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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. 70-FM-14

February 16, 1970

RTCC REQUIREMENTS FOR APOLLO 14: NON-FREE-RETURN MODES OF THE TRANSLUNAR MIDCOURSE CORRECTION PROCESSOR

Lunar Mission Analysis Branch
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

The Flight Software Branch concurs with the above recommendations.

James C. Stokes, Jr., Chief
Flight Software Branch

Enclosure

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Mission Planning and Analysis Division
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IN REPLY REFER TO: 70-FM54-36

Feb. 5, 1970

MEMORANDUM TO: See list below

FROM : FM5/Chief, Lunar Mission Analysis Branch

SUBJECT : RTCC requirements for Apollo 14 (H-3): Non-free return modes of the Translunar Midcourse Correction Processor

The enclosed MSC Internal Note 70-FM-14 presents the requirements for computing options 4 and 5 in the Translunar Midcourse Correction Processor. Option 4 is the fixed-orbit non-free return, and option 5 is the free-orbit non-free return. The major changes included in this updated document are as follows:

1. Division of the conic full mission select into two portions ("double select" or "split select"), for both options

2. Provision for computing plane changes ("bootstrap" photography) from a circular lunar parking orbit following the first pass over the landing site, for both options

3. Use of backward integration in lunar orbit to model LOI1 and DOI geometry, for option 4 only

4. Provision of a MED on perilune altitude to control LOI1, for option 5 only

5. Provision for assessing the skeleton flight plan table to determine flight path angle at LOI, for option 5 only

This internal note supersedes MSC Internal Note 69-FM-287.

Ronald L. Berry
Ronald L. Berry

APPROVED BY:

John P. Mayer
Chief, Mission Planning
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NASA - Manned Spacecraft Center

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5. Author(s): Quentin A. Holmes and Kenneth T. Zeiler

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PROJECT APOLLO

RTCC REQUIREMENTS FOR APOLLO 14: NON-FREE-RETURN MODES OF THE TRANSLUNAR MIDCOURSE CORRECTION PROCESSOR

By Quentin A. Holmes and Kenneth T. Zeiler
Lunar Mission Analysis Branch

February 16, 1970

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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RTCC REQUIREMENTS FOR APOLLO 14:
NON-FREE-RETURN MODES OF THE
TRANSLUNAR MIDCOURSE CORRECTION PROCESSOR

By Quentin A. Holmes and Kenneth T. Zeiler

SUMMARY AND INTRODUCTION

There are two situations in which it is desirable to relax the free-return constraint on translunar trajectories. The first situation occurs when translunar injection is so far from nominal that a lunar orbital mission which uses free-return trajectories is impossible. For some of these cases, it is possible to salvage a lunar orbital mission by the use of a non-free-return trajectory. The second, and more interesting, situation occurs in the hybrid mission profile (ref. 1). In this profile, the TLI maneuver is made to place the spacecraft on a free-return trajectory with a high perilune altitude; after transposition and docking is completed, a planned midcourse maneuver is made which transfers the spacecraft to a non-free-return trajectory with a perilune altitude of approximately 60 n. mi. Compared to free-return missions, the hybrid profile affords substantial performance gains because the spacecraft travels slower at the start of LOI and because ϕ_{pc} is less constrained.

The non-free BAP options of the real-time midcourse processor are designed to meet these needs. Two distinct options are available: option 4, a fixed orbit non-free-return BAP; and option 5, a free orbit non-free-return BAP. Revisions of the formulation presented in reference 2 for options 4 and 5 are presented in the flow diagrams. The new formulation is based on the vector offset method for simulation of integrated trajectories with a conic trajectory computer. This technique makes it possible to reoptimize rapidly and accurately a lunar mission during a translunar coast.

ABBREVIATIONS

AZM	azimuth
BAP	best adaptive path
DPS	descent propulsion system
g.e.t.	ground elapsed time
G.m.t.	Greenwich mean time
HT	height
INCL	inclination
INT	integrated
LAT	latitude
LONG	longitude
LLS	lunar landing site
LM	lunar module
LOI	lunar orbit insertion
LPO	lunar parking orbit
MAX	maximum
MCC	midcourse correction
MED	manual entry device
PC	plane change
RTCC	Real-Time Computer Complex
SEA	sun elevation angle
SPS	service propulsion system
TEI	transearth injection
TLI	translunar injection
TLMC	first guess logic (backward iterator) for ΔV, $\Delta\gamma$, $\Delta\psi$ of the mission maneuver

SYMBOLS

R	radius
S'	auxiliary state
X, Y, Z	Cartesian components of position vector
$\dot{X}, \dot{Y}, \dot{Z}$	Cartesian components of velocity vector
V	velocity
γ	flight-path angle
ψ	azimuth
Δ	change
T	time

Subscripts:

emp	earth-moon plane
pl	perilune
pfd	preflight data
nd	node
tlc	translunar coast
I	integrated

TRANSLUNAR FLIGHT TIME

Specification of perilune latitude and altitude does not determine translunar flight time on a non-free-return trajectory. Lack of need for these specifications plays a key role in the performance gains afforded by non-free-return trajectories. The range of acceptable flight times is determined by two considerations. The first consideration is crew safety, and the second consideration is proper lighting at the time of lunar landing. Translunar flight time is closely associated with perilune position and velocity. For a given inclination at perilune, time to the node can be bounded (min ΔT_{DPS}, max ΔT_{DPS}) to enforce the DPS abort constraint. If the range is not violated, then the LM DPS has the ability to transfer the spacecraft to a free-return trajectory shortly after perilune is passed. Sun elevation at lunar landing is determined by the G.m.t. of LM landing. The acceptable range of SEA at lunar landings is entered as a range in G.m.t. The corresponding limits (min ΔT_{SEA}, max ΔT_{SEA}) for time to the node are obtained by use of the nominal delta time in LPO to first pass. The range used by the program insures that both the DPS and the lighting constraints are satisfied. The upper and lower limits on translunar flight time can be overridden by a MED.

A polynomial $\delta(\Delta t)$ is used to predict the optimum time to the node. This polynomial (ref. 3) can be safely used only with midcourse corrections that occur within 30 hours of TLI; it is used in the first guess logic whenever the value that it predicts is within the range of acceptable values. The difference between nominal time of the node and expected time of the node δT is used to estimate perilune velocity to start the first guess logic.

METHOD

The underlying assumption of the vector offset method is that the difference between two conic trajectories is a close approximation of the difference between the corresponding pair of integrated trajectories. For full mission optimization, a velocity offset is applied at each end of the translunar trajectory. This permits the MCC, LOI, PC, and TEI maneuvers to be optimized as a set by the use of conic trajectories. Moreover, the resultant nodal conditions (h_{nd}, ϕ_{nd}, λ_{nd}, T_{nd}) are optimum for integrated trajectories.

Based on a state vector in translunar coast, a midcourse maneuver is computed to transfer the spacecraft to a conic trajectory which satisfies all mission constraints (full mission select). Next, an integrated midcourse maneuver is targeted to the conic node.

As far as the midcourse maneuver is concerned, the discrepancy between conic and integrated trajectories is reflected in the difference in their respective midcourse maneuvers ($\Delta\dot{X}$, $\Delta\dot{Y}$, $\Delta\dot{Z}$). An auxiliary state S' is built according to

$$S' = S2C - \Delta\dot{X}_I - \Delta\dot{Y}_I - \Delta\dot{Z}_I \qquad (1)$$

where S2C is the state vector that results after the conic midcourse and where $\Delta\dot{X}_I$, $\Delta\dot{Y}_I$, $\Delta\dot{Z}_I$ are integrated values. Prior to optimization S' is substituted for the premidcourse state; the ΔV, $\Delta\gamma$, and $\Delta\psi$ required to regain S2C are computed and are used as first guesses for the midcourse maneuver.

At LOI, the discrepancy between conic and integrated trajectories is only in the magnitude and direction of their respective velocity vectors at the common node.

A velocity offset ($\Delta\dot{X}''$, $\Delta\dot{Y}''$, $\Delta\dot{Z}''$) at LOI is computed according to

$$\Delta\dot{X}'' = (S3I - S3C)_{\dot{x}\text{ component}} \tag{2}$$

$$\Delta\dot{Y}'' = (S3I - S3C)_{\dot{y}\text{ component}} \tag{3}$$

$$\Delta\dot{Z}'' = (S3I - S3C)_{\dot{z}\text{ component}} \tag{4}$$

During optimization, the offset is made available to the trajectory computer. After conic propagation to the node, the offset is applied before the LOI maneuver is computed. This offset permits a coupled full-mission optimization of the midcourse correction, the LOI maneuver, lunar orbit plane change, and transearth injection to be performed using conic trajectories.

Because the translunar flight time changes as a result of optimization, the original offsets may be slightly in error. This error is manifested as a difference between the predicted and the actual characteristic velocities of the MCC and LOI maneuvers. When appropriate, revised offsets are built with the new end conditions, and the optimization is repeated.

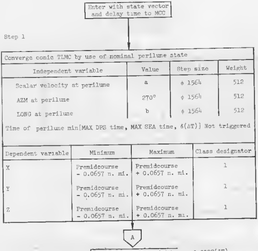
OPTION 4 - FIXED ORBIT NON-FREE-RETURN BAP

The steps involved in computation of a non-free-return BAP with a fixed lunar orbit are shown in flow chart 1. The principal changes are division of the conic full mission select into two segments (split select), the use of backward integration in lunar orbit to model the LOI1 and DOI geometry, and the provision for computing plane changes (bootstrap photography) from a circular LPO following 1st pass over the lunar landing site.

OPTION 5 - FREE ORBIT NON-FREE-RETURN BAP

Flow chart 2 shows the logic used to compute a free orbit non-free-return BAP. Split select has been incorporated, a crude control on LOI1 is afforded by providing a MED on height of perilune (height of lunar orbit will be scaled to the value indicated by the H_{LO} system parameter) and accessing the skelton flight plan for the value of gamma at LOI1. Bootstrap photography has also been included.

Option 4: Fixed orbit non-free-return BAP



Enter with state vector and delay time to MCC

Step 1

Converge conic TLMC by use of nominal perilune state

Independent variable	Value	Step size	Weight
Scalar velocity at perilune	a	ϕ 1564	512
AZM at perilune	270°	ϕ 1564	512
LONG at perilune	b	ϕ 1564	512

Time of perilune min[MAX DPS time, MAX SEA time, $\delta(\Delta T)$] Not triggered

Dependent variable	Minimum	Maximum	Class designator
X	Premidcourse - 0.0657 n. mi.	Premidcourse + 0.0657 n. mi.	1
Y	Premidcourse - 0.0657 n. mi.	Premidcourse + 0.0657 n. mi.	1
Z	Premidcourse - 0.0657 n. mi.	Premidcourse + 0.0657 n. mi.	1

[a] Computed as $v = \sqrt{0.18406305 + 0.5530824/r_{pc}} - 0.0022(\delta T) - 13.5\ (\lambda_{pfd} - 180°)$

[b] Computed as $\lambda = \lambda_{pfd} - 0.25(\delta T)$

Flow chart 1.- Fixed orbit non-free-return BAP.

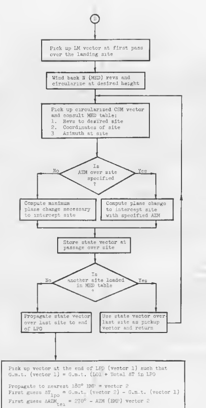
Step 2

Select and optimize for 50 iterations

Independent variables	First guess	Step size	Weight
Δ flight-path angle LOI	Fixed	--	--
ΔAZM MCC	Step 1	ϕ 1564	8
Δ flight-path angle MCC	Step 1	ϕ 1544	8
ΔV MCC	Step 1	ϕ 1544	8

Dependent variables	Minimum	Maximum	Weight	Class designator
θ	- 0.01°	- 0.01°	--	1
INCL of perilune	90°	182°	64	0
ΔHT_{NODE}	- 0.1 n. mi.	+ 0.1 n. mi.	--	1
Mass after LOI	100 000 lb	100 000 lb	--	3
AZM of LLS	Nominal - 0.01°	Nominal + 0.01°	--	1
ΔT to node	MAX of [Min ΔT DPS, min ΔT SEA] - 2 hrs MIN of [Max ΔT DPS, max ΔT SEA] + 2 hrs		0.125	0

Flow chart 1.- Continued



Flow chart 1 - Continued.

C

Compute transearth flight time (TEFT)

TEFT (NEW) = ΔT_{tlc} (nominal) - ΔT_{tlc} (step 2) + TEFT (nominal)

Step 2A

Select a conic transearth trajectory with a specified flight time using time state vector at the end of LPO

Independent variable	First guess	Step size	Weight
ΔT_{lpo}	Equation	01564	10^{-6}
ΔV of TEI	2800 fpa	01564	1
Δ flight-path angle at TEI	0°	01564	1
ΔAZM of TEI	Equation	01564	1

Dependent variable	Minimum	Maximum	Weight	Class designator
HT of entry	Nominal - 1.735 n. mi.	Nominal + 1.735 n. mi.	--	1
INCL of pr. return	0°	40°	8	0
Transearth flight time	Equation - 0.1 hr	Equation + 0.1 hr	--	1

Step 2B

Select and optimize for 100 iterations

Independent variable	First guess	Step size	Weight
ΔT_{lpo}	Previous step	01564	10^{-6}
ΔV of TEI	Previous step	01564	1
Δ flight-path at TEI	Previous step	01564	1
ΔAZM of TEI	Previous step	01564	1

Dependent variable	Minimum	Maximum	Weight	Class designator
Mass after TEI	Select + 6000 lb	Select + 6000 lb	--	3
HT of entry	Nominal - 1.735 n. mi.	Nominal + 1.735 n. mi.	--	1
INCL of pr. return	0°	40°	8	0
Transearth flight time	Previous step - 8 hr	Previous step + 8 hr	0.125	0
δLONG earth landing	-0.2°	+0.2°	--	1

D

Flow chart .- Continued.

D

Store conic postmidcourse state (S2C) and conic state at start of LOI (S3C)

Step 3

Con[illegible] ntegrated TLMC by use of nodal state from step 2

Independent variable	Value	Step size	Weight
Scalar velocity at the node	Step 2	ϕ 1564	512
AZM at the node	Step 2	ϕ 1564	512
LONG of the node	Step 2	ϕ 1564	512
Time of the node	Step 2	Not triggered	

Dependent variables	Minimum	Maximum	Class designator
X	Premidcourse position - 0.657 n. mi.	Premidcourse position + 0.657 n. mi.	1
Y	Premidcourse position - 0.657 n. mi.	Premidcourse position + 0.657 n. mi.	1
Z	Premidcourse position - 0.675 n. mi.	Premidcourse position + 0.657 n. mi.	1

Step 4

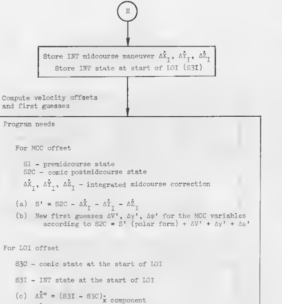
Converge a precision trajectory to the node obtained in step 2

Independent variable	Value	Step size	Weight
ΔAZM of MCC	Step 3	ϕ 1544	512
Δ flight-path angle at MCC	Step 3	ϕ 1544	512
ΔV of MCC	Step 3	ϕ 1524	512
Time of the node	Step 3	Not triggered	

Dependent variable	Minimum	Maximum	Weight	Class
HT of node	Step 2 - 0.5 n. mi	Step 2 + 0.5 n. mi.	--	1
LAT of node	Step 2 - 0.01°	Step 2 + 0.01°	--	1
LONG of node	Step 2 - 0.01°	Step 2 + 0.01°	--	-
INCL of perilune	90°	182°	64	0

E

1 chart ..- Continued.



Store INT midcourse maneuver $\Delta\dot{X}_I$, $\Delta\dot{Y}_I$, $\Delta\dot{Z}_I$
Store INT state at start of LOI (S3I)

Compute velocity offsets
and first guesses

Program needs

For MCC offset

S1 - premidcourse state
S2C - conic postmidcourse state
$\Delta\dot{X}_I$, $\Delta\dot{Y}_I$, $\Delta\dot{Z}_I$ - integrated midcourse correction

(a) $S' = S2C - \Delta\dot{X}_I - \Delta\dot{Y}_I - \Delta\dot{Z}_I$
(b) New first guesses $\Delta V'$, $\Delta\gamma'$, $\Delta\psi'$ for the MCC variables according to $S2C = S'$ (polar form) $+ \Delta V' + \Delta\gamma' + \Delta\psi'$

For LOI offset

S3C - conic state at the start of LOI

S3I - INT state at the start of LOI

(c) $\Delta\dot{X}'' = (S3I - S3C)_{\dot{x}}$ component
$\Delta\dot{Y}'' = (S3I - S3C)_{\dot{y}}$ component
$\Delta\dot{Z}'' = (S3I - S3C)_{\dot{z}}$ component

Flow chart 1.- Continued.

F

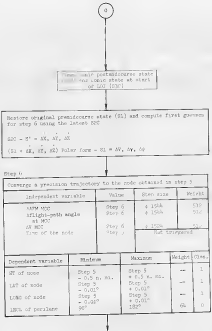
Step 5

With conic trajectories, optimize mass after TEI by use of S' as the state vector and by offset of the state at start of LOI prior to computation of LOI maneuver

Independent variable	Value	Step size	Weight
Δ flight-path angle at TEI	Step 2	ϕ 1544	8
ΔAZM TEI	Step 2	ϕ 1544	8
ΔV TEI	Step 2	ϕ 1544	1
Time in lunar orbit	Step 2	ϕ 1544	10^{-6}
ΔAZM of MCC	$\Delta\psi'$	ϕ 1564	512
Δ flight-path angle at MCC	$\Delta\gamma'$	ϕ 1544	512
ΔV of MCC	$\Delta V'$	ϕ 1544	512

Dependent variable	Minimum	Maximum	Weight	Class designator
θ	- 0.01°	+ 0.01°	--	1
INCL of perilune	90°	182°	64	0
ΔH_{node}	- 0.1 n. mi.	+ 0.1 n. mi.	--	1
Delta time to node	Lower limit: max (min ΔT_{dps}, min ΔT_{sea})	Upper limit: min (max ΔT_{dps}, max ΔT_{sea})	0.125	0
INCL of powered return	0°	40°	0.125	0
ΔLONG of earth landing	-0.2°	+0.2°	--	1
HT of entry	Nominal -1.735 n. mi.	Nominal +1.735 n. mi.	--	1
Mass after TEI	Step 2 + 6000 lb	Step 2 + 6000 lb	--	-1

G



[illegible] onic postmidcourse state [illegible] and conic state at start of LOI (S3C)

Restore original premidcourse state (S1) and compute first guesses for step 6 using the latest S2C

$S2C - S' = \Delta\dot{X}, \Delta\dot{Y}, \Delta\dot{Z}$

$(S1 + \Delta\dot{X}, \Delta\dot{Y}, \Delta\dot{Z})$ Polar form $- S1 = \Delta V, \Delta\gamma, \Delta\psi$

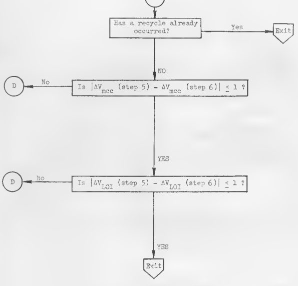
Step 6

Converge a precision trajectory to the node obtained in step 5

Independent variable	Value	Step size	Weight
ΔAZM MCC	Step 6	¢ 1544	512
Δflight-path angle at MCC	Step 6	¢ 1544	512
ΔV MCC	Step 6	¢ 1524	512
Time of the node	Step 5	Not triggered	

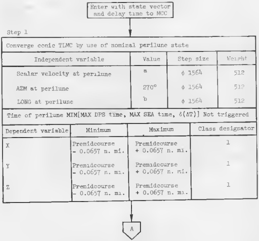
Dependent variable	Minimum	Maximum	Weight	Class
HT of node	Step 5 − 0.5 n. mi.	Step 5 + 0.5 n. mi.	--	1
LAT of node	Step 5 − 0.01°	Step 5 + 0.01°	--	1
LONG of node	Step 5 − 0.01°	Step 5 + 0.01°	--	1
INCL of perilune	90°	182°	64	0

Flow chart 1.- Concluded.



Flow chart 1.- Concluded.

Option 5: Free orbit non-free-return BAP



Enter with state vector and delay time to MCC

Step 1

Converge conic TLMC by use of nominal perilune state

Independent variable	Value	Step size	Weight
Scalar velocity at perilune	[a]	ϕ 1564	512
AZM at perilune	270°	ϕ 1564	512
LONG at perilune	[b]	ϕ 1564	512

Time of perilune MIM[MAX DPS time, MAX SEA time, δ(ΔT)] Not triggered

Dependent variable	Minimum	Maximum	Class designator
X	Premidcourse - 0.0657 n. mi.	Premidcourse + 0.0657 n. mi.	1
Y	Premidcourse - 0.0657 n. mi.	Premidcourse + 0.0657 n. mi.	1
Z	Premidcourse - 0.0657 n. mi.	Premidcourse + 0.0657 n. mi.	1

[a] Computed as $v = \sqrt{.18406305 + .5530824/r_{pc}} - .0022(\delta T) -13.5(\lambda_{pfd} - 180°)$

[b] Computed as $\lambda = 3.1 - 0.25(\delta T)$

Flow chart 2.- Free orbit nonfree return BAP.

A

Step 2

Select and optimize for 50 iterations

Independent variable	First guess	Step size	Weight
ΔT to first pass	Nominal	ϕ1574	10^{-3}
Δ flight-path angle at LOI	Fixed	--	--
ΔAZM of LOI	Nominal	ϕ1564	1
ΔAZM of MCC	Step 1	ϕ1564	8
Δ flight-path angle at MCC	Step 1	ϕ1544	8
ΔV of MCC	Step 1	ϕ1544	8

Dependent variable	Minimum	Maximum	Weight	Class designator
HT of perilune	Nominal/MED -0.1 n. mi.	Nominal/MED +0.1 n. mi.	--	1
INCL of perilune	90°	182°	64	0
HT of LPO	Nominal - 0.5 n. mi.	Nominal + 0.5 n. mi.	--	1
LAT of LLS	Nominal - 0.01°	Nominal + 0.01°	--	1
LONG LLS	Nominal - 0.01°	Nominal + 0.01°	--	1
Mass after LOPC	Select + 6000 lb	Select + 6000 lb	--	-1
AZM of LLS	Nominal - 0.01°	Nominal + 0.01°	--	1
ΔT to node	MAX of [MIN ΔT DPS, MIN ΔT SEA] - 2 hr	MIN of [MAX ΔT DPS, MAX ΔT SEA] + 2 hr	0.125	0

Pick up vector at the end of LPO (vector 1) such that G.m.t. (vector 1) = G.m.t. LOI + total ΔT in LPO

Propagate to nearest 180° EMP = vector 2

First guess ΔT_{lpo} = G.m.t. (vector 2) - G.m.t. (vector 1)

First guess ΔAZM_{tei} = 270° - AZM_{emp} (vector 2)

B

Flow chart 2.- Continued.

B

Compute transearth flight time (TEFT)

TEFT (NEW) = ΔT_{tlc} (nominal) − ΔT_{tlc} (step 2) + TEFT (nominal)

Step 2A

Select a conic transearth trajectory with a specified flight time using time state vector at the end of LPO

Independent variable	First guess	Step size	Weight
ΔT_{lpo}	Equation	ϕ 1564	10^{-6}
ΔV of TEI	2800 fps	ϕ 1564	1
Δ flight-path angle of TEI	0°	ϕ 1564	1
ΔAZM of TEI	Equation	ϕ 1564	1

Dependent variable	Minimum	Maximum	Weight	Class designator
HT of entry	Nominal − 1.735 n. mi.	Nominal + 1.735 n. mi.	--	1
INCL of pr. return	0°	40°	8	0
Transearth flight time	Equation − 0.01 hr	Nominal + 0.01 hr	--	1

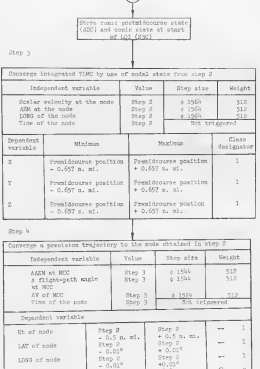
Step 2B

Select and optimize for 100 iterations

Independent variables	First guess	Step size	Weight
ΔT LPO	Previous step	ϕ 1564	10^{-6}
ΔV of TEI	Previous step	ϕ 1564	1
Δ flight-path angle of TEI	Previous step	ϕ 1564	1
ΔAZM of TEI	Previous step	ϕ 1564	1

Dependent variable	Minimum	Maximum	Weight	Class designator
Mass after TEI	Select + 6000 lbs	Select + 6000 lbs	--	−1
HT of entry	Nominal − 1.735 n. mi.	Nominal + 1.735 n. mi.	--	1
INCL of pr. return	0°	40°	8	0
Transearth flight time	Previous step − 8 hr	Previous step + 8 hr	0.125	0
ΔLONG of earth landing	−0.01°	+0.01°	--	1

Flow chart .- Continued.



Store conic postmidcourse state (S2C) and conic state at start of LOI (S3C)

Step 3

Converge integrated TLMC by use of nodal state from step 2

Independent variable	Value	Step size	Weight
Scalar velocity at the node	Step 2	ϕ 1564	512
AZM at the node	Step 2	ϕ 1564	512
LONG of the node	Step 2	ϕ 1564	512
Time of the node	Step 2	Not triggered	

Dependent variable	Minimum	Maximum	Class designator
X	Premidcourse position - 0.657 n. mi.	Premidcourse poaition + 0.657 n. mi.	1
Y	Premidcourse position - 0.657 n. mi.	Premidcourse position + 0.657 n. mi.	1
Z	Premidcourse position - 0.657 n. mi.	Premidcourse postion + 0.657 n. mi.	1

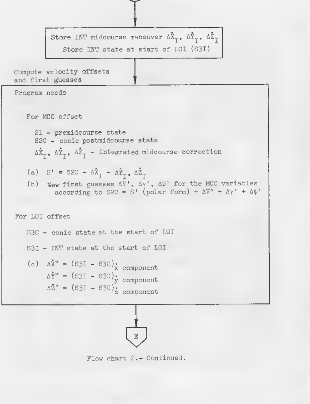
Step 4

Converge a precision trajectory to the node obtained in step 2

Independent variable	Value	Step size	Weight
ΔAZM at MCC	Step 3	ϕ 1544	512
Δ flight-path angle at MCC	Step 3	ϕ 1544	512
ΔV of MCC	Step 3	ϕ 1524	512
Time of the node	Step 3	Not triggered	

Dependent variable				
Ht of node	Step 2 - 0.5 n. mi.	Step 2 + 0.5 n. mi.	--	1
LAT of node	Step 2 - 0.01°	Step 2 + 0.01°	--	1
LONG of node	Step 2 - 0.01°	Step 2 +0.01°	--	1
INCL of perilune	90°	182°	64	0

Flow chart 2.- Continued.



Store INT midcourse maneuver $\Delta\dot{X}_I$, $\Delta\dot{Y}_I$, $\Delta\dot{Z}_I$
Store INT state at start of LOI (S3I)

Compute velocity offsets
and first guesses

Program needs

For MCC offset

S1 - premidcourse state
S2C - conic postmidcourse state
$\Delta\dot{X}_I$, $\Delta\dot{Y}_I$, $\Delta\dot{Z}_I$ - integrated midcourse correction

(a) $S' = S2C - \Delta\dot{X}_I - \Delta\dot{Y}_I, \Delta\dot{Z}_I$
(b) New first guesses $\Delta V'$, $\Delta\gamma'$, $\Delta\psi'$ for the MCC variables according to $S2C = S'$ (polar form) $+ \Delta V' + \Delta\gamma' + \Delta\psi'$

For LOI offset

S3C - conic state at the start of LOI

S3I - INT state at the start of LOI

(c) $\Delta\dot{X}'' = (S3I - S3C)_{\dot{x}}$ component
$\Delta\dot{Y}'' = (S3I - S3C)_{\dot{y}}$ component
$\Delta\dot{Z}'' = (S3I - S3C)_{\dot{z}}$ component

Flow chart 2.- Continued.

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Step 5

With conic trajectories, optimize mass after TEI by use of S' as the state vector and by offset of the state at start of LOI prior to computation of LOI maneuver

Independent variable	Value	Step size	Weight
Δ flight-path angle at TEI	Step 2	ϕ 1564	8
ΔAZM at TEI	Step 2	ϕ 1544	8
ΔV of TEI	Step 2	ϕ 1544	1
Time in lunar orbit	Step 2	ϕ 1544	10^{-6}
ΔT to first pass	Step 2	ϕ 1574	10^{-3}
ΔAZM at LOI	Step 4	ϕ 1564	1
ΔAZM at MCC	Δψ'	ϕ 1564	512
Δ flight-path angle at MCC	Δγ'	ϕ 1544	512
ΔV of MCC	ΔV'	ϕ 1544	512

Dependent variable	Minimum	Maximum	Weight	Class designator
HT of perilune	Nominal/MED -0.1 n. mi.	Nominal/MED +0.1 n. mi.	--	1
INCL of perilune	90°	182°	64	0
HT of lunar orbit	Nominal - 0.5 n. mi.	Nominal + 0.5 n. mi.	--	1
LAT of lunar landing site	Nominal - 0.01°	Nominal + 0.01°	--	1
LONG of lunar landing site	Nominal - 0.01°	Nominal + 0.01°	--	1
AZM over lunar landing site	MED	MED	1	0
Delta time to node	Lower limit: max (min ΔT_{dps}, min ΔT_{sea}) Upper limit: min (max ΔT_{dps}, max ΔT_{sea})		0.125	0
INCL of powered return	0°	40°	0.125	0
Delta LONG of earth landing	- 0.2°	+ 0.2°	--	1
HT of entry	Nominal -1.735 n. mi.	Nominal +1.736 n. mi.	--	1
Mass after TEI	Step 2 + 6000 lb	Step 2 + 6000 lb	--	1

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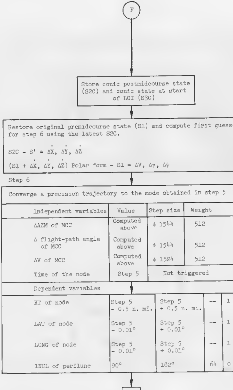
Flow chart 2.- Continued.



Store conic postmidcourse state (S2C) and conic state at start of LOI (S3C)

Restore original premidcourse state (S1) and compute first guesses for step 6 using the latest S2C.

$S2C - S' = \Delta\dot{X}, \Delta\dot{Y}, \Delta\dot{Z}$

$(S1 + \Delta\dot{X}, \Delta\dot{Y}, \Delta\dot{Z})$ Polar form $- S1 = \Delta V, \Delta\gamma, \Delta\psi$

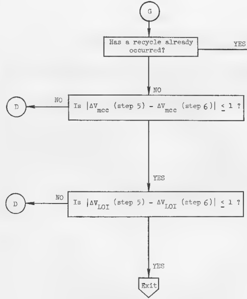
Step 6

Converge a precision trajectory to the mode obtained in step 5

Independent variables	Value	Step size	Weight
ΔAZM of MCC	Computed above	ϕ 1544	512
Δ flight-path angle of MCC	Computed above	ϕ 1544	512
ΔV of MCC	Computed above	ϕ 1524	512
Time of the node	Step 5	Not triggered	

Dependent variables				
HT of node	Step 5 - 0.5 n. mi.	Step 5 + 0.5 n. mi.	--	1
LAT of node	Step 5 - 0.01°	Step 5 + 0.01°	--	1
LONG of node	Step 5 - 0.01°	Step 5 + 0.01°	--	1
INCL of perilune	90°	182°	64	0

Flow chart 2.- Continued.



Flow chart 2.- Concluded.

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3. Sears, G.; and Redwine, W.: Optimum Translunar Flight Times for Premature TLI Shutdown. IOC 3423.8-25, April 20, 1967.