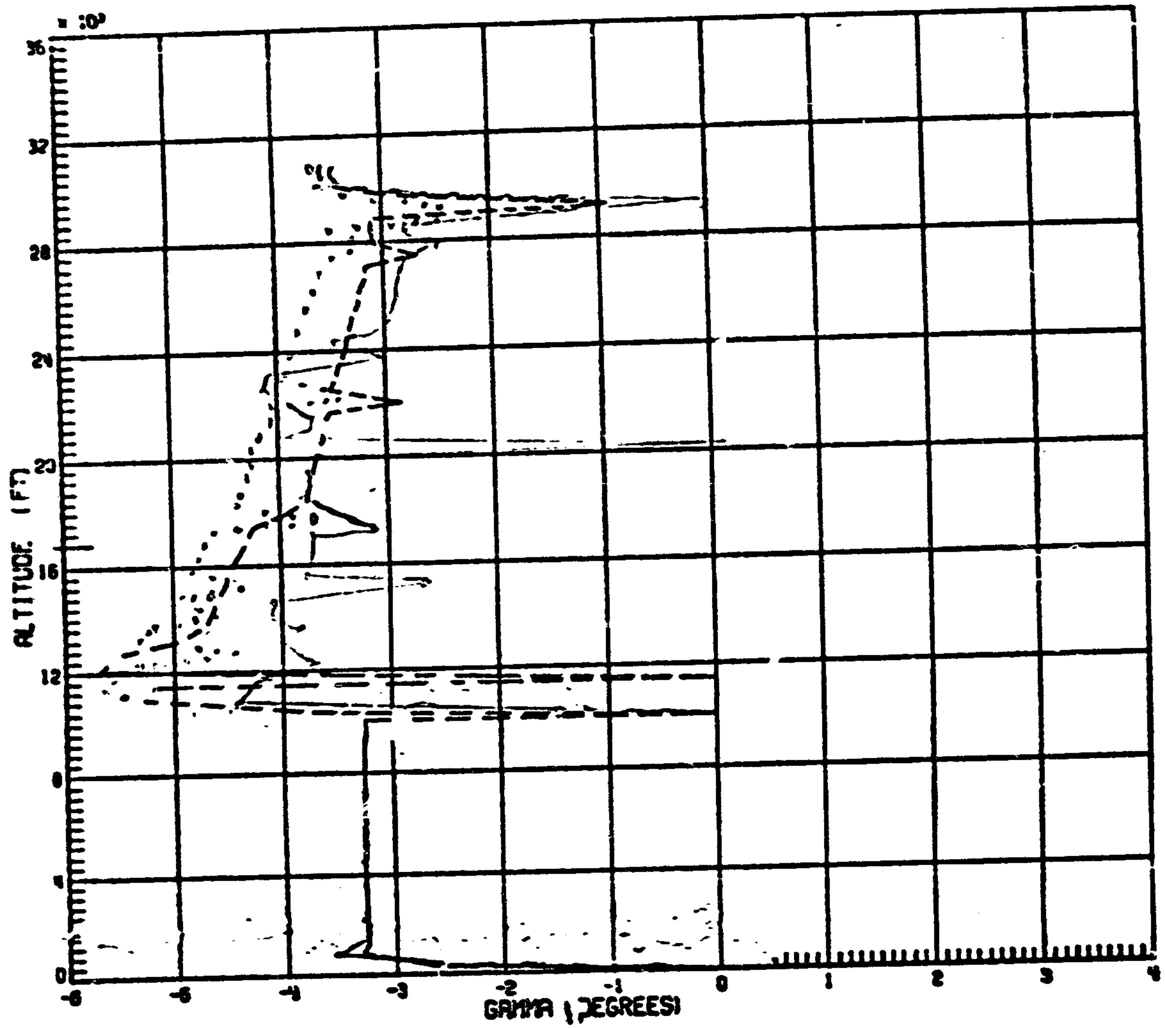

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Figure 35.4 (b)

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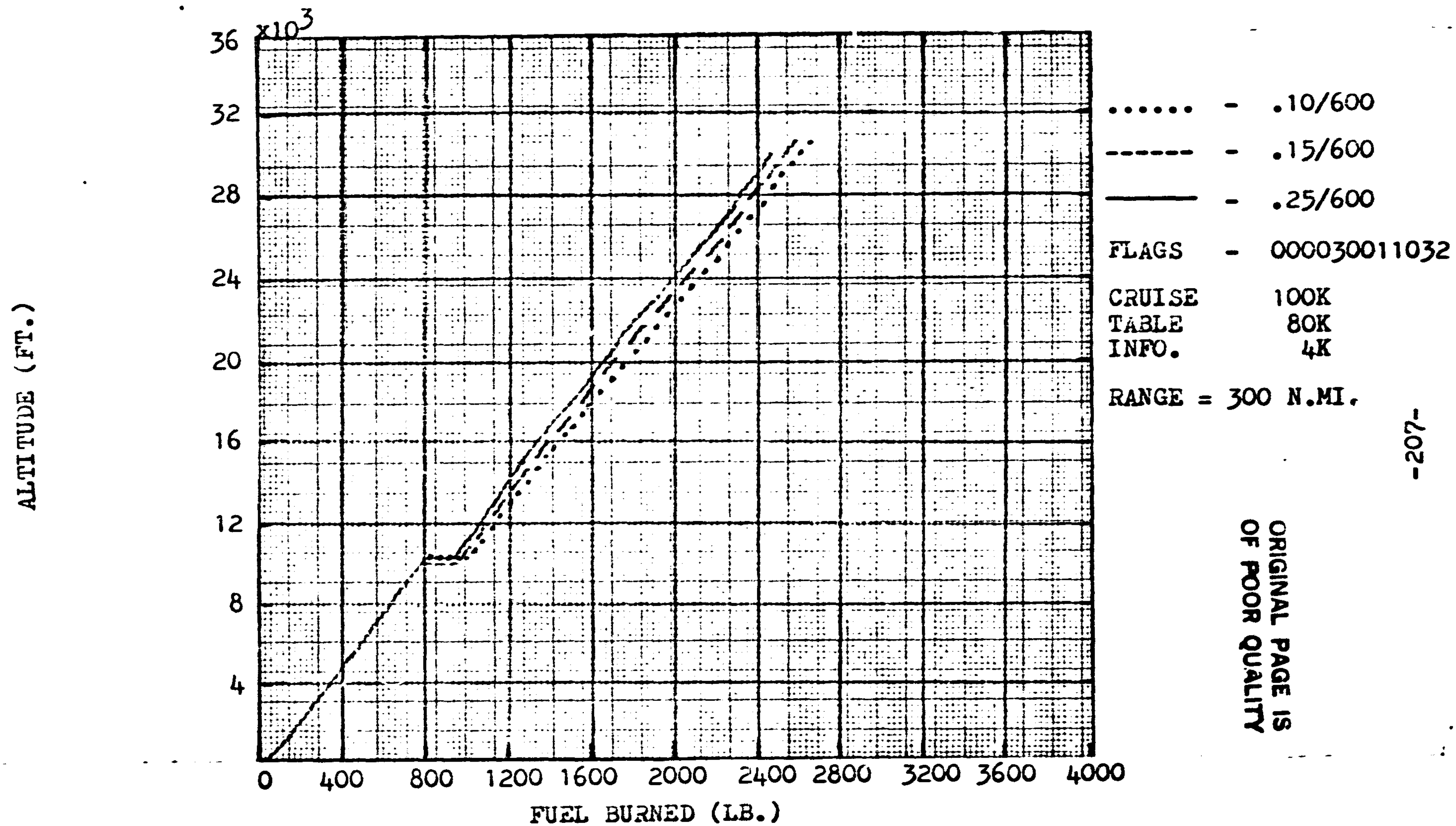

Figure 35.5(a)

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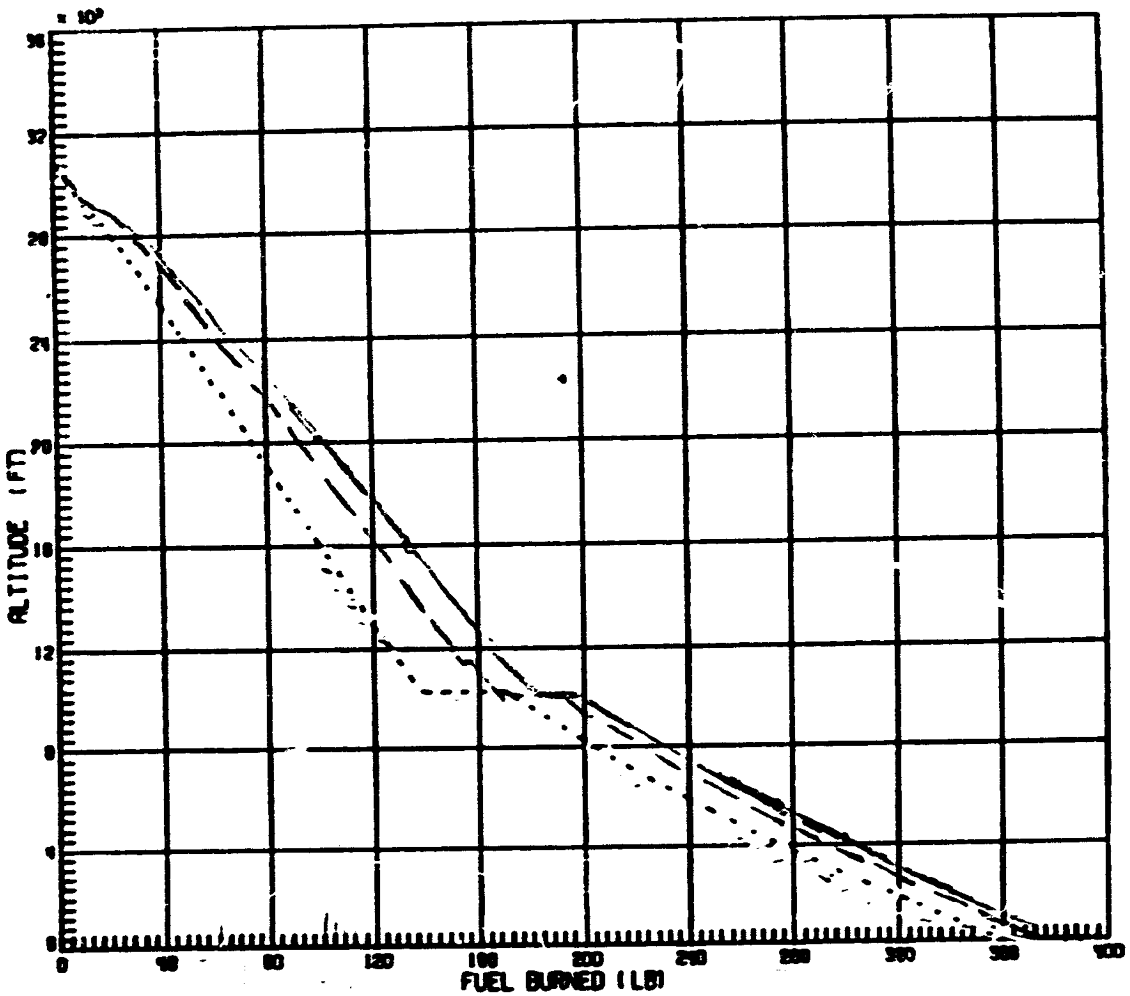

Figure 35.5 (b)

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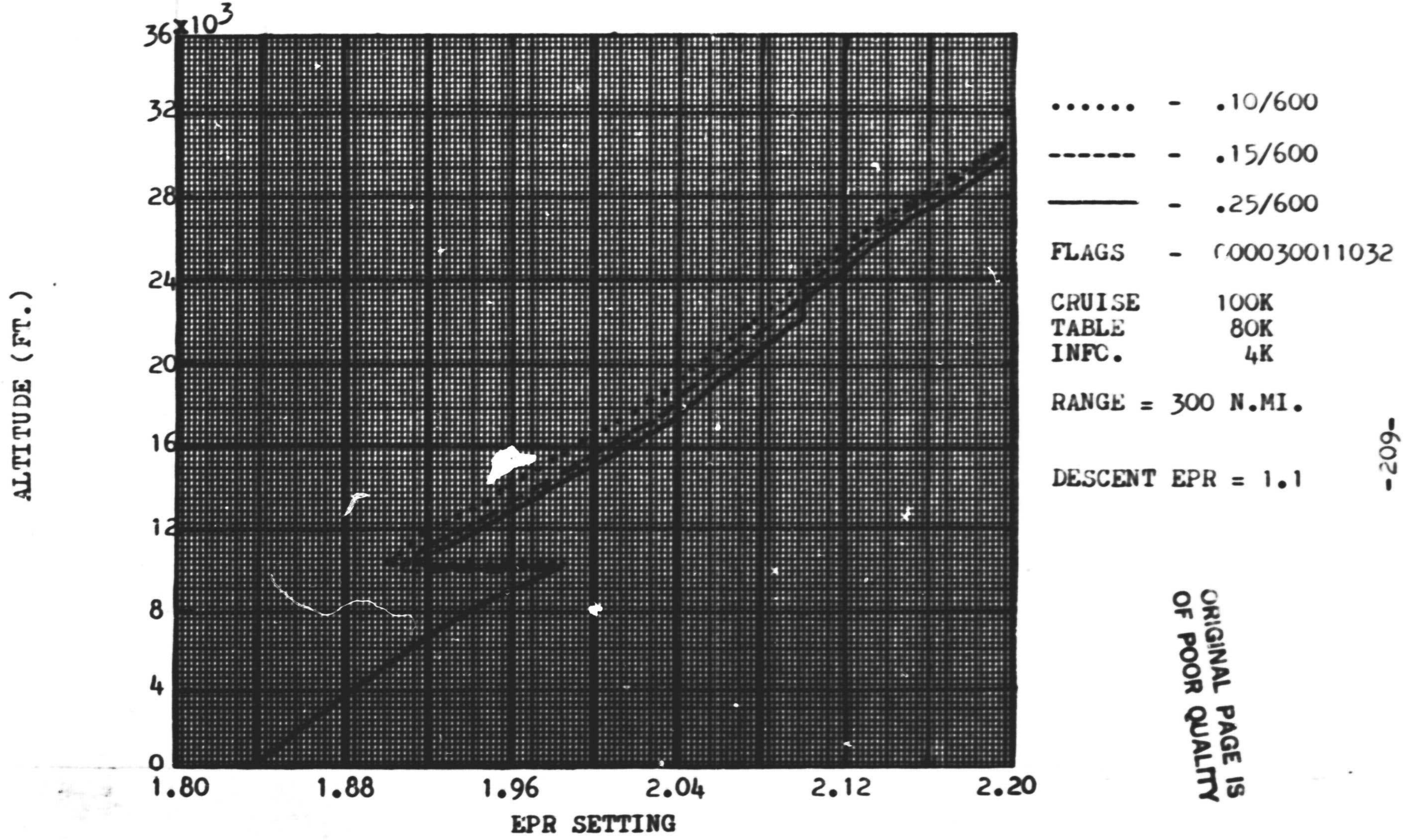

Figure 35.6

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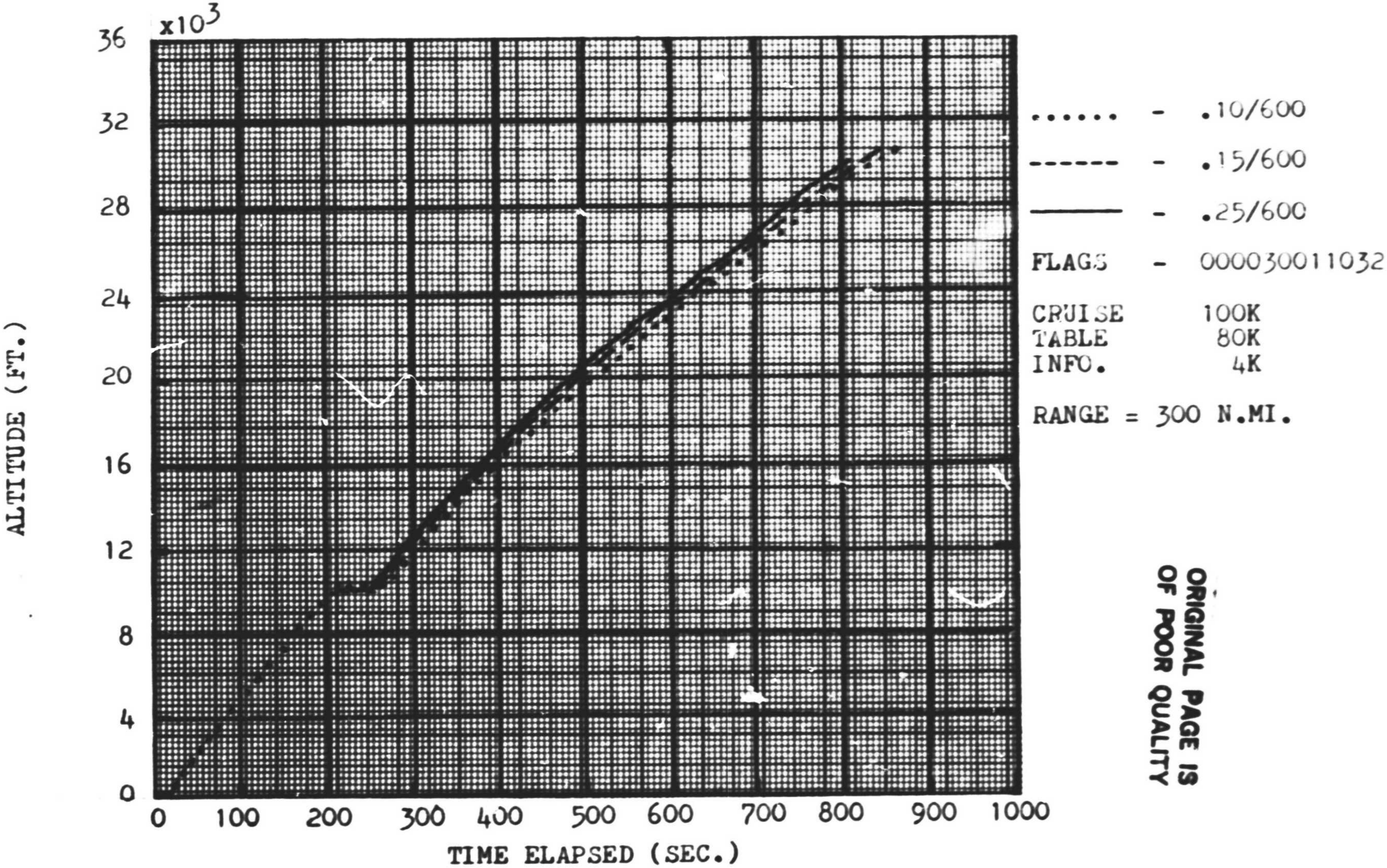

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Figure 35.7(a)

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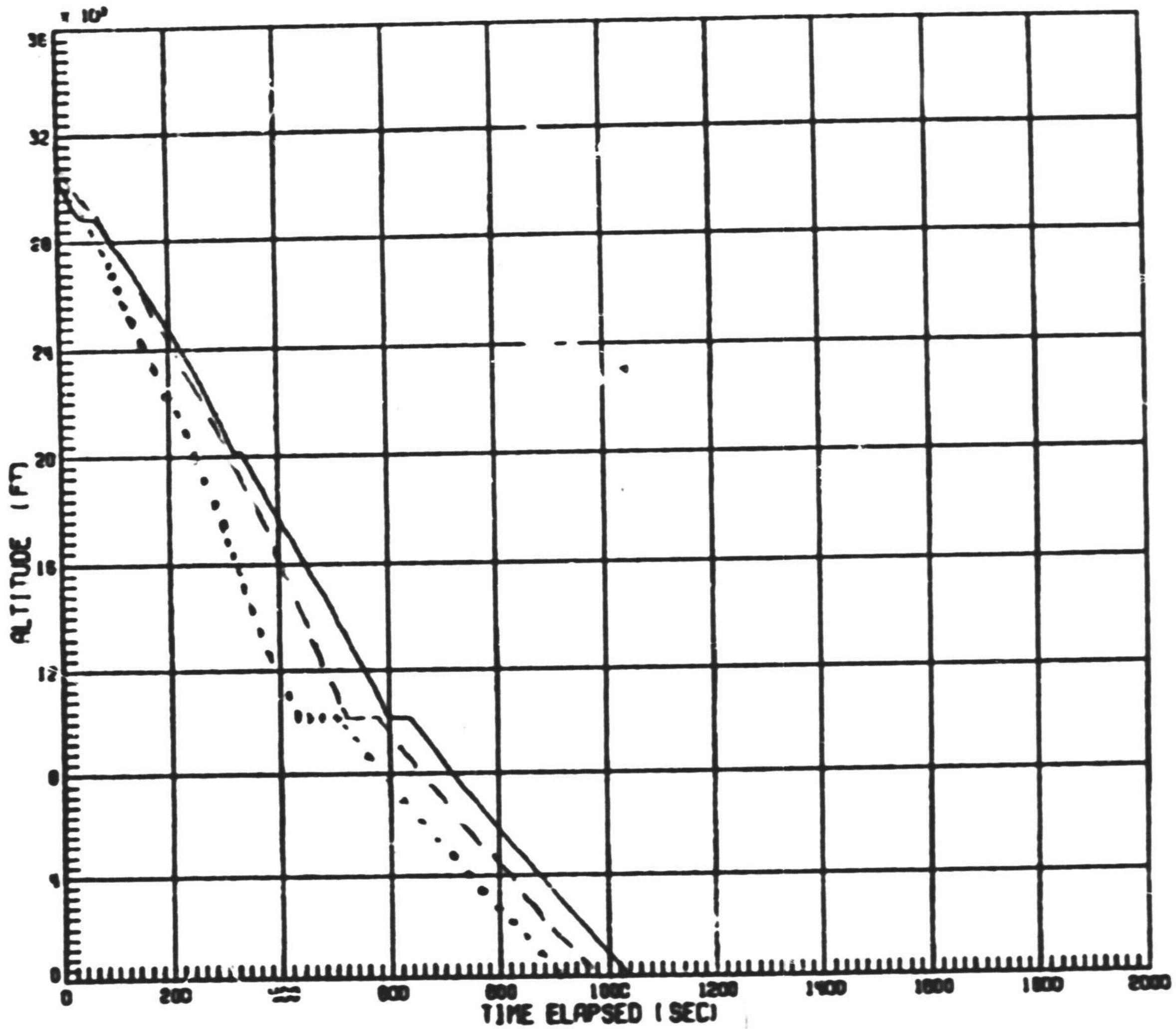

Figure 35.7 (b)

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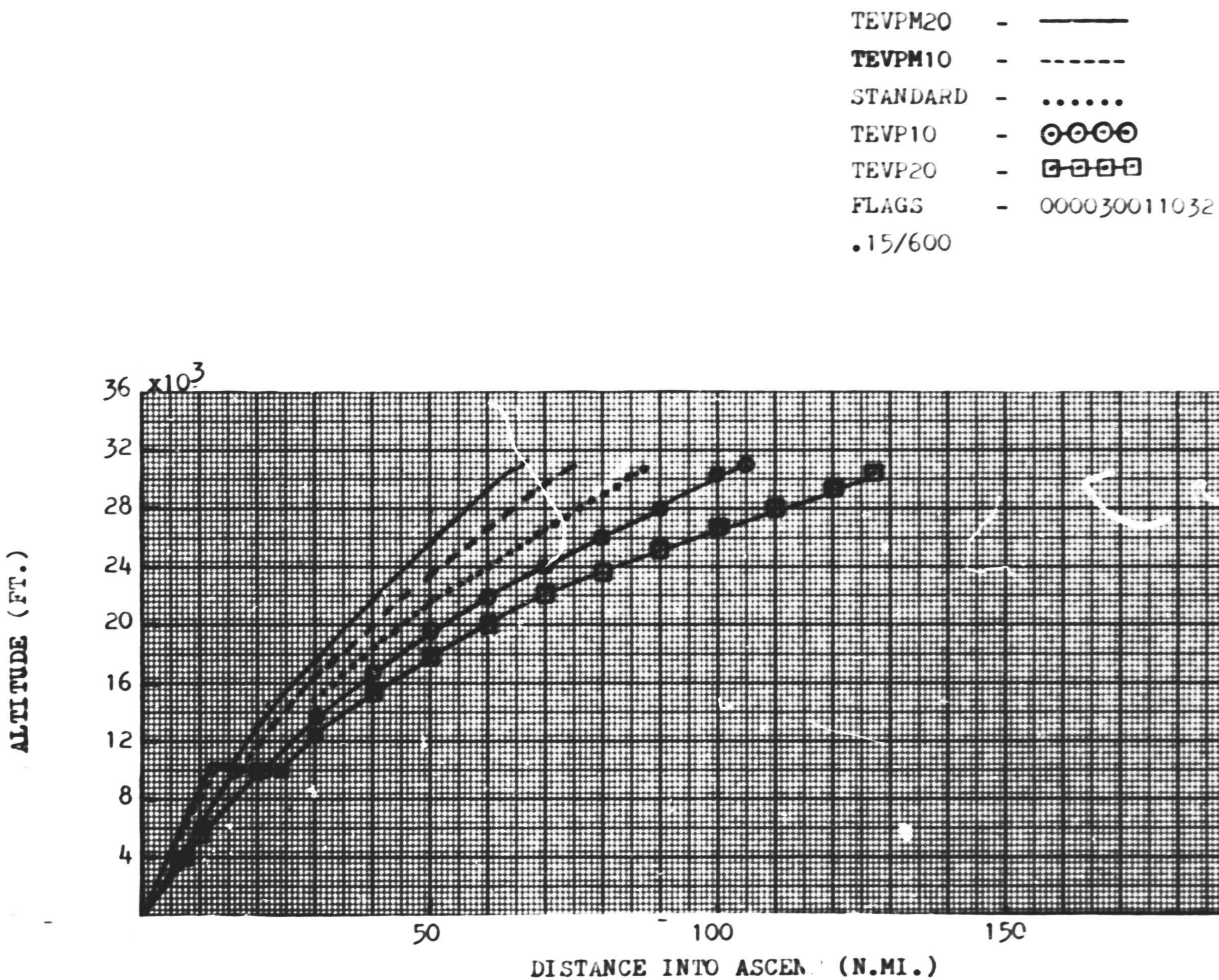

Figure 36.1 - Effect of temperature variation from standard day on ascent profile (std. day = $59^{\circ}F$ at S.L.).

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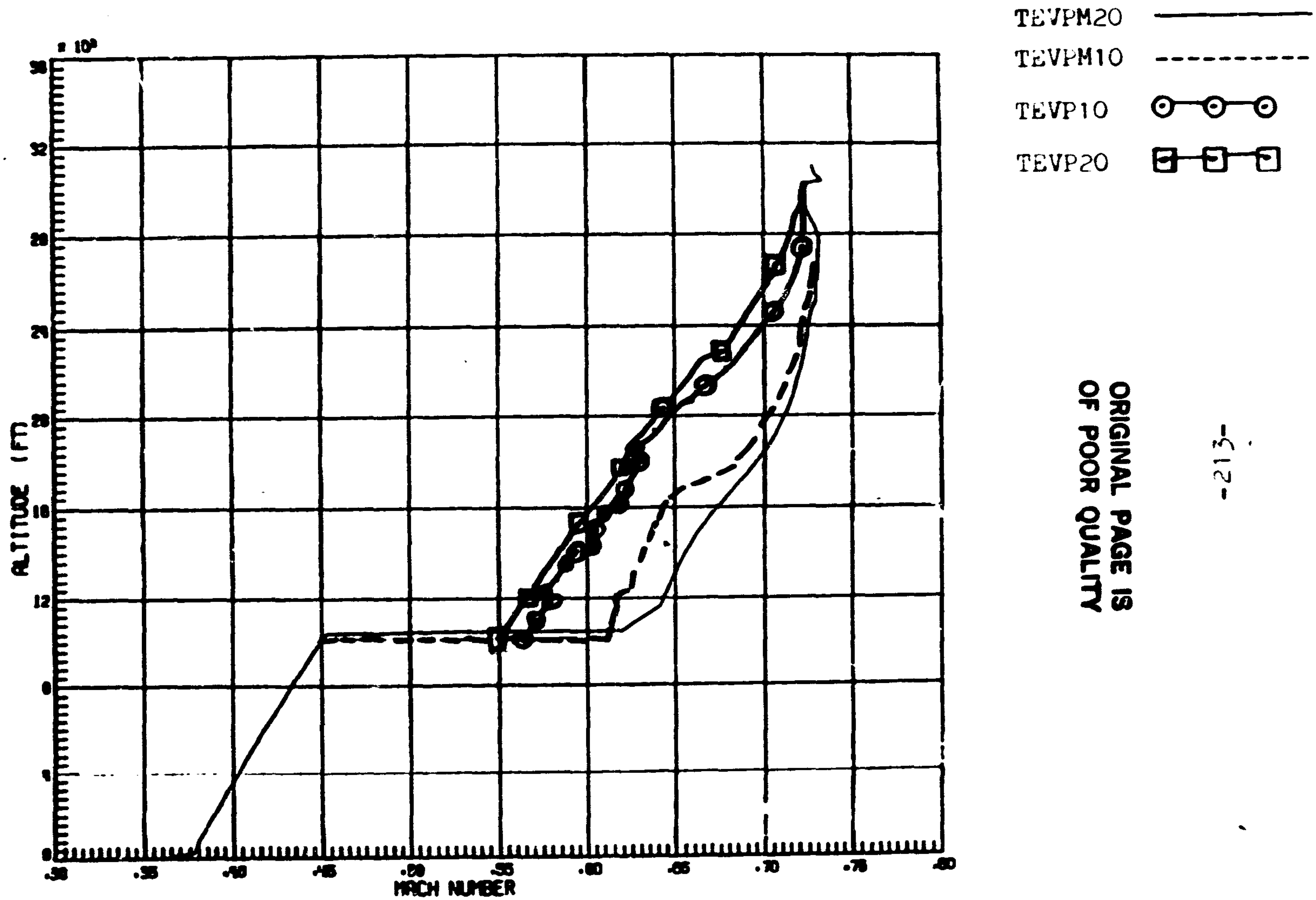

Figure 36.2 - MACH NUMBER-ALTITUDE

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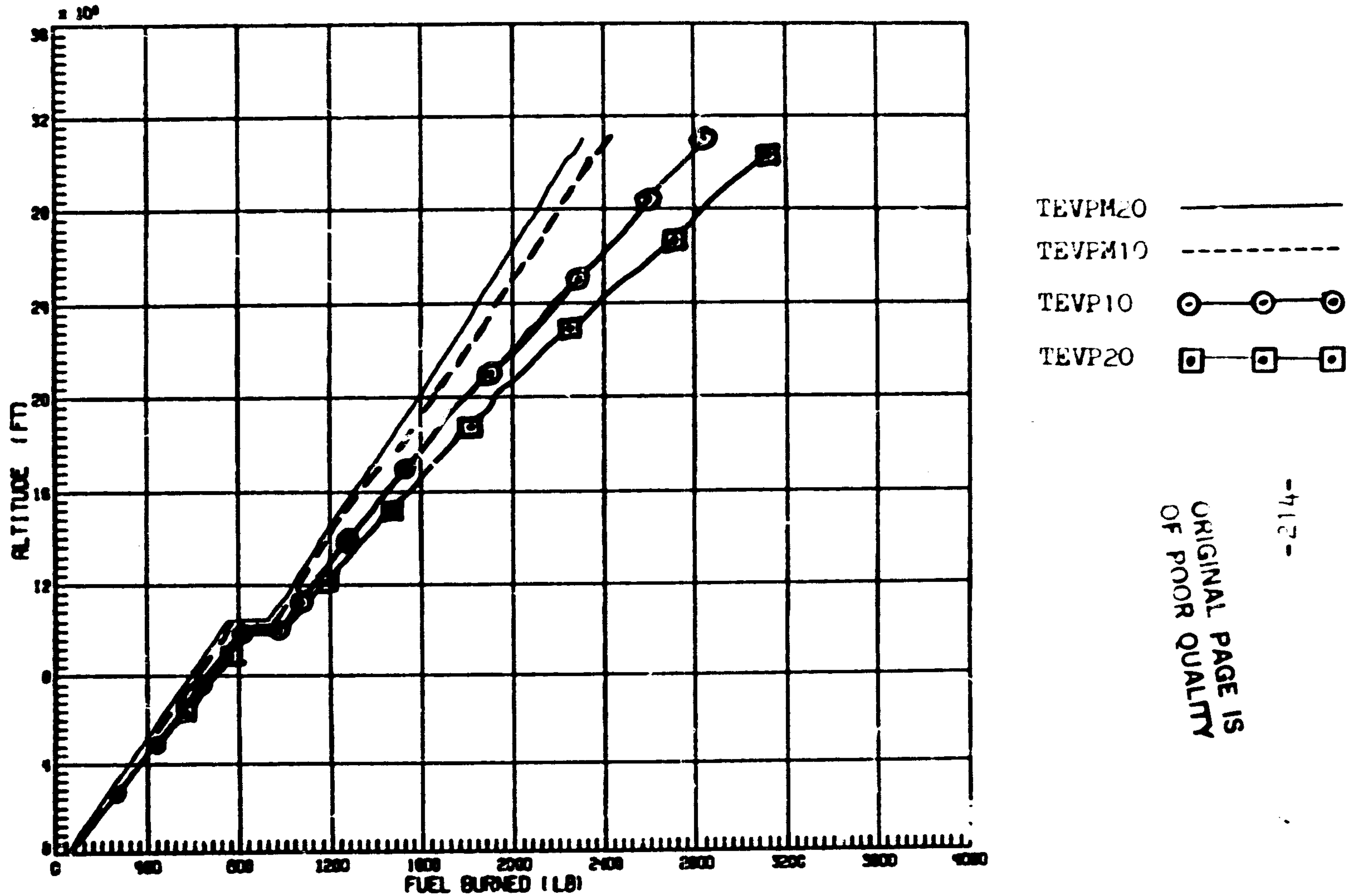

Figure 36.3 - FUEL BURNED -ALTITUDE

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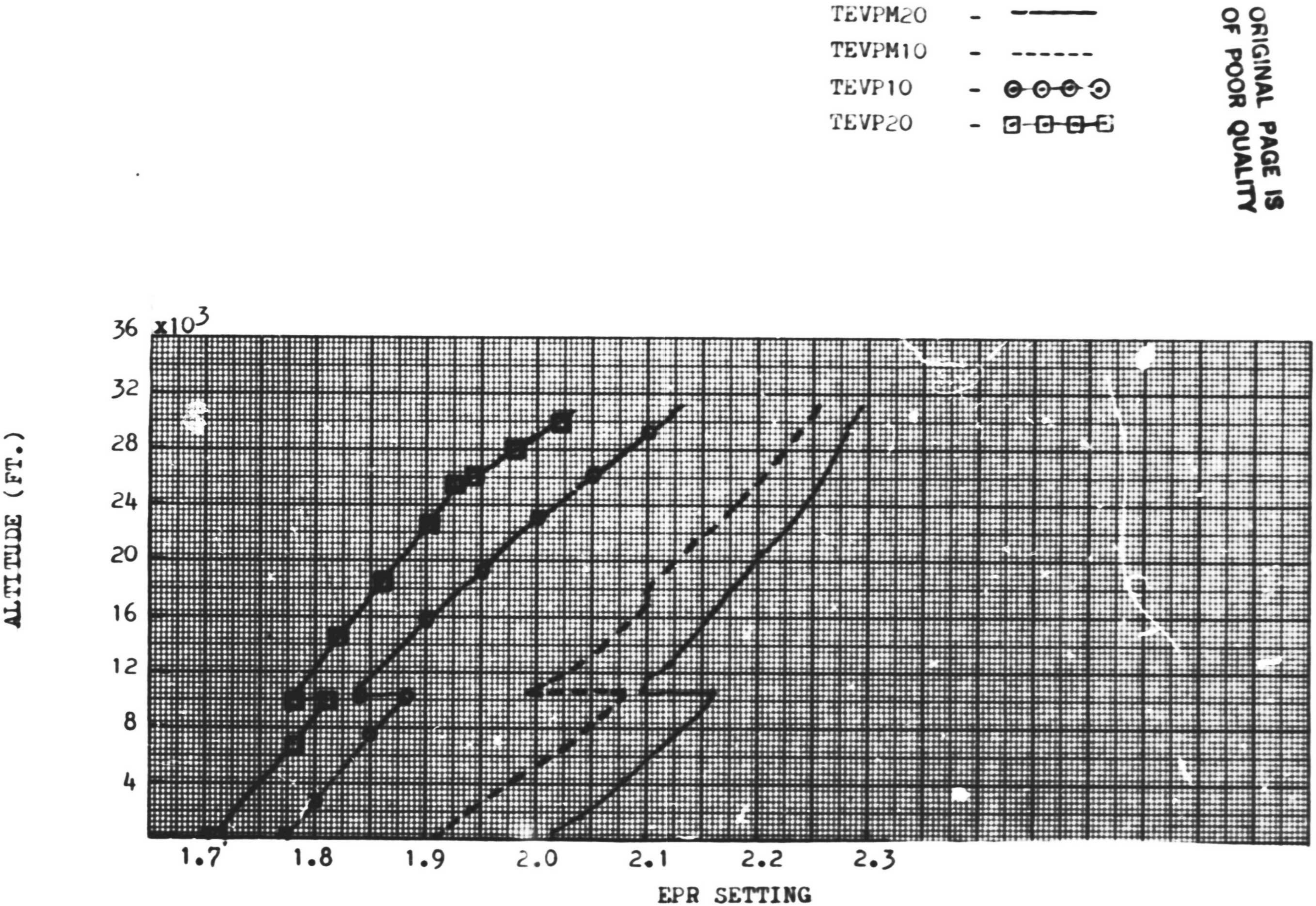

Figure 36.4

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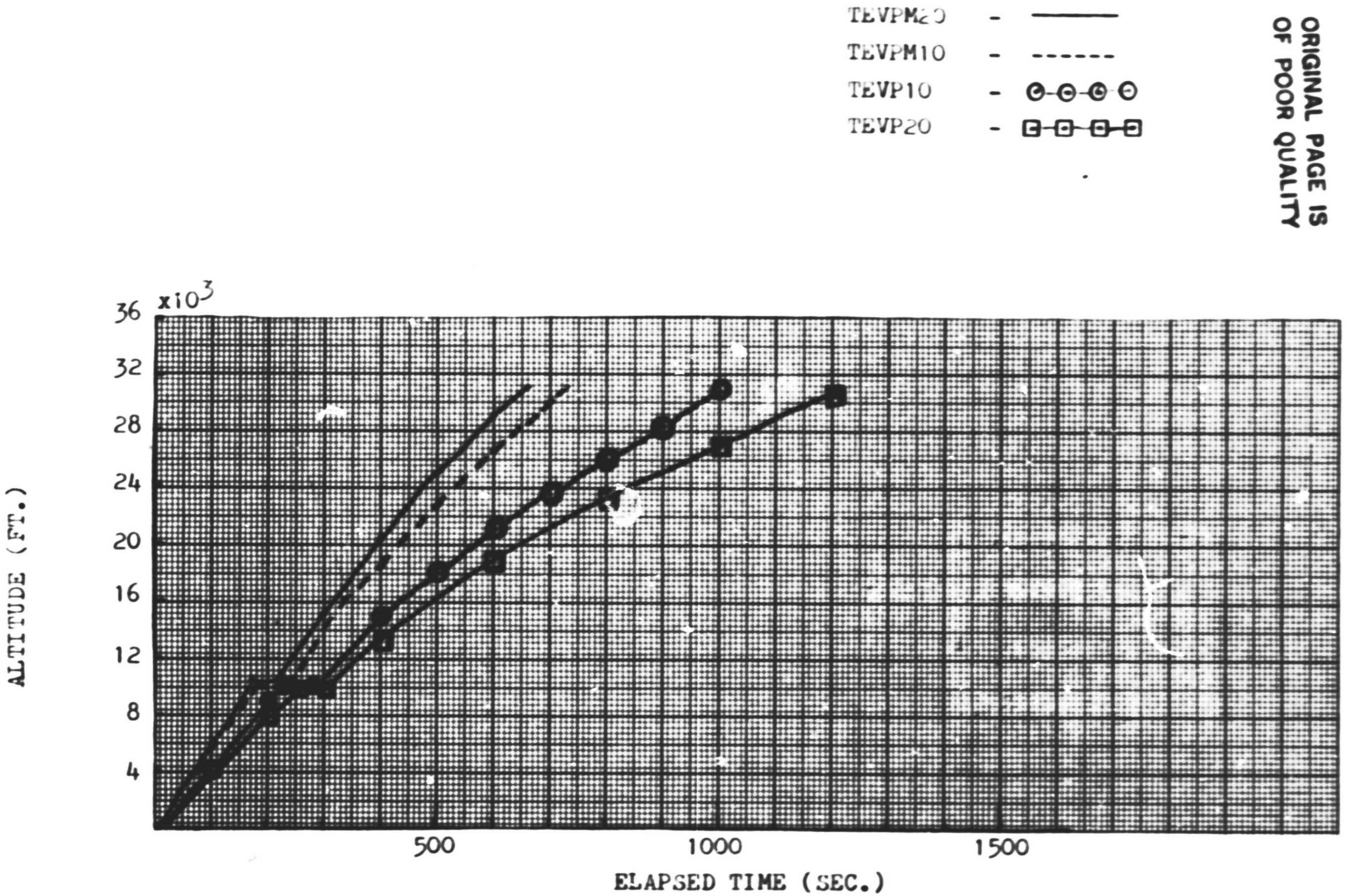

Figure 36.5

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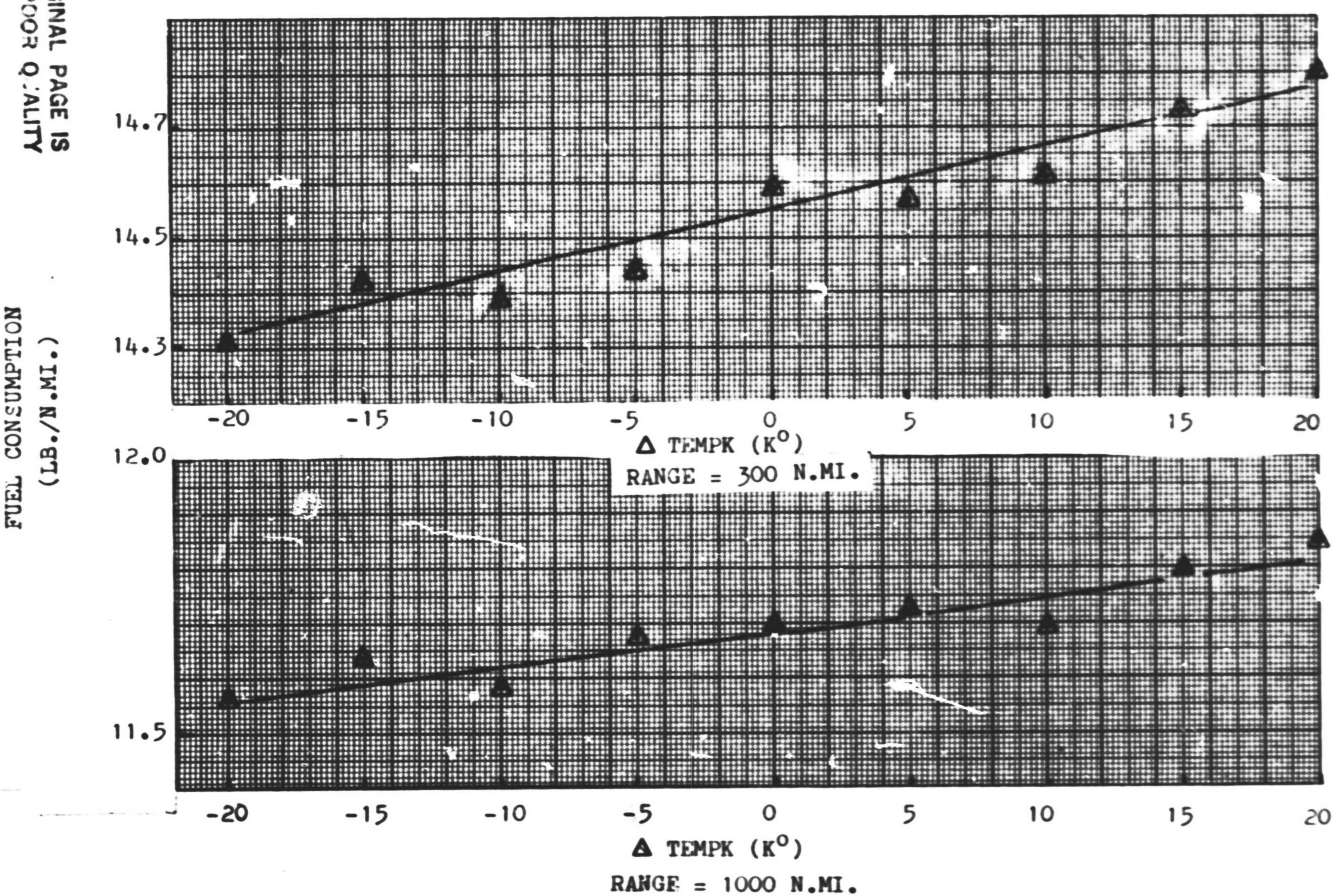

Figure 37.1 - Atmospheric effect on fuel consumption.

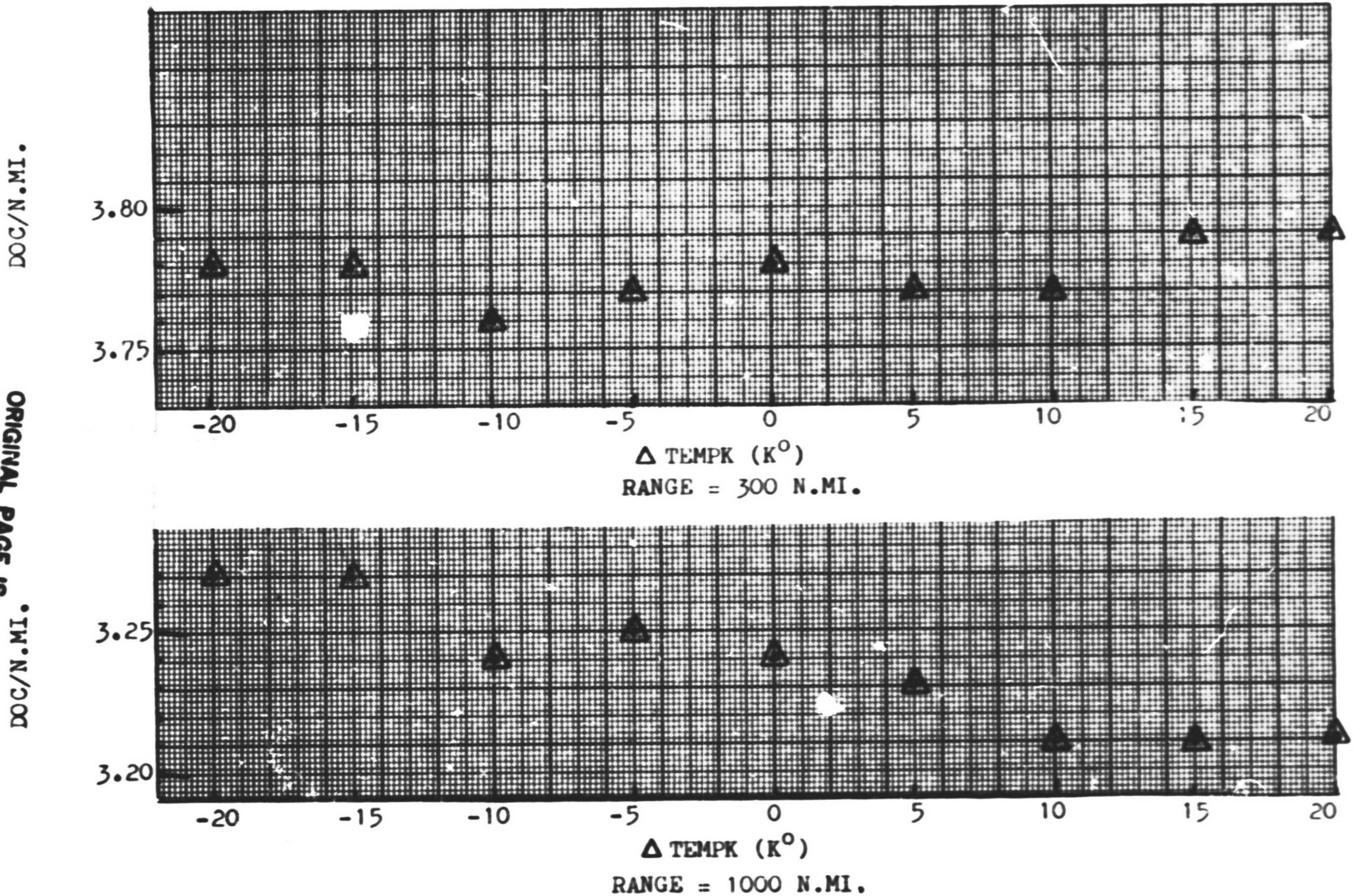

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Figure 37.2 - Atmospheric effect on direct operating cost.

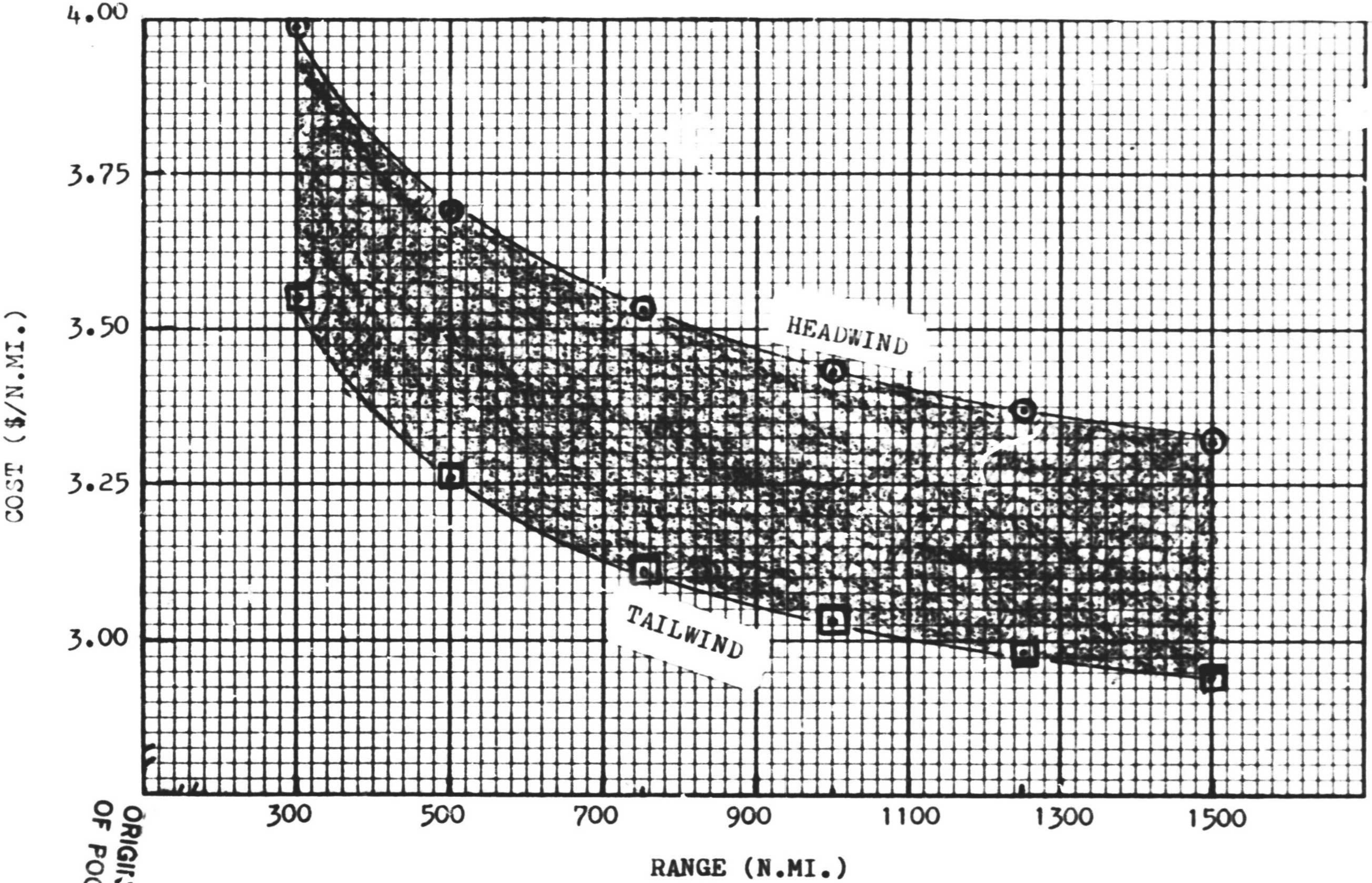

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Figure 38 - Wind envelope direct operating cost for .15/600 optimals with flags 000130011032.

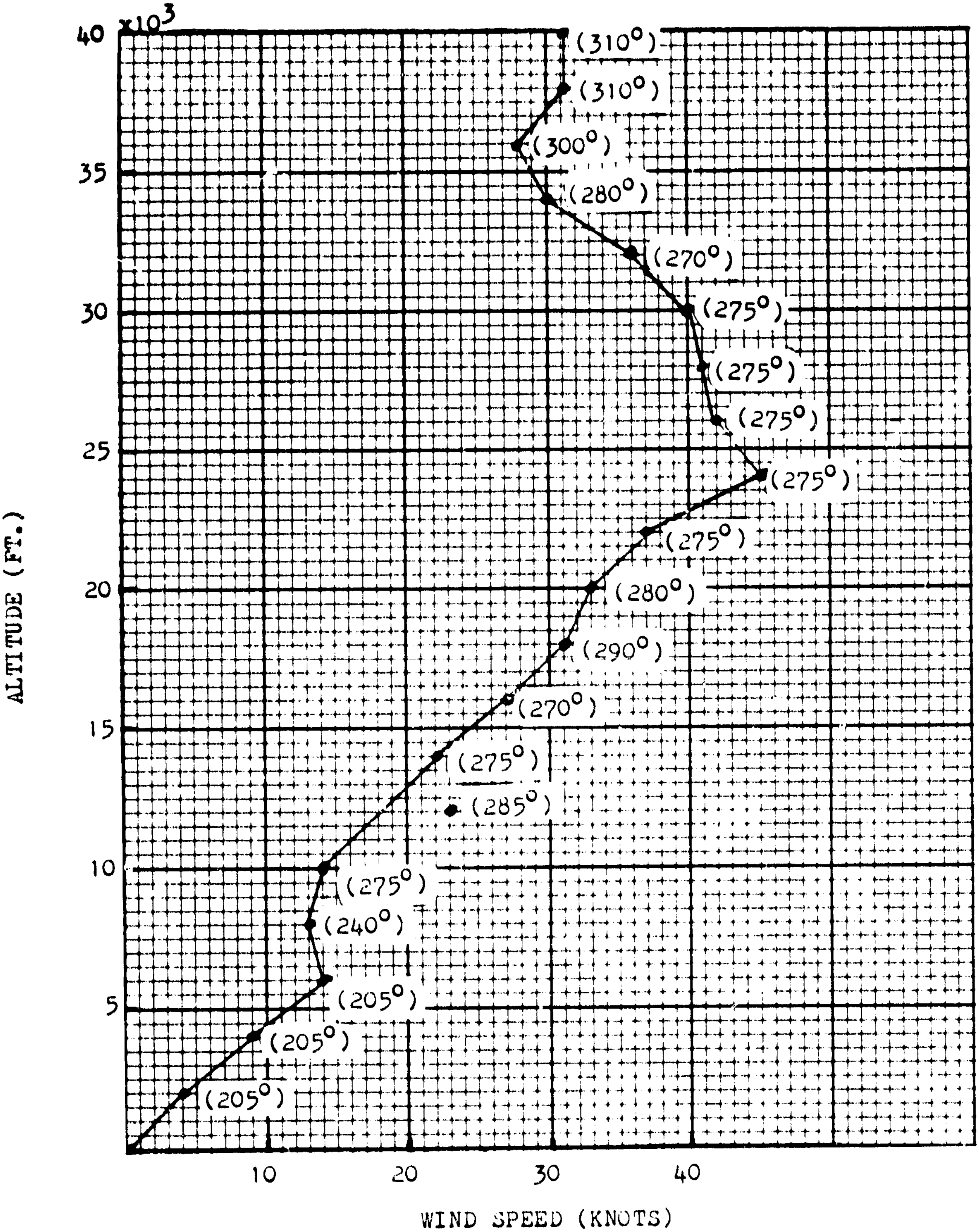

Figure 39 - Wind Model Used

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*Number in parenthesis is source direction

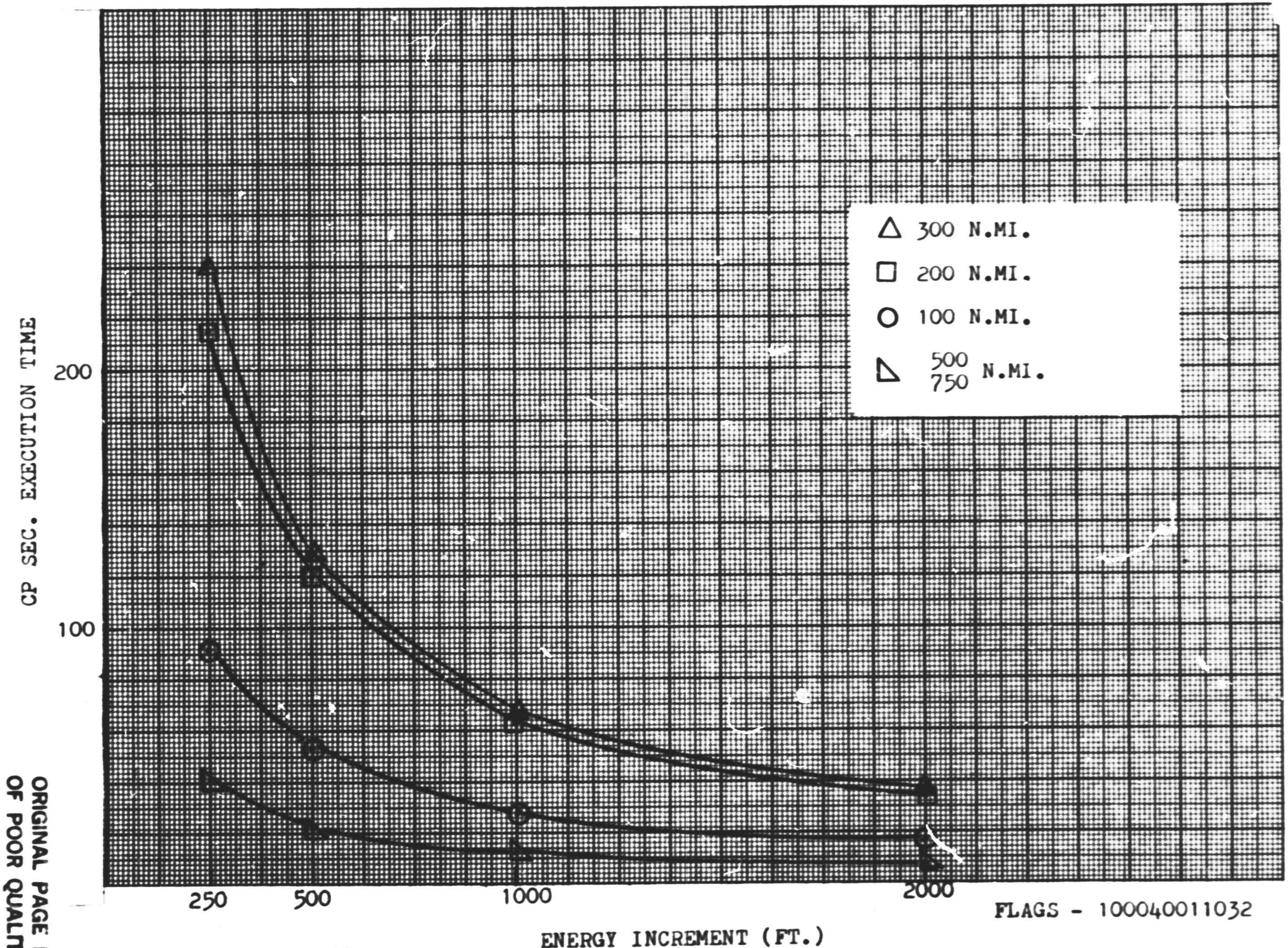

Figure 40. - Dependence of central processing unit execution time on energy increment for ranges of 100,200, 300,500 and 750 N. Mi.

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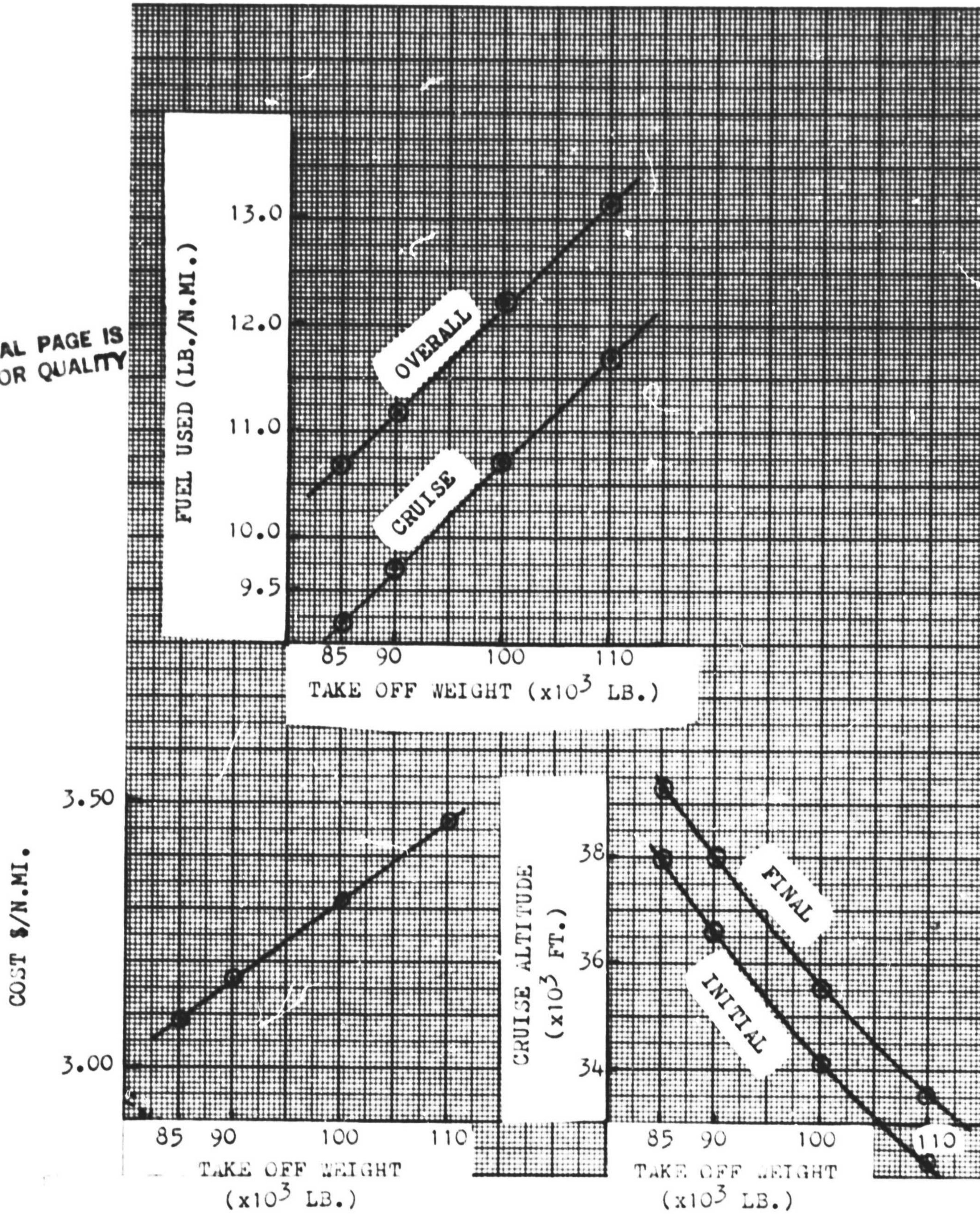

FLAGS (0030001130) 750 N.MI. FLIGHT

Figure 41 - Weight effect on DOC optimal profile cost/n.mi, fuel efficiency and cruise altitude.

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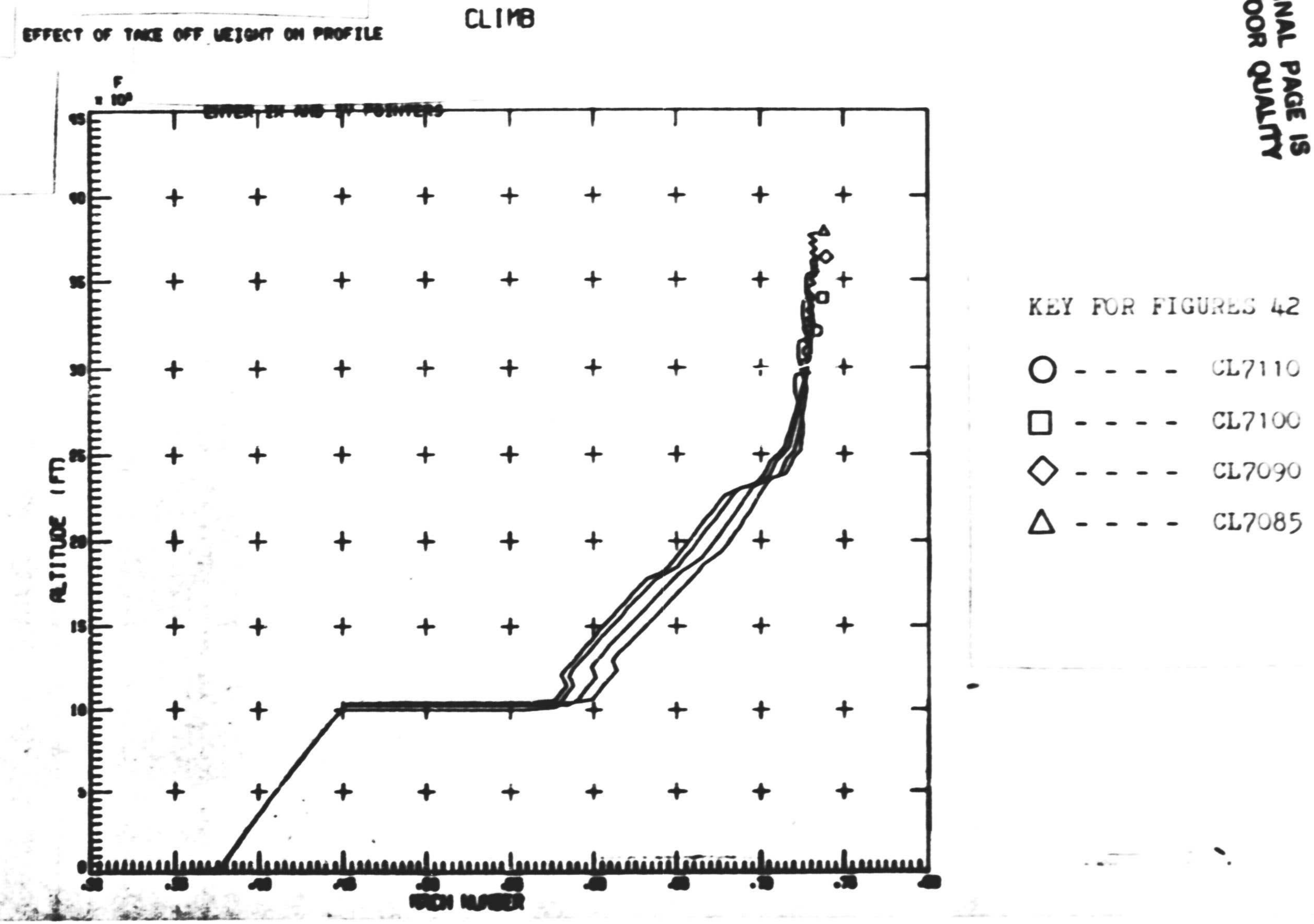

Figure 42.1 - Physical vertical profiles for DOC optimal trajectories as functions of take off weight.

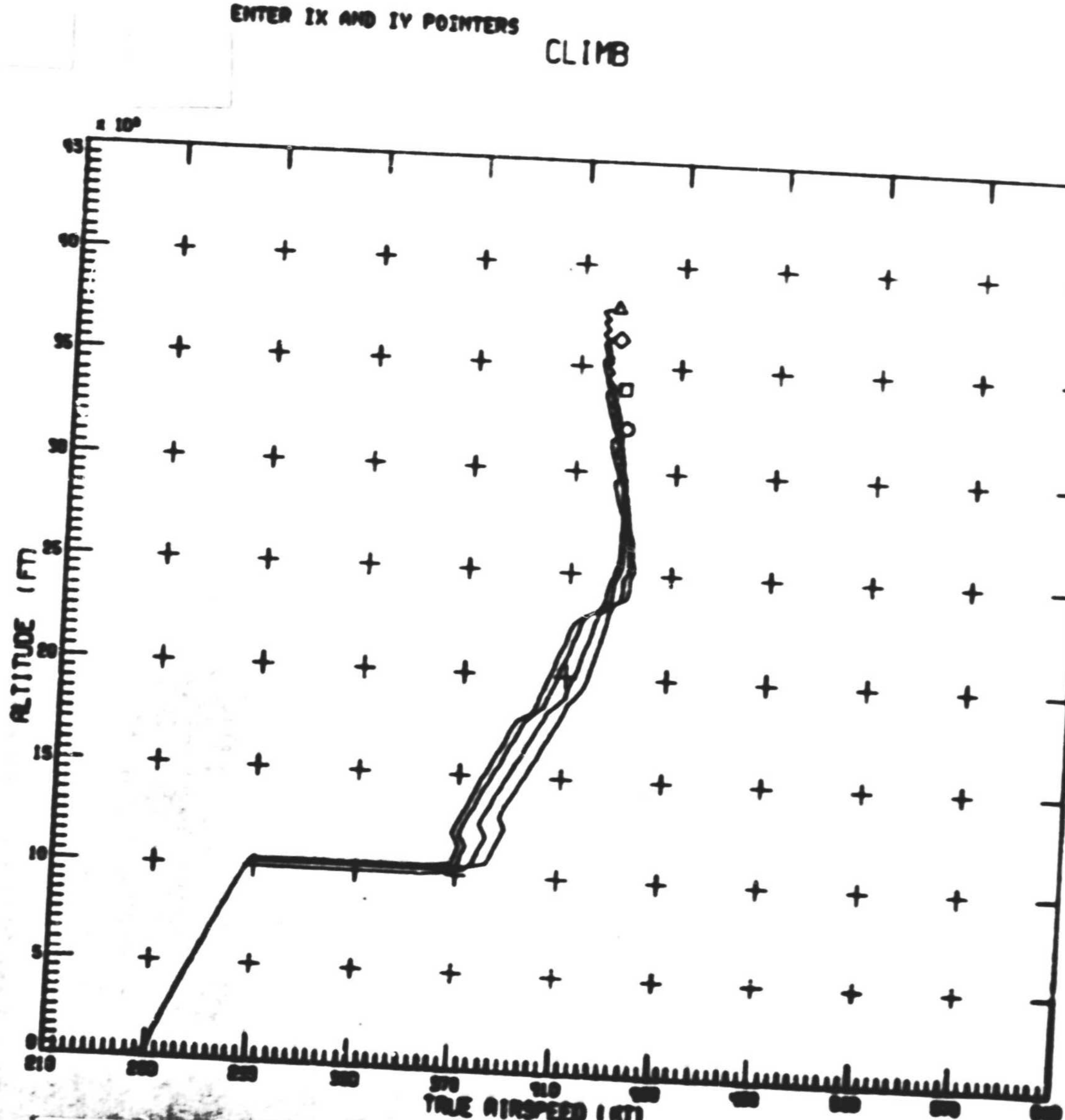

Figure 42.2

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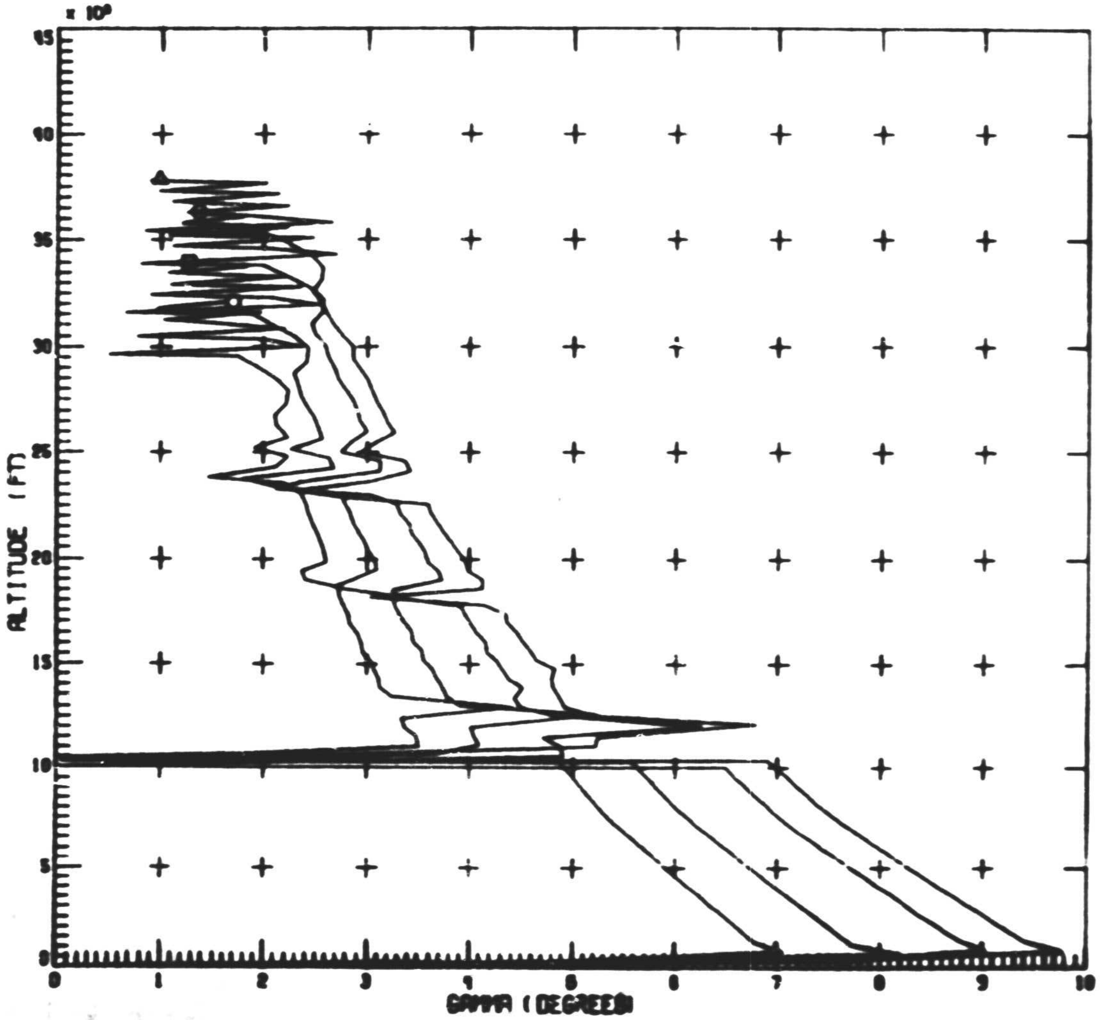

Figure 42.3

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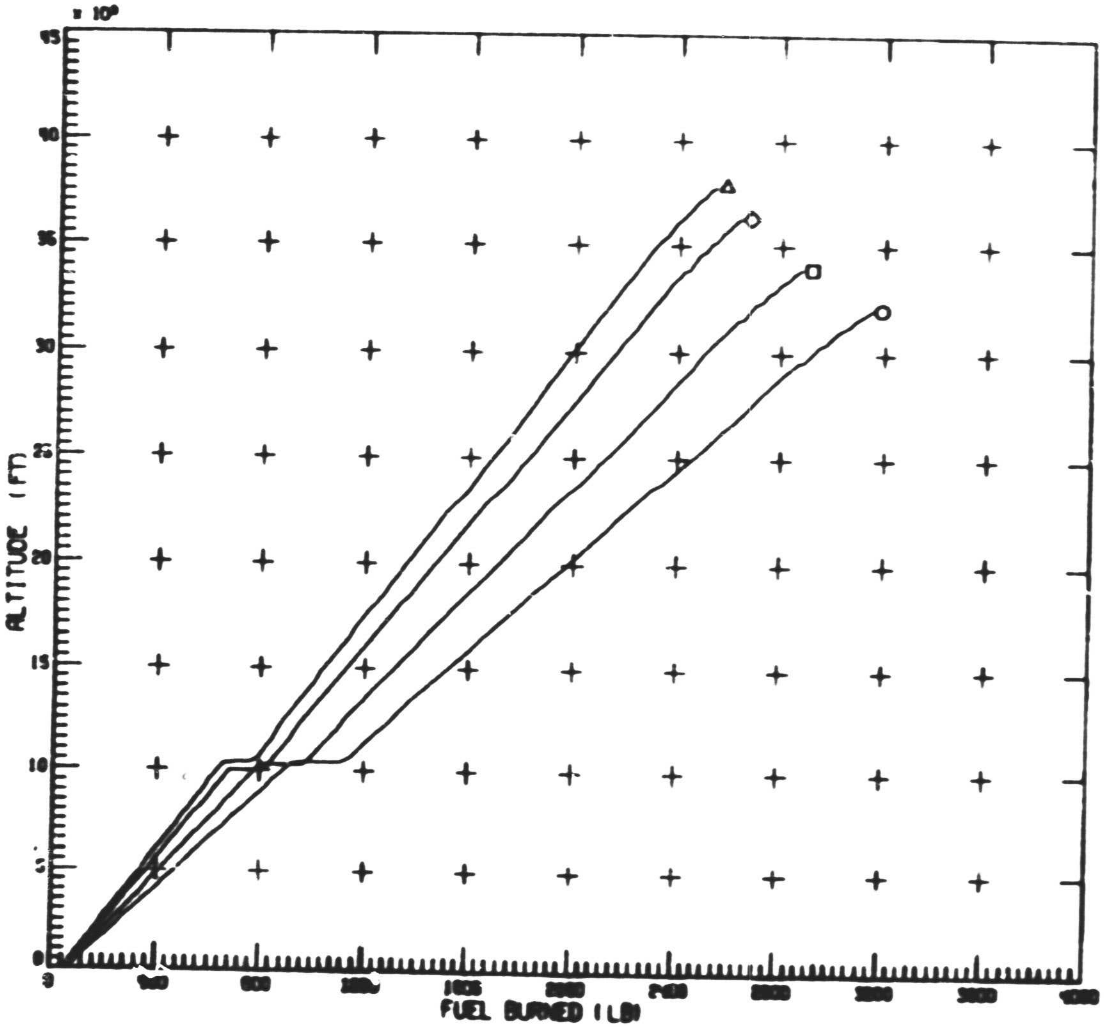

Figure 42.4

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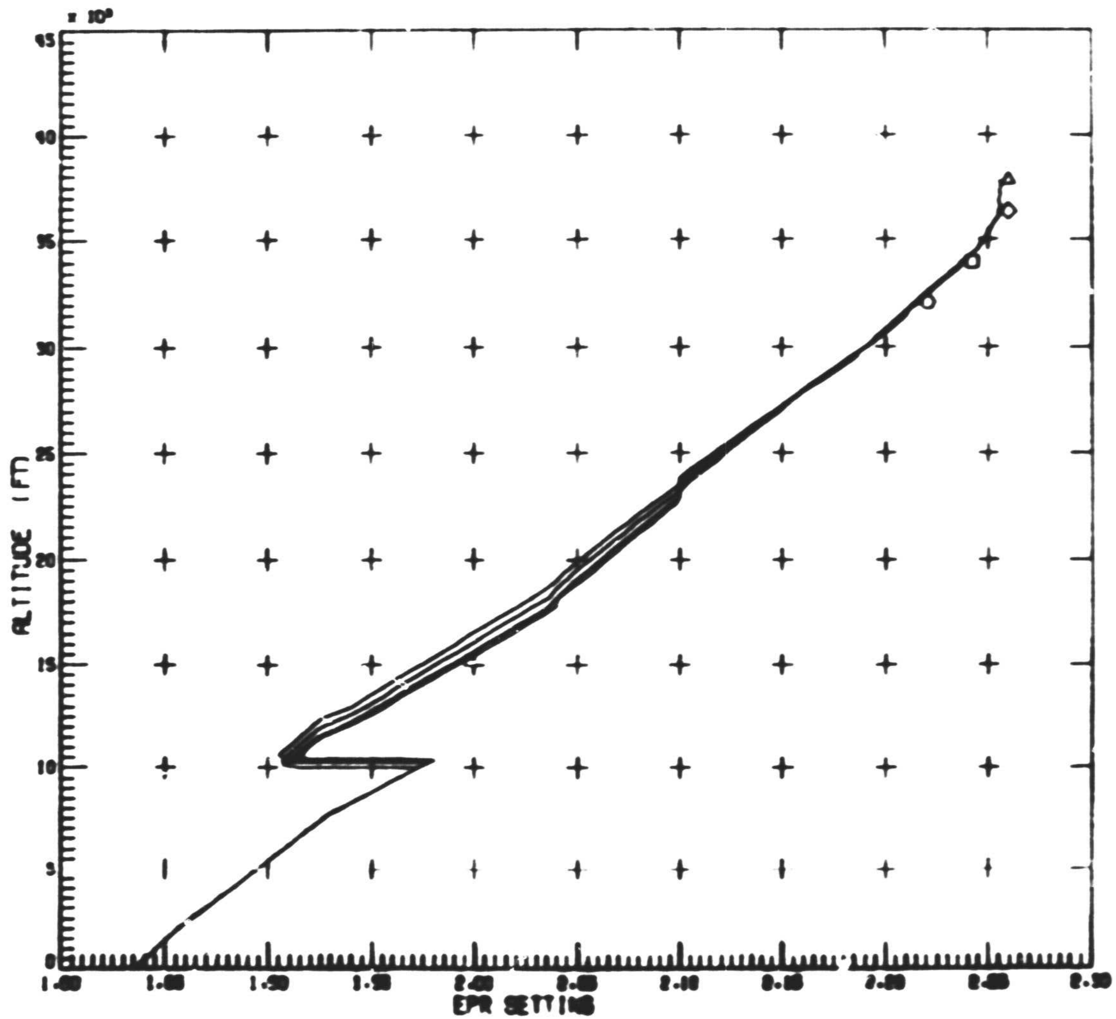

Figure 42.5

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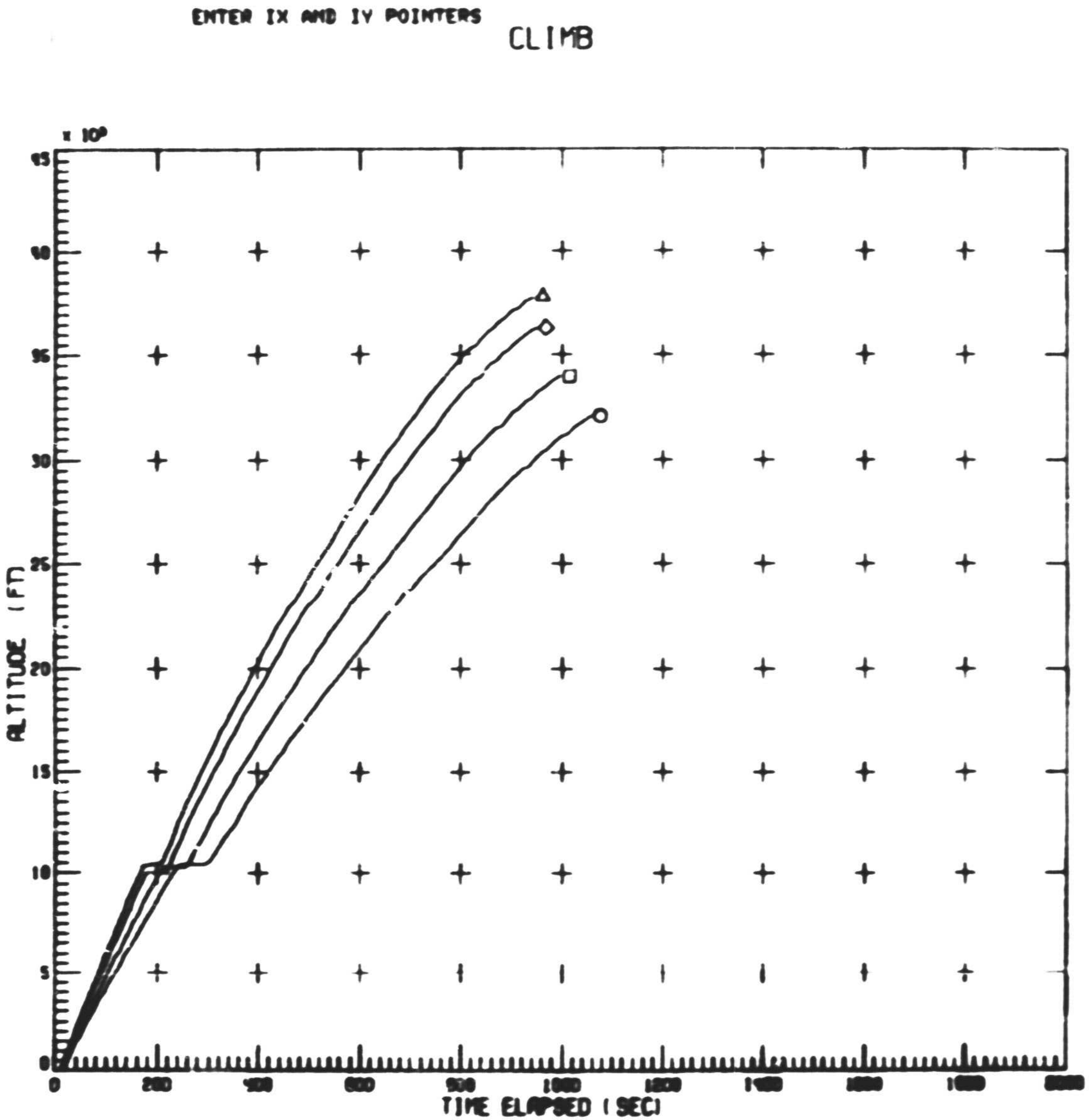

Figure 42.6

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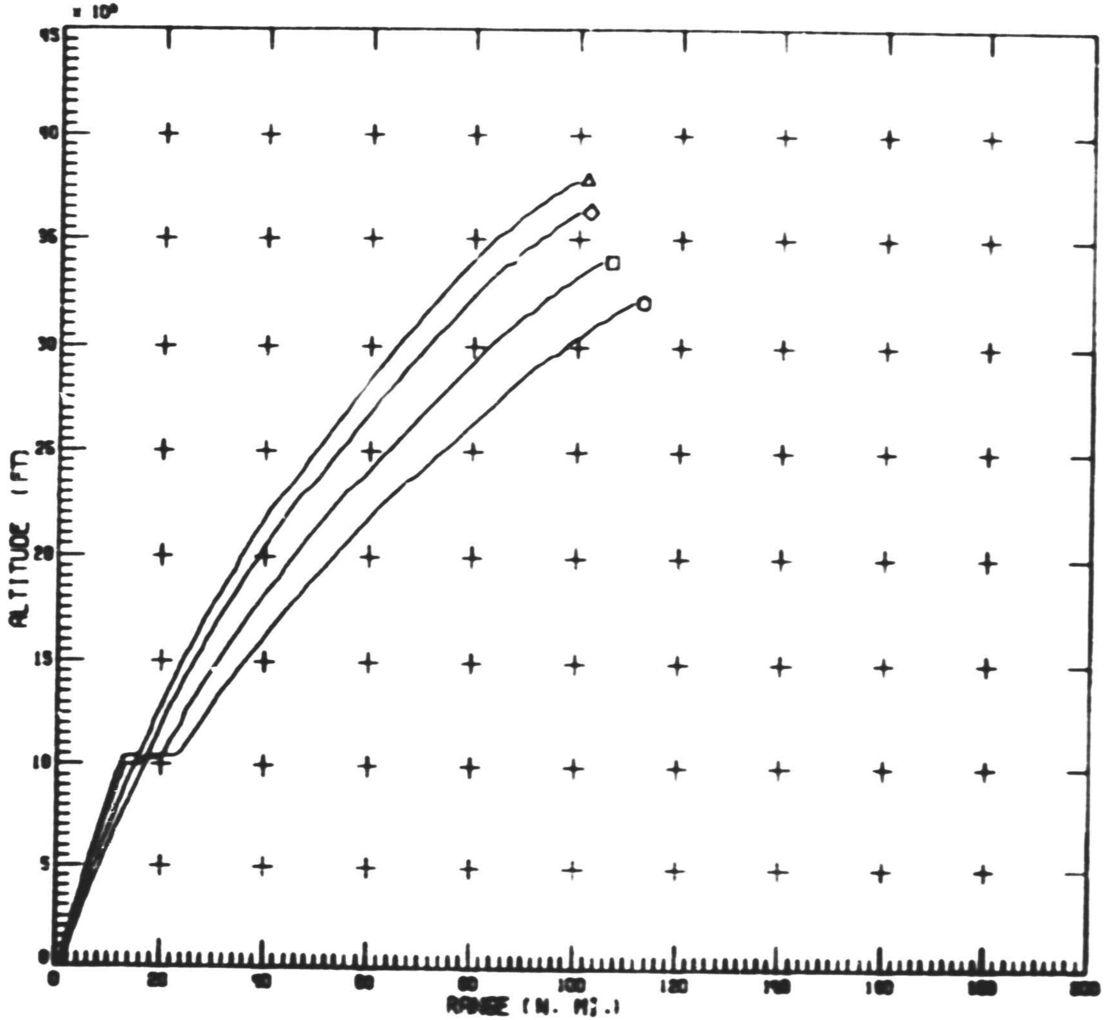

Figure 42.7

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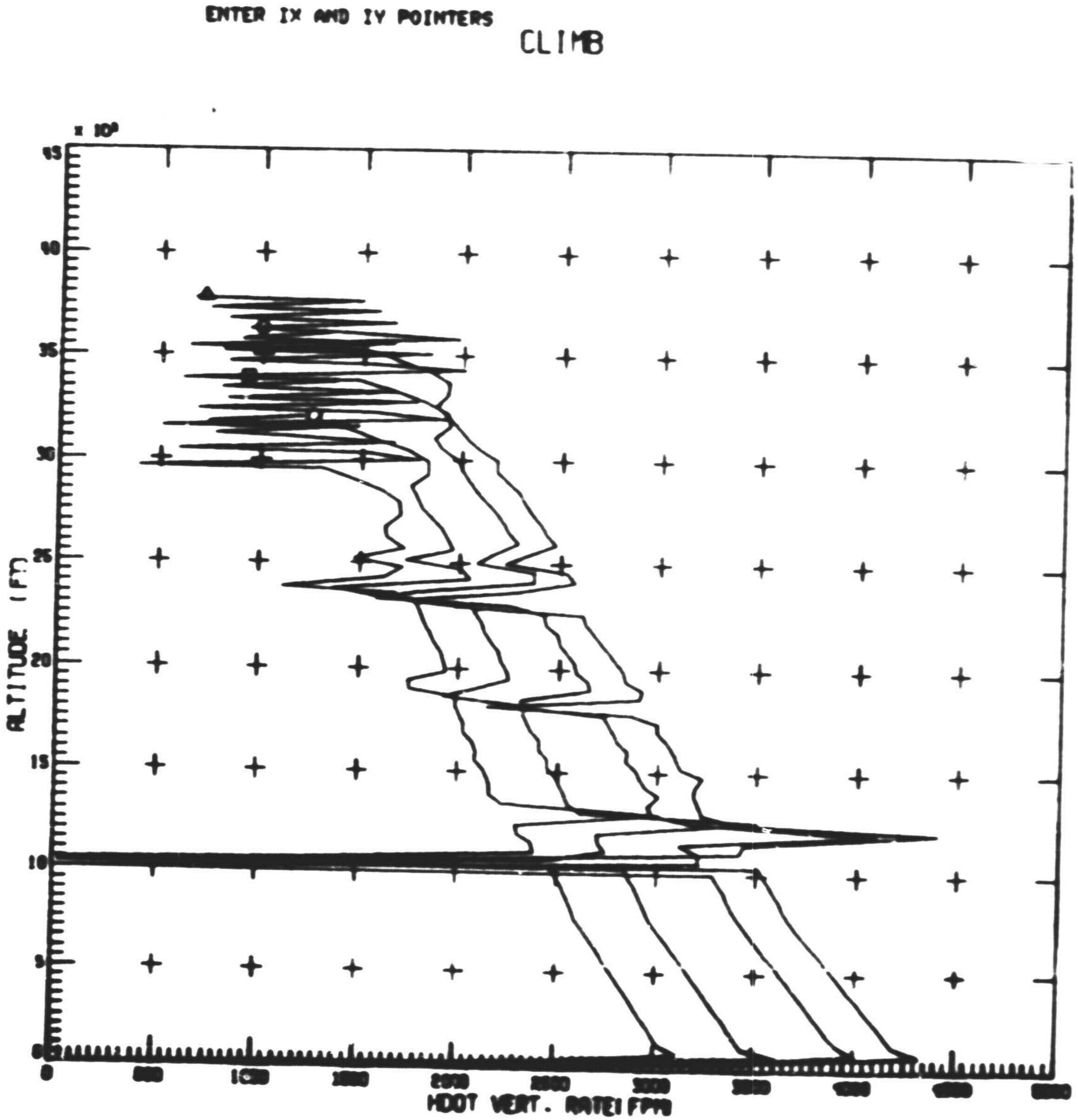

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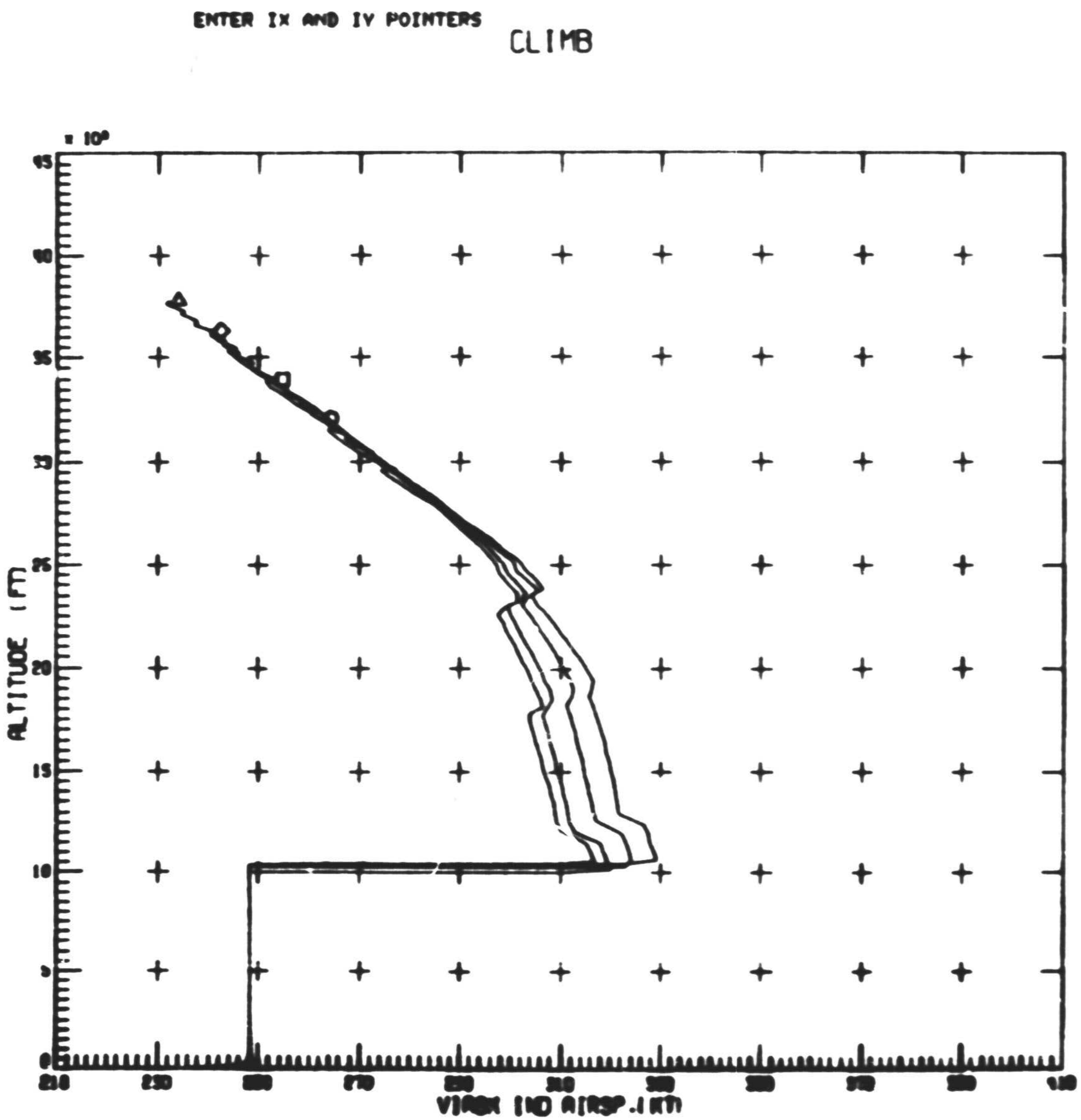

Figure 42.9

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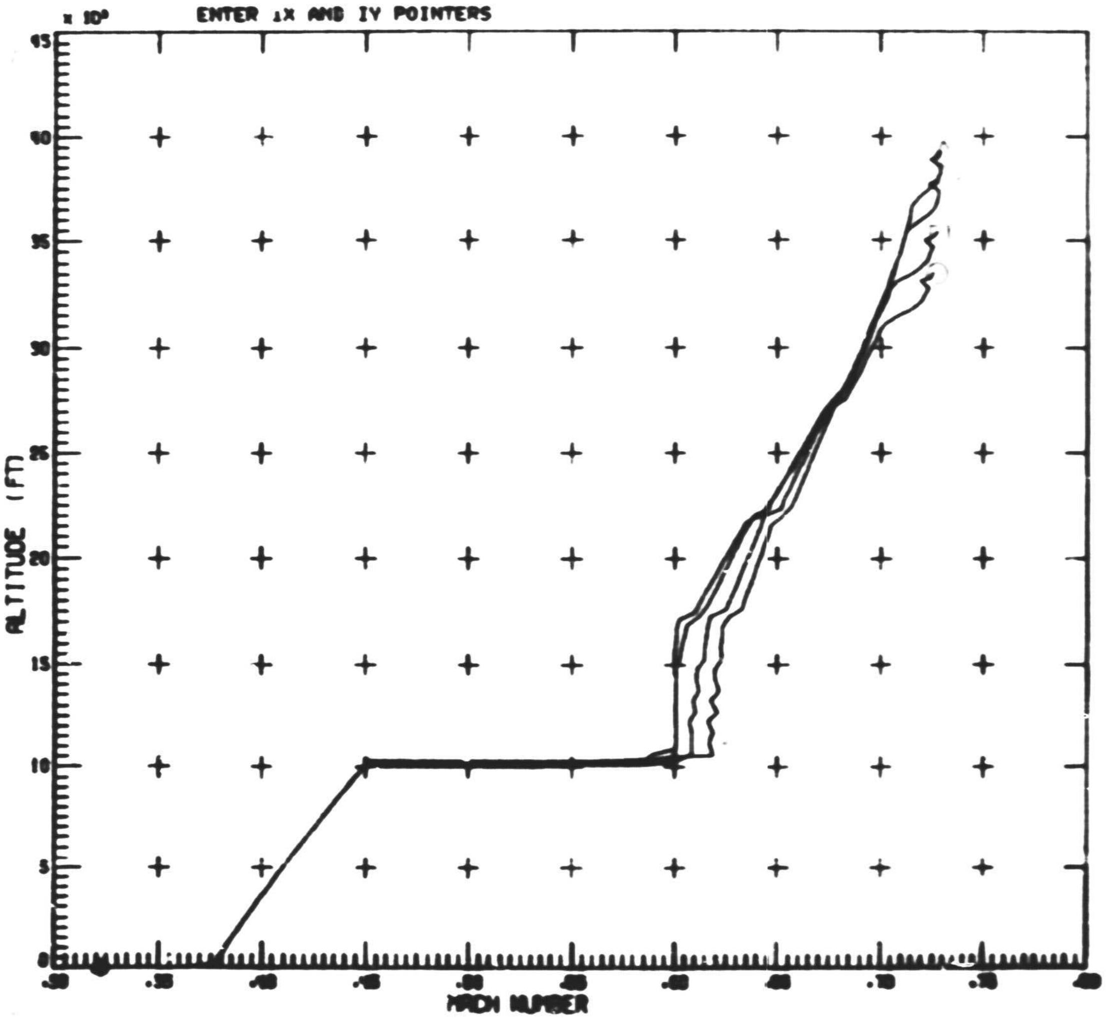

Figure 42.10

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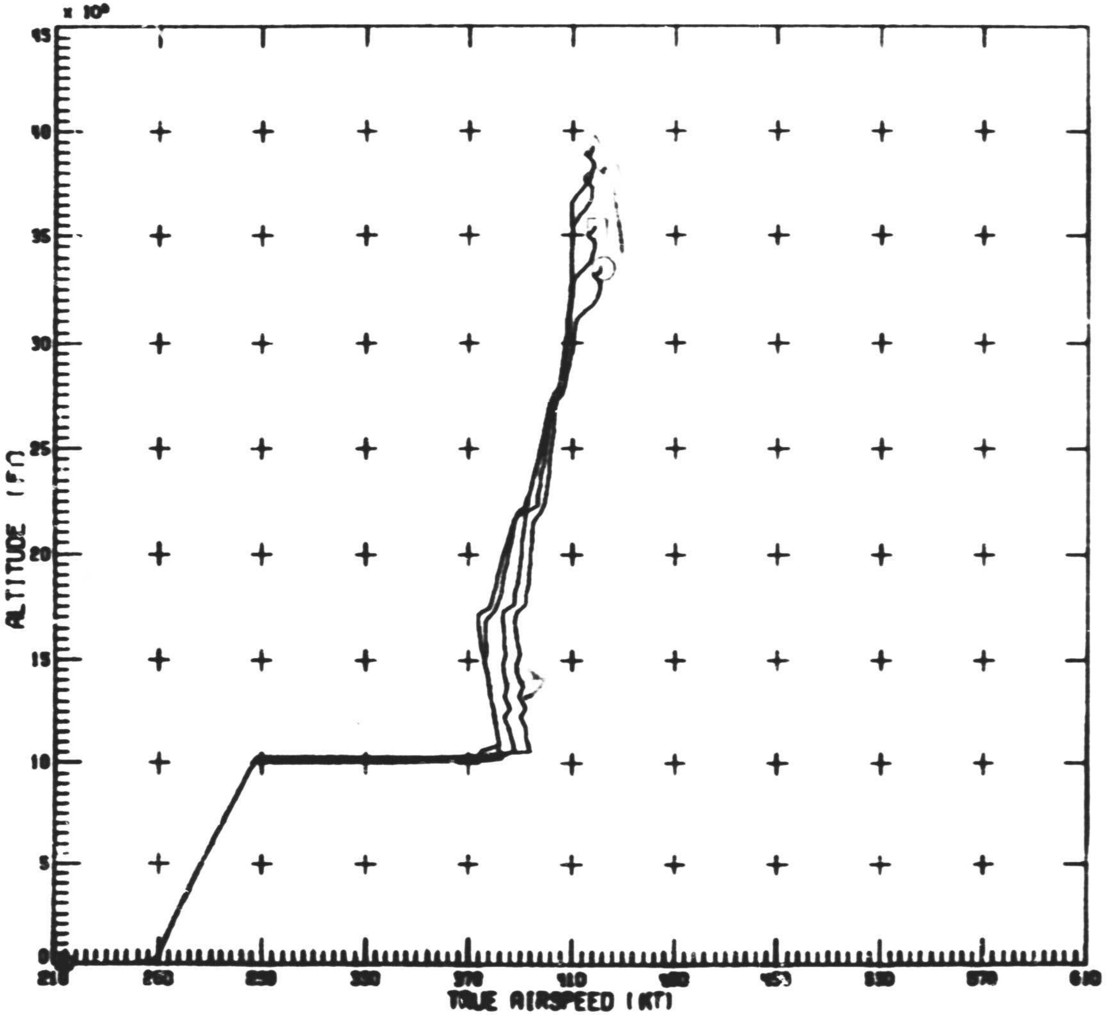

Figure 42.11

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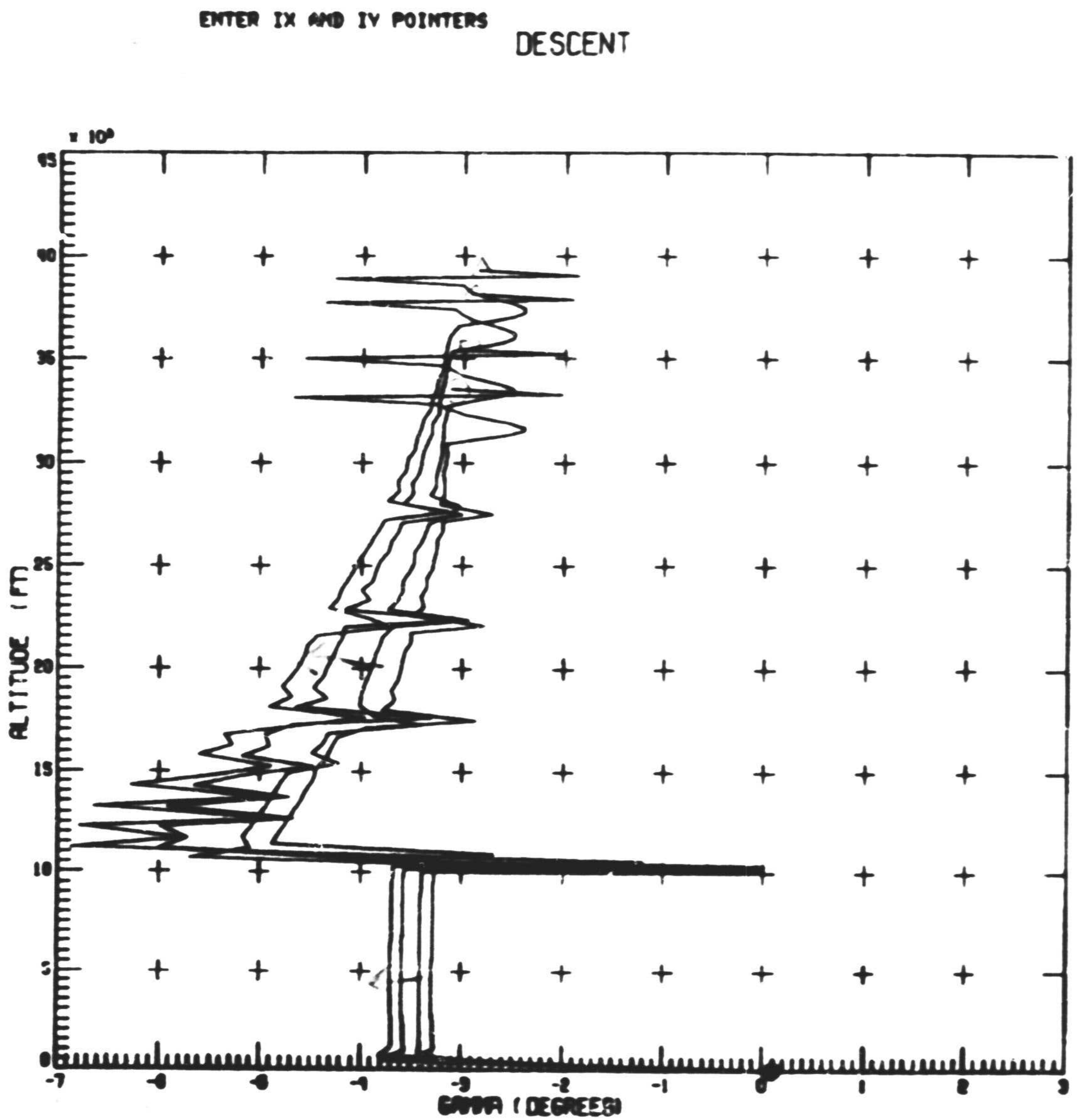

Figure 42.12

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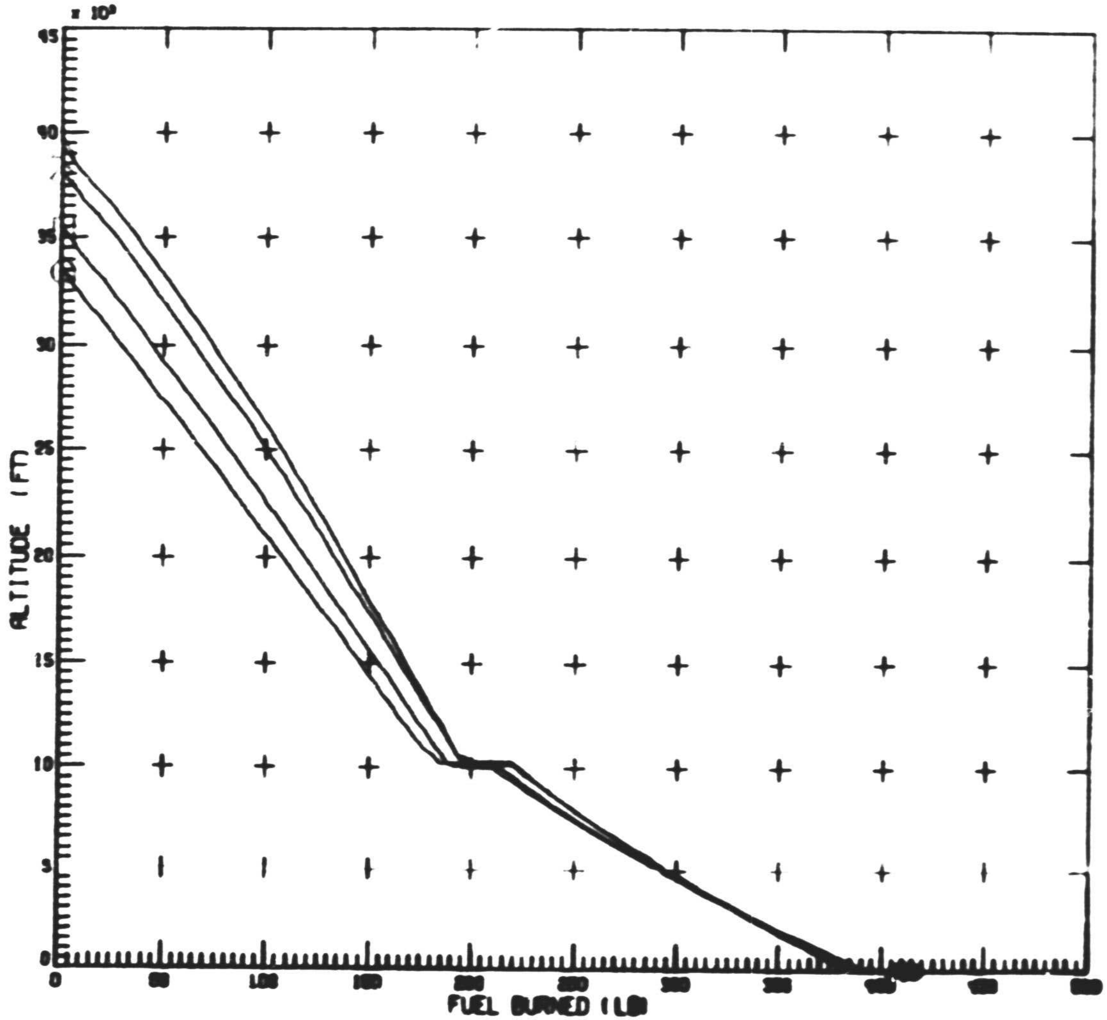

Figure 42.13

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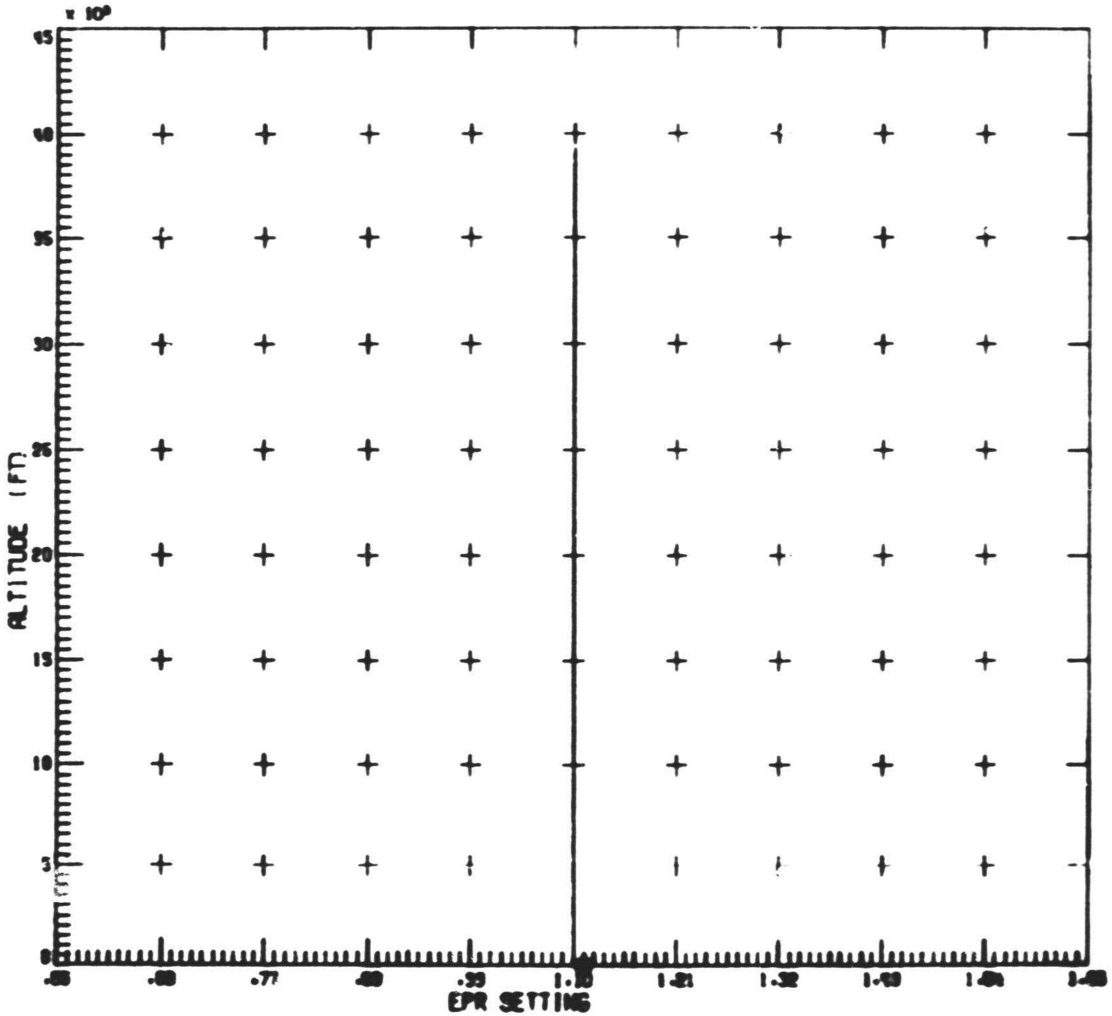

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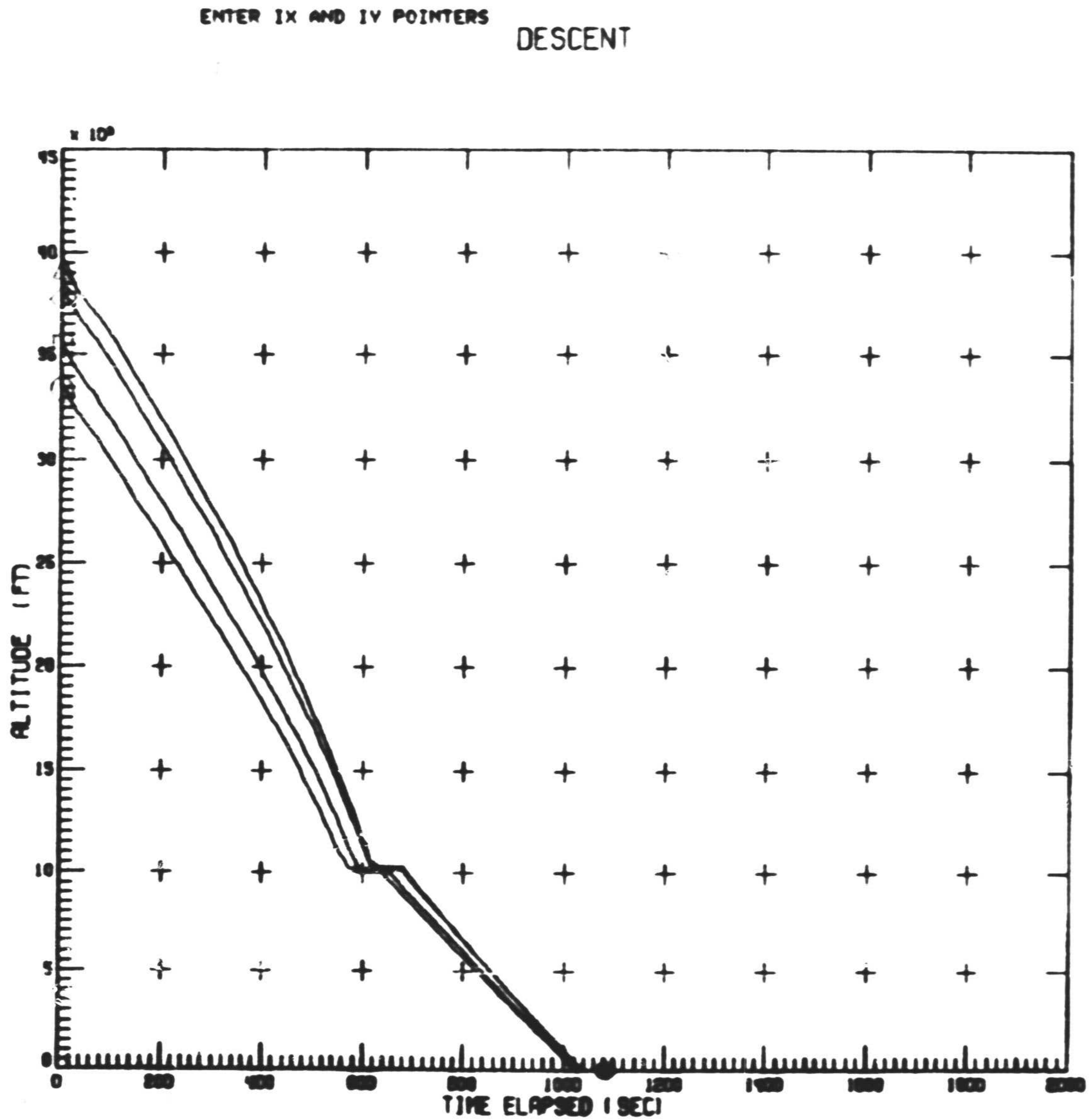

Figure 42.15

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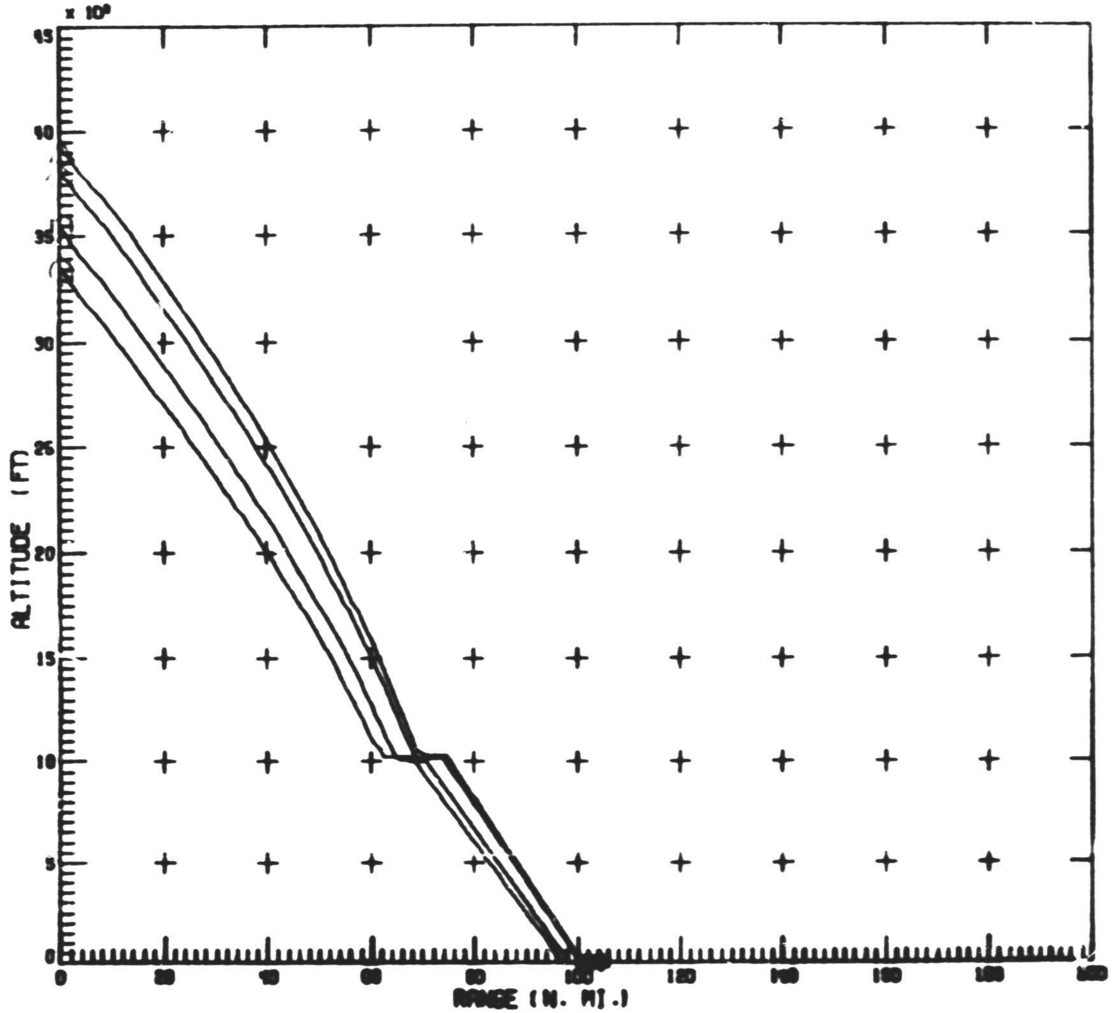

Figure 42.16

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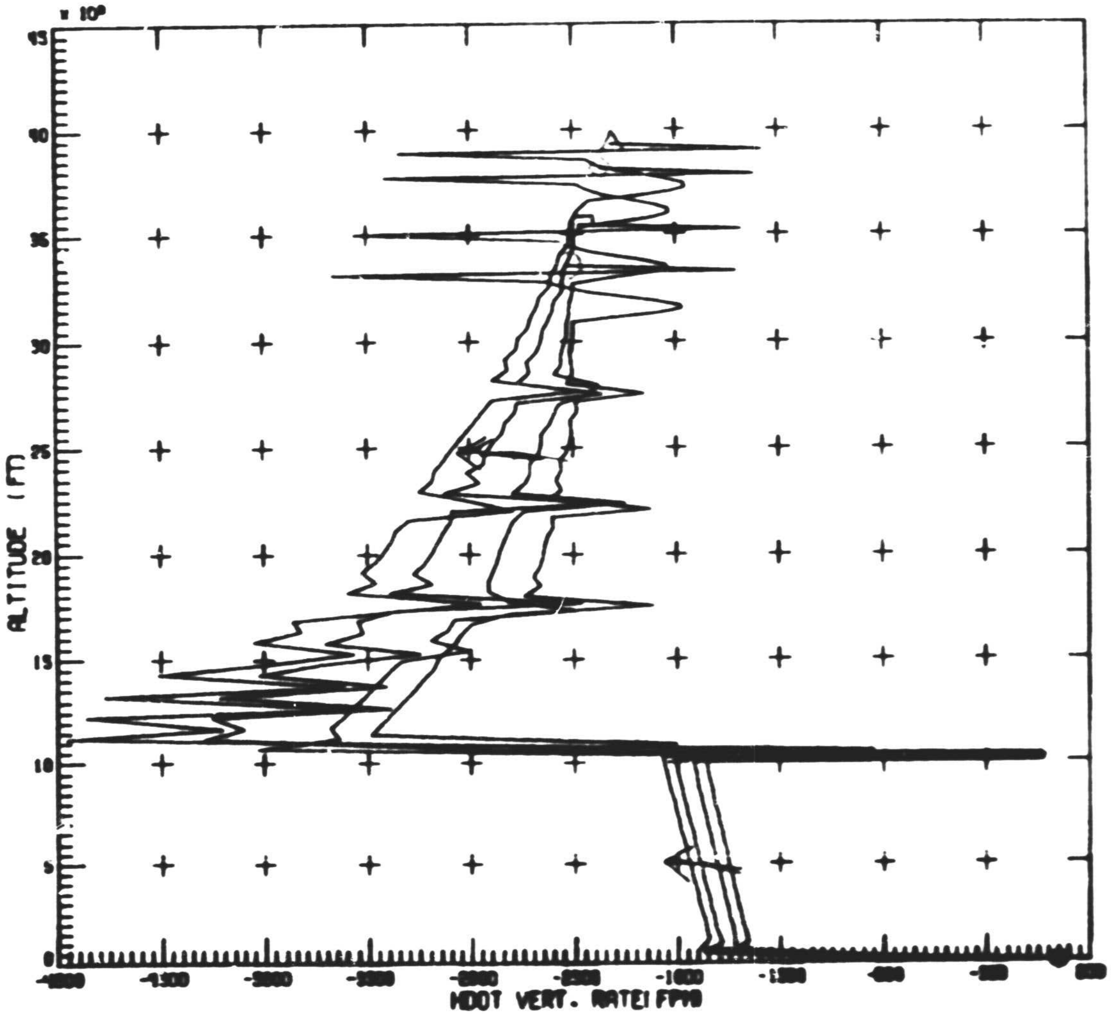

Figure 42.17

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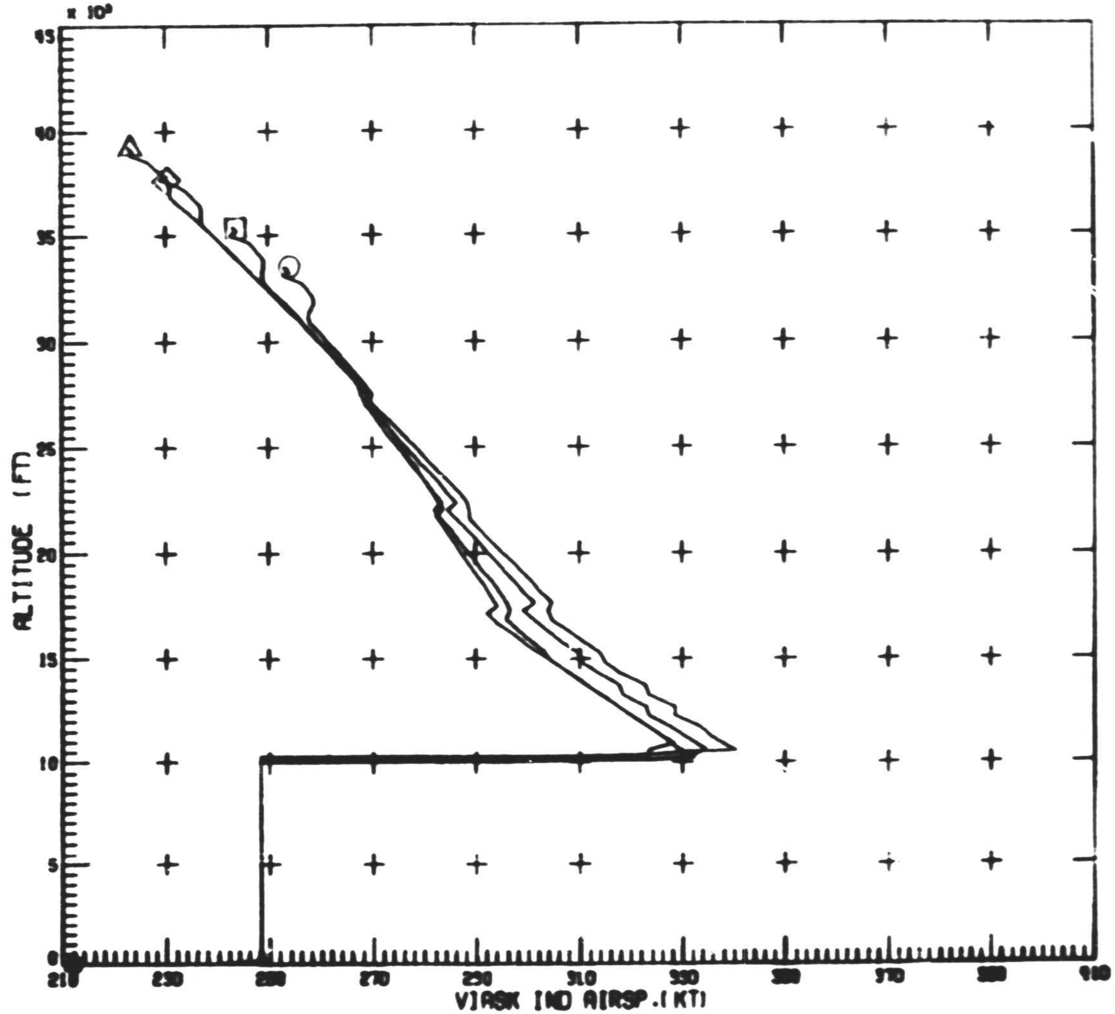

Figure 42.18

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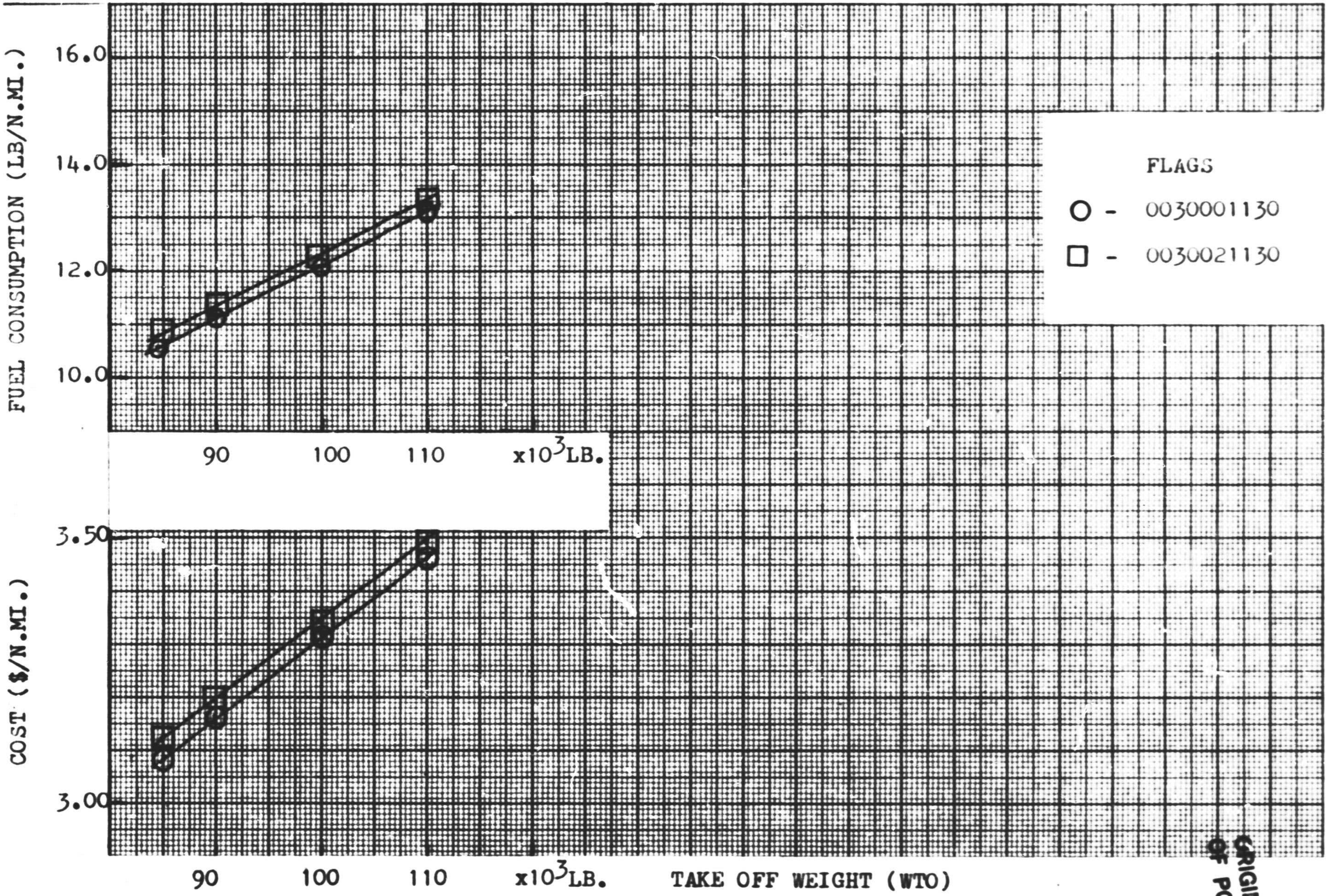

Figure 43 - Comparison of Step Climb Option vs. Variable Altitude results for DOC optimal profiles.

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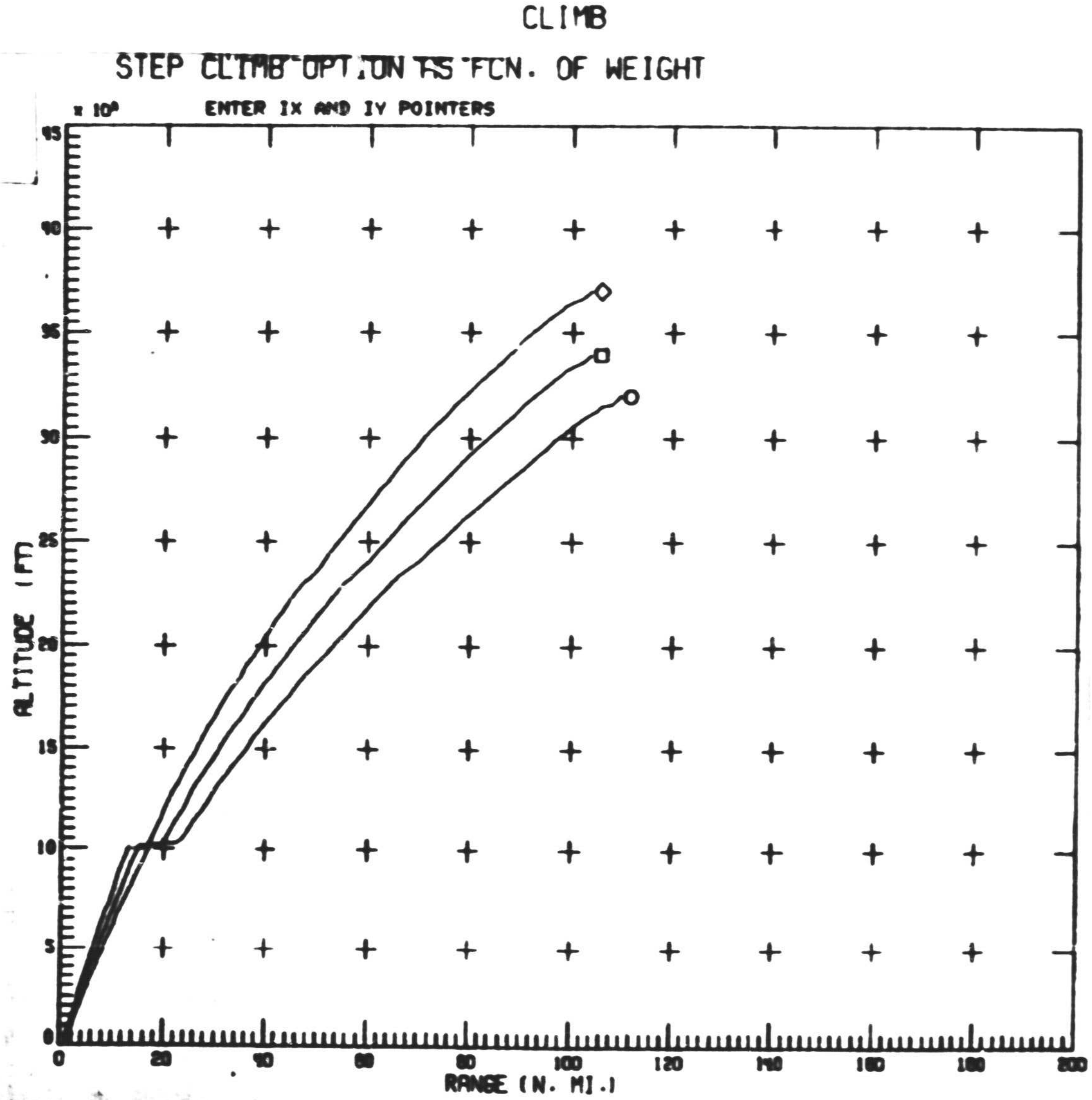

KEY FOR FIGURES 44

○ - - - - - SCL110
(110,000 LB. TAKEOFF WEIGHT)

□ - - - - - SCL100
(100,000 LB. TAKEOFF WEIGHT)

◇ - - - - - SCL090
(90,000 LB. TAKEOFF WEIGHT)

FLAGS

0030021130

Figure 44.1 - Step Climb trajectories as functions of initial weight at 750 N.MI.

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CLIMB

STEP CLIMB OPTION AS FCN. OF WEIGHT

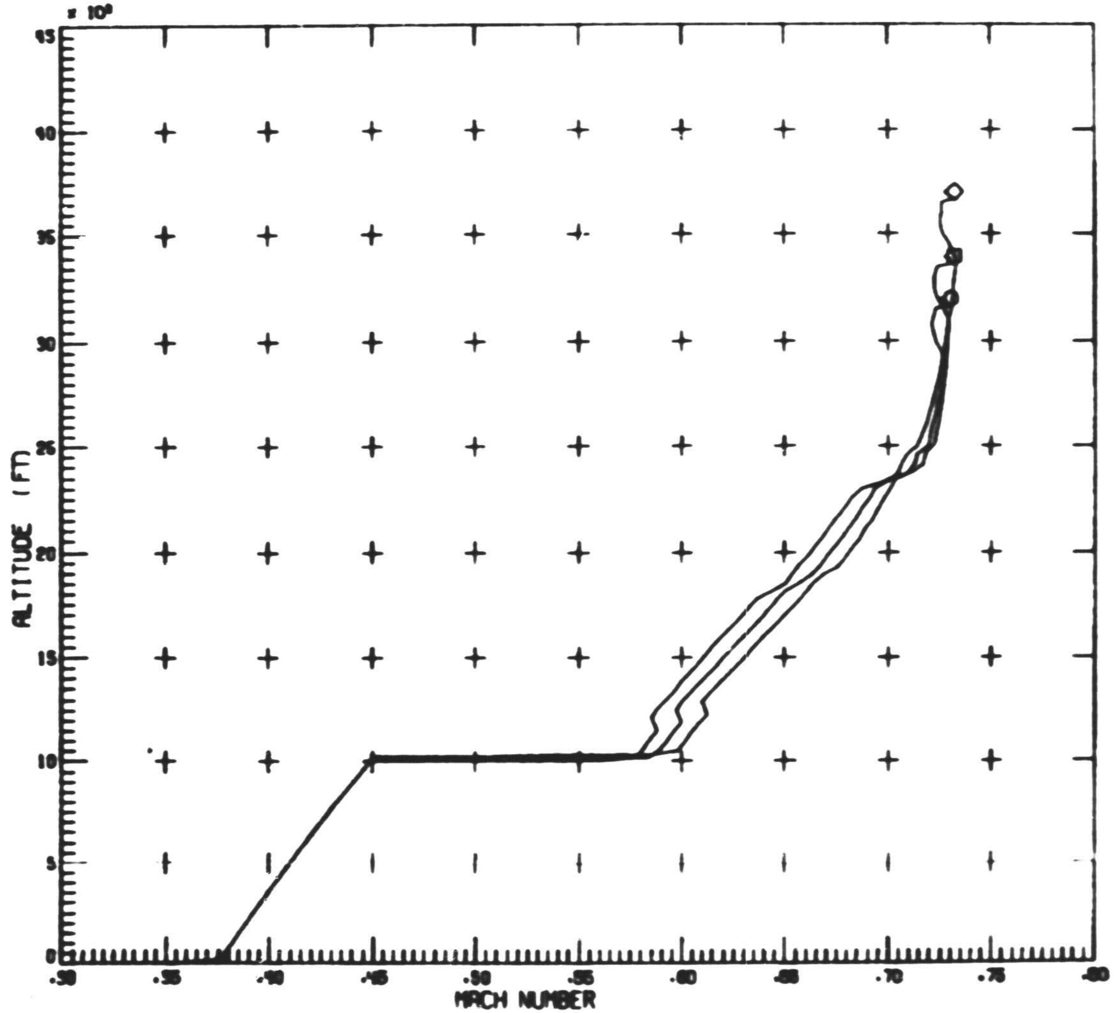

Figure 44.2

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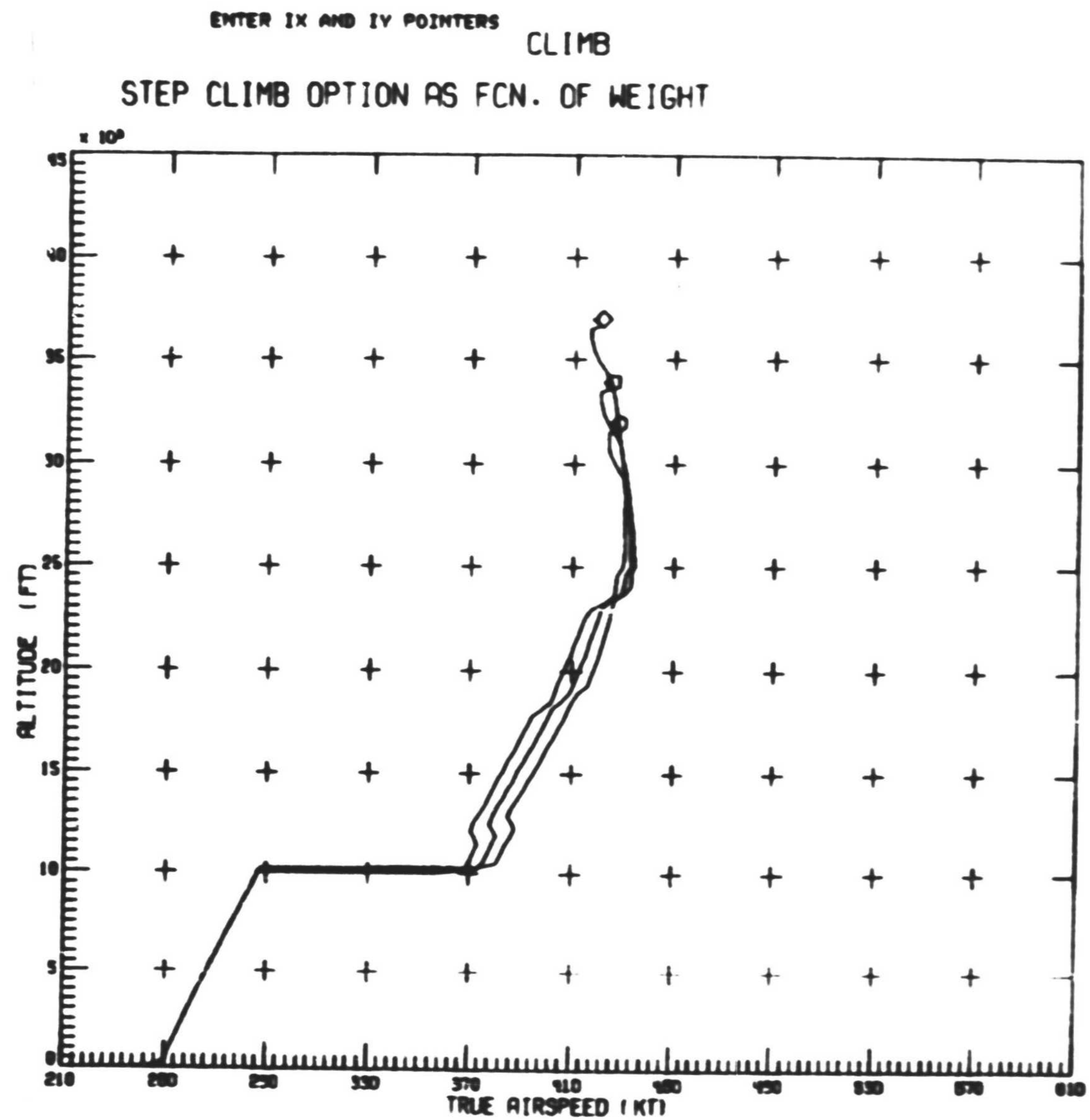

Figure 44.3

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CLIMB

STEP CLIMB OPTION AS FCN. OF WEIGHT

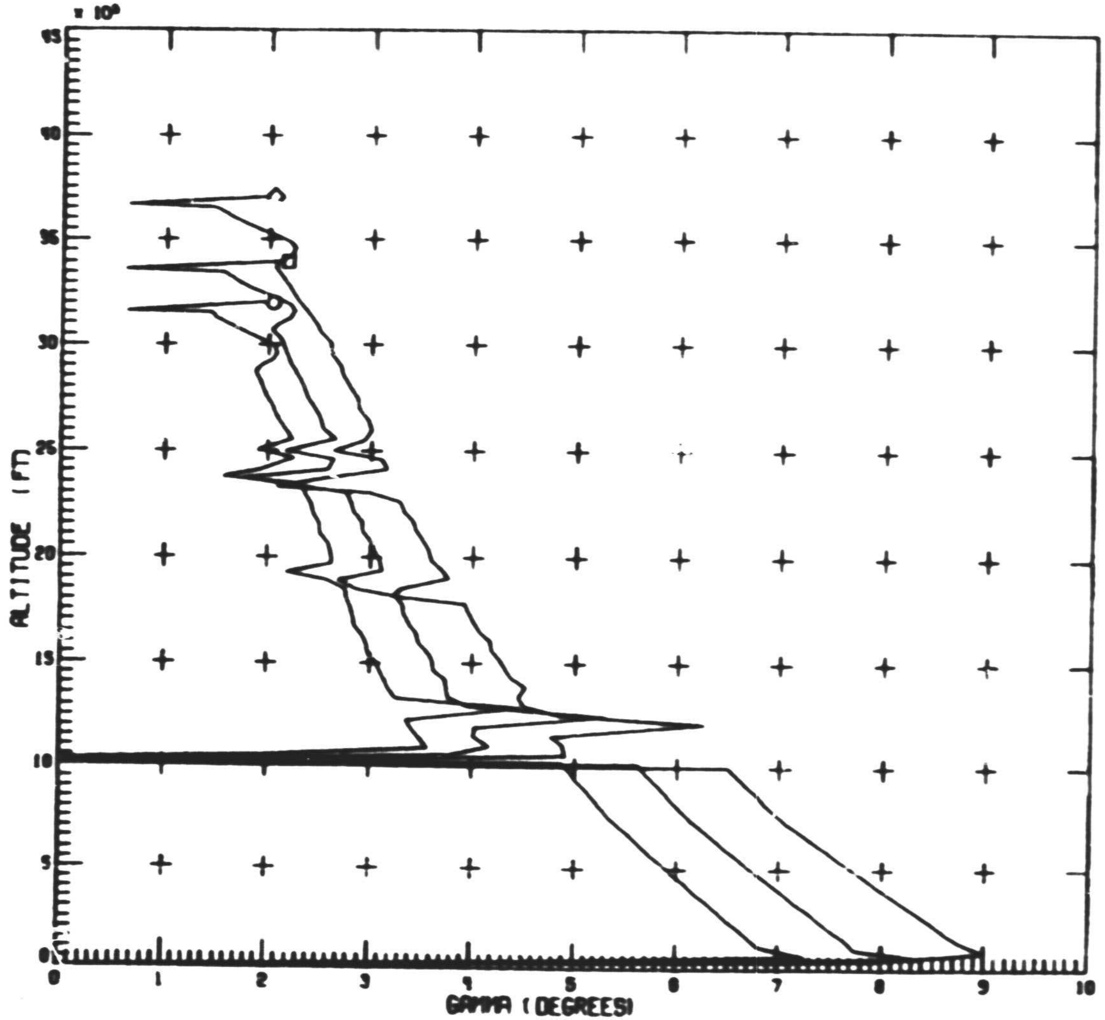

Figure 44.4

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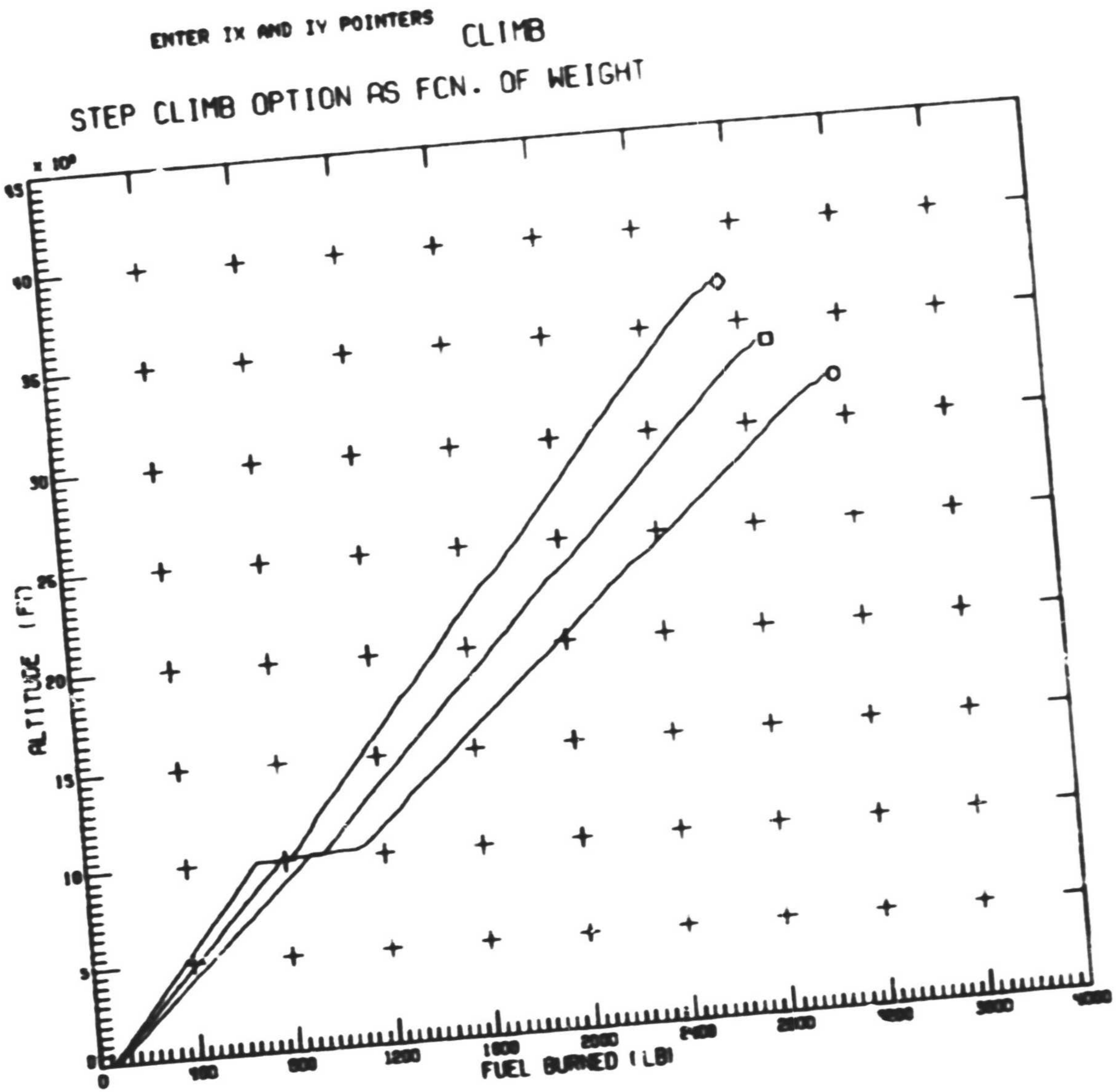

Figure 44.5

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STEP CLIMB OPTION AS FCN. OF WEIGHT

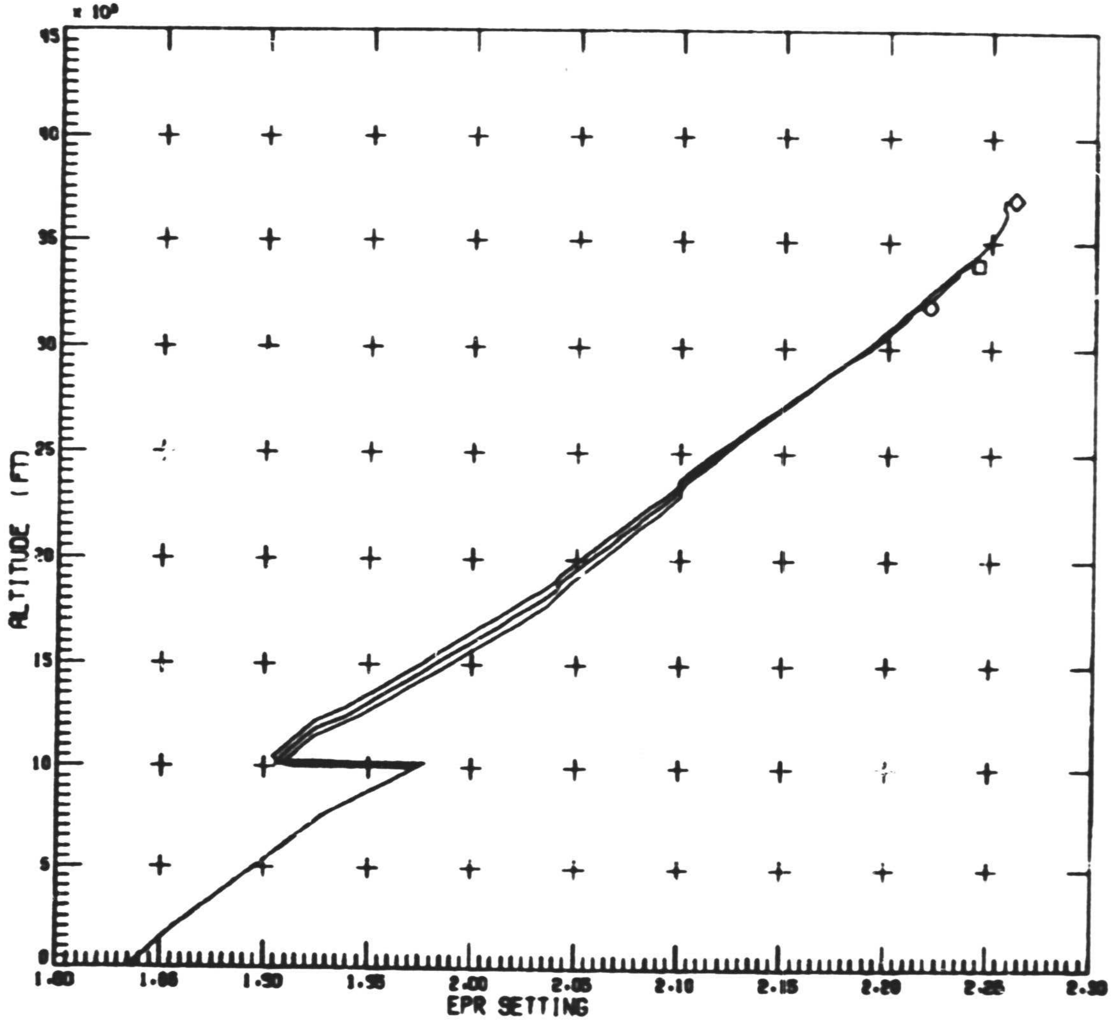

Figure 44.6

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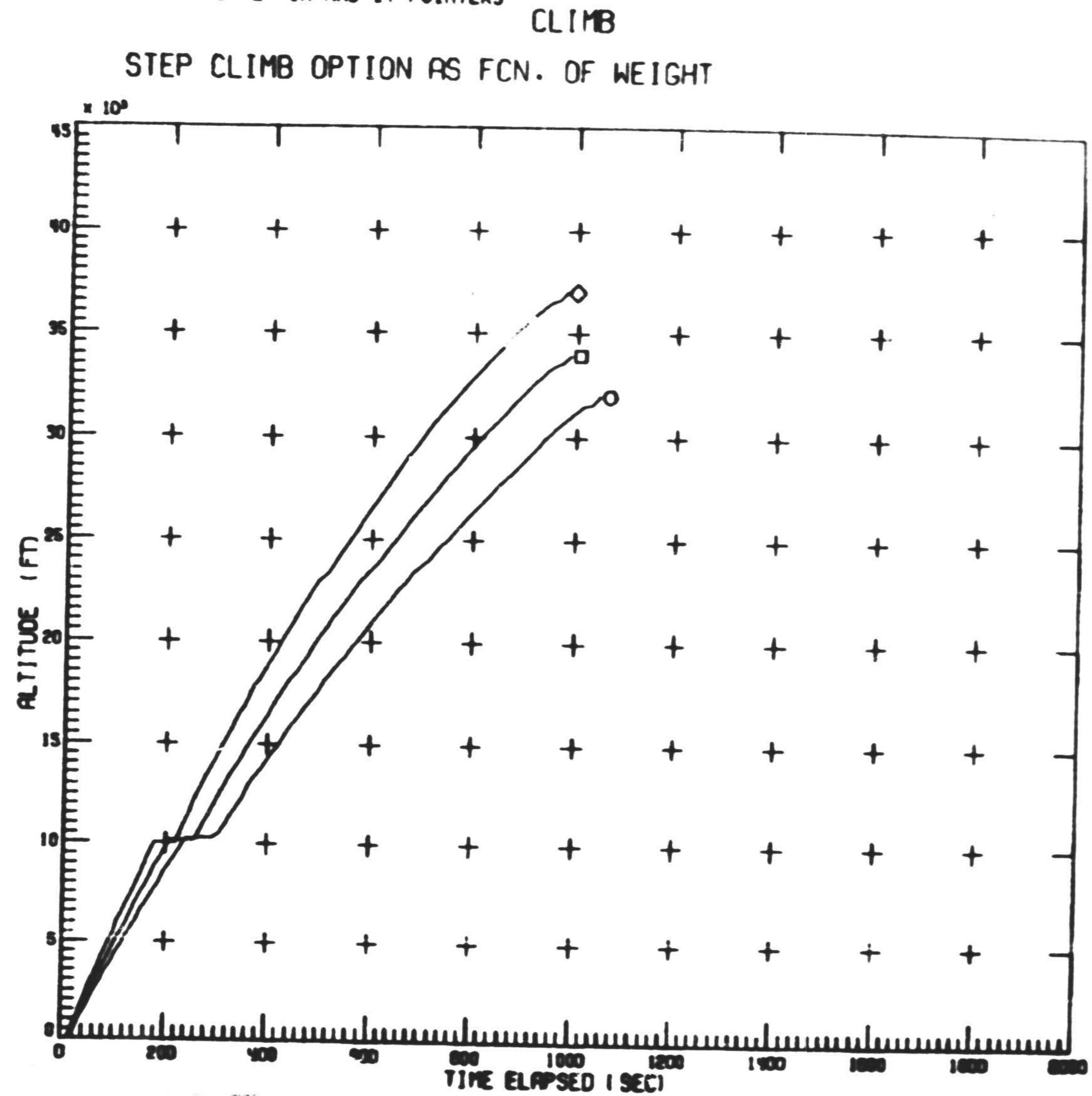

Figure 44.7

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CLIMB

STEP CLIMB OPTION AS FCN. OF WEIGHT

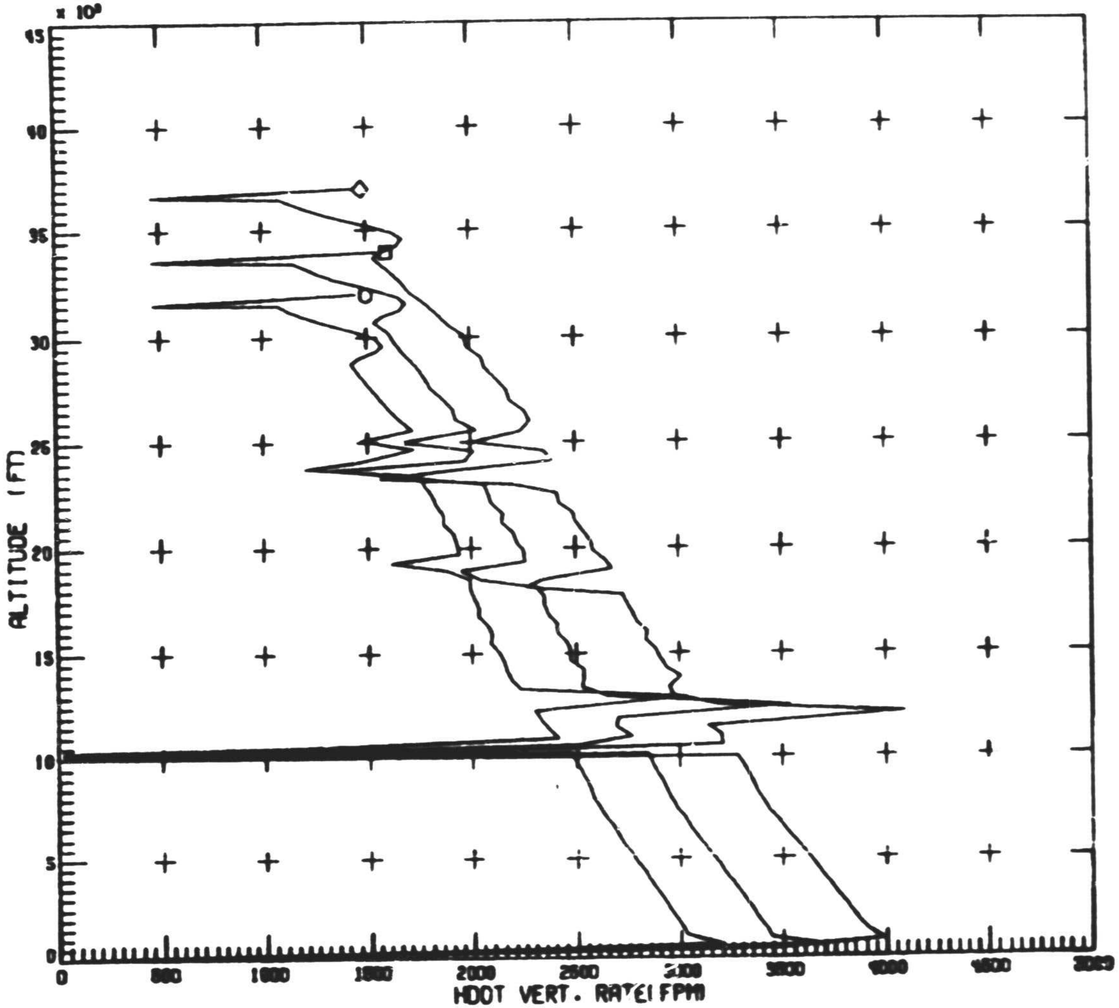

Figure 44.8

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CLIMB

STEP CLIMB OPTION AS FCN. OF WEIGHT

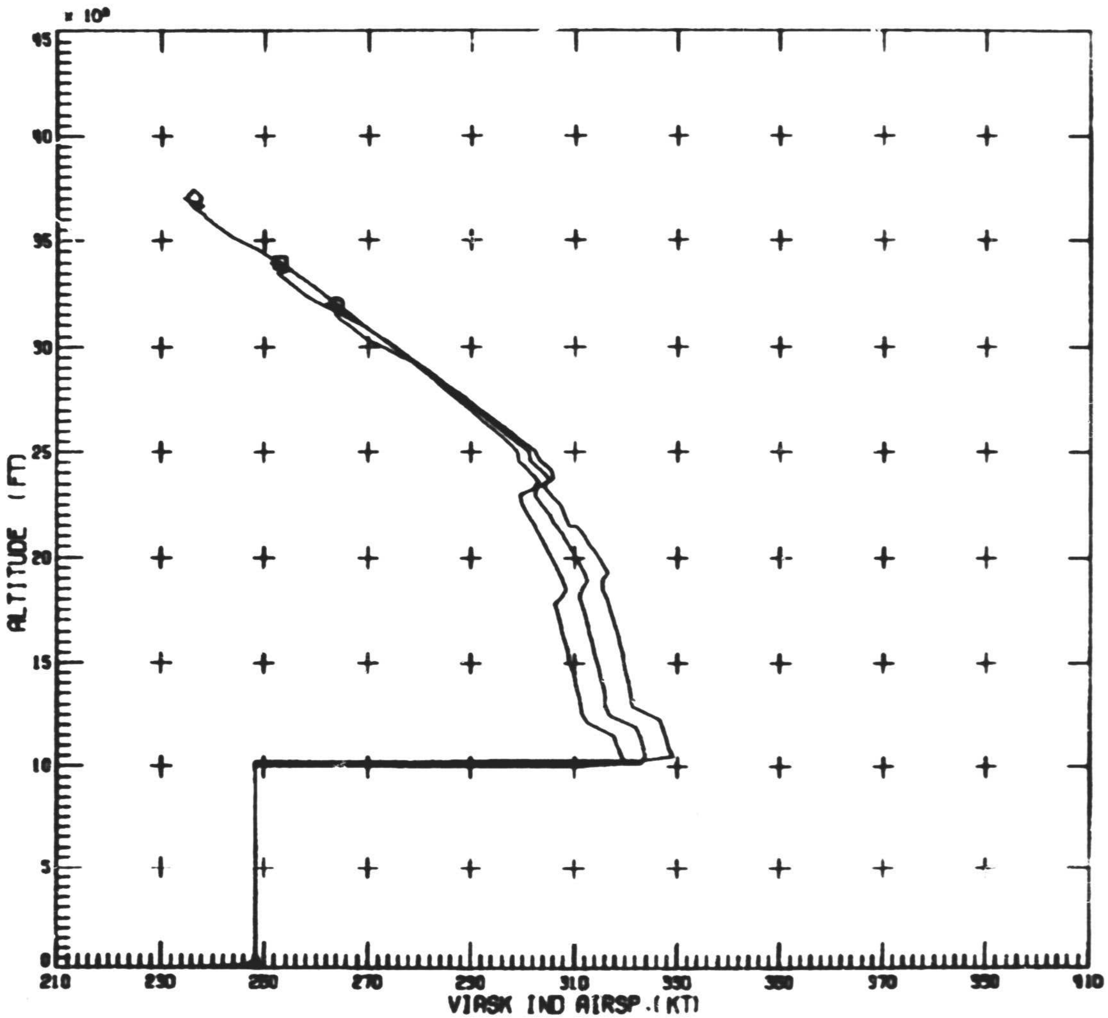

Figure 44.9

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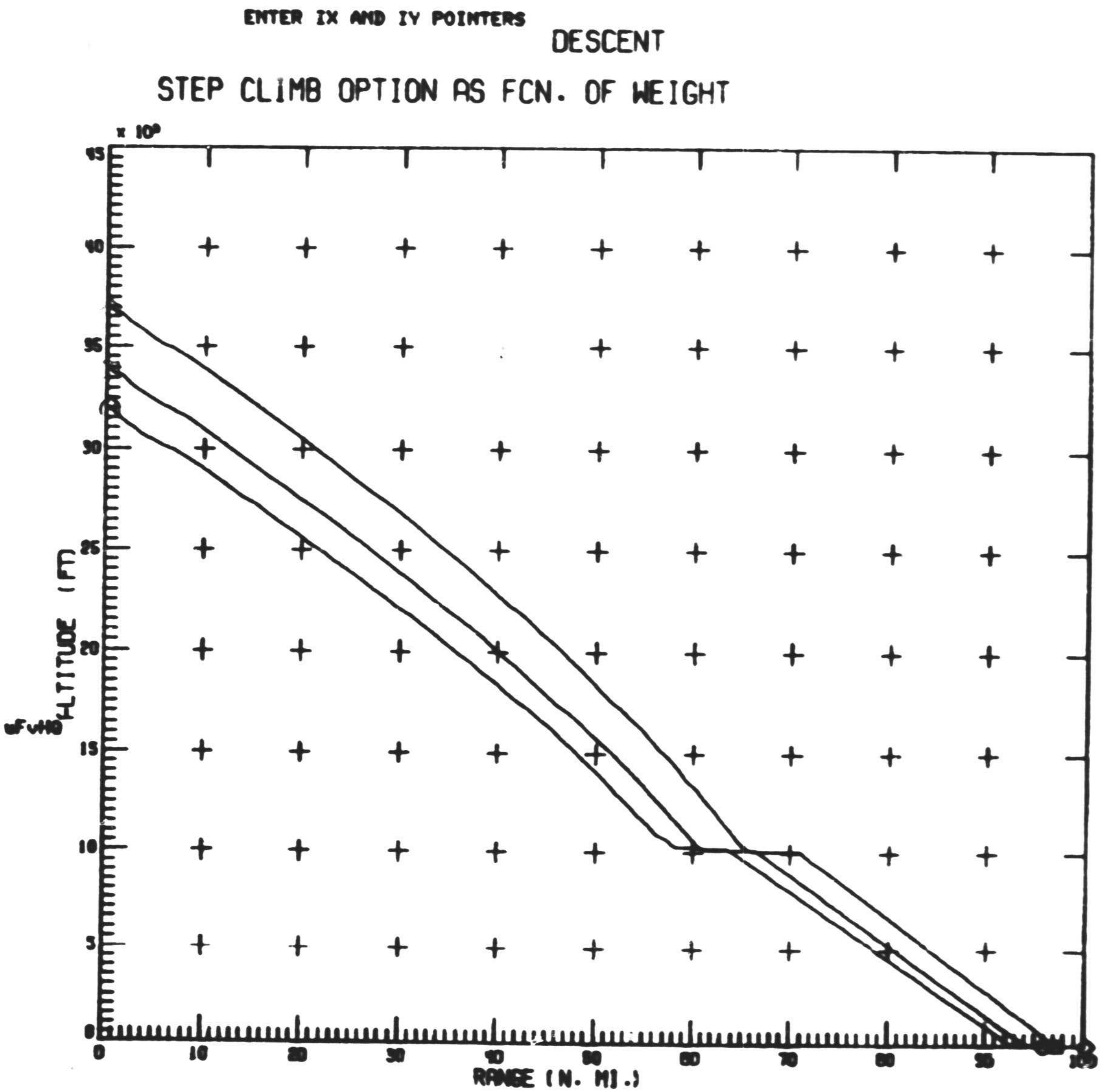

Figure 44.10

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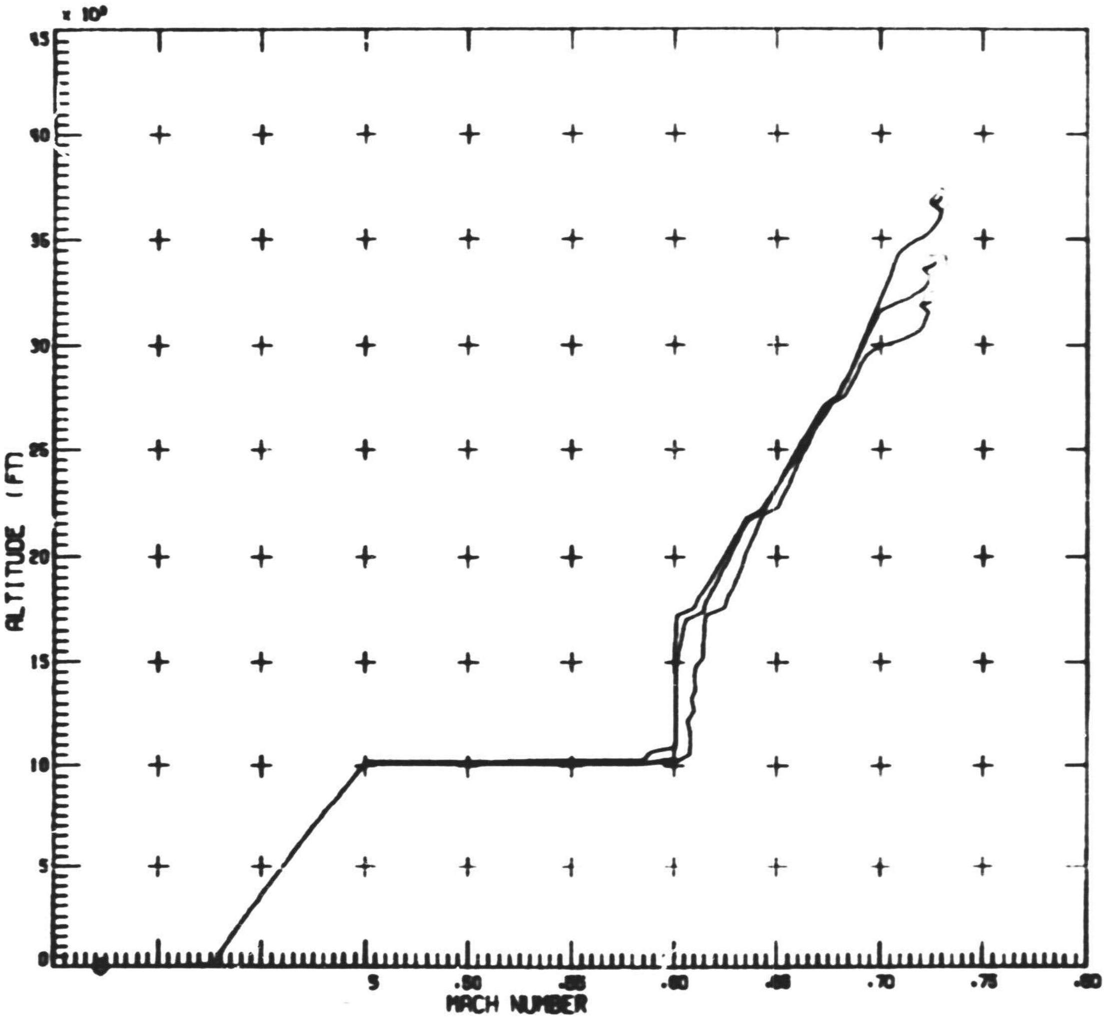
STEP CLIMB OPTION AS FCN. OF WEIGHT



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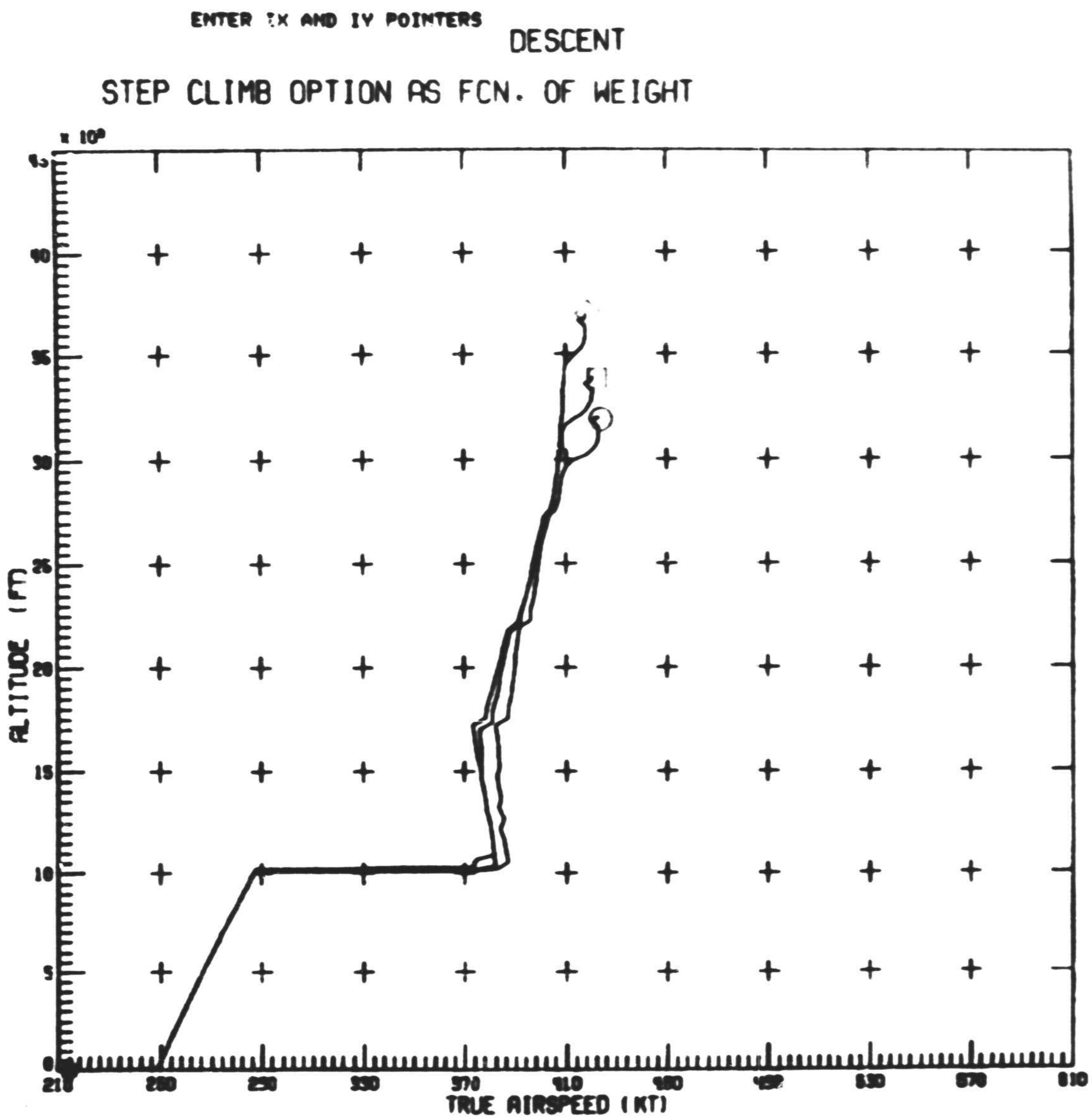

Figure 44.12

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ENTER IX AND IV POINTERS

DESCENT

STEP CLIMB OPTION AS FCN. OF WEIGHT

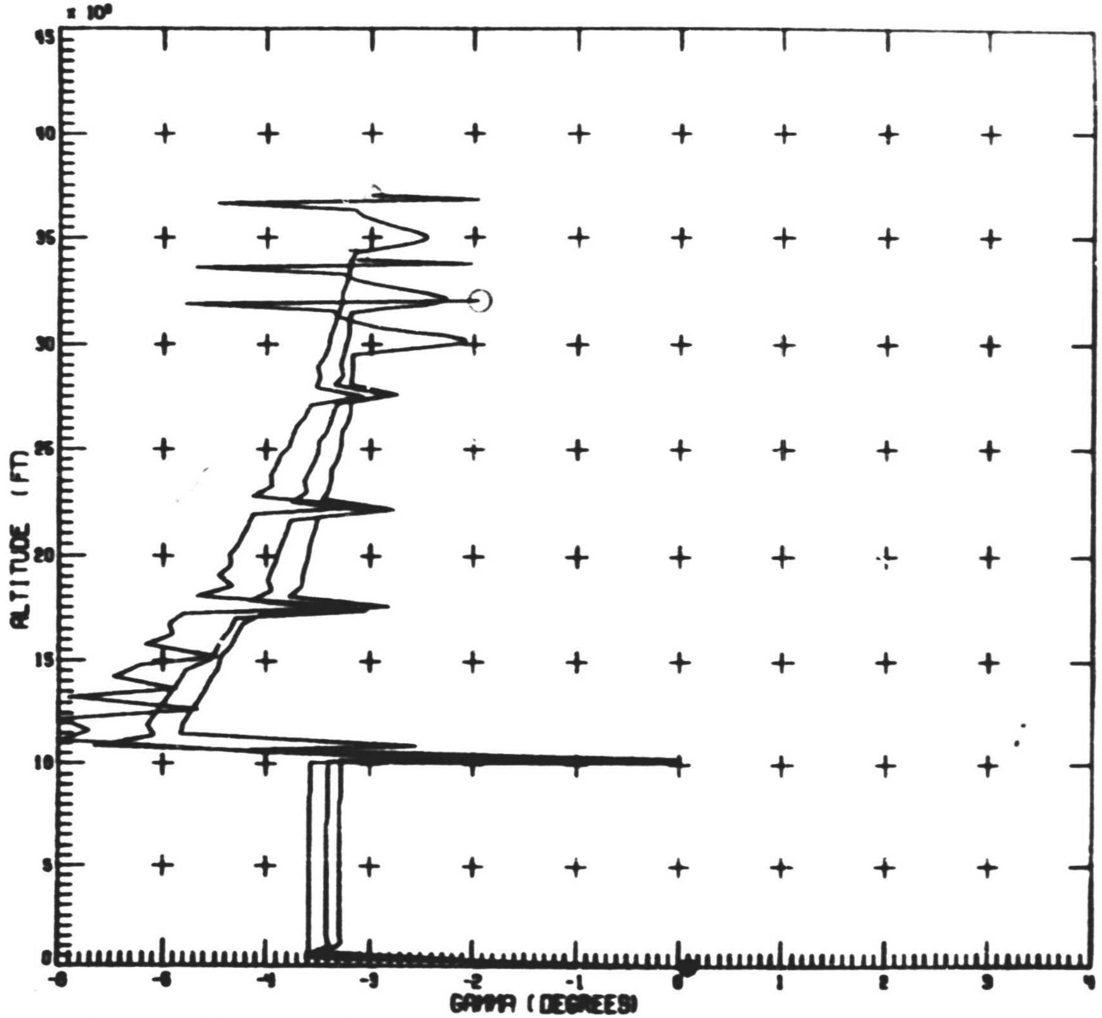

Figure 44.13

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STEP CLIMB OPTION AS FCN. OF WEIGHT

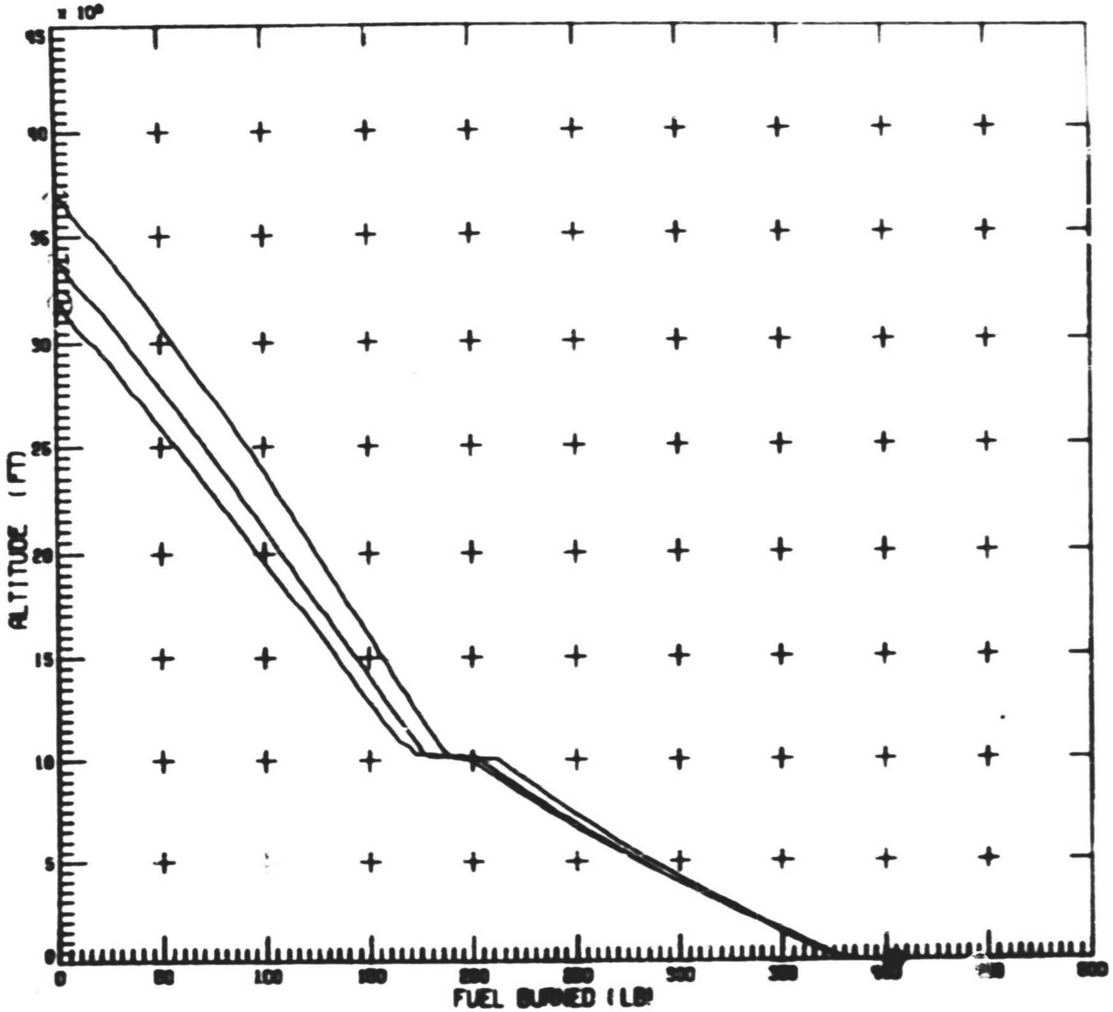

Figure 44.14

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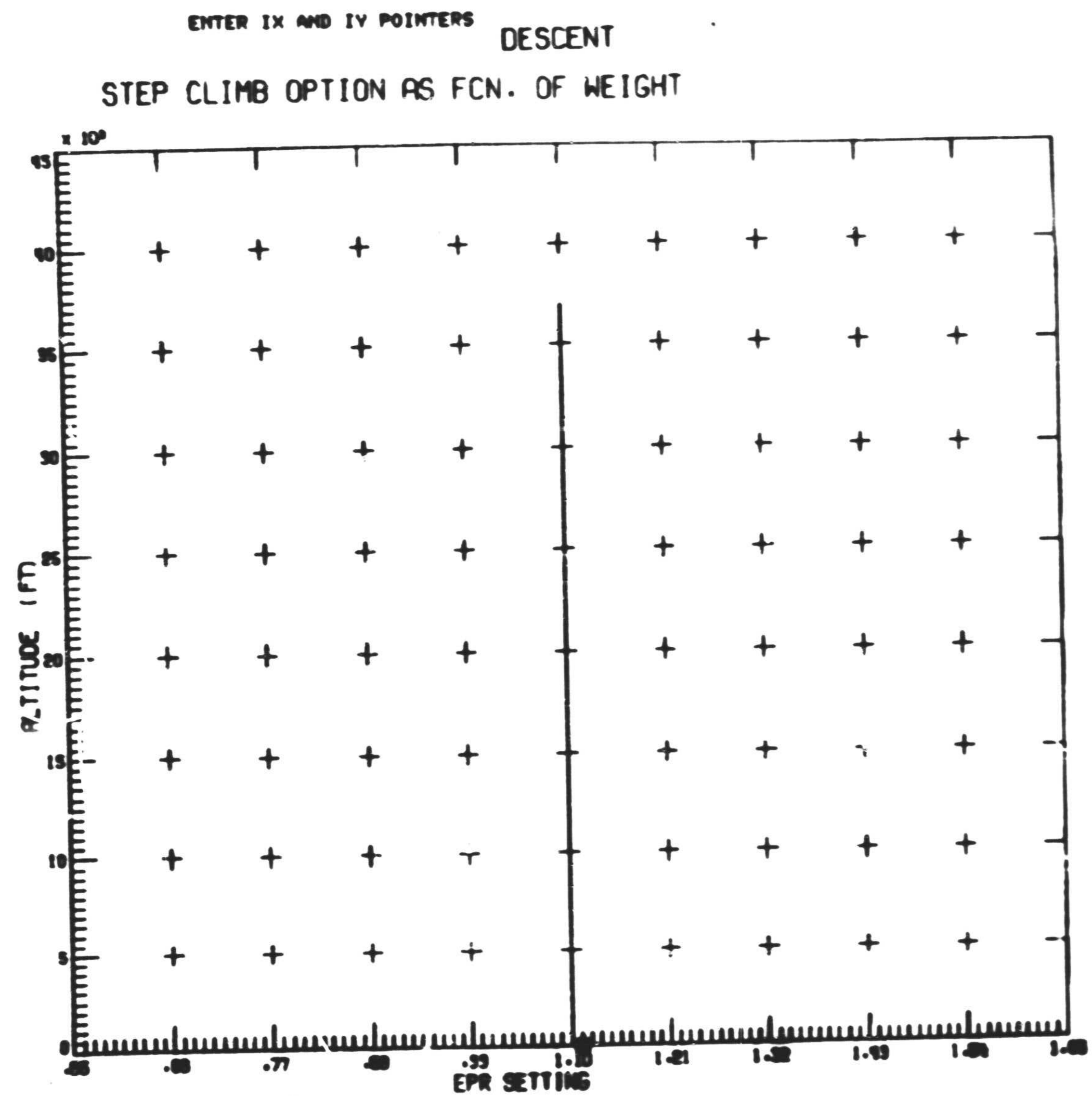

Figure 44.15

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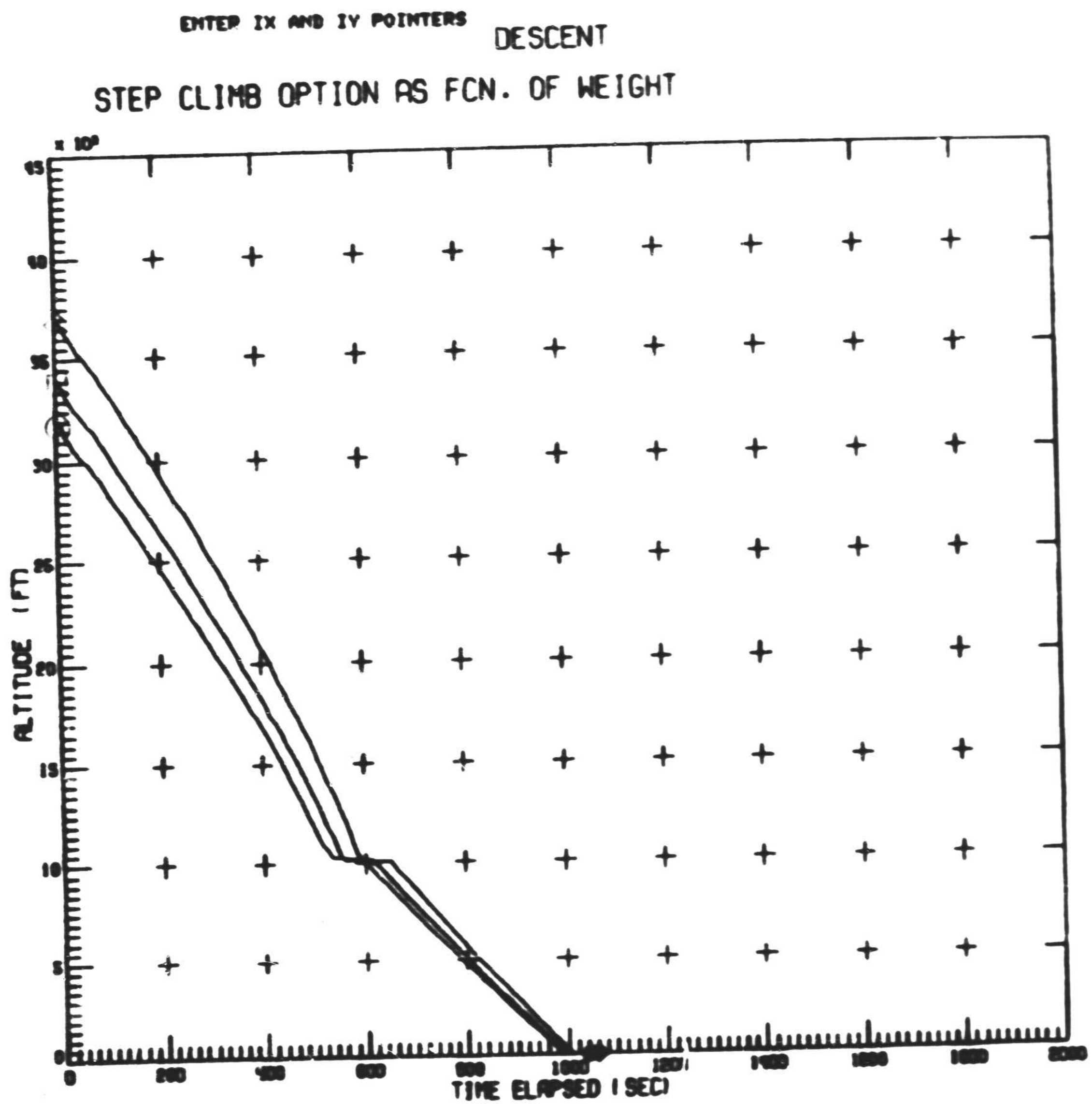

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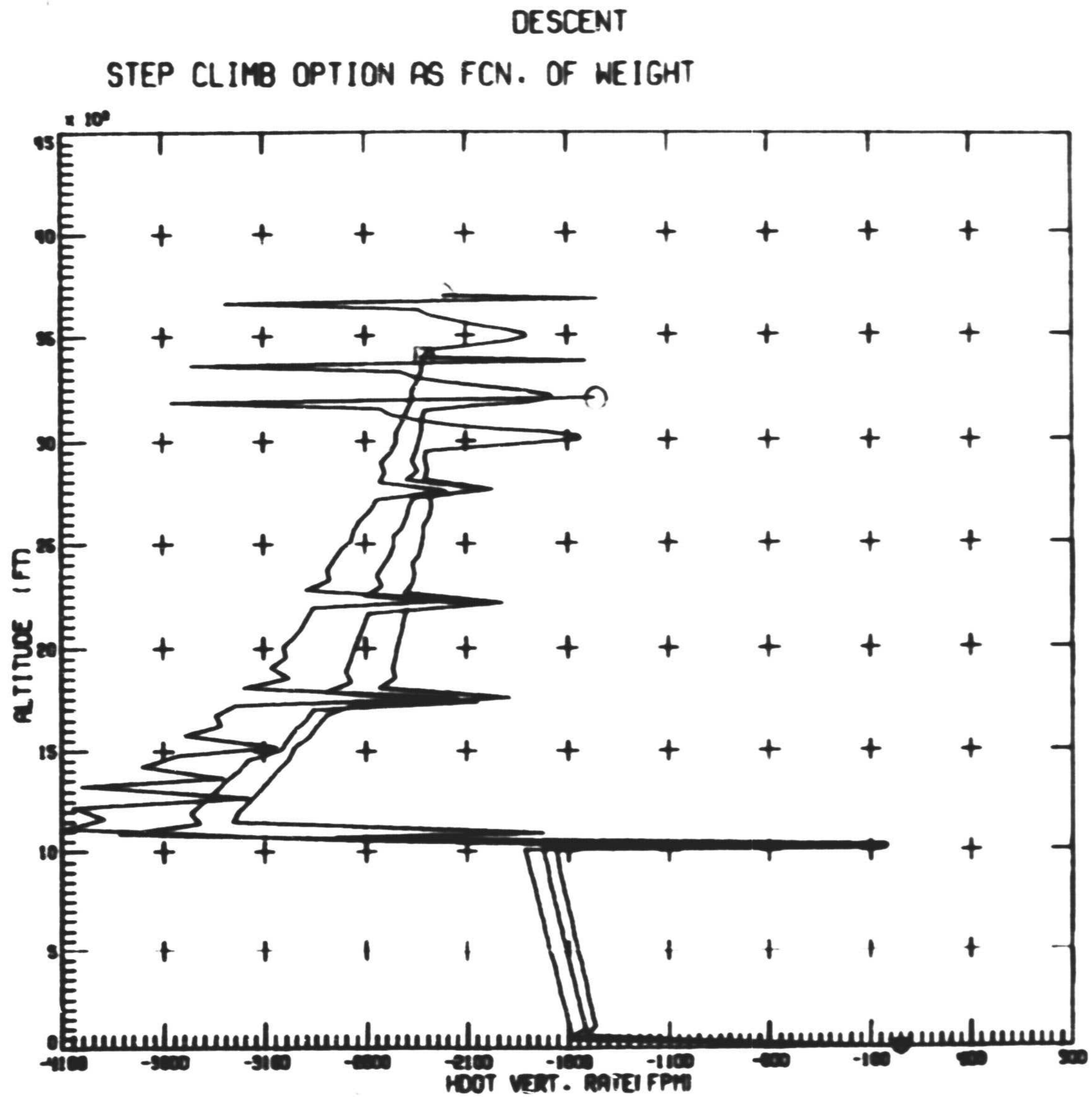

Figure 44.17

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STEP CLIMB OPTION AS FCN. OF WEIGHT

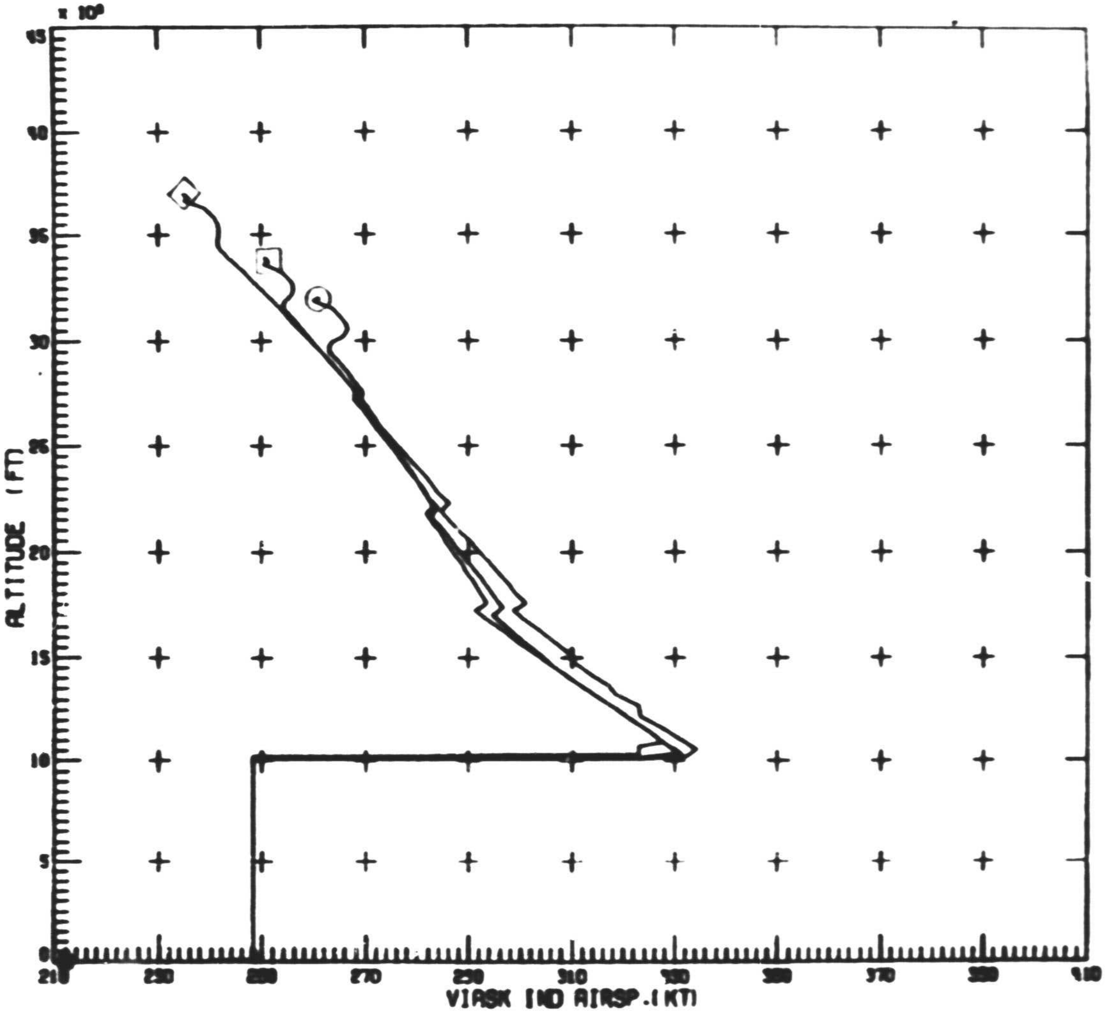

Figure 44.18

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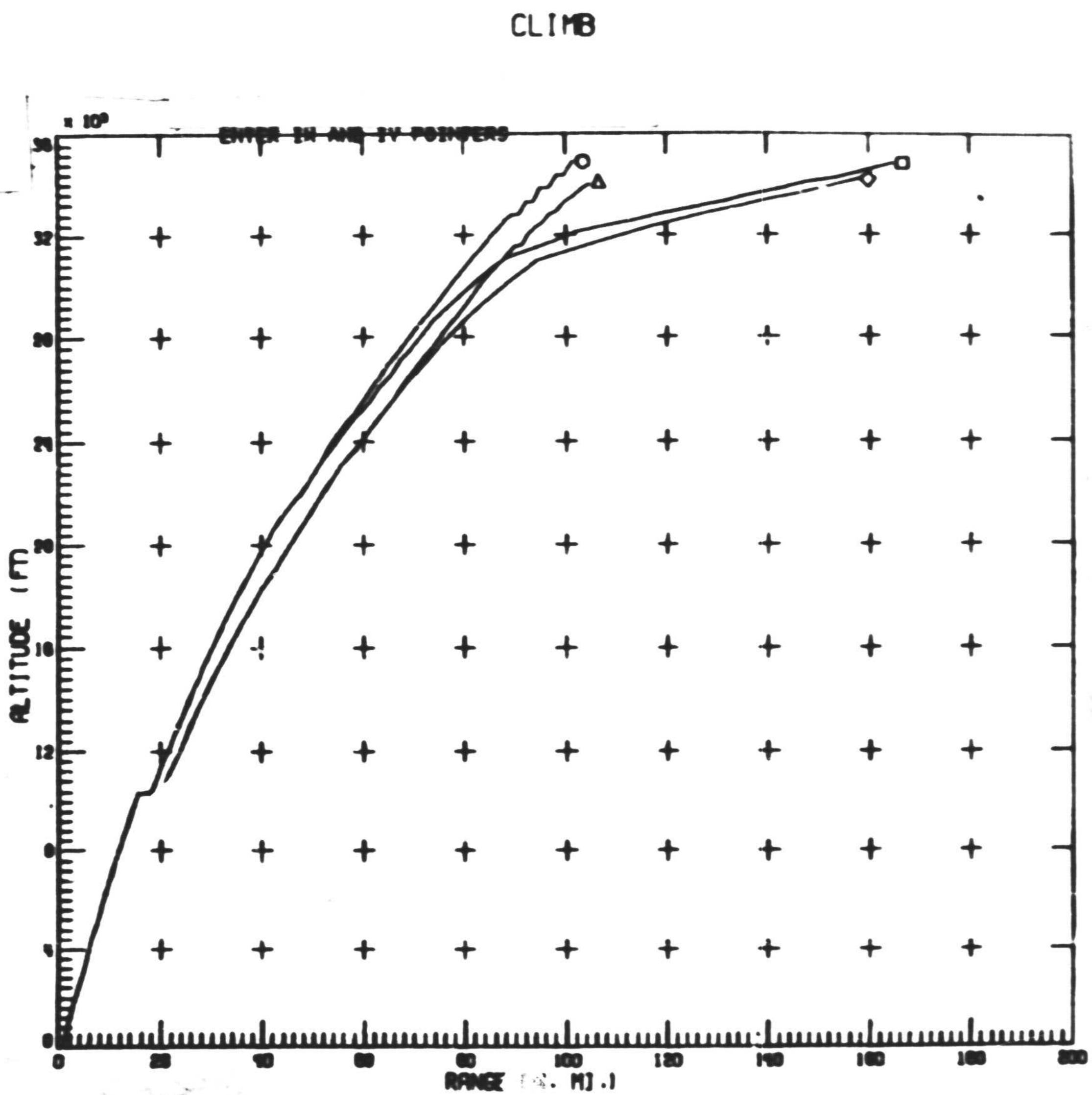

KEY FOR FIGURES 45

○ - RUNFA 0020001130 .15/0

□ - RUNFB 0021001130 .15/0

◇ - RUNDA 0021001130 .15/600

△ - RUNDB 0020001130 .15/600

Figure 45.1 - Comparisons of 750 N.MI., fuel and DOC optimal trajectories with one and two controls.

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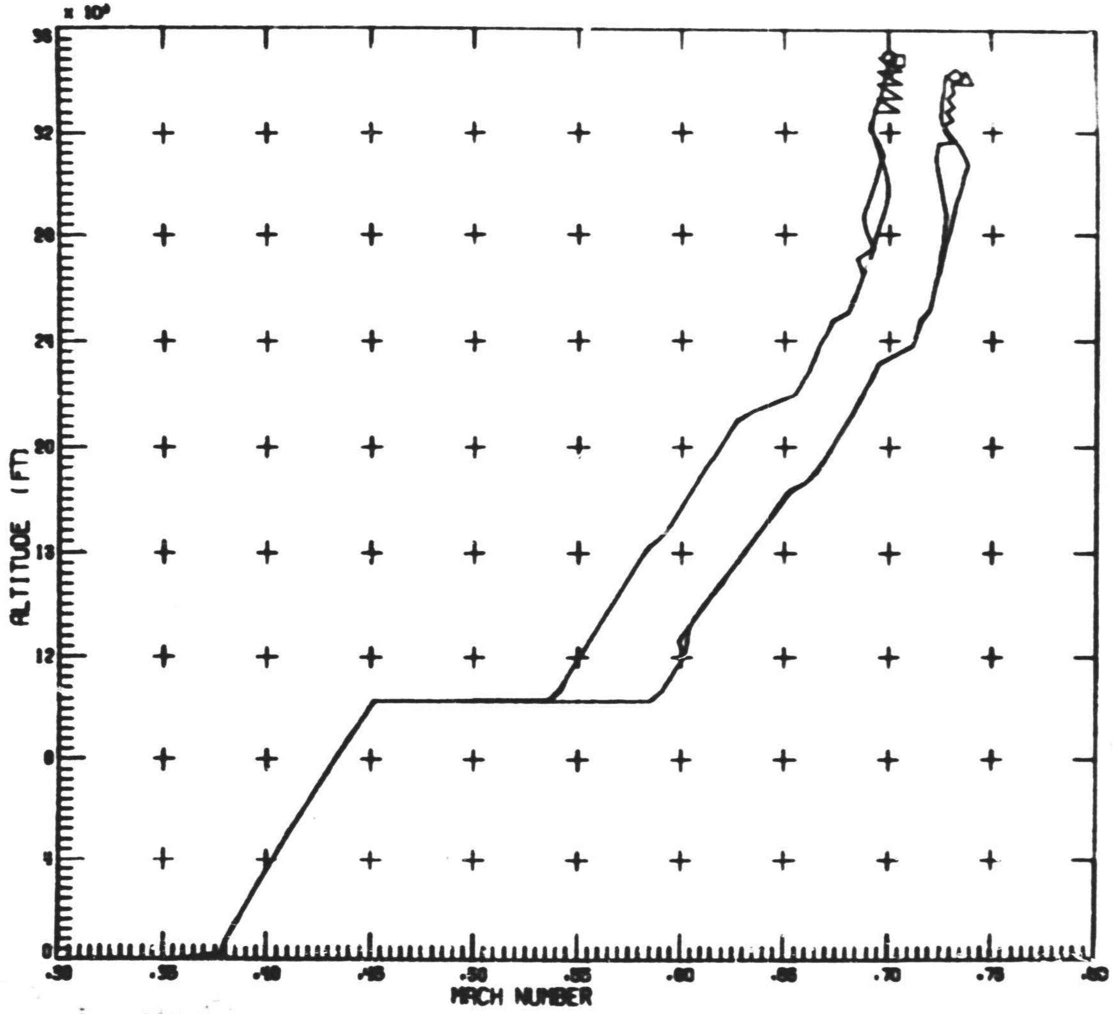

Figure 45.2

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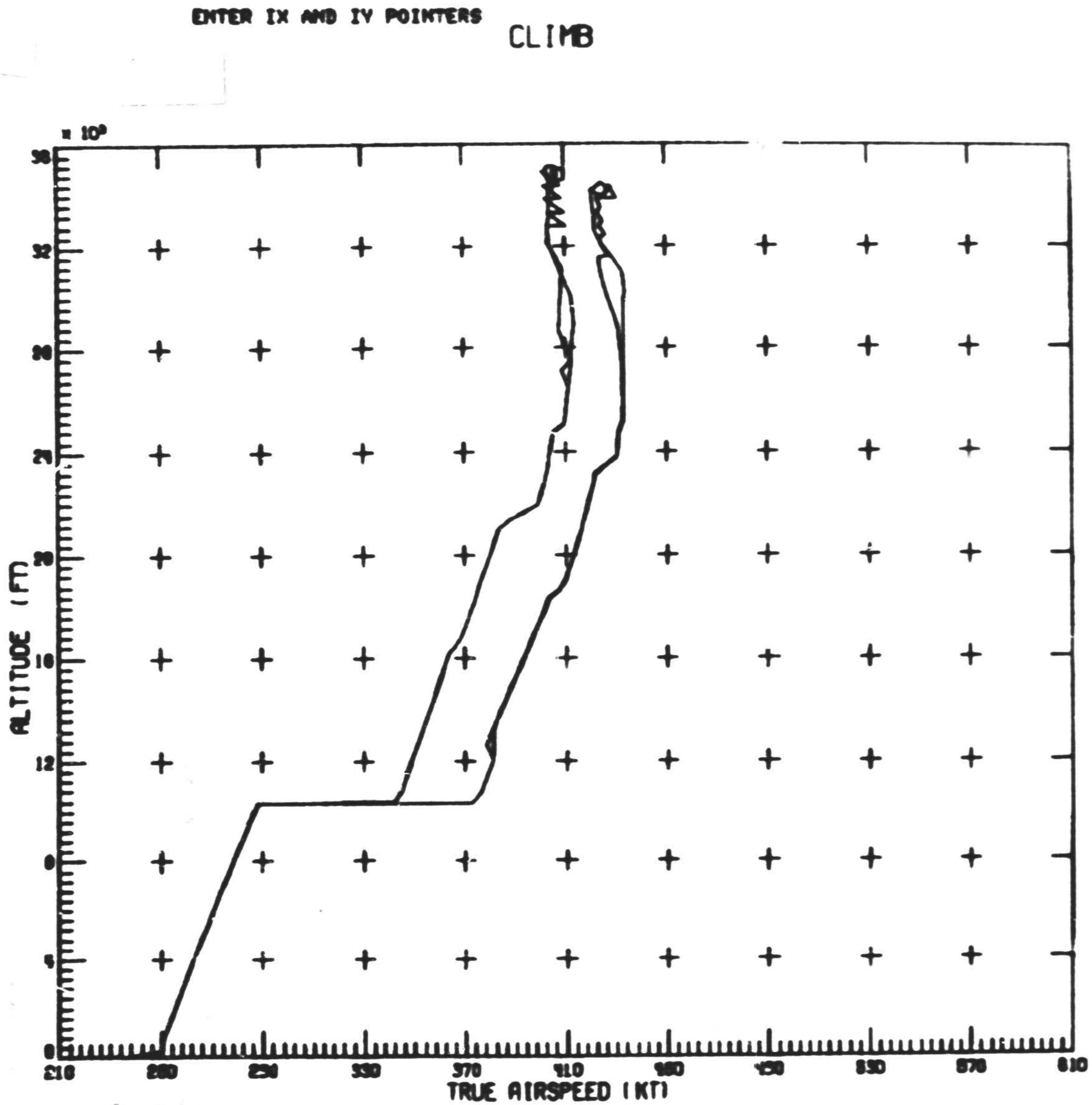

Figure 45.3

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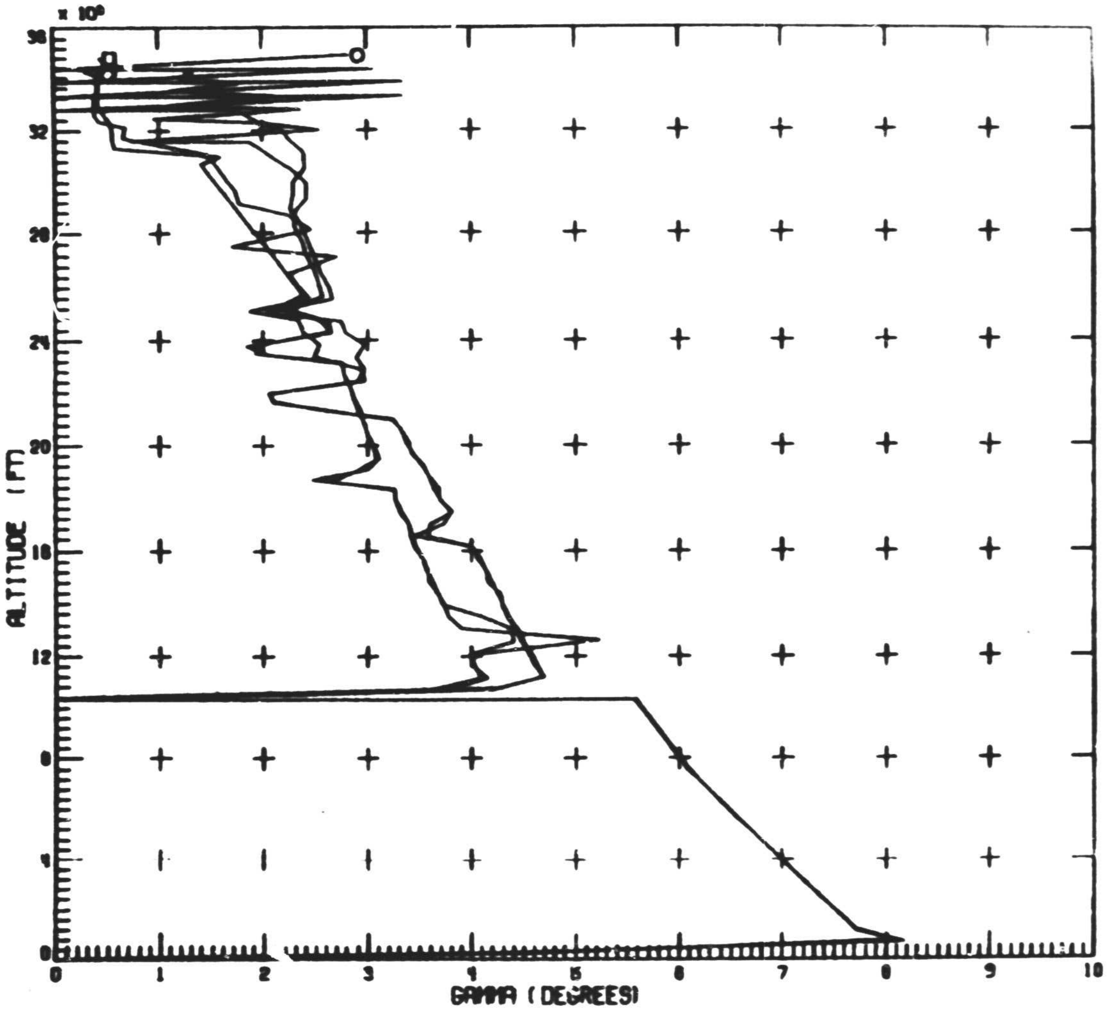

Figure 45.4

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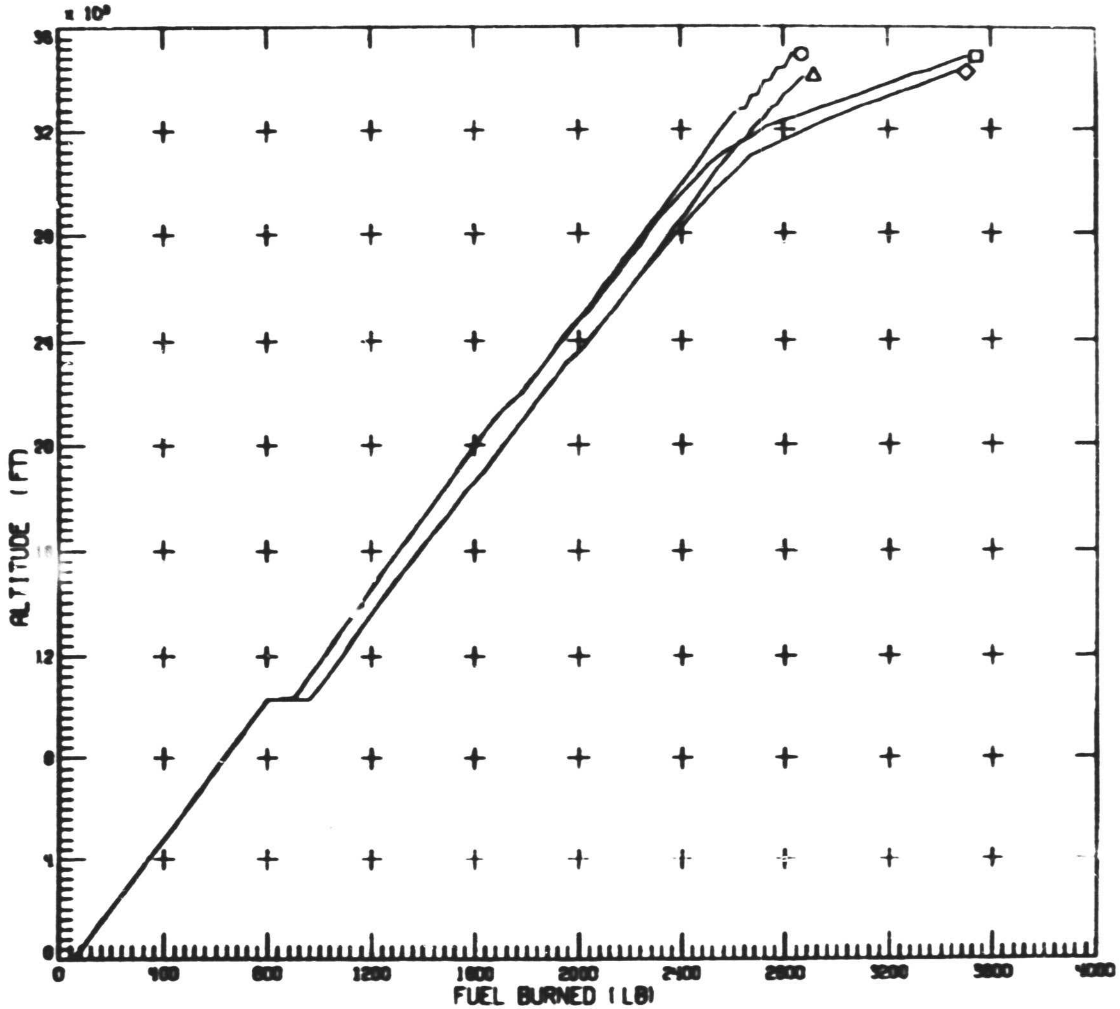

Figure 45.5

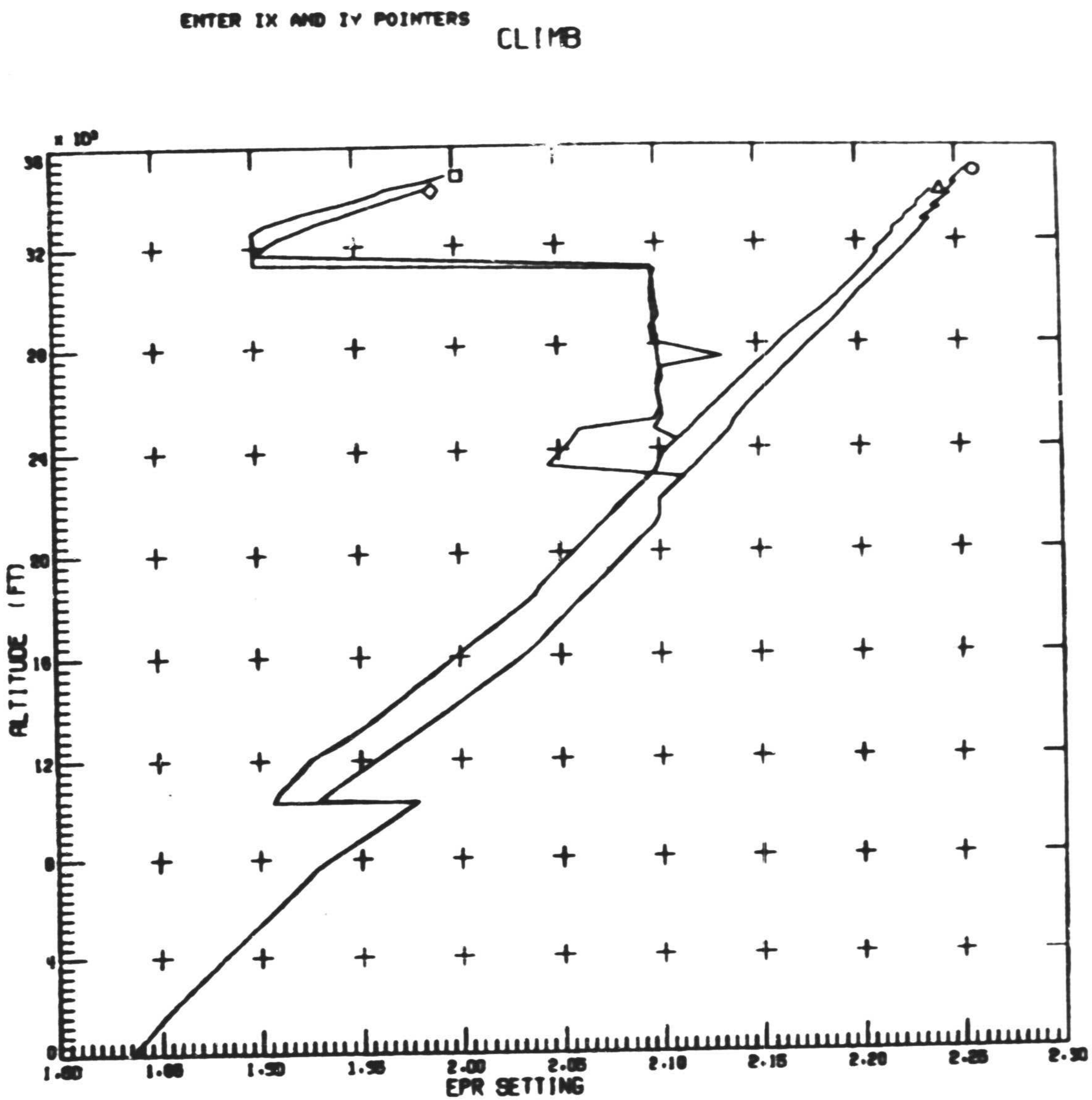

Figure 45.6

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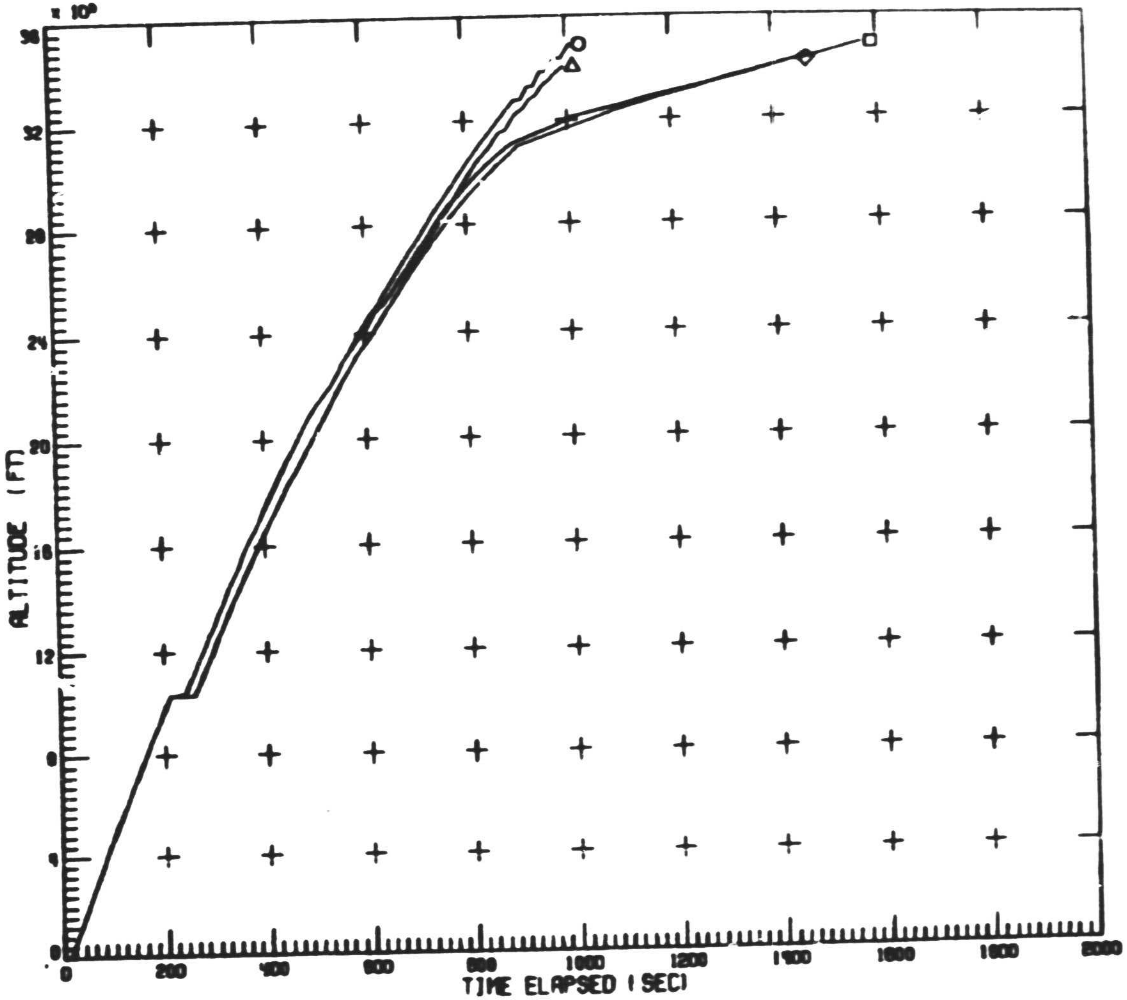

Figure 45.7

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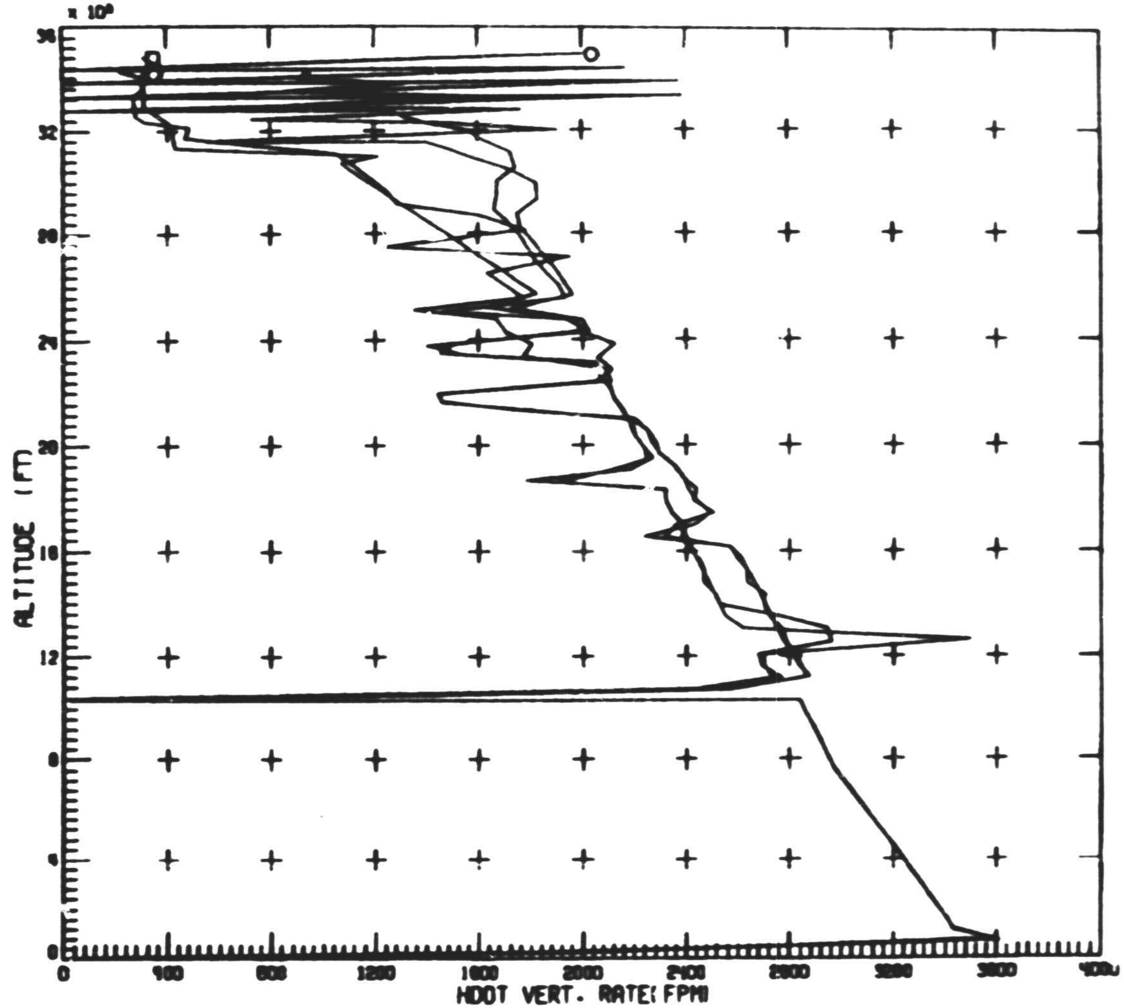

Figure 45.8

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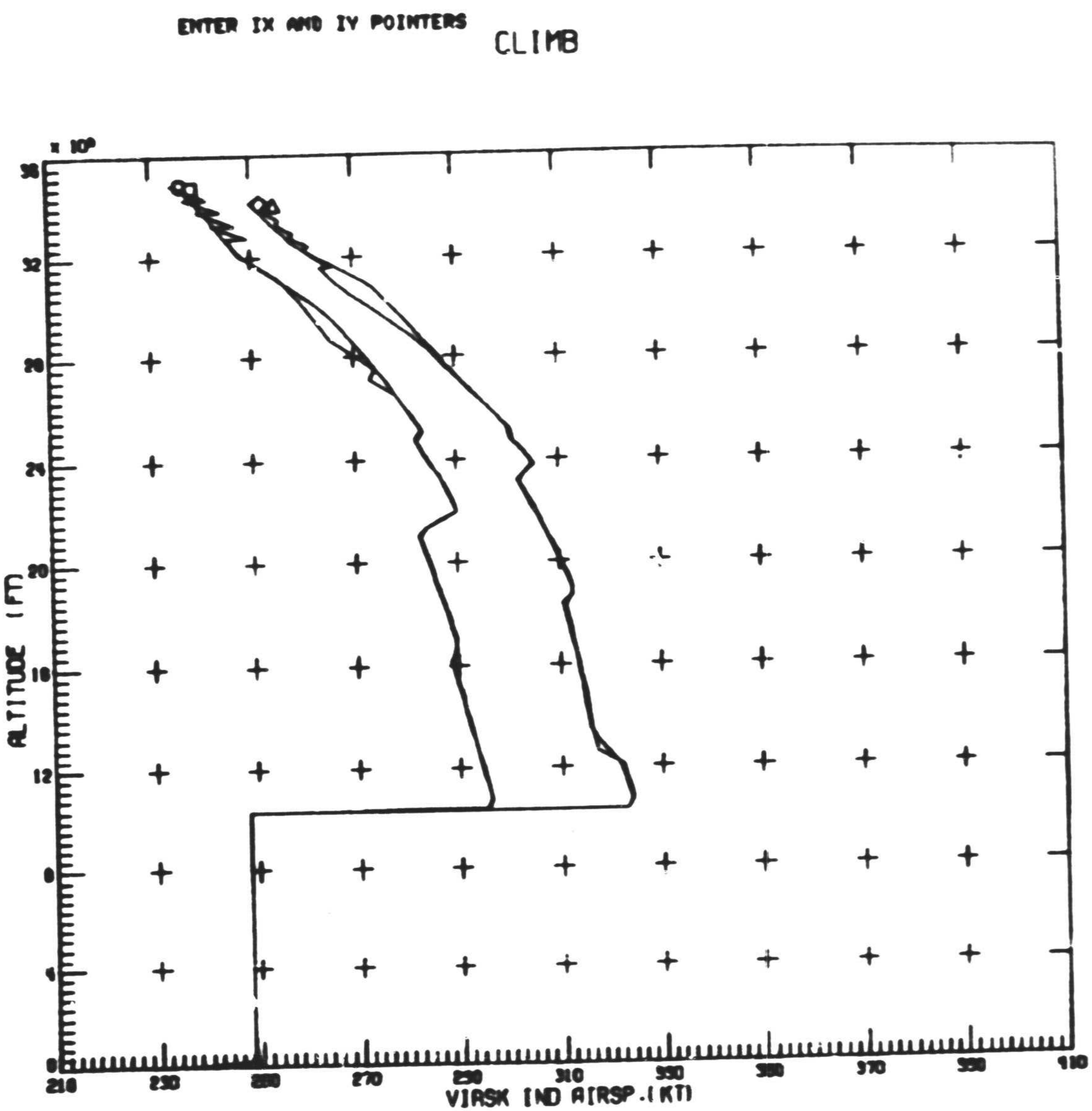

Figure 45.9

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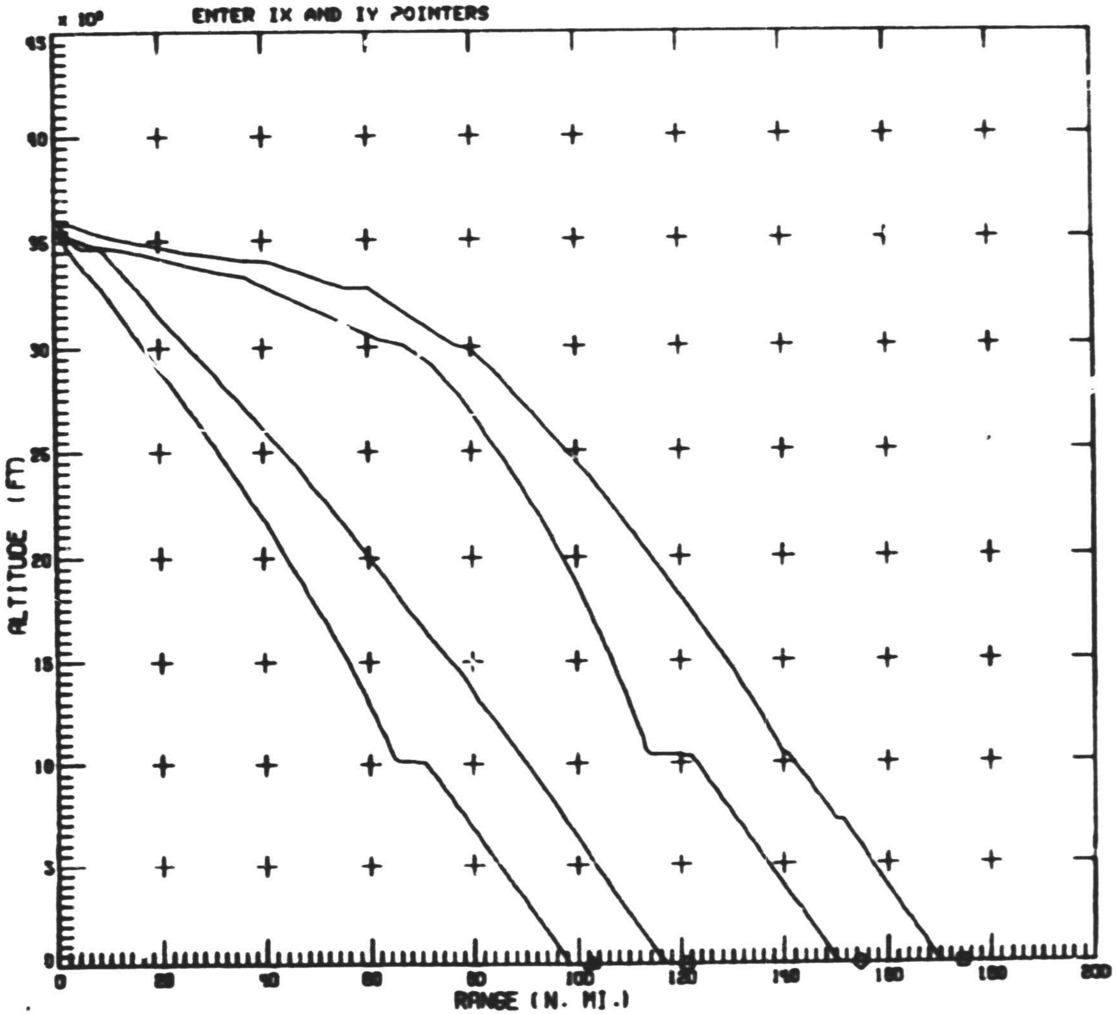

Figure 45.10

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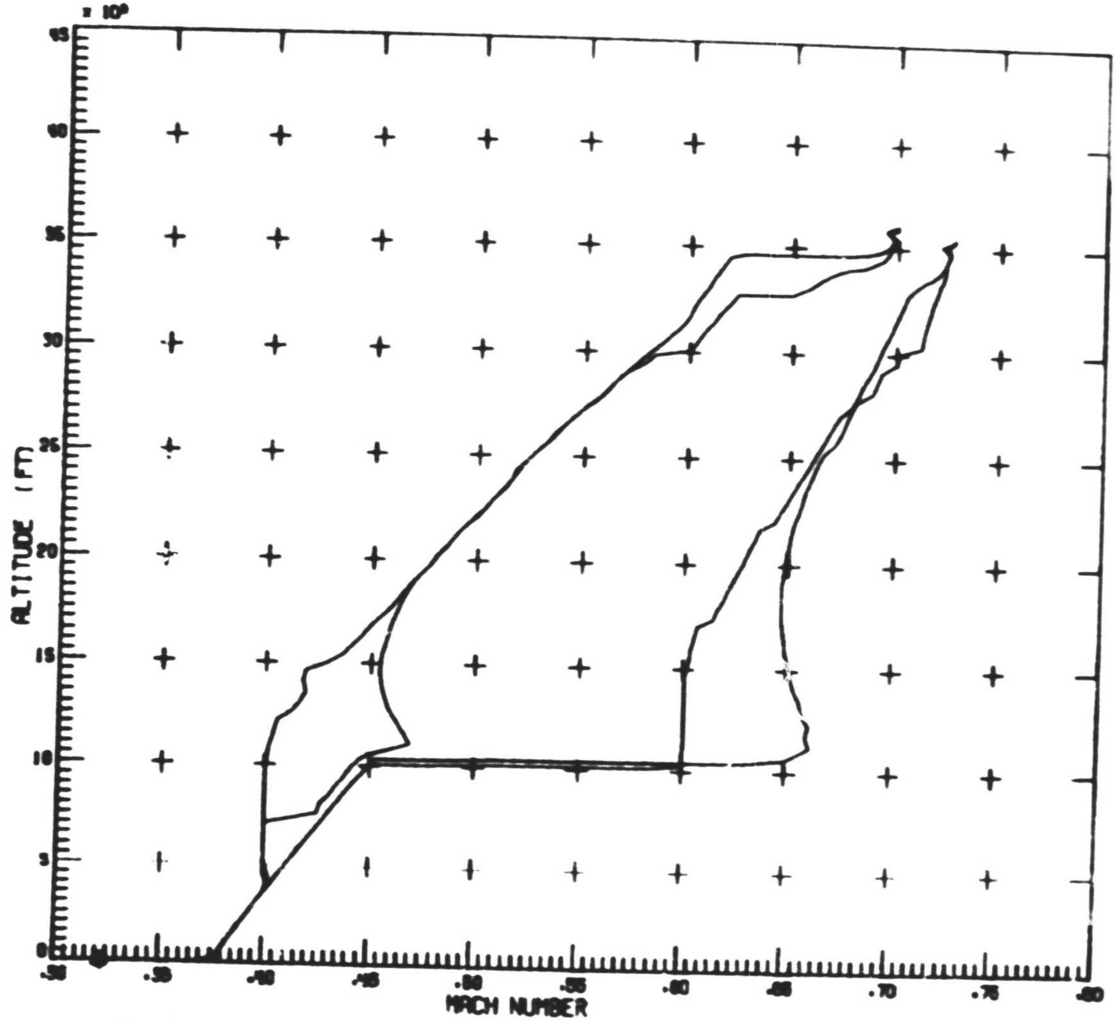

Figure 45.11

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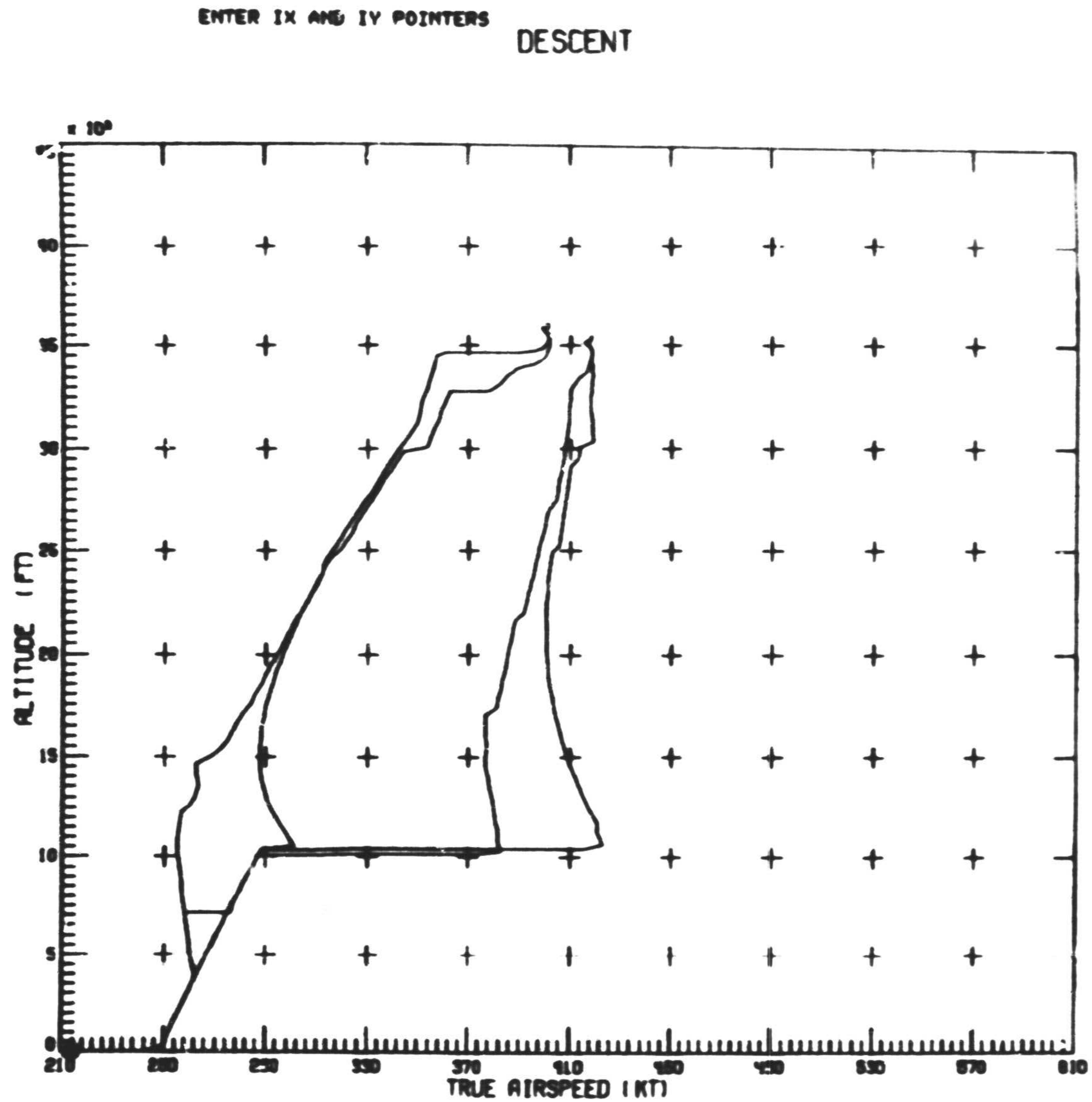

Figure 45.12

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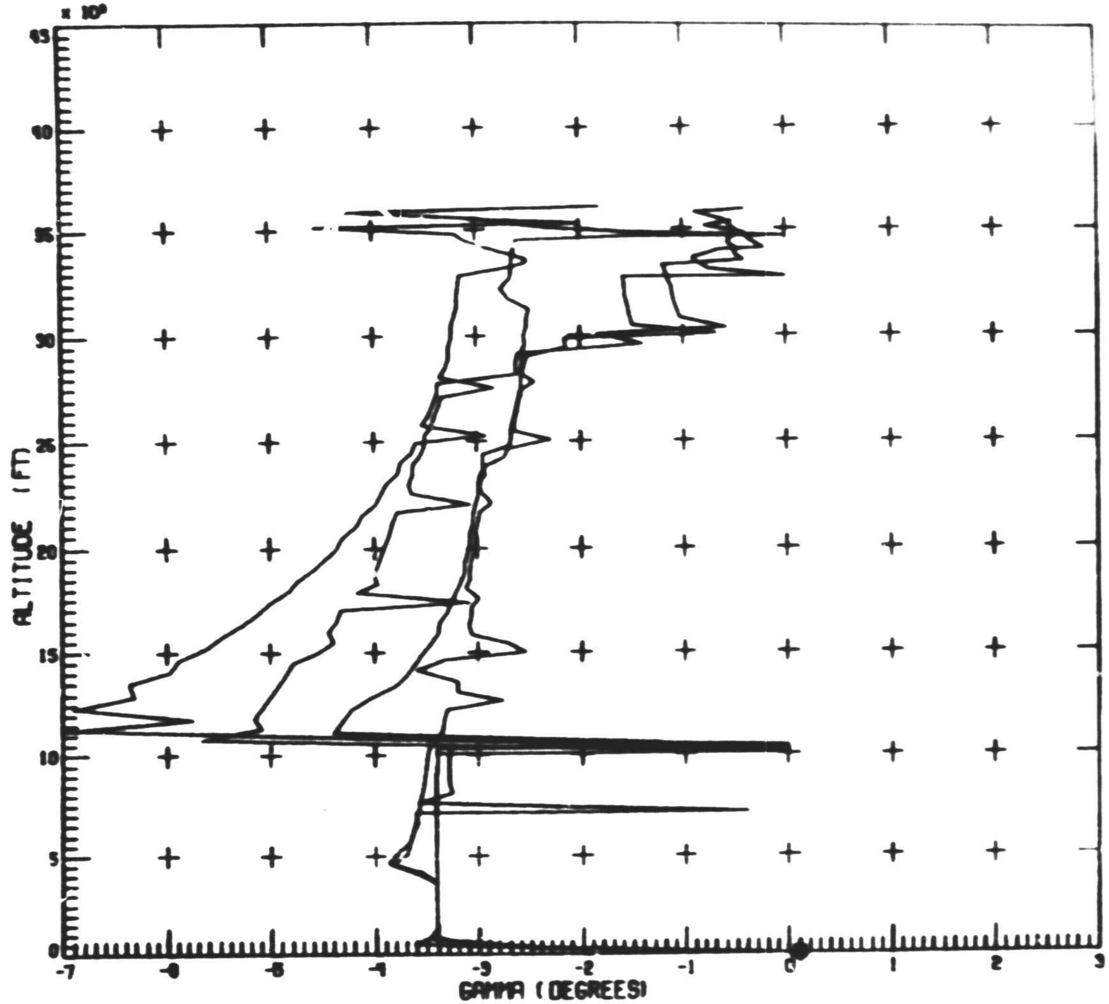

Figure 45.13

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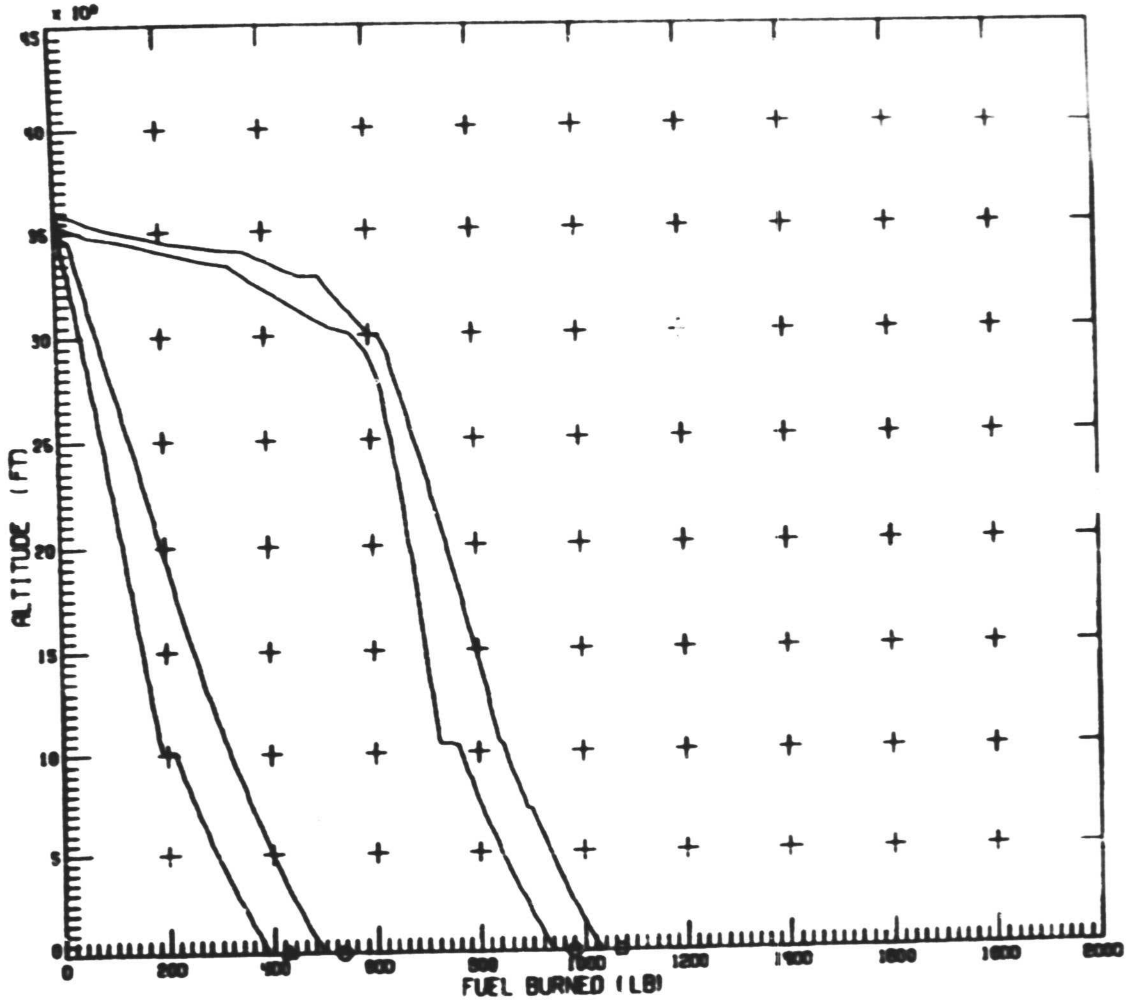

Figure 45.14

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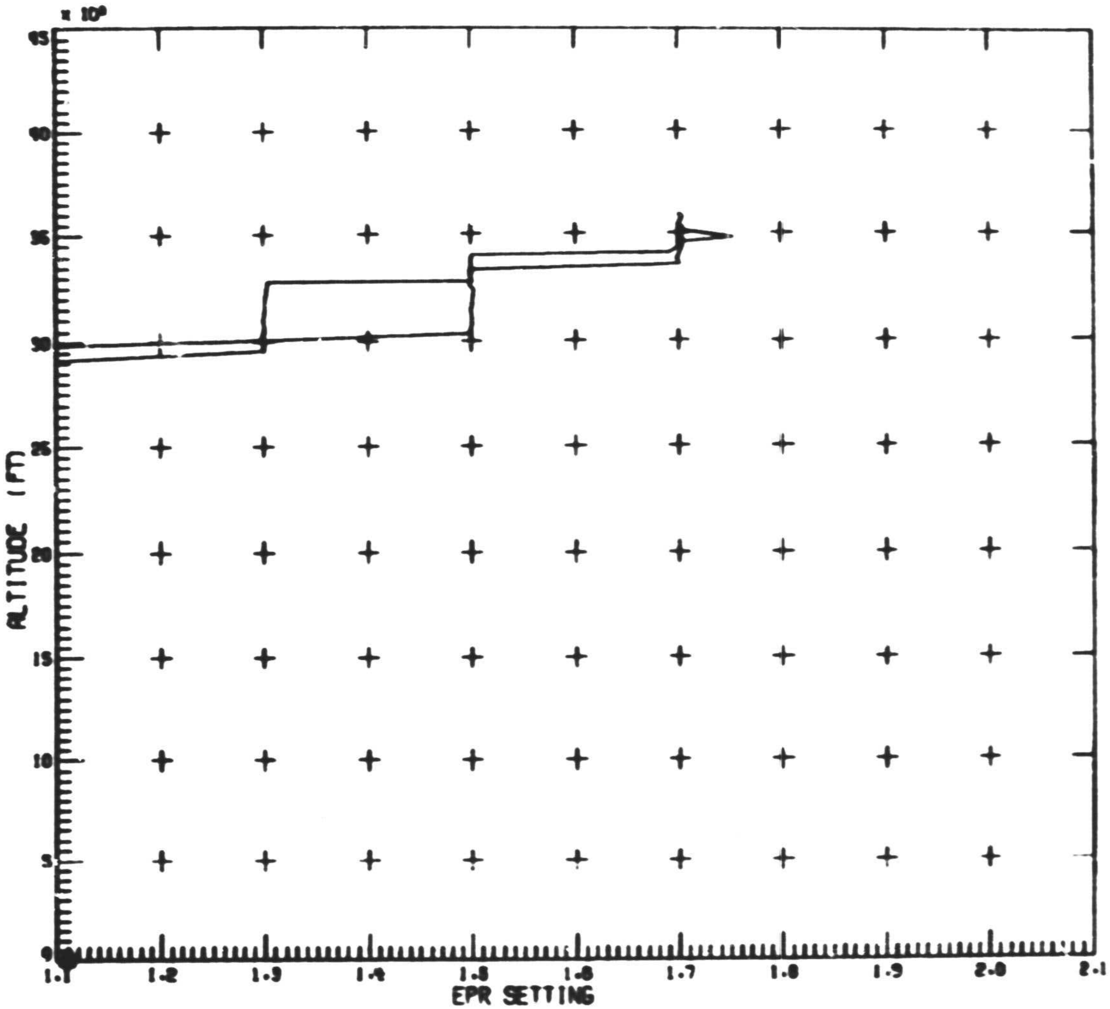

Figure 45.15

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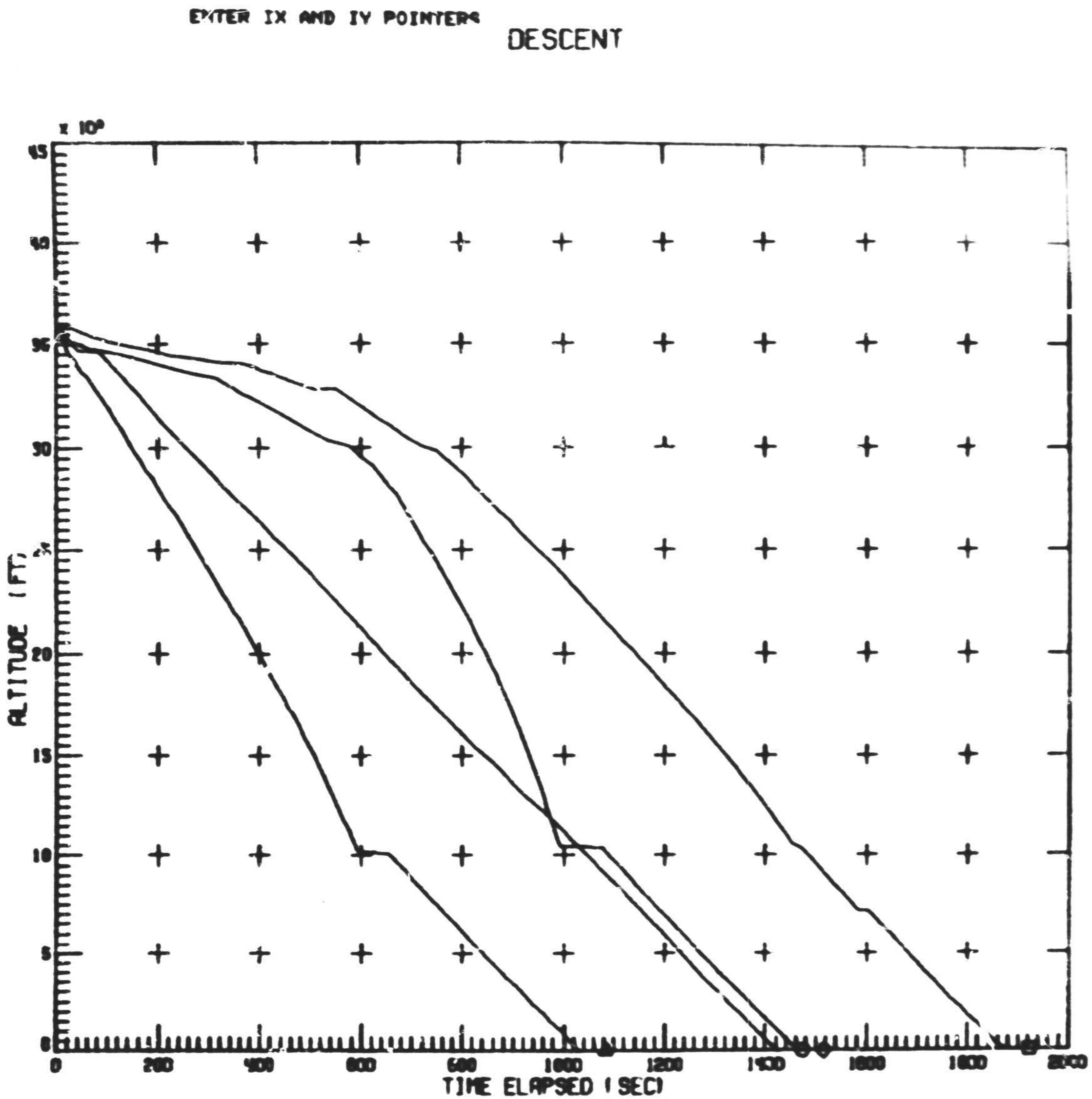

Figure 45.16

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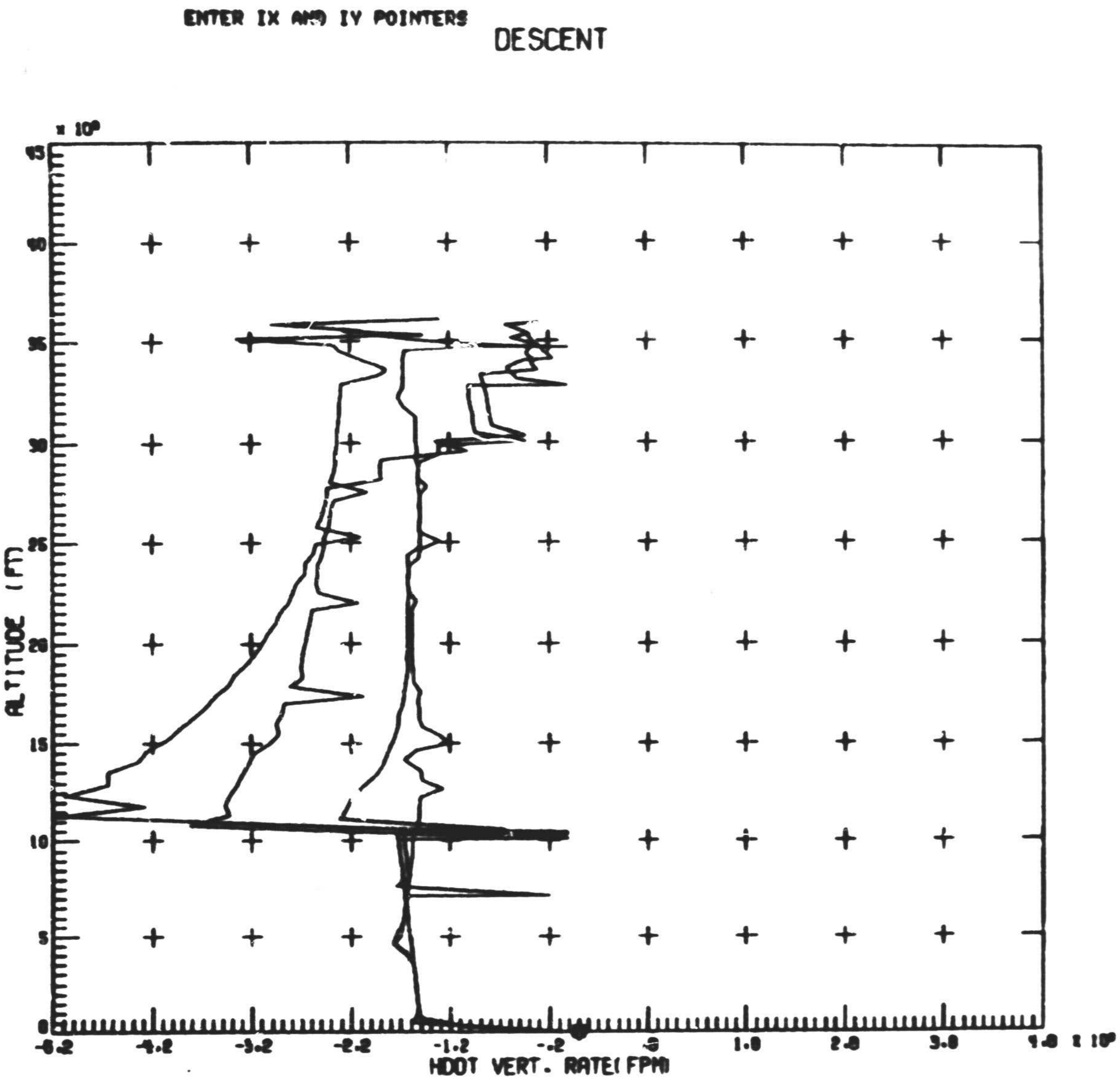

Figure 45.17

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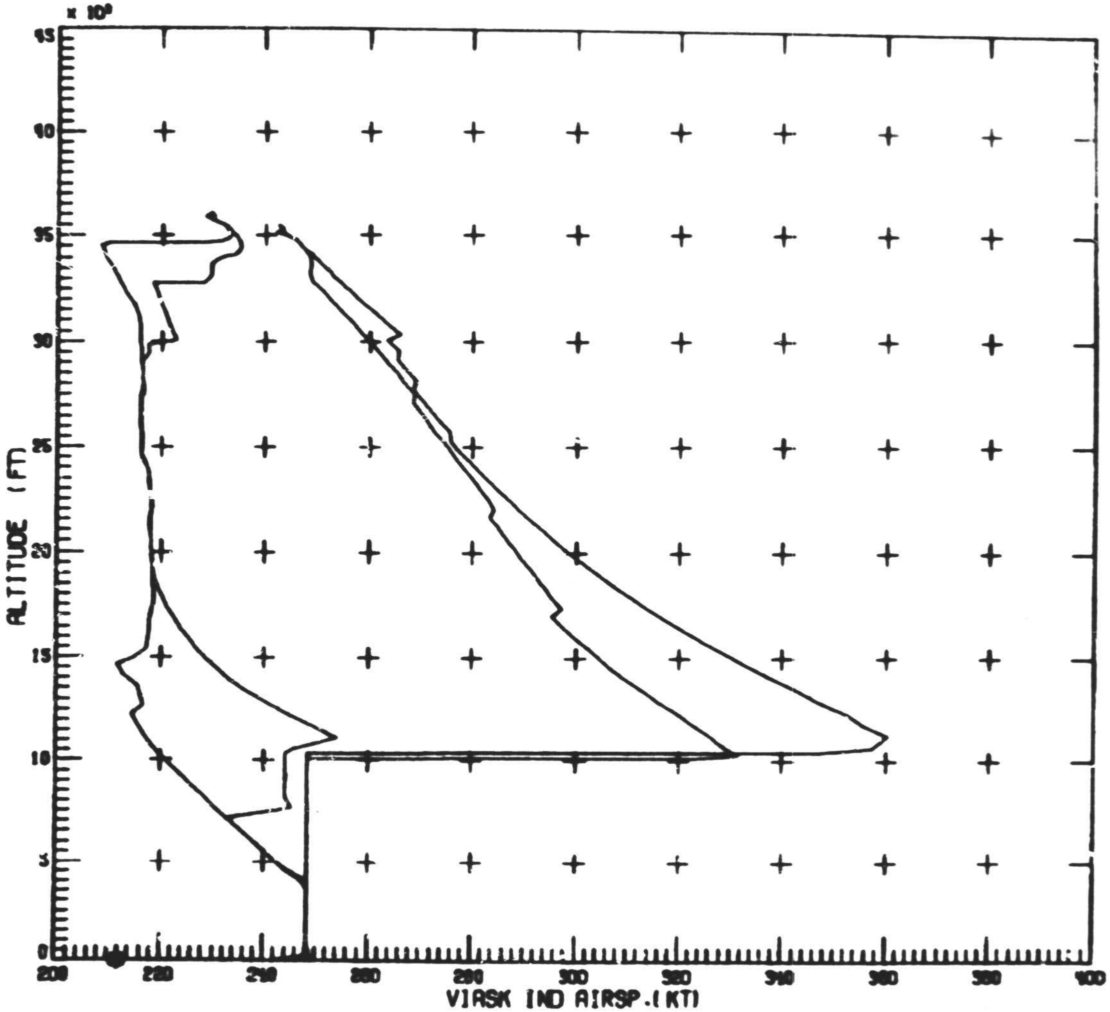

Figure 45.18

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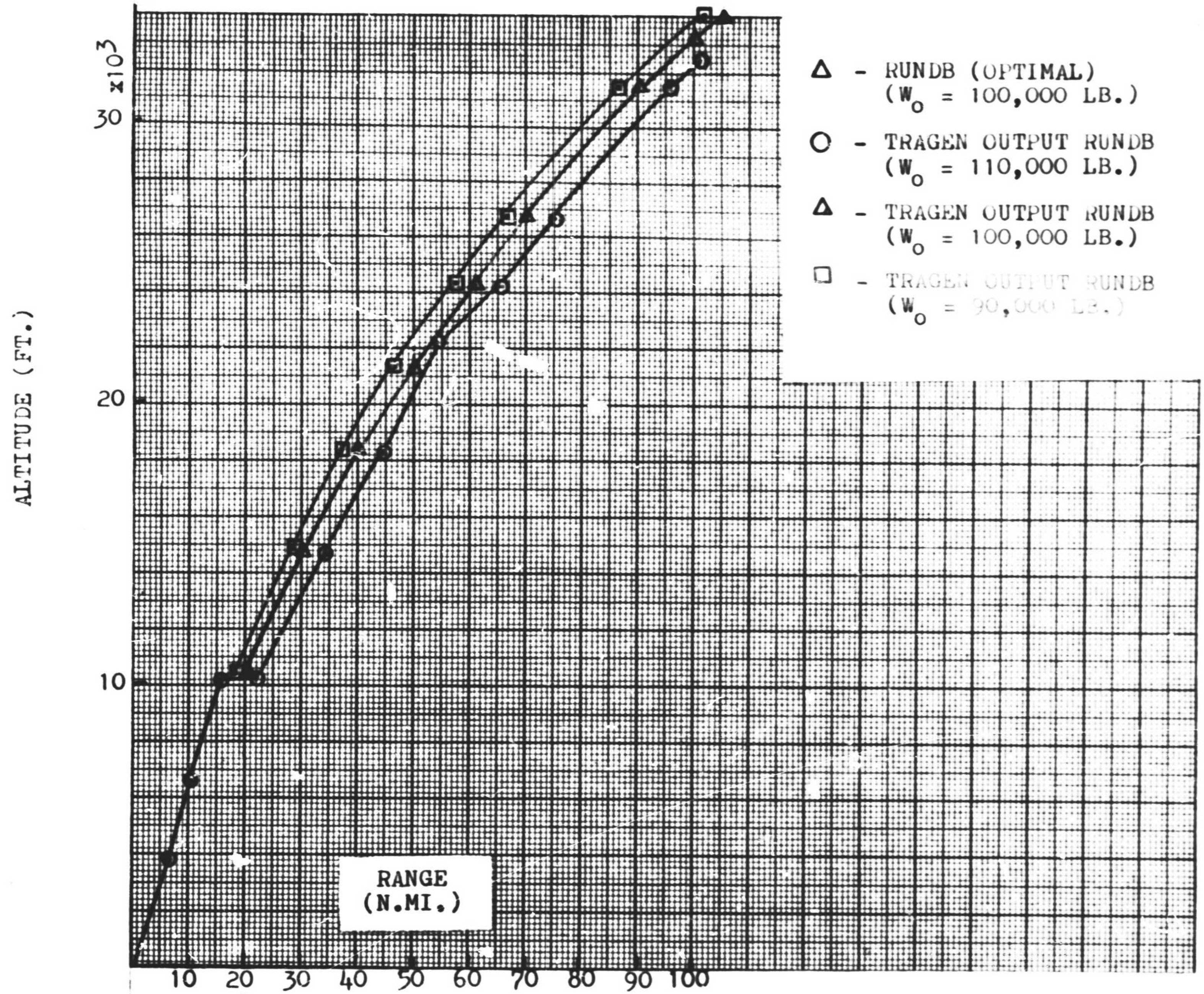

Figure 46 - Suboptimal trajectories generated by TRAGEN (RUNDB INPUT) at weights of 90 - 110,000 lb.