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RAE-B LAUNCH OPPORTUNITY ANALYSIS

HOBART SWARTWOOD, JR.

RAE-B MISSION ANALYSIS REPORT NO. 1

MAY 1971

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

Launch opportunities for the Radio Astronomy Explorer-B during the period March through December 1973 are determined. It is assumed that the flight time to the Moon is 110 hours; that all rocket engine burns are impulsive; and that the maximum allowable velocity increment to insert into and circularize the lunar orbit is 0.720 km/sec. Thermal and power requirements constrain the spin axis-Sun angle to be maintained between 60° and 120° throughout the lunar transfer. The circular lunar orbit is required to be inclined 116°.5 to the lunar equator; to be at an altitude of 1100 km; and to be entirely in sunlight for at least 50 days. Shadows during the park orbit, injection, and transfer phases are determined. It is shown that imposition of the above assumptions and constraints yields from two to seven launch opportunities per month if no transfer shadows are allowed and no restrictions are placed on park orbit duration or shadows. Most of the prime launch dates have one acceptable launch opportunity, but a few have two. Similarities and differences of the two opportunities are discussed in detail. The effect of varying the launch azimuth and flight time is also examined.

CONTENTS

RAE-B LAUNCH OPPORTUNITY ANALYSIS

I. INTRODUCTION

Present plans call for the Radio Astronomy Explorer-B (RAE-B) scientific satellite to be placed into a nearly circular orbit around the Moon. The orbit will be inclinded 116.5 degrees to the Moon's equator and will be at an altitude of 1100 km. Proposed launch dates for the mission are during the period March through December 1973. Constraints imposed by thermal and electrical power considerations, by spacecraft gravity gradient utilization considerations, and by on-board propulsion system limitations all serve to limit the number of possible launch dates. It is the purpose of this report to define acceptable launch opportunities in this period which are consistent with these launch and transfer conditions.

For the purpose of this analysis, it is assumed that the launch azimuth is 90 degrees and that no out of plane maneuvers are made. The nominal flight time is assumed to be 110 hours. The effect of varying the launch azimuth and flight time is examined in considerable detail, and comparisons are made.

The spacecraft will be inserted into lunar orbit at closest approach to the Moon via the solid propellant retro motor. The lunar orbit will then be circularized by means of the Velocity Control Propulsion System (VCPS). The sum of these two Δv's shall be referred to as the velocity increment to attain circular orbit from the approach trajectory (ΔV_c). The maximum allowable ΔV_c is currently 0.720 km/sec. After lunar orbit insertion and circularization, the spacecraft will be stabilized in its gravity gradient mode. To assure adequate time for completion of this operation before encountering any lunar shadows, it is desirable that the orbit be totally sunlit for at least 50 days.

The thermal and power requirements through the lunar transfer impose the constraint that the spin axis-Sun angle be maintained between 60° and 120°. It is shown that a considerable number of launch dates are rendered unacceptable under this constraint. Therefore the limits have been extended to 50° to 130° with the realization that a post-injection attitude maneuver may be necessary to achieve operational bounds.

Launch opportunities are also influenced by shadow conditions in the park, injection, and transfer phases of the trajectory. The transfer trajectory shadows are the most serious as they are generally very lengthy and pose difficulties from thermal and electrical power considerations. Entirely shadow-free trajectories are few, but there are many with no shadows in the transfer phase.

II. TRAJECTORY CHARACTERISTICS AND GEOMETRY

A. Computer Program

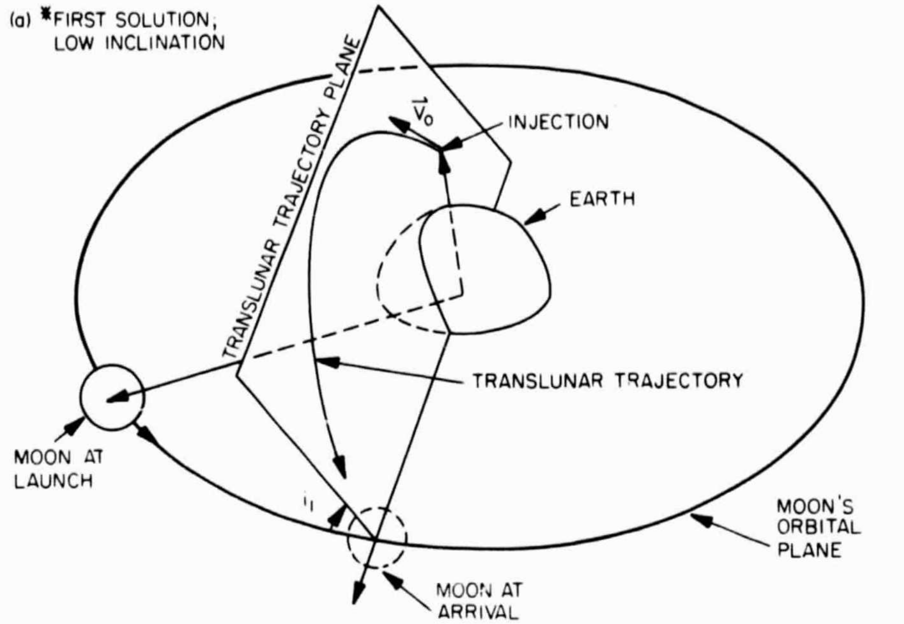
It has been shown (Ref. 1) that the "multi-conic" method of trajectory generation yields very good agreement with numerical integration programs while requiring only a fraction of the computer time. The Advanced Mission Analysis Program (AMAP) (Ref. 2) was modified to use the multi-conic technique, and that program was used to generate the transfer trajectories for this analysis.

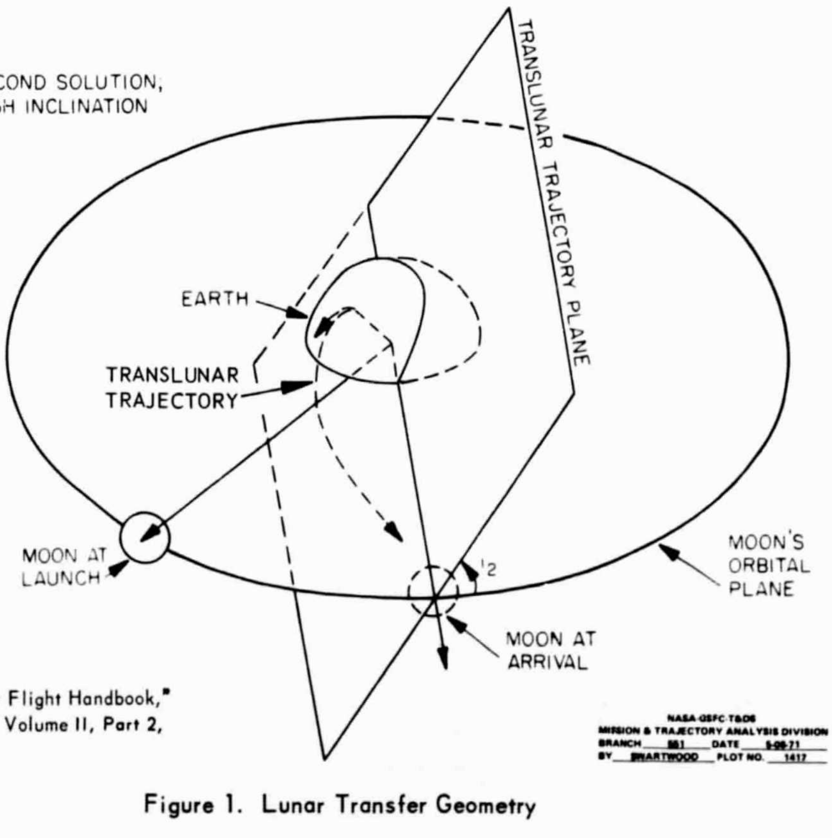
Inputs to AMAP include: launch date, launch azimuth, launch vehicle trajectory geometry, park orbit altitude and the desired target parameters (flight time, perilune radius and inclination of the lunar orbit). The program generates a "first guess" solution based on a geocentric conic trajectory to a massless moon. This guess is then refined through an iterative process to satisfy the target parameters by adjusting launch time, park orbit time and injection velocity. Upon converging to a final targeted trajectory, information relating to the RAE-B constraints is output along with the normal trajectory parameters.

B. Launch Time

With the assumption that no expensive out-of-plane engine burns are allowed, the park orbit orientation is determined by the launch azimuth and launch time on a given day, and will remain essentially inertially fixed. (Actually, perturbations will cause the orbit to change, but over such short time intervals as the period of the orbit, we can consider the orbit to remain inertially fixed.) Due to errors in the Delta launch vehicle guidance system it is desirable to have a short park orbit coast time, and in all cases it should be less than the period of the park orbit. Under these considerations then we see that to construct a trajectory from Earth to Moon, the park orbit plane must contain the Moon at arrival. Since the park orbit "rotates with the Earth," some time later, within 24 hrs., the park orbit plane will again align itself with the position of the Moon at arrival, and so yielding a total of two launch times per day. This is best illustrated by the accompanying figures. Figure 1(a) depicts a favorable geometry (launch time) for lunar transfer. Figure 1(b) is also a favorable geometry, but is at a different time on the same day.

The two solutions are qualitatively different. Figure 2 shows how the inclination of the transfer trajectory to the Moon's orbit plane varies with launch date for





*From "Lunar Flight Handbook," NASA SP34, Volume II, Part 2, p. V, 15.

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Figure 1. Lunar Transfer Geometry

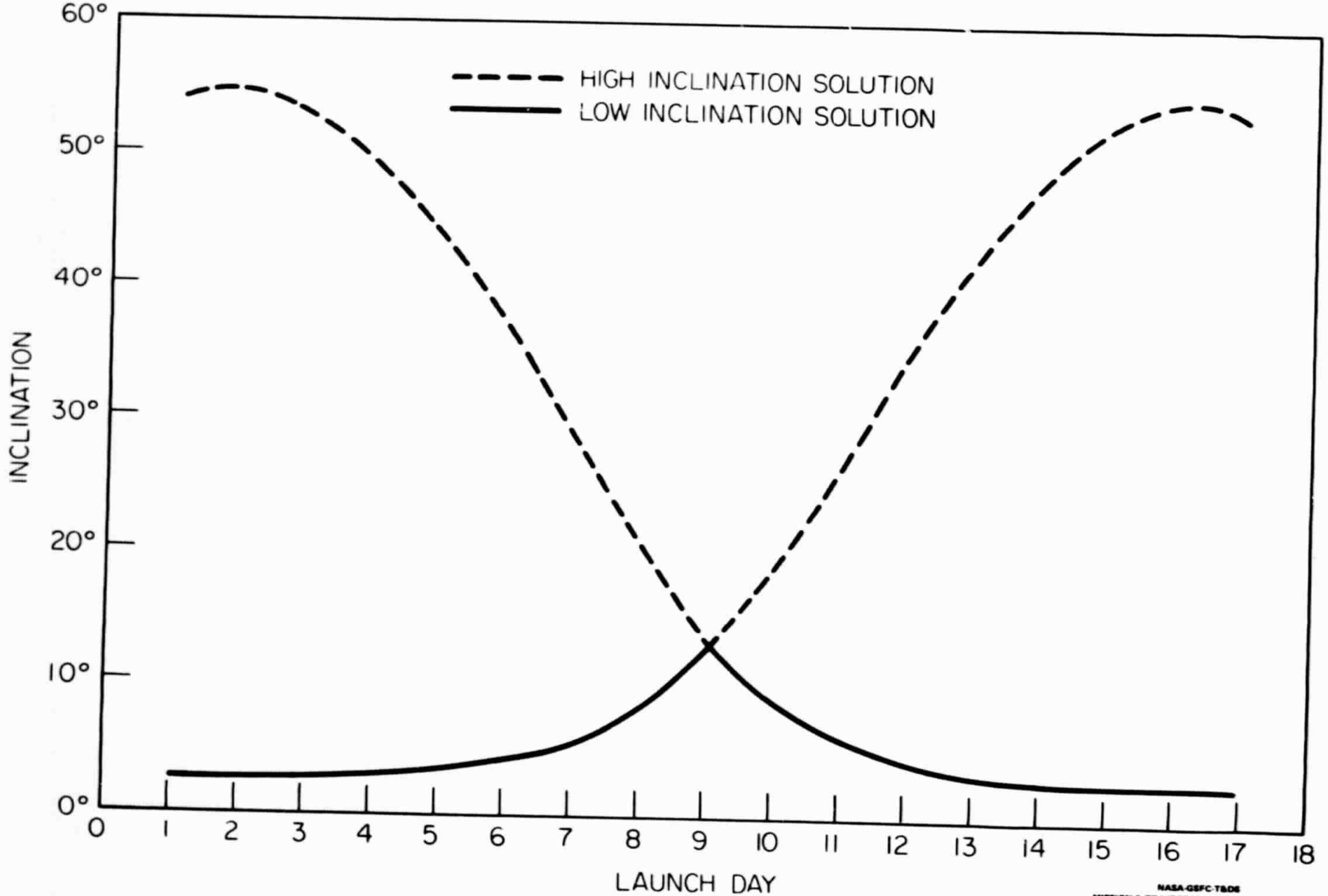

Figure 2. Inclination of Transfer to Moon's Orbit Plane vs Launch Day

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a typical period. Note that on each day there are two solutions. The difference in inclination of the two solutions is a maximum when the Moon is coincident with the intersection of Earth's equator and the Moon's orbital plane, and is a minimum when the Moon is at its maximum and minimum declination relative to the Earth's equator. The two solutions are referred to as "high" and "low" with reference to their inclination. The park orbit coast times are different for the two solutions; the difference varies from essentially zero to about 4500 sec. The high inclination solutions have consistently higher arrival energies (C_3) at the Moon, and correspondingly higher velocity increments to circularize the lunar orbit. Thus few of the high inclination transfer trajectories are acceptable, as an upper limit is placed on the ΔV_c.

C. Shadow

Shadows in the park orbit and transfer trajectory can pose problems from the spacecraft power system standpoint. If the park orbit coast time is very long, i.e., greater than about 3/5 of a period, the vehicle will certainly enter shadow in the park orbit, and may remain in shadow for a maximum of about 41 min. For the short coast times, the vehicle may or may not enter shadow depending upon the lunar phase. When launch is during the "new moon" phase, shadows will be unavoidable in the park orbit; when the Moon is near its "full moon" phase, shadows in the transfer trajectory can arise. These shadows can be quite long and pose serious problems from thermal and power considerations and should be avoided.

The shadow times for each date were determined using a precision numerical integration program.

III. ASSUMPTIONS AND CONSTRAINTS

Acceptable launch dates must be consistent with certain launch and lunar arrival constraints and assumptions. To determine these dates it was assumed that:

- the flight time from translunar injection to closest approach to the Moon is 110 hours,
- all rocket engine burns are impulsive and in-plane,
- the vehicle's spin axis is coincident with its velocity vector at translunar injection,
- the powered flight ascent from the launch pad to park orbit insertion takes 600 sec. and burns through an Earth-fixed central angle of 21°,

- the park orbit coast time is less than one revolution.

Constraints are imposed on both the launch and the arrival conditions. Thermal and power requirements through the spin stabilized phases of the mission require the spin axis-Sun angle as determined at translunar injection to be maintained between 60° and 120°. This orientation assures an adequate power profile and thermal balance across the spacecraft. This constraint can be relaxed for short periods during the mission. In order to gain a larger number of launch opportunities it was assumed that the bounds can be extended to 50° to 130° at translunar injection, with the realization that a post-injection attitude maneuver may be necessary to establish adequate operational conditions. This sequence will provide additional acceptable launch dates with little compromise.

It has been shown (Ref. 3) that to minimize growth in eccentricity for the RAE-B lunar orbit, the selenographic inclination should be approximately 116°.5. Thus the lunar orbit is constrained to be initially inclined at 116°.5, circular, and at an altitude of 1100 km.

The lunar orbit is subject to perturbations primarily from lunar gravitational anomalies and from the Earth. The net result of these effects is to cause a regression of the line of nodes, Ω, (the intersection of the orbit plane and the ecliptic plane) of the orbit. Using a numerical integration program including perturbations from presently known lunar gravitational anomalies and the sun and planets, the nodal regression rate can be determined. Then, if we add to this the rate of rotation of the Moon-Sun line, we obtain the net nodal regression rate with respect to the Moon-Sun line. This effect will cause some part of the orbit to be in Moon shadow at times, and sometimes completely in sunlight, see Figure 3. The RAE-B lunar orbit is constrained to be in sunlight at least 50 days for satellite calibration and boom deployment purposes.

During the lunar transfer it will be necessary to make mid-course guidance corrections. Each correction requires some amount of fuel and so the weight of the spacecraft at perilune will vary accordingly. The retro motor for lunar orbit insertion is a solid propellant motor of fixed total impulse. Thus the net velocity increment of which it is capable is a function of spacecraft weight, an unknown quantity. After orbit insertion the on-board hydrazine system (VCPS) will be used for trimming the orbit to make it circular. The maximum allowable velocity increment to circularize the orbit, ΔV_c (the sum of the insertion and circularization ΔV's) is currently limited to 0.720 km/sec. This constraint can be affected by changes in spacecraft weight and/or the VCPS fuel margin needed for contingencies.

We can get a qualitative picture of how the launch and arrival constraints vary with launch date for a typical two month period under consideration from Figure 4.

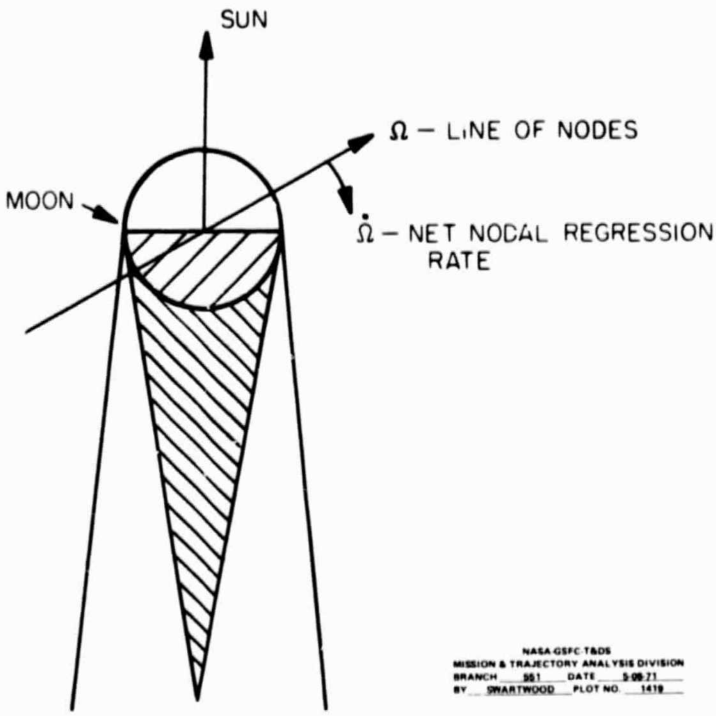

Figure 3. Showing Line of Nodes and Net Nodal Regression Rate Dur to Perturbations and Motion About Sun.

The sunlit orbit time varies linearly with launch date up to a maximum of approximately 106 days, at which time the orbit enters shadow, again for a maximum of about 106 days. The spin axis-Sun angle varies fr   a few degrees (because the transfer trajectory is inclined slightly with re   t to the ecliptic plane) up to almost 180° (again, never 180° for the same reason). The circular velocity increment is periodic and varies from about 0.698 km/sec to about 0.743 km/sec. Figure 4 is for the low inclination solution only. The sunlit orbit time and spin axis-Sun angle should not be significantly different for the high inclination solution. The energy curve should vary from slightly higher to significantly higher through a lunar month.

The Moon is in an eccentric orbit about the Earth, and thus, for a fixed flight time, the arrival energy, and thus ΔV_c, varies with a period of one lunar month depending upon whether arrival is during lunar perigee or apogee. Notice that the velocity increment constraint is generally satisfied since it is below the upper limit value of 0.720 km/sec most of the time, approximately 18 or 19 days per month.

The spin axis-Sun angle and sunlit orbit time constraints, however, are satisfied for only short periods since their slopes are so great. In May, for example, the

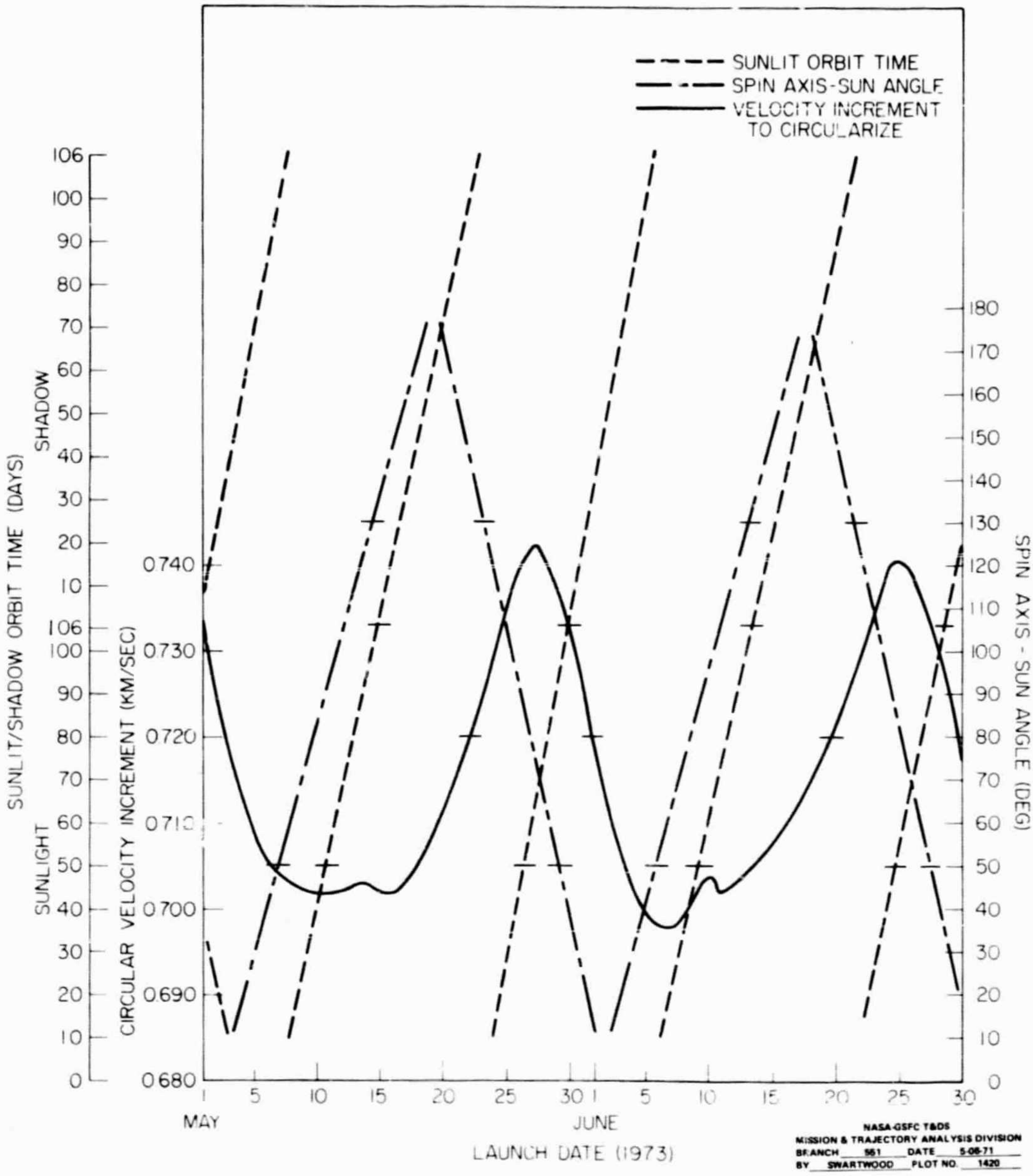

Figure 4. RAE-B Launch and Arrival Constraints vs Launch Date

velocity increment requirement is satisfied from May 4 through May 22; the spin axis-Sun angle requirement is satisfied May 7 through May 14, the sunlit orbit time from May 11 through May 14. The only period when all are satisfied is May 11 through May 14. Continuing in this fashion, one can generate acceptable launch dates for the entire period under consideration. The possibility of shadows in the park orbit and transfer trajectory must now be considered.

IV. RESULTS

If all the assumptions and constraints which are considered in this study are imposed, then only a few days in the March to December 1973 launch period comply. Table I gives the acceptable dates with their corresponding launch and arrival parameters neglecting any shadow constraints. Recall that a 90° launch azimuth and a 110 hour flight time were assumed. Certain of the columns in Table I deserve some explanation. Launch time, Park Orbit Coast Time, and Spin Axis-Sun Angle are self-explanatory. Shadow time is divided into three logical sections: Park – the duration of shadow during the park orbit coast; Injection – the duration in shadow in the transfer from injection to shadow exit: Transfer – shadow time during the transfer trajectory. The Lunar Phase Angle at Arrival is the angle measured from the Moon-Earth line to the Moon-Sun line. This angle is 0 degrees at full Moon and 180 degrees at new Moon. Sunlit Orbit Time is the total time after lunar orbit insertion that the orbit will be in complete sunlight. ΔV for Circular Orbit is self-explanatory.

Table II also deserves some comment. The inclination of an orbit is defined by the mathematical relation

$$i = \cos^{-1} \frac{(\vec{r} \times \vec{v} \cdot \hat{z})}{|\vec{r} \times \vec{v}|}$$

where,

$\vec{r} \equiv$ position vector of the spacecraft,

$\vec{v} \equiv$ velocity vector of the spacecraft,

$\hat{z} \equiv$ unit normal to the reference plane.

It is seen in Figure 5 that two possible approach trajectories yield the same inclination. These are referred to as "northern" and "southern" with respect to the lunar equator. The normal to the plane can be represented by its spherical

Table I
Launch and Arrival Parameters

Launch Date	Launch Time (GMT)	Park Orbit Coast Time (sec)	Spin Axis-Sun Angle (deg)	Shadow Time			Lunar Phase Angle At Arrival (deg)	Sunlit Orbit Time (days)	ΔV for Circular Orbit (km/sec)
				Park (min)	Injection (min)	Transfer (hrs)			
3-13-73	23:20	3703	94	37	0	0	- 4	53	0.713
-14-	23:23	3876	106	37	0	0	- 8	68	0.711
-15-	23:27	4042	118	37	0	4.3	19	84	0.709
-16-	23:33	4196	130	36	0	2.7	31	99	0.706
4-11-73	21:38	3979	87	41	0	0	- 12	47	0.707
-12-	21:43	4136	98	41	0	0	0	63	0.706
-13-	21:52	4279	110	41	0	4.8	11	78	0.705
-14-	22:06	4402	121	41	0	4.1	22	92	0.703
-14-	16:04	279	111	0	0	0	19	84	0.716
-15-	17:23	179	123	0	0	0	31	100	0.709
5-11-73	20:14	4358	91	41	0	0	- 8	57	0.702
-12-	20:34	4458	102	41	0	11.2	3	72	0.703
-12-	15:07	215	97	0	0	0	17	64	0.711
-13-	21:08	4511	113	41	0	5.6	14	86	0.703
-13-	16:16	148	108	0	0	0	18	79	0.706
-14-	17:08	143	120	0	0	0	23	94	0.703
-14-	22:00	4503	123	41	0	0	19	101	0.706
6-09-73	19:09	4493	83	41	0	0	- 15	51	0.701
-10-	19:55	4506	94	41	0	0	- 4	66	0.704
-10-	15:03	144	91	0	0	0	- 7	58	0.703
-11-	15:42	180	103	0	0	0	4	73	0.702
-11-	20:58	4457	105	41	0	0	7	81	0.709
-12-	16:05	265	114	0	0	0	15	86	0.703
-12-	22:13	4360	113	40	0	0	18	95	0.716
-13-	16:20	381	125	0	0	2.5	26	99	0.705
7-09-73	14:09	239	85	0	0	0	- 14	52	0.701
-10-	14:26	345	96	0	0	0	- 3	65	0.703
-11-	14:37	474	107	0	0	11.4	9	78	0.706
-12-	14:44	617	118	0	0	5.0	19	91	0.709
-13-	14:49	769	129	0	0	2.8	31	104	0.712
8-08-73	12:53	568	88	0	0	0	- 11	55	0.706
-09-	12:59	717	99	0	0	0	1	68	0.710
-10-	13:03	874	111	0	0	0	12	81	0.714
-11-	13:06	1125	122	0	0	0	24	94	0.714

Table I–(continued)

Launch Date	Launch Time (GMT)	Park Orbit Coast Time (sec)	Spin Axis-Sun Angle (deg)	Shadow Time Park (min)	Shadow Time Injection (min)	Shadow Time Transfer (hrs)	Lunar Phase Angle At Arrival (deg)	Sunlit Orbit Time (days)	ΔV for Circular Orbit (km/sec)
9-06-73	11:13	813	80	0	0	0	- 19	45	0.711
-07-	11:17	973	92	0	0	0	- 7	57	0.715
-08-	11:21	1140	104	0	0	0	5	70	0.720
-09-	11:25	1397	116	0	0	0	18	83	0.720
-22-	10:51	3916	76	24	9	0	-174	64	0.718
-23-	10:58	4080	63	27	7	0	-161	80	0.715
-24-	11:08	4225	51	30	5	0	-149	96	0.711
10-21-73	9:16	4165	83	22	10	0	179	59	0.710
-22-	9:30	4299	71	25	8	0	-170	74	0.708
-23-	9:51	4404	59	28	6	0	-158	90	0.706
11-19-73	7:55	4365	91	25	11	0	170	53	0.703
-20-	8:24	4442	79	26	9	0	-178	68	0.703
-21-	9:07	4468	69	27	8	0	-167	84	0.704
-22-	4:36	203	61	3	7	0	-159	90	0.702
-23-	5:04	274	50	5	5	0	-148	105	0.702
12-18-73	7:04	4459	99	27	12	0	162	47	0.701
-19	2:33	197	91	3	11	0	170	52	0.700
-20-	3:07	251	80	4	9	0	-179	68	0.700
-21-	3:28	344	69	6	8	0	-168	82	0.701
-22-	3:41	461	58	8	6	0	-157	95	0.703

components, and serves to orient the planet inertially. The spherical components are its right ascension, measured from Aries, and its declination, measured from Earth's equator. Table II gives the spherical celestial coordinates of the orbit normal for each launch date in Table I.

All the launch and arrival parameters listed are for the northern approach except for the last two columns in Table II which are for the southern approach. The southern approach involves only a small change in launch time and park time; all the other parameters should remain essentially the same.

Notice that the number of launch dates per month varies from only 3 in October, to 7 in September. On some days there are two launch opportunities, one with the high inclination transfer, and one with the low. The two solutions differ

Table II

Launch Date	Celestial Coordinates of Orbit Normal				Launch Date	Celestial Coordinates of Orbit Normal			
	Northern Approach		Southern Approach			Northern Approach		Southern Approach	
	α*† (deg)	δ** (deg)	α (deg)	δ (deg)		α (deg)	δ (deg)	α (deg)	δ (deg)
3-13-73	166.9	-21.7	10.1	-26.3	7-09-73	300.8	-48.0	107.5	- 3.9
-14-	180.0	-27.4	21.8	-21.3	-10-	316.4	-45.2	118.3	- 5.5
-15-	193.8	-33.2	33.1	-16.6	-11-	330.0	-41.7	128.9	- 7.9
-16-	208.6	-38.7	44.3	-10.2	-12-	341.1	-37.7	139.5	-10.0
4-11-73	189.6	-31.5	29.6	-18.0	-13-	353.2	-33.5	144.0	-14.7
-12-	203.9	-37.0	40.7	-13.6	8-08-73	337.9	-39.2	135.8	- 9.8
-13-	219.2	-42.0	51.7	-10.0	-09-	349.3	-25.1	146.2	-13.3
-14-	236.0	-46.1	62.7	- 7.0	-10-	359.9	-30.8	156.7	-17.4
-14-	226.7	-44.0	63.4	- 6.8	-11-	10.0	-26.4	161.1	-22.0
-15-	245.0	-47.6	74.3	- 4.8	9-06-73	355.9	-32.5	152.7	-15.7
5-11-73	230.1	-45.0	59.4	- 7.8	-07-	6.1	-28.1	163.3	-20.1
-12-	248.6	-48.1	70.4	- 5.4	-08-	15.9	-23.8	174.1	-24.8
-12-	239.2	-46.7	70.9	- 5.3	-09-	25.7	-19.6	184.0	-29.8
-13-	267.4	-49.6	81.3	- 3.9	-22-	181.2	-28.1	22.2	-21.0
-13-	258.1	-49.1	81.8	- 3.8	-23-	195.9	-34.1	33.8	-16.2
-14-	277.1	-49.7	92.6	- 3.3	-24-	211.4	-39.8	45.4	-11.8
-14-	286.3	-49.3	92.2	- 3.3	10-22-73	206.2	-38.0	41.5	-13.2
6-09-73	261.8	-49.4	77.9	- 4.2	-22-	222.3	-43.1	52.9	- 9.4
-10-	280.7	-49.6	88.9	- 3.3	-23-	240.1	-47.1	64.4	- 6.4
-10-	271.3	-49.7	89.3	- 3.3	11-19-73	234.7	-46.1	61.0	- 7.1
-11-	289.5	-49.1	100.2	- 3.4	-20-	253.3	-48.9	72.4	- 4.8
-11-	299.1	-48.1	99.7	- 3.4	-21-	273.0	-50.0	83.8	- 3.4
-12-	306.1	-47.1	111.0	- 4.4	-22-	281.9	-49.8	95.6	- 3.0
-12-	316.0	-45.2	110.6	- 4.3	-23-	299.8	-48.3	107.1	- 3.7
-13-	320.9	-44.1	121.8	- 6.2	12-18-73	267.3	-49.9	80.5	- 3.6
					-19-	276.3	-50.0	92.3	- 3.0
					-20-	294.5	-49.0	103.6	- 3.3
					-21-	310.9	-46.5	114.9	- 4.7
					-22-	325.4	-43.2	125.9	- 6.9

*–Right Ascension
**–Declination
†–Right Ascension Rate is Approximately +0.14 deg/day.

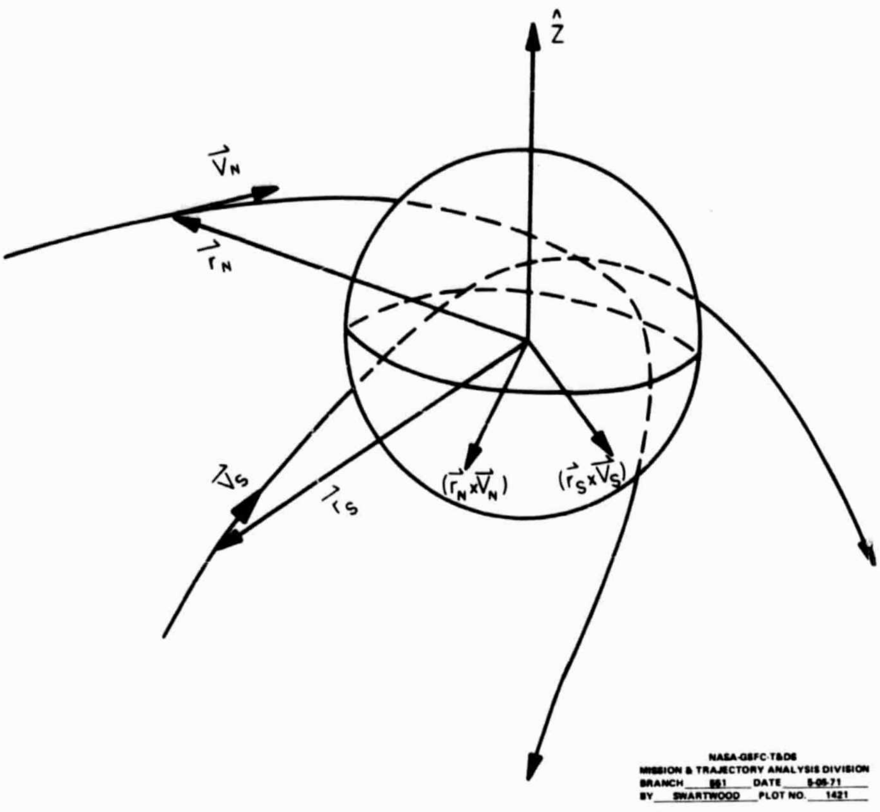

Figure 5. Northern and Southern
Lunar Approach Trajectories

greatly in their park orbit coast time, and their shadow time. In addition, the high inclination solution requires a higher velocity increment for lunar orbit circularization. The difference in sunlit orbit time is typically 8 or 9 days.

Shadow in the transfer trajectory is a limiting factor in March, April, May, and July. There are no transfer shadows in June. From Table I we see that from August through December, there are no transfer shadows, and relatively short park and injection shadows. The park shadows in the early months vary from about 36 min. to the maximum possible, 41 min. Notice that a few dates have no shadow at all.

Flight times between 100 hours and 120 hours are needed to minimize VCPS propellant requirements. Thus, 110 hours was arbitrarily chosen as a typical flight time to conduct the study. The 90 degree launch azimuth was selected to maximize payload capability. The effect of varying these two parameters can be obtained from an analysis of Tables III, IV, V, VI and VII for the typical launch

Table III

7-09-73 Flight Time	Launch Azimuth (deg)	Launch Time (GMT)	Park Orbit Coast Time (sec)	Spin Axis Sun Angle (deg)	Shadow Time Injection: Park (min)	Shadow Time Injection: Injection (min)	Shadow Time Injection: Transfer (hrs)	Lunar Phase Angle (deg)	Sunlit Orbit Time (days)	ΔV for Circular Orbit (km/sec)
90 hrs	70	10:12	861	77	0	0	0	-25	56	0.741
	90	13.43	212	77	0	0	0	-24	59	0.737
	110	15:23	5208	79	41	0	0	-22	60	0.741
110 hrs	70	10:47	861	84	0	0	0	-16	48	0.704
	90	14:09	239	85	0	0	0	-14	52	0.701
	110	15.55	5216	86	41	0	0	-13	52	0.704
130 hrs	70	11:14	894	92	0	0	0	- 7	45	0.700
	90	14:27	300	93	0	0	0	- 5	47	0.698
	110	16:21	5255	94	41	0	0	- 4	48	0.701

Table IV

7-10-73 Flight Time	Launch Azimuth (deg)	Launch Time (GMT)	Park Orbit Coast Time (sec)	Spin Axis Sun Angle (deg)	Shadow Time Injection: Park (min)	Shadow Time Injection: Injection (min)	Shadow Time Injection: Transfer (hrs)	Lunar Phase Angle (deg)	Sunlit Orbit Time (days)	ΔV for Circular Orbit (km/sec)
90 hrs	70	10:48	907	87	0	0	0	-14	70	0.742
	90	14:09	287	88	0	0	0	-13	73	0.739
	110	15:56	5263	90	41	0	0	-11	73	0.742
110 hrs	70	11:15	935	94	0	0	0	- 5	62	0.705
	90	14:26	345	96	0	0	0	- 3	65	0.703
	110	16:21	5296	97	41	0	0	- 2	65	0.706
130 hrs	70	11:36	988	102	0	0	17.5	5	58	0.703
	90	14:39	426	104	0	0	14.7	6	61	0.701
	110	16:40	56	105	0	0	12.0	7	61	0.703

Table V

7-11-73		Launch Time (GMT)	Park Orbit Coast Time (sec)	Spin Axis Sun Angle (deg)	Shadow Time Injection			Lunar Phase Angle (deg)	Sunlit Orbit Time (days)	ΔV for Circular Orbit (km/sec)
Flight Time	Launch Azimuth (deg)				Park (min)	Injection (min)	Transfer (hrs)			
90 hrs	70	11:15	984	98	0	0	0	- 3	83	0.743
	90	14.25	397	99	0	0	2.9	- 1	86	0.741
	110	16:21	5346	100	41	0	15.0	0	87	0.744
110 hrs	70	11:36	1032	105	0	0	12.5	7	75	0.707
	90	14:37	474	107	0	0	11.4	8	78	0.706
	110	16:40	99	107	0	0	9.3	9	78	0.708
130 hrs	70	11:53	1100	113	0	0	4.1	16	71	0.705
	90	14:46	568	115	0	0	6.0	17	74	0.704
	110	16:56	170	116	0	0	3.7	18	74	0.706

Table VI

7-12-73		Launch Time (GMT)	Park Orbit Coast Time (sec)	Spin Axis Sun Angle (deg)	Shadow Time Injection			Lunar Phase Angle (deg)	Sunlit Orbit Time (days)	ΔV for Circular Orbit (km/sec)
Flight Time	Launch Azimuth (deg)				Park (min)	Injection (min)	Transfer (hrs)			
90 hrs	70	11:35	1083	108	0	0	9.5	8	98	0.745
	90	14:35	528	110	0	0	8.9	10	99	0.743
	110	16:39	152	111	0	0	7.5	11	99	0.745
110 hrs	70	11:52	1145	116	0	0	4.0	18	88	0.710
	90	14:44	617	118	0	0	5.0	19	91	0.709
	110	16:55	216	118	0	0	3.5	20	91	0.710
130 hrs	70	12:07	1223	125	0	0	2.5	27	84	0.709
	90	14:51	718	126	0	0	3.1	29	86	0.708
	110	17:10	295	127	0	0	2.3	30	87	0.709

Table VII

7-13-73 Flight Time	Launch Azimuth (deg)	Launch Time (GMT)	Park Orbit Coast Time (sec)	Spin Axis Sun Angle (deg)	Shadow Time Injection Park (min)	Injection (min)	Transfer (hrs)	Lunar Phase Angle (deg)	Sunlit Orbit Time (days)	ΔV for Circular Orbit (km/sec)
90 hrs	70	11:51	1198	120	0	0	3.7	20	- 3	0.746
	90	14:42	673	121	0	0	4.2	21	- 5	0.745
	110	16:54	269	122	0	0	3.3	22	- 6	0.746
110 hrs	70	12:06	1270	127	0	0	2.4	30	- 5	0.712
	90	14:49	769	129	0	0	2.8	31	103	0.711
	110	17:08	342	130	0	0	2.2	32	104	0.713
130 hrs	70	12:19	1355	136	0	0	1.4	39	97	0.712
	90	14:55	875	138	0	0	1.9	40	100	0.711
	110	17:22	428	138	0	0	1.6	41	100	0.712

period July 9 through July 13. The launch and arrival parameters for flight times of 90 hours, 110 hours, and 130 hours and launch azimuths of 70°, 90° and 110° are compared for each launch date. Notice that for a given launch date and flight time, the park orbit coast time decreases with launch azimuth. For a given launch azimuth, the park orbit coast time increases with flight time. Perhaps the most important observation is that the ΔV_c requirement for the 90 hour flight time is consistently much greater than that for the longer flights, and in this period at least, it is prohibitively high.

V. CONCLUSIONS

Summarily, then, Table I gives all acceptable launch opportunities neglecting the constraint of no shadow in the translunar phase and short park orbit coasts. These two constraints limit the realm of possibilities. If compromises are made though, there exist several launch opportunities per month. Shorter flight times pose the problem of excessive velocity increments to circularize the lunar orbit.

For the time period from March through December 1973, the following table, Table VIII, summarizes the available launch dates for various levels of constraints.

Table VIII
Number of Days Meeting Constraints

Month 1973	Spin Axis - Sun Angle + Sunlit Orbit Time + Arrival Energy	Plus No Transfer Traj. Shadows	Plus Short Park Orbit Coast	Plus No Park Orbit Shadow
March	4	2	0	0
April	5	4	2	2
May	4	4	3	3
June	5	5	4	4
July	5	2	2	2
August	4	4	4	4
September	7 (2 periods)	7	4	4
October	3	3	0	0
November	5	5	2	0
December	5	5	4	0

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