BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 12078

SUBJECT: The Effect of Lunar Time of Arrival on S-IVB Second Opportunity Injection Propellant Requirements for the J-1 Mission - Case 310

DATE: December 31, 1970

FROM: R. J. Stern

ABSTRACT

Launch vehicle second opportunity translunar injection propellant costs for a specified launch azimuth are parametrically examined as a function of lunar time of arrival. For a given launch azimuth and arrival time the required plane change during translunar injection is uniquely determined. It is shown that the behavior of the required S-IVB propellant is strongly affected by the translunar dihedral angle. For the relatively low dihedral angles associated with the J-1 Hadley mission it was found that the use of a coplanar TLI for the second injection opportunity does not result in the minimum S-IVB propellant requirements in all cases. In particular for the July, 1971 opportunity the plane change required for the optimum second opportunity TLI is approximately 0.5 degree for a launch azimuth of 72 degrees and approximately 1.7 degrees for launch azimuths of 84 and 96 degrees.

(NASA-CR-116279) THE EFFECT OF LUNAR TIME OF ARRIVAL ON S-4B SECOND OPPORTUNITY INJECTION PROPELLANT REQUIREMENTS FOR THE J-1 MISSION (Bellcomm, Inc.) 16 p

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MEMORANDUM FOR FILE

Introduction

The launch and injection policy for Apollo missions is such that a plane change for a first opportunity* translunar injection (TLI) from earth parking orbit (EPO) will not be required. In the event that a first opportunity TLI cannot occur, a second injection opportunity is available on the next orbital revolution, approximately 90 minutes later. Previous targeting policy has maintained a constant translunar flight time (nearly constant energy) for second opportunity injections. This policy required a plane change at second opportunity TLI to reach the desired landing site. Due to the energy restriction for free return trajectories with constant perilune altitude, a common translunar and earth parking orbit plane is not possible for the second injection opportunity. A common translunar plane could be used with the hybrid profile by changing the perilune altitude for first and second opportunity. The relaxed free return profile does not have this restriction since the trajectory is non-free from TLI and the translunar energy may be independently specified within the DPS abort constraint. This study considers the effect of varying the translunar energy for the second opportunity injection on S-IVB propellant requirements and LOI ΔV. The results of the study are useful in the selection of targeting parameters for second opportunity injections.

Method

Precision integrated, first opportunity injection trajectories were generated for missions to Hadley with launch dates 7/26/71 and 8/24/71. Launch azimuths of 72, 84 and 96 degrees were investigated for the July launch date and a 72 degree azimuth was investigated for the August opportunity. Launch vehicle performance was simulated using the data of Reference 1. The important trajectory parameters for these missions and first injection opportunity data are presented in Table 1. Values of actual S-IVB propellant may differ from that of Reference 1 due to limitations of the launch vehicle simulation employed. However, variations in S-IVB propellant consumption for changes in targeting parameters are accurate. Using the first opportunity launch date and

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*A first opportunity injection occurs during the second revolution in EPO. A second opportunity injection occurs during the third revolution.

time obtained from these trajectories, second opportunity injection precision trajectories were generated for varying values of translunar energy or equivalently differing times of lunar arrival (LOI ignition). For the second opportunity trajectories, the approach azimuth to the landing site was maintained at the same value as for the first injection opportunity.

Results

Figures 1-4 present the required S-IVB propellant for the second opportunity injection burn relative to the propellant required for the first opportunity injection and the injection plane change as a function of lunar time of arrival. Also presented in the figures are the nominal time of lunar arrival (first opportunity injection) and the time of arrival that results when the translunar flight time is maintained constant for both injection opportunities.

Examination of Figures 1-4 indicates that the behavior of the S-IVB propellant curves as a function of time of arrival is strongly dependent upon the translunar dihedral angle.* When this angle is relatively high as for the August opportunity (see Table I)** the slope of the plane change curve (Figure 4) is high and the plane change dominates the behavior of the required S-IVB propellant. Thus, in this case the required S-IVB propellant is minimized for zero TLI plane change which occurs when the time of lunar arrival is approximately 1.5 hours earlier than that for the first opportunity injection. As the dihedral angle decreases (July launch, 72° launch azimuth) the S-IVB propellant is minimized at a time of arrival later than that corresponding to zero TLI plane change. This indicates that the effects on S-IVB propellant due to plane change and energy change (longer flight times) are comparable. The sensitivity of the required propellant to time of arrival also decreases due to the lessened effect (lower slope) of the TLI plane change curve.

For still lower values of dihedral angle such as those occurring for the July opportunity with launch azimuths of 84 and 96 degrees the sensitivity of required S-IVB propellant to time of lunar arrival decreases further and the minimum value shifts still later to the time of arrival corresponding to constant translunar flight time.

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*Angle between the translunar trajectory plane and the Earth-Moon Plane.

**The values of dihedral angle for the second opportunity injections are close to those for the first opportunity. The relative magnitude of the dihedral angle for the Hadley missions with respect to all values during the lunar cycle is illustrated in Figure A-1. Locations along the horizontal axis of Figure A-1 represent the time of arrival at the MSI converted to a day number by means of Table A-1.

Figures 5-8 illustrate the LOI ΔV, translunar injection energy and translunar flight time as a function of lunar time of arrival for the second opportunity injections of Figures 1-4. For the July launch (Figures 5-7) the LOI ΔV decreases with increasing lunar time of arrival or decreasing translunar energy. Therefore, a tradeoff between S-IVB propellant and LOI ΔV may be made. LOI ΔV for the first opportunity injections is presented in Table I. For the August launch (Figure 8) the LOI ΔV has a minimum at approximately the same time of arrival that minimizes the S-IVB propellant. This minimum in LOI ΔV is due to an increasing LOI plane change ΔV requirement as time of arrival increases, while the ΔV requirement for energy change decreases. For the July launch opportunities both energy and plane change ΔV requirements for LOI decrease with increasing time of arrival.

Conclusions

The sensitivity of required second opportunity injection S-IVB propellant to lunar time of arrival, as well as the magnitude of the TLI plane change corresponding to the minimum required S-IVB propellant, are strongly affected by the mission translunar dihedral angle. For the low dihedral angles associated with the July 1971 Hadley mission the sensitivity of S-IVB propellant to lunar time of arrival is relatively low and a coplanar TLI does not minimize the required S-IVB propellant. In addition, the plane change associated with the optimum TLI varies with launch azimuth. This is a direct result of the change in dihedral angle due to launch azimuth variations.

Lunar time of arrival for the optimum TLI can be earlier or later than the first opportunity arrival time. For the July opportunity at 72° launch azimuth the optimum second opportunity TLI arrival time is approximately 2 hours earlier than the first opportunity arrival time. For an 84° launch azimuth the optimum injection results in a nearly two-hour later arrival.

R. J. Stern

2013-RJS-slr

R. J. Stern

Attachments

Reference 1: Memorandum S&E-AERO-MFT-76-70, Saturn V Performance Study for AS 511-515, Boeing Company, June 2, 1970.

TABLE I - FIRST OPPORTUNITY INJECTION TRAJECTORY PARAMETERS

Landing Site, Launch Date	Launch Azimuth	Translunar Flight Time (hr)	Date, Time of Lunar Arrival (LOI)	Sun Elevation At LM Landing (deg)	Approach Azimuth to Landing Site (deg)	S-IVB Propellant (Second Burn-lbs)	LOI ΔV (ft/sec)	Translunar Dihedral Angle* (deg)
Hadley 7/26/71	72°	75.07	7/29/71 18 HR 55.3 MIN	10.25	-91.0	157,443	3115.0	6.93
Hadley 7/26/71	84°	73.75	7/29/71 18 HR 38.33 MIN	10.14	-91.0	158,398	3193.4	1.92
Hadley 7/26/71	96°	72.10	7/29/71 18 HR 29.5 MIN	10.07	-91.0	158,564	3251.7	1.92
Hadley 8/24/71	72°	88.60	8/28/71 7 HR 13.7 MIN	10.32	-91.0	156,816	2810.6	10.22

*Defined for osculating conic trajectory at TLI.

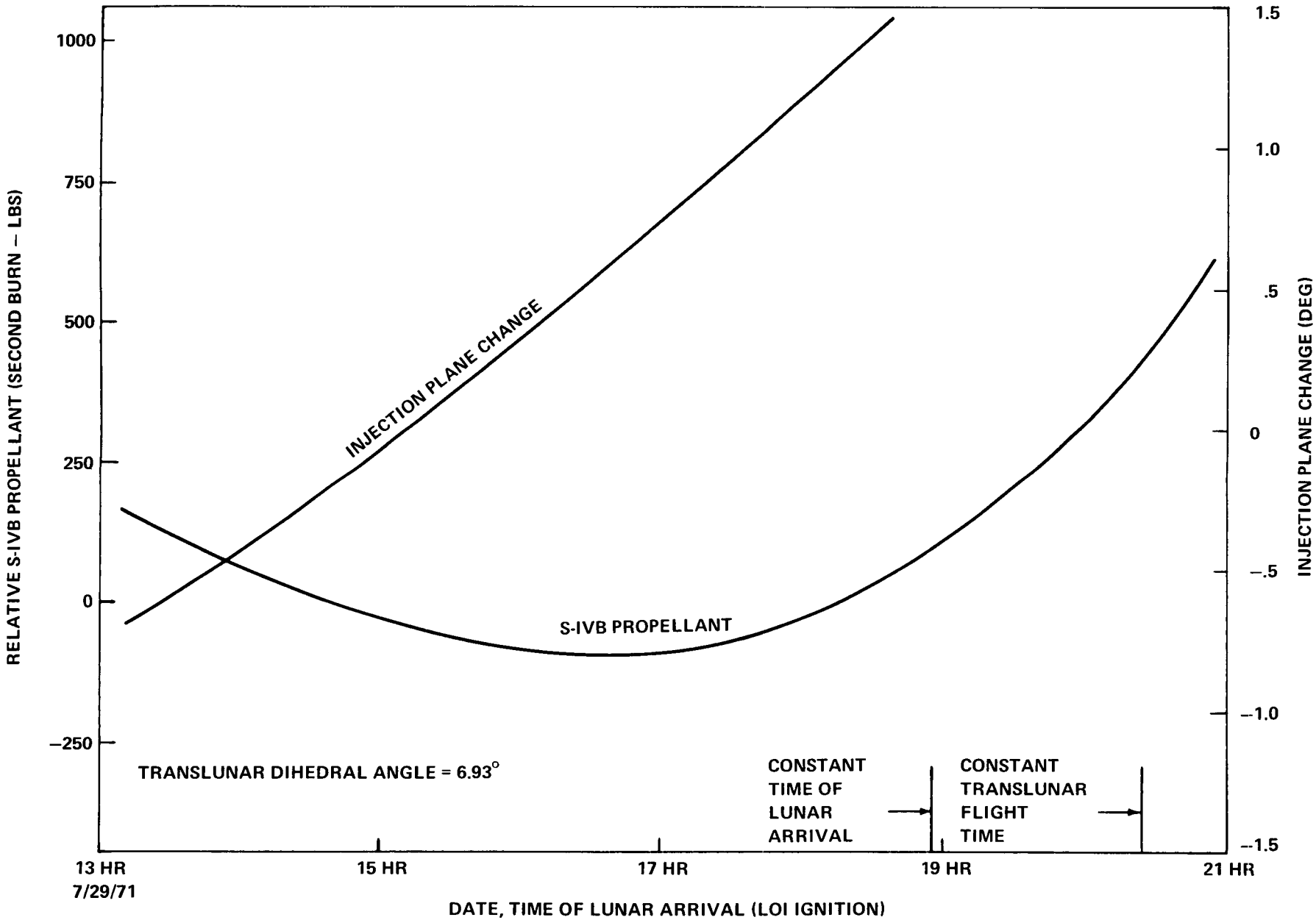

FIGURE 1 - RELATIVE S-IVB PROPELLANT AND INJECTION PLANE CHANGE VS. LUNAR ARRIVAL TIME (7/26/71, 72° LAUNCH AZIMUTH)

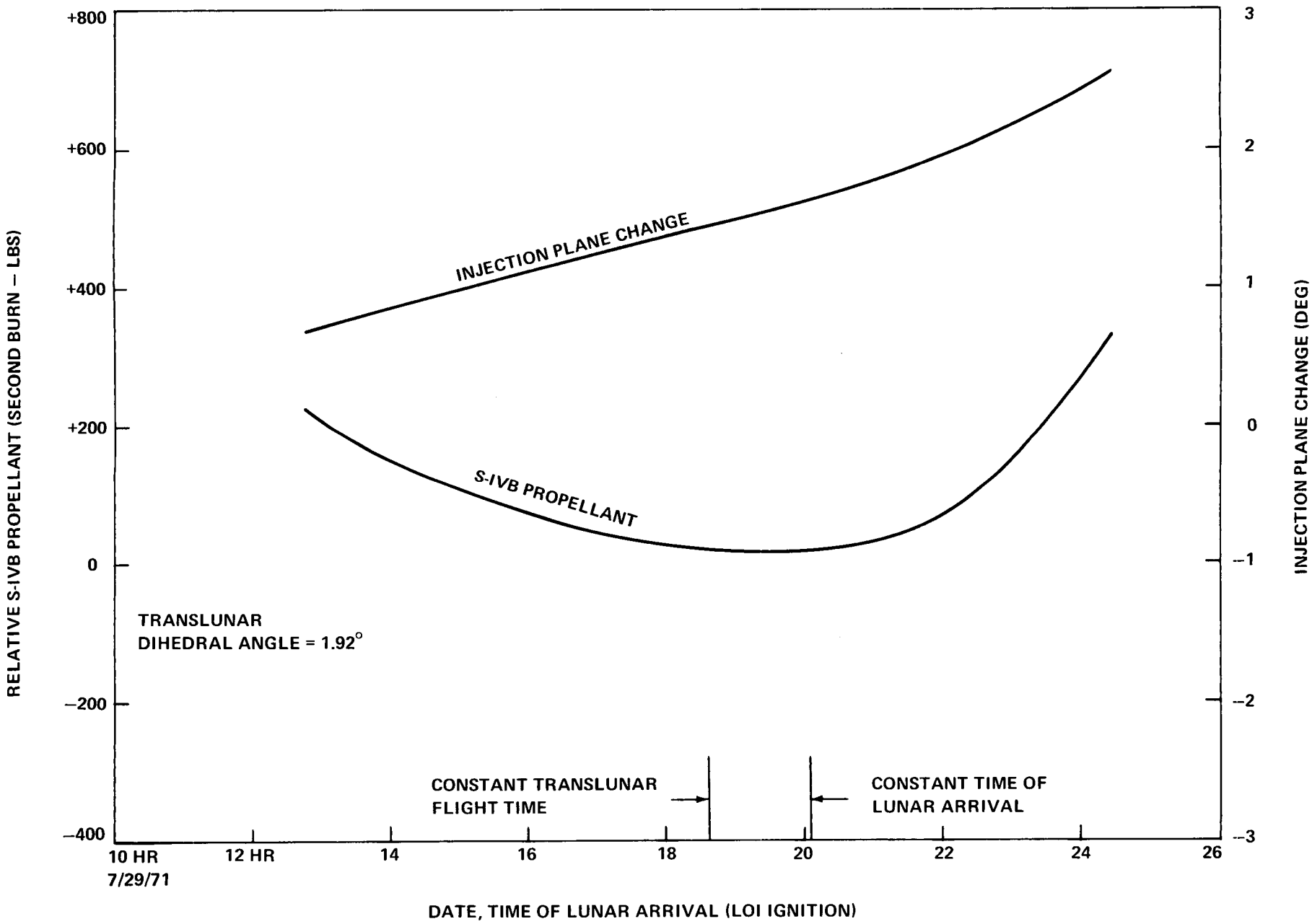

FIGURE 2 - RELATIVE S-IVB PROPELLANT AND INJECTION PLANE CHANGE VS. LUNAR ARRIVAL TIME (7/26/71, 84° LAUNCH AZIMUTH)

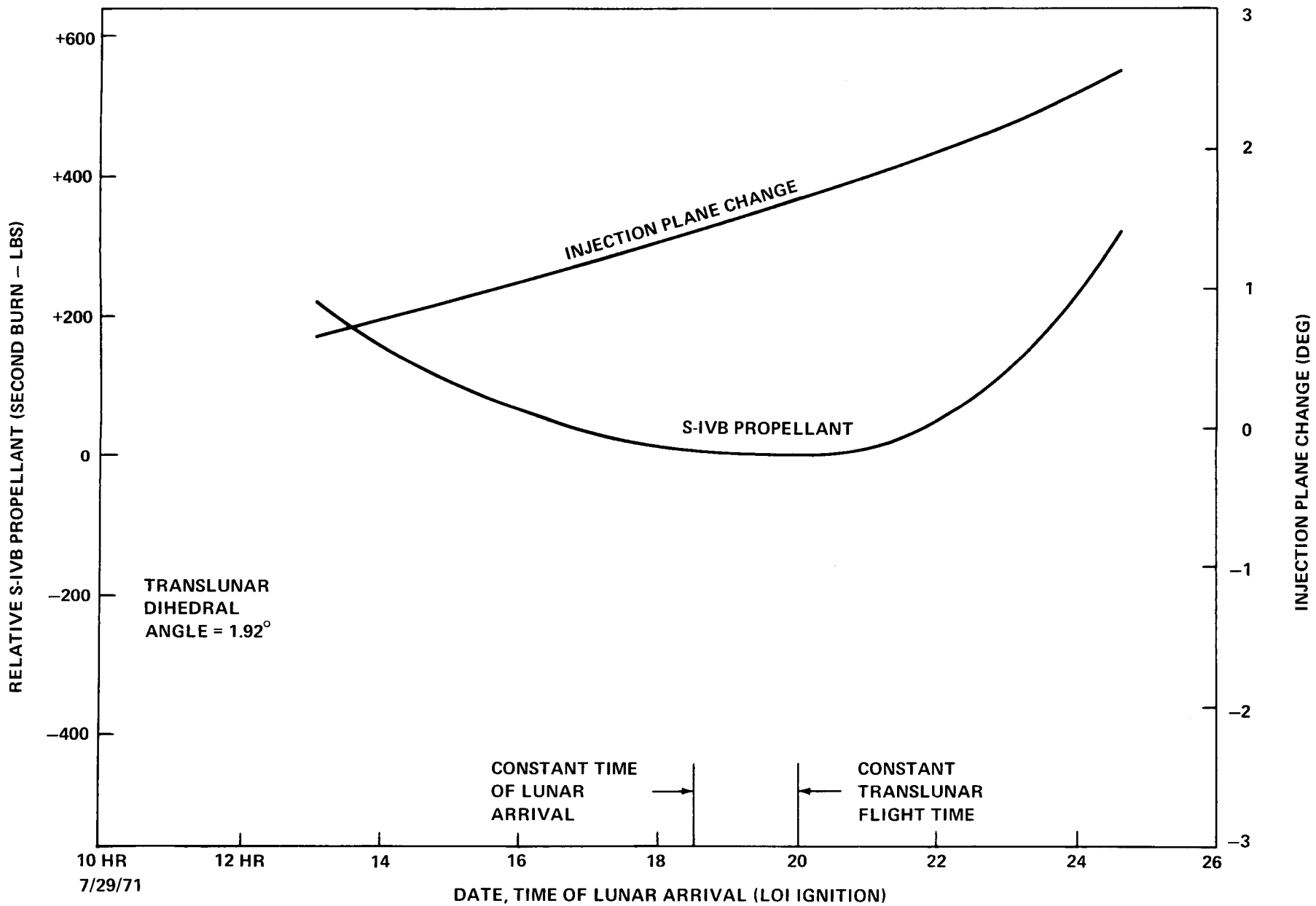

FIGURE 3 - RELATIVE S-IVB PROPELLANT AND INJECTION PLANE CHANGE VS. LUNAR ARRIVAL TIME (7/26/71, 96° LAUNCH AZIMUTH)

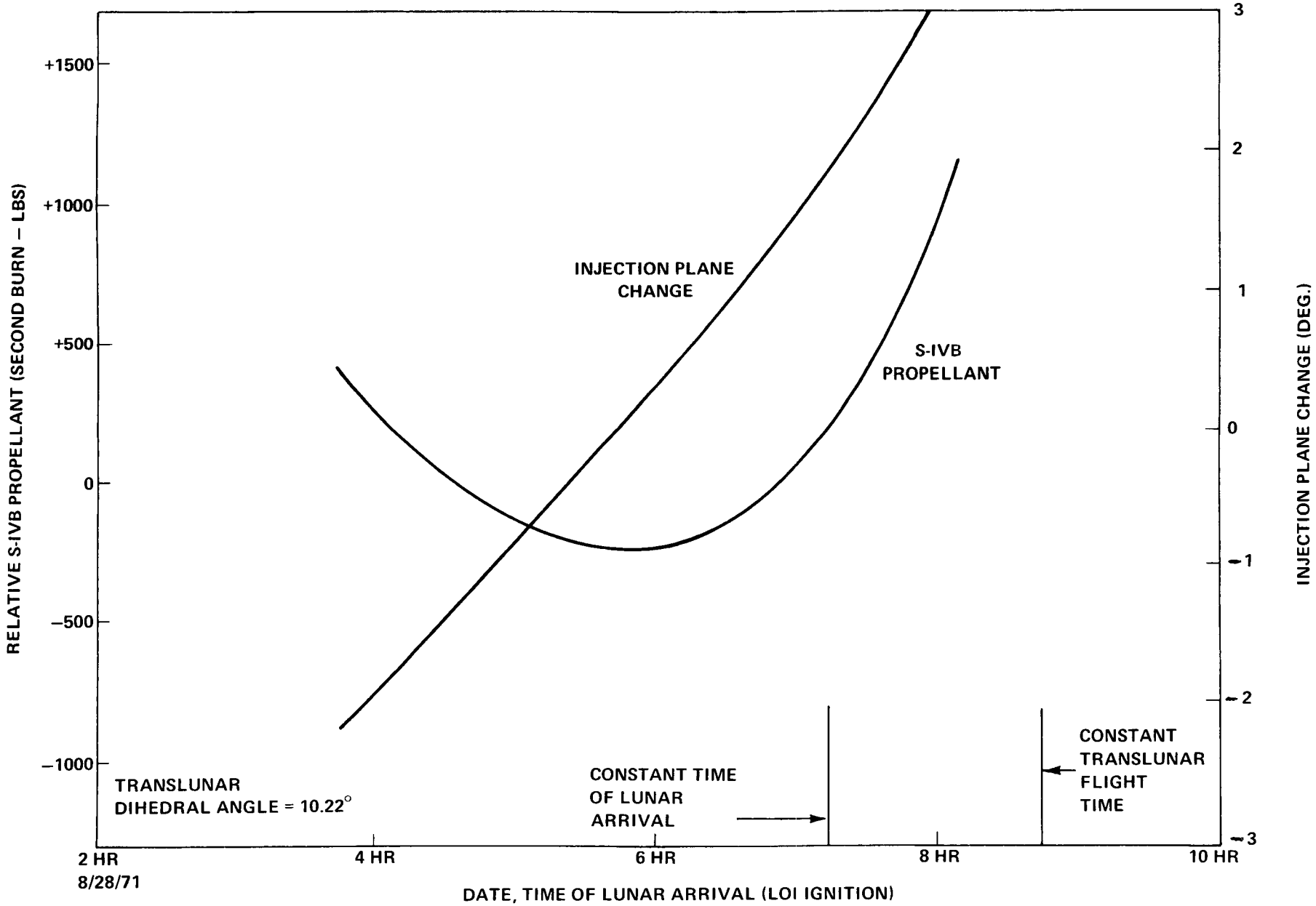

FIGURE 4 - RELATIVE S-IVB PROPELLANT AND INJECTION PLANE CHANGE VS. LUNAR ARRIVAL TIME (8/24/71, 72° LAUNCH AZIMUTH)

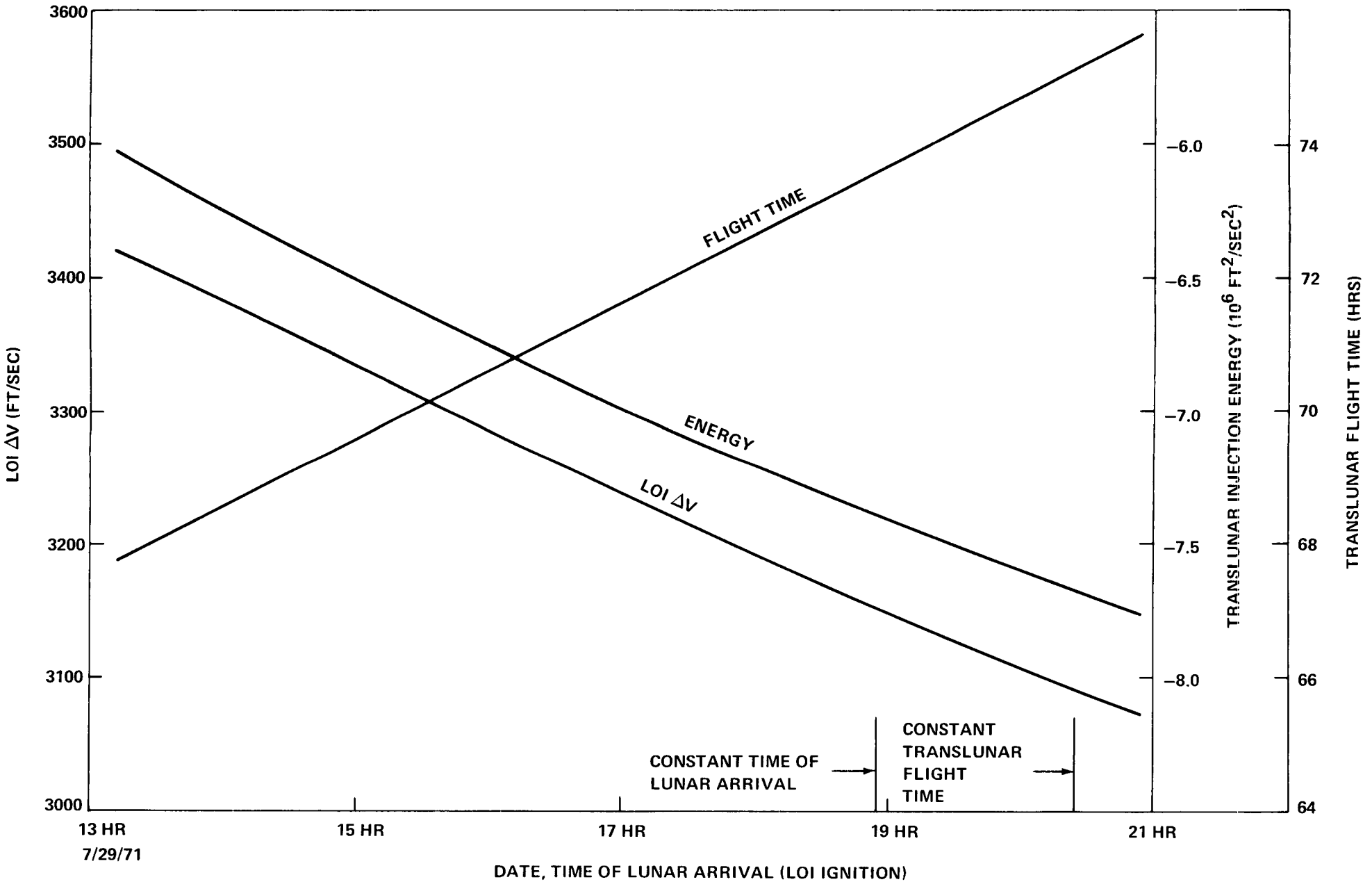

FIGURE 5 - LOI ΔV, TRANSLUNAR ENERGY AND FLIGHT TIME VS. LUNAR ARRIVAL TIME (7/26/71, 72° LAUNCH AZIMUTH

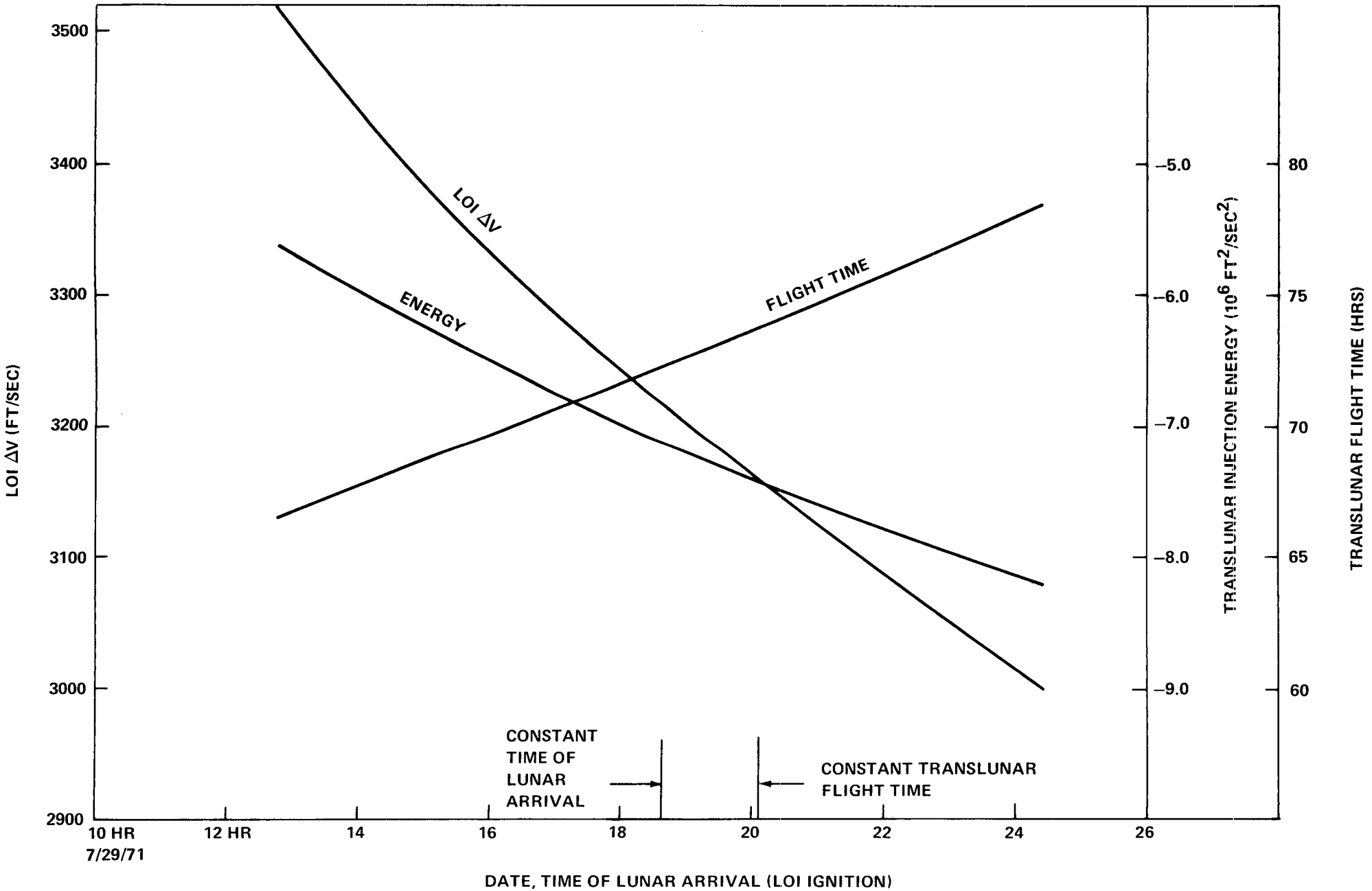

FIGURE 6 - LOI ΔV, TRANSLUNAR ENERGY AND FLIGHT TIME VS. LUNAR ARRIVAL TIME (7/26/71, 84° LAUNCH AZIMUTH)

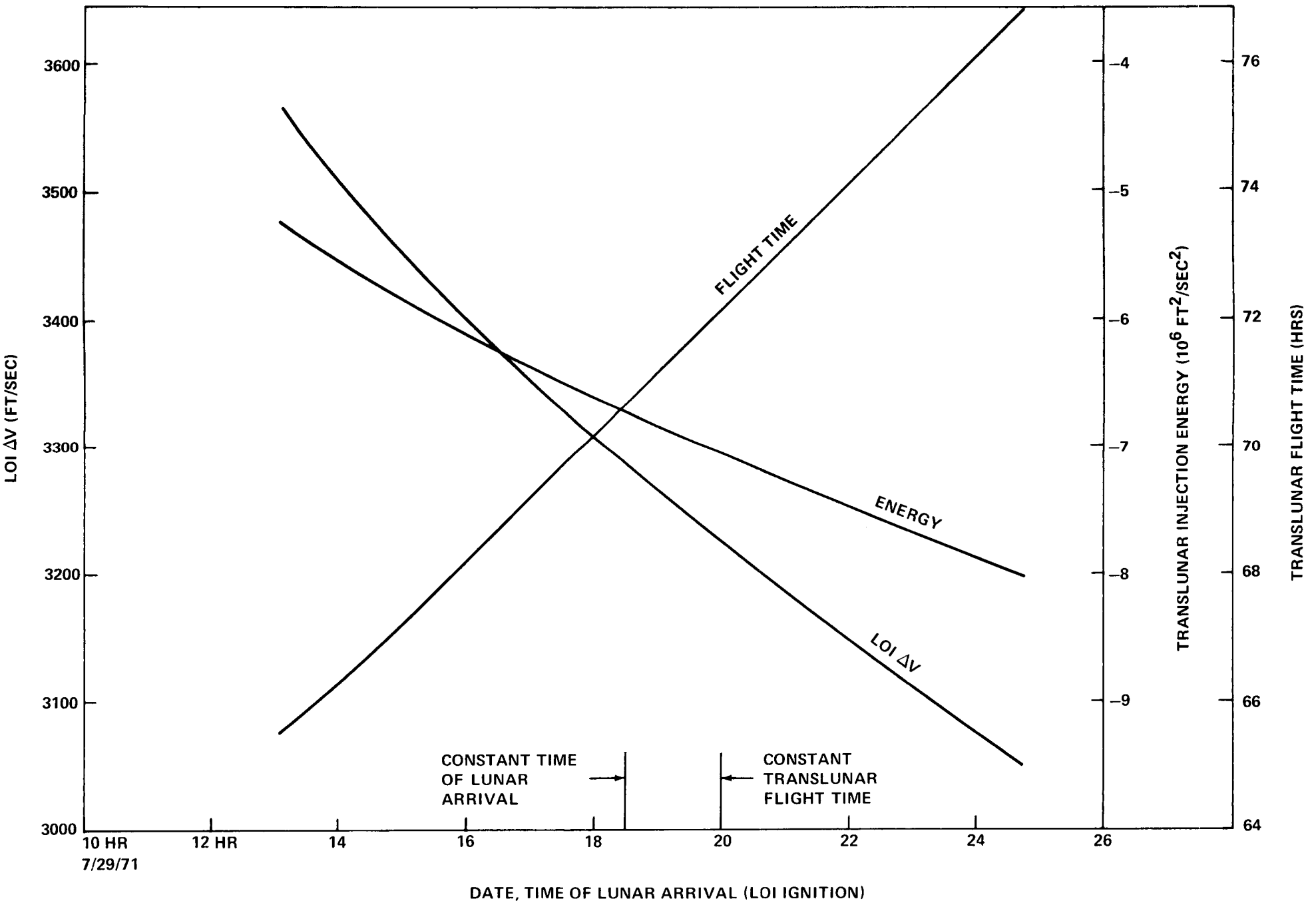

FIGURE 7 - LOI ΔV, TRANSLUNAR ENERGY AND FLIGHT TIME VS. LUNAR ARRIVAL TIME (7/26/71, 96° LAUNCH AZIMUTH)

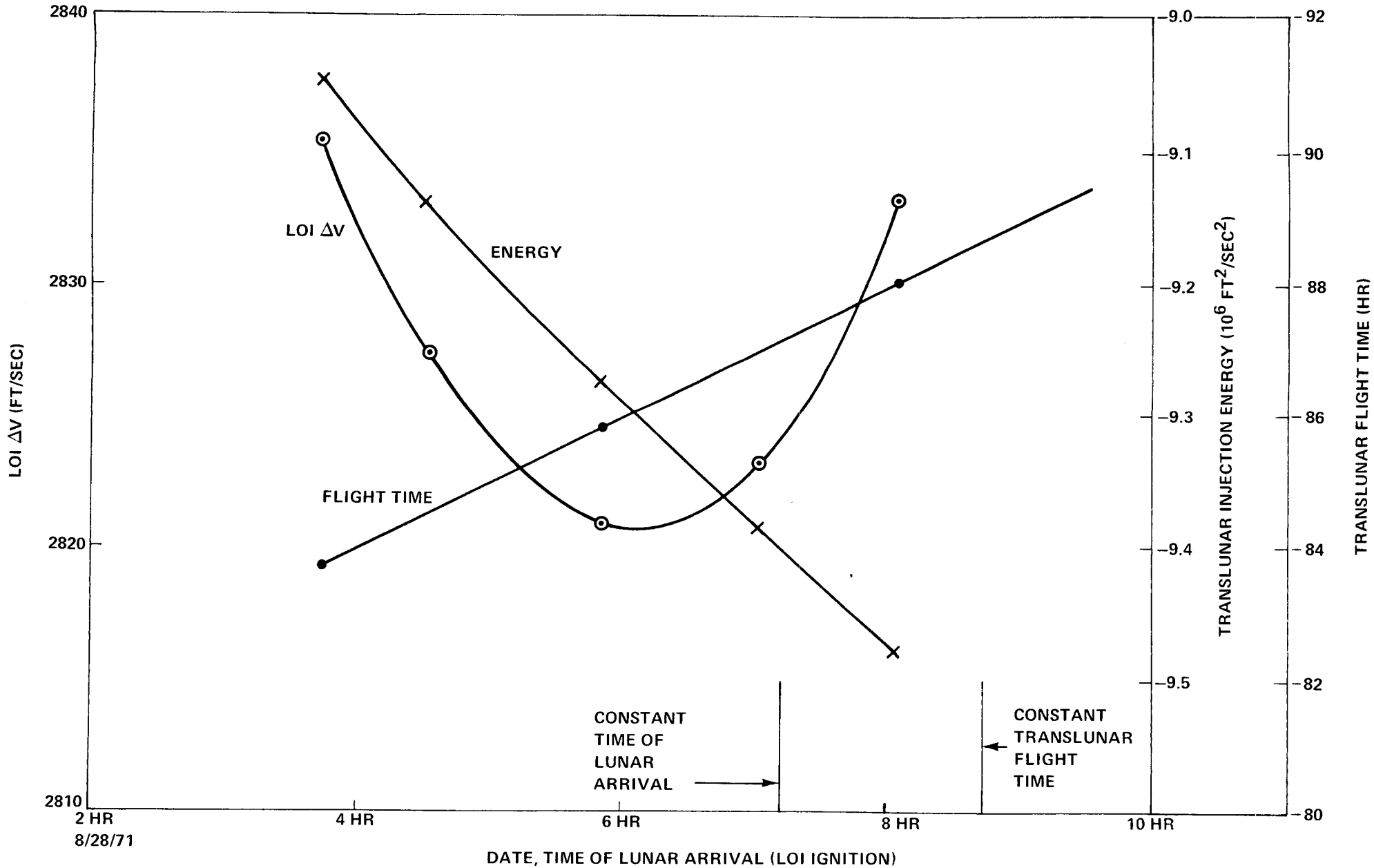

FIGURE 8 - LOI ΔV, TRANSLUNAR ENERGY AND FLIGHT TIME VS. LUNAR ARRIVAL TIME (8/24/71, 72° LAUNCH AZIMUTH)

TABLE A-1 NUMBERS CORRESPONDING TO DAY OF THE YEAR AFTER JANUARY 0

(NONLEAP YEARS)

Day of month	Day of year											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	1	32	60	91	121	152	182	213	244	274	305	335
2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	69	100	130	161	191	222	253	283	314	344
11	11	42	70	101	131	162	192	223	254	284	315	345
12	12	43	71	102	132	163	193	224	255	285	316	346
13	13	44	72	103	133	164	194	225	256	286	317	347
14	14	45	73	104	134	165	195	226	257	287	318	348
15	15	46	74	105	135	166	196	227	258	288	319	349
16	16	47	75	106	136	167	197	228	259	289	320	350
17	17	48	76	107	137	168	198	229	260	290	321	351
18	18	49	77	108	138	169	199	230	261	291	322	352
19	19	50	78	109	139	170	200	231	262	292	323	353
20	20	51	79	110	140	171	201	232	263	293	324	354
21	21	52	80	111	141	172	202	233	264	294	325	355
22	22	53	81	112	142	173	203	234	265	295	326	356
23	23	54	82	113	143	174	204	235	266	296	327	357
24	24	55	83	114	144	175	205	236	267	297	328	358
25	25	56	84	115	145	176	206	237	268	298	329	359
26	26	57	85	116	146	177	207	238	269	299	330	360
27	27	58	86	117	147	178	208	239	270	300	331	361
28	28	59	87	118	148	179	209	240	271	301	332	362
29	29		88	119	149	180	210	241	272	302	333	363
30	30		89	120	150	181	211	242	273	303	334	364
31	31		90		151		212	243		304		365

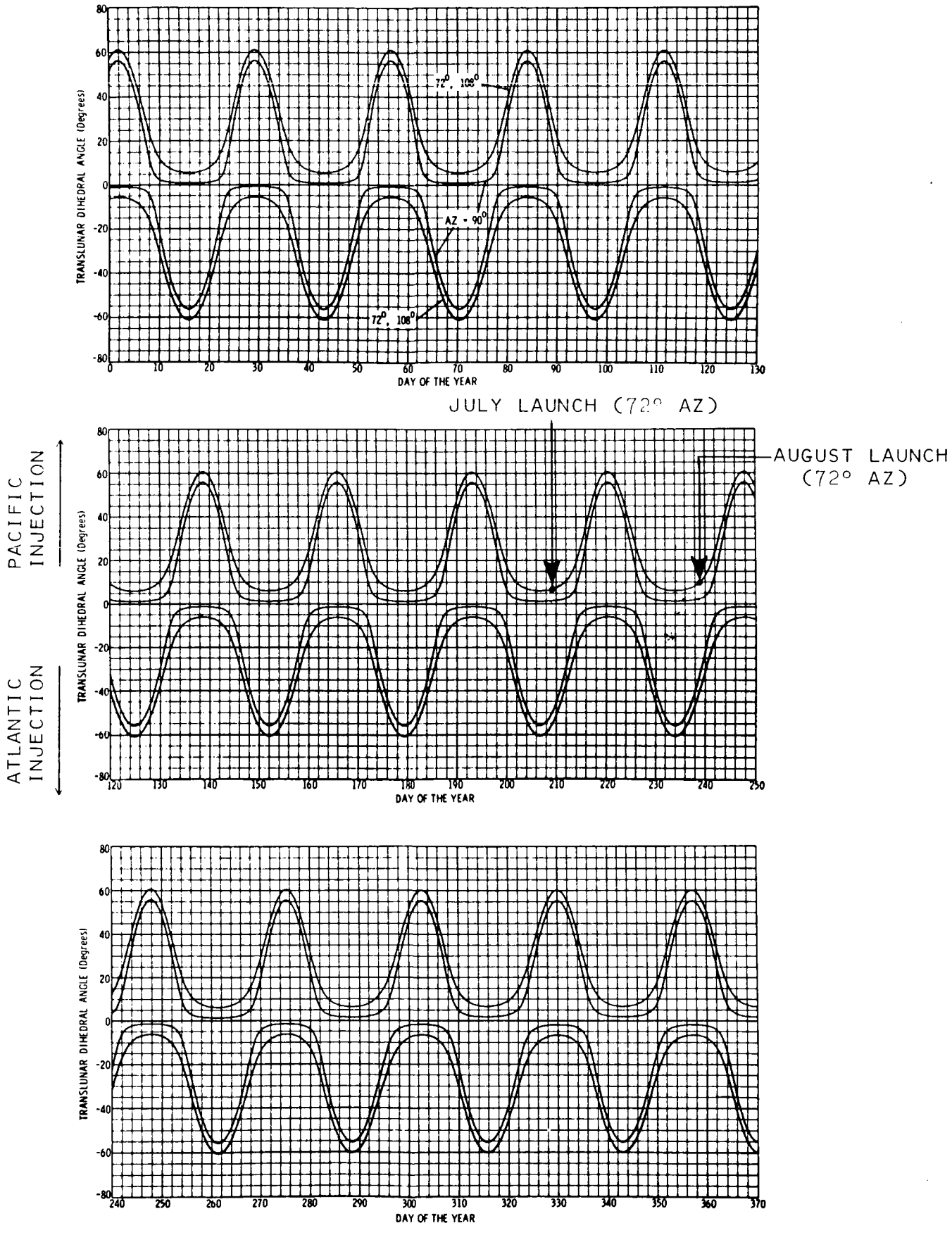

FIGURE A-1. TRANSLUNAR DIHEDRAL ANGLES

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From: R. J. Stern

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