MSC-06016
Volume II

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. 72-FM-39

February 10, 1972

SPACECRAFT OPERATIONAL TRAJECTORY FOR APOLLO 16 (MISSION J-2) LAUNCHED APRIL 16, 1972 VOLUME II - TRAJECTORY PARAMETERS

Mission Integration Branch
and Flight Performance Branch
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
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PROJECT APOLLO

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By Mission Integration Branch and Flight Performance Branch

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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FOREWORD

This operational trajectory document contains the operational trajectory data for an April 16, 1972, launch. It supersedes the Apollo 16 documents MSC IN 71-FM-388, MSC IN 71-FM-401, and MSC IN 72-FM-14. The document comprises two volumes. Volume I contains a verbal and graphical description of the mission, and volume II contains the trajectory printout.

At this time no revision to this trajectory document is planned. Any mission changes that occur subsequent to publication will be published as changes notifications.

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TABLES

SPACECRAFT OPERATIONAL TRAJECTORY

FOR APOLLO 16 (MISSION J-2)

LAUNCHED APRIL 16, 1972

VOLUME II - TRAJECTORY PARAMETERS

By Mission Integration Branch and Flight Performance Branch

1.0 SUMMARY AND INTRODUCTION

1.1 Summary

In volumes I and II of the Spacecraft Operational Trajectory, a detailed description of the mission profile for Apollo 16 is presented. The nominal launch date of April 16, 1972, was used for this trajectory simulation.

Translunar injection places the spacecraft on a translunar trajectory with a 71.4-n. mi. perilune altitude. This trajectory exceeds the requirements that the spacecraft be earth-returnable within RCS capability up to TLI + 5 hours, and/or be returnable within DPS capability at perilune + 2 hours in the event of no LOI burn. An evasive maneuver is performed by the S-IVB prior to the LOX dump as was done on Apollo 15. This maneuver will place the discarded S-IVB on a lunar impact trajectory.

The lunar orbit time line from LOI to LM landing has been decreased by one orbit from that of Apollo 15 because one orbit between CSM/LM separation and LM landing was deleted. The lunar surface stay time has been increased to 37 revolutions or 73 hours. After LM jettison, there is a LM ascent stage deorbit maneuver which results in a lunar impact as was done on Apollo 15. There is a plane change after LM jettison and there is a 1-day lunar orbit science period. TEI occurs at the end of revolution 75.

For the nominal mission, the launch time is 11^h54^m c.s.t., and the flight azimuth is $\sim 72.0^\circ$. Translunar injection occurs during the second revolution over the Pacific Ocean.

The mission duration is approximately 12 days, 3 hours. The translunar flight time is $71^h 50^m$. The time spent in lunar orbit is approximately $147^h 46^m$, and the transearth flight time is $67^h 59^m$.

1.2 Introduction

Many aspects of mission operations require a foreknowledge of the spacecraft trajectory - both its shape and its schedule of events. This document is the best and most complete prelaunch estimate of that trajectory. The trajectory event schedule presented will be followed as near as possible during the actual flight. This information will provide input data for preflight simulations and will be the basis for the preliminary ground station tracking schedule. Many other facets of the mission operations, however, also require these data.

This trajectory reflects all known constraints, guidelines, and mission requirements as documented in reference 1, and is based on the spacecraft characteristics defined by the Spacecraft Operational Data Book (ref. 2). The launch portion of the trajectory, which is generated by the Marshall Space Flight Center, is omitted from this document.

SEQUENCE OF MAJOR EVENTS

TABLE 1-I.- SEQUENCE OF MAJOR EVENTS

Event	Time, hr:min:sec, g.e.t.	Time, hr:min:sec, c.s.t.	Data summary	
Launch	00:00:00	April 16, 1972 11:54:00.0	Flight azimuth, deg	72.0
			Launch complex	39A
EPO insertion	00:11:57.2	12:05:57.2	Geodetic latitude, deg	32.7
			Longitude, deg	-52.1
			Geodetic altitude, n. mi.	93.3
			Velocity, fps	25 603.7
Translunar injection[a]				
Burn initiation	02:33:15.1	14:27:15.1	Geodetic latitude, deg	-24.8
			Longitude, deg	137.3
			Velocity, fps	25 630.7
			Apogee altitude, n. mi.	95.8
			Geodetic altitude, n. mi.	88.9
Burn termination (guidance cutoff signal)	02:38:50.0	14:32:50.0	Geodetic latitude, deg	-12.5
			Longitude, deg	161.7
			Burn duration, sec	334.9
			Plane change, deg	0.0
			Apogee altitude, n. mi.	266 387.7
			Geodetic altitude, n. mi.	154.6
Post-TLI events[a]				
CSM/S-IVB separation	03:03:50.0	14:57:50.0		
Docking	03:13:50.0	15:07:50.0		
CSM/LM ejection	03:58:50.0	15:52:50.0		
Evasive maneuver[a] (performed by S-IVB)	04:21:50.0	16:15:50.0	ΔV, fps	9.8
Translunar coast, midcourse correction maneuvers				
MCC-1	TLI + 9 hr	23:32:50.0	Geodetic altitude, n. mi.	≈56 500
MCC-2	TLI + 28 hr	April 17, 1972 18:32:50.0	Geodetic altitude, n. mi.	≈119 000
MCC-3	LOI - 22 hr	April 18, 1972 16:22:38.6	Geodetic altitude, n. mi.	≈166 500
MCC-4	LOI - 5 hr	April 19, 1972 9:22:38.6	Altitude above mean lunar radius, n. mi.	≈12 200

[a]This information is approximate and is presented for information only. The official source is the MSFC LV operational trajectory (ref. 2).

TABLE 1-I.- SEQUENCE OF MAJOR EVENTS - Continued

Event	Time, hr:min:sec, g.e.t.	Time, hr:min:sec, c.s.t.	Data summary	
		April 19, 1972		
SIM door jettison	LOI - 4.5 hr	9:52:38.6	Average ΔV imparted to door, fps	13.7
Lunar orbit insertion (LOI)				
Burn initiation	74:28:38.6	14:22:38.6	Mass, lb	102 642.7
			Altitude above LLS radius, n. mi.	95.1
			Selenographic latitude, deg	8.1
			Selenographic longitude, deg	-166.9
			Perilune altitude above LLS radius, n. mi.	71.4
			Selenographic inclination, deg	8.1
			Velocity, fps	8104.0
Burn termination	74:34:53.6	14:28:53.6	Altitude above LLS radius, n. mi.	77.5
			Selenographic latitude, deg	7.1
			Selenographic longitude, deg	169.2
			Selenographic inclination, deg	9.0
			Burn duration, sec	375.0
			Inertial burn arc, deg	23.7
			Plane change, deg	2.3
			ΔV, fps	2807.0
			SPS propellant used, lb	24 838.4
			Velocity, fps	5388.4
			Orbital period, hr:min:sec	02:08:46.4
			Perilune altitude above LLS radius, n. mi.	58.5
			Apolune altitude above LLS radius, n. mi.	170.6
S-IVB predicted lunar impact	74:30:08.0	14:24:08.0	Selenographic latitude, deg	-2.3
			Selenographic longitude, deg	-31.7
Descent orbit insertion (DOI)				
Burn initiation	78:35:30.3	18:29:30.3	Mass, lb	77 770.4
			Altitude above LLS radius, n. mi.	58.6
			Selenographic latitude, deg	8.7
			Selenographic longitude, deg	-140.9
			Perilune altitude above LLS radius, n. mi.	58.6
			Apolune altitude above LLS radius, n. mi.	170.4
			Velocity, fps	5486.2

TABLE 1-I.- SEQUENCE OF MAJOR EVENTS - Continued

Event	Time, hr:min:sec g.e.t.	Time, hr:min:sec, c.s.t.	Data summary	
DOI		April 19, 1972		
Burn termination	78:35:54.4	18:29:54.4	Altitude above LLS radius, n. mi.	58.6
			Selenographic latitude, deg	8.8
			Selenographic longitude, deg	-142.2
			Selenographic inclination, deg	9.0
			Burn duration, sec	24.1
			Inertial burn arc, deg	1.2
			Plane change, deg	0.0
			ΔV, fps	206.0
			Velocity, fps	5280.2
			SPS propellant used, lb	1566.2
			Orbital period, hr:min:sec	01:54:25.2
			Perilune altitude above LLS radius, n. mi.	10.9
			Apolune altitude above LLS radius, n. mi.	58.6
			Revolution number	2
		April 20, 1972		
CSM/LM undock and SEP	96:13:30.8	12:07:30.8	Selenographic latitude, deg	2.2
			Selenographic longitude, deg	121.0
			Revolution number	12
Circularization (CSM)				
Burn initiation	97:41:44.5	13:35:44.5	Mass, lb	39 318.1
			Selenographic latitude, deg	9.0
			Selenographic longitude, deg	-159.8
			Selenographic inclination, deg	9.0
			Altitude above LLS, n. mi.	59.8
			Perilune altitude above LLS, n. mi.	9.3
			Velocity, fps	5274.0
			Revolution number	12
Burn termination	97:41:50.4	13:35:50.4	ΔV, fps	99.6
			Burn duration, sec	5.9
			Altitude above LLS, n. mi.	59.8
			Perilune altitude above LLS, n. mi.	51.8
			Apolune altitude above LLS, n. mi.	68.2
			Velocity, fps	5343.8
			SPS propellant consumed, lb	384.7
			Burn arc, deg	0.3
			Orbital period, hr:min:sec	01:58:54.4
			Revolution number	12

TABLE 1-I.- SEQUENCE OF MAJOR EVENTS - Continued

Event	Time, hr:min:sec, g.e.t.	Time, hr:min:sec, c.s.t.	Data summary	
		April 20, 1972		
PDI (DPS ignition time)	98:34:40.9	14:28:40.9	Altitude above LLS, ft	52 707.3
			Velocity, fps	5571.1
			Revolution number	13
High gate (P63 to P64)	98:44:00.9	14:38:00.9	Altitude above LLS, ft	7900.3
			Velocity, fps	355.0
Low gate	98:45:22.9	14:39:22.9	Altitude above LLS, ft	605.5
			Velocity, fps	79.6
Vertical descent (P64 to P65)	98:46:02.9	14:40:02.9	Altitude above LLS, ft	213.7
			Velocity, fps	10.3
LM landing	98:46:42.4	14:40:42.4	ΔV, fps	6696.3
			Burn duration, sec	721.5
			DPS propellant consumed, lb	18 100.3
			Revolution number	13
			Selenographic latitude, deg	-9.0
			Selenographic longitude, deg	15.5
CSM first pass over LLS	98:43:06.7	14:37:06.7	Revolution number	13
First CSM plane change		April 22, 1972		
Burn initiation	152:28:48.1	20:22:48.1	Mass, lb	38 752.8
			Selenographic latitude, deg	-4.9
			Selenographic longitude, deg	-67.8
			Altitude above LLS, n. mi.	57.4
			Perilune altitude above LLS, n. mi.	57.3
			Apolune altitude above LLS, n. mi.	62.2
			Revolution number	40
			Velocity, fps	5355.6
Burn termination	152:28:57.2	20:22:57.2	SPS propellant consumed, lb	602.3
			ΔV, fps	158.7
			Burn duration, sec	9.1
			Selenographic latitude, deg	-4.9
			Selenographic longitude, deg	-68.3
			Altitude above LLS, n. mi.	57.4
			Perilune altitude above LLS, n. mi.	57.3
			Apolune altitude above LLS, n. mi.	62.0
			Plane change, deg	1.7
			Selenographic inclination, deg	10.5
			Velocity, fps	5355.4
			Revolution number	40

TABLE 1-I.- SEQUENCE OF MAJOR EVENTS - Continued

Event	Time, hr:min:sec, g.e.t.	Time, hr:min:sec, c.s.t.	Data summary	
		April 23, 1972		
CSM second pass over LLS	171:46:10.3	15:40:10.3	Revolution number	50
Ascent				
LM lift-off	171:45:08.6	15:39:08.6	Mass, lb	10 892.2
			Selenographic latitude, deg	-9.0
			Selenographic longitude, deg	15.5
			Revolution number	50
LM insertion	171:52:22.9	15:46:22.9	Mass, lb	5923.9
			ΔV, fps	6047.9
			Burn duration, sec	434.3
			Latitude, deg	-9.8
			Longitude, deg	5.3
			Altitude above LLS, ft	59 889.1
			Perilune altitude above LLS, ft	54 783.9
			Apolune altitude above LLS, ft	276 088.1
Rendezvous				
TPI (APS ignition) Preceded by a 10-sec RCS ullage ΔV =	172:39:22.9	16:33:22.9	Burn duration, sec	2.5
			ΔV, fps	
			Propellant used, lb	30.0
			Resultant h_a/h_p, n. mi.	61.9/44.0
			Range at cutoff, n. mi.	32.0
			Range rate at cutoff, fps	-132.5
			Propulsion system	APS
			Revolution number	50
Braking	173:20:16.4	17:14:16.4	Burn duration, sec	30.2
			ΔV, fps	33.4
			Propellant used, lb	21.6
			Range at final braking, n. mi.	0.02
			Range rate at final braking, fps	-0.23
			h_a/h_p at final braking, n. mi.	59.8/59.3
			Propulsion system	LM RCS
			Revolution number	51
Docking	173:40:00.0	17:34:00.0		

TABLE 1-I.- SEQUENCE OF MAJOR EVENTS - Continued

Event	Time, hr:min:sec, g.e.t.	Time, hr:min:sec, c.s.t.	Data summary	
		April 23, 1972		
LM jettison	177:31:15.0	21:25:15.0	Selenographic latitude, deg	-4.5
			Selenographic longitude, deg	46.7
			Revolution number	53
CSM/LM separation				
Burn initiation	177:36:15.0	21:30:15.0	Revolution number	53
Burn termination	177:36:28.2	21:30:28.2	Mass, lb	38 514.8
			ΔV, fps	2.0
			Burn duration, sec	13.2
			Selenographic latitude, deg	-6.9
			Selenographic longitude, deg	30.9
			Altitude above LLS radius, n. mi.	59.6
			Perilune altitude above LLS radius, n. mi.	59.5
			Apolune altitude above LLS radius, n. mi.	61.7
			Plane change, deg	0.0
			Selenographic inclination, deg	10.4
			Velocity, fps	5346.0
			Revolution number	53
LM deorbit	179:16:29.2	23:10:29.2	Mass, lb	5253.9
			ΔV, fps	229.6
			Burn duration, sec	95.5
			Selenographic latitude, deg	2.7
			Selenographic longitude, deg	86.2
LM impact	179:39:28.6	23:33:28.6	Mass, lb	5122.2
			Selenographic latitude, deg	-9.5
			Selenographic longitude, deg	15.0
			Velocity, fps	5550.1
			CSM revolution number	54
Second CSM plane change		April 24, 1972		
Burn initiation	193:13:46.2	13:07:46.2	Mass, lb	38 433.2
			Selenographic latitude, deg	0.1
			Selenographic longitude, deg	65.0
			Altitude above LLS, n. mi.	58.0
			Perilune altitude above LLS, n. mi.	57.9
			Apolune altitude above LLS, n. mi.	62.9
			Velocity, fps	5354.5
			Revolution number	61

TABLE 1-I.- SEQUENCE OF MAJOR EVENTS - Continued

Event	Time, hr:min:sec, g.e.t.	Time, hr:min:sec, c.s.t.	Data summary	
Second CSM plane change		April 24, 1972		
Burn termination	193:14:02.0	13:08:02.0	SPS propellant consumed, lb	1056.8
			ΔV, fps	282.5
			Burn duration, sec	15.8
			Selenographic latitude, deg	0.0
			Selenographic longitude, deg	64.2
			Altitude above LLS, n. mi.	58.0
			Perilune altitude above LLS, n. mi.	57.9
			Apolune altitude above LLS, n. mi.	62.9
			Plane change, deg	3.0
			Selenographic inclination, deg	13.4
			Velocity, fps	5354.5
			Revolution number	61
Shaping burn		April 25, 1972		
Burn initiation	216:49:11.7	12:43:11.7	Mass, lb	37 305.3
			Altitude above LLS radius, n. mi.	55.8
			Selenographic latitude, deg	7.8
			Selenographic longitude, deg	87.6
			Perilune altitude above LLS, n. mi.	55.7
			Apolune altitude above LLS, n. mi.	65.2
			Selenographic inclination, deg	13.4
			Velocity, fps	5366.4
			Revolution number	73
Burn termination	216:49:13.9	12:43:13.9	Selenographic latitude, deg	7.7
			Selenographic longitude, deg	87.5
			Perilune altitude above LLS, n. mi.	55.0
			Apolune altitude above LLS, n. mi.	85.0
			Burn duration, sec	2.2
			Inertial burn arc, deg	0.1
			Plane change, deg	0.0
			ΔV, fps	38.0
			SPS propellant used, lb	139.6
			Velocity, fps	5391.6
Subsatellite jettison	218:02:08.3	13:56:08.3	Altitude above LLS radius, n. mi.	78.5
			Selenographic latitude, deg	0.0
			Selenographic longitude, deg	-128.0
			Velocity, fps	5272.0
			Perilune altitude above LLS, n. mi.	55.4
			Apolune altitude above LLS, n. mi.	85.0
			Revolution number	73

TABLE 1-I.- SEQUENCE OF MAJOR EVENTS - Concluded

Event	Time, hr:min:sec, g.e.t.	Time, hr:min:sec, c.s.t.	Data summary	
Transearth injection		April 25, 1972		
Burn initiation	222:20:32.8	18:14:32.8	Mass, lb	37 025.0
			Altitude above LLS radius, n. mi.	65.7
			Selenographic latitude, deg	10.3
			Selenographic longitude, deg	179.7
			Perilune altitude above LLS, n. mi.	54.7
			Selenographic inclination, deg	13.4
			Velocity, fps	5339.3
			Revolution number	76
Burn termination	222:23:03.3	18:17:03.3	Altitude above LLS radius, n. mi.	67.3
			Selenographic latitude, deg	11.9
			Selenographic longitude, deg	170.0
			Perilune altitude above LLS, n. mi.	64.7
			Selenographic inclination, deg	15.5
			Burn duration, sec	150.5
			Inertial burn arc, deg	9.7
			Plane change, deg	3.3
			ΔV, fps	3212.2
			SPS propellant used, lb	10 059.7
			Velocity, fps	8521.2
Transearth coast midcourse correction maneuvers		April 26, 1972		
MCC-5	TEI + 17 hr	11:17:03.3	Geodetic altitude, n. mi.	≈181 000
MCC-6	EI - 22 hr	April 27, 1972 16:16:45.4	Geodetic altitude, n. mi.	≈106 500
MCC-7	EI - 3 hr	April 28, 1972 11:16:45.4	Geodetic altitude, n. mi.	≈25 500
CM/SM sep	EI - 15 min	14:01:45.4	Geodetic altitude, n. mi.	1971.0
Entry interface	290:22:45.4	14:16:45.4	Transearth coast time, hr	68
			Inertial velocity, fps	36 175.8
			Geodetic altitude, n. mi. (ft)	65.8 (399 681.0)
			Inertial flight-path angle, deg	-6.5
			Geodetic latitude, deg	-13.0
			Longitude, deg	-167.2
			Equatorial inclination (ascending), deg	61.8
CM landing	290:36:03	14:30:03.0	Geodetic latitude, deg	5.0
			Longitude, deg	-158.7

LAUNCH WINDOW SUMMARY

TABLE 1-II.- LAUNCH WINDOW SUMMARY

Launch date	April 16, 1972
Site	Descartes
Flight azimuth, deg	72 to 100
Launch time, hr:min, c.s.t.	11:54 to 15:43
Translunar flight time, hr:min	71:50 to 66:43
Lunar orbit inclination, deg	9.0
Approach azimuth at landing, deg	-90.0
Sun elevation at landing, deg	11.9
Goldstone landing coverage, hr:min	12:20
Lunar surface stay time, hr	73.0
Total lunar orbit stay time	147:46, 75 revs
Transearth flight time, hr	68
Total mission time, hr	290:36 to 286:47

SYMBOL DEFINITIONS AND
COORDINATE SYSTEM DESCRIPTION

2.0 SYMBOL DEFINITIONS AND

COORDINATE SYSTEM DESCRIPTION

EARTH-CENTERED INERTIAL COORDINATE SYSTEM

The primary reference coordinate system in which all trajectory computations are made is a mean-of-epoch system. In this system the epoch is the beginning of a Besselian year nearest to the mission base time. The beginning of the Besselian (fictitious) solar year is when the right ascension of the fictitious mean sun, affected by aberration and measured from the mean equinox, is 18^h40^m. This instant always occurs near the beginning of the calendar year and is denoted by the notation .0 after the year; i.e., the beginning of the Besselian solar year 1960 is January $1^d.345$ E.T. = 1960.0. The crossover time for changing the reference epoch is 180 calendar days into the year (4320 hr from $0,0^h$ January 1). This change of epoch time corresponds to 24^h (midnight) June 29 in a common year and 24^h June 28 in a leap year.

After the reference epoch has been defined, the inertial geocentric coordinate system is described by the X-axis coincident with the intersection of the mean equatorial plane and the mean ecliptic plane of epoch. The intersection of these planes is known as the mean-of-epoch line of equinoxes. The X-Y plane is the mean equatorial plane of epoch and the Z-axis is coincident with the earth's mean axis of rotation.

PRINT FORMAT

The print block headings denote the coordinate system reference or other type of vehicle information which is printed immediately below it.

The following symbol definitions are referenced to the line they are printed on under the particular print block heading. When it is desired to obtain the definition of a particular print symbol, attention should be focused on the print block heading since print blocks which have no pertinence to current vehicle activities are deleted; i.e., the THRUST block is not printed if the vehicle is not thrusting. The lines of the heading print, which appear at the top of the trajectory print, define the vehicle to which the trajectory events are related, reference body, and appropriate time references. The coordinate system definition relative to a given print block is footnoted on the page that the print block heading occurs.

Heading Print

Symbol	Definition
CSM/MOON REF.	vehicle identification/reference body (earth or moon)
MEAN-OF-EPOCH (YEAR)	year to which epoch is referenced
(DATE)	calendar date of trajectory print
__HRS__MINS__SECS G.M.T.	Greenwich mean time of day
T__HRS FROM LAUNCH	time in total hours from launch
__HRS__MINS__SECS G.E.T.	time from launch in hours, minutes, and seconds (ground elapsed time)
RAGR	right ascension of the Greenwich meridian, deg
PHASE ELAPSED TIME__SECS	the elapsed time in seconds from the beginning of a trajectory phase
RESTART COORDINATES (ER AND ER/HR)	
RXYZ	inertial position coordinates with respect to the reference body (earth or moon) in double precision, e.r.
RDXYZ	inertial velocity coordinates with respect to the reference body in double precision, e.r./hr
GD(N) THRUST***	guidance identification (N) used during a thrusting phase GD4; indicates external ΔV guidance
ENGINE IGNITION (or CUTOFF)	thrust subtitle indicating the initiation or termination of a thrust

Symbol	Definition
THRUST	
THETA	angle between the thrust acceleration vector and the local horizontal plane, deg
BETA	azimuth of the thrust acceleration vector with respect to the projection of the velocity vector into the local horizontal plane, deg
PROP,PRPNT	total propellant consumed during phase, lb
TM	thrust magnitude, lbf
VELG	velocity to be gained to achieve the magnitude of the required velocity, fps
TACC	thrust acceleration, ft/sec^2
BARC	range angle or burn arc, deg
DELV	velocity gained during thrust period, fps
MASS	instantaneous mass of the vehicle, lb
MSFL	mass flow rate of propellant, lbm/sec
SPI	specific impulse, sec
VEXH	exhaust velocity, fps
VRX, VRY, VRZ	inertial components of the velocity required, fps
VDX, VDY, VDZ	inertial components of the velocity to be gained (VELG), fps

Symbol	Definition
THRUST - Continued	
TGO	time to go to thrust cutoff, sec
FC	commanded thrust, lbf
GMLP	engine gimbal angle about Y-axis, deg
GMLY	engine gimbal angle about Z-axis, deg
PLCHG	total orbital plane change since thrust initiation, deg
TDELV	total velocity increment applied since the beginning of the case, fps
DELRN	change in vehicle's radial distance measured along the line of intersection between the burn initiation and burnout orbit planes; the line of intersection nearest the burnout position is used
WOXID	instantaneous oxidizer propellant for the main engine, lb
WFUEL	instantaneous fuel propellant for the main engine, lb
WODOT	oxidizer propellant flow rate of the main engine, lb/sec
WFDOT	fuel propellant flow rate of the main engine, lb/sec
TB	total main engine burn time, sec
MR	mixture ratio of the main engine, oxidizer/fuel

Symbol	Definition
THRUST - Concluded	
PC	chamber stagnation pressure at the nozzle inlet, lbf/in.
TMRCS	thrust magnitude of the RCS jet, lbf
MDRCS	propellant flow rate of the RCS jet, lb/sec
RCSPA	instantaneous RCS propellant of quad A, lb
RCSPB	instantaneous RCS propellant of quad B, lb
RCSPC	instantaneous RCS propellant of quad C, lb
RCSPD	instantaneous RCS propellant of quad D, lb
MENGP	instantaneous total propellant of the main engine, lb; it is a negative number only if IMASS was used to specify the vehicle mass
PALV	angle between the thrust acceleration vector and the local vertical, deg
VDLVX VDLVY VDLVZ	total local horizontal velocity components applied since beginning of the burn, fps

Symbol	Definition
SELENOCENTRIC[a]	
XL, YL, ZL	coordinates of vehicle position, n. mi.
DXL, DYL, DZL	coordinates of vehicle velocity, fps
RL, DECL, RAL	radius, declination, right ascension, n. mi., deg
VL, PTHL, AZL	velocity, flight-path angle, azimuth, fps, deg
DRB	declination of the reference body with respect to the vehicle, deg
RARB	right ascension of the reference body with respect to the vehicle, deg
DNRB	declination of the nonreference body with respect to the vehicle, deg
RANRB	right ascension of the nonreference body with respect to the vehicle, deg
DSV	declination of the sun with respect to the vehicle, deg
RASV	right ascension of the sun with respect to the vehicle, deg

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[a] The axes of the selenocentric coordinate system are directed parallel to those of the inertial geocentric system.

Symbol	Definition
GEOCENTRIC[a]	
X, Y, Z	inertial components of vehicle position, n. mi.
DX, DY, DZ	inertial components of vehicle velocity, fps
R	radius magnitude, n. mi.
DEC	declination, angle between radius vector and the equatorial plane, positive northward, deg
RA	right ascension, angle between the vehicle meridian and vernal equinox (X-axis), deg
V	velocity magnitude, fps
PTH	flight-path angle measured positive up from the local horizontal plane, deg
AZ	azimuth, the angle between the projections of the vehicle meridian and the velocity vector in the local horizontal plane, measured from the north toward east, deg

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[a]The geocentric coordinate system is the basic earth-centered inertial program coordinate system defined above.

Symbol	Definition
GEOGRAPHIC[a]	
XG, YG, ZG	components of vehicle position, n. mi.
DXG, DYG, DZG	components of vehicle velocity, fps
ALT	geodetic altitude, n. mi.
LAT	geodetic latitude, deg
LON	geographic longitude, deg
VE	rotational velocity, fps
PTE	rotational flight-path angle, deg
AZE	rotational azimuth, deg
HVLP	altitude of vehicle with respect to the launch pad, n. mi.

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[a]The geographic or earth-fixed coordinate system is defined such that the Z-axis is directed along the earth's rotational axis, positive north, the X-axis passes through the Greenwich meridian and lies in the equatorial plane, and the Y-axis completes the standard right-handed system. The velocity components are referenced to a rotating earth, and the geodetic latitude and altitude are computed separately as a function of declination. The equatorial plane is the same as described for the geocentric inertial coordinate system.

Symbol	Definition
SELENOGRAPHIC[a]	
XS, YS, ZS	components of vehicle position, n. mi.
DXS, DYS, DZS	components of vehicle velocity, fps
ALTS	altitude, n. mi.
LATS	latitude, deg
LONS	longitude, deg
VRS	velocity vector magnitude, fps
PTR	flight-path angle, deg
AZR	azimuth, deg
LTS	selenographic latitude of the sun, deg
LNS	selenographic longitude of the sun, deg
LTE	selenographic latitude of the earth, deg
LNE	selenographic longitude of the earth, deg

[a]The selenographic equatorial plane is perpendicular to the lunar axis of rotation. The X-axis of the system lies in the equatorial plane and is directed through the moon's prime meridian. The Z-axis is directed perpendicular to the equatorial plane along the lunar axis of rotation. The Y-axis completes the standard right-handed coordinate system. Altitude is the distance above the mean spherical moon. Longitude is positive eastward from the X-axis of the rotational selenographic reference frame. Latitude is the angle between the position vector and the lunar equator. The system is fixed in the moon and rotates with it.

Symbol	Definition
SELENOGRAPHIC - Concluded	
DSMP	declination of the sun with respect to the earth-moon plane, deg
RSMP	right ascension of sun with respect to the earth-moon coordinate system, deg
LIN	selenographic inclination of the flight plane of the vehicle, deg
LAN	selenographic longitude of the ascending node, deg
LAP	selenographic argument of periapsis, deg
DR	radial components of velocity, fps
VT	tangential component of velocity, fps
SOLSV	sun elevation angle at sub-vehicle point, deg
TRALT	vehicle altitude above lunar landing site radius, n. mi.
RPALT	perigee altitude above radius of LLS, n. mi.
APALT	apogee altitude above radius of LLS, n. mi.

Symbol	Description
EARTH-MOON PLANE[a]	
XMP, YMP, ZMP	position of vehicle with respect to current reference body, n. mi.
DXMP, DYMP, DZMP	velocity of vehicle with respect to current reference body, fps
RMP, DEMP, RAMP	radius, declination, and right ascension with respect to current reference body, n. mi. and deg
VMP, PTMP, AZMP	velocity, flight-path angle, and azimuth, fps and deg
XME, YME, ZME	position coordinates of vehicle with respect to the earth, n. mi.
DXME, DYME, DZME	velocity coordinates of vehicle with respect to the earth, fps
DIA[b]	declination of incoming asymptote, deg
LIA[b]	right ascension of incoming asymptote, deg

[a]The earth-moon plane coordinate system is defined by the instantaneous radius and velocity vectors of the moon at the particular time in question. The X-axis lies along the earth-moon line, positive toward the earth from the moon. The Z-axis is normal to the earth-moon plane, parallel to the moon's angular momentum vector, positive in a northerly direction. The Y-axis completes the standard right-handed system. The right ascension is the angle measured in the earth-moon plane from the earth-moon line (X-axis) to the projection of the radius vector in the earth-moon plane. The declination is the angle between the radius vector and the earth-moon plane. This coordinate system is redefined at the beginning of each computational cycle and is centered in the current reference body.

[b]This line is printed only when trajectory is hyperbolic.

Symbol	Definition
EARTH-MOON PLANE - Concluded	
DOA[a]	declination of outgoing asymptote, deg
LOA[a]	right ascension of outgoing asymptote, deg
DRP[a]	declination of the periapsis vector, deg
LRP[a]	right ascension of the periapsis vector, deg
PLANETARY COORDINATES[b]	
XM, YM, ZM	inertial geocentric position coordinates of the moon, n. mi.
DXM, DYM, DZM	inertial geocentric velocity of the moon, fps
RM, DEM, RAM	radius, declination, and right ascension of the moon, deg and n. mi.
LOM, VM, ARGM	longitude, velocity, and argument of the moon, deg and fps
XSUN, YSUN, ZSUN	position of the sun in inertial geocentric Cartesian coordinates, n. mi.
RAS, LOS, DES	right ascention, longitude, and declination of the sun, deg

[a]This line is printed only when trajectory is hyperbolic.

[b]The planetary coordinates are always referenced to the earth.

Symbol	Definition
GEOCENTRIC (or SELENOCENTRIC) UNIT VECTORS	
WX, WY, WZ	inertial components of unit angular momentum vector, n.d.
PX, PY, PZ	inertial components of unit periapsis vector, n.d.
QX, QY, QZ	inertial components of the unit vector in orbit plane normal to the periapsis vector direction, n.d.
SXO, SYO, SZO	components of the unit vector of the outgoing asymptote, n.d. (set to zero if trajectory is not hyperbolic)
BODY ATTITUDES AND FORCES	
RRAT, PRAT, YRAT	vehicle attitude roll, pitch, and yaw rates, deg/sec
IGA, MGA, OGA	vehicle IMU inner, middle, and outer gimbal angles, deg
XTX[a] XTY XTZ	inertial coordinates of a unit vector along the vehicle X-axis, n.d.
YTX[a] YTY YTZ	inertial coordinate of a unit vector along the vehicle Y-axis, n.d.
ZTX[a] ZTY ZTZ	inertial coordinates of a unit vector along the vehicle Z-axis, n.d.

[a]The second, third, and fourth lines should be read in column format instead of across.

Symbol	Description
BODY ATTITUDES AND FORCES - Continued	
ALO[a] BTO GMO	Euler angles of vehicle orientation with respect to its attitude at phase initiation, taken in the order of pitch, yaw, and roll (Y, Z, X rotation), deg
ALLV[a] BTLV GMLV	pitch, yaw, and roll (Euler angles) of the vehicle with respect to the local horizontal coordinate system[b], deg
ALLI[a] BTLI GMLI	pitch, yaw, and roll of the vehicle with respect to the launch inertial coordinate system, deg

[a]The second, third, and fourth lines should be read in column format instead of across.

[b]The local horizontal (or local vertical) coordinate system is formed by the X-axis directed along the projection of the velocity vector in the local horizontal plane, the Z-axis is directed down along the negative radius vector and the Y-axis completes the right-handed system.

Symbol	Definition
GEOCENTRIC (or SELENOCENTRIC) UNIT VECTORS	
WX, WY, WZ	inertial components of unit angular momentum vector, n.d.
PX, PY, PZ	inertial components of unit periapsis vector, n.d.
QX, QY, QZ	inertial components of the unit vector in orbit plane normal to the periapsis vector direction, n.d.
SXO, SYO, SZO	components of the unit vector of the outgoing asymptote, n.d. (set to zero if trajectory is not hyperbolic)
BODY ATTITUDES AND FORCES	
RRAT, PRAT, YRAT	vehicle attitude roll, pitch, and yaw rates, deg/sec
IGA, MGA, OGA	vehicle IMU inner, middle, and outer gimbal angles, deg
XTX[a] XTY XTZ	inertial coordinates of a unit vector along the vehicle X-axis, n.d.
YTX[a] YTY YTZ	inertial coordinate of a unit vector along the vehicle Y-axis, n.d.
ZTX[a] ZTY ZTZ	inertial coordinates of a unit vector along the vehicle Z-axis, n.d.

[a]The second, third, and fourth lines should be read in column format instead of across.

Symbol	Description
BODY ATTITUDES AND FORCES - Continued	
ALO[a] BTO GMO	Euler angles of vehicle orientation with respect to its attitude at phase initiation, taken in the order of pitch, yaw, and roll (Y, Z, X rotation), deg
ALLV[a] BTLV GMLV	pitch, yaw, and roll (Euler angles) of the vehicle with respect to the local horizontal coordinate system[b], deg
ALLI[a] BTLI GMLI	pitch, yaw, and roll of the vehicle with respect to the launch inertial coordinate system, deg

[a]The second, third, and fourth lines should be read in column format instead of across.

[b]The local horizontal (or local vertical) coordinate system is formed by the X-axis directed along the projection of the velocity vector in the local horizontal plane, the Z-axis is directed down along the negative radius vector and the Y-axis completes the right-handed system.

Symbol	Definition
GEOCENTRIC OSCULATING ELEMENTS	
SMA	semimajor axis, n. mi.
ECC	eccentricity, n.d.
INC	inclination of vehicle flight plane to the earth equatorial plane, deg
RAN	right ascension of the ascending node, deg
APF	argument of perigee, deg
RP	radius at perigee, n. mi.
VH	hyperbolic excess velocity for hyperbola or present escape velocity deficit for ellipse, fps
RNMP	right ascension of ascending node in earth-moon plane coordinates, deg
APMP	argument of periapsis vector in earth-moon plane coordinates, deg
INMP	inclination of vehicle flight plane to the earth-moon plane, deg
APO	apogee radius, n. mi.
TFP	time (G.E.T.) at which periapsis passage occurs, hr
TA	true anomaly, deg
EA	eccentric anomaly, deg
MA	mean anomaly, deg

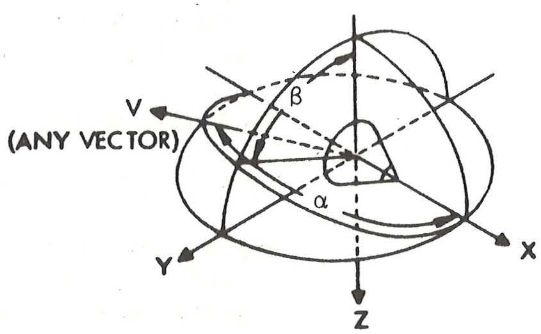
Symbol	Definition
GEOCENTRIC OSCULATING ELEMENTS - Concluded	
SLR	semilatus rectum, n. mi.
PER	period, hr
MTA	maximum true anomaly (360° in ellipse, calculated value in hyperbola), deg
SELENOCENTRIC OSCULATING ELEMENTS	
SMAS	
ECCS	
INCS	
RANS	
APFS	
RPS	
VHS	
RNMPS	all symbols and their units are the same as the geocentric osculating elements except that the reference is selenocentric
APMPS	
INMPS	
APOS	
TFPS	
TAS	
EAS	
MAS	
SLRS	
PERS	
MTAS	

Symbol	Definition
BODY ATTITUDES AND FORCES - Concluded	
ALS, BTS[a]	vehicle look angles α and β to the sun, deg
ALE, BTE	vehicle look angles α and β to the earth, deg
ALM, BTM	vehicle look angles α and β to the moon, deg
ALEI, BTEI	look angles α and β to the earth in the IMU coordinate system, deg
SOLSV	sun elevation angle at sub-vehicle point, deg

[a]Vehicle look angles or aspect angles of a line of sight or vehicle referenced vector are defined as illustrated:

α the angle between the vehicle X-axis and the vector, deg

β the angle between the -Z-axis and the projection of the vector in the Y-Z plane, measured positive toward +Y, deg



Symbol	Definition
TOPOCENTRIC SIGHTING ANGLES	
ALLH	angle between the X-axis and the other vehicle line of sight in the local horizontal coordinate system, deg
BTLH	angle between the projection of the other vehicle line of sight into the Y-Z plane and the negative Z-axis in the local horizontal coordinate system. The angle measured positively from the negative Z-axis toward the positive Y-axis, deg
ALDLH	time derivative of ALLH, deg/sec
BTDLH	time derivative of BTLH, deg/sec
ALSC	angle between the X-axis and the other vehicle line of sight in the vehicle attitude coordinate system, deg
BTSC	angle between the projection of the other vehicle line of sight into the Y-Z plane and the negative Z-axis in the vehicle attitude coordinate system. The angle is measured positively from the negative Z-axis toward the positive Y-axis, deg
ALDSC	time derivative of ALSC, deg/sec
BTDSC	time derivative of BTSC, deg/sec
ALIMU	angle between the X-axis and the other vehicle line of sight in the IMU coordinate system, deg

Symbol	Definition
TOPOCENTRIC SIGHTING ANGLES - Concluded	
BTIMU	angle between the projection of the other vehicle line of sight into the Y-Z plane and the negative Z-axis in the IMU coordinate system. The angle is measured positively from the negative Z-axis toward the positive Y-axis, deg
ADIMU	time derivative of ALIMU, deg/sec
BDIMU	time derivative of BTIMU, deg/sec
ALWD1	angle between the center of window 1 and the other vehicle line of sight, deg
ALWD2	angle between the center of window 2 and the other vehicle line of sight, deg
ALELH	angle between the X-axis and the earth line of sight in the local horizontal coordinate system, deg
BTELH	angle between the projection of the earth line of sight into the Y-Z plane and the negative Z-axis in the local horizontal coordinate system. The angle is measured positively from the negative Z-axis toward the positive Y-axis, deg
AEDLH	time derivative of ALELH, deg/sec
BEDLH	time derivative of BTELH, deg/sec
PHI	central angle between the two vehicles, deg

Symbol	Definition
RENDEZVOUS PARAMETERS	
ACLS	sun-LM-CSM angle, deg
ACLE	LM-earth-CSM angle, deg
ARBD	LM-moon-earth angle, deg
ACLV	moon-LM-CSM angle, deg
ATH	angle between the projection of the LM position vector into the flight plane of the CSM and the position vector of the CSM, deg; the angle is positive when the target vehicle is ahead
DEL	angle between the position vector of the LM and the flight plane of the CSM, deg; the angle is positive when the LM is to the right of the flight plane of the CSM when viewed in the direction of motion
RANGE	distance between the LM and the CSM, n. mi.
RRATE	rate of change of range, fps
ALDCK	vehicle pitch for the LM to dock with the CSM, deg
BTDCK	vehicle yaw for the LM dock with the CSM, deg
GMDCK	vehicle roll for the LM to dock with the CSM, deg

Symbol	Definition
RENDEZVOUS PARAMETERS - Concluded	
ERR	angle between the LM rendezvous radar shaft axis and the X-body axis of the LM. The angle is measured positively when the shaft rotates toward the -Z-body axis of the LM, deg
ARR	LM rendezvous radar azimuth angle. A positive azimuth angle occurs when the radar line of sight is rotated toward the positive Y-axis, deg
MODE	LM rendezvous radar mode indicator. =1 ERR must be between +60 and -70° for tracking =2 ERR must be between +40 and +155° for tracking ARR must be between +55 and -55° for tracking
RCX, RCY, RCZ	this set of coordinates yields the arc distances required for the LM to rendezvous with the CSM. For positive coordinates, the sequence is as follows: through the arc RCX to bring the LM into the CSM flight plane; vertically through RCY to gain the required altitude; then down range through the arc RCZ to the position vector of the CSM
RELV	magnitude of the relative velocity, fps
XLR, YLR, ZLR XDLR, YDLR, ZDLR	the rendezvous coordinate system is centered in the inactive vehicle; the Y-axis is along this vehicle's negative angular momentum, and the Z-axis is along the negative of the projection of the active vehicle's position into the inactive flight plane

Symbol	Definition
LANDING SITE COORDINATES	
ALLS	angle between the line of sight to the landing site and the X-axis of the vehicle, deg
BTLS	angle between the projection of the line of sight to the landing site into the Y-Z plane and the negative Z-axis of the vehicle, measured positively from the negative Z-axis toward the positive Y-axis, deg
ALLSW1	angle between the center line of window 1 and the line of sight to the landing site, deg
ALLSW2	angle between the center line of window 2 and the line of sight to the landing site, deg
LATLS	latitude of the landing site, deg
LONLS	longitude of the landing site, deg
RANG	range from vehicle to landing site, n. mi.
ELV	elevation angle of vehicle measured from a plane tangent to the target body at the landing site, deg
AZM	azimuth of the vehicle with respect to the landing site, deg
DRNL	range rate, deg

Symbol	Definition
LANDING SITE COORDINATES	
RLSX RLSY RLSZ	selenocentric position vector of the landing site, n. mi.
VLSX VLSY VLSZ	selenocentric velocity vector of the landing site, fps
SOLLS	sunlight incidence angle on landing site (elevation of sun measured from geocentric or selenocentric horizontal at the landing site; negative value indicates sunlight not incident), deg
TRALT	altitude above the landing site, n. mi.
ALTST	altitude of landing site above the mean radius of the moon, n. mi.
TANG	thrust attitude of vehicle 2 with reference to line of sight, deg
SPRANG	surface range, n. mi.

MISSION GUIDELINES AND CONSTRAINTS

3.0 MISSION GUIDELINES AND CONSTRAINTS

The design of the mission and the monthly and daily launch windows were based on the following guidelines and constraints.

a. The primary lunar landing site is the Descartes region. There is no backup site.

b. Daylight launch is highly desirable.

c. The launch windows and profiles will be designed to achieve favorable lunar lighting at the lunar landing sites. For the primary launch date, the sun elevation is 11.9°.

d. The flight azimuth range following launch is limited to 72° to 100°.

e. The mission will be designed for a translunar injection over the Pacific Ocean.

f. Two TLI opportunities will be targeted: the first on the second revolution and the second on the third revolution.

g. The translunar trajectory must be restricted such that the spacecraft is earth-returnable within RCS capability up to TLI + 5 hours, and, in the event that LOI is not performed, the spacecraft must be returnable within DPS capability at perilune + 2 hours.

h. The S-IVB will perform an evasive maneuver prior to the LOX dump. The LOX dump will be targeted to achieve an S-IVB lunar impact.

i. The LOI maneuver will result in a 58- by 170-n. mi. elliptical orbit. DOI will be performed with the SPS after two revs in the 58- by 170-n. mi. orbit established by LOI. The targeting will be biased to place the spacecraft in an approximately 52 500-foot by 60-n. mi. orbit at the time of PDI on rev 13.

j. The lunar surface stay time will be approximately 73 hours. The CSM lunar orbit orientation will be restricted to permit an any-orbit LM lift-off.

k. A CSM plane change will be made on rev 40 approximately 10 revolutions prior to LM ascent to place the landing site in the orbital plane at the planned time of lift-off on rev 50.

l. The LM ascent stage will be deorbited for lunar impact. A second CSM plane change of 3° will be made on rev 61 to increase lunar surface coverage for photography. A shaping burn will be performed by the CSM on rev 73 to achieve proper orbital lifetime for the subsatellite jettisoned on rev 73.

m. The lunar orbit will be designed within the SPS capability to return to earth from an orbit, including the cryogenic tank failure situation.

n. The TEI maneuver will be targeted to return as soon as possible to the prime recovery area within the available ΔV capability.

o. The earth relative entry range will be 1190 n. mi.

LUNAR LANDING SITE POSITION

TABLE 5-I.- LUNAR LANDING SITE POSITION

Launch date	April 16, 1972
Lunar site name	Descartes
Latitude, deg	-9.00028
Longitude, deg	15.51639
Altitude,[a] n. mi.	-0.1405

[a]All altitudes shown are referenced to mean lunar radius of 938.4935 n. mi.