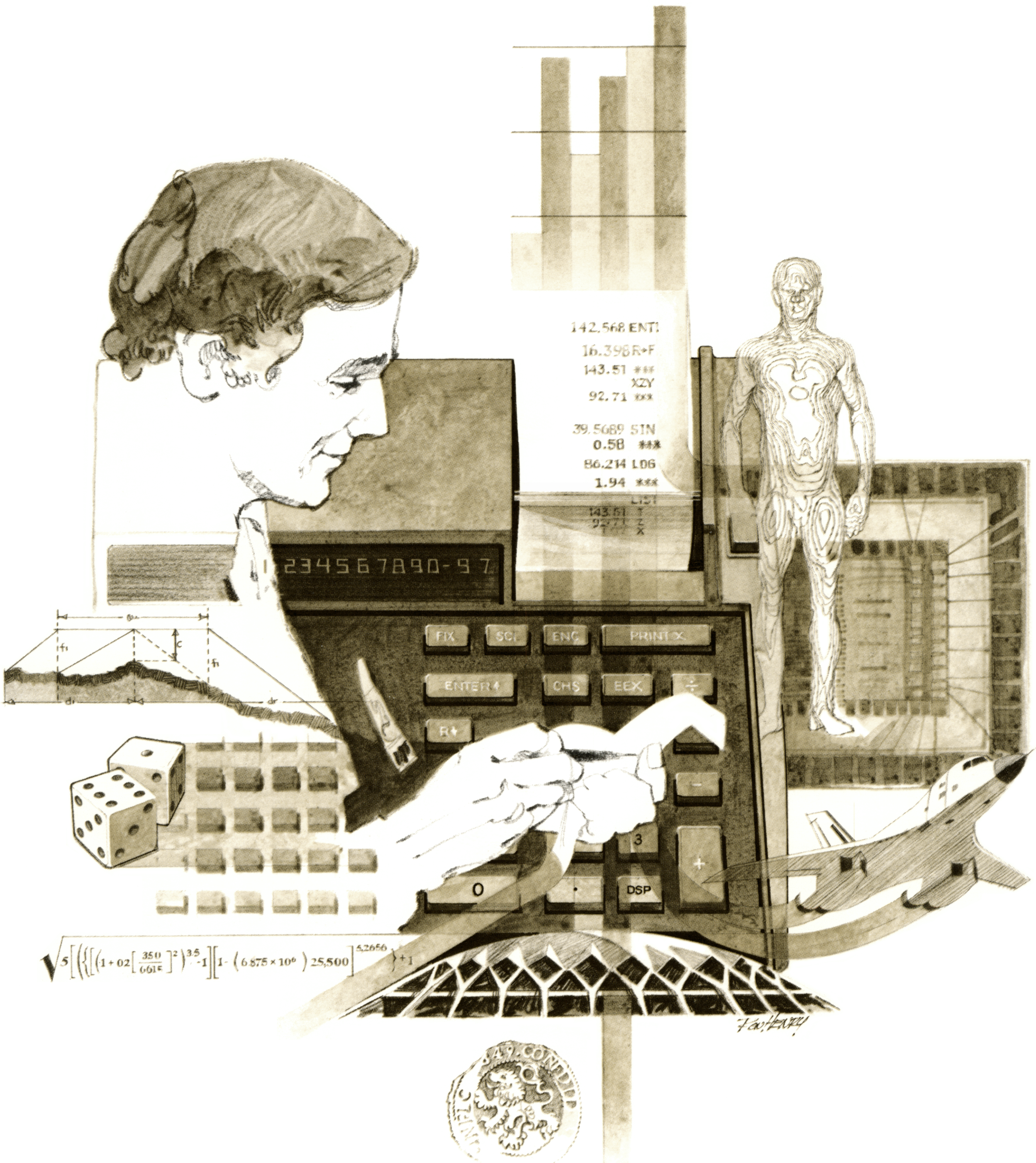
HEWLETT-PACKARD

HP-67/HP-97

Users' Library Solutions

Space Science



INTRODUCTION

In an effort to provide continued value to it's customers, Hewlett-Packard is introducing a unique service for the HP fully programmable calculator user. This service is designed to save you time and programming effort. As users are aware, Programmable Calculators are capable of delivering tremendous problem solving potential in terms of power and flexibility, but the real genie in the bottle is program solutions. HP's introduction of the first handheld programmable calculator in 1974 immediately led to a request for program **solutions** — hence the beginning of the HP-65 Users' Library. In order to save HP calculator customers time, users wrote their own programs and sent them to the Library for the benefit of other program users. In a short period of time over 5,000 programs were accepted and made available. This overwhelming response indicated the value of the program library and a Users' Library was then established for the HP-67/97 users.

To extend the value of the Users' Library, Hewlett-Packard is introducing a unique service—a service designed to save you time and money. The Users' Library has collected the best programs in the most popular categories from the HP-67/97 and HP-65 Libraries. These programs have been packaged into a series of low-cost books, resulting in substantial savings for our valued HP-67/97 users.

We feel this new software service will extend the capabilities of our programmable calculators and provide a great benefit to our HP-67/97 users.

A WORD ABOUT PROGRAM USAGE

Each program contained herein is reproduced on the standard forms used by the Users' Library. Magnetic cards are not included. The Program Description I page gives a basic description of the program. The Program Description II page provides a sample problem and the keystrokes used to solve it. The User Instructions page contains a description of the keystrokes used to solve problems in general and the options which are available to the user. The Program Listing I and Program Listing II pages list the program steps necessary to operate the calculator. The comments, listed next to the steps, describe the reason for a step or group of steps. Other pertinent information about data register contents, uses of labels and flags and the initial calculator status mode is also found on these pages. Following the directions in your HP-67 or HP-97 **Owners' Handbook and Programming Guide,** "Loading a Program" (page 134, HP-67; page 119, HP-97), key in the program from the Program Listing I and Program Listing II pages. A number at the top of the Program Listing indicates on which calculator the program was written (HP-67 or HP-97). If the calculator indicated differs from the calculator you will be using, consult Appendix E of your **Owner's Handbook** for the corresponding keycodes and keystrokes converting HP-67 to HP-97 keycodes and vice versa. No program conversion is necessary. The HP-67 and HP-97 are totally compatible, but some differences do occur in the keycodes used to represent some of the functions.

A program loaded into the HP-67 or HP-97 is not permanent—once the calculator is turned off, the program will not be retained. You can, however, permanently save any program by recording it on a blank magnetic card, several of which were provided in the Standard Pac that was shipped with your calculator. Consult your **Owner's Handbook** for full instructions. A few points to remember:

> The Set Status section indicates the status of flags, angular mode, and display setting. After keying in your program, review the status section and set the conditions as indicated before using or permanently recording the program.
>
> REMEMBER! To save the program permanently, **clip** the corners of the magnetic card once you have recorded the program. This simple step will protect the magnetic card and keep the program from being inadvertently erased.

As a part of HP's continuing effort to provide value to our customers, we hope you will enjoy our newest concept.

TABLE OF CONTENTS

Program Description I

Program Title Precession of Right Ascension and Declination

Contributor's Name Rex H Shudde

Address 27105 Arriba Way

City Carmel **State** CA **Zip Code** 93921

Program Description, Equations, Variables Let α_0, δ_0 and α, δ denote the right ascension and declination for the initial epoch t_0 and the final epoch t, respectively. Then,

$$\begin{pmatrix} \cos\delta\cos(\alpha - z) \\ \cos\delta\sin(\alpha - z) \\ \sin\delta \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} \cos\delta_0\cos(\alpha_0+\zeta_0) \\ \cos\delta_0\sin(\alpha_0+\zeta_0) \\ \sin\delta_0 \end{pmatrix}$$

where

$$\zeta_0 = (2304.''250 + 1.''396 T_0)T + 0.''302 T^2 + 0.018 T^2,$$

$$z = \zeta_0 + 0.''791 T^2,$$

$$\theta = (2004.''682 - 0.853 T_0)T - 0.''426 T^2 - 0.''042 T^3,$$

and

$$t_0 = 1900.0 + 100 T_0, \quad \text{and } t = 1900.0 + 100(T_0 + T).$$

T_0 and T are measured in tropical centuries.

Operating Limits and Warnings

α_0 and α are measured in hours, minutes, and seconds

Note: The display is initialized by DSP 4, but the calculations are accurate to DSP 6 if desired.

Program Description II

Sketch(es)

Sample Problem(s)

1. Calculate the mean coordinates of ε Octantis for 1950.0 given that (α_0, δ_0) for 1900.0 are 22h 08m 50s and −80°56'15"

2. Using the initial 1900.0 data above, calculate the mean coordinates of ε Octantis for 1 Nov. 1975 (Julian Day Number = 2442718

Solution(s)

1. 1900 [f][A] 0.0000 = T_0 ; 1950.0 [f][B] 0.5000 = T ;
22.0850 [↑] −80.5615 [E] 22h14m32s = α [R/S] −80°41'23"

2. (1900 [f][A] 0.0000 = T_0. This need not be reentered);
2442718 [B] 0.7563 = T ; 22.0850 [↑] −80.5615 [E]
22h17m23s = α [R/S] −80°33'37"

Reference(s)

1. P. Escobal, "Methods of Astrodynamics", Wiley 1968
2. "Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac", Her Majesty's Stationery Office, London, 1961.

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program card				
2	Enter the initial epoch. Either				
a	Julian Day Number, or	JD #	A		T_0
b	Besselian Year (and fraction of year)	YYYY.FF	f	A	T_0
3	After step 2, enter the final epoch. Either				
a	Julian Day Number, or	JD #	B		T
b	Besselian Year (and fraction)	YYYY.FF	f	B	T
4a	Key in α_0	HH.MMSS	↑		
b	Key in δ_0	±DD.MMSS			
c	Compute α		E		HH.MMSS
d	Compute δ		R/S		±DD.MMSS
5	Repeat from either Step 2 or Step 3 as desired.				

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	f LBL A	31 25 11	Initial Epoch JD#
	f GSB 9	31 22 09	
	STO 0	33 00	
	R/S	84	
	f LBL B	31 25 12	Final Epoch JD#
	f GSB 9	31 22 09	
	f LBL 7	31 25 07	Compute Precession Angles
	RCL 0	34 00	
	−	51	
010	STO 1	33 01	
	1	01	
	8	08	
	x	71	
	3	03	
	0	00	
	2	02	
	+	61	
	RCL 1	34 01	
	x	71	
020	1	01	
	3	03	
	9	09	
	6	06	
	RCL 0	34 00	
	x	71	
	+	61	
	2	02	
	3	03	
	0	00	
030	4	04	
	2	02	
	5	05	
	0	00	
	+	61	
	RCL 1	34 01	
	x	71	
	3	03	
	6	06	
	EEX	43	
040	5	05	
	STO 5	33 05	
	÷	81	
	STO 2	33 02	Store ζ_0
	RCL 1	34 01	
	f x^2	32 54	
	7	07	
	9	09	
	1	01	
	x	71	
050	RCL 5	34 05	
	÷	81	
	+	61	
	STO 3	33 03	Store z
	4	04	
	2	02	
	CHS	42	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	RCL 1	34 01	
	x	71	
	4	04	
060	2	02	
	6	06	
	−	51	
	RCL 1	34 01	
	x	71	
	8	08	
	5	05	
	3	03	
	RCL 0	34 00	
	x	71	
070	−	51	
	2	02	
	0	00	
	0	00	
	4	04	
	6	06	
	8	08	
	2	02	
	+	61	
	RCL 1	34 01	
080	x	71	
	RCL 5	34 05	
	÷	81	
	STO 4	33 04	Store θ
	RCL 1	34 01	
	R/S	84	
	f LBL E	31 25 15	Input initial α, δ
	f H←	31 74	
	h x⇄y	35 52	
	f H←	31 74	
090	1	01	
	5	05	
	x	71	
	RCL 2	34 02	
	+	61	
	h x⇄y	35 52	
	1	01	
	f R←	31 72	
	h R↓	35 53	
	h x⇄y	35 52	
100	h R↑	35 54	
	f R←	31 72	
	h x⇄y	35 52	
	STO 6	33 06	y-coord
	h R↓	35 53	
	h x⇄y	35 52	
	g →P	32 72	
	h x⇄y	35 52	
	RCL 4	34 04	
	−	51	
110	h x⇄y	35 52	
	f R←	31 72	
	STO 7	33 07	z-coord

REGISTERS

0	1	2	3	4	5	6	7	8	9
T_0	T	ζ_0	z	θ	36E5	y-coord	z-coord		

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
	h RI	35 53	
	RCL 6	34 06	
	h X⇄Y	35 52	
	g →P	32 72	
	h X⇄Y	35 52	
	RCL 3	34 03	
	+	61	
120	3	03	
	6	06	
	0	00	
	÷	81	
	1	01	
	+	61	
	g FRAC	32 83	
	2	02	
	4	04	
	×	71	
130	g →HMS	32 74	Display new α
	R/S	84	
	RCL 7	34 07	Display new δ
	g SIN⁻¹	32 62	
	g →HMS	32 74	
	R/S	84	
	f LBL 9	31 25 09	Transform Julian Day Number to Tropical Centuries from JD1900.0
	2	02	
	4	04	
	1	01	
140	5	05	
	0	00	
	2	02	
	0	00	
	.	83	
	3	03	
	1	01	
	3	03	
	−	51	
	3	03	
150	6	06	
	5	05	
	2	02	
	4	04	
	.	83	
	2	02	
	2	02	
	÷	81	
	h RTN	35 22	
	g LBL a	32 25 11	Initial Epoch Besselian
160	f GSB 8	31 22 08	
	STO 0	33 00	
	R/S	84	
	g LBL b	32 25 12	Final Epoch Besselian
	f GSB 8	31 22 08	
	GTO 7	22 07	
	f LBL 8	31 25 08	
	1	01	
	9	09	
	0	00	Transform Besselian Epoch to Tropical Centuries from 1900.0
170	0	00	
	−	51	
	1	01	
	0	00	
	0	00	
	÷	81	
	h RTN	35 22	
		84	
180			
190			
200			
210			
220			

LABELS

A ✓	B ✓	C	D	E ✓
a ✓	b ✓	c	d	e
0	1	2	3	4
5	6	7 ✓	8 ✓	9 ✓

FLAGS: 0, 1, 2, 3

SET STATUS

FLAGS (ON / OFF)	TRIG	DISP
0 ☐ ☐	DEG ☑	FIX ☑
1 ☐ ☐	GRAD ☐	SCI ☐
2 ☐ ☐	RAD ☐	ENG ☐
3 ☐ ☐		n 4

Program Description I

Program Title Local Sidereal Time & Obliquity from Local Standard Time

Contributor's Name Rex H Shudde

Address 27105 Arriba Way

City Carmel **State** CA **Zip Code** 93921

Program Description, Equations, Variables

1. Compute the number of days from 0 Jan 1900 using an unpublished routine by Richard C. Singleton: $I = 12Y + M - 3$, then

$$JD_{1900} = \left\lfloor \frac{2\,\mathrm{mod}(I,12) + 7 + 365I}{12} \right\rfloor + D + \left\lfloor \frac{I}{48} \right\rfloor - \left\lfloor \frac{I}{1200} \right\rfloor + \left\lfloor \frac{I}{4800} \right\rfloor - 693901$$

where Y = year, M = month, D = day, $\lfloor arg \rfloor$ is the integer part of arg.

2. Compute T, the number of Julian centuries from Greenwich Mean Noon, Jan 0, 1900: $T = (t_G/24 + JD_{1900} - 0.5)/36525$, where the Greenwich mean time t_G = (local standard time) + (time-zone), + for West, − for East.

3. Compute R_G, the Greenwich mean sidereal time:

$$R_G = (23925^s.84 + 8640184^s.54\,T + 0^s.09\,T^2)/3600 + t_G \ (\mathrm{mod}\ 24) \text{ hours.}$$

4. Compute LST, the local sidereal time:

$$LST = R_G - \lambda/15$$

where λ is the geographical longitude in degrees (+ for West, − for East).

5. Compute ϵ, the mean obliquity of the ecliptic:

$$\epsilon = (84428260 - 46845T - 5.9T^2)/3600000 \text{ degrees}$$

Operating Limits and Warnings

Negative dates (B.C.) are not properly handled by this calendar routine. Julian dates must be converted to Gregorian dates prior to usage.

Program Description II

Sketch(es)

Sample Problem(s)

OBSERVATIONS are to be made from an observatory of 121°57' West longitude at 2000, 2015, 2030, and 2045 hrs. local standard time (time zone 8). Compute the local sidereal time for these hours for 14 October 1974. Also compute the obliquity for this date.

	Local Standard Time	Local Sidereal Time
1.	2000	21h 25m 25s
2.	2015	21h 40m 28s
3.	2030	21h 55m 30s
4.	2045	22h 10m 33s

Solution(s) Keystrokes: Outputs:

10.141974 [A] 121.57 [B] 8 [C]

Keystrokes		Outputs
20.00 [E]	→	21.2525
20.15 [E]	→	21.4028
20.30 [E]	→	21.5530
20.45 [E]	→	22.1033
[R/S]	→	22.2633

Reference(s)

"Explanatory Supplement to the Astronomical Ephemeris & Nautical Almanac," Her Majesty's Stationery Office, London 1961.

User Instructions

Local Sidereal Time & Obliquity from Local Std. Time				
Date MM.DDYYYY	Longitude DDD.MMSS + West − East	Time Zone + West − East		Local Std Time HH.MMSS Compute Local Sider. Time [R/S] ε

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter Program			
2	Enter the date in the form MM.DDYYYY where MM is the 2-digit month, DD is the 2-digit day & YYYY is the 4-digit Gregorian Year (Note that a decimal point must separate MM from DD)	MM.DDYYYY	A	JD$_{1900}$
	In any order, enter:			
3	Longitude in DDD.MMSS (+ for West, − for East)	DDD.MMSS	B	—
4	Time zone as an integer digit(s) (+ for West, − for East)	T. Z.	C	—
	Then:			
5a	Enter the Local Standard Time in HH.MMSS & compute Local Sidereal Time in HH.MMSS	Local Standard Time	E	Local Sidereal Time
b	Compute obliquity of ecliptic		R/S	DD.MMSS
6	Repeat step 5 or steps 3 through 5 for subsequent computations on the same date			
7	For a new date, repeat from Step 2.			

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	f LBL A	31 25 11	Unpack date and compute JD_{1900}
	↑	41	
	f INT	31 83	
	STO 7	33 07	
	—	51	
	EEX	43	
	2	02	
	×	71	
	↑	41	
010	f INT	31 83	
	STO 8	33 08	
	—	51	
	EEX	43	
	4	04	
	×	71	
	1	01	
	2	02	
	STO 9	33 09	
	×	71	
020	RCL 7	34 07	
	+	61	
	3	03	
	—	51	
	↑	41	
	STO 6	33 06	
	RCL 9	34 09	
	÷	81	
	f INT	31 83	
	RCL 9	34 09	
030	×	71	
	—	51	
	↑	41	
	+	61	
	7	07	
	+	61	
	3	03	
	6	06	
	5	05	
	RCL 6	34 06	
040	×	71	
	+	61	
	RCL 9	34 09	
	÷	81	
	f INT	31 83	
	RCL 8	34 08	
	+	61	
	RCL 6	34 06	
	4	04	
	8	08	
050	÷	81	
	f INT	31 83	
	+	61	
	h LST x	35 82	
	2	02	
	5	05	
	÷	81	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	f INT	31 83	
	—	51	
	h LST x	35 82	
060	4	04	
	÷	81	
	f INT	31 83	
	+	61	
	6	06	
	9	09	
	3	03	
	9	09	
	0	00	
	1	01	
070	—	51	
	STO 1	33 01	
	R/S	84	
	f LBL 0	31 25 00	Error routine
	0	00	
	÷	81	
	GTO 0	22 00	
	f LBL B	31 25 12	Convert longitude to time
	↑	41	
	f H←	31 74	
080	1	01	
	5	05	
	÷	81	
	STO 3	33 03	
	h R↓	35 53	
	R/S	84	
	GTO 0	22 00	
	f LBL C	31 25 13	Store time zone
	STO 5	33 05	
	R/S	84	
090	GTO 0	22 00	
	f LBL E	31 25 15	Store Local Standard time and compute t_G
	f H←	31 74	
	RCL 5	34 05	
	+	61	
	STO A	33 11	
	2	02	
	4	04	
	÷	81	
	RCL 1	34 01	
100	+	61	
	.	83	
	5	05	
	—	51	Compute and store T
	3	03	
	6	06	
	5	05	
	2	02	
	5	05	
	÷	81	
110	STO 0	33 00	- - - - - - - -
	.	83	
	0	00	

REGISTERS

0	1	2	3	4	5	6	7	8	9
T	JD_{1900}	E	Longitude in hours	ST	T.Z.	I	MM	DD	12

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
GMT t_G					

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
	9	09	
	x	71	
	8	08	
	6	06	
	4	04	
	0	00	
	1	01	
120	8	08	
	4	04	
	.	83	
	5	05	
	4	04	
	+	61	
	RCL 0	34 00	
	x	71	
	2	02	Compute
	3	03	
130	9	09	R_G
	2	02	
	5	05	
	.	83	
	8	08	
	4	04	
	+	61	
	3	03	
	6	06	
	0	00	
140	0	00	
	÷	81	
	RCL A	34 11	
	+	61	
	RCL 3	34 03	
	−	51	
	2	02	Compute and
	4	04	
	÷	81	display
	g FRAC	32 83	
150	1	01	Local
	+	61	
	g FRAC	32 83	Sidereal
	2	02	Time
	4	04	
	x	71	
	g →HMS	32 74	
	R/S	84	
	5	05	
	.	83	
160	9	09	Compute
	CHS	42	
	RCL 0	34 00	and
	x	71	
	4	04	display
	6	06	
	8	08	
	4	04	obliquity
	5	05	
	−	51	
170	RCL 0	34 00	
	x	71	
	8	08	
	4	04	
	4	04	
	2	02	
	8	08	
	2	02	
	6	06	
	0	00	
180	+	61	
	3	03	
	6	06	
	EEX	43	
	5	05	
	÷	81	
	STO 2	33 02	
	g →HMS	32 74	
	R/S	84	
		84	
190			
200			
210			
220			

LABELS

A ✓	B ✓	C ✓	D	E ✓
a	b	c	d	e
0 ✓	1	2	3	4
5	6	7	8	9

FLAGS: 0, 1, 2, 3

SET STATUS

FLAGS (ON / OFF)	TRIG	DISP
0 ☐ ☐	DEG ☑	FIX ☑
1 ☐ ☐	GRAD ☐	SCI ☐
2 ☐ ☐	RAD ☐	ENG ☐
3 ☐ ☐		n 4

Program Description I

Program Title SPACE SCIENCE AND TECHNOLOGY NO (1), HORIZON DISTANCE, GREAT CIRCLE DISTANCE

Contributor's Name ROBERT C. WYCKOFF

Address 9517 CORDERO AVE.

City TUJUNGA **State** CALIFORNIA **Zip Code** 91042

Program Description, Equations, Variables As a function of altitude, the slant distance to the horizon of a spherical body of radius R is given by (1) $L = (2Rh + h^2)^{1/2}$. The sub-tended angle Ø is given by (2) $\tan Ø/2 = R/L$, and the central angle between the horizon and the sub-altitude point is (3) $90 - Ø/2 = \theta$

The smaller great circle distance between two points on the sphere is given by the Law of Cosines of a Spherical Triangle, where the central angle is θ. (4) $\cos\theta = (\sin LatA)(\sin LatB) + \cos(LongA).(\cos LongB)(\cos(LongA - LongB))$

where Lat A, Lat B, Long A, and Long B are the usual geographical coordinates of the two points on the sphere. The distance over the surface along a great circle is given by (5) $S = R\theta$. The larger great circle central angle is given by $2\pi - \theta$ where θ is in radians. The greater great circle distance again follows from the Rθ relation.

Southern latitudes are entered as (-) and Northern, as (+). Longitudes are entered as Eastern from 0 to 360 degrees and are all (+). In addition, to provide for common usage, both latitudes and longitudes are entered in degrees, minutes, and seconds. The radius of the sphere is entered in km, but the values of L and S are given both in km and nautical miles. There appears to be no prohibition against either the latitude or longitude being 0, ±90, 0 or 180/360 degrees respectively.

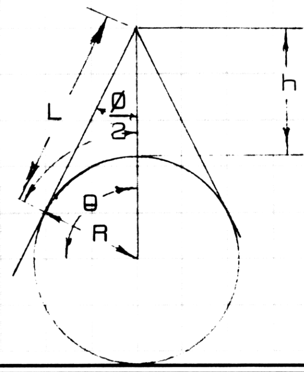
Values of mean radii of various astronomical bodies are loaded from the program card into the secondary register, with the value for the moon being in R_{10}, the first or closest planet Mercury, in R_{11}, Venus, in R_{12}, earth in R_{13} etc.

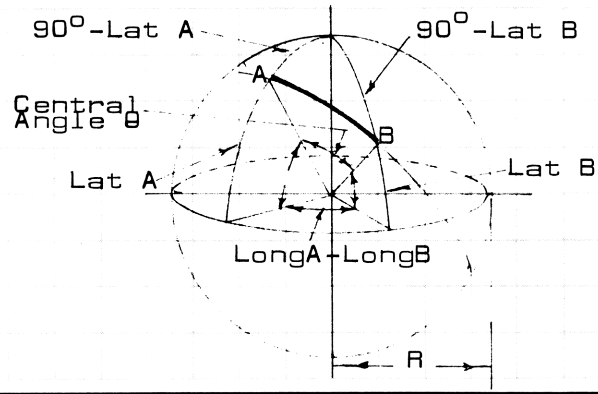
Operating Limits and Warnings

Remember that when the second side of the card is loaded into the HP-67, the above constants are loaded first into the primary register. These then must be transfered to the secondary register. This is necessitated by the program being loaded on the first side of the card. Additional operating instructions are given on page 3. Provision is made for re-iterative operation.

Program Description II

Sketch(es)





Sample Problem(s) PROBLEM NO I: A satellite is orbiting the planet MARS in a circular, concentric orbit of constant altitude of 850 km. What is (a) the distance to the satellite from a fixed ground observation site as the satellite first appears above the horizon, (b) the total angle subtended by the diameter of MARS as seen from the satellite, (c) the angle at the center of MARS subtended by the sub-satellite point and the ground site, (d) the distance over the surface of MARS from the sub-satellite point and the ground site?

PROBLEM NO II: The Soviets announced the VENUS 9 and 10 landing coordinates of the descent capsules as 33°N, 293°E and 15°N, 295° East respectively. What is (a) the smaller angle at the center of VENUS between these two landing locations, (b) the smaller great circle distance between them, and (c), the larger great circle distance?

SOLUTION NO. I: Load both sides of the program card. Side 1 contains the program and side 2, the radii in km of the moon and planets in increasing distance from the sun, with the value for the moon in R_{10}, MERCURY in R_{11}, VENUS in R_{12}, EARTH in R_{13}, etc. After loading side 2, IMMEDIATELY interchange primary and secondary registers, since the presence of the program on side 1 "fooled" the HP-67 into believing

Solution(s) side 1 was empty. Next enter 14 in display, press h STO I, RCL(i) and see in the display the contents of the storage register R_{14}, or the radius of MARS in km as 3387.55. Store this value in primary register R_0. Load 1.852 in R_1, and 850 in R_2. Press Key A for solution of (a) and observe 2545.85 km. Press R/S for solution in n. miles, which is 1374.65. Press R/S again to prepare for Key B operation. You again have 2545.85 in the display. Press Key B for solution (b) giving 106.15°. Key C gives (c) as 36.93°. Key D gives the distance over the surface (d) as 2183.21 km while R/S gives this distance in n. miles as 1178.84.

See page 2a for the solution of PROBLEM NO. II.

Reference(s)

SPACE SCIENCE AND TECHNOLOGY NO. (1) HORIZON DISTANCE, GREAT CIRCLE DISTANCE.

SOLUTION NO. II : Place 12 in display. Press h STO I, RCL (i) and observe 6052 km as the radius of VENUS. Store this value in R_0. Place 33 in R_4, 293 in R_5, 15 in R_6, and 295 in R_7. (If these were not given in even degrees, they MUST BE ENTERED AS DEGREES, MINUTES, AND SECONDS).

Press Key E for (a) and observe 18.09°. Press R/S and observe 1910.93 km as the solution for (b), with R/S again giving the solution in nautical miles as 1031.82. Press f Key A and observe 36,114.90 km as the solution for (c). R/S gives this greater distance in n. miles as 19,500.49

CAUTION: It is not advised to recall the constants from the secondary register by interchanging them with the primary register, since the primary registers are no longer filled with zeros, and the particular sequence of operations chosen can easily destroy certain values of the planetary radii originally placed in the secondary register.

Of course, the radius of ANY body can be stored in R_0 for application to this program. Some additional planetary satellite radii, as mentioned on page 3, follow:

Jupiter: Io = 1670 km, Europa = 1460 km, Ganymede = 2550 km, Callisto = 2360 km

Saturn: Titan = 2440 km

Neptune: Triton = 2000 km

The remaining planetary satellites have much smaller radii, and have masses so small they probably do not have even roughly a spherical shape (through gravitational effects).

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program, Side 1 first, side 2 last			
2	Interchange primary and secondary reg.			
3	Recall desired planetary radius through	h STO I, RCL	(i)	
4.	Load R_0 with above value. Load 1.852 in			
	R_1, the altitude h in R_2, delta h			
	in R_3(for re-iterative operation)			
	Lat. A in R_4, Long A in R_5, Lat. B in			
	R_6, and Long. B in R_7, all in degrees,			
	minutes, and seconds, NEVER DEC. DEGREES.			
5.	Key A computes L in km		A	L in km
6	R/S computes L in n. miles		R/S	L in n. m.
7	R/S for initializing Key B operation		R/S	L in km
8	Key B computes subtended total angle		B	Ø in dec °
9	Key C computes central angle		C	θ in dec. °
10	Key D computes distance S in km		D	S in km
11	R/S computes S in n. miles		R/S	S in n. m.
12	FOR RE-ITERATIVE OPERATION , press R/S	again.	R/S	new h
	(New h = h + delta h appears in display)			
	R/S again re-iterates Key A through D			
	Store proper value of planetary radius in R_0			
	through h-sto-i			
13	Key E computes central angle between points		E	θ smaller
	A and B for smaller great circle distance			
14	R/S computes smaller great circle distance in km		R/S	S in km (S)
15	R/S competes above in n. miles		R/S	S in n.m.
16	f Key A computes S larger in km		F-A	S in km (L)
17	R/S computes larger S in n. miles		R/S	S in n.m. (L)

Secondary registers are loaded as follows:

R_{10} =	Radius of	Moon	=	1739.29	km
R_{11} =	"	" Mercury	=	2420.99	km
R_{12} =	"	" Venus	=	6052	km
R_{13} =	"	" Earth	=	6371.017	km
R_{14} =	"	" Mars	=	3387.55	km
R_{15} =	"	" Jupiter	=	71375	km
R_{16} =	"	" Saturn	=	60400	km
R_{17} =	"	" Uranus	=	23500	km
R_{18} =	"	" Neptune	=	25000	km
R_{19} =	"	" Pluto	=	2930	km

Notice that the radii of the planetary bodies are entered in order of their INCREASING DISTANCE from the sun. Thus, Earth, being the THIRD planet from the sun, has its radius loaded into R_{13}.

Additional planetary satellite radii as given on page 2 a may be stored in R_{20} - R_{25}

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	F-LBL-A	31-25-11	
	RCL-2	34-02	h
	ENT	41	
	g-x²	32-54	
	h x/y	35-52	
	RCL-0	34-00	R
	2	02	
	×	71	
	×	71	
010	+	61	
	F-(x)½	31-54	L
	R/S	84	L in km
	ENT	41	
	ENT	41	
	RCL-1	34-01	1.852
	./.	81	
	R/S		L in n. miles
	h-7	35-52	
	h-RTN	35-22	L in km
020	F-LBL-B	31-25-12	
	RCL-0	34-00	R
	h-7	35-52	
	./.	81	tan Ø/2
	g tan⁻¹	32-64	Ø/2 in dec. deg.
	2	02	
	×	71	Ø
	h-RTN	35-22	Ø in dec. deg.
	F-LBL-C	31-25-13	
	2	02	
030	./.	81	
	9	09	
	0	00	90
	h-7	35-52	
	-		90-Ø = θ
	h-RTN	35-22	θ in dec. deg.
	F-LBL-D	31-25-14	
	g-RAD	32-73	θ in Rad.
	RCL-0	34-00	R
	×	71	Rθ = S
040	R/S	84	S in Km.
	RCL-1	34-01	1.852
	./.	81	
	R/S	84	S in n. miles
	RCL-3	34-03	delta h
	STO+2	33-61-02	
	RCL-2	34-02	iterative h
	R/S	84	
	F-GTO-A	31-22-11	
	F-LBL-E	31-25-15	
050	RCL-4	34-04	Lat A
	f H	31-74	
	f-sin	31-62	sin A
	RCL-6	34-06	Lat B
	f H	31-74	
	f-sin	31-62	sin B
	×	71	
	RCL-4	34-04	Lat A
	f H	31-74	
	f-cos	31-63	cos A
060	RCL-6	34-06	Lat B
	f-H	31-74	
	f-cos	31-63	cos B
	×	71	
	RCL-5	34-05	Long A
	f	31-74	
	RCL-7	34-07	Long B
	f-H	31-74	
	-	51	
	h-ABS	35-64	
070	f-cos	31-63	
	×	71	
	+	61	
	g-cos	32-63	θ
	R/S	84	θ in dec. deg.
	g-Rad	32-73	
	STO-8	33-08	
	RCL-0	34-00	R
	×	71	Rθ = S
	R/S	84	S in km (smaller)
080	RCL-1	34-01	1.852
	./.	81	
	h-RTN	35-22	S in n. miles
	g-LBL-A	32-25-11	
	h-π	35-73	
	2	02	
	×	71	
	RCL-8	34-08	θ
	-	51	θ_1
	RCL-0	34-00	R
090	×	71	$R\theta_1$
	R/S	84	S_1 in km (larger)
	RCL-1	34-01	1.852
	./.	81	
	h-RTN	35-22	S_1 in n. miles.
100			
110			

REGISTERS

0	1	2	3	4	5	6	7	8	9
Radius = R	1.852	h (km)	delta h (km)	Lat A ° ' "	Long A ° ' "	Lat B ° ' "	Long B ° ' "	θ rad. (prog)	

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title SPACE SCIENCE AND TECHNOLOGY NO. (2), VIS VIVA AND PATH ANGLE RELATIONS

Contributor's Name Robert C. Wyckoff

Address 9517 Cordero Ave.

City TUJUNGA **State** California **Zip Code** 91042

Program Description, Equations, Variables For a body moving in an ellipse, the VIS VIVA equation is

(1) $V_o = \left[u\left[\frac{2}{r_o} - \frac{1}{a}\right]\right]^{1/2}$ where V_o is the velocity of the body at a point on the ellipse where the focal radius is r_o, the semi-major axis is a, and u = GM, where G is the constant of Universal gravitation and M is the mass of the primary. The circular velocity is given by (2) $V_c = \left[\frac{u}{r_g}\right]^{1/2}$ where r_c is the radius of the circular path. The escape velocity is given by

(3) $V_e = (2)^{1/2} V_c$. From Kepler's Third Law, we have the period of the motion, T, given by

(4) $T = \left[\frac{4\pi^2 a^3}{u}\right]^{1/2}$ Figure (1) on page 2 illustrates these parameters.

The path angle Ø is given by

(5) $\sin \emptyset = \frac{\left[ua(1 - e^2)\right]^{1/2}}{r_o V_o}$ where e is the eccentricity of the ellipse, and is given by

(6) $e = \frac{(a - r_m)}{a}$ where r_m is the periapsis distance.

The larger and smaller focal radii for any given path angle Ø is given by:

(7) $r = a \pm \frac{a}{\sin \emptyset}\left[\sin^2 \emptyset - 1 + e^2\right]^{1/2}$ Figure (2) on page 2 illustrates thes e parameters.

The values of u for the planetary bodies, plus the moon and sun, are stored in the secondary registers on side No. 2 of the program card.

Operating Limits and Warnings For an hyperbolic orbit, the value of the semi-major axis, a, is to be entered as a negative number. Other operating instructions are given on page (3)

Program Description II

Sketch(es)

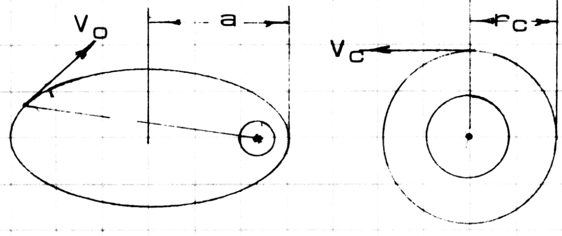


Figure (1)

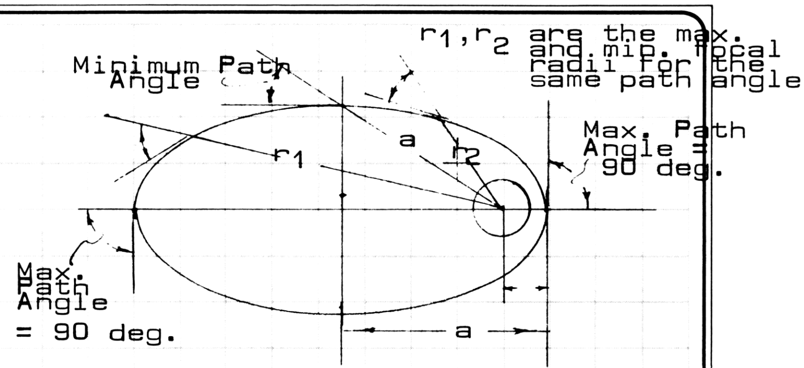


Figure (2)

Sample Problem(s) PROBLEM NO. 1: An earth satellite vehicle is in a highly elliptical orbit to explore cis-linar space. The semi-major axis is 300,000 km. Radar range data gives the distance to the probe as 200,000 km. Assuming the range distance was determined from the center of the earth, what is (a) the orbital velocity at this distance, (b), the circular velocity at an altitude of 1000 km, and (c), the escape velocity AT THIS ALTITUDE.

PROBLEM NO 2: A lunar probe is launched from Earth in an elliptical orbit with a semi-major axis of 200,000 km. The periapsis distance is 8000 km. The mid-course maneuver correction is to be performed at a distance of 100,000 km from the center of the Earth. What is (a), the path angle at the time and place of the mid-course correction, (b), the NEAREST distance from the center of the Earth to the probe when the path angle is 20 degrees.

Solution(s)

SOLUTION NO (1): Load both sides of program card. Recall contents of R_{13}. Observe 3.986012 x 10^5. Place this value in R_0. Place 200,000 in R_1 and 300,000 in R_2. Press Key A and observe V_o as 1.630135373 km/sec for (a). Place 1000 + the radius of the Earth (6371) = 7371 in R_1. Press Key B and observe 7.353703163 km/sec for part (b). Key C gives 10.39970674 km/sec for the escape velocity. This is about 1 km/sec less than for launch at the surface of the earth, which demonstrates the advantage of launching from a parking orbit.

SOLUTION NO. (2): With both sides of program card entered, place 13 h st I, STO 0, 200,000 in R_2, 100,000 in R_1, 8000 in R_4, and 20 in R_6. Press Key A to load the square of the eccentricity, (e^2) in R_5. Observe 2.445203059 in display as the VIS VIVA velocity. Press f Key A and observe 18.86359066 dec. degrees as the solution to (a). Press f Key B and observe the MAXIMUM focal radius as 318854.2098 km. Press R/S for the MINIMUM focal radius and observe 199981.1364 km as the solution to part (b).

Reference(s) Any standard work on ASTRODYNAMICS such as

SPACE TECHNOLOGY - H. Seifert, John Wiley and Sons, Inc. or

HANDBOOK OF ASTRONAUTICAL ENGINEERING - Koelle, McGraw-Hill.

Values of u, in km^3/sec^2 for various planetary satellites

Primary	Satellite	u
Jupiter	Io	4890
	Europa	3130
	Ganymede	10319
	Callisto	6455
Saturn	Mimas	2.523
	Enceladus	5.722
	Tethys	43.035
	Dione	68.465
	Rhea	146.67
	Titan	9390
	Hyperion	2.934 (less than)
	Iapetus	92.17
Neptune	Triton	8.803

User Instructions

SPACE SCIENCE AND TECHNOLOGY No. (2)

VIS VIVA, KEPLER'S THIRD LAW, AND PATH ANGLE.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load both sides of card. Interchange primary and secondary registers. Recall the appropriate value of u through operation of h-RCL (i). Place this in R_0. Load the focal radius in R_1, and the semi-major axis distance in R_2. If KEPLER'S THIRD LAW solutions are desired, place the period, T, in R_3. Place the periapsis distance, r_m in R_4 and the path angle Ø in R_6 for path angle operation.			
2	Key A gives the VIS VIVA velocity V_o		A	V_o in km/sec
3	Key B gives the circular velocity V_c		B	V_c in km/sec
4	Key C gives the escape velocity V_e		C	V_e in km/sec
5.	Key D gives the orbital period T in seconds		D	T in sec.
6	Key E gives the semi-major axis in km		E	a in km
	For path angle computations, Key A must initially be pressed in order to compute and load e^2 in R_5. The VIS VIVA velocity will appear in the display. Disregard this.			
7	Key f-A gives the path angle Ø in dec.°		FA	Ø in dec.°
8	Key f-B gives the larger focal radius, r_{max}.		FB	r_{max} in km
9	R/S gives the smaller focal radius, r_{min}.		R/S	r_{min} in km
	For Key C operation, Key B must first be pressed, in order to compute the circular velocity V_c.			
	Values of u in km^3/sec^2 are on the side 2 of the program card, and can be placed in the secondary register if desired.			

Body	u	Register
Moon	4.90098×10^3	R_{10}
Mercury	2.15215×10^4	R_{11}
Venus	3.24815×10^5	R_{12}
Earth	3.986012×10^5	R_{13}
Mars	4.30430×10^4	R_{14}
Jupiter	1.26658×10^8	R_{15}
Saturn	3.79416×10^7	R_{16}
Uranus	5.77892×10^6	R_{17}
Neptune	6.85500×10^6	R_{18}
Sun	1.324948×10^{11}	R_{19}

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
	Additional values of u for various satellites are given on page 2a.			
	Re-iterative operation is not provided, in as much as generally discreet values of the parameters are desired.			

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STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	
002	2	02	
003	RCL1	36 01	
004	÷	-24	
005	RCL2	36 02	
006	1/X	52	
007	-	-45	
008	RCL0	36 00	
009	×	-35	
010	√X	54	V_o
011	STO7	35 07	
012	RTN	24	V_o in km
013	*LBLB	21 12	
014	RCL0	36 00	
015	RCL1	36 01	
016	÷	-24	
017	√X	54	V_c
018	RTN	24	V_c in km
019	*LBLC	21 13	
020	2	02	
021	√X	54	
022	×	-35	V_e
023	RTN	24	V_e in km
024	*LBLD	21 14	
025	RCL2	36 02	
026	3	03	
027	Y^X	31	
028	Pi	16-24	
029	X²	53	
030	4	04	
031	×	-35	
032	×	-35	
033	RCL0	36 00	
034	÷	-24	
035	√X	54	T
036	RTN	24	T in seconds
037	*LBLE	21 15	
038	RCL0	36 00	
039	RCL3	36 03	
040	X²	53	
041	×	-35	
042	Pi	16-24	
043	X²	53	
044	4	04	
045	×	-35	
046	÷	-24	
047	3	03	
048	1/X	52	
049	Y^X	31	a
050	RTN	24	a in km
051	*LBLa	21 16 11	
052	RCL2	36 02	
053	ENT↑	-21	
054	ENT↑	-21	
055	RCL4	36 04	
056	-	-45	
057	X⇄Y	-41	
058	÷	-24	
059	X²	53	
060	STO5	35 05	
061	1	01	
062	X⇄Y	-41	
063	-	-45	
064	RCL2	36 02	
065	RCL0	36 00	
066	×	-35	
067	×	-35	
068	√X	54	
069	RCL1	36 01	
070	RCL7	36 07	
071	×	-35	
072	÷	-24	Ø
073	SIN⁻¹	16 41	Ø in dec. °
074	RTN	24	
075	*LBLb	21 16 12	
076	RCL6	36 06	
077	SIN	41	
078	ENT↑	-21	
079	ENT↑	-21	
080	×	-35	
081	X⇄Y	-41	
082	RCL2	36 02	
083	X⇄Y	-41	
084	÷	-24	
085	X⇄Y	-41	
086	1	01	
087	-	-45	
088	RCL5	36 05	
089	+	-55	
090	√X	54	
091	×	-35	
092	ENT↑	-21	
093	RCL2	36 02	
094	+	-55	r(max) in km
095	R/S	51	
096	X⇄Y	-41	
097	RCL2	36 02	
098	X⇄Y	-41	r(min) in km
099	-	-45	
100	RTN	24	
110			

REGISTERS

0	1	2	3	4	5	6	7	8	9
u	r_o km	a km	T sec	r_m km	e^2 (prog)	Ø dec°	V_o (prog)		

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
u Moon	u Mercury	u Venus	u Earth	u Mars	u Jupiter	u Saturn	u Uranus	u Neptune	u sun

A	B	C	D	E	I

Program Description I

Program Title SPACE SCIENCE AND TECHNOLOGY NO. (4), BALLISTIC MISSILE RANGE

Contributor's Name Rex H. Shudde and Robert C. Wyckoff

Address 27105 Arriba Way
9517 Cordero Ave.

City Carmel
Tujunga

State California
California

Zip Code 93921
91042

Program Description, Equations, Variables Computation of the surface range of a ballistic missile is fairly common in the literature, but it is generally assumed that the launch and target point are located on the surface of the body. The unasymetric case is more difficult and seldom seen. This program, utilizing Newtonian 2-body theory, gives an exact solution. The basic assumptions are that the body is a sphere, is non-rotating, and has no atmosphere. The latter assumption is nearly correct, since the large portion of the trajectory is above the atmosphere. The various astronomical and planetary constants are held on a data card and are loaded into the primary and secondary registers, where the appropriate values of -he gravitational constant u, and the mean radius of the body r are selected as desired.

The path of the missile is a portion of an ellipse of semi-major axis a, given by

(1) $1/a = [2/R_1 - V_1^2/u]$, where R_1 is the radius of the body plus the altitude of burn-out, and V_1 is the burn-out velocity. R& a are given km and V_1 is in km/sec^2. u is in km^3/sec^2. The semi-latus rectum of the ellipse is given by

(2) $p = \frac{(R_1 V_1 \cos \phi)^2}{u}$ where ϕ is the elevation angle (to the local horizon) at burn-out. The eccentricity of the ellipse is

(3) $e = (1-p/a)^{1/2}$ The true anomaly of the launch point is given by

(4) $f_1 = \cos^{-1}[(p/R_1 - 1)\,1/e]$ where $0 \leq f_1 \leq \Pi$ The true anomaly of the target point is given by

(5) $f_t = 2\Pi - \cos^{-1}[(p/R_t - 1)\,1/e]$ where $\Pi \leq f_t \leq 2\Pi$ Range over the surface between perpendicularies through the launch and target points, is given by (6) $S = R(f_t - f_1)$ where R is the radius of the body radius of the body + the altitude of the target locationgenerally equals R_t

To compute the time of flight we need to calculate the eccentric anomalys, E_1 and E_t.

(continued on page 1a)

Operating Limits and Warnings

The line of apses must separate the burn-out location and the target point, i.e, the elevation angle ϕ at burn-out must be $0 < \phi < \Pi/2$

Observe operating conditions given on page 3.

Remember, the planetary constants are loaded in the registers from the data card in order of INCREASING DISTANCE from the sun, with the Moon, as 0, Mercury as 1, Venus as 2, Earth as 3, Mars as 4, Jupiter as 5, Saturn as 6, Uranus as 7, Neptune as 8 and Pluto as 9. Values for the sun are loaded in Register A,B. The numbers above ARE NOT REGISTER NUMBERS, but index no's, used to recall the proper values from the regsiters.

E_1 is given by (7) $E_1 = \cos^{-1}\left[\left(1 - R_1/a\right) 1/e\right]$ where $0 \leqslant E_1 \leqslant \Pi$

and

(8) $E_t = 2\Pi - \cos^{-1}\left[\left(1 - R_t/a\right) 1/e\right]$ where $\Pi \leqslant E_t \leqslant 2\Pi$

The time of flight is given by

(9) $$t_s = \frac{a^{3/2}}{u^{1/2}}\left[(E_t - E_1) - e(\sin E_t - \sin E_1)\right]$$

The maximum ordinate is given by

(10) $h_m = a(1 + e) - R$ and the velocity at burn-out and max altitude are

(11) $V_c = (u/R_1)^{1/2}$ and $V_{c,m} = (u/R+h_m)^{1/2}$

The value of the semi-latus rectum which correspondes to the elevation angle for maximum surface range is

(12) $$p_{opt} = \frac{2}{\dfrac{1}{2a - R_t} + \dfrac{1}{2a - R_1}}$$

while the value of $\emptyset$ for maximum surface range is

(13) $$\emptyset_{max} = \cos^{-1}\left[\frac{(up_{opt})^{1/2}}{R_1 V_1}\right]$$

Registers are Loaded as follows:

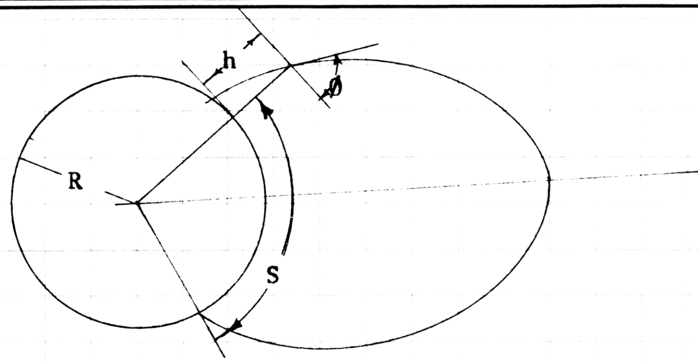
	PREG
4.900980000+03	0
1.739290000+03	1
2.152150000+04	2
2.420990000+03	3
3.248150000+05	4
6.052000000+03	5
3.986012000+05	6
6.371017000+03	7
4.304300000+04	8
3.387550000+03	9
1.324948000+11	A
6.960000000+05	B
0.000000000+00	C
0.000000000+00	D
0.000000000+00	E
0.000000000+00	I

F+3

	PREG
1.266580000+08	0
7.137500000+04	1
3.794160000+07	2
6.040000000+04	3
5.778920000+06	4
2.350000000+04	5
6.855000000+06	6
2.500000000+04	7
3.312370000+05	8
2.930000000+03	9
1.324948000+11	A
6.960000000+05	B
0.000000000+00	C
0.000000000+00	D
0.000000000+00	E
0.000000000+00	I

Program Description II

Sketch(es)



Sample Problem(s) I An IRBM is launched vertically from the earth and after a gravity turn burns out at an altitude of 60 km, a burn-out velocity of 1.5 km/sec, and an elevation angle of 30 °. What is: (a) the range, (b) the maximum ordinate, (c) the flight time, (d) elev. angle for maximum range, ϕ max. and (e) the maximum range.

II Calculate the above for a burn-out altitude of 20 km the same burn-out velocity, and a target altitude of 3 km. Use 30° for the elvation angle.

III Perform problem I for the moon.

SOLUTIONS: I Load program and data cards. Since Earth is the 3rd planet from the sun, place 3 in display. Do f-E. Enter 60, do f-A. Enter 1.5, do f-B, enter 30, do f-C, enter 0, do f-D.
Key A gives 281.81 km for (a). Key B gives 90.14 km for (b). Key C gives 219.48 sec. for (c), Key D gives 38.54° for (d), Key A gives 290.32 km for (e).

II Enter 20, do f-A. Enter 30, do f-C. Enter 3, do f-D.
Key A gives 230.66 km for (a). Key B gives 49.76 km for (b). Key C gives 179.05 sec. for (c). Key D gives 42.50° for (d). Key A gives 250.78 km for (e).

III Load data card again. The index no. for the moon is 0. Place 0 in

Solution(s)

display and do f-E. Enter 60, do f-A. Enter 1.5, do f-B. Enter 30, do f-C. Enter 0, do f-D.

Key A gives 2725.60 km for (a). Key B gives 593.74 km for (b). Key C gives 3032.18 sec. for (c). Key D gives 21.00° for (d). Key A gives 2858.99 km for (e).

Reference(s) (1) HANDBOOK OF ASTRONAUTICAL ENGINEERING, by H. H. Koelle, Ch. 7, 1961. McGraw-Hill

(2) NONSYMETRIC BALLISTIC RANGE, HEIGHT, TIME OF FLIGHT, AND OPTIMUM FLIGHT PATH ANGLE COMPUTATION WITH PROGRAMS FOR HP-65 CALCULATOR, R. H. Shudde, Naval Post-Graduate School Technical Report, NPS 55Su76031, Mar 1976

User Instructions

SPACE SCIENCE AND TECHNOLOGY, No. (4), BALLISTIC MISSILE RANGE, MAXIMUM ORDINATE, TIME OF FLIGHT, ELEVATION ANGLE FOR MAXIMUM RANGE

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load Program and Data Cards.				
2	Select and enter body index no., do f-E (*)	n	f-E		u for index body
3	Enter burn-out altitude, (in km) do f-A	h	f-A		h in km.
4	Enter burn-out velocity, (in km/sec), do f-B	V_1	f-B		V_1 in km/sec
5	Enter elevation angle, dec.°, do f-C	Ø	f-C		Ø in dec.°
6	Enter target altitude (in km,; generally 0)	h_t			
	do f-D		f-D		h_t in km
7	Key A computes Range in km		A		S in km
8	Key B computes maximum ordinate in km		B		h_{max} in km
9	R/S computes circular vel.(km/sec) for h_{max}		R/S		$V_{c,max}$ in km/sec
10	R/S computes circular vel.(km/sec) for h		R/S		$V_{c,h}$ in km/sec
11	Key C computes flight time in seconds		C		t_s in sec
12	Key D computes Ø for maximum range, (dec. °)		D		Ø max.
13	Key E computes any distance, Key A or B to n. miles		E		S, h_{max} in n.m.

Step 2 must be performed BEFORE any subsequent step.
Step 7 must be performed BEFORE any subsequent KEY oper.
If a new body is selected, DATA CARD and step 2 must initially be performed.

Primary and Secondary Registers are loaded from the data card as follows:

Index No.	Body	u (km^3/sec^2)	Radius (km)	Registers
0	Moon	4.90098×10^3	1.73929×10^3	0/1
1	Mercury	2.15215×10^4	2.42099×10^3	2/3
2	Venus	3.24815×10^5	6.052×10^3	4/5
3	Earth	3.986012×10^5	6.371017×10^3	6/7
4	Mars	4.3043×10^4	3.38755×10^3	8/9
	Sun	1.324948×10^{11}	6.96000×10^5	A/B
5	Jupiter	1.26658×10^8	7.1375×10^4	10/11
6	Saturn	3.79416×10^7	6.0400×10^4	12/13
7	Uranus	5.77892×10^6	2.3500×10^4	14/15
8	Neptune	6.85500×10^6	2.5000×10^4	16/17
9	Pluto	3.31237×10^5	2.960×10^3	18/19
	Sun	1.324948×10^{11}	6.96000×10^5	A/B

CAUTION: If the sun is used as the primary body, no index number is used. Value of u is already in register A. Recall contents of register B, and load in register C. Then go to step 3 etc.

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11		057	D→R	16 45	
002	RCLC	36 13		058	-	-45	
003	RCLD	36 14		059	RCLC	36 13	
004	+	-55		060	×	-35	
005	STO0	35 00		061	RTN	24	Computes Range in km
006	2	02		062	GTO0	22 00	
007	X⇄Y	-41		063	*LBLB	21 12	
008	÷	-24		064	RCL3	36 03	
009	RCLB	36 12		065	1	01	
010	X^2	53		066	+	-55	
011	RCLA	36 11		067	RCL1	36 01	
012	÷	-24		068	1/X	52	
013	-	-45	Computes 1/a	069	×	-35	
014	STO1	35 01		070	RCLC	36 13	
015	RCL0	36 00		071	-	-45	Computes h_{max}
016	RCLB	36 12		072	R/S	51	
017	×	-35		073	RCLC	36 13	
018	RCLE	36 15		074	+	-55	
019	COS	42		075	RCLA	36 11	
020	×	-35		076	X⇄Y	-41	
021	X^2	53		077	÷	-24	
022	RCLA	36 11		078	√X	54	
023	÷	-24	Computes p	079	R/S	51	Computes V_{cmax}
024	STO2	35 02		080	RCLA	36 11	
025	RCL1	36 01		081	RCL0	36 00	
026	×	-35		082	÷	-24	
027	1	01		083	√X	54	
028	X⇄Y	-41		084	RTN	24	Computes V_c
029	-	-45		085	GTO0	22 00	
030	√X	54	Computes e	086	*LBLC	21 13	
031	STO3	35 03		087	1	01	
032	RCL2	36 02		088	RCL0	36 00	
033	RCL0	36 00		089	RCL1	36 01	
034	÷	-24		090	×	-35	
035	1	01		091	-	-45	
036	-	-45		092	RCL3	36 03	
037	X⇄Y	-41		093	÷	-24	
038	÷	-24		094	COS^{-1}	16 42	Computes E_1
039	COS^{-1}	16 42	Computes f_1	095	STO4	35 04	
040	RCL2	36 02		096	1	01	
041	RCLC	36 13		097	RCLC	36 13	
042	RCL9	36 09		098	RCL9	36 09	
043	+	-55		099	+	-55	
044	÷	-24		100	RCL1	36 01	
045	1	01		101	×	-35	
046	-	-45		102	-	-45	
047	RCL3	36 03		103	RCL3	36 03	
048	÷	-24		104	÷	-24	
049	COS^{-1}	16 42		105	COS^{-1}	16 42	
050	2	02		106	D→R	16 45	
051	Pi	16-24		107	2	02	
052	×	-35		108	Pi	16-24	
053	X⇄Y	-41		109	×	-35	
054	D→R	16 45		110	X⇄Y	-41	
055	-	-45	Computes f_t	111	-	-45	Computes E_t
056	X⇄Y	-41		112	R→D	16 46	

REGISTERS

0	1	2	3	4	5	6	7	8	9
R_1 in km	1/a in km	p in km	e	E_1 dec°	E_t dec°				h in km Target
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
u in km^3/sec^2	V_1 in km/sec	R_E in km	h in km	∅ dec °	

97 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	STO5	35 05	
114	D→R	16 45	
115	X⇄Y	-41	
116	D→R	16 45	
117	-	-45	
118	RCL5	36 05	
119	SIN	41	
120	RCL4	36 04	
121	SIN	41	
122	-	-45	
123	RCL3	36 03	
124	×	-35	
125	-	-45	
126	RCL1	36 01	
127	1/X	52	
128	3	03	
129	ENT↑	-21	
130	2	02	
131	÷	-24	
132	Y^X	31	
133	RCLA	36 11	
134	√X	54	
135	÷	-24	
136	×	-35	
137	RTN	24	Computes t_s in sec.
138	GTO0	22 00	
139	*LBLD	21 14	
140	RCL1	36 01	
141	1/X	52	
142	2	02	
143	×	-35	
144	RCLC	36 13	
145	RCL9	36 09	
146	+	-55	
147	-	-45	
148	1/X	52	
149	RCL1	36 01	
150	1/X	52	
151	2	02	
152	×	-35	
153	RCL0	36 00	
154	-	-45	
155	1/X	52	
156	+	-55	
157	2	02	
158	X⇄Y	-41	
159	÷	-24	Computes p opt.
160	RCLA	36 11	
161	×	-35	
162	√X	54	
163	RCL0	36 00	
164	RCLB	36 12	
165	×	-35	
166	÷	-24	
167	COS^{-1}	16 42	Computes ∅ max.
168	STOE	35 15	

STEP	KEY ENTRY	KEY CODE	COMMENTS
169	RTN	24	
170	GTO0	22 00	
171	*LBLE	21 15	
172	1	01	
173	.	-62	
174	8	08	
175	5	05	
176	2	02	
177	÷	-24	
178	RTN	24	
179	*LBLe	21 16 15	
180	2	02	
181	×	-35	
182	STOI	35 46	
183	RCLi	36 45	
184	ISZI	16 26 46	
185	RCLi	36 45	
186	STOC	35 13	
187	R↓	-31	
188	STOA	35 11	
189	R/S	51	
190	*LBLa	21 16 11	
191	STOD	35 14	
192	R/S	51	
193	*LBLb	21 16 12	
194	STOB	35 12	
195	R/S	51	
196	*LBLc	21 16 13	
197	STOE	35 15	
198	R/S	51	
199	*LBLd	21 16 14	
200	STO9	35 09	
201	R/S	51	
210			
220			

LABELS

A	B	C	D	E
S=Range	Max. Ord.	t_s=T of F.	∅ Opt.	km to n.m.
a	b R/S = Circular Vel for Max. Ord.	c	d	e
0	1 R/S = Circular Velocity for Burn-Out Altitude	2	3	4
5	6	7	8	9

FLAGS

0	
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☐	DEG	☐	FIX	☐
1	☐	☐	GRAD	☐	SCI	☐
2	☐	☐	RAD	☐	ENG	☐
3	☐	☐			n ______	

Program Description I

Program Title CELESTIAL POSITION

Contributor's Name JOSEPH R. HOBART
Address 8723 BRADY AVENUE
City SPRING VALLEY **State** CA **Zip Code** 92077

Program Description, Equations, Variables PROGRAM CALCULATES LOCAL SIDERIAL TIME AND AZIMUTH AND ALTITUDE AND HOURLY RATES OF CHANGE OF THE AZIMUTH AND ALTITUDE OF A CELESTIAL BODY AS A FUNCTION OF DATE AND TIME, OBSERVER'S GEOGRAPHIC POSITION, AND CELESTIAL COORDINATES OF THE BODY.
FORMATS: LATITUDE, LONGNITUDE, AND DECLINATION ARE IN DEGREES-MINUTES-SECONDS; RIGHT ASCENSION AND ALL TIMES ARE IN HOURS-MINUTES-SECONDS; AND AZIMUTH AND ALTITUDE OUTPUTS ARE IN DECIMAL DEGREES.

PROGRAM STEPS 72-78 ARE A SIDERIAL CONSTANT THAT MATCHES THE ZEROTH HOUR OF 0 JANUARY FOR THE YEAR GIVEN IN STEPS 8-11:

$$\text{CONSTANT}^{*} = \frac{\text{SIDERIAL TIME (DECIMAL HOURS) FOR } 0^{h} \text{ JAN } 0}{24}$$

THE SIDERIAL TIME IS AVAILABLE IN THE UNIVERSAL AND SIDERIAL TIMES TABLES OF AN EPHEMERIS. NOTE THAT THE

Operating Limits and Warnings INPUT SOUTHERN LATITUDES AND DECLINATIONS AND EASTERN LONGNITUDES AS NEGITAVE NUMBERS. STEPS 8-11 AND 72-78 MUST BE CHANGED EACH YEAR. ANY INPUT OF MONTH AND DAY MUST BE PRECEDED BY LATITUDE AND LONGNITUDE INPUTS TO ENSURE THE YEAR IS ENTERED INTO THE CALCULATION FOR DAY OF THE YEAR.

Program Description I

Program Title

Contributor's Name

Address

City **State** **Zip Code**

Program Description, Equations, Variables VALUE FOR DECEMBER 31 OF ONE YEAR IS EQUIVELENT TO THE VALUE FOR JANUARY 0 OF THE NEXT YEAR

* SOME CONSTANTS : 1977 ⇒ .276518
1978 ⇒ .275851

FOR APPARENT SIDERIAL TIME.

IF MEAN SIDERIAL TIME IS ACCEPTABLE :

1976 ⇒ .274436
1977 ⇒ .276511
1978 ⇒ .275848
1979 ⇒ .275185
1980 ⇒ .274522

Operating Limits and Warnings ENSURE DATE USED MATCHES GMT; THE GMT DATE CHANGES AT 0^h GMT NOT AT 0^h LOCAL TIME.

Program Description II

Sketch(es)

Sample Problem(s) AT 1800 PST 15 JAN 1977 (0200 GMT 16 JAN), FOR AN OBSERVER AT 32°42′ N LATITUDE 117° 05′ W LONGNITUDE FIND LOCAL SIDERIAL TIME AND THE POSITION OF VENUS AND RATE OF CHANGE OF POSITION. FROM AN EPHEMERIS, VENUS IS 7° 20′ 55.33″ SOUTH DECLINATION AND $22^h 56^m 47.42^s$ IN RIGHT ASCENSION AT THIS TIME.

SOLUTION:	32.42 ENT↑ 117.05 f A	→ 1977
	1 ENT↑ 16 f B	→ 16 (DAY OF YEAR)
	7.205533 CHS ENT↑ 22.564742 A	→ 7.
	2 B	→ $1^h 53^m 15.7^s$
	C	→ 234.5°
	D	→ 32.0°
	f C	→ 12.453 °/HR
	f D	→ −10.437 °/HR

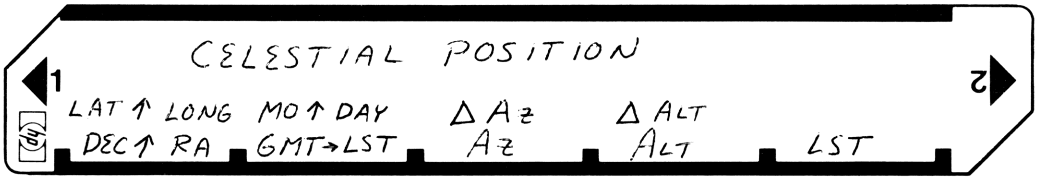
VENUS IS IN THE SOUTHWESTERN SKY 32° ABOVE THE HORIZON; IT IS MOVING NORTHWARD 12.453 °/HR AND TOWARD THE HORIZON 10.437 °/HR (NEGLECTING ATMOSPHERIC REFRACTION).

	E	→ $2^h 03^m 17.4^s$

NEW LST (AFTER COMPUTING Δ) IS FOR ORIGINAL GMT + 10^m

Reference(s) THE AMERICAN EPHEMERIS AND NAUTICAL ALMANAC, PRINTED EACH YEAR BY THE U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	LOAD SIDES 1 AND 2				
2	INPUT LATITUDE AND LONGNITUDE	LAT / D.MS	ENT		
		LONG / D.MS	f	A	YEAR
3	INPUT MONTH AND DAY	1 TO 12	ENT		
		1 TO 31	f	B	YEAR DAY
4	INPUT OBJECT DECLINATION AND	DEC / D.MS	ENT		
	RIGHT ASCENSION	RA / H.MS	A		
5	CONVERT GMT TO LST	GMT / H.MS	B		LST / H.MS
6	COMPUTE AZIMUTH		C		DEG
7	COMPUTE ALTITUDE		D		DEG
8	COMPUTE Δ AZIMUTH / HOUR		f	C	DEG / HR
9	COMPUTE Δ ALTITUDE / HOUR		f	D	DEG / HR
	RETURN TO STEPS 4 OR 5 AS DESIRED. TO CHANGE MONTH AND DAY EITHER PERFORM STEP 2 FIRST OR ENTER YEAR IN STACK PRIOR TO MONTH. STEP 8 ADDS 10 MINUTES TO ORIGINAL GMT.				
	THIS PROGRAM WAS DESIGNED TO PROVIDE POSITIONING AND TRACKING DATA FOR A SEMI-PORTABLE ALT-AZ TELESCOPE.				
	LST CAN BE RECALLED ANY TIME AFTER STEP 5		E		LST / H.MS

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	LBL a	32 25 11	
	DSP 5	23 05	
	→ H	31 74	
	STO 2	33 02	
	X ⇄ Y	35 52	
	→ H	31 74	
	STO 1	33 01	
	1	01	MUST MATCH DATE OF COMPUTATION
	9	09	
010	7	07	
	7	07	
	DSP 0	23 00	
	RTN	35 22	
	LBL b	32 25 12	
	X ⇄ Y	35 52	
	STO 4	33 04	
	3	03	
	X > Y	32 81	
	GTO 1	22 01	
020	GSB 1	31 22 01	
	R↑	35 54	
	4	04	
	÷	81	
	FRAC	32 83	
	X = 0	31 51	
	1	01	
	RCL 3	34 03	
	+	61	
	INT	31 83	
030	RCL 4	34 04	
	•	83	
	4	04	
	X	71	
	2	02	
	•	83	
	3	03	
	+	61	
	INT	31 83	
	−	51	
040	STO 3	33 03	
	RTN	35 22	→ YEAR DAY
	LBL 1	31 25 01	
	R↓	35 53	
	1	01	
	−	51	
	3	03	
	1	01	
	X	71	
	+	61	
050	STO 3	33 03	
	RTN	35 22	
	LBL A	31 25 11	
	SF 0	35 51 00	
	GSB 2	31 22 02	
	STO 6	33 06	
	X ⇄ Y	35 52	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	→ H	31 74	
	STO 5	33 05	
	RTN	35 22	
060	LBL B	31 25 12	
	SF 0	35 51 00	
	STO C	33 13	
	RCL 2	34 02	
	3	03	
	6	06	
	0	00	
	STO 7	33 07	
	÷	81	
	1	01	
070	X ⇄ Y	35 52	
	−	51	
	•	83	SIDERIAL CONSTANT MUST MATCH YEAR STEPS 8 TO 11
	2	02	
	7	07	
	6	06	
	5	05	
	1	01	
	8	08	
	+	61	
080	X ⇄ Y	35 52	
	→ H	31 74	
	2	02	
	4	04	
	÷	81	
	RCL 3	34 03	
	+	61	
	1	01	
	•	83	
	0	00	
090	0	00	
	2	02	
	7	07	
	3	03	
	7	07	
	9	09	
	X	71	
	+	61	
	FRAC	32 83	
	2	02	
100	4	04	
	X	71	
	→ H.MS	32 74	
	STO 0	33 00	
	DSP 5	23 05	
	RTN	35 22	
	LBL C	31 25 13	
	RCL 0	34 00	
	CF 0	35 61 00	
	GSB 2	31 22 02	
110	RCL 6	34 06	
	−	51	
	STO 8	33 08	

REGISTERS

0	1	2	3	4	5	6	7	8	9
LST	LAT	LONG	YR DAY	MONTH	DEC	RA	360	LHA	SIN ALT

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
ALT	AZ	GMT	ALT/ΔALT	AZ/Δ AZ	

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
	RCL 1	34 01	
	SIN	31 62	
	RCL 5	34 05	
	SIN	31 62	
	X	71	
	RCL 1	34 01	
	COS	31 63	
120	RCL 5	34 05	
	COS	31 63	
	X	71	
	RCL 8	34 08	
	COS	31 63	
	X	71	
	+	61	
	STO 9	33 09	
	SIN^{-1}	32 62	
	STO A	33 11	
130	RCL 5	34 05	
	SIN	31 62	
	RCL 9	34 09	
	RCL 1	34 01	
	SIN	31 62	
	X	71	
	—	51	
	RCL 1	34 01	
	COS	31 63	
	÷	81	
140	RCL A	34 11	
	COS	31 63	
	÷	81	
	COS^{-1}	32 63	
	RCL 8	34 08	
	SIN	31 62	
	DSP 1	23 01	
	X<0	31 71	
	GTO 3	22 03	
	R↓	35 53	
150	RCL 7	34 07	
	X⇄Y	35 52	
	—	51	
	STO B	33 12	
	RTN	35 22	→ Az
	LBL 3	31 25 03	
	R↓	35 53	
	STO B	33 12	
	RTN	35 22	→ Az
	LBL 4	31 25 04	
160	RTN	35 22	→ ALT
	LBL E	31 25 15	
	DSP 5	23 05	
	RCL 0	34 00	
	RTN	35 22	→ LST
	LBL C	31 25 13	
	DSP 1	23 01	
	RCL B	34 12	
	GTO 4	22 04	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	LBL D	31 25 14	
170	F?0	35 71 00	
	GSB C	31 22 13	
	DSP 1	23 01	
	RCL A	34 11	
	GTO 4	22 04	
	LBL 2	31 25 02	
	→H	31 74	
	1	01	
	5	05	
	X	71	
180	RTN	35 22	
	LBL c	32 25 13	
	RCL A	34 11	
	STO D	33 14	
	RCL B	34 12	
	STO E	33 15	
	RCL C	34 13	
	•	83	
	1	01	
	+	61	
190	GSB B	31 22 12	
	GSB C	31 22 13	
	RCL E	34 15	
	—	51	
	6	06	
	X	71	
	STO E	33 15	
	DSP3	23 03	
	RTN	35 22	→ Δ Az
	LBL d	32 25 14	
200	RCL A	34 11	
	RCL D	34 14	
	—	51	
	6	06	
	X	71	
	STO D	33 14	
	DSP3	23 03	
	RTN	35 22	→ Δ ALT
210			
220			

LABELS

A DEC↑ RA↑	B GMT→LST	C → Az	D → ALT	E → LST
a LAT↑ LONG↑	b MO↑ DAY↑	c → Δ Az	d → Δ ALT	e
0	1 YR DAY	2 H→ D	3 → Az	4 → ALT
5	6	7	8	9

FLAGS

0	CONTROL
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	5

Program Description I

Program Title BINARY STAR EPHEMERIS

Contributor's Name William C. Wickes

Address Dept. of Physics, Jadwin Hall, Princeton University

City Princeton **State** NJ **Zip Code** 08540

Program Description, Equations, Variables For a given date, the program calculates the apparent position angle θ and angular separation ρ of a binary star system from the following equations:

"Mean Anomaly" $M = \frac{2\pi}{P}(t-T) = E - e\sin E$

radius vector $r = a(1 - E\cos e)$

$\tan(\frac{\nu}{2}) = \sqrt{\frac{1+e}{1-e}}\tan\frac{E}{2}$

$\tan(\nu+\omega) = \tan(\theta-\Omega)\sec i$

$\rho = r\cos(\nu+\omega)$

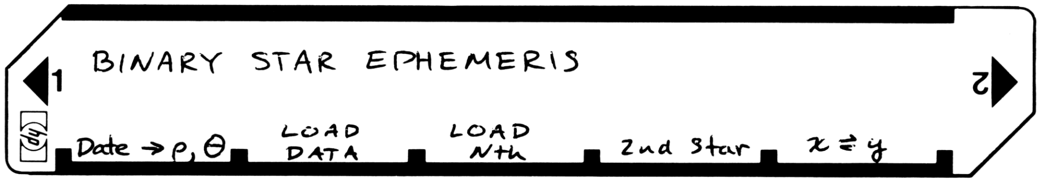
Input data are $P, T, e, a, \omega, i, \Omega$

For any t, program computes ρ and θ

P = period of orbit
t = ephemeris Date
T = epoch of periastron passage
E = "eccentric anomaly"
a = semi-major axis
e = eccentricity
ν = "true anomaly"
ω = angle in true orbit between line of nodes and periastron
Ω = position angle of line of nodes
i = inclination of true orbit to plane of sky
θ = apparent position angle
ρ = apparent angular separation

Operating Limits and Warnings Angular quantities are input and output in degrees.

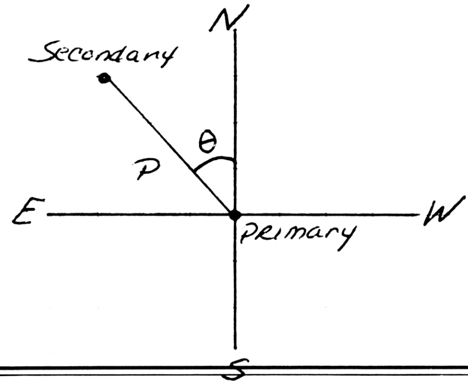
User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1.	Load Orbit Parameters		B	
	a. As 0. flashes, data card may be entered			
	b. If no card will entered, data is entered manually. 1 through 7 will be displayed during which successive orbit parameters are entered. If no entry is made during pause display, execution halts. Enter in following order:			
	1.	P (years)		
	2.	T (years)		
	3.	e		
	4.	a (arc-sec)		
	5.	ω (°)		
	6.	i (°)		
	7.	Ω (°)		
	[c. To resume after delayed entry		R/S]	
	[d. To enter nth parameter	n	C	n]
2.	Enter ephemeris date	t (year)	A	ρ, θ
3.	For new date, go to 2.			
4.	For new star, saving old parameters		D	
	Note: Following data entry, "Crd" will display, indicating that data may be recorded by entering a magnetic card.			

Program Description II

Sketch(es)



Sample Problem(s) THE DOUBLE STAR SS-TAU has orbital elements AS FOLLOWS

P = 91.044y
T = 1897.58y
e = .604
a = 0.″561
ω = 131°.28
i = 52°.86
Ω = 64°.28

Find the orbital positions FOR 1976.9

Solution(s) B → 0. ; (when 1.000 displays) 91.044 [R/S] → "2", 1897.58 [R/S] → "3", .604 [R/S] → "4", .561 [R/S] → "5", 131°.28 [R/S] → "6", 52°.86 [R/S] → "7", 64°.28 [R/S] → "Crd." [R/S] 1976.9 [A] → 0″.498, 71°.661

Reference(s) Aitken, The Binary Stars (DOVER Publications, NEW YORK 1964)

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	LBL A	31 25 11	Enter t		×	71	
	STO A	33 11			TAN⁻¹	32 64	
	RCL 2	34 02			2	02	
	−	51		060	×	71	
	2	02	Compute M		RCL 5	34 05	
	×	71			+	61	
	π	35 73			↑	41	
	×	71			TAN	31 64	
	RCL 1	34 01			RCL 6	34 06	Compute θ − Ω
010	÷	81			COS	31 63	
	STO 8	33 08			×	71	
	RAD	35 42			TAN⁻¹	32 64	
	LBL 0	31 25 00			x⇄y	35 52	
	↑	41		070	COS	31 63	
	SIN	31 62			RCL 8	34 08	Compute ρ
	RCL 3	34 03			×	71	
	×	71			x⇄y	35 52	
	RCL 8	34 08			COS	31 63	
	+	61			LST X	35 82	
020	−	51	Compute E		R↓	35 53	
	LST X	35 82	by iteration		÷	81	Compute θ
	↑	41			R↑	35 54	
	R↓	35 53			RCL 7	34 07	
	÷	81		080	+	61	
	ABS	35 64			R↓	35 53	
	EEX	43			x<0	31 71	if $\rho < 0$:
	CHS	42			SF 2	35 51 02	$\lvert\rho\rvert \to \rho$
	5	05	Accuracy $1/10^5$		ABS	35 64	
	x≤y	32 71			STO B	33 12	$180+\theta \to \theta$
030	SF 2	35 51 02			CLX	44	
	R↑	35 54			1	01	
	F2?	35 71 02			8	08	
	GTO 0	22 00			0	00	
	↑	41		090	R↑	35 54	
	COS	31 63			F2?	35 71 02	
	RCL 3	34 03			+	61	
	×	71			360	03	
	1	01			6	06	If $\theta > 360°$
	x⇄y	35 52	Compute r		0	00	
040	−	51			x>y	32 81	$\theta - 360° \to \theta$
	RCL 4	34 04			CLX	44	
	×	71			−	51	
	STO 8	33 08			STO C	33 13	
	R↓	35 53		100	RCL B	34 12	
	2	02			−x−	31 84	Display ρ
	÷	81			x⇄y	35 52	Display θ
	TAN	31 64			RTN	35 22	
	DEG	35 41			LBL B	31 25 12	Enter data
	1	01	Compute ν		CF 3	35 61 03	
050	RCL 3	34 03			7	07	
	+	61			ST I	35 33	
	1	01			0	00	
	RCL 3	34 03			−x−	31 84	Display 0 to
	−	51		110	MERGE	32 41	enter card
	÷	81			PAUSE	35 72	
	√x	31 54			F3?	35 71 03	

REGISTERS

0	1	2	3	4	5	6	7	8	9
	p_1	T_1	e_1	a_1	ω_1	i_1	Ω_1	USED	

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
	P_2	T_2	e_2	a_2	ω_2	i_2	Ω_2	USED	

A	B	C	D	E	I
t	ρ	θ			

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
	RTN	35 22	
	1	01	
	ST I	35 33	
	LBL 1	31 25 01	
	CF 3	35 61 03	
	PAUSE	35 72	
	F3?	35 71 03	
120	GTO 3	22 03	Stop if no data
	R/S	84	entered
	LBL 2	31 25 02	
	STO (i)	33 24	
	ISZ	31 34	
	7	07	
	RC I	35 34	
	x≤y	32 71	
	GTO i	22 01	
	CLX	44	
130	W/DATA	31 41	
	RTN	35 22	
	LBL D	31 25 14	P⇄S for new
	P⇄S	31 42	star
	RTN	35 22	
	LBL C	31 25 13	
	ST I	35 33	Start data entry
	GTO i	22 01	at nth parameter
	LBL E	31 25 15	
	x⇄y	35 52	
140	RTN	35 22	
150			
160			
170			
180			
190			
200			
210			
220			

LABELS

A	B	C	D	E
DATE → P,B	LOAD DATA	LOAD N	New Star	x⇄y
a	b	c	d	e
0 USED	1 USED	2 USED	3	4
5	6	7	8	9

FLAGS

0	
1	
2	USED
3	USED

SET STATUS

FLAGS	ON	OFF
0	☐	☒
1	☐	☒
2	☐	☒
3	☐	☒

TRIG	
DEG	☒
GRAD	☐
RAD	☐

DISP	
FIX	☒
SCI	☐
ENG	☐
n	3

Program Description I

Program Title PRECESSION/GALACTIC COORDINATES

Contributor's Name Edward J. Groth III

Address Physics Dept., Princeton University

City Princeton, NJ **State** NJ **Zip Code** 08540

Program Description, Equations, Variables 1. Precesses right ascension (α_0) and declination (δ_0) at an initial epoch (IE) to right ascension (α) and declination (δ) at a final epoch (FE). Uses formulae given in the Explanatory Supplement to the Ephemeris, pp. 30-31. These formulae include the effects of general and luni-solar precession.

2. Converts 1950.0 equatorial coordinates (α_{50}, δ_{50}) to new galactic longitude (ℓ) and new galactic latitude (b). Formulae are given by Allen, Astrophysical Quantities, 3rd ed., p. 283.

3. Converts equatorial coordinates for any epoch to galactic coordinates by $(\alpha_0, \delta_0) \rightarrow (\alpha_{50}, \delta_{50}) \rightarrow (\ell, b)$

4. Converts galactic coordinates to equatorial coordinates for any epoch by $(\ell, b) \rightarrow (\alpha_{50}, \delta_{50}) \rightarrow (\alpha, \delta)$

A. Epochs are in years, e.g. 1950.0

B. b and ℓ are in decimal degrees, δ is in degrees, minutes, seconds, α is in hours, minutes, seconds. On input/output, δ or b is in y and α or ℓ is in x. $0^\circ \leq \ell < 360^\circ$, $0^h \leq \alpha < 24^h$.

C. For operations 3 or 4 above, the final or initial epoch, respectively, must be 1950.0 and the precess flag (flag 1) must be set.

Operating Limits and Warnings To prevent outputs in H.MS or D.MS format from appearing as 10.5960 (i.e. rounded 10.59597), the program rounds in H.MS format, converts to H format and converts back to H.MS format. To prevent rounding, the no round flag (flag 0) must be set. Rounding should not be used with less than 3 digits to right of decimal point as it will not work properly when rounding from seconds to minutes or from minutes to hours/degrees in H.MS format.

Program Description II

Sketch(es)

Sample Problem(s) The Abell Cluster 1656 has 1855.0 coordinates

$\alpha_{1855} = 12^h\ 52.^m8$

$\delta_{1855} = 28^\circ\ 46'$

What are its galactic coordinates?

Solution(s)

	Keys	Display	Comment
Solution	[f] [A]	1.0000	(Set NO RND Flag)
	[f] [B]	1.0000	(Set PRECESS Flag)
	1855 [A] 1950 [B]	1950.0000	(IE and FE)
	28.4600 [ENTER] 12.5248	12.5248	δ_{1855}, α_{1855}
	[D]	58.1767	ℓ (decimal deg)
	[h] [x ⇄ y]	87.9582	b (decimal deg)
Transform back to check results	[f] [C], [h] [x ⇄ y]		(interchange IE, FE, restore b in y, ℓ in x)
	[E]	12.5248	α_{1855}
	[h] [x ⇄ y]	28.4560	δ_{1855} (NO RND)

Reference(s)

1. Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac, 1961, London, Her Majesty's Stationery Office.

2. C. W. Allen, Astrophysical Quantities 3rd ed., 1973, University of London, Athlone Press.

User Instructions

PRECESSION / GALACTIC COORDINATES PROGRAM CARD

1					2
	NO ROUND?	PRECESS?	IE ⇄ FE	IE→y, FE→x	
	IE	FE	$\delta_0 \uparrow \alpha_0 \to \delta, \alpha$	$\delta \uparrow \alpha \to b, \ell$	$b \uparrow \ell \to \delta, \alpha$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load sides 1 and 2 of program card				
	Load sides 1 and 2 of constants card				
	For Precession:				
2	Enter initial epoch (when loaded IE = 1900.0)	IE (years)	A		IE → y FE → x
3	Enter final epoch (when loaded FE = 1900.0)	FE (years)	B		IE → y FE → x
4	Precess δ_0, α_0 to δ, α	$\delta_0 \uparrow \alpha_0$	C		$\delta \to y$ $\alpha \to x$
	For new case with same IE, FE, go to step 4				
	To change IE, go to step 2				
	To change FE, go to step 3				
	1950.0 equatorial ⇄ galactic conversion:				
5	Transform 1950.0 δ, α to b, ℓ	$\delta_{1950} \uparrow \alpha_{1950}$	D		$b \to y$ $\ell \to x$
6	Transform b, ℓ to 1950.0 δ, α	$b \uparrow \ell$	E		$\delta_{1950} \to y$ $\alpha_{1950} \to x$
	Optional:				
7	Change NO ROUND flag		f	a	1 ⇒ NO ROUND 0 ⇒ ROUND
8	Change PRECESS flag		f	b	1 ⇒ PRECESS 0 ⇒ NO PREC
9	Exchange IE, FE leaving x, y unchanged		f	c	x, y unchanged
10	Display current IE, FE		f	d	IE → y FE → x
11	Transform α_0, δ_0 at initial epoch to ℓ, b				
11A*	Set NO ROUND flag (step 7)				
11B	Set PRECESS flag (step 8)				
11C	Enter IE (step 2)				
11D	FE = 1950.0 (step 3)				
11E	Transform α_0, δ_0 to ℓ, b	$\delta_0 \uparrow \alpha_0$	D		$b \to y$ $\ell \to x$
	For new case with same IE go to step 11E				
12	Transform ℓ, b to α, δ at final epoch				
12A*	Set NO ROUND flag (step 7)				
12B	Set PRECESS flag (step 8)				
12C	IE = 1950.0 (step 2)				
12D	Enter FE (step 3)				
12E	Transform ℓ, b to α, δ	$b \uparrow \ell$	E		$\delta \to y$ $\alpha \to x$
	For new case with same FE go to step 12E				
*	Optional - avoids rounding of intermediate results				

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001 A	f LBL A	31 25 11	ENTER NEW IE (NIE)
	1	01	
	9	09	
	0	00	
	0	00	
	−	51	
	ENTER	41	
	CHS	42	
	RCL 4	34 04	
010	+	61	
	STO +5	33 61 05	FE − NIE → 5
	h R↓	35 53	
	STO 4	33 04	NIE − 1900 → 4
	GTO 1	22 01	GTO PREC. CONST. SUB.
B	f LBL B	31 25 12	ENTER NEW FE (NFE)
	1	01	
	9	09	
	0	00	
	0	00	
020	−	51	
	RCL 4	34 04	
	−	51	
	STO 5	33 05	NFE − IE → 5
1	f LBL 1	31 25 01	UPDATE PREC CONST.
	RCL 9	34 09	
	RCL 5	34 05	
	x	71	
	RCL 8	34 08	
	+	61	
030	RCL 5	34 05	
	x	71	
	RCL 4	34 04	
	RCL 7	34 07	
	x	71	
	+	61	
	RCL 6	34 06	
	+	61	
	RCL 5	34 05	
	x	71	
040	STO 0	33 00	$\zeta_0 \to 0$
	RCL 5	34 05	
	g x^2	32 54	
	RCL A	34 11	
	x	71	
	+	61	
	STO 2	33 02	$z \to 2$
	RCL E	34 15	
	RCL 5	34 05	
	x	71	
050	RCL D	34 14	
	+	61	
	RCL 5	34 05	
	x	71	
	RCL 4	34 04	
	RCL C	34 13	
	x	71	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	+	61	
	RCL B	34 12	
	+	61	
060	RCL 5	34 05	
	x	71	
	STO 1	33 01	$\theta \to 1$
d	g LBL d	32 25 14	IE → y, FE → x
	RCL 4	34 04	
	1	01	
	9	09	
	0	00	
	0	00	
	+	61	
070	STO 3	33 03	
	RCL 5	34 05	
	+	61	
	RCL 3	34 03	
	h x⇄y	35 52	
	h RTN	35 22	
C	f LBL C	31 25 13	PRECESS
	f GSB 5	31 22 05	→ H, ROTATE
	f GSB 2	31 22 02	→ H.MS, ROUND
	h RTN	35 22	
080 5	f LBL 5	31 25 05	Convert α, δ to decimal degrees
	f H←	31 74	
	1	01	
	5	05	
	x	71	
	h x⇄y	35 52	
	f H←	31 74	
0	f LBL 0	31 25 00	Rotate sub.
	STO 3	33 03	
	h x⇄y	35 52	Rotate about z by 1st Euler angle
090	RCL 0	34 00	
	+	61	
	h x⇄y	35 52	Convert to polar in x-z plane
	f cos	31 63	
	f R←	31 72	
	RCL 3	34 03	
	f SIN	31 62	
	g →P	32 72	
	h x⇄y	35 52	rotate about y by 2nd Euler angle
	RCL 1	34 01	
100	−	51	
	h x⇄y	35 52	Convert to rect in x-z plane
	f R←	31 72	
	g $\sin^{-1}$	32 62	
	STO 3	33 03	
	h R↓	35 53	Convert to polar in x-y plane
	g →P	32 72	
	h x⇄y	35 52	
	RCL 2	34 02	Rotate about z by third Euler angle
	+	61	
110	1	01	
	0	00	
	8	08	

REGISTERS

0	1	2	3	4	5	6	7	8	9
ζ_0	θ	z	used	IE − 1900	FE − IE	6.400694444 $\times 10^{-3}$	3.877777778 $\times 10^{-8}$	8.388888889 $\times 10^{-9}$	5.0 $\times 10^{-12}$

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
167.75	62.6	−57	used						

A	B	C	D	E	I
2.197222222 $\times 10^{-8}$	5.568561111 $\times 10^{-3}$	−2.369444444 $\times 10^{-8}$	−1.183333333 $\times 10^{-8}$	−1.166666667 $\times 10^{-11}$	

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
	0	00	
	+	61	
	3	03	
	6	06	GET
	0	00	0 ≤ α/θ < 360
	÷	81	
	g FRAC	32 83	
120	3	03	
	6	06	
	0	00	
	x	71	
	RCL 3	34 03	
	h RTN	35 22	
2	f LBL 2	31 25 02	→H.MS & ROUND SUB
	g →H.MS	32 74	δ → H.MS
	h x⇄y	35 52	
	1	01	
130	5	05	
	÷	81	
	g →H.MS	32 74	α → H.MS
	h F? 0	35 71 00	CHECK FLAG
	h RTN	35 22	SET ⇒ NO ROUND
	f RND	31 24	
	f H←	31 74	
	g →H.MS	32 74	
	h x⇄y	35 52	ROUND
	f RND	31 24	
140	f H←	31 74	
	g →H.MS	32 74	
	h x⇄y	35 52	
	h RTN	35 22	
D	f LBL D	31 25 14	EQUAT. → GAL.
	h F? 1	35 71 01	PRECESS FLAG?
	f GSB C	31 22 13	SET ⇒ PRECESS
	f P⇄S	31 42	EULER ANGLES FOR CONV
	f GSB 5	31 22 05	→ H.MS, ROTATE
	h x⇄y	35 52	
150	f P⇄S	31 42	RESTORE REG'S
	h RTN	35 22	
E	f LBL E	31 25 15	GAL. → EQUAT.
	f P⇄S	31 42	GET EULER ANGLES
	f GSB 6	31 22 06	INVERT FOR INVERSE TRAN.
	h x⇄y	35 52	
	f GSB 0	31 22 00	ROTATE
	f GSB 2	31 22 02	→ H.MS + ROUND
	f GSB 6	31 22 06	REINVERT ANGLES
	f P⇄S	31 42	RESTORE REG'S
160	h F? 1	35 71 01	CHECK PRECESS FLAG
	f GSB C	31 22 13	SET ⇒ PRECESS
	h RTN	35 22	
c	g LBL c	32 25 13	EXCHANGE IE, FE
	RCL 4	34 04	
	RCL 5	34 05	
	CHS	42	
	STO 5	33 05	
	−	51	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	STO 4	33 04	
170	h R↓	35 53	
6	f LBL 6	31 25 06	INVERT EULER ANGLES
	RCL 0	34 00	
	CHS	42	
	RCL 2	34 02	
	CHS	42	
	STO 0	33 00	
	h R↓	35 53	
	STO 2	33 02	
	CLX	44	
180	RCL 1	34 01	
	CHS	42	
	STO 1	33 01	
	h R↓	35 53	
	h RTN	35 22	
a	g LBL a	32 25 11	NO ROUND FLAG TOGGLE
	h F? 0	35 71 00	
	GTO 3	22 03	
	h SF 0	35 51 00	
	1	01	
190	h RTN	35 22	
3	f LBL 3	31 25 03	
	h CF 0	35 61 00	
	0	00	
	h RTN	35 22	
b	g LBL b	32 25 12	PRECESS FLAG TOGGLE
	h F? 1	35 71 01	
	GTO 4	22 04	
	h SF 1	35 51 01	
	1	01	
200	h RTN	35 22	
4	f LBL 4	31 25 04	
	h CF 1	35 61 01	
	0	00	
	h RTN	35 22	
210			
220			

CONTENTS OF DATA REGISTERS – TO BE STORED ON CONSTANTS CARD:

0–5. 0.0
6. 6.400694444 −3
7. 3.877777778 −8
8. 8.388888889 −9
9. 5.0 −12
10. 167.75
11. 62.6
12. −57.0
13–19. 0.0
20. 2.197222222 −8
21. 5.568561111 −3
22. −2.369444444 −8
23. −1.183333337 −8
24. −1.166666667 −11
25. 0.0

LABELS

A ENTER IE	B ENTER FE	C PRECESS	D EQU → GAL	E GAL → EQU
a NO ROUND FLAG TOGGLE	b PRECESS FLAG TOGGLE	c IE ⇄ FE	d FE → X, IE → Y	e
0 ROTATES	1 COMPUTES PREC. EULER ANGLES	2 H → H.MS + ROUND	3 CF 0	4 CF 1
5 H.MS → H + ROTATE	6 INVERTS EULER ANGLES	7	8	9

FLAGS

0 0 ⇒ ROUND, 1 ⇒ NO ROUND
1 0 ⇒ NO PRECESS, 1 ⇒ PRECESS
2
3

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☐	RAD	☐	ENG	☐
3	☐	☐			n 4	

Program Description I

Program Title SPACE SCIENCE AND TECHNOLOGY, NO.(5) KEPLER'S EQUATION

Contributor's Name Robert C. WYCKOFF

Address 9517 Cordero Ave.

City TUJUNGA State California Zip Code 91042

Program Description, Equations, Variables Kepler's Equation is the only relation which introduces time after some epoch into the classical Newtonian two body dynamics. All other relations deal with the various position parameters of the body in orbit. Kepler's Equation is

(1) $\Delta t = \frac{E - e\sin E}{n}$ Δt is the time after the time at perifocus, E is the eccentric anomaly (See Figure L, Page 2), e is the eccentircity, and n is the mean motion in radians/sec, degrees/hr. etc.

In this program, (2) $n = \frac{2\pi}{T}$ where T is the period. E is given by

(3) $E = \cos^{-1}\left[\frac{1 - r/a}{e}\right]$ where r is the focal radius, and a is the semi-major axis. a is computed by (4) $a = \left[\frac{\mu T^2}{4\pi^2}\right]^{1/3}$ and

(5) $r = \frac{a(1-e^2)}{1+e\cos\nu}$ where ν is the true anomaly (See Figure 1 page 2) e is computed by (6) $e = \left[1 - \frac{r_p}{a}\right]$ where r_p is the periapsis distance from the primary.

μ = GM where G is the Constant of Universal Gnavitation and M is the mass of the primary

n is given by $\frac{2\pi}{T}$

The velocity of the body at a point on the ellipse, and the path angle are frequently desired. They are given by

(7) Velocity $= v = \left[\mu\left(\frac{2}{r} - \frac{1}{a}\right)\right]^{1/2}$ and

Path Angle to the local vertical $= \beta_v = \sin^{-1}\left[\frac{[\mu a(1-e^2)]^{1/2}}{rv}\right]$

The path angle to the local horizon is given by $\beta_h = 90 - \beta_v$

(Continued Page 1a)

Operating Limits and Warnings Equation (1) breaks down around 180 degrees, due to the cosine function rounding off to a value slightly larger than one, and beyond 360 degrees. The solution to the latter is to simply add the period initially to the time at perifocus and proceed on into the n+1 orbit. The actual region around 180 degrees is very small, being something like (179.995 to 180.005) degrees. Page 3 will show how to avoid this situation.

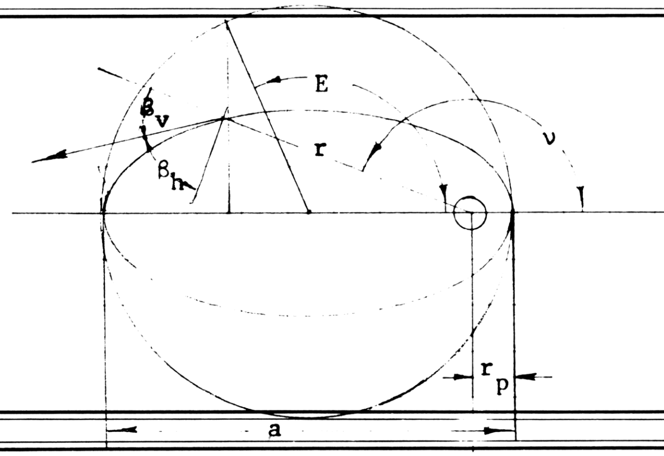
For a new iteration involving Key C, the original value of $\Delta\nu$ must be replaced in R_4, since it has been reduced through successive divisions by a factor of 5 in step 117. For Key C operation, the original value of $\Delta\nu$ must be placed in R_4 after the end of an iteration, since it has been successively ~~decreased by a factor of 5 during the first iteration process.~~

The inverse process for equation (1) is another matter. The equation cannot be solved explicitly. It must be solved through a matter of successive approximations or iterations. We wish to solve for the true anomaly given a particular time for the body in the ellipse.

We start by entering a trial value of ν and computing the time. If this time is less than the desired time, we augment the original value of ν by $\Delta\nu$ a sufficient number of times until the calculated time is greater than the true time. The value of ν_x is then decreased by $\Delta\nu$ and a smaller $\Delta\nu$ established, saw 1/5 th $\Delta\nu$. The iteration is then performed until the computed time is again greater than the true time, and the process is repeated with ever smaller $\Delta\nu$'s. When the difference between the computed and true time is smaller than a predetermined interval, say 1 second (it can be any value from seconds down to fractions of seconds) the program stops and displays the true anomaly. Register y holds the associated focal radius.

Program Description II

Sketch(es)



Sample Problem(s) A satellite is in orbit about the moon, with a period of 3 hours, and a periapsis altitude of 50 km. On orbit x, the time at perifocus is 1653:19 GMT. What is:

a) The GMT when the true anomaly is 40^o
b) The velocity in the orbit at that time of a).
c) The focal distance (focal radius) at the above time.
d) The path angle to the vertical at the above time.
e) The true anomaly at a GMT of 1900:26 in the same orbit.
f) The focal radius at the time in e).

SOLUTIONS: Load program. Place 4.90098×10^3 (from the table on page 4a) which is μ for the moon in R_A. Load the period, 3 x 60 x 60 = 10800 seconds in R_B. Place the periapsis distance from the center of the primary, 1739.29 + 50 = 1789.29 km in R_C. The mean radius of the moon also is taken from page 4a. Place the perifocus time of 16.5319 in R_D and 3600 in R_E.
Key A must be used to initialize. This computes the semi-major axis, the eccentricity, and $2\pi/T = n$ in radians per second in R_0, R_C and R_3 respectively. Observe 0.000581776 radians per second in display. Place 40 in display and do Key B. Program will pause and display 694 seconds, which will become 17.0453 GMT for the answer to part a). Key D gives 1.788 km/sec as answer to part b). Recall

Solution(s) contents of R_2, 1881.76 km for answer to part c)(The focal radius).
Key h R↓.Key E gives 81.918° for the value of β_v for part d).

Place 20 for Δν in R_4.
Place the new time of 19.0026 in R_9. Let us place 0.0001 (for one second) in R_7 which will determine that the program stops when the calculated time minus the true time is less than one second. Place a trial true anomaly of 200^o in display. Press Key C. You will see displayed for two seconds each the values 6383, 7288. 8070, 7455, 7617, 7773, 7648, 7623, 7629, 7624, 7625, 7627 after which the program run will stop and display 228.256^o as the value of ν which results in the calculated time in orbit of 7627 seconds AFTER 1653:19 GMT. Roll down the stack to y and see 2752.31 km for the focal radius. These last two results are the solutions to part e) and f) respectively. One could modify the program at step 124 to do this by a R/S if desired.

Reference(s) Any standard text on Astrodynamics such as AN INTRODUCTION TO ASTRODYNAMICS by R. M. L. Baker and M. W. Makemson, Academic Press, New York 1960 or THEORETICAL PHYSICS by G. Joos, Hafner Publishing Co, Inc. New York or EINFUEHRUNG IN DIE THEORETISCHE PHYSIK by C. Schaefer, Walter de Gruyter & Co. Berlin and Leipzig, 1929 or
JPL Technical Memorandum 33-414 DETERMINATION OF INTERPLANETARY TRAJECTORIES, H. F. Lesh 1968

User Instructions

SPACE SCIENCE AND TECHNOLOGY, No. (5)
KEPLER'S EQUATION

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Load program. Select the astronomical body from the table below and load the value of μ in R_A. Place the period, T, in seconds in R_B and the value of the periapsis distance (TO THE CENTER OF THE BODY) in R_C. Place the time at periapsis in hh.mmss in R_D and 3600 in R_E				
2	Key A initializes the program by computing a, e, and n and placing them in R_0, R_C, and R_3		A		a, e, n
3	Place the value of ν in display, for which the time is desired.	ν			
4	Key B computes the time after periapsis time in seconds(displays for 2 seconds) and the final GMT value		B		Δt in sec. t in hms
5	After any operation of Key B, the vis viva velocity and the path angles can be computed by				
6	Key D computes the vis viva velocity in km/sec		D		v
7	Key E computes the path angle to the vertical		E		β_{vert}
	R/S computes the path angle to the horizontal		R/S		β_{horiz}
	FOR DETERMINATION OF TRUE ANOMALY				
8	Load the new time in hh.mmss in R_9. Load in R_7 a difference constant(generally tens or fractions of one second, such as (0.0001 for a one second accuracy). Program will now stop when the difference netween the true and the calculated times is less than one second.				
9	Place a trial value of the true anomaly in the display.	trial ν			
10	Key C will compute successive values of Δt's in seconds and successively display them for 2 seconds. The values quickly bracket the correct Δt in seconds (GMT at periapsis - GMT at each computed value of ν_i's, expressed in seconds) and stop when the difference is less than the value placed in R_7. Displayed is the corresponding value of ν in decimal °.		C		successive Δt's and final value of ν in dec. degrees
11	The corresponding focal radius is in the y register.				
12	At any part of the above, the value of the semi-major axis is found in R_0, the particular value of ν (ν+ Δν) in R_1, the focal radius r, in R_2, the eccentricity in R_C, the value of n in R_3 and Δν in R_4				
	See page 3a for additional information				

Some experience is needed in choosing the initial value of ν and Δν. Generally Δν will be less than ν if some idea before hand is available as to the relative magnitude of the parameters. The period, expressed in seconds is very useful, as T/2 immediately is associated with a true anomaly value of 180°. If the value of the time is such that its difference from the periapsis time is greater (expressed in seconds) than one half the period, then Δν should be considerably less than ν so that upon the first iteration, the value of ν + Δν is not greater than 360 degrees. If the time, (in R_9) is close to the periapsis time (say T/4 or less) then one should start with a relatively small ν (say 60 degrees) and a large Δν, say 90 degrees. Care should be taken to see that the initial ν + Δν does not equal 180 degrees, (for instance 120° and 60°) An error will then result. Simple start with a slightly different ν or Δν (say 120 degrees and 59 degrees.

One can always start, in a completely unknown situation, with a small ν and Δν, say 5 or 10 degrees, and 10 degrees for Δν. but then a large number of iterations will be probable. From a knowledge of the Δ times, $t_p - t_x$ or just t_p and the period (for Key B operation), one can make a sensible estimate of the initial value of ν and Δν.

Values of μ and the mean radius of various astronomical bodies follow

Body	μ in km^3/sec^2	R in km
Moon	4.90098×10^3	1.73929×10^3
Mercury	2.15215×10^4	2.42099×10^3
Venus	3.24815×10^5	6.052×10^3
Earth	3.986012×10^5	6.371017×10^3
Mars	4.3043×10^4	3.38755×10^3
Jupiter	1.26658×10^8	7.1375×10^4
Saturn	3.79416×10^7	6.0400×10^4
Uranus	5.77892×10^6	2.3500×10^4
Neptune	6.85500×10^6	2.5000×10^4
Pluto	3.31237×10^5	2.960×10^3
Sun	1.324948×10^{11}	6.9600×10^5
Titan	9.300×10^3	2.900×10^3
Io	5.950×10^3	1.829×10^3
Europa	3.250×10^3	1.500×10^3
Ganymede	9.940×10^3	2.500×10^3
Callisto	7.100×10^3	2.635×10^3

67 Program Listing I

KEPLER'S EQUATION

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	f-LBL-A	31-25-11	
	1	01	
	RCL-B	34-12	
	g - x^2	32-54	
	RCL-A	34-11	
	x	71	
	h - π	35-73	
	g - x^2	32-54	
	4	04	
010	x	71	
	./.	81	
	h-x/y	35-52	
	3	03	
	./.	81	
	h - y^x	35-63	computes a
	STO-0	33-00	
	RCL-C	34-13	
	h- x/y	35-52	
	./.	81	
020	-	51	computes e
	STO-C	33-13	
	h - π	35-73	
	2	02	
	x	71	
	RCL-B	34-12	
	./.	81	computes n
	STO-3	33-03	
	h - RTN	35-22	INITIALIZATION
	f-LBL-B	31-25-12	Place ν in x
030	STO-1	33-01	
	1	01	
	h- x/y	35-52	
	1	01	
	RCL-C	34-13	
	g - x^2	32-54	
	-	51	
	RCL-0	34-00	
	x	71	
	h- x/y	35-52	
040	f -cos	31-63	
	RCL-C	34-13	
	x	71	
	1	01	
	+	61	
	./.	81	computes r
	STO - 2	33-02	
	RCL-0	34-00	
	./.	81	
	-	51	
050	RCL-C	34-13	
	./.	81	
	h-RAD	35-42	
	g - cos	32-63	computes E
	ENT	41	
	ENT	41	
	RCL-1	34-01	
	g-RAD	32-73	
	h - π	35-73	
	g-x y	32-81	
060	GTO-1	22-01	
	GTO-2	22-02	
	f-LBL-1	31-25-01	
	h-down	35-53	
	h-down	35-53	
	GTO-3	33-03	
	f-LBL-3	31-25-03	
	f-sine	31-62	
	RCL-C	34-13	
	x	71	
070	-	51	
	RCL-3	34-03	
	./.	81	Δt in sec.
	h-pause	35-72	
	h-deg	35-41	
	RCL-E	34-15	
	./.	81	Δt in dec. hrs.
	g-hms	32-74	Δt in hms
	RCL-D	34-14	
	h-hms+	35-83	t
080	h-RTN	35-22	time after periapsis
	f-LBL-2	31-25-02	
	h- x/y	35-52	
	CLX	44	
	2	02	
	x	71	
	h- x/y	35-52	
	-	51	
	ENT	41	
	GTO-3	22-03	
090	f-LBL-C	31-25-13	
	f-GSB-B	31-22-12	
	STO-8	33-08	
	RCL-9	34-09	
	g x y	32-81	
	GTO-4	22-04	
	GTO-5	22-05	
	f-LBL-4	31-25-04	
	RCL-1	34-01	
	RCL-4	34-04	
100	+		
	GTO-C	22-13	
	f-LBL-5	31-25-05	
	RCL-8	34-08	
	RCL-9	34-09	
	CHS	42	
	h-hms+	35-83	
	h-ABS	35-64	
	RCL-7	34-07	
	g -x y	32-71	
110	GTO-6	22-06	
	GTO-7	22-07	
	f-LBL-6	31-25-06	

REGISTERS

0	1	2	3	4	5	6	7	8	9
a Km	ν	r km	n	Δν			Δt diff.	t (last)	t_x
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I
μ km^3/sec^2	T seconds	r_p km (e) (prog)	t_p	3600	

KEPLER'S EQUA.

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
	RCL-1	34-01	
	RCL-4	34-04	
	-	51	
	RCL-4	34-04	
	5	05	
	./.	81	
	STO-4	33-04	
120	+	61	
	GTO-C	22-13	
	f-LBL-7	31-25-07	
	RCL-2	34-02	r in x
	RCL-1	34-01	ν in x
	h-RTN	35-22	ν in x; r in y
	f-LBL-D	31-25-14	
	2	02	
	RCL-2	34-02	
	./.	81	
130	RCL-0	34-00	
	h - 1/x	35-62	
	-	51	
	RCL-A	34-11	
	x	71	
	f - $x^{1/2}$	31-54	
	h -RTN	35-22	V in km/sec.
	f-LBL-E	31-25-15	
	1	01	
	RCL-C	34-13	
140	g - x^2	32-54	
	-	51	
	RCL-0	34-00	
	x	71	
	RCL-A	34-11	
	x	71	
	f - $x^{1/2}$	31-54	
	h- x/y	35-52	
	RCL-2	34-02	
	x	71	
150	./.	81	
	g-sin $^{-1}$	32-62	β_v (vertical)
	R/S	84	
	9	09	
	0	00	
	h- x/y	35-52	
	-	51	
	h-RTN	35-22	β_h (horizontal)
160			
170			
180			
190			
200			
210			
220			

LABELS					FLAGS
A	B	C	D	E	0
a	b	c	d	e	1
0	1	2	3	4	2
5	6	7	8	9	3

SET STATUS

FLAGS	ON	OFF	TRIG	DISP
0	☐	☐	DEG ☐	FIX ☐
1	☐	☐	GRAD ☐	SCI ☐
2	☐	☐	RAD ☐	ENG ☐
3	☐	☐		n ____

Program Description I

Program Title Orbit Determination by the Method of Gauss

Contributor's Name Rex H Shudde

Address 27105 Arriba Way

City Carmel **State** CA **Zip Code** 93921

Program Description, Equations, Variables Given $\mathbf{r}_1(x_1, y_1, z_1)$ at t_1 and $\mathbf{r}_2(x_2, y_2, z_2)$ at t_2, find $\dot{\mathbf{r}}_1(\frac{dx_1}{dt_1}, \frac{dy_1}{dt_1}, \frac{dz_1}{dt_1})$ at time t_1. Let k = gravitation constant ($\ell^{3/2} t^{-1}$ units) & μ = normalized mass. Then compute $\tau = k(t_2 - t_1)$; $r_i = \sqrt{\mathbf{r}_i \cdot \mathbf{r}_i}$ $i = 1, 2$; $\cos(v_2 - v_1) = (\mathbf{r}_1 \cdot \mathbf{r}_2)/(r_1 r_2)$; $\ell = \frac{r_1 + r_2}{4\sqrt{r_1 r_2}\cos\left(\frac{v_2 - v_1}{2}\right)} - \frac{1}{2}$; and

$$m = \frac{\mu \tau^2}{\left[2\sqrt{r_1 r_2}\cos\left(\frac{v_2 - v_1}{2}\right)\right]^3}.$$

Then set $y = 1$ and loop through the following equations until y remains unchanged: $x = m/y^2 - \ell$; $\cos\left(\frac{E_2 - E_1}{2}\right) = 1 - 2x$; $\sin\left(\frac{E_2 - E_1}{2}\right) = \sqrt{4x(1-x)}$; $X = [(E_2 - E_1) - \sin(E_2 - E_1)]/\sin^3\left(\frac{E_2 - E_1}{2}\right)$; and $y = 1 + X(\ell + x)$. When y has stabilized, compute: $a^{1/2} = \tau\sqrt{\mu}/\left[2y\sqrt{r_1 r_2}\cos\left(\frac{v_2 - v_1}{2}\right)\sin\left(\frac{E_2 - E_1}{2}\right)\right]$; $f = 1 - \frac{a}{r_1}[1 - \cos(E_2 - E_1)]$; $g = \tau - a^{3/2}[(E_2 - E_1) - \sin(E_2 - E_1)]/\sqrt{\mu}$; $g' = g/k$, and finally,

$$\dot{\mathbf{r}}_1 = \frac{\mathbf{r}_2 - f\mathbf{r}_1}{g'}.$$

The orbital elements of the body at time t_1 are consider to be $\mathbf{r}_1$ and $\dot{\mathbf{r}}_1$. These orbital elements may be converted to classical elements using companion program ( ).

Operating Limits and Warnings This method suffers from instability of convergence when the angle from $\mathbf{r}_1$ to $\mathbf{r}_2$ is greater than 90°. It is also assumed that the orbit has an eccentricity of less than 1, that is, the orbit is elliptical or circular.

Program Description II

Sketch(es)

Sample Problem(s) Given the following data: $k = 0.07436574\ (e.r.)^{3/2}/min$, $\mu = 1.0$ e.m. and $\mathbf{r}_1 = (2.460809, 2.040523, 0.143819)$ e.r. at $t_1 = 0$ min, and $\mathbf{r}_2 = (1.988041, 2.503334, 0.314554)$ e.r. at $t_2 = 15.0395328$ minutes, compute $\dot{\mathbf{r}}_1$ at $t_1 = 0$ min.

Input:

```
    1.0000 ENT↑
 .07436574 GSBA

0.00000000 ENT↑
 .14381900 ENT↑
2.04052300 ENT↑
2.46080900 GSBB

15.03953280 ENT↑
 .31455400 ENT↑
2.50333400 ENT↑
1.98804100 GSBC
```

Solution(s)

```
                      GSBE
```

Output: Stack contents

```
 0.000000000+00   T  ← Ignore
 1.160747099-02   Z  ← ż
 3.356191327-02   Y  ← ẏ
-2.850818940-02   X  ← ẋ
```

Reference(s)

P.R. Escobal, "Methods of Orbit Determination", Wiley and Sons, 1965

User Instructions

Orbit Determination – Gauss Method				
$\mu \uparrow k$	$t_1 \uparrow z_1 \uparrow y_1 \uparrow x_1$	$t_2 \uparrow z_2 \uparrow y_2 \uparrow x_2$		Compute

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program card.			
2	Enter normalized mass	μ	↑	
	Enter gravitational constant	k	A	
3	Enter reference point: time	t_1	↑	
		z_1	↑	
	$\mathbf{r}_1$ components	y_1	↑	
		x_1	B	
4	Enter second point time	t_2	↑	
		z_2	↑	
	$\mathbf{r}_2$ components	y_2	↑	
		x_2	C	
5	Compute		E	
6	Output is automatically printed on the HP-97 (ignore T-register)			
7	On the HP-67, roll the stack down			$\dot{x}_1$
	to obtain $\dot{\mathbf{r}}_1$.		R↓	$\dot{y}_1$
	$\dot{x}_1$ is in the X-register		R↓	$\dot{z}_1$
	$\dot{y}_1$ " " " Y-register			
	$\dot{z}_1$ " " " Z-register			
8	Repeat from Step 2 or Step 3 or Step 4 as desired			
	NOTE: The step 4 input data is internally destroyed, so do not repeat step 3 without repeating step 4			
	NOTE: The "Classical Orbital Element" Program can be used immediately with no further input required.			

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	Store
002	STOA	35 11	μ & k
003	R↓	-31	
004	STOB	35 12	
005	R/S	51	
006	*LBLB	21 12	Store
007	STO1	35 01	r_1 & t_1
008	R↓	-31	
009	STO2	35 02	
010	R↓	-31	
011	STO3	35 03	
012	R↓	-31	
013	STOC	35 13	
014	R/S	51	
015	*LBLC	21 13	
016	STO4	35 04	Store
017	R↓	-31	r_2 & t_2
018	STO5	35 05	
019	R↓	-31	
020	STO6	35 06	
021	R↓	-31	
022	STOD	35 14	
023	R/S	51	
024	*LBLE	21 15	
025	RAD	16-22	
026	RCLD	36 14	
027	RCLC	36 13	Compute:
028	-	-45	
029	RCLA	36 11	
030	×	-35	τ
031	STOD	35 14	
032	RCL1	36 01	
033	RCL2	36 02	
034	→P	34	
035	RCL3	36 03	
036	→P	34	
037	STO0	35 00	r_1
038	RCL4	36 04	
039	RCL5	36 05	
040	→P	34	
041	RCL6	36 06	
042	→P	34	
043	STO7	35 07	r_2
044	RCL1	36 01	
045	RCL4	36 04	
046	×	-35	
047	RCL2	36 02	
048	RCL5	36 05	
049	×	-35	
050	+	-55	
051	RCL3	36 03	
052	RCL6	36 06	$r_1 \cdot r_2$
053	×	-35	
054	+	-55	
055	RCL0	36 00	
056	÷	-24	

STEP	KEY ENTRY	KEY CODE	COMMENTS
057	RCL7	36 07	
058	÷	-24	
059	COS^{-1}	16 42	$v_2 - v_1$
060	2	02	
061	÷	-24	
062	COS	42	
063	RCL0	36 00	$\cos\left(\frac{v_2-v_1}{2}\right)$
064	RCL7	36 07	
065	×	-35	
066	√X	54	
067	×	-35	$\sqrt{r_1 r_2}\cos\left(\frac{v_2-v_1}{2}\right)$
068	STOE	35 15	
069	RCL0	36 00	
070	RCL7	36 07	
071	+	-55	
072	RCLE	36 15	
073	÷	-24	
074	4	04	
075	÷	-24	
076	.	-62	
077	5	05	
078	-	-45	l
079	RCLD	36 14	
080	X^2	53	
081	RCLB	36 12	
082	×	-35	
083	RCLE	36 15	
084	2	02	
085	×	-35	
086	3	03	
087	Y^X	31	
088	÷	-24	m
089	P⇄S	16-51	Exchange P & S registers
090	STO0	35 00	
091	R↓	-31	
092	STO1	35 01	Store m & l
093	1	01	
094	STO2	35 02	Initialize y
095	*LBL9	21 09	Loop
096	RCL2	36 02	
097	X^2	53	
098	1/X	52	
099	RCL0	36 00	
100	×	-35	
101	RCL1	36 01	
102	-	-45	
103	STO4	35 04	x
104	4	04	
105	×	-35	
106	1	01	
107	RCL4	36 04	
108	-	-45	
109	×	-35	
110	√X	54	$\sin\left(\frac{E_2-E_1}{2}\right)$
111	STO5	35 05	
112	1	01	

REGISTERS

0	1	2	3	4	5	6	7	8	9
r_1	x_1	y_1	z_1	x_2	y_2	z_2	r_2	$a^{3/2}$	E_2-E_1
S0	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
m	l	y		x	$\sin\left(\frac{E_2-E_1}{2}\right)$	E_2-E_1			

A	B	C	D	E	I
k	μ	t_1	t_2 & τ	Used & c^{g}/k	f

97 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	RCL4	36 04	
114	2	02	
115	x	-35	
116	-	-45	$\cos\left(\frac{E_2-E_1}{2}\right)$
117	→P	34	
118	X⇄Y	-41	
119	2	02	
120	x	-35	
121	STO6	35 06	(E_2-E_1)
122	ENT↑	-21	
123	SIN	41	
124	-	-45	
125	RCL5	36 05	
126	3	03	
127	Yˣ	31	
128	÷	-24	X
129	RCL1	36 01	
130	RCL4	36 04	
131	+	-55	
132	x	-35	
133	1	01	
134	+	-55	New value of ε
135	RCL2	36 02	
136	X⇄Y	-41	
137	STO2	35 02	
138	÷	-24	Test for
139	1	01	convergence
140	-	-45	
141	FIX	-11	
142	DSP9	-63 09	
143	RND	16 24	
144	X≠0?	16-42	Loop if not
145	GTO9	22 09	converged
146	RCLD	36 14	
147	RCLB	36 12	
148	√X	54	
149	x	-35	$\tau\sqrt{\mu}$
150	2	02	
151	÷	-24	
152	RCL2	36 02	
153	÷	-24	
154	RCLE	36 15	
155	÷	-24	
156	RCL5	36 05	$a^{1/2}$
157	÷	-24	
158	RCL6	36 06	
159	P⇄S	16-51	Exchange P & S
160	STO9	35 09	E_2-E_1
161	X⇄Y	-41	
162	STO8	35 08	$a^{1/2}$
163	X²	53	a
164	ST×8	35-35 08	$a^{3/2}$
165	RCL0	36 00	
166	÷	-24	
167	RCL9	36 09	
168	COS	42	
169	1	01	
170	-	-45	
171	x	-35	
172	1	01	
173	+	-55	
174	STOI	35 46	ξ
175	RCL9	36 09	
176	SIN	41	
177	LSTX	16-63	
178	-	-45	
179	RCL8	36 08	
180	x	-35	
181	RCLB	36 12	
182	√X	54	
183	÷	-24	
184	RCLD	36 14	
185	+	-55	ε
186	RCLA	36 11	
187	÷	-24	
188	STOE	35 15	$\varepsilon' = \varepsilon/k$
189	DSP9	-63 09	
190	RCL4	36 04	
191	RCL1	36 01	
192	GSB8	23 08	
193	STO4	35 04	$\dot{x}_1$
194	RCL5	36 05	
195	RCL2	36 02	
196	GSB8	23 08	
197	STO5	35 05	
198	RCL6	36 06	
199	RCL3	36 03	
200	GSB8	23 08	
201	STO6	35 06	$\dot{z}_1$
202	0	00	
203	X⇄Y	-41	
204	RCL5	36 05	
205	RCL4	36 04	
206	PRST	16-14	Print stack
207	R/S	51	
208	GTO0	22 00	Error display
209	*LBL8	21 08	Subroutine
210	SCI	-12	
211	RCLI	36 46	
212	x	-35	$\dot{r}_1 = \frac{r_2 - \xi r_1}{\varepsilon'}$
213	-	-45	
214	RCLE	36 15	
215	÷	-24	
216	RTN	24	
217	R/S	51	
220			

LABELS

A Input	B r_1 & t_1	C r_2 & t_2	D	E Compute
a	b	c	d	e
0 Error	1	2	3	4
5	6	7	8 ✓	9 Loop

FLAGS

0	
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☑	DEG	☐	FIX	☑
1	☐	☑	GRAD	☒	SCI	☐
2	☐	☑	RAD	☐	ENG	☐
3	☐	☑			n	4

NOTES

NOTES

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Revision C 12-78