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Advanced Mission Design Branch

MISSION PLANNING AND ANALYSIS DIVISION

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By Gregory A. Zambo
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HOUSTON, TEXAS

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ROUND TRIP LANDING MISSIONS TO THE ASTEROID EROS, 1981 OPPORTUNITY

By Gregory A. Zambo

SUMMARY

The asteroids may provide a key link in understanding the origin of the solar system and to this end a study of round trip landing missions to the asteroid Eros in the 1981 opportunity was conducted.

A comprehensive ΔV study of short staytime (0 to 30 days), short total trip time (10 to 160 days) round trip landing missions (fast missions) is presented. In addition, the characteristics of three selected round trip landing missions are described. These three missions have the following characteristics.

a. Mission A (fast mission): 120-day total trip time, 0-day staytime, 73 000-fps total mission ΔV

b. Mission B (opposition class): 380-day total trip time, 0-day staytime, 52 000-fps total mission ΔV

c. Mission C (conjunction class): 540-day total trip time, 175-day staytime, 39 000-fps total mission ΔV

A study using three different propulsion stages, the large-tank Agena, the chemical propulsion stage (CPS), and a nuclear stage was conducted to determine which and how many stages could perform each of the three missions. A payload of 5000 pounds was assumed. The propulsion requirements for mission A were found to be two large-tank Agenas and ten CPS's (or alternatively, two large-tank Agenas and five nuclear stages) while mission B required two large-tank Agenas and two CPS's. Mission C, the conjunction class mission, can be performed with one large-tank Agena and one CPS.

INTRODUCTION

As in reference 1,

> As long as the asteroids were regarded as fragments of a broken-up planet, interest in them was limited. There are now good reasons to believe that the asteroidal belt represents an intermediate stage in the formation of planets. This links the present conditions in the asteroidal region with the epoch in which the earth and the other planets were accreting from interplanetary grains. Hence, in order to understand how the solar system originated it may be essential to explore the asteroids.

Round trip landing missions to the asteroid Eros (designated number 433) in the 1981 opportunity are considered using a 262- by 262-n. mi. altitude orbit at Earth departure and a 200- by 38 529-n. mi. altitude (1-day period) orbit at Earth return. The "landing" at Eros is actually a rendezvous with Eros, because of the small gravitational attraction of the asteroid. In fact, the concept has been discussed of capturing a small asteroid, bringing it back to Earth, and storing it in orbit about the Earth for later investigations (ref. 1). The three missions presented herein (missions A, B, and C) are representative of direct missions to Eros in the 1981 opportunity. Both two-impulse direct and three-impulse (intermediate heliocentric impulse) direct one-way trajectories were considered in this study.

The author acknowledges Stanley R. Sudol and Gus R. Babb of the Advanced Mission Design Branch for their assistance.

SYMBOLS

a	semimajor axis
e	eccentricity
I_{sp}	specific impulse
i	inclination relative to the ecliptic plane
M	mean anomaly
m_f	mass of usable propellant

m_s	burnout mass of stage
V_∞	magnitude of hyperbolic excess velocity vector
ΔV	magnitude of impulsive velocity-change vector
Ω	longitude of ascending node, heliocentric ecliptic system
ω	argument of periapsis, heliocentric ecliptic system

Subscripts

AE	arrive Earth
AR	arrive Eros
DE	depart Earth
DR	depart Eros
I	intermediate impulse

PROCEDURE

A computer program that minimizes one-way (Earth to Eros, or Eros to Earth) three-impulse ΔV was developed and used in this study. For a given launch date from the departure planet and flight time to the arrival planet, the sum of the departure ΔV, the intermediate impulse ΔV, and the arrival ΔV is minimized as a function of four independent variables: the position vector (dimensioned three) of the intermediate impulse, and the time from the departure planet to the intermediate impulse. A gradient method is used in the minimization process. The two-impulse one-way ΔV (Lambert's solution) is also calculated by the program.

This program uses an analytic Earth ephemeris based on reference 2 and a two-body motion ephemeris for Eros (a = 1.4581 astronomical unit, e = 0.2228, i = 10.828°, Ω = 304.012°, ω = 178.084°, and M = 238.913° on January 6, 1941). A 262- by 262-n. mi. altitude orbit at Earth departure and a 200- by 38 529-n. mi. altitude capture orbit at Earth return were used in this study. The ΔV on arrival at Eros was assumed to be equal to the V_∞ upon arrival at Eros and the ΔV on departure from Eros was assumed to be equal to the V_∞ upon departure from Eros. A massless planet model (V_∞ vector defined as the heliocentric-transfer-conic velocity vector minus the velocity vector of the planet) was assumed throughout. Impulsive (ideal) ΔV's and collinear burns at Earth departure, Eros arrival, Eros departure, and Earth arrival were also assumed throughout. Only one-way trajectories with transfer angles of less than 360° were considered.

The propulsion stages used herein were defined as follows:

a. Large-tank Agena: m_s = 1985 pounds; m_f = 35 000 pounds; I_{sp} = 292.5 seconds

b. CPS: m_s = 60 000 pounds; m_f = 540 000 pounds; I_{sp} = 460 seconds

c. Nuclear stage: m_s = 88 000 pounds; m_f = 300 000 pounds; I_{sp} = 784 seconds

RESULTS

Table I presents Earth to Eros one-way minimum two-impulse and three-impulse ΔV requirements. In generating this table, only arrival Julian dates at Eros of 2 444 960 through 2 445 020, in increments of 5 days, and Earth to Eros flight times of 5 days through 100 days, in increments of 5 days, were considered.

Table II presents Eros to Earth one-way minimum two-impulse and three-impulse ΔV requirements. In generating this table, only departure from Eros Julian dates of 2 444 980 through 2 445 040, in increments of 5 days, and Eros to Earth flight times of 5 days through 100 days, in increments of 5 days, were considered. In tables I and II, only one-way legs with a minimum three-impulse ΔV of less than 900 000 fps are presented.

Table III presents the launch dates, the flight times, and the two-impulse and three-impulse minimum total mission ΔV's for round trip missions. On each subtable of table III, the staytime at Eros is held fixed and the total trip time is varied. Each mission of table III was generated by choosing from all possible combinations of one-way trajectories from tables I and II, the round trip mission having, for the given minimum staytime and the given total trip time, the minimum total mission ΔV. Staytimes of 0 through 30 days, in increments of 5 days, and total trip times of 10 through 160 days, in increments of 5 days, are presented in table III.

Figure 1 graphically presents the table III results. Minimum total mission ΔV is plotted against total trip time, with the contour lines being lines of fixed minimum staytime at Eros. No difference between two-impulse and three-impulse total mission ΔV was found, therefore figure 1 represents identically both two-impulse and three-impulse round trip missions.

Three missions representative of the 1981 opportunity were selected and their characteristics are presented in figures 2, 3, and 4. Mission A, a "fast mission" to Eros, is represented in figure 2. This mission has a

0-day staytime at Eros and is seen to be the 120-day total trip time mission of table III(a). Mission B, an "opposition class" mission to Eros, is characterized in figure 3 while mission C, a "conjunction class" mission to Eros, is shown in figure 4.

Table IV presents the vehicle configurations capable of performing each of three aforementioned missions. A gross cost comparison is also presented.

CONCLUSIONS

The "fast mission" to Eros (120-day total trip time) required 73 000-fps total mission ΔV and is too costly to be considered seriously. The "opposition class" mission (380-day total trip time) requires 52 000-fps total mission ΔV and can be performed with two large-tank Agenas and two CPS's. The "conjunction class" mission (540-day total trip time) requires 39 000-fps total mission ΔV and, although 160 days longer in total trip time than the "opposition class" mission, it requires only one large-tank Agena and one CPS. Furthermore, it has a staytime at Eros of 175 days as compared to the 0-day staytime of the "opposition class" mission.

For an unmanned (5000-lb payload) mission to Eros in the 1981 opportunity, a cost consideration dictates the "conjunction class" mission as the obvious choice.

TABLE I.- 1981-82 EARTH TO EROS ONE-WAY MINIMUM ΔV REQUIREMENTS

JDDE = Julian date of Earth departure - 2 440 000

TFL = Earth to Eros flight time, days

DV2 = Two-impulse one-way ΔV requirement = $\Delta V_{DE} + \Delta V_{AR}$, fps

DV3 = Three-impulse one-way ΔV requirement = $\Delta V_{DE} + \Delta V_{I} + \Delta V_{AR}$, fps

262- by 262-n. mi. altitude at Earth departure

JDDE	TFL	DV2	DV3
4985	5	848882	848882
4990	5	506193	506193
4995	5	319702	319702
4970	10	793438	793438
4975	10	605805	605805
4980	10	419820	419820
4985	10	248317	248317
4990	10	152267	152267
4995	10	237934	237934
4950	15	885992	885992
4955	15	770550	770550
4960	15	650644	650644
4965	15	527371	527371
4970	15	402315	402315
4975	15	278458	278458
4980	15	164538	164538
4985	15	99420	99420
4990	15	152070	152070
4940	20	745352	745352
4945	20	663368	663368
4950	20	577192	577192
4955	20	487522	487522
4960	20	395229	395229
4965	20	301579	301579
4970	20	208958	208958
4975	20	124148	124148
4980	20	74919	74919
4985	20	110606	110606
4990	20	192862	192862
4935	25	594734	594734
4940	25	529860	529860
4945	25	461446	461446
4950	25	390083	390083
4955	25	316521	316521
4960	25	241849	241849
4965	25	168120	168120
4970	25	100975	100975
4975	25	61498	61498
4980	25	86788	86788
4985	25	151096	151096
4990	25	868138	868138
4995	25	871118	871118
4930	30	493914	493914
4935	30	440674	440674
4940	30	384302	384302
4945	30	325320	325320
4950	30	264398	264398
4955	30	202518	202518
4960	30	141522	141522
4965	30	86283	86283
4970	30	53420	53420
4975	30	71707	71707
4980	30	123785	123785
4985	30	185054	185054
4990	30	707816	707816
4925	35	421385	421385
4930	35	376647	376647
4935	35	329060	329060
4940	35	279090	279090
4945	35	227351	227351
4950	35	174749	174749
4955	35	122975	122975
4960	35	76332	76332
4965	35	48252	48252
4970	35	61545	61545
4975	35	104672	104672
4980	35	156843	156843
4985	35	592323	592323
4920	40	366456	366456
4925	40	328241	328241
4930	40	287399	287399
4935	40	244342	244342
4940	40	199634	199634
4945	40	154123	154123
4950	40	109384	109384
4955	40	69257	69257
4960	40	44800	44800
4965	40	54401	54401
4970	40	90637	90637
4975	40	135875	135875
4980	40	183728	183728
4915	45	323255	323255
4920	45	290207	290207
4925	45	254728	254728
4930	45	217176	217176
4935	45	178066	178066
4940	45	138194	138194
4945	45	99030	99030
4950	45	64029	64029
4955	45	42421	42421
4960	45	49223	49223
4965	45	79955	79955
4970	45	119684	119684
4975	45	162275	162275
4910	50	288316	288316
4915	50	259438	259438
4920	50	228327	228327
4925	50	195278	195278
4930	50	160756	160756
4935	50	125502	125502
4940	50	90893	90693
4945	50	60044	60044
4950	50	40740	40740
4955	50	45384	45384
4960	50	71598	71598
4965	50	106806	106806
4970	50	145118	145118
4905	55	259478	259478
4910	55	233996	233996
4915	55	206496	206496
4920	55	177200	177200
4925	55	146516	146516
4930	55	115131	115131
4935	55	84327	84327
4940	55	56919	56919
4945	55	39530	39530
4950	55	42491	42491
4955	55	64921	64921
4960	55	96313	96313
4965	55	131050	131050
4900	60	235352	235352
4905	60	212623	212623
4910	60	188127	188127
4915	60	161994	161994
4920	60	134569	134569
4925	60	106479	106479
4930	60	78914	78914
4935	60	54412	54412
4940	60	38644	38644
4945	60	40284	40284
4950	60	59495	59495
4955	60	87598	87598
4960	60	119272	119272
4895	65	215028	215028
4900	65	194478	194478
4905	65	172475	172475
4910	65	149025	149025
4915	65	124394	124394
4920	65	99143	99143
4925	65	74369	74369
4930	65	52359	52359
4935	65	37988	37988
4940	65	38584	38584
4945	65	55030	55030
4950	65	80245	80245
4955	65	109241	109241
4890	70	197940	197940
4895	70	179000	179000
4900	70	159033	159033
4905	70	137853	137853
4910	70	115627	115627
4915	70	92843	92843
4920	70	70498	70498
4925	70	50646	50646
4930	70	37497	37497
4935	70	37268	37268
4940	70	51319	51319
4945	70	73963	73963
4950	70	100577	100577
4885	75	183812	183812
4890	75	165828	165828
4895	75	147451	147451
4900	75	128172	128172
4905	75	108016	108016
4910	75	87380	87380
4915	75	67162	67162
4920	75	49197	49197
4925	75	37124	37124
4930	75	36245	36245
4935	75	46212	46212
4940	75	66542	66542
4945	75	93005	93005
4880	80	172714	172714
4885	80	154775	154775
4890	80	137501	137501
4895	80	119766	119766
4900	80	101378	101378
4905	80	82616	82616
4910	80	64265	64265
4915	80	47957	47957
4920	80	36841	36841
4925	80	35451	35451
4930	80	45597	45597
4935	80	63828	63828
4940	80	86325	86325
4875	85	165291	165291
4880	85	145852	145852
4885	85	129057	129057
4890	85	112495	112495
4895	85	95587	95587
4900	85	78449	78449
4905	85	61736	61736
4910	85	46888	46888
4915	85	36625	36625
4920	85	34833	34833
4925	85	43388	43388
4930	85	59705	59705
4935	85	80388	80368
4870	90	163443	163443
4875	90	139370	139370
4880	90	122111	122111
4885	90	106278	106278
4890	90	90557	90557
4895	90	74805	74805
4900	90	59526	59526
4905	90	45962	45962
4910	90	36460	36460
4915	90	34355	34355
4920	90	41517	41517
4925	90	56082	56082
4930	90	75078	75078
4865	95	172279	148028
4870	95	136240	133059
4875	95	116812	116812
4880	95	101098	101098
4885	95	86237	86237
4890	95	71639	71639
4895	95	57598	57598
4900	95	45160	45160
4905	95	36336	36336
4910	95	33988	33988
4915	95	39928	39928
4920	95	52890	52890
4925	95	70309	70309
4860	100	204618	139461
4865	100	138802	126695
4870	100	113602	112235
4875	100	97030	97030
4880	100	82615	82615
4885	100	68918	68918
4890	100	55930	55930
4895	100	44470	44470
4900	100	36245	36245
4905	100	33706	33706
4910	100	38579	38579
4915	100	50070	50070
4920	100	66011	66011

TABLE II.- 1982 EROS TO EARTH ONE-WAY MINIMUM ΔV REQUIREMENTS

JDDR = Julian date of Eros departure - 2 440 000

TFL = Eros to Earth flight itme, days

DV2 = Two-impulse one-way ΔV requirement = $\Delta V_{DR} + \Delta V_{AE}$, fps

DV3 = Three-impulse one-way ΔV requirement = $\Delta V_{DR} + \Delta V_{i} + \Delta V_{AE}$, fps

200- by 38 529-n. mi. altitude (1 day period) parking orbit at Earth return

JDDR	TFL	DV2	DV3
5000	5	320196	320196
5005	5	514504	514504
5010	5	856370	856370
4995	10	228689	228689
5000	10	152566	152566
5005	10	250720	250720
5010	10	420618	420618
5015	10	605003	605003
5020	10	791097	791097
4995	15	144752	144752
5000	15	99388	99388
5005	15	164905	164905
5010	15	277093	277093
5015	15	399454	399454
5020	15	523171	523171
5025	15	645141	645141
5030	15	763710	763710
5035	15	877733	877733
4990	20	182366	182366
4995	20	104172	104172
5000	20	74461	74461
5005	20	123428	123428
5010	20	206536	206536
5015	20	297740	297740
5020	20	390155	390155
5025	20	481283	481283
5030	20	569791	569791
5035	20	654766	654766
5040	20	735480	735480
4980	25	874010	874010
4985	25	869730	869730
4990	25	141105	141105
4995	25	80806	80806
5000	25	60565	60565
5005	25	99533	99533
5010	25	165063	165063
5015	25	237443	237443
5020	25	310947	310947
5025	25	383426	383426
5030	25	453727	453727
5035	25	521063	521063
5040	25	584812	584812
4980	30	709865	709865
4985	30	173367	173367
4990	30	114078	114078
4995	30	65946	65946
5000	30	51995	51995
5005	30	84296	84296
5010	30	138028	138028
5015	30	197737	197737
5020	30	258500	258500
5025	30	318392	318392
5030	30	376376	376376
5035	30	431748	431748
5040	30	483958	483958
4980	35	593625	593625
4985	35	145253	145253
4990	35	95134	95134
4995	35	55869	55869
5000	35	46342	46342
5005	35	73894	73894
5010	35	119147	119147
5015	35	169694	169694
5020	35	221222	221222
5025	35	271971	271971
5030	35	320988	320988
5035	35	367630	367630
5040	35	411403	411403
4980	40	170933	170933
4985	40	124325	124325
4990	40	81201	81201
4995	40	48723	48723
5000	40	42424	42424
5005	40	66425	66425
5010	40	105278	105278
5015	40	148850	148850
5020	40	193325	193325
5025	40	237075	237075
5030	40	279217	279217
5035	40	319157	319157
5040	40	356457	356457
4980	45	149425	149425
4985	45	108148	108148
4990	45	70585	70585
4995	45	43485	43485
5000	45	39603	39603
5005	45	60842	60842
5010	45	94680	94680
5015	45	132735	132735
5020	45	171607	171607
5025	45	209792	209792
5030	45	246460	246460
5035	45	281070	281070
5040	45	313243	313243
4980	50	132208	132208
4985	50	95273	95273
4990	50	62273	62273
4995	50	39549	39549
5000	50	37504	37504
5005	50	56525	56525
5010	50	86318	86318
5015	50	119877	119877
5020	50	154168	154168
5025	50	187794	187794
5030	50	219985	219985
5035	50	250256	250256
5040	50	278283	278283
4980	55	118087	116087
4985	55	84784	84784
4990	55	55629	55629
4995	55	36534	36534
5000	55	35900	35900
5005	55	53086	53086
5010	55	79538	79538
5015	55	109349	109349
5020	55	139808	139808
5025	55	169623	169623
5030	55	198085	198085
5035	55	224761	224761
5040	55	249405	249405
4980	60	106268	106268
4985	60	76078	76078
4990	60	50229	50229
4995	60	34186	34186
5000	60	34643	34643
5005	60	50278	50278
5010	60	73917	73917
5015	60	100546	100546
5020	60	127744	127744
5025	60	154324	154324
5030	60	179638	179638
5035	60	203316	203316
5040	60	225192	225192
4980	65	96212	96212
4985	65	68743	68743
4990	65	45785	45785
4995	65	32334	32334
5000	65	33631	33631
5005	65	47929	47929
5010	65	69162	69162
5015	65	93055	93055
5020	65	117447	117447
5025	65	141253	141253
5030	65	163888	163888
5035	65	185058	185058
5040	65	204700	204700
4980	70	87538	87538
4985	70	62488	62488
4990	70	42089	42089
4995	70	30855	30855
5000	70	32800	32800
5005	70	45925	45925
5010	70	65078	65078
5015	70	86593	86593
5020	70	108547	108547
5025	70	129956	129956
5030	70	150309	150309
5035	70	169394	169394
5040	70	187301	187301
4980	75	79974	79974
4985	75	57102	57102
4990	75	38992	38992
4995	75	29664	29664
5000	75	32100	32100
5005	75	44186	44186
5010	75	61521	61521
5015	75	80954	80954
5020	75	100779	100779
5025	75	120113	120113
5030	75	138527	138527
5035	75	155918	155918
5040	75	172618	172618
4980	80	73317	73317
4985	80	52429	52429
4990	80	36380	36380
4995	80	28692	28692
5000	80	31496	31496
5005	80	42654	42654
5010	80	58390	58390
5015	80	75992	75992
5020	80	93951	93951
5025	80	111491	111491
5030	80	128278	128278
5035	80	144369	144369
5040	80	160531	160531
4980	85	67416	67416
4985	85	48353	48353
4990	85	34164	34164
4995	85	27893	27893
5000	85	30965	30965
5005	85	41286	41286
5010	85	55610	55610
5015	85	71595	71595
5020	85	87921	87921
5025	85	103922	103922
5030	85	119384	119384
5035	85	134624	134624
5040	85	151290	151290
4980	90	62156	62156
4985	90	44779	44779
4990	90	32278	32278
4995	90	27225	27225
5000	90	30488	30488
5005	90	40052	40052
5010	90	53123	53123
5015	90	67683	67683
5020	90	82584	82584
5025	90	97285	97285
5030	90	111745	111745
5035	90	126747	126747
5040	90	145943	145943
4980	95	57445	57445
4985	95	41636	41636
4990	95	30664	30664
4995	95	26661	26661
5000	95	30049	30049
5005	95	38929	38929
5010	95	50887	50887
5015	95	64192	64192
5020	95	77862	77862
5025	95	91505	91505
5030	95	105352	105352
5035	95	121130	120422
5040	95	147727	134681
4980	100	53214	53214
4985	100	38864	38864
4990	100	29277	29277
4995	100	26176	26176
5000	100	29640	29640
5005	100	37899	37899
5010	100	48870	48870
5015	100	61075	61075
5020	100	73703	73703
5025	100	86553	86553
5030	100	100342	100342
5035	100	118944	114055
5040	100	167155	126193

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES

(a) Staytime at Eros ≥ 0 days

TTT = Total trip time, days
DV2 = Total mission ΔV, two-impulse
DV3 = Total mission ΔV, three-impulse
JDDE = Julian date of Earth departure - 2 440 000

T1 = Earth to Eros flight time, days
S = Staytime at Eros, days
T2 = Eros to Earth flight time, days
JDDR = Julian date of Eros departure - 2 440 000

			TWO-IMPULSE					THREE-IMPULSE				
TTT	DV2	DV3	JDDE	T1	S	T2	JDDR	JDDE	T1	S	T2	JDDR
10	639898	639898	4995	5	0	5	5000	4995	5	0	5	5000
15	472268	472268	4995	5	0	10	5000	4995	5	0	10	5000
20	304833	304833	4990	10	0	10	5000	4990	10	0	10	5000
25	251655	251655	4990	10	0	15	5000	4990	10	0	15	5000
30	198808	198808	4985	15	0	15	5000	4985	15	0	15	5000
35	173881	173881	4985	15	0	20	5000	4985	15	0	20	5000
40	149380	149380	4980	20	0	20	5000	4980	20	0	20	5000
45	135484	135484	4980	20	0	25	5000	4980	20	0	25	5000
50	122063	122063	4975	25	0	25	5000	4975	25	0	25	5000
55	113493	113493	4975	25	0	30	5000	4975	25	0	30	5000
60	105415	105415	4970	30	0	30	5000	4970	30	0	30	5000
65	99762	99762	4970	30	0	35	5000	4970	30	0	35	5000
70	94594	94594	4965	35	0	35	5000	4965	35	0	35	5000
75	90676	90676	4965	35	0	40	5000	4965	35	0	40	5000
80	87224	87224	4960	40	0	40	5000	4960	40	0	40	5000
85	84403	84403	4960	40	0	45	5000	4960	40	0	45	5000
90	82024	82024	4955	45	0	45	5000	4955	45	0	45	5000
95	79925	79925	4955	45	0	50	5000	4955	45	0	50	5000
100	78244	78244	4950	50	0	50	5000	4950	50	0	50	5000
105	76640	76640	4950	50	0	55	5000	4950	50	0	55	5000
110	75383	75383	4950	50	0	60	5000	4950	50	0	60	5000
115	74173	74173	4945	55	0	60	5000	4945	55	0	60	5000
120	73161	73161	4945	55	0	65	5000	4945	55	0	65	5000
125	72275	72275	4940	60	0	65	5000	4940	60	0	65	5000
130	71444	71444	4940	60	0	70	5000	4940	60	0	70	5000
135	70744	70744	4940	60	0	75	5000	4940	60	0	75	5000
140	70088	70088	4935	65	0	75	5000	4935	65	0	75	5000
145	69484	69484	4935	65	0	80	5000	4935	65	0	80	5000
150	68953	68953	4935	65	0	85	5000	4935	65	0	85	5000
155	68462	68462	4930	70	0	85	5000	4930	70	0	85	5000
160	67985	67985	4930	70	0	90	5000	4930	70	0	90	5000

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Continued

(b) Staytime at Eros ≥5 days

			TWO-IMPULSE					THREE-IMPULSE				
TTT	DV2	DV3	JDDE	T1	S	T2	JDDR	JDDE	T1	S	T2	JDDR
15	826389	826389	4990	5	5	5	5000	4990	5	5	5	5000
20	568513	568513	4985	10	5	5	5000	4985	10	5	5	5000
25	400883	400883	4985	10	5	10	5000	4985	10	5	10	5000
30	317104	317104	4980	15	5	10	5000	4980	15	5	10	5000
35	263926	263926	4980	15	5	15	5000	4980	15	5	15	5000
40	222848	222848	4985	15	5	20	5005	4985	15	5	20	5005
45	198347	198347	4980	20	5	20	5005	4980	20	5	20	5005
50	174452	174452	4980	20	5	25	5005	4980	20	5	25	5005
55	159215	159215	4980	20	5	30	5005	4980	20	5	30	5005
60	145794	145794	4975	25	5	30	5005	4975	25	5	30	5005
65	135392	135392	4975	25	5	35	5005	4975	25	5	35	5005
70	127314	127314	4970	30	5	35	5005	4970	30	5	35	5005
75	119845	119845	4970	30	5	40	5005	4970	30	5	40	5005
80	114262	114262	4970	30	5	45	5005	4970	30	5	45	5005
85	109094	109094	4965	35	5	45	5005	4965	35	5	45	5005
90	104777	104777	4965	35	5	50	5005	4965	35	5	50	5005
95	101325	101325	4960	40	5	50	5005	4960	40	5	50	5005
100	97886	97886	4960	40	5	55	5005	4960	40	5	55	5005
105	95078	95078	4960	40	5	60	5005	4960	40	5	60	5005
110	92699	92699	4955	45	5	60	5005	4955	45	5	60	5005
115	90350	90350	4955	45	5	65	5005	4955	45	5	65	5005
120	88346	88346	4955	45	5	70	5005	4955	45	5	70	5005
125	86607	86607	4955	45	5	75	5005	4955	45	5	75	5005
130	84926	84926	4950	50	5	75	5005	4950	50	5	75	5005
135	83394	83394	4950	50	5	80	5005	4950	50	5	80	5005
140	82026	82026	4950	50	5	85	5005	4950	50	5	85	5005
145	80792	80792	4950	50	5	90	5005	4950	50	5	90	5005
150	79582	79582	4945	55	5	90	5005	4945	55	5	90	5005
155	78459	78459	4945	55	5	95	5005	4945	55	5	95	5005
160	77429	77429	4945	55	5	100	5005	4945	55	5	100	5005

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Continued

(c) Staytime at Eros ≥10 days

			TWO-IMPULSE					THREE-IMPULSE				
TTT	DV2	DV3	JDDE	T1	S	T2	JDDR	JDDE	T1	S	T2	JDDR
20	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
25	740016	740016	4980	10	10	5	5000	4980	10	10	5	5000
30	499037	499037	4985	10	10	10	5005	4985	10	10	10	5005
35	413222	413222	4985	10	10	15	5005	4985	10	10	15	5005
40	329443	329443	4980	15	10	15	5005	4980	15	10	15	5005
45	287966	287966	4980	15	10	20	5005	4980	15	10	20	5005
50	247576	247576	4975	20	10	20	5005	4975	20	10	20	5005
55	223681	223681	4975	20	10	25	5005	4975	20	10	25	5005
60	200508	200508	4970	25	10	25	5005	4970	25	10	25	5005
65	185271	185271	4970	25	10	30	5005	4970	25	10	30	5005
70	170579	170579	4965	30	10	30	5005	4965	30	10	30	5005
75	160177	160177	4965	30	10	35	5005	4965	30	10	35	5005
80	150226	150226	4960	35	10	35	5005	4960	35	10	35	5005
85	142757	142757	4960	35	10	40	5005	4960	35	10	40	5005
90	135682	135682	4955	40	10	40	5005	4955	40	10	40	5005
95	130099	130099	4955	40	10	45	5005	4955	40	10	45	5005
100	124871	124871	4950	45	10	45	5005	4950	45	10	45	5005
105	120554	120554	4950	45	10	50	5005	4950	45	10	50	5005
110	116569	116569	4945	50	10	50	5005	4945	50	10	50	5005
115	113130	113130	4945	50	10	55	5005	4945	50	10	55	5005
120	109773	109773	4965	35	10	75	5010	4965	35	10	75	5010
125	106321	106321	4960	40	10	75	5010	4960	40	10	75	5010
130	103190	103190	4960	40	10	80	5010	4960	40	10	80	5010
135	100410	100410	4960	40	10	85	5010	4960	40	10	85	5010
140	97923	97923	4960	40	10	90	5010	4960	40	10	90	5010
145	95544	95544	4955	45	10	90	5010	4955	45	10	90	5010
150	93308	93308	4955	45	10	95	5010	4955	45	10	95	5010
155	91291	91291	4955	45	10	100	5010	4955	45	10	100	5010
160	89610	89610	4950	50	10	100	5010	4950	50	10	100	5010

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Continued

(d) Staytime at Eros ≥15 days

			TWO-IMPULSE					THREE-IMPULSE				
TTT	DV2	DV3	JDDE	T1	S	T2	JDDR	JDDE	T1	S	T2	JDDR
25	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
30	924705	924705	4995	5	15	10	5015	4995	5	15	10	5015
35	668935	668935	4985	10	15	10	5010	4985	10	15	10	5010
40	525410	525410	4985	10	15	15	5010	4985	10	15	15	5010
45	441631	441631	4980	15	15	15	5010	4980	15	15	15	5010
50	371074	371074	4980	15	15	20	5010	4980	15	15	20	5010
55	329601	329601	4980	15	15	25	5010	4980	15	15	25	5010
60	289211	289211	4975	20	15	25	5010	4975	20	15	25	5010
65	262176	262176	4975	20	15	30	5010	4975	20	15	30	5010
70	239003	239003	4970	25	15	30	5010	4970	25	15	30	5010
75	220122	220122	4970	25	15	35	5010	4970	25	15	35	5010
80	205430	205430	4965	30	15	35	5010	4965	30	15	35	5010
85	191561	191561	4965	30	15	40	5010	4965	30	15	40	5010
90	180963	180963	4965	30	15	45	5010	4965	30	15	45	5010
95	170847	170847	4975	25	15	55	5015	4975	25	15	55	5015
100	162044	162044	4975	25	15	60	5015	4975	25	15	60	5015
105	153966	153966	4970	30	15	60	5015	4970	30	15	60	5015
110	146475	146475	4970	30	15	65	5015	4970	30	15	65	5015
115	140013	140013	4970	30	15	70	5015	4970	30	15	70	5015
120	134374	134374	4970	30	15	75	5015	4970	30	15	75	5015
125	129206	129206	4965	35	15	75	5015	4965	35	15	75	5015
130	124244	124244	4965	35	15	80	5015	4965	35	15	80	5015
135	119847	119847	4965	35	15	85	5015	4965	35	15	85	5015
140	115935	115935	4965	35	15	90	5015	4965	35	15	90	5015
145	112444	112444	4965	35	15	95	5015	4965	35	15	95	5015
150	108992	108992	4960	40	15	95	5015	4960	40	15	95	5015
155	105875	105875	4960	40	15	100	5015	4960	40	15	100	5015
160	103496	103496	4955	45	15	100	5015	4965	45	15	100	5015

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Continued

(e) Staytime at Eros ≥ 20 days

			TWO-IMPULSE					THREE-IMPULSE				
TTT	DV2	DV3	JDDE	T1	S	T2	JDDR	JDDE	T1	S	T2	JDDR
30	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
35	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
40	840438	840438	4980	10	20	10	5010	4980	10	20	10	5010
45	647771	647771	4985	10	20	15	5015	4985	10	20	15	5015
50	542422	542422	4990	10	20	20	5020	4990	10	20	20	5020
55	462278	462278	4980	15	20	20	5015	4980	15	20	20	5015
60	401981	401981	4980	15	20	25	5015	4980	15	20	25	5015
65	357920	357920	4985	15	20	30	5020	4985	15	20	30	5020
70	320642	320642	4985	15	20	35	5020	4985	15	20	35	5020
75	292745	292745	4985	15	20	40	5020	4985	15	20	40	5020
80	268244	268244	4980	20	20	40	5020	4980	20	20	40	5020
85	246526	246526	4980	20	20	45	5020	4980	20	20	45	5020
90	229087	229087	4980	20	20	50	5020	4980	20	20	50	5020
95	214727	214727	4980	20	20	55	5020	4980	20	20	55	5020
100	201306	201306	4975	25	20	55	5020	4975	25	20	55	5020
105	189242	189242	4975	25	20	60	5020	4975	25	20	60	5020
110	178945	178945	4975	25	20	65	5020	4975	25	20	65	5020
115	170045	170045	4975	25	20	70	5020	4975	25	20	70	5020
120	161967	161967	4970	30	20	70	5020	4970	30	20	70	5020
125	154199	154199	4970	30	20	75	5020	4970	30	20	75	5020
130	147371	147371	4970	30	20	80	5020	4970	30	20	80	5020
135	141341	141341	4970	30	20	85	5020	4970	30	20	85	5020
140	136004	136004	4970	30	20	90	5020	4970	30	20	90	5020
145	130836	130836	4965	35	20	90	5020	4965	35	20	90	5020
150	126114	126114	4965	35	20	95	5020	4965	35	20	95	5020
155	121955	121955	4965	35	20	100	5020	4965	35	20	100	5020
160	118503	118503	4960	40	20	100	5020	4960	40	20	100	5020

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Continued

(f) Staytime at Eros ≥25 days

			TWO-IMPULSE					THREE-IMPULSE				
TTT	DV2	DV3	JDDE	T1	S	T2	JDDR	JDDE	T1	S	T2	JDDR
35	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
40	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
45	964843	964843	4995	5	25	15	5025	4995	5	25	15	5025
50	771488	771488	4985	10	25	15	5020	4985	10	25	15	5020
55	633550	633550	4990	10	25	20	5025	4990	10	25	20	5025
60	535693	535693	4990	10	25	25	5025	4990	10	25	25	5025
65	470659	470659	4990	10	25	30	5025	4990	10	25	30	5025
70	417812	417812	4985	15	25	30	5025	4985	15	25	30	5025
75	371391	371391	4985	15	25	35	5025	4985	15	25	35	5025
80	336495	336495	4985	15	25	40	5025	4985	15	25	40	5025
85	309212	309212	4985	15	25	45	5025	4985	15	25	45	5025
90	284711	284711	4980	20	25	45	5025	4980	20	25	45	5025
95	262713	262713	4980	20	25	50	5025	4980	20	25	50	5025
100	244542	244542	4980	20	25	55	5025	4980	20	25	55	5025
105	229243	229243	4980	20	25	60	5025	4980	20	25	60	5025
110	215822	215822	4975	25	25	60	5025	4975	25	25	60	5025
115	202751	202751	4975	25	25	65	5025	4975	25	25	65	5025
120	191454	191454	4975	25	25	70	5025	4975	25	25	70	5025
125	181611	181611	4975	25	25	75	5025	4975	25	25	75	5025
130	172989	172989	4975	25	25	80	5025	4975	25	25	80	5025
135	164911	164911	4970	30	25	80	5025	4970	30	25	80	5025
140	157342	157342	4970	30	25	85	5025	4970	30	25	85	5025
145	150705	150705	4970	30	25	90	5025	4970	30	25	90	5025
150	144925	144925	4970	30	25	95	5025	4970	30	25	95	5025
155	139757	139757	4965	35	25	95	5025	4965	35	25	95	5025
160	134805	134805	4965	35	25	100	5025	4965	35	25	100	5025

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Concluded

(g) Staytime at Eros ≥30 days

			TWO-IMPULSE					THREE-IMPULSE				
TTT	DV2	DV3	JDDE	T1	S	T2	JDDR	JDDE	T1	S	T2	JDDR
40	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
45	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
50	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
55	889493	889493	4995	5	30	20	5030	4995	5	30	20	5030
60	722058	722058	4990	10	30	20	5030	4990	10	30	20	5030
65	605994	605994	4990	10	30	25	5030	4990	10	30	25	5030
70	528643	528643	4990	10	30	30	5030	4990	10	30	30	5030
75	473255	473255	4990	10	30	35	5030	4990	10	30	35	5030
80	420408	420408	4985	15	30	35	5030	4985	15	30	35	5030
85	378637	378637	4985	15	30	40	5030	4985	15	30	40	5030
90	345880	345880	4985	15	30	45	5030	4985	15	30	45	5030
95	319405	319405	4985	15	30	50	5030	4985	15	30	50	5030
100	294904	294904	4980	20	30	50	5030	4980	20	30	50	5030
105	273004	273004	4980	20	30	55	5030	4980	20	30	55	5030
110	254557	254557	4980	20	30	60	5030	4980	20	30	60	5030
115	238807	238807	4980	20	30	65	5030	4980	20	30	65	5030
120	225228	225228	4980	20	30	70	5030	4980	20	30	70	5030
125	211807	211807	4975	25	30	70	5030	4975	25	30	70	5030
130	200025	200025	4975	25	30	75	5030	4975	25	30	75	5030
135	189776	189776	4975	25	30	80	5030	4975	25	30	80	5030
140	180882	180882	4975	25	30	85	5030	4975	25	30	85	5030
145	172804	172804	4970	30	30	85	5030	4970	30	30	85	5030
150	165165	165165	4970	30	30	90	5030	4970	30	30	90	5030
155	158772	158772	4970	30	30	95	5030	4970	30	30	95	5030
160	153604	153604	4965	35	30	95	5030	4965	35	30	95	5030

TABLE IV.- VEHICLE CONFIGURATIONS AND COST COMPARISON
(5000-LB PAYLOAD)

Mission	A	B	C
Mission type	Fast	Opposition class	Conjunction class
Total trip time, days	120	380	540
Staytime at Eros, days	0	0	175
Total mission ΔV required, fps	73 000	52 000	39 000
Vehicle configuration (stages capable of performing mission, in tandem)	[a]2 large-tank Agenas + 10 CPS	2 large-tank Agenas + 2 CPS	1 large-tank Agena + 1 CPS
ΔV capability of vehicle configuration, fps	74 500	54 000	44 000
Relative cost	10	2	1

[a]Two large-tank Agenas and 5 nuclear stages can be used here instead (75 500 fps ΔV capability).

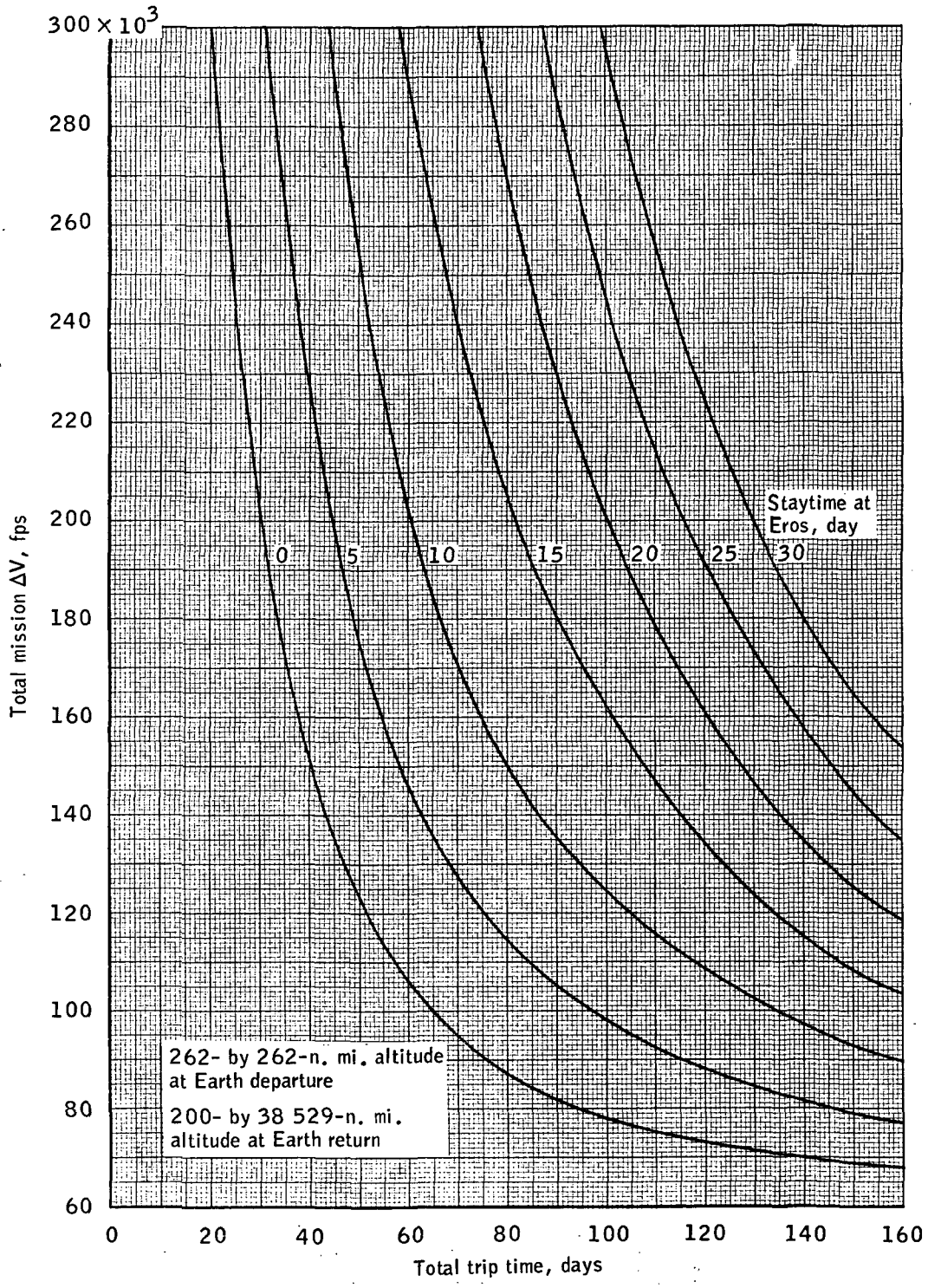


Figure 1.- Total mission ΔV versus total trip time for "fast" round trip landing missions to Eros in the 1981 opportunity.

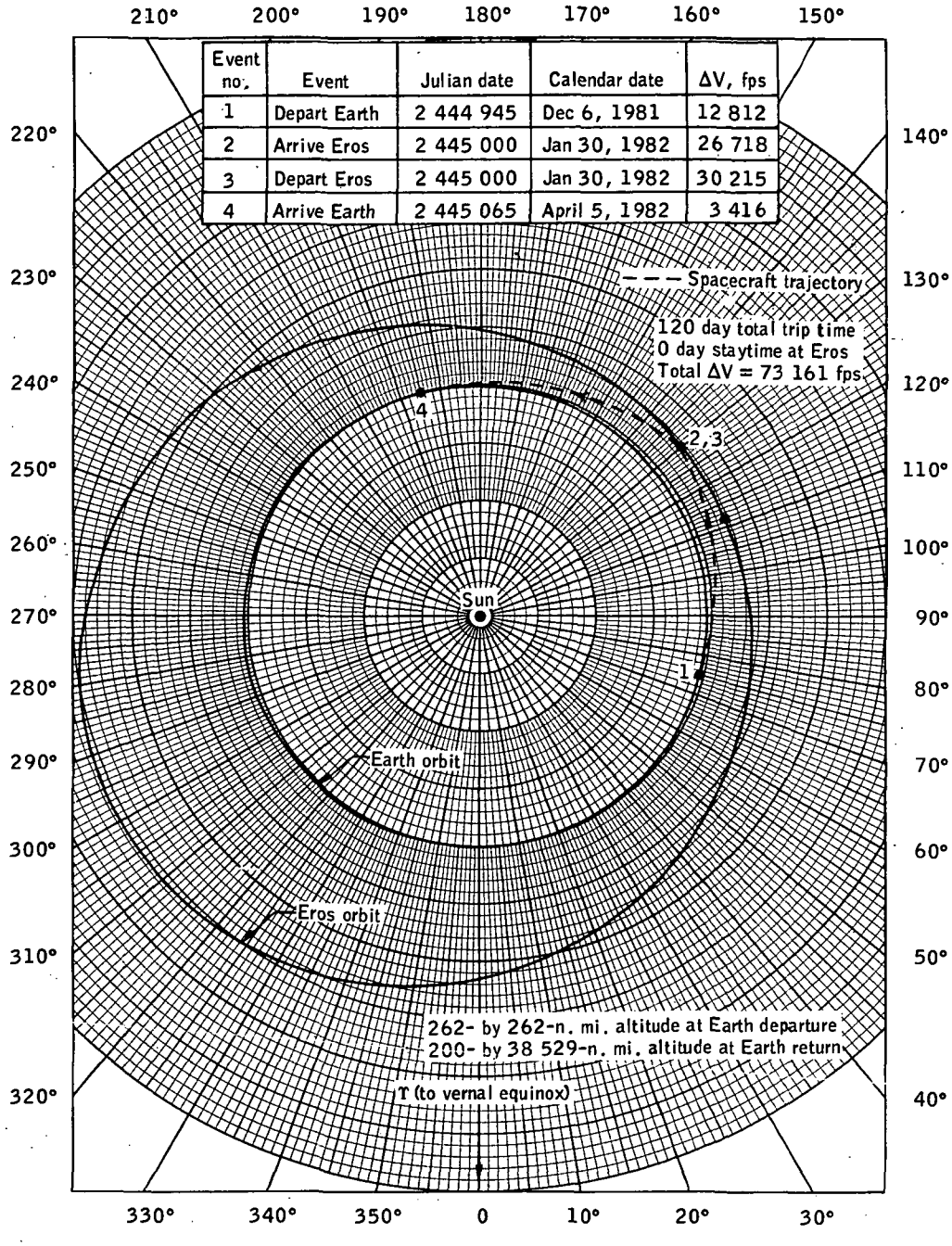
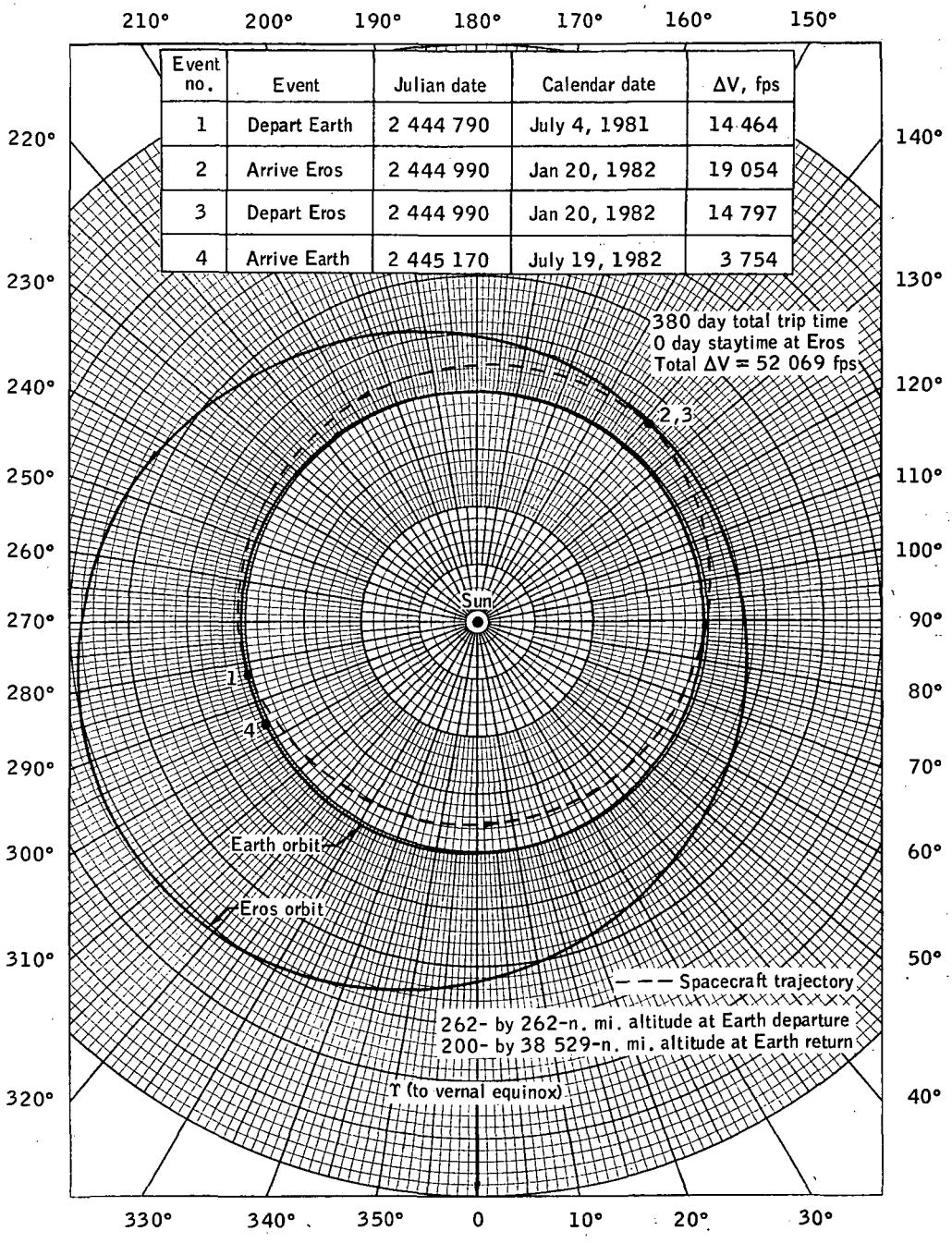


Figure 2.- Characteristics and heliocentric sketch of mission A (fast mission).



Event no.	Event	Julian date	Calendar date	ΔV, fps
1	Depart Earth	2 444 790	July 4, 1981	14 464
2	Arrive Eros	2 444 990	Jan 20, 1982	19 054
3	Depart Eros	2 444 990	Jan 20, 1982	14 797
4	Arrive Earth	2 445 170	July 19, 1982	3 754

Figure 3.- Characteristics and heliocentric sketch of mission B (opposition class mission).

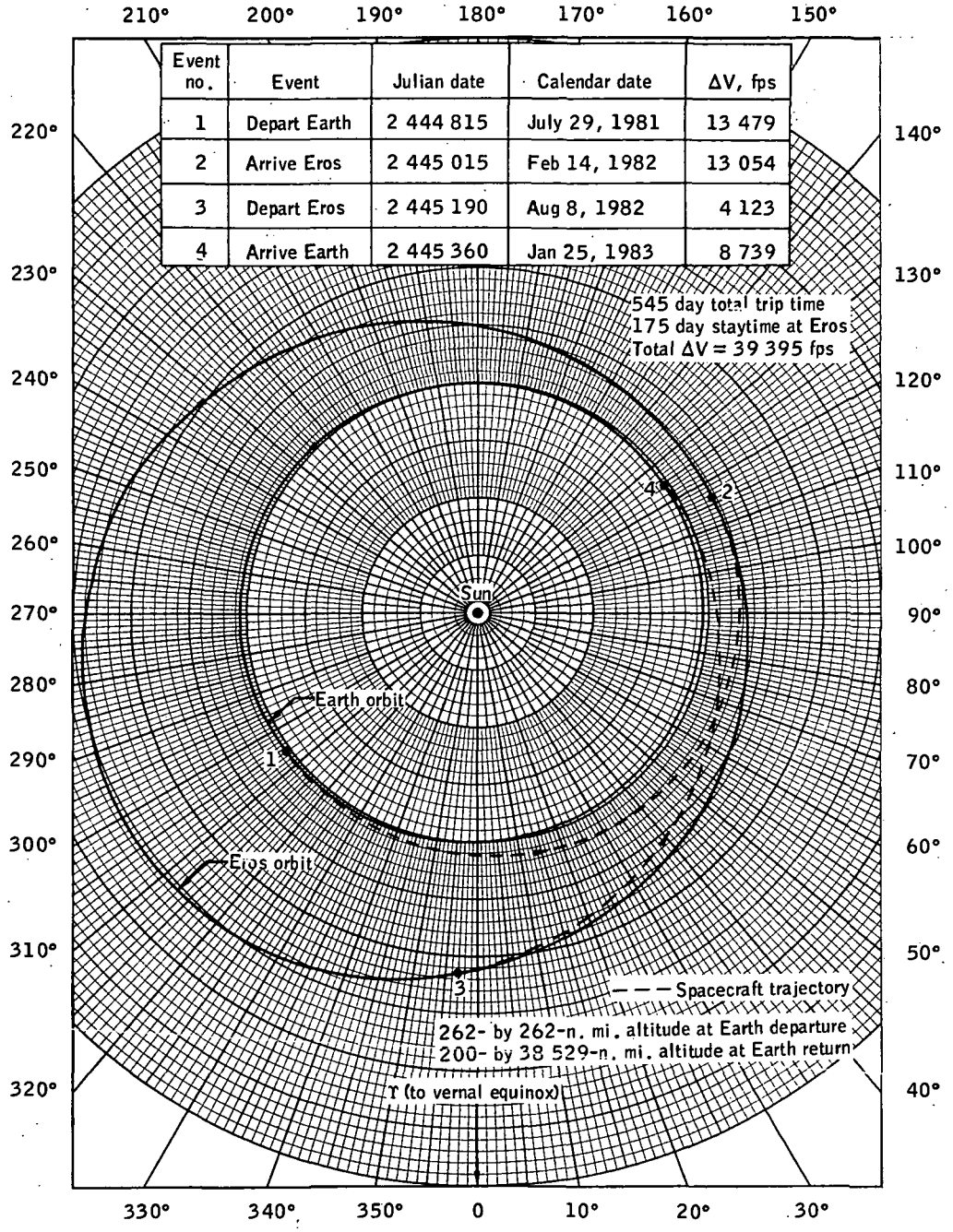


Figure 4.- Characteristics and heliocentric sketch of mission C (conjunction class mission).

REFERENCE

1. Alfven, H.; and Arrhenius, G.: Mission to an Asteroid. Science, Vol. 167, Jan. 9, 1970, pp. 139-141.