HUMAN MARS MISSION

PERFORMANCE

CREW TAXI PROFILE

FINAL REPORT

REF: Order Number H-28653D
(Part I)

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Submitted to:
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TAXI PERFORMANCE SUMMARIES

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MANNED MARS MISSION TAXI

The various cases studied are:

FILE	DESCRIPTION
ABORT	Abort at 750 x 750 phasing orbit with main taxi engines. Taxi and Stage tracked to top of atmosphere.
CASEI	Similar to abort, but with simple taxi aerobraking entry to Edwards.
POSTN	Delayed 2 burn rendezvous. 5 hours to apogee after TPF. DV 3860 m/s.
POSTZ	Delayed 2 burn rendezvous. 3 hours to apogee after TPF. DV 3415 m/s.
RENDN	Nominal taxi profile. 2 burn rendezvous.
RENDZ	Modified taxi profile. 3 burn rendezvous.

Working files can be delivered on request. Three file extensions are used:

INPUT FILE	*.DAT
BASE OUTPUT	*.TXT
SUMMARY TIMELINES	*.SUM

VAD/ALPHA TECH/ 1 SEP 99

ABORT FROM THE PHASING ORBIT
SEP RENDEZVOUS MISSION DESIGN

This timeline was generated on the Integrated Mission Program (IMP). All burn events over 2 seconds are finite with IMP solving a two point boundary value setup for begin burn time, burn time and control angles. Perigee and apogee shown above are mean orbital values.

Significant events are listed. Each finite thrust event has two lines. The first is the beginning time showing the initial conditions, thrust and ISP used. The second has the end burn conditions and the delta V and time of burn.

This case is an abort from the 750 x 750 phasing abort, using the taxi's main engines. An abort using the RCS system was also investigated but required a large increase in RCS propellant and was abandoned.

ABORT FROM THE PHASING ORBIT

INTEGRATED MISSION PROGRAM SUMMARY 30 AUG 1999 PAGE 1

TIME HR: MIN	EVENT	PERI (KM)	APOG (KM)	WGT (LB)	THRUST (LB)	ISP (SEC)	DELTA-V (M/S)	TBURN (S)
		SHUTTLE						
0-10.0	INSERTION	93.	190.	180000.	0.	0.	0.0	0.0
0-52.8	TO 190 X 200	93.	190.	180000.	12000.	314.	0.0	0.0
0-53.6		190.	200.	178132.	0.	0.	32.1	48.8
1-36.8	CIRCULARIZE	190.	200.	178132.	12000.	314.	0.0	0.0
1-36.8		200.	200.	177963.	0.	0.	2.9	4.4
45-52.7	RAISE APOGEE	199.	201.	177963.	12000.	314.	0.0	0.0
45-53.3		199.	275.	176695.	0.	0.	22.0	33.2
59-15.0	DROP TAXI	199.	275.	51942.	0.	0.	0.0	0.0
		TAXI						
59-15.0	INERTIAL DV	199.	275.	51942.	100.	225.	0.0	0.0
59-15.9		199.	278.	51918.	0.	0.	1.0	53.0
60-45.3	TO PHASING	199.	278.	51918.	49500.	466.	0.0	0.0
60-45.5		199.	750.	50445.	0.	0.	131.6	13.9
61-32.2	CIRCULARIZE	199.	750.	50445.	49500.	466.	0.0	0.0
61-32.5		750.	750.	48797.	0.	0.	151.7	15.5
		DEORBIT						
63-45.3	DEBOOST	752.	752.	48797.	49500.	466.	0.0	0.0
63-45.6		-17.	752.	46544.	0.	0.	216.1	21.2
64-45.6	DROP STAGE	-18.	750.	17710.	0.	0.	0.0	0.0
64-46.6	SEPERATE	-19.	750.	17710.	100.	225.	0.0	0.0
64-46.8		-18.	751.	17706.	0.	0.	0.5	9.0
75- 2.5	TAXI ENTRY	-17.	752.	17706.	0.	0.	0.0	0.0
		STAGE						
64-45.6	RETRIEVED	-18.	750.	28834.	0.	0.	0.0	0.0
75- 2.4	STAGE ENTRY	-17.	751.	28834.	0.	0.	0.0	0.0

PROPELLANT TOTAL TIME: 75 HR: 2 MIN: 21.443 SEC

ISP	314.000	225.000	466.000	0.000	0.000
SUM	3305.	24.	5374.	0.	0.

ABORT FROM THE PHASING ORBIT
SEP RENDEZVOUS MISSION DESIGN

This case is an abort from the 750 x 750 phasing abort, using the taxi's main engines. After reaching the top of the atmosphere a simple aerobrake entry is used to guide to Edwards. The case ends about 60 nm short of Edwards but can be adjusted by the time of deboost. Times below are from 73 hrs-40.3 min. Atmosphere top.

ENTRY PARAMETERS				(M-S)
85KM VRL	7625.55	M/S	AT	4-15.00
MAX QDOT	25.85	BTU/SQFT/SEC	AT	9-32.00
AT ALT	67.81	KM		
VRL	5618.32	M/S		
NOSE RADIUS	5.0	FT		
MAX DYNP	79.46	LBS/SQFT	AT	10-52.50
MAX ACC	4.26	GRAVS	AT	10-52.50
AVG ACC	1.08	GRAVS		
MAX STMP	2222.09	DEGS F		
Q INPUT	10369.	BTU/SQFT		

ATMOSPHERE US62

FINAL LAT	35.03 (D)	: LON -118.52 (D)
AIR ANGLE	43.56 (D)	
AIR TIME	879.00 (S)	
TARGET LAT	34.50 (D)	: LON -117.50 (D)
DRANGE TO GO	59.32 (NM)	
CRANGE TO GO	0.62 (NM)	
DISTANCE	59.32 (NM)	
RELATIVE BRNG	0.60 (D)	

CASE I ABORT, WITH MAINS, TO EDWARDS

INTEGRATED MISSION PROGRAM SUMMARY 24 AUG 1999 PAGE 1

TIME HR: MIN	EVENT	PERI (KM)	APOG (KM)	WGT (LB)	THRUST (LB)	ISP (SEC)	DELTA-V (M/S)	TBURN (S)
		SHUTTLE						
0-10.0	INSERTION	93.	190.	180000.	0.	0.	0.0	0.0
0-52.8	TO 190 X 200	93.	190.	180000.	12000.	314.	0.0	0.0
0-53.6		190.	200.	178132.	0.	0.	32.1	48.8
1-36.8	CIRCULARIZE	190.	200.	178132.	12000.	314.	0.0	0.0
1-36.8		200.	200.	177963.	0.	0.	2.9	4.4
45-52.7	RAISE APOGEE	199.	201.	177963.	12000.	314.	0.0	0.0
45-53.3		199.	275.	176695.	0.	0.	22.0	33.2
		TAXI						
59-15.0	TAXI	199.	275.	51942.	0.	0.	0.0	0.0
59-15.0	SEPERATE	199.	275.	51942.	100.	225.	0.0	0.0
59-15.9		199.	278.	51918.	0.	0.	1.0	53.0
60-45.3	TO PHASING	199.	278.	51918.	49500.	466.	0.0	0.0
60-45.5		199.	750.	50445.	0.	0.	131.6	13.9
61-32.2	CIRCULARIZE	199.	750.	50445.	49500.	466.	0.0	0.0
61-32.5		750.	750.	48797.	0.	0.	151.7	15.5
		DEORBIT						
73- 1.5	DEBOOST	751.	751.	48797.	49500.	466.	0.0	0.0
73- 1.8		71.	751.	46815.	0.	0.	189.5	18.7
73- 3.8	DROP STAGE	71.	751.	17710.	0.	0.	0.0	0.0
73-40.3	TOP ATMOS	72.	752.	17710.	0.	0.	0.0	0.0
73-54.9	AT 5 KM	-6370.	5.	17710.	0.	0.	0.0	0.0

PROPELLANT TOTAL TIME: 73 HR: 54 MIN: 55.547 SEC

ISP	314.000	225.000	466.000
SUM	3305.	24.	5103.

DELAYED TPI DURING THE SEP RENDEZVOUS TERMINAL PHASE

REF: Delayed TPI During the SEP Rendezvous Terminal Phase
Robert Merriam, Aeroscience & Flight Mechanics Branch,
EG5 JSC, 08/03/99

This timeline was generated on the Integrated Mission Program (IMP). All burn events over 2 seconds are finite with IMP solving a two point boundary value setup for begin burn time, burn time and control angles. Perigee and apogee shown above are mean orbital values.

Significant events are listed. Each finite thrust event has two lines. The first is the beginning time showing the initial conditions, thrust and ISP used. The second has the end burn conditions and the delta V and time of burn.

The mission profile can be compared to that of the reference, which was used as a model. However delta v's were calculated independently by IMP.

This profile allows about 5 hours after TPF for docking and transferring crew. IMP calculates about 3800 m/s DV vice the reference's 3433 m/s. The precession of the Taxi's orbit is different from the SEP's and a plane change is necessary at TPI and TPF. Another major factor is TPI time of transit, a function of transfer angle.

If a profile allowing only 2 hours after TPF for docking and transferring crew is used, a DV closer to the reference 3433 can be attained.

DELAYED RENDEZVOUS - DOCK 5 HOURS BEFORE APOGEE

INTEGRATED MISSION PROGRAM SUMMARY 30 AUG 1999 PAGE 1

TIME HR: MIN	EVENT	PERI (KM)	APOG (KM)	WGT (LB)	THRUST (LB)	ISP (SEC)	DELTA-V (M/S)	TBURN (S)
		SHUTTLE						
0-10.0	INSERTION	93.	190.	180000.	0.	0.	0.0	0.0
0-52.8	TO 190 X 200	93.	190.	180000.	12000.	314.	0.0	0.0
0-53.6		190.	200.	178132.	0.	0.	32.1	48.8
1-36.8	CIRCULARIZE	190.	200.	178132.	12000.	314.	0.0	0.0
1-36.8		200.	200.	177963.	0.	0.	2.9	4.4
45-52.7	RAISE APOGEE	199.	201.	177963.	12000.	314.	0.0	0.0
45-53.3		199.	275.	176695.	0.	0.	22.0	33.2
59-15.0	DROP TAXI	199.	275.	51942.	0.	0.	0.0	0.0
		TAXI						
59-15.0	SEPERATE	199.	275.	51942.	100.	225.	0.0	0.0
59-15.9		199.	278.	51918.	0.	0.	1.0	53.0
60-45.3	TO PHASING	199.	278.	51918.	49500.	466.	0.0	0.0
60-45.5		199.	750.	50445.	0.	0.	131.6	13.9
61-32.2	CIRCULARIZE	199.	750.	50445.	49500.	466.	0.0	0.0
61-32.5		750.	750.	48797.	0.	0.	151.7	15.5
		DELAYED RENDEZVOUS						
65-25.4	TPI	752.	752.	48797.	49500.	466.	0.0	0.0
65-28.9		739.	111610.	26327.	0.	0.	2819.9	211.5
70-57.6	TPF	739.	111612.	26327.	49500.	466.	0.0	0.0
70-58.4		800.	70379.	21056.	0.	0.	1020.8	49.6
	DOCK	800.	70379.	20964.	0.	0.	20.0	0.9
75-38.4	AT APOGEE	800.	70379.	20964.	0.	0.	0.0	0.0

PROPELLANT TOTAL TIME: 75 HR: 38 MIN: 22.094 SEC

ISP	314.000	225.000	466.000	0.000
SUM	3305.	26.	30953.	0.

DELAYED RENDEZVOUS - DOCK 3 HOURS BEFORE APOGEE

INTEGRATED MISSION PROGRAM SUMMARY 30 AUG 1999 PAGE 1

TIME HR: MIN	EVENT	PERI (KM)	APOG (KM)	WGT (LB)	THRUST (LB)	ISP (SEC)	DELTA-V (M/S)	TBURN (S)
		SHUTTLE						
0-10.0	INSERTION	93.	190.	180000.	0.	0.	0.0	0.0
0-52.8	TO 190 X 200	93.	190.	180000.	12000.	314.	0.0	0.0
0-53.6		190.	200.	178132.	0.	0.	32.1	48.8
1-36.8	CIRCULARIZE	190.	200.	178132.	12000.	314.	0.0	0.0
1-36.8		200.	200.	177963.	0.	0.	2.9	4.4
45-52.7	RAISE APOGEE	199.	201.	177963.	12000.	314.	0.0	0.0
45-53.3		199.	275.	176695.	0.	0.	22.0	33.2
59-15.0	DROP TAXIENT	199.	275.	51942.	0.	0.	0.0	0.0
		TAXI						
59-15.0	SEPERATE	199.	275.	51942.	100.	225.	0.0	0.0
59-15.9		199.	278.	51918.	0.	0.	1.0	53.0
60-45.3	TO PHASING	199.	278.	51918.	49500.	466.	0.0	0.0
60-45.5		199.	750.	50445.	0.	0.	131.6	13.9
61-32.2	CIRCULARIZE	199.	750.	50445.	49500.	466.	0.0	0.0
61-32.5		750.	750.	48797.	0.	0.	151.7	15.5
		DELAYED RENDEZVOUS						
65-25.2	TPI	752.	752.	48797.	49500.	466.	0.0	0.0
65-28.7		754.	83960.	26958.	0.	0.	2711.6	205.6
72-39.6	TPF	755.	83961.	26958.	49500.	466.	0.0	0.0
72-40.2		800.	70379.	23207.	0.	0.	684.6	35.3
	DOCKED	800.	70379.	23106.	0.	0.	20.0	1.0
75-38.4	AT APOGEE	800.	70379.	23106.	0.	0.	0.0	0.0

PROPELLANT TOTAL TIME: 75 HR: 38 MIN: 22.094 SEC

ISP	314.000	225.000	466.000
SUM	3305.	25.	28811.

SEP RENDEZVOUS MISSION DESIGN

REF: SEP Rendezvous Mission Design, Robert Merriam
Aeroscience & Flight Mechanics Branch, EG5
JSC, 08/03/99

This timeline was generated on the Integrated Mission Program (IMP). All burn events over 2 seconds are finite with IMP solving a two point boundary value setup for begin burn time, burn time and control angles. Perigee and apogee shown above are mean orbital values.

Significant events are listed. Each finite thrust event has two lines. The first is the beginning time showing the initial conditions, thrust and ISP used. The second has the end burn conditions and the delta V and time of burn.

The mission profile can be compared to that of the reference, which was used as a model. However delta v's were calculated independently by IMP and verify those of the reference.

Slight differences in DV are accounted for by gravity losses. Differences in the timeline are also very minor, and are the result of IMP's algorithms used to solve the constrained boundary value problems encountered.

NOMINAL 2 BURN RENDEZVOUS

INTEGRATED MISSION PROGRAM SUMMARY 30 AUG 1999 PAGE 1

TIME HR: MIN	EVENT	PERI (KM)	APOG (KM)	WGT (LB)	THRUST (LB)	ISP (SEC)	DELTA-V (M/S)	TBURN (S)
		SHUTTLE						
0-10.0	INSERTION	93.	190.	180000.	0.	0.	0.0	0.0
0-52.8	TO 190 X 200	93.	190.	180000.	12000.	314.	0.0	0.0
0-53.6		190.	200.	178132.	0.	0.	32.1	48.8
1-36.8	CIRCULARIZE	190.	200.	178132.	12000.	314.	0.0	0.0
1-36.8		200.	200.	177963.	0.	0.	2.9	4.4
45-52.7	RAISE APOGEE	199.	201.	177963.	12000.	314.	0.0	0.0
45-53.3		199.	275.	176695.	0.	0.	22.0	33.2
59-15.0	DROP TAXI	199.	275.	51942.	0.	0.	0.0	0.0
		TAXI						
59-15.0	SEPERATE	199.	275.	51942.	100.	225.	0.0	0.0
59-15.9		199.	278.	51918.	0.	0.	1.0	53.0
60-45.3	TO PHASING	199.	278.	51918.	49500.	466.	0.0	0.0
60-45.5		199.	750.	50445.	0.	0.	131.6	13.9
61-32.2	CIRCULARIZE	199.	750.	50445.	49500.	466.	0.0	0.0
61-32.5		750.	750.	48797.	0.	0.	151.7	15.5
		RENDEZVOUS						
63-43.4	TPI	752.	752.	48797.	49500.	466.	0.0	0.0
63-46.8		761.	70081.	27394.	0.	0.	2638.3	201.5
65-57.2	TPF	760.	70081.	27394.	49500.	466.	0.0	0.0
65-57.2		800.	70379.	27357.	0.	0.	6.1	0.3
72-43.9	DOCKED	800.	70379.	27238.	0.	0.	20.0	1.1
73-13.9	OFF LOAD CREW	800.	70379.	25918.	0.	0.	0.0	0.0
75-38.1	SEPERATE	800.	70379.	25918.	100.	225.	0.0	0.0
75-38.6		783.	70379.	25905.	0.	0.	1.0	27.6
		DEORBIT						
76- 8.3	DEBOOST	783.	70379.	25905.	49500.	466.	0.0	0.0
76- 8.4		113.	70378.	25671.	0.	0.	41.5	2.2
77- 8.4	DROP STAGE	113.	70378.	17710.	0.	0.	0.0	0.0
77- 9.4	SEPERATE	113.	70378.	17710.	100.	225.	0.0	0.0
77- 9.4		116.	70378.	17708.	0.	0.	0.2	3.6
87-22.6	TAXI ENTRY	116.	70378.	17708.	0.	0.	0.0	0.0
		STAGE						
77- 8.4	RETRIEVED	113.	70378.	7961.	0.	0.	0.0	0.0
87-22.4	STAGE ENTRY	113.	70378.	7961.	0.	0.	0.0	0.0

PROPELLANT TOTAL TIME: 87 HR: 22 MIN: 24.538 SEC

ISP	314.000	225.000	466.000
SUM	3305.	37.	24914.

MODIFIED RENDEZVOUS
SEP RENDEZVOUS MISSION DESIGN

REF: SEP Rendezvous Mission Design, Robert Merriam
Aeroscience & Flight Mechanics Branch, EG5
JSC, 08/03/99

This timeline was generated on the Integrated Mission Program (IMP). All burn events over 2 seconds are finite with IMP solving a two point boundary value setup for begin burn time, burn time and control angles. Perigee and apogee shown above are mean orbital values.

Significant events are listed. Each finite thrust event has two lines. The first is the beginning time showing the initial conditions, thrust and ISP used. The second has the end burn conditions and the delta V and time of burn.

The profile of the reference was modified to a 3 burn rendezvous. The transfer time of TPI was shortened and it was retargeted to end up about 2 kilometers astern of the SEP. At this point a safety braking burn reduces the closing speed to about 1 meter per second. This allows a very gradual final approach to the SEP and a TPF of about 1 meter per second.

MODIFIED 3 BURN

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TIME HR: MIN	EVENT	PERI (KM)	APOG (KM)	WGT (LB)	THRUST (LB)	ISP (SEC)	DELTA-V (M/S)	TBURN (S)
		SHUTTLE						
0-10.0	INSERTION	93.	190.	180000.	0.	0.	0.0	0.0
0-52.8	TO 190 X 200	93.	190.	180000.	12000.	314.	0.0	0.0
0-53.6		190.	200.	178132.	0.	0.	32.1	48.8
1-36.8	CIRCULARIZE	190.	200.	178132.	12000.	314.	0.0	0.0
1-36.8		200.	200.	177963.	0.	0.	2.9	4.4
45-52.7	RAISE APOGEE	199.	201.	177963.	12000.	314.	0.0	0.0
45-53.3		199.	275.	176695.	0.	0.	22.0	33.2
59-15.0	DROP TAXI	199.	275.	51942.	0.	0.	0.0	0.0
		TAXI						
59-15.0	SEPEARATE	199.	275.	51942.	100.	225.	0.0	0.0
59-15.9		199.	278.	51918.	0.	0.	1.0	53.0
60-45.3	RAISE APOGEE	199.	278.	51918.	49500.	466.	0.0	0.0
60-45.5		199.	750.	50445.	0.	0.	131.6	13.9
61-32.2	CIRCULARIZE	199.	750.	50445.	49500.	466.	0.0	0.0
61-32.5		750.	750.	48797.	0.	0.	151.7	15.5
		RENDEZVOUS						
63-43.4	TPI	752.	752.	48797.	49500.	466.	0.0	0.0
63-46.8		763.	69961.	27392.	0.	0.	2638.7	201.5
65-15.5	SAFETY BURN	763.	69961.	27392.	49500.	466.	0.0	0.0
65-15.5		802.	70429.	27345.	0.	0.	7.7	0.4
65-45.3	TPF	802.	70429.	27345.	100.	225.	0.0	0.0
65-45.6		800.	70379.	27335.	0.	0.	0.8	22.4
69-45.6	DOCKED	800.	70379.	27086.	0.	0.	20.0	555.0
70-15.6	OFF LOAD CREW	800.	70379.	25766.	0.	0.	0.0	0.0
75-38.1	SEPERATE	800.	70379.	25766.	100.	225.	0.0	0.0
75-38.6		783.	70379.	25754.	0.	0.	1.0	27.5
		DEORBIT						
76- 8.3	DEBOOST	783.	70379.	25754.	49500.	466.	0.0	0.0
76- 8.4		1.	70378.	25480.	0.	0.	48.8	2.6
77- 8.4	DROP STAGE	1.	70378.	17710.	0.	0.	0.0	0.0
77- 9.4	END COAST	1.	70378.	17710.	0.	0.	0.0	0.0
77- 9.4	SEPERATE	1.	70378.	17710.	100.	225.	0.0	0.0
77- 9.4		-2.	70377.	17708.	0.	0.	0.2	3.6
87-18.9	TAXI ENTRY	-2.	70378.	17708.	0.	0.	0.0	0.0
		STAGE						
77- 8.4	RETRIEVED	1.	70378.	7770.	0.	0.	0.0	0.0
87-19.0	STAGE ENTRY	1.	70378.	7770.	0.	0.	0.0	0.0

PROPELLANT TOTAL TIME: 87 HR: 18 MIN: 58.633 SEC

ISP	314.000	225.000	466.000	0.000	0.000
SUM	3305.	296.	24845.	0.	0.

* * * INTEGRATED MISSION PROGRAM * * *
* * * IMP * * *
DEVELOPED AND PROGRAMMED
BY

V. A. DAURO, SR.
PHONE 256-852-5492

* * * ABSTRACT * * *

"IMP" IS A SIMULATION LANGUAGE THAT IS USED TO MODEL MOST PRESENT OR FUTURE MISSIONS ABOUT THE EARTH, MARS, MOON OR OTHER BODY. MISSIONS ARE USER CONTROLLED THROUGH SELECTION FROM A LARGE EVENT/MANUEVER MENU. MISSION PROFILES, TIMELINES, PROPELLANT REQUIREMENTS, FEASIBILITY AND PERTURBATION ANALYSIS MAY BE QUICKLY, ACCURATELY CALCULATED. ONE, TWO OR THREE SPACECRAFT MAY BE USED: A MAIN, A TARGET AND AN OBSERVER.

* A FEHLBERG 7/13 RUNGE-KUTTA INTEGRATOR WITH ERROR AND STEP SIZE CONTROL IS USED TO NUMERICALLY INTEGRATE THE EQUATIONS OF MOTION.

* OBLATE OR SPHERICAL GRAVITY CAN BE USED FOR THE CENTRAL BODY. ADDITIONAL EFFECTS OF SUN GRAVITY, SOLAR PRESSURE, OR MOON GRAVITY ARE AVAILABLE. WHEN ADDED, THE SUN OR MOON GRAVITY IS SPHERICAL. EARTH/MARS ATMOSPHERIC EFFECTS ARE INCLUDED WHEN REQUESTED.

* INPUT/OUTPUT HAS BEEN SIMPLIFIED AND IS IN METRIC UNITS, WITH THE EXCEPTION OF THRUST AND WEIGHT WHICH ARE IN ENGLISH UNITS. INPUT IS READ FROM THE VDT KEYBOARD AND THE USER'S INPUT FILE. REAL TIME KEYBOARD INPUT HAS BEEN MINIMIZED.

* MAIN OUTPUT IS TO A USER NAMED PRINT FILE, TO A PLOT FILE, AND TO A DEBUG FILE. MAJOR MANUEVERS ALSO USE THEIR OWN PRENAMED FILES TO OUTPUT ADDITIONAL DATA IN TABULAR AS WELL AS PLOT FORM.

* EVENTS/MANUEVERS MAY INVOLVE NONE, ONE, OR MULTI VELOCITY CHANGES. THE VELOCITY CHANGES MAY BE IMPULSIVE, OR OF FINITE DURATION WITH GUIDANCE CALCULATED INTERNALLY OR PRESET BY THE USER. ALGORITHMS FOR TWO POINT BOUNDARY VALUES PROBLEMS INVOLVING VELOCITY CHANGES AND GUIDANCE ARE AUTOMATICALLY INVOKED AS NEEDED. BOOKKEEPING OF PROPELLANT USAGE AND DELTA-V SUMS ARE AUTOMATIC.

* THE CODE IS PROGRAMMED IN DOUBLE PRECISION FORTRAN AND COMPILES WITHOUT ERRORS TO THE STANDARDS OF LAHEY (TM) FORTRAN 90.

THE PROGRAM WAS INITIALLY CODED FOR MARSHALL SPACE FLIGHT CENTER, (MSFC), SE-AERO-G, HUNTSVILLE, AL. THE AUTHOR WAS EMPLOYED BY NORTHROP SERVICES, INC., HUNTSVILLE, AL. LATER THE AUTHOR WAS A MISSION ANALYST AT PRELIMINARY DESIGN, PD33, MSFC. THERE HE EXTENSIVELY MODIFIED AND ADDED TO THE CODE. SINCE RETIREMENT HE HAS CONTINUED TO IMPROVE IMP.

VAD/ALPHA TECH/ 1 SEP 99

GENERAL NOTES
INTEGRATED MISSION PROGRAM (IMP)

IMP integrates the differential equations of motion using a RK713 integrator with a variable limited time step and error correction. For this study, an oblate earth with harmonics J2, J3, and J4 was used. Hohmann and circularization velocities are calculated to include the J2 harmonic effects. An oblate Lambert solution is used for all intercept type events.

In implementing velocity changes, numerical predictor corrector algorithms are programmed to include all 3 harmonics. All burn events over 2 seconds are finite burns with IMP solving a two point boundary value setup for begin burn time, burn time and control angles. The algorithm used is determined by the constraints at the end of the burn.

Mission profiles are very flexible, and are controlled by the user's selection from a large menu. IMP executes as it reads. ie The user creates/orders an input file with events he desires. IMP reads the event name and description, executes it, and then reads the next.

VAD/ALPHA TECH/ 1 SEP 99

This contains a brief description of the IMP directories.
They are:

C:\IMP — The main directory for IMP. Contains the source FORTRAN code. And the following subdirectories.

- BACKUP — Contains a copy of the IMP FORTRAN source files.
- CURVE — Source FORTRAN for the curvefit routine. Least Squares, LogFit, PowerFit.
- DATA — Miscellaneous test cases.
- IMPAUX — Auxiliary routines that may be added and used as IMPW, the work routine.
- ITEST — Basic test cases to verify IMP and serve as models for the events.
- LIBRATE — Test cases for the libration events. Earth-Sun, Moon-Earth, and Mars-Sun.
- MARS — Base directory for the Manned Mars Mission study Contains the following subdirectories
    - ABORTS — Test cases for the Crew Taxi. Abort from orbit before rendezvous.
    - DELAYS — Test cases for the Crew Taxi. Orbit delay before rendezvous.
    - MSAVE — Miscellaneous Manned Mars test cases.
    - REPORT — The basic Manned Mars Mission profiles for a two-burn rendezvous, a three burn rendezvous, two delay cases, and abort cases. Contains files with extensions:
        - .DAT IMP input file
        - .TXT IMP output file
        - .SUM IMP summary file

      Also contains a file RECANT.TXT which has data pertaining to the use of Libration points and an explanation of IMP's simulation of them.
- PLOT — Fortran source files for the PLOT90 routine used to read and plot from the IMP plotfiles.
- USERS — Contains the 10 User manuals for IMP.

C:\ZXEQ — Seperate from C:\IMP. Contains the executables for IMP, PLOT90, SEQN, and some useful BAT files. ex DBUG displays the IMP DEBUG file.

SEQN reads an input file, sequences it in columns 76-80 and outputs with an extension *.NEW, Returns and asks for name of next to read. Blank ends.

IMP

A PERFORMANCE TOOL

V. A. DAURO, SR

ORIENTATION

MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE ,AL

10 JUN 1999

TITLE: IMP, A PERFORMANCE TOOL

AUTHOR: VINCENT A DAURO, SR
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OVERVIEW

"IMP" (INTEGRATED MISSION PROGRAM) is a simulation language and code used to model present and future Earth, Moon, or Mars missions. The missions' profiles are user controlled by SELECTION from a extensive menu of events and maneuvers. A Fehlberg 7/13 Runge–Kutta integrator with error and step size control is used to numerically integrate the differential equations of motion (DEQ) of three spacecraft, a main, a target, and an observer. Through selection, the DEQ'S my include guided thrust, oblate gravity, atmosphere drag and lift, solar pressure, drag chutes, and 3 body gravity effects. Guide parameters for thrust events and performance parameters of velocity changes, propellant usage (Maximum of eight systems) are developed as needed. Print, plot, summary, and debug files are output.

HISTORICALLY

"IMP" was initially coded for "MSFC SE-AERO-G" by the author while employed by Northrop Services Incorporated, Huntsville, Al (1970). In 1981, it was revived by the author, installed on the UNIVAC 1108, then the DEC VAX 11/780 at MSFC. Since then it has been continuously improved and upgraded. During retirement the author adapted IMP to PC'S using Lahey F90. This version should operate on most systems.

EXPERIENCE

Mission profiles and performance parameters developed by "IMP" has been used in studies of the following craft or systems.

OMV Orbital Maneuvering Vehicle
CTV Cargo Transfer Vehicle
STV Space Transfer Vehicle
SIRTF Solar Infra–red Telescope Facility
LTT Lunar Transit Telescope
SSF Space Station Freedom (assembly and resupply)
HLLV Heavy lift Vehicle
SH–C Shuttle–C
AFE Aeroassist Flight Experiment
SEI Space Exploration Initiative

IMP can generate profiles from liftoff to touchdown and its major limit is the User's imagination and dexterity in building the input file and in chaining sequence of events. Although not an interplanetary code, profiles to the Moon and to the Earth–Moon or Earth–Sun Libration points may be obtained. The author will gladly discuss improvements and additions to the code.

INTEGRATED MISSION PROGRAM "IMP"

A SIMULATION LANGUAGE 80+ MENU ITEMS
(EVENTS OR MANEUVERS)

MISSION PROFILES ABOUT THE EARTH, MOON, AND MARS

THREE VEHICLES MAIN-TARGET-OBSERVER

NUMERICAL INTEGRATION WITH ERROR AND .STEP SIZE CONTROL OF THE DIFFERENTIAL EQUATIONS OF MOTION

IMP MENU OF EVENTS

EVENT	ACTION
AEROBRAKE#	AEROBRAKING OPTIONS (7 EVENTS)
ALTITUDE	COAST TO ALTITUDE
ATMOSPHERE	ATMOSPHERE ON/OFF (5 EARTH, 3 MARS)
ATTITUDE	PROPELLANT USE FOR ATTITUDE ON/OFF
AUXFILE	OPEN/CLOSE AUXILIARY PLOT FILE
BALLOON#	BALLOON ASCENT
BURNGUIDE	SET AUXILIARY GUIDE FLAGS
CDCL	SET CD, CL = F (MACH OR ALPHA)
CHUTE	ADD DRAG CHUTE
CIRCLE	CIRCULARIZATION W/WO PLANE CHANGE
COAST	COAST OPTIONS (9 OPTIONS)
COMMENT	READ AND PRINT USER COMMENTS
COORDINATES	PRINT X,Y,Z,XDOT,YDOT,ZDOT
CROSS	FORCE INTERSECTION WITH TGT
DATE	SET PROGRAM DATE OF LAUNCH
DEBOOST#	DEBOOST OPTIONS (6 OPTIONS)
DEBUG	SET DEBUG FLAGS ON/OFF
DENSE	SET DENSE OUTPUT FLAG FOR BURNS
DISPOSAL#	CHECK DISPOSAL SITES
DVTOTAL	OUTPUT DVTOTAL TO VDT
ELLIPTIC#	ELLIPTIC TRANSFERS TO/FROM GEOSYNCH
EPHEMERIS#	SUN, MOON, PLANET EPHEMERIDES
ESCAPE#	PARALLEL BURN TO ESCAPE
FIXBURN	FIXED ATTITUDE THRUST EVENT
FLYER#	SIMULATE JET A/C FLIGHT
FORMATION#	INTERCEPT AND FLY FORMATION
HOHMAN	HOHMAN TRANSFER (4 OPTIONS)
INCLINATION	CHANGE INCLINATION
INPUT	CHANGE INPUT FILE
INSERT	BEGIN A NEW CASE SUB/ORBITAL
INTERCEPT	INTERCEPT GATE WRT TARGET
IONENGINE#	SPECIAL SPIRAL TO GEO
LIBHCK#	SET E/S OR E/M LIBRATION SYSTEM
LIFTOFF#	LAUNCH PROFILE SINGLE OR TWO STAGE
#	COMPLEX EQUIVALENT TO A MAIN PROGRAM

IMP MENU CONTINUED

EVENT	ACTION
LTRAN#	TRANSFER TO LIBRATION POINT
MAIN	SET MAIN TO TARGET OR OBSERVER
MECO	BEGIN AT MAIN ENGINE CUTOFF
MLIFT#	MULTI PHASE LIFT OFF
MTRAN#	TRANSFER EARTH TO MOON
NEAR#	CPA CHECKS OBSERVER/PLUME/MISSILE
NTRAN#	TRANSFER MOON TO EARTH
OBSERVER	OBSERVER OPERATIONS
ORB#	GENERAL ORBIT CHANGE
OUTPUT	REDIRECT OUTPUT SCRATCH/NORMAL
PARAMETERS	INPUT PLANET X PARAMETERS
PHASE	MAIN TO TARGET PHASING CHECK/EXECUTE
PLANE#	PLANE CHANGE (7 OPTIONS)
POST MECO#	POST MECO MANUEVERS
PRESET	PRESET DATA GUIDE/STAGE+HALF/OBLATE DV
PRINT	OUTPUT MAIN OR TARGET OR OBSERVER
PROPELLANT	ON/OFF SUM USEAGE MAXIMUM 5 ISP'S
PROXIMITY	ESTIMATE PROPELLANT, DELTA–V PROX OPS
PTRANSFER#	PROXIMITY TRANSFER ARRIVAL/DEPARTURE
RANDOM	RESET RANDOM MARS GRAM ATMOSPHERE
RENDEZVOUS#	RENDEZVOUS WITH TARGET (7 OPTIONS)
RKCONTROL	RK713 CONSTANTS CHANGE FOR SPECIAL USE
SIGHT	LINE OF SIGHT MAIN/TARGET/OBSERVER
SOFTLAND#	LAND SOFT EARTH/MOON/MARS
SPIRAL	SIMILAR TO IONENGINE
STATE	SAVE/RETRIEVE STATE
STOP	END THIS RUN
SUMMARY	PRINT PRESENT SUMMARY TABLE
SUNMOON	ADD GRAVITY, SOLAR PRESSURE IN DEQS
SUNSAIL#	SOLAR SAIL SPIRAL
SWAP	INTERCHANGE VEHICLES
SWITCH	SWITCH SYSTEM E TO M, M TO E
TARGET	TARGET OPERATIONS
TETHER	DEPLOY, TROLL, RECOVER TETHER BALL

IMP MENU CONTINUED

EVENT	ACTION
SCALE	SCALES SRM
THRUST	SETS DEFAULT,POLYNOMIALS, TABLES
TRACE	TRACE/TRACK SUN/STATION ACQUISITION
TRANSFER	HOHMANN TRANSFER
TSRM	SRM TEST DATA MASSAGING
TWOBODY	TESTS USING KEPLERIAN VALUES
UTILITY#	PRINT/PLOT FILES 8 OPTIONS
VELOCITY#	MISCELANEOUS VELOCITY CHANGES
VLIFTOFF#	SPECIAL LAUNCH PROFILE PAD TO ORBIT
WEIGHT	WEIGHT CHANGE OPTIONS
WIND	ADD WIND
WORK	USER PROGRAMMED EVENT
ZABORT	PROCESS LIFT OFF OUTPUT FOR ABORT DATA
ZACC#	ACCELERATION ALONG A TRACK (MAGLEV)
ZMBURN#	MULTIPLE LOW THRUST BURNS (SOLAR, ETC)
ZMISS	AIR TO GROUND MISSILE
ZMOTOR	TSL, TVAC, AEX, EFAC
ZTRANSFER#	MISCELLANEOUS TRANSFERS

COMPLEX EQUIVALENT TO A MAIN PROGRAM

NUMERICAL INTEGRATION

DIFFERENTIAL EQUATIONS OF MOTION

FEHLBERG RUNGE KUTTA 7/13

STEP SIZE AUTOMATED
NORMAL MAXIMUM 360 SECOND

ERROR
LESS THAN 40 METERS AFTER
100 ORBITS AT 200 NM
STEP SIZE ABOUT 200 SECONDS

RUNGE KUTTA 44
STEP SIZE 1 SEC
PRESET FOR SOME ROUTINES

EQUATIONS OF MOTION

$$A = G + T + D + L + G3 + S + C$$

G = BASE GRAVITY (OBLATE/SPHERICAL)

T = THRUST

D = ATMOSPHERIC DRAG

L = ATMOSPHERIC LIFT

G3 = 3RD BODY PERTURBING GRAVITY (SPHERICAL)

S = SOLAR PRESSURE

C = PARACHUTE DRAG

USER ORIENTATED

INPUT FILE

SEQUENTIAL ORDER

EVENT TO EVENT
SIMPLE TASK
COMPLEX TASK (EQUIVALENT TO A MAIN PROGRAM)

PROGRAM OUTPUT

VDT DISPLAY (WHAT'S UP DOC)

DEBUG (MOST VDT OUTPUT STORED FOR DEBUGGING)

PRINT (MAIN SIGNIFICANT POINTS) (SOME EVENTS HAVE DENSE PRINT OPTION)

SUMMARY PRINT, PLOT

OTHER (UTILITY, DENSE, PLOT FILES)

ALGORITHMS

(SELF STARTING, NO USER GUESSES)

MANEUVERING DELTA-V

FINITE BURN GUIDE

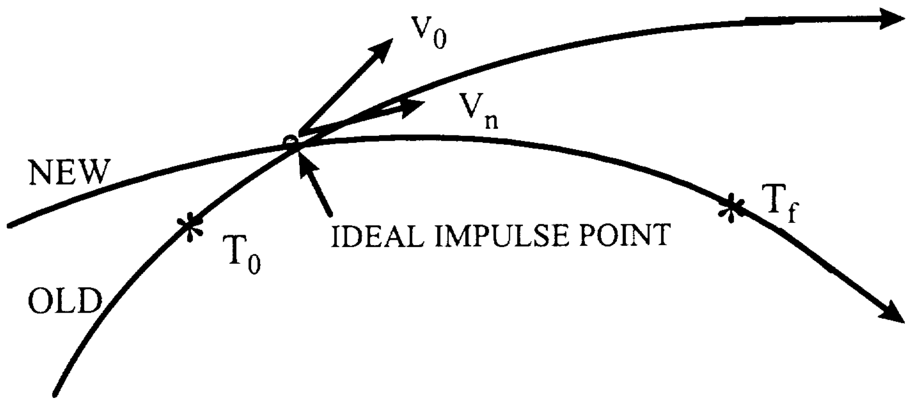
DELTA-V ALGORITHMS

NORMAL ORBIT TO ORBIT
HOHMAN, CIRCLE, PLANE, GENERAL

INTERCEPT (BURN–COAST) LAMBERT (SPECIAL)

CORRECTORS
J2 OBLATENESS (HOHMAN, CIRCLE)
GENERAL (ATMOSPHERE, 3RD BODY, SOLAR PRESSURE)

ORBIT TO ORBIT

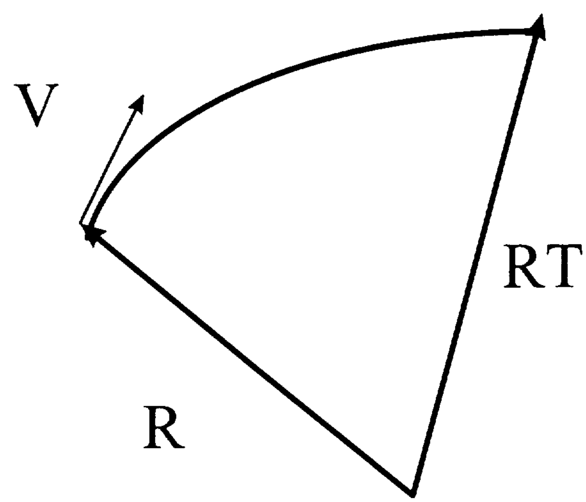


$$\Delta V = V_n - V_o$$

$$T_f = T_0 + T_b$$

LAMBERT ALGORITHM

DEYST'S METHOD
BATTIN'S UNIVERSAL VARIABLES
DAURO'S NORMALIZATION, CONVERGENCE



DETERMINE V AT R TO ARRIVE AT RT AT A FIXED TIME

FINITE BURN ALGORITHMS

NORMAL ORBIT TO ORBIT
5 CONTROLS, 5 CONSTRAINTS
USES BEGIN BURN TIME TO OPTIMIZE

INTERCEPT (BURN–COAST)
5 CONTROLS, 5 CONSTRAINTS
USES BEGIN BURN TIME TO OPTIMIZE

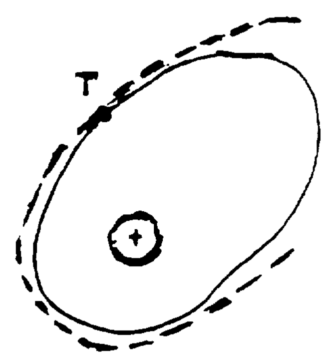
MATCH (STATE)
6 CONTROLS, 6 CONSTRAINTS

LIFTOFF
TO SUBORBIT/ORBIT
STAGE, STAGE + HALF, TWO STAGE, MULTI PHASE
GUESSES NEEDED

SOFT LAND
TOUCHDOWN AT ZERO RELATIVE VELOCITY W/WO HOVER

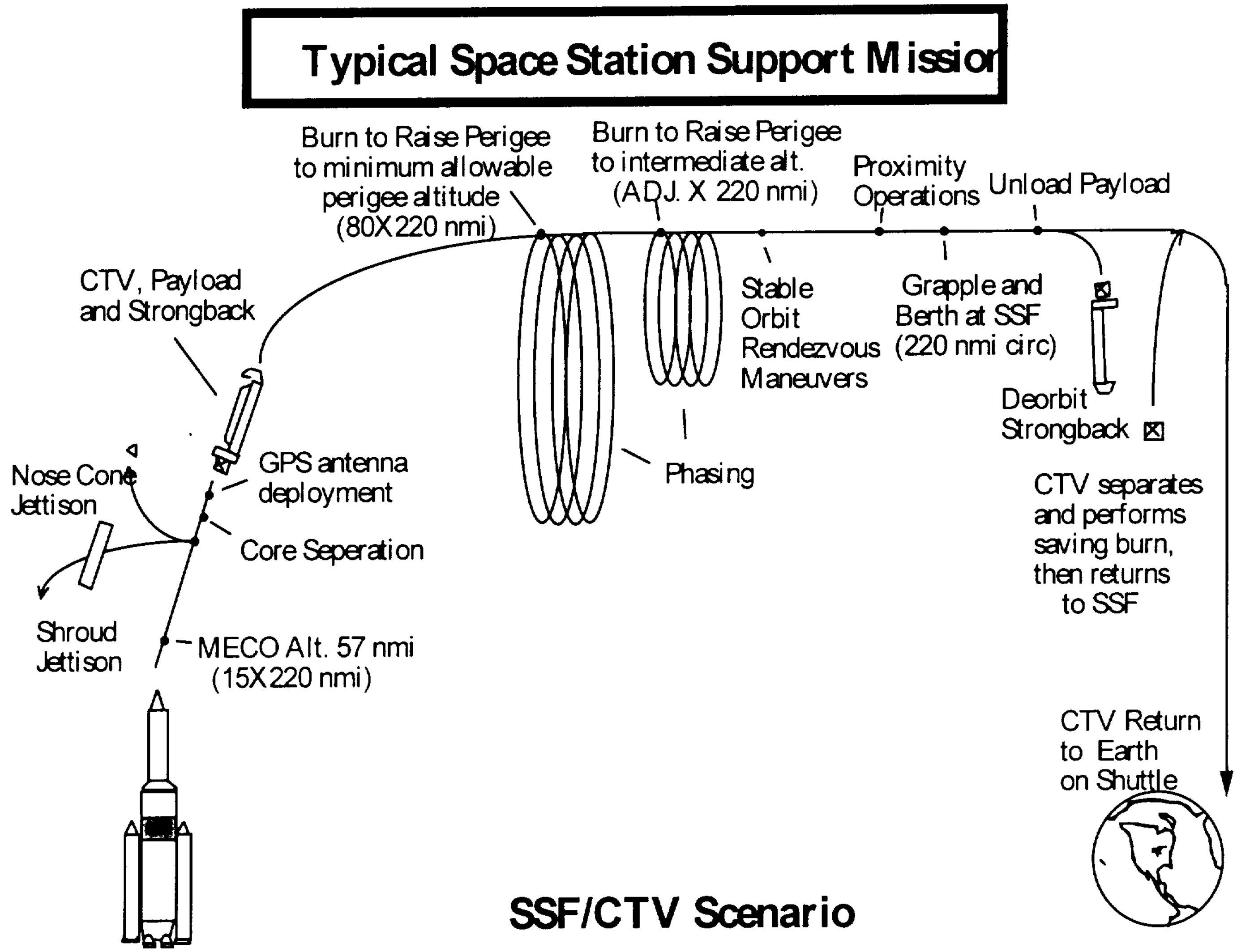
ORBIT TO ORBIT STAGE AND HALF
SPECIAL ALGORITHM (SINGLE BURN EVENT)

ORBITAL ELEMENTS



OSCULATING ORBIT
NEWTONIAN GRAVITY
KEPLERIAN ELEMENTS

ACTUAL ORBIT
OBLATE GRAVITY


Typical Space Station Support Missio
Burn to Raise Perigee to minimum allowable perigee altitude (80X220 nmi)
Burn to Raise Perigee to intermediate alt. (ADJ. X 220 nmi)
Proximity Operations
Unload Payload
CTV, Payload and Strongback
Stable Orbit Rendezvous Maneuvers
Grapple and Berth at SSF (220 nmi circ)
Deorbit Strongback
Phasing
GPS antenna deployment
Nose Cone Jettison
Core Seperation
CTV separates and performs saving burn, then returns to SSF
Shroud Jettison
MECO Alt. 57 nmi (15X220 nmi)
CTV Return to Earth on Shuttle
SSF/CTV Scenario

TYPICAL INPUT

```
COMMENT
         LIFTOFF: DEBOOST: SOFT:
               18 FEB 1993
        GENERAL DYNAMICS MODEL SSTO
               LV-107-20-201

        GLOW                                    1277 KLB
        DRY                         116.8
        ENGINES             33.90
        PROPELLANT ASCENT          1122.025
           ON ORBIT/DEBOOST          27.000

        PROPULSION 12 MODULES
        SEA LEVEL                  1600 KLBF @ 348 S
        VACUUM                     2000 KLBF @ 467 S
END
DATE                    3    1  2000.     6.
DEBUG              0011000010
PROP                         1 467.4      460.0
ATMOS                   1       200.      0.10
LIFTOFF                 00 0001 0.        0.          1277000.  333000.   460.0
 28.5         -80.5        .1            .05          89.          90.
 140.         7833.33057   .54922        28.5         191.4        2.
 84.          86.          4.49          90.          10.
 33.957068    -.271368     -1.412661      .013684     298.093510
 2000000.     1600000.     467.4
PROP                        12
COAST                   3
CIRCLE                       2
PROP                        12
COAST                   1       1.091
DEBOOST                 1    2 28.1       -115.4    60.
 1100.        1852.        121.92        -1.25        32.          500.
 0.
PROP                        12
ATMOS                   1       200.      0.10
SOFT                  000    02 0.        0.0       1.3000
DVTOTAL
PROP                        22
STOP
```

SAMPLE MAIN OUTPUT INTEGRATED MISSION PROGRAM

```
                    INTEGRATED MISSION PROGRAM
D'EQM INTEGRATION       By V. A. DAURO SR.                   PAGE    8

    CIRCLE                     0    2        0.0000
 BEGIN FINITE BURN, IDEAL TIME         15.45119 (SEC)
                    IDEAL DELTA-V       151.146 (M/S): NGD 1
 ANGLES WRT F SYSTEM AT IMPULSE TIME
 IMPULSIVE PITCH       -0.01536       YAW         0.00000 (DEGS)

    TIME       2.28334       0 DAYS    2 HOURS   17 MINS    0.012 SECS
                             CALENDAR DATE TUE  1/21/2014  14.2833 GMT

            *** STATE VARIABLES WRT  OBLATE   EARTH ***
                                       GEOCENTRIC  *  *  *  GEODETIC
    LATITUDE                             30.75525 (DEGS)     30.92464
    LONGITUDE                           112.36927 (DEGS)    146.71309 I
    RADIUS                              7128052.4 (M)
    VELOCITY                           7327.58303 (M/S)    7011.53184 R
    FLIGHT PATH ANGLE                     0.03467 (DEGS)      0.03624 R
    AZIMUTH                             133.71615 (DEGS)    136.23953 R
    ALTITUDE           404.92 (NM)        749.912 (KM)        755.525

            *** ORBIT PARAMETERS ***
                                      SMOOTH MEAN  *  *  * OSCULATING
    ASCEND NODE LON  -15.242 (D/HR)     -39.49205 (DEGS)     -5.14823 I
    INCLINATION                          51.59918 (DEGS)     51.60194
    ARGUMENT OF PERIGEE                 319.72474 (DEGS)    320.10588
    TRUE ANOMALY      0.05889 (D/S)     179.54507 (DEGS)    179.16394
    C3                                   -58.1571 (KM/S)**2  -58.1467
    PERIGEE            108.71 (NM)         201.32 (KM)         203.97
    APOGEE             404.93 (NM)         749.92 (KM)         749.94
    ECCENTRICITY                          0.04002             0.03982
    PERIOD                                1.56860 (HRS)       1.56902
    NODAL PERIOD                          1.56763 (HRS)
    SEMI MAJOR AXIS                     6853868.6 (M)       6855099.4

            *** SUMMARY ***
    PRESENT WEIGHT                      50449.104 (LBS)
    EVENT DELTA WEIGHT                      0.000 (LBS)
    ISP          466.000 (S)    THRUST   49500.00 (LBS)
    EVENT DELTA V                           0.000 (M/S)
    TOTAL DELTA V                         133.271 (M/S)
     OPTIONS:  MODE 000  IMS 00000  ATMOS 1  BURN 002
        AREA      55.42 (M**2) CD  2.1000 CL  0.0000
                VACUUM THRUST FACTOR 1.000
```

SAMPLE MAIN OUTPUT INTEGRATED MISSION PROGRAM

```
                          INTEGRATED MISSION PROGRAM
D'EQM INTEGRATION             By V. A. DAURO SR.                  PAGE    9

 END GUIDED BURN, ANGLES WRT F SYSTEM MOVING F(T)
   PZERO           PDOT          YZERO          YDOT          TBURN          TBZ
  (DEGS)          (D/S)         (DEGS)          (D/S)          (SEC)         (HRS)
-0.42419        0.05358        0.00034      -0.00004       15.45119       2.28334

     TIME       2.28763        0 DAYS    2 HOURS    17 MINS    15.463 SECS
                               CALENDAR DATE TUE  1/21/2014  14.2876 GMT

              *** STATE VARIABLES WRT  OBLATE   EARTH ***
                                      GEOCENTRIC   *   *   *  GEODETIC
     LATITUDE                           30.11760 (DEGS)       30.28491
     LONGITUDE                         113.07294 (DEGS)      147.48131 I
     RADIUS                            7128092.7 (M)
     VELOCITY                         7478.78030 (M/S)      7162.77150 R
     FLIGHT PATH ANGLE                   0.01499 (DEGS)        0.01565 R
     AZIMUTH                           134.10610 (DEGS)      136.61004 R
     ALTITUDE          404.94 (NM)       749.953 (KM)          755.357

              *** ORBIT PARAMETERS ***
                                     SMOOTH MEAN  *   *   * OSCULATING
     ASCEND NODE LON  -15.216 (D/HR)   -39.55724 (DEGS)       -5.14886 I
     INCLINATION                        51.59926 (DEGS)       51.60252
     ARGUMENT OF PERIGEE               140.18962 (DEGS)       90.46527
     TRUE ANOMALY     0.06011 (D/S)      0.00000 (DEGS)       49.72435
     C3                                 -55.9192 (KM/S)**2   -55.9074
     PERIGEE           404.94 (NM)        749.95 (KM)           749.09
     APOGEE            404.94 (NM)        749.95 (KM)           753.98
     ECCENTRICITY                        0.00000               0.00034
     PERIOD                              1.66370 (HRS)         1.66423
     NODAL PERIOD                        1.66269 (HRS)
     SEMI MAJOR AXIS                   7128162.1 (M)         7129673.6

              *** SUMMARY ***
     PRESENT WEIGHT                    48807.829 (LBS)
     EVENT DELTA WEIGHT                -1641.275 (LBS)
     ISP          466.000 (S)    THRUST  49500.00 (LBS)
     EVENT DELTA V                       151.146 (M/S)
     TOTAL DELTA V                       284.417 (M/S)
      OPTIONS:  MODE 000  IMS 00000  ATMOS 1  BURN 002
       ATT CON --  RCS SYSTEM :F 0.001 :ISP  225.000
         AREA      55.42 (M**2) CD  2.1000 CL  0.0000
                VACUUM THRUST FACTOR 1.000
```

* * * PLOTFILE STRUCTURE * * *

RECORD	PURPOSE	FORMAT (SET IN BLKDATA.FOR)	
1	TITLE,LABEL	FMT1 (5X,A,2X,A)	
2	NUMBER OF VARIABLES	FMT2 (I6)	(MAX 30)
3	NAME OF VARIABLES UP TO 3 RECORDS AS NEEDED	FMT3 (10A8)	(10 PER RECORD)
N	DATA POINTS STORED IN ORDER OF NAMES	FMT4 (5E16.7)	(5 PER RECORD)

* * * PLOTFILE EXAMPLE * * *

```
LOW THRUST IONENGINE TO GEO              LOW THRUST
 14
 E-HRS  LATC-D  LONG-D  ALT-Km VEL-M/SF.P.A.-D  AZMI-D  WGT-LBFORCE-LB  DV-M/S
VT-M/S APOG-KM  AINC-D TIME-HR
 0.8333333E-01  0.8954301E+01  0.1561756E+02  0.5000591E+03  0.8201840E+
 0.3514731E-02  0.6283433E+02  0.1999900E+04  0.2000000E+01  0.2942069E+
 0.2942069E+01  0.5105894E+03  0.2848788E+02  0.8333333E-01
 0.1666667E+00  0.1711326E+02  0.3204773E+02  0.5005263E+03  0.8203733E+
 0.2242148E-01  0.6687370E+02  0.1999800E+04  0.2000000E+01  0.2942216E+
 0.5884284E+01  0.5208804E+03  0.2848037E+02  0.1666667E+00
 0.2500000E+00  0.2361558E+02  0.4991272E+02  0.5020360E+03  0.8204256E+
 0.5532930E-01  0.7360882E+02  0.1999700E+04  0.2000000E+01  0.2942363E+
 0.8826647E+01  0.5308729E+03  0.2847150E+02  0.2500000E+00
 0.3333333E+00  0.2757933E+02  0.6933393E+02  0.5050800E+03  0.8203187E+
 0.9851632E-01  0.8264667E+02  0.1999600E+04  0.2000000E+01  0.2942510E+
 0.1176916E+02  0.5405346E+03  0.2846505E+02  0.3333333E+00
 0.4166667E+00  0.2833427E+02  0.8962707E+02  0.5099607E+03  0.8200430E+
 0.1464013E+00  0.9286403E+02  0.1999500E+04  0.2000000E+01  0.2942657E+
 0.1471181E+02  0.5498132E+03  0.2846375E+02  0.4166667E+00
 0.5000000E+00  0.2574668E+02  0.1095322E+03  0.5167357E+03  0.8195974E+
 0.1925465E+00  0.1025946E+03  0.1999400E+04  0.2000000E+01  0.2942804E+
 0.1765462E+02  0.5586126E+03  0.2846812E+02  0.5000000E+00
```

* * * USER MANUALS * * *

* * * NORMAL MOTOR* * *

THE NORMAL IMP THRUST MOTOR IS A VARIABLE TIME OF BURN, CONSTANT VACUUM THRUST, CONSTANT FLOW RATE, CONSTANT ISP DEVICE. DEFAULT VALUES ARE SET BY EACH EVENT INITIATING A NEW VEHICLE. THESE MAY BE CHANGED AS NEEDED.

* * * SPECIAL MOTORS * * *

* * * FIXED TIME OF BURN MOTORS #1

A SOLID/LIQUID MOTOR OF FIXED THRUST*SECONDS CAN BE SIMULATED FOR MOST EVENTS USING NGD=1. SET TBCON WITH THE THRUST EVENT. THEN IF TBCON .GE. INTERNAL TBURN, TBURN WILL BE SET TO TBCON. IF TBCON .LT. TBURN, TBURN IS SET TO 1.0001*TBURN. IN THIS CASE THE SOLUTION WILL NOT BE VALID FOR THE PRESENT FIXED TIME MOTOR IN THE FIXED TBURN MODE, TBZ IS ITERATED WITH THE CONTROLS OF NGD=1 TO SOLVE THE 2 POINT BOUNDARY VARIABLES PROBLEM.

* * * VARIABLE THRUST MOTORS

A VARIABLE THRUST LEVEL MOTOR MAY BE USED. USE THE THRUST SET EVENT TO TURN ON THE VARIABLE MOTOR FLAG, AND TO READ IN THE MOTOR PARAMETERS. IF POLYNOMIAL COEFFICIENTS ARE INPUT, THE DEGREE IS LIMITED TO 7 (8 COEFFICIENTS). PROPELLANT USEAGE IS CALCULATED INTERNALLY. AVERAGE ISP AND THRUST MAY BE ENTERED OR INTERNALLY SET.

MODELING A VARIABLE THRUST MOTOR BY A CONSTANT THRUST DEVICE CAN BE VERY DECEIVING. EVEN THOUGH THE SAME IMPULSE (LBF-SEC) ARE REACHED, THE RESULTS MAY NOT BE SATISFACTORY. IN GENERAL FOR MODERATE ORBIT MANUEVERING, GOOD RESULTS CAN BE OBTAINED. FOR EVENTS REQUIRING LARGE DELTA-V, SUCH AS LIFTOFF, A USEABLE RESULT MAY NOT OCCUR. SEE NEXT PAGE.

#1 THIS OPTION MAY BE USED FOR MOST SINGLE BURN EVENTS ($G). A SPECIAL GUIDE ALGORITHM IS AUTOMATICALLY ASSUMED. HOWEVER IN SOME CASES, CONVERGENCE MAY NOT OCCUR.

NEWTON'S LAWS

I A constant mass remains at rest or moves with constant velocity in a straight line unless acted upon by a force.

If m is constant, and **A** = zero, then **V** is constant.

II. A mass acted upon by a force moves so that the time rate of change of its linear momentum equals the force.

$$\mathbf{F} = d(m\mathbf{V})/dt$$

III. If two masses act on each other, the force exerted by the first on the second is equal in magnitude and opposite in direction to the force exerted by the second on the first.

$$\mathbf{F}12 = -\mathbf{F}21$$

IV. Any material body in the universe attracts any other body with a force which varies directly as the product of their masses and inversely as the square of the distance between them, and which acts along the line joining the bodies.

F = k*m1*m2/r**2

KEPLER'S WORLD

Johannes Kepler, in the early 1600's, after a study of tabulated observations by Tycho Brahe, formulated three laws pertaining to orbits. The law of equal area, the law of elliptical orbits, and the law of periods. These are the laws that Newton proved and extended. We will develop them using primarily vector, differential and integral calculus techniques.

In most real worlds, mass density varies with position, i.e with radius, latitude, and longitude. In a Keplerian world, we assume that it varies with radius only. Thus Newton's gravity law is used for the gravity force.

Newton also proved that if the density of the attracting mass was a function of its distance from the center of the mass only, then its effect was the same as if all the mass were located at the center.

VEHICLE STATE VARIABLES

R = (X, Y, Z) POSITION

V = (XD, YD, ZD) VELOCITY

H = **RxV** ANGULAR MOMENTUM

* * * IMP * * *

* * * LIBRATION SIMULATIONS * * *

LIBRATION SIMULATIONS CAN BE CHAOTIC. CALCULATIONS, EVEN DOUBLE PRECISION, ARE NOT STABLE FOR LONG TIMES. ROUNDOFF AND TRUNCATION DEGRADE ACCURACY. THE DOUBLE PRECISION SIMULATION IN IMP IS STABLE FOR AT LEAST TWO HALO ORBITS.

LIBRATION SIMULATIONS MAY BE

1) AN IDEAL RESTRICTED THREE-BODY SOLUTION USING CIRCULAR ORBITS, SPHERICAL GRAVITY, IDEALIZED CONSTANTS, (MU, RADII, ETC) AND EITHER

   A) CLOSED FORM EQUATIONS OR,

   B) NUMERICAL INTEGRATION OF EQUATIONS OF MOTION

2) A REAL WORLD SIMULATION USING ELLIPTICAL ORBITS, OBLATE GRAVITY, EPHEMERIDES, CURRENT CONSTANTS, (MU, RADII, ETC) AND EITHER

   A) APPROXIMATIONS USING PERTURBATION ANALYSIS OF THE IDEAL AND ASSUMED CLOSED FORM EQUATIONS

   B) NUMERICAL INTEGRATION OF EQUATIONS OF MOTION

IT IS EVIDENT THAT THE ABOVE ARE ALL USEFUL TOOLS IN STUDYING LIBRATION. 1A IS USED FOR FAST PRELIMINARY RESULTS AND AT MOST IS ONLY ADVISORY. 1B IS USED TO TEST THE IDEAL EQUATIONS AND THE RESULTS OF ROUND OFF AND TRUNCATION. 2A AGAIN GIVES FAST RESULTS AND IN GENERAL IS USED FOR PRELIMINARY PLANNING. 2B REQUIRES A LOT OF COMPUTER TIME AND IS NORMALLY USED LAST TO REFINE SOLUTIONS OBTAINED BY THE OTHER METHODS.

IMP USES NUMERICAL INTEGRATION OF THE EQUATIONS OF MOTION, AND CAN BE USED IN THE IDEAL (1B) OR PERTURBED (2B) MODES

KEATON'S EQUATIONS AS SHOWN IN REFERENCE 4, WERE ADAPTED AND USED IN IMP FOR LIBRATION STUDIES. REFERENCES 6, 7, AND 8 WERE ALSO USED IN PREPARING THE SIMULATION. THESE ARE ALL EXAMPLES OF THE CLOSED FORM IDEAL EQUATIONS.

BY DEFINITION, THE SUM OF FORCES AT A LIB POINT IS ZERO. EACH SYSTEM HAS 5 PLACES WERE THAT CAN OCCUR. THE FIRST THREE EARTH SUN ARE ON THE EARTH SUN LINE. L1 ON THE SUNNY SIDE, L2 ON THE DARK SIDE, AND L3 ON THE SIDE OF THE SUN AWAY FROM THE EARTH, L4 IS AHEAD OF THE EARTH IN ITS ORBIT, AND L5 TRAILS THE EARTH IN ITS ORBIT. L4(L5) WITH THE EARTH AND SUN FORMS AN EQUILATERAL TRIANGLE. IMP HAS SIMULATIONS FOR L1, L2, L4 AND L5. L3 IS NOT NORMALLY STUDIED.

IT IS KNOWN THAT THE LIB POINTS 1, AND 2 ARE UNSTABLE. HALO ORBITS ABOUT L1 OR L2 CAN BE MADE STABLE IN THE RESTRICTED 3 BODY CASE.

L4 AND L5 ARE STABLE AT WHAT ARE TERMED THE TROJAN POINTS. HALO ORBITS DO NOT EXIST ABOUT L4 AND L5.

HALO ORBITS ABOUT L1 AND L2 ARE USUALLY WHAT INVESTIGATORS STUDY. WE INTEND STATIONING FOR A PERIOD OF TIME, IF PERTURBATIONS ARE PRESENT, INSTABILITY MAY RESULT. IN FACT, TRUNCATION OR ROUND OFF EVENTUALLY DISTURB THE SIMULATION OF THE SYSTEM. THEREFORE IN TESTING, WE NEED TO EVALUATE THE IDEAL AS WELL AS THE REAL WORLD.

TESTS SHOW THAT IMP'S EQUATIONS, ARE ACCEPTABLE FOR AT LEAST ONE IDEAL EARTH/SUN, MOON/EARTH OR MARS/SUN HALO ORBIT. THAT IS, IN THE NON PERTURBED RESTRICTED 3 BODY MODE, THE PROGRAM WILL SIMULATE HALO ORBITS ABOUT E/S, E/M OR M/S LIBRATION POINTS L1 AND L2. AS A MEASURE OF THE SIMULATIONS RELIABILITY, A HALO ORBIT ABOUT THE EARTH/SUN L1 POINT, RESTRICTED 3 BODY SOLUTION, NEEDS LESS THAN 1 M/S DELTA V TO ACCOUNT FOR ROUND OFF AND TRUNCATION.

IDEAL STATIONING AT L4 AND L5 IS ALSO MODELED IN IMP, AND 90 DAYS AT THE EARTH-SUN L5 POINT REQUIRES NO CORRECTIVE DELTA-V.

AS PART OF THE INVESTIGATION, PARAMETERS FOR THE IDEAL AND PERTURBED SYSTEMS WERE CALCULATED. FOR THE THREE SYSTEMS MODELED IN IMP, THE DATA OBTAINED ARE GIVEN NEXT.

IDEAL LIBRATION SYSTEM S/E

GM1	M**3/S**2	0.398601200000E+15
GM2	M**3/S**2	0.132718490000E+21
MEAN R	M	149600000000.00
OMG SYS	DEG/DAY	0.98561057
	DEG/S	0.114075297544E-04
PERIOD	DAYS	365.25582281
OMG M1	DEG/SEC	0.417807419642E-02

LIBRATION DATA SYS S/E POINT 1 YEAR 2000 DATA

	YEAR MAX	MIN	DIF	P/C
RSYS KM	152099637.21	147100396.94	4999240.27	3.29
OMG-D/S	0.00001170	0.00001113	0.00000057	4.89
RLIB-KM	1516472.63	1466628.91	49843.72	3.29
VLIB-M/S	29737.631	29244.837	492.794	1.66
BC-KM	456.81	441.79	15.01	3.29

PRESENT PARAMETERS AT LIB POINT 1 JAN 2001

GRAVITY	PARTIAL	FORCE	
EARTH	-0.25268695E-12	0.18530256E-03	(M/S**2)
SUN	-0.85931048E-13	0.62573515E-02	(M/S**2)
CENTRIFUGAL		0.60720489E-02	(M/S**2)

DISTANCES

SYSTEM	147103226.55	(KM)
LP TO EARTH	1466657.12	(KM)
BC TO SUN	441.80	(KM)

IDEAL LIBRATION SYSTEM E/M

GM1	M**3/S**2	0.490200000000E+13
GM2	M**3/S**2	0.398601200000E+15
MEAN R	M	384388740.00
OMG SYS	DEG/DAY	13.19483247
	DEG/S	0.152717968433E-03
PERIOD	DAYS	27.28340816
OMG M1	DEG/SEC	0.152717968433E-03

LIBRATION DATA SYS E/M POINT 1 YEAR 2000 DATA

	YEAR MAX	MIN	DIF	P/C
RSYS KM	406383.70	357577.09	48806.60	12.01
OMG-D/S	0.00017021	0.00014049	0.00002972	17.46
RLIB-KM	61334.07	53967.86	7366.21	12.01
VLIB-M/S	889.048	833.953	55.094	6.20
BC-KM	4936.99	4344.06	592.93	12.01

PRESENT PARAMETERS AT LIB POINT 1 JAN 2001

GRAVITY	PARTIAL	FORCE	
MOON	-0.43837852E-10	0.13304665E-02	(M/S**2)
EARTH	-0.20020519E-10	0.34182968E-02	(M/S**2)
CENTRIFUGAL		0.20878302E-02	(M/S**2)

DISTANCES

SYSTEM	402178.77	(KM)
LP TO MOON	60699.44	(KM)
BC TO EARTH	4885.91	(KM)

IDEAL LIBRATION SYSTEM S/M

GM1	M**3/S**2	0.428283200000E+14
GM2	M**3/S**2	0.132718490000E+21
MEAN R	M	228937816800.00
OMG SYS	DEG/DAY	0.52062600
	DEG/S	0.602576392361E-05
PERIOD	DAYS	691.47525849
OMG M1	DEG/SEC	0.417269243059E-02

LIBRATION DATA SYS S/M POINT 1 YEAR 2000 DATA

	YEAR MAX	MIN	DIF	P/C
RSYS KM	249235293.24	246757440.45	2477852.80	0.99
OMG-D/S	0.00000695	0.00000530	0.00000165	23.72
RLIB-KM	1183438.05	1171672.52	11765.53	0.99
VLIB-M/S	25135.410	22966.447	2168.963	8.63
BC-KM	80.43	79.63	0.80	0.99

PRESENT PARAMETERS AT LIB POINT 1 JAN 2001

GRAVITY	PARTIAL	FORCE	
MARS	-0.53252782E-13	0.31197411E-04	(M/S**2)
SUN	-0.17920571E-13	0.22005186E-02	(M/S**2)
CENTRIFUGAL		0.27163268E-02	(M/S**2)

DISTANCES

SYSTEM	246757440.45	(KM)
LP TO MARS	1171672.52	(KM)
BC TO SUN	79.63	(KM)

* * * PERTURBED RESULTS * * *

STUDIES OF WHAT HAPPENS WHEN THE GRAVITY IS NON KEPLERIAN, OR ECCENTRIC ORBITS ARE USED, OR A FOURTH BODY IS PRESENT YIELD SOME INTERESTING RESULTS.

HALO ORBITS ABOUT THE E/S LIBRATION POINTS L1 AND L2 ARE FAIRLY STABLE. THEY ARE AFFECTED BY THE EARTH'S ORBIT, AND THE PRESENCE OF THE MOON, BUT THEY REQUIRE VERY LITTLE ENERGY TO REMAIN ON STATION.

HALO ORBITS ABOUT THE M/E LIBRATION POINTS, ARE AFFECTED BY THE MOON'S UNUSUAL ORBIT. CONSIDER MOON EVECTION. WHENEVER THE MOON'S VELOCITY IS DIRECTED TOWARD THE SUN, IT SPEEDS UP. IT SLOWS DOWN WHEN MOVING AWAY FROM THE SUN. THIS EFFECT IS ALSO FELT BY THE 3RD BODY IN ITS HALO ORBIT. THE SUN'S PRESENCE HAS AN EFFECT ON M/E HALO ORBITS ABOUT A LIBRATION POINT. STATIONING IS HOWEVER NOT AS DIFFICULT AS I ONCE THOUGHT. THE SUN'S EVECTION EFFECT IS EFFECTIVELY CANCELLED TO A GREAT DEGREE AND I NOW CONCLUDE THAT:

* HALO ORBITS ABOUT THE M/E LIBRATION POINTS (L1 OR L2) CAN BE USED AS TRANSPORTATION NODES. DELTA-V FOR STATIONING IS OF THE SAME MAGNITUDE AS THE EARTH SUN SYSTEM.

THE FOLLOWING EQUATIONS ARE MODELED IN IMP

IDEAL LIBRATION NODE/HALO SYSTEM
(SEE REFERENCES 4,5,6,7, AND 8)

```
B1   SMALLER BODY  WITH GRAVITY GM1
B2   LARGER   "               "   GM2
BC   BARYCENTER OF SYSTEM

L1   LIBRATION POINT    B2 >>>> L1 > B1
L2   LIBRATION POINT    B2 >>>> B1 > L2
```

DISTANCES

```
RS   B1 TO B2            SYSTEM
R1   L1 TO B1
R2   L1 TO B2
R3   B2 TO BC
R4   BC TO L1
```

OMEGA SYSTEM ROTATION RATE

```
OMEGA**2 = (GM1+GM2)/RS**3
```

CALCULATIONS

```
ALPHA = GM2/(GM1+GM2)
R3 =  (ONE-ALPHA)*RS
```

ITERATE R1 UNTIL SUM OF F = VERY SMALL

```
R2 = F(LIB POINT, R1, RS)
R4 = R2-RS

F1= GM1/R1**2           GRAVITY BODY1
F2=-GM2/R2**2           GRAVITY BODY2
F3= R4*OMEGA**2         CENTRIFUGAL FORCE AROUND BC

F1+F2+F3 = ZERO
```

THEN SET KEATON'S EQUATIONS REFERENCE 4

```
FSQ=(ONE-ALPHA)*(RS/R1)**3+ALPHA*(RS/R2)**3
F=SQRT(FSQ)
BSQ=ONE-FSQ/TWO+F*SQRT(2.25D0*FSQ-TWO)
B=SQRT(BSQ)
GAMH=(ONE+BSQ+TWO*FSQ)/(TWO*B)
BOMGS=B*OMEGA
FOMGS=F*OMEGA
SPER= 2*PI/OMEGA              SYSTEM PERIOD
HPER=SPER/B                   HALO PERIOD
```

COORDINATE SYSTEMS

THE INTEGRATION OF THE DEQS OF MOTION IS DONE WITH THE BODY B1 AS THE CENTER OF THE COORDINATE SYSTEM. LIBRATION NODES ARE SET IN THIS SYSTEM AND USED AS THE CENTER OF THE HALO COORDINATE SYSTEM (HX, HY, HZ).

HX POINTS FROM B1 TO B2
HY IS TO LEFT VIEWED FROM TOP IN ROTATION PLANE
HZ COMPLETES A RIGHT HAND SYSTEM

```
T0   INSERTION TIME            (ONLY AT BANG = ZERO, OR PI)
X0   INSERTION POSITION        ALWAYS POSITIVE
Y0   ALWAYS AT ZERO
Z0   OUT OF PLANE COMPONENT AT INSERTION ALWAYS POSITIVE
PHASE0  INSERTION PHASE  ZERO IF INSERT AT BANG = ZERO
                         PI   IF INSERT AT BANG = PI
T = POSITION TIME

THALO = T - T0
BANG=BOMGS*THALO+PHASE0
FANG=FOMGS*THALO+PHASE0
                              HALO POSITION
HX= X0*COS(BANG)
HY=-X0*GAMH*SIN(BANG)
HZ= Z0*COS(FANG)
                              HALO VELOCITY
HXD=-X0*BOMGS*SIN(BANG)
HYD=-X0*BOMGS*GAMH*COS(BANG)
HZD=-Z0*FOMGS*SIN(FANG)
```

* * * LIBRATION NOTES * * *

IT IS IMPORTANT THAT THE USER KNOW THE DIFFERENCE BETWEEN THE RESTRICTED THREE BODY SYSTEM (IDEAL) AND THE REAL WORLD. IN THE IDEAL SYSTEM, THERE ARE ONLY THREE BODIES PRESENT. THESE ARE IN IMP'S SIMULATION, DESIGNATED B1, B2, AND B3. THE MASSES ARE SUCH THAT

$$B3 \ll B1 < B2.$$

B1 AND B2 ROTATE ABOUT A COMMON BARYCENTER WITH A CONSTANT RATE AND AT A CONSTANT DISTANCE. THIS IMPLIES SPHERICAL GRAVITY FIELDS FOR BOTH B1 AND B2, AND THAT B3, AT THE LIBRATION POINT, HAS A MINIMAL INFLUENCE ON THE SYSTEM.

IN THE REAL WORLD, THERE ARE PERTURBATIONS.

IN THE SUN-EARTH SYSTEM, THE EARTH IS IN AN ELLIPTICAL ORBIT ABOUT THE BARYCENTER. ALTHOUGH THE DISTANCE TO THE SUN IS SUCH THAT THE SUN APPEARS TO HAVE A SPHERICAL GRAVITY FIELD, THE THIRD BODY IS CLOSE ENOUGH TO THE EARTH SO THAT IT IS SEES AN OBLATE EARTH GRAVITY FIELD. FURTHER, THERE IS A FOURTH BODY, THE MOON, CLOSE ENOUGH TO EFFECT THE SYSTEM. HOWEVER, FOR B3 AT THE EARTH-SUN LIBRATION POINTS, THE MOON IS FAR ENOUGH AWAY SO THAT ITS EFFECTS ARE MINIMAL.

FOR THE EARTH-MOON SYSTEM, THE SUN IS A FOURTH BODY THAT DOES AFFECT THE SYSTEM, AND MUST BE ACCOUNTED FOR IN A SIMULATION. ADDITIONALLY, THE MOONS ORBIT IS 3 TIME MORE ECCENTRIC THAN THE EARTH, AND THE MOON ORBITS THE EARTH ABOUT 13 TIMES A YEAR.

* * * STATIONING * * *

THE EVENTS LIBHCK, STOWCK, AND TROJCK ARE USED TO ESTIMATE DELTA V REQUIREMENTS FOR STATIONING. IN IMP, FOR L1 AND L2 THERE ARE TWO PREDICTOR-CORRECTOR ALGORITHMS THAT MAY BE USED. SEE ALSO REFERENCE 9 FOR COMPARISON.

* *

LIBHCK		00 NANO ERTOL	ANMCK	FPT	THRUST	ISP
	TYPICAL INPUT	18 .100	20.	5.		

NANO = NUMBER OF CHECK POINTS
ERTOL = ERROR ALLOWED KM
ANMCK = CHECK EVERY ANMCK DEG IN ANOMALY
FPT = PRINT EVERY ANMCK/FPT DEG

WHEN IMP ARRIVES AT A CHECK POINT, COMPUTES REQUIRED V TO MOVE TO NEXT CHECK POINT WITH AN ERROR LESS THAN ERTOL. COMPUTES DV TO ITS ARRIVAL VELOCITY, APPLIES. INTEGRATES TO NEXT CHECK POINT AND REPEATS.

* *

LIBHCK	NPD NDAY ERTOL	STPCK	DTF	THRUST	ISP

TYPICAL
NPD = 24 STEPS/DAY (HOURLY)
ERTOL = .050 KM
NUSTP = 1 EVERY STEP
DTF = 0.

NPD SETS THE NUMBER OF STEPS PER DAY. NDAY THE NUMBER OF DAYS DESIRED, AND NUSTP WHEN TO UPDATE. ie NUSTP =1 MEANS UPDATE EVERY STEP. UPDATE IS DONE BY PREDICTING AHEAD WHERE THE MSC WILL BE AND COMPARING IT TO WHERE IT SHOULD BE. IF DTF IS ENTERED IT IS USED AS HOW FAR AHEAD TO PREDICT, OTHER WISE, DTF = 3600/NPD. THE COMPARISON TOLERANCE IS ERTOL, AND IF THE ERROR IS MORE THAN THAT, A CORRECTION ALGORITHM IS INVOKED. BASICALLY A FIRST ORDER LAW INVOLVING ERROR AND ERROR RATE.

IF THE ERROR TOLERANCE IS MADE LARGE, DELTA-V FOR CORRECTION STARTS BECOMING EXPONENTIAL. THAT IS WHEN THE MSC MOVES AWAY FROM IT'S PROPER PLACE, PERTURBATION FORCES START INCREASING DRASTICALLY, AND DV INCREASES. REMEMBER IN ANY CORRECTION, THE DV USED WILL USUALLY NEED TO BE NEUTRALIZED ON REACHING THE DESIRED STATIONING POINT.

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