

HEWLETT-PACKARD

HP-67/HP-97

Users' Library Solutions
Space Science



INTRODUCTION

In an effort to provide continued value to its 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.

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Program Description I

1

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,*

$$\begin{pmatrix} \cos \delta \cos(\alpha - z) \\ \cos \delta \sin(\alpha - z) \\ \sin \delta \end{pmatrix} = \begin{pmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{pmatrix} \begin{pmatrix} \cos \delta_0 \cos(\alpha_0 + S_0) \\ \cos \delta_0 \sin(\alpha_0 + S_0) \\ \sin \delta_0 \end{pmatrix}$$

where

$$S_0 = (2304''.250 + 1''.396 T_0)T + 0''.302 T^2 + 0''.018 T^3,$$

$$z = S_0 + 0''.791 T^2,$$

$$\theta = (2004''.682 - 0''.853 T_0)T - 0''.426 T^2 - 0''.042 T^3,$$

and

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

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.

This program has been verified only with respect to the numerical example given in Program Description II. User accepts and uses this program material AT HIS OWN RISK, in reliance solely upon his own inspection of the program material and without reliance upon any representation or description concerning the program material.

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Program Description II

Sketch(es)

Sample Problem(s)

1. Calculate the mean coordinates of ϵ Centauris for 1950.0 given that (α_0, δ_0) for 1900.0 are $22^h 06^m 50^s$ and $-80^\circ 56' 15''$
2. Using the initial 1900.0 data above, calculate the mean coordinates of ϵ Centauris for 1 Nov. 1975 (Julian Day Number = 2442718)

Solution(s)

1. $1900 \boxed{S/A} 0.0000 = T_0$; $1950.0 \boxed{S/B} 0.5000 = T$;
 $22.0650 \boxed{U} -80.5615 \boxed{E} 22^h 14^m 32^s = \alpha \boxed{R/S} -80^\circ 41' 23''$
2. $(1900 \boxed{F/A} 0.0000 = T_0 \text{ This need not be reentered})$;
 $2442718 \boxed{B} 0.7563 = T$; $22.0650 \boxed{U} -80.5615 \boxed{E}$
 $22^h 17^m 23^s = \alpha \boxed{R/S} -80^\circ 33' 37''$

Reference(s)

1. P. Escobar, "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.

3

[illegible]

67 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	\$LBLE A	31 25 11	Initial Epoch JD#		RCL 1	34 01	
	\$G5B 9	31 22 09			X	71	
	STD 0	33 00			4	04	
	R 15	84		060	2	02	
	\$LBLE B	31 25 12	Final Epoch JD#		6	06	
	\$G5B 9	31 22 09			-	51	
	\$LBLE 7	31 25 07			RCL 1	34 01	
	RCL C	34 00			X	71	
	-	51	Compute Precession Angles		8	08	
010	STD 1	33 01			5	05	
	1	01			3	03	
	8	08			RCL 0	34 00	
	X	71			X	71	
	3	03		070	-	51	
	0	00			2	02	
	2	02			0	00	
	+	61			0	00	
	RCL 1	34 01			4	04	
	X	71			6	06	
020	1	01			8	08	
	3	03	Store S ₀		2	02	
	9	09			+	61	
	6	06			RCL 1	34 01	
	RCL 0	34 00		080	X	71	
	X	71			RCL 5	34 05	Store 0
	+	61			÷	81	
	2	02			STD 4	33 04	
	3	03			RCL 1	34 01	
	0	00	Store S ₁		R 15	84	
030	4	04			\$LBLE	31 25 15	
	2	02			\$H←	31 74	
	5	05			h X⇌Y	35 52	Input initial α, δ
	0	00			\$H←	31 74	
	+	61		090	1	01	
	RCL 1	34 01			5	05	
	X	71			X	71	
	3	03			RCL 2	34 02	
	6	06			+	61	
	EEX	43	Store S ₂		h X⇌Y	35 52	
040	5	05			1	01	
	STD 5	33 05			\$R←	31 72	
	÷	81			h R↓	35 53	
	STD 2	33 02			h X⇌Y	35 52	Y-coord
	RCL 1	34 01		100	h R↑	35 54	
	\$X^2	32 54			\$R←	31 72	
	7	07			h X⇌Y	35 52	
	9	09	Store Z		STD 6	33 06	
	1	01			h R↓	35 53	
	X	71			h X⇌Y	35 52	
050	RCL 5	34 05			\$→P	32 72	
	÷	81			h X⇌Y	35 52	Z-coord
	+	61			RCL 4	34 04	
	STD 3	33 03			-	51	
	4	04		110	h X⇌Y	35 52	
	2	02			\$R←	31 72	
	CHS	42			STD 7	33 07	

REGISTERS

0	T ₀	1	T	2	S ₀	3	Z	4	Θ	5	36E5	6	Y-coord	7	Z-coord	8		9	
S0		S1		S2		S3		S4		S5		S6		S7		S8		S9	
A		B			C			D			E			I					

2

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS										
	h R/L	35 53			0	00	Transform Besselian Epoch to Tropical Centuries from 1900.0										
	RCL 6	34 06		170	0	00											
	h X $\Rightarrow$ Y	35 52			-	51											
	S $\rightarrow$ P	32 72			1	01											
	h X $\Rightarrow$ Y	35 52			0	00											
	RCL 3	34 03			0	00											
	+	61			$\div$	81											
120	3	03			h RTN	35 22											
	6	06				84											
	0	00															
	$\div$	81															
	1	01		180													
	+	61															
	S FRAC	32 83															
	2	02															
	4	04															
	X	71															
130	S $\rightarrow$ HMS	32 74	Display new α														
	R/S	84	-----														
	RCL 7	34 07	Display														
	S SIN ⁻¹	32 62	new δ	190													
	h $\rightarrow$ HMS	32 74															
	R/S	84															
	S LBL 9	31 25 09	Transform														
	2	02	Julian Day														
	4	04	Number														
	1	01	to														
140	5	05	Tropical														
	0	00	Centuries														
	2	02	from														
	0	00	JD 1900.0	200													
	0	00															
	3	03															
	1	01															
	3	03															
	-	51															
	3	03															
150	6	06															
	5	05															
	2	02															
	4	04															
	0	00															
	2	02		210													
	2	02															
	$\div$	81															
	h RTN	35 22															
	S LBL a	32 25 11	Initial Epoch														
160	S GSB B	31 22 06	Besselian														
	STD 0	33 00															
	R/S	84															
	S LBL b	32 25 12	Final Epoch														
	S GSB B	31 22 06	Besselian	220													
	GTO 7	22 07															
	S LBL B	31 25 08															
	1	01															
	9	09															
LABELS				FLAGS		SET STATUS											
A	✓	B	✓	C		D		E	✓	0		FLAGS		TRIG		DISP	
a	✓	b	✓	c		d		e		1		ON	OFF	DEG	☒	FIX	☒
0		1		2		3		4		2		☐	☐	GRAD	☐	SCI	☐
5		6		7	✓	8	✓	9	✓	3		☐	☐	RAD	☐	ENG	☐
												☐	☐			n	4

Program Description I

Program Title *Local Sidereal Time & Oblliquity 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

$$JD_{1900} = \left\lfloor \frac{2 \text{ mod}(I, 12) + 7 + 365I}{12} \right\rfloor + D + \left\lfloor \frac{I}{48} \right\rfloor - \left\lfloor \frac{I}{1200} \right\rfloor + \left\lfloor \frac{I}{14600} \right\rfloor - 693901$$

where Y = year, M = month, D = day, Int 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 $t_G = (\text{local standard time}) + (\text{time zone})$, + for West, - for East.

3. Compute R_G , the Greenwich mean sidereal time:

$$R_G = (23925.54 + 8640184.54T + 0.09T^2)/3600 + t_G (\text{mod } 24) \text{ hours.}$$

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.

This program has been verified only with respect to the numerical example given in Program Description II. User accepts and uses this program material AT HIS OWN RISK, in reliance solely upon his own inspection of the program material and without reliance upon any representation or description concerning the program material.

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Program Description II

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Sketch(es)

Sample Problem(s)

OBSERVATIONS ARE to be made FROM an observatory of $121^{\circ}57'$ 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]

20.00 [E] →

21.2525

20.15 [E] →

21.4028

20.30 [E] →

21.5530

20.45 [E] →

22.1033

[RIS] →

22.2633

Reference(s)

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

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A	B	C	D	E	F
GMT 19					

67 Program Listing II

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

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 θ is given by [2] $\tan \theta/2 = R/L$, and the central angle between the horizon and the sub-altitude point is [3] $90 - \theta/2 = \theta$. 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] $\cos \theta = [\sin \text{LatA}][\sin \text{LatB}] + \cos [\text{LongA}][\cos \text{LongB}][\cos(\text{LongA}-\text{LongB})]$

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 $R\theta$ 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

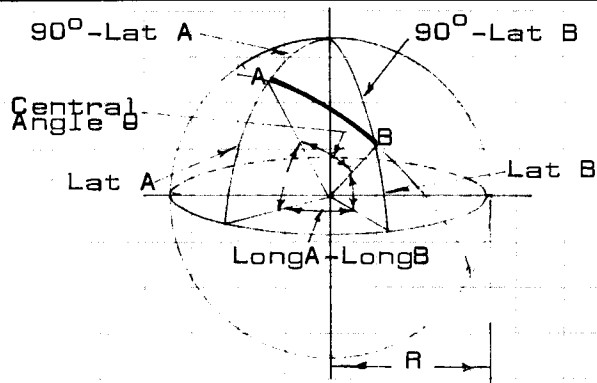
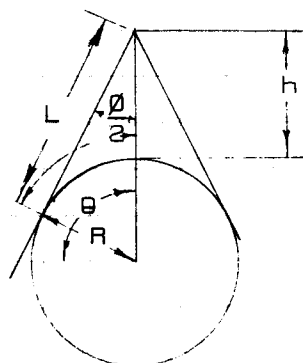
Remember that when the second side of the card is loaded into the HP-67, the above constants are loaded first into the primary register. These then must be transferred to the secondary register. This is necessitated by the program being loaded on the first side of the card. Additional operating instructions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

This program has been verified only with respect to the numerical example given in *Program Description II*. User accepts and uses this program material AT HIS OWN RISK, in reliance solely upon his own inspection of the program material and without reliance upon any representation or description concerning the program material.

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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°E 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 $\text{STO } I$, $\text{RCL}(i)$ 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

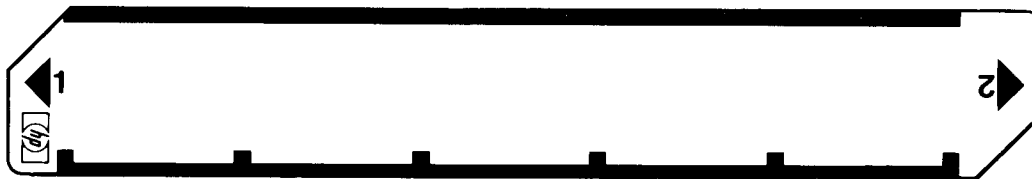
Saturn: Titan = 2440 km

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, <u>NEVER DEC. DEGREES.</u>		☐ ☐	
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 ☐	θ 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. [New h = h + delta h appears in display] R/S again re-iterates Key A through D		R/S ☐	new h
	Store proper value of planetary radius in R_0 through h-sto-i		☐ ☐	
13	Key E computes central angle between points A and B for smaller great circle distance		E ☐	θ smaller
14	R/S computes smaller great circle distance in km		R/S ☐	S in km [S]
15	R/S computes 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			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} .
	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			
	Additional planetary satellite radii as given on page 2 may be stored in $R_{20} - R_{25}$			

67 Program Listing I

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STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	F-LBL-A	31-25-11			RCL-4	34-04	Lat A
	RCL-2	34-02	h		F H	31-74	
	ENT	41			F-cos	31-63	cos A
	g-x ²	32-54		060	RCL-6	34-06	Lat B
	h X/Y	35-52			F H	31-74	
	RCL-0	34-00	R		F-cos	31-63	cos B
	2	02			x	71	
	x	71			RCL-5	34-05	Long A
	x	71			F	31-74	
010	+	61			RCL-7	34-07	Long B
	F-[x] ^{1/2}	31-54	L		F H	31-74	
	R/S	84	L in km		-	51	
	ENT	41			h-ABS	35-64	
	ENT	41		070	F-cos	31-63	
	RCL-1	34-01	1.852		x	71	
	./.	81			+	61	
	R/S		L in n. miles		g-cos	32-63	θ
	h-7	35-52			R/S	84	θ in dec. deg.
	h-RTN	35-22	L in km		g-Rad	32-73	
020	F-LBL-B	31-25-12			STO-8	33-08	
	RCL-0	34-00	R		RCL-0	34-00	R
	h-7	35-52			x	71	Rθ = S
	./.	81	tan θ/2		R/S	84	S in km [smaller]
	g tan ⁻¹	32-64	θ/2 in dec. deg	080	RCL-1	34-01	1.852
	2	02			./.	81	
	x	71	θ		h-RTN	35-22	S in n. miles
	h-RTN	35-22	θ in dec. deg.		g-LBL-A	32-25-11	
	F-LBL-C	31-25-13			h-"	35-73	
	2	02			2	02	
030	./.	81			x	71	
	g	09			RCL-8	34-08	θ
	0	00	90		-	51	θ ₁
	h-7	35-52			RCL-0	34-00	R
	-		90-θ = θ	090	x	71	Rθ ₁
	h-RTN	35-22	θ in dec. deg.		R/S	84	S ₁ in km [larger]
	F-LBL-D	31-25-14			RCL-1	34-01	1.852
	g-RAD	32-73	θ in Rad.		./.	81	
	RCL-0	34-00	R		h-RTN	35-22	S ₁ in n. miles.
	x	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	100			
	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		110			
	f-sin	31-62	sin B				
	x	71					

REGISTERS

0 Radius = R	1.852	2 h [km]	3 Delta h [km]	4 Lat ₀ A	5 Long ₀ A	6 Lat ₀ B	7 Long ₀ B	8 θ rad. [prog]	9
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
A	B	C	D	E	F	G	H	I	J

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] $V_o = \left[u \left[\frac{2}{r_o} - \frac{1}{a} \right] \right]^{\frac{1}{2}}$ 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] $V_c = \left[\frac{u}{r_g} \right]^{\frac{1}{2}}$ where r_g is the radius of the circular path. The escape velocity is given by

[3] $V_e = [2]^{\frac{1}{2}} V_c$. From Kepler's Third Law, we have the period of the motion, T , given by

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

The path angle $\emptyset$ is given by

[5] $\sin \emptyset = \frac{[ua(1 - e^2)]^{\frac{1}{2}}}{r_o V_o}$ 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 $\emptyset$ is given by:

[7] $r = a \frac{1 + e \cos \emptyset}{\sin \emptyset}$ Figure [2] on page 2 illustrates these 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]

This program has been verified only with respect to the numerical example given in *Program Description II*. User accepts and uses this program material AT HIS OWN RISK, in reliance solely upon his own inspection of the program material and without reliance upon any representation or description concerning the program material.

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Program Description II

Sketch(es)

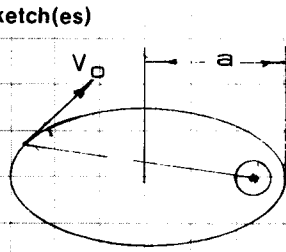


Figure [1]

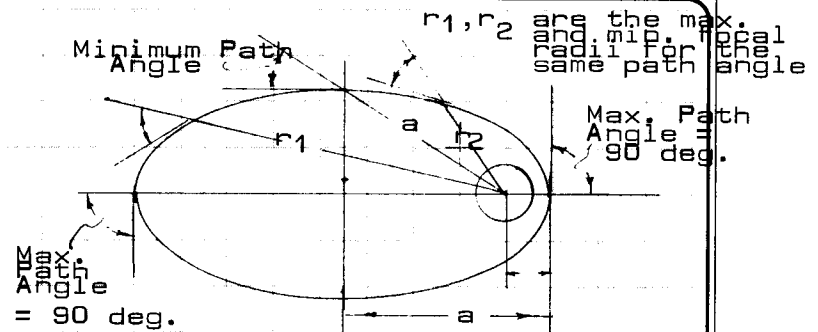
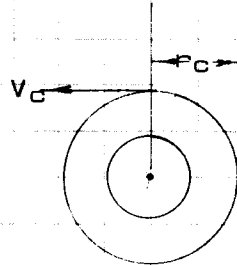


Figure [2]

Sample Problem(s) PROBLEM NO. 1: An earth satellite vehicle is in a highly elliptical orbit to explore cis-lunar 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 perigee 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 NO [1]: Load both sides of program card. Recall contents of R_{13} . Observe 3.986012×10^6 . Place this value in R_6 . Place 200,000 in R_1 and 300,000 in R_2 . Press Key A and observe V_0 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_5 . 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 deg. 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

<u>Primary</u>	<u>Satellite</u>	<u>u</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]
Neptune	Iapetus	92.17
	Triton	8.803

User Instructions

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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 ϕ in R_5 for path angle operation.																																				
2	Key A gives the VIS VIVA velocity V_0		A	V_0 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 ϕ in dec. ^o		FA	ϕ in dec. ^o																																	
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.																																				
	<table><thead><tr><th>Body</th><th>u</th><th>Register</th></tr></thead><tbody><tr><td>Moon</td><td>4.90098×10^3</td><td>R_{10}</td></tr><tr><td>Mercury</td><td>2.15215×10^4</td><td>R_{11}</td></tr><tr><td>Venus</td><td>3.24815×10^5</td><td>R_{12}</td></tr><tr><td>Earth</td><td>3.986012×10^5</td><td>R_{13}</td></tr><tr><td>Mars</td><td>4.30430×10^4</td><td>R_{14}</td></tr><tr><td>Jupiter</td><td>1.26658×10^8</td><td>R_{15}</td></tr><tr><td>Saturn</td><td>3.79416×10^7</td><td>R_{16}</td></tr><tr><td>Uranus</td><td>5.77892×10^6</td><td>R_{17}</td></tr><tr><td>Neptune</td><td>6.85500×10^6</td><td>R_{18}</td></tr><tr><td>Sun</td><td>1.324948×10^{11}</td><td>R_{19}</td></tr></tbody></table>	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}			
Body	u	Register																																			
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Sun	1.324948×10^{11}	R_{19}																																			
	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.																																				

97 Program Listing I

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

REGISTERS									
0 u	1 r_o km	2 a km	3 T sec	4 r_m km	5 e^2 (prog)	6 $\emptyset$ dec $^{\circ}$	7 V_o (prog)	8	9
S0 u Moon	S1 u Mercury	S2 u Venus	S3 u Earth	S4 u Mars	S5 u Jupiter	S6 u Saturn	S7 u Uranus	S8 u Neptune	S9 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

California
State California

93921
Zip Code 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 unasymmetric 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 the 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 in km and V_1 is in km/sec². u is in km³/sec². 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) $f_1 = \cos^{-1}[(p/R_1 - 1)/e]$ where $0 < f_1 < \pi$ The true anomaly of the target point is given by

(5) $f_t = 2\pi - \cos^{-1}[(p/R_t - 1)/e]$ where $\pi < f_t < 2\pi$ Range over the surface between perpendiculars 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 location and generally equals R_t

To compute the time of flight we need to calculate the eccentric anomalies, 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 registers.

This program has been verified only with respect to the numerical example given in Program Description II. User accepts and uses this program material AT HIS OWN RISK, in reliance solely upon his own inspection of the program material and without reliance upon any representation or description concerning the program material.

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

$$(8) \quad E_t = 2\pi - \cos^{-1}[(1 - R_t/a)1/e] \quad \text{and} \quad \text{where } \pi \leq E_t \leq 2\pi$$

The time of flight is given by

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

The maximum ordinate is given by

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

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

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

$$(12) \quad p_{opt} = \frac{2}{\frac{1}{2a - R_t} + \frac{1}{2a - R_1}} \quad \text{while the value of } \emptyset \text{ for maximum surface range is}$$

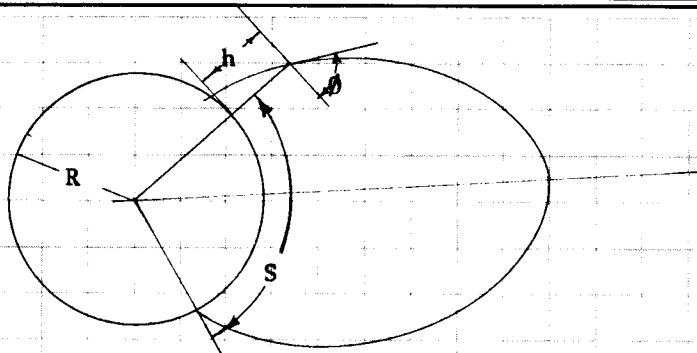
$$(13) \quad \emptyset_{max} = \cos^{-1} \left[\frac{(u p_{opt})^{1/2}}{R_1 V_1} \right]$$

Registers are Loaded
as follows:

PREG		F#5 PREG
4.900980000+03	0	1.266580000+00 0
1.739290000+03	1	7.137500000+04 1
2.152150000+04	2	3.794160000+07 2
2.420990000+03	3	6.040000000+04 3
3.248150000+05	4	5.778920000+06 4
6.052000000+03	5	2.350000000+04 5
3.986012000+05	6	6.855000000+06 6
6.371017000+03	7	2.500000000+04 7
4.304300000+04	8	3.312370000+05 8
3.387550000+03	9	2.930000000+03 9
1.324948000+11	A	1.324948000+11 A
6.960000000+05	B	6.960000000+05 B
0.000000000+00	C	0.000000000+00 C
0.000000000+00	D	0.000000000+00 D
0.000000000+00	E	0.000000000+00 E
0.000000000+00	I	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 elevation 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 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.

Solution(s)

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.

(2) NONSYMMETRIC 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

dy

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. $^\circ$, do f-C	$\emptyset$	f-C		$\emptyset$ in dec. $^\circ$
6	Enter target altitude (in km,; generally 0) do f-D	h_t			
			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 $\emptyset$ for maximum range, (dec. $^\circ$)		D		$\emptyset$ 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 x 10 ³ 1.73929 x 10 ³ 0/1				
	1 Mercury 2.15215 x 10 ⁴ 2.42099 x 10 ³ 2/3				
	2 Venus 3.24815 x 10 ⁵ 6.052 x 10 ³ 4/5				
	3 Earth 3.986012 x 10 ⁵ 6.371017 x 10 ³ 6/7				
	4 Mars 4.3043 x 10 ⁴ 3.38755 x 10 ³ 8/9				
	Sun 1.324948 x 10 ¹¹ 6.96000 x 10 ⁵ A/B				
	5 Jupiter 1.26658 x 10 ⁸ 7.1375 x 10 ⁴ 10/11				
	6 Saturn 3.79416 x 10 ⁷ 6.0400 x 10 ⁴ 12/13				
	7 Uranus 5.77892 x 10 ⁶ 2.3500 x 10 ⁴ 14/15				
	8 Neptune 6.85500 x 10 ⁶ 2.5000 x 10 ⁴ 16/17				
	9 Pluto 3.31237 x 10 ⁵ 2.960 x 10 ³ 18/19				
	Sun 1.324948 x 10 ¹¹ 6.96000 x 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

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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	RCLC	36 14		059	RCLC	36 13	
004	+	-55		060	X	-35	
005	STO0	35 00		061	RTN	24	Computes Range in km
006	2	02		062	GT00	22 00	
007	XZY	-41		063	*LBLB	21 12	
008	=	-24		064	RCL3	36 03	
009	RCLB	36 12		065	1	01	
010	X²	53		066	+	-55	
011	RCLA	36 11		067	RCL1	36 01	
012	=	-24		068	1/X	52	
013	-	-45	Computes 1/a	069	X	-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	X	-35		073	RCLC	36 13	
018	RCLC	36 15		074	+	-55	
019	COS	42		075	RCLA	36 11	
020	X	-35		076	XZY	-41	
021	X²	53		077	=	-24	
022	RCLA	36 11		078	JX	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	X	-35		082	=	-24	
027	1	01		083	JX	54	
028	XZY	-41		084	RTN	24	Computes V_c
029	-	-45		085	GT00	22 00	
030	JX	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	X	-35	
035	1	01		091	-	-45	
036	-	-45		092	RCL3	36 03	
037	XZY	-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	X	-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	X	-35		108	Pi	16-24	
053	XZY	-41		109	X	-35	
054	D+R	16 45		110	XZY	-41	
055	-	-45	Computes f_t	111	-	-45	Computes E_t
056	XZY	-41		112	R+D	16 46	

REGISTERS

0 R_1 in km	1 $1/a$ in km	2 p in km	3 e	4 E_1 dec °	5 E_t dec °	6	7	8	9 h in km target
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
A u in km³/sec²	B V_1 in km/sec	C R_E in km	D h in km	E $\emptyset$ dec °	I				

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
113	STO5	35 05		169	RTN	24	
114	D→R	16 45		170	GT00	22 00	
115	X→Y	-41		171	*LBL E	21 15	
116	D→R	16 45		172	1	01	
117	-	-45		173	.	-62	
118	RCL5	36 05		174	8	08	
119	SIN	41		175	5	05	
120	RCL4	36 04		176	2	02	
121	SIN	41		177	÷	-24	
122	-	-45		178	RTN	24	
123	RCL3	36 03		179	*LBL e	21 15 15	
124	x	-35		180	2	02	
125	-	-45		181	x	-35	
126	RCL1	36 01		182	STOI	35 46	
127	1/X	52		183	RCL i	36 45	
128	3	03		184	ISZ I	16 26 46	
129	ENT↑	-21		185	RCL i	36 45	
130	2	02		186	STOC	35 13	
131	÷	-24		187	R↓	-31	
132	Y*	31		188	STOA	35 11	
133	RCLA	36 11		189	R/S	51	
134	JX	54		190	*LBL a	21 16 11	
135	÷	-24		191	STOB	35 14	
136	x	-35		192	R/S	51	
137	RTN	24	Computes t _g in sec.	193	*LBL b	21 16 12	
138	GT00	22 00		194	STOB	35 12	
139	*LBLD	21 14		195	R/S	51	
140	RCL1	36 01		196	*LBL c	21 16 13	
141	1/X	52		197	STOE	35 15	
142	2	02		198	R/S	51	
143	x	-35		199	*LBL d	21 16 14	
144	RCLC	36 13		200	STOG	35 09	
145	RCL9	36 09		201	R/S	51	
146	+	-55					
147	-	-45					
148	1/X	52					
149	RCL1	36 01					
150	1/X	52					
151	2	02					
152	x	-35					
153	RCL0	36 00					
154	-	-45		210			
155	1/X	52					
156	+	-55					
157	2	02					
158	X→Y	-41					
159	÷	-24	Computes p opt.				
160	RCLA	36 11					
161	x	-35					
162	JX	54					
163	RCL0	36 00					
164	RCLB	36 12		220			
165	x	-35					
166	÷	-24					
167	COS ⁻¹	16 42	Computes θ max.				
168	STOE	35 15					

LABELS

A S=Range	B Max. Ord.	C t _g = T of F.	D θ Opt.	E km to n.m.
a	b	c	d	e
0	R/S = Circular Vel for Max. Ord.			1
5	R/S = Circular Velocity for Burn-Out Altitude			2
				3

FLAGS

0	1	2	3						
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ON		OFF		DEG		GRAD		RAD	
				☐		☐		☐	
				☐		☐		☐	
				☐		☐		☐	
				☐		☐		☐	

SET

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, LONGITUDE, 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:

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

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 LONGITUDES AS NEGATIVE NUMBERS. STEPS 8-11 AND 72-78 MUST BE CHANGED EACH YEAR. ANY INPUT OF MONTH AND DAY MUST BE PRECEDED BY LATITUDE AND LONGITUDE INPUTS TO ENSURE THE YEAR IS ENTERED INTO THE CALCULATION FOR DAY OF THE YEAR.

This program has been verified only with respect to the numerical example given in Program Description II. User accepts and uses this program material AT HIS OWN RISK, in reliance solely upon his own inspection of the program material and without reliance upon any representation or description concerning the program material.

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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 EQUIVALENT TO THE VALUE FOR JANUARY 0 OF
THE NEXT YEAR

* SOME CONSTANTS : 1977 $\Rightarrow$.276518
1978 $\Rightarrow$.275851

FOR APPARENT SIDERIAL TIME.

IF MEAN SIDERIAL TIME IS ACCEPTABLE :

1976 $\Rightarrow$.274436
1977 $\Rightarrow$.276511
1978 $\Rightarrow$.275848
1979 $\Rightarrow$.275185
1980 $\Rightarrow$.274522

Operating Limits and Warnings

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

This program has been verified only with respect to the numerical example given in *Program Description II*. User accepts and uses this program material AT HIS OWN RISK, in reliance solely upon his own inspection of the program material and without reliance upon any representation or description concerning the program material.

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Program Description II

Sketch(es)

Sample Problem(s) AT 1800 PST 15 JAN 1977 (0200 GMT 16 JAN), FOR AN OBSERVER AT $32^{\circ}42'N$ LATITUDE $117^{\circ}05'W$ LONGITUDE FIND LOCAL SIDERIAL TIME AND THE POSITION OF VENUS AND RATE OF CHANGE OF POSITION. FROM AN EPHEMERIS, VENUS IS $7^{\circ}20'55.33''$ SOUTH DECLINATION AND $22^h56^m47.42^s$ IN RIGHT ASCENSION AT THIS TIME.

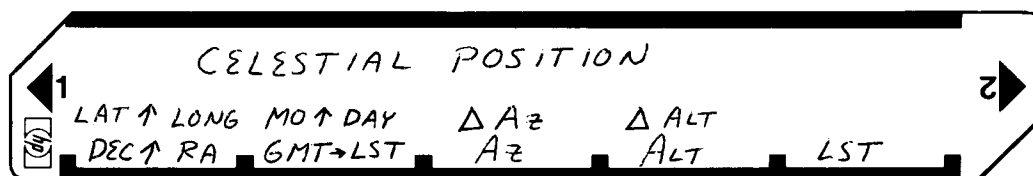
SOLUTION: $32.42 \text{ ENT} \uparrow 117.05 \text{ f A} \rightarrow 1977$
 $1 \text{ ENT} \uparrow 16 \text{ f B} \rightarrow 16 \text{ (DAY OF YEAR)}$
 $7.205533 \text{ CHS ENT} \uparrow 22.564742 \text{ A} \rightarrow 7.$
 $2 \text{ B} \rightarrow 1^h53^m15.7^s$
 $\text{C} \rightarrow 234.5^{\circ}$
 $\text{D} \rightarrow 32.0^{\circ}$
 $\text{f C} \rightarrow 12.453^{\circ}/\text{HR}$
 $\text{f D} \rightarrow -10.437^{\circ}/\text{HR}$

VENUS IS IN THE SOUTHWESTERN SKY 32° ABOVE THE HORIZON; IT IS MOVING NORTHWARD $12.453^{\circ}/\text{HR}$ AND TOWARD THE HORIZON $10.437^{\circ}/\text{HR}$ (NEGLECTING ATMOSPHERIC REFRACTION).

$E \rightarrow 2.03^h17.4^s$
 NEW LST (AFTER COMPUTING Δ) IS $\text{FOR } \Delta$ 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

[illegible]

67 Program Listing I

31

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	LBL a	32 25 11			→ H	31 74	
	DSP 5	23 05			STO 5	33 05	
	→ H	31 74			RTN	35 22	
	STO 2	33 02		060	LBL B	31 25 12	
	X $\Rightarrow$ Y	35 52			SFO	35 51 00	
	→ H	31 74			STOC	33 13	
	STO 1	33 01			RCL 2	34 02	
	1	01	} MUST MATCH DATE OF COMPUTATION		3	03	
	9	09			6	06	
010	7	07			0	00	
	7	07			STO 7	33 07	
	DSP 0	23 00			÷	81	
	RTN	35 22			1	01	
	LBL b	32 25 12		070	X $\Rightarrow$ Y	35 52	
	X $\Rightarrow$ Y	35 52			-	51	
	STO 4	33 04			.	83	} SIDERIAL CONSTANT MUST MATCH YEAR STEPS 8 TO 11
	3	03			2	02	
	X > Y	32 81			7	07	
	GTO 1	22 01			6	06	
020	GSB 1	31 22 01			5	05	
	R ↑	35 54			1	01	
	4	04			8	08	
	÷	81			+	61	
	FRAC	32 83		080	X $\Rightarrow$ Y	35 52	
	X = 0	31 51			→ H	31 74	
	1	01			2	02	
	RCL 3	34 03			4	04	
	+	61			÷	81	
	INT	31 83			RCL 3	34 03	
030	RCL 4	34 04			+	61	
	.	83			1	01	
	4	04			.	83	
	X	71			0	00	
	2	02		090	0	00	
	.	83			2	02	
	3	03			7	07	
	+	61			3	03	
	INT	31 83			7	07	
	-	51			9	09	
040	STO 3	33 03			X	71	
	RTN	35 22	→ YEAR DAY		+	61	
	LBL 1	31 25 01			FRAC	32 83	
	R ↓	35 53			2	02	
	1	01		100	4	04	
	-	51			X	71	
	3	03			→ H-MS	32 74	
	1	01			STO 0	33 00	
	X	71			DSP 5	23 05	
	+	61			RTN	35 22	
050	STO 3	33 03			LBL C	31 25 13	
	RTN	35 22			RCL 0	34 00	
	LBL A	31 25 11			CFO	35 61 00	
	SFO	35 51 00			GSB 2	31 22 02	
	GSB 2	31 22 02		110	RCL 6	34 06	
	STO 6	33 06			-	51	
	X $\Rightarrow$ Y	35 52			STO 8	33 08	

REGISTERS

⁰ LST	¹ LAT	² LONG	³ YR DAY	⁴ MONTH	⁵ DEC	⁶ RA	⁷ 360	⁸ LHA	⁹ SIN ALT
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
^A ALT	^B AZ	^C GMT	^D ALT/ΔALT	^E AZ/ΔAZ					

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
	RCL 1	34 01			LBL D	31 25 14	
	SIN	31 62		170	F? O	35 71 00	
	RCL 5	34 05			GSBC	31 22 13	
	SIN	31 62			DSP 1	23 01	
	X	71			RCL A	34 11	
	RCL 1	34 01			GTO 4	22 04	
	COS	31 63			LBL 2	31 25 02	
120	RCL 5	34 05			→ H	31 74	
	COS	31 63			1	01	
	X	71			5	05	
	RCL 8	34 08			X	71	
	COS	31 63		180	RTN	35 22	
	X	71			LBL c	32 25 13	
	+	61			RCL A	34 11	
	STO 9	33 09			STO D	33 14	
	SIN ⁻¹	32 62			RCL B	34 12	
	STO A	33 11			STO E	33 15	
130	RCL 5	34 05			RCL C	34 13	
	SIN	31 62			.	83	
	RCL 9	34 09			1	01	
	RCL 1	34 01			+	61	
	SIN	31 62		190	GSB B	31 22 12	
	X	71			GSBC	31 22 13	
	-	51			RCL E	34 15	
	RCL 1	34 01			-	51	
	COS	31 63			6	06	
	÷	81			X	71	
140	RCL A	34 11			STO E	33 15	
	COS	31 63			DSP 3	23 03	
	÷	81			RTN	35 22	→ Δ Az
	COS ⁻¹	32 63			LBL d	32 25 14	
	RCL 8	34 08		200	RCL A	34 11	
	SIN	31 62			RCL D	34 14	
	DSP 1	23 01			-	51	
	X < 0	31 71			6	06	
	GTO 3	22 03			X	71	
	R ↓	35 53			STO D	33 14	
150	RCL 7	34 07			DSP 3	23 03	
	X = Y	35 52			RTN	35 22	→ Δ ALT
	-	51					
	STO B	33 12					
	RTN	35 22	→ Az				
	LBL 3	31 25 03		210			
	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		220			
	DSP 1	23 01					
	RCL B	34 12					
	GTO 4	22 04					

LABELS					FLAGS	SET STATUS		
A DEC ↑ RA ↑	B GMT → LST	C → Az	D → ALT	E → LST	0 Control	FLAGS	TRIG	DISP
a LAT ↑ LONG ↑	b MO ↑ DAY ↑	c → Δ Az	d → Δ ALT	e	1	ON OFF		
0	1 YR DAY	2 H → D	3 → Az	4 → ALT	2	0 ☐ ☒	DEG ☒	FIX ☒
5	6	7	8	9	3	1 ☐ ☒	GRAD ☐	SCI ☐
						2 ☐ ☒	RAD ☐	ENG ☐
						3 ☐ ☒		n <u>5</u>

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:

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

$$\text{radius vector } r = a(1 - E \cos E)$$

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

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

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

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 = sem-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

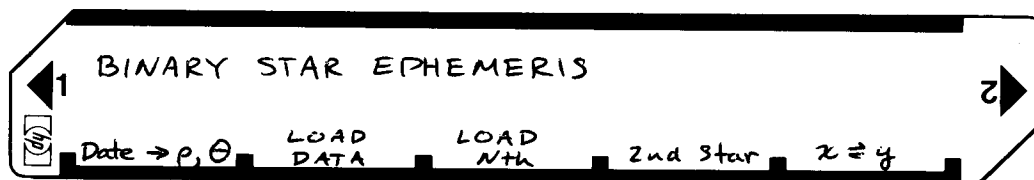
ρ = apparent angular separation

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

This program has been verified only with respect to the numerical example given in *Program Description II*. User accepts and uses this program material AT HIS OWN RISK, in reliance solely upon his own inspection of the program material and without reliance upon any representation or description concerning the program material.

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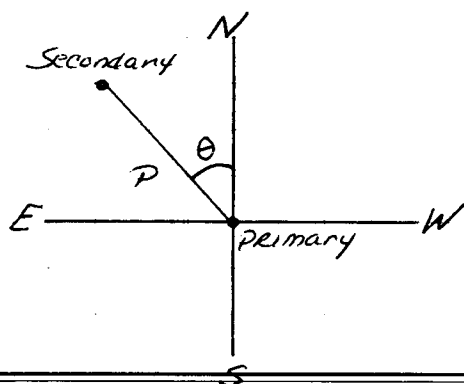
User Instructions



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)	P (years)		
	2. T (years)	T (years)		
	3. e	e		
	4. a (arc-sec)	a (arc-sec)		
	5. ω ($^{\circ}$)	ω ($^{\circ}$)		
	6. i ($^{\circ}$)	i ($^{\circ}$)		
	7. Ω ($^{\circ}$)	Ω ($^{\circ}$)		
	[c. To resume after delayed entry		R/S	
	[d. To enter nth parameter	n	C	n
2.	Enter ephemeris date	t(years)	A	p, 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

$$P = 91.044y$$

$$T = 1897.58y$$

$$e = .604$$

$$a = 0''.561$$

$$\omega = 131^\circ.28$$

$$i = 52^\circ.86$$

$$\Omega = 64^\circ.28$$

Find the orbital positions FOR 1976.9

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

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 Compute M		X	71			
	STO A	33 11			TAN ⁻¹	32 64			
	RCL 2	34 02			2	02			
	-	51		060	X	71			
	2	02			RCL 5	34 05			
	X	71			+	61			
	π	35 73			$\uparrow$	41			
	X	71			TAN	31 64			
	RCL 1	34 01			RCL 6	34 06			
010	+	81			COS	31 63			
	STO B	33 08			X	71	Compute $\theta - R$		
	RAD	35 42			TAN ⁻¹	32 64			
	LBL O	31 25 00			$X \neq y$	35 52			
	$\uparrow$	41		070	COS	31 63			
	SIN	31 62			RCL 8	34 08			
	RCL 3	34 03			X	71			
	X	71			$X \neq y$	35 52			
	RCL 8	34 08			COS	31 63			
	+	61			LST X	35 82			
020	-	51		Compute E by iteration		R $\downarrow$		35 53	Compute p
	LST X	35 82			+	81			
	$\uparrow$	41			R $\uparrow$	35 54			
	R $\downarrow$	35 53			RCL 7	34 07			
	+	81	080		+	61			
	ABS	35 64			R $\downarrow$	35 53			
	EEV	43			X < 0	31 71			
	CHS	42			SF2	35 51 02			
	5	05			ABS	35 64			
	$X \leq y$	32 71			STO B	33 12			
030	SF2	35 51 02	Accuracy $1/10^5$		CLX	44	if $p < 0$: $ p \rightarrow p$ $180 + \theta \rightarrow \theta$		
	R $\uparrow$	35 54			1	01			
	F2?	35 71 02			8	08			
	GTO O	22 00			0	00			
	$\uparrow$	41		090	R $\uparrow$	35 54			
	COS	31 63			F2?	35 71 02			
	RCL 3	34 03			+	61			
	X	71			360	03			
	1	01			6	06			
	$X \neq y$	35 52			0	00			
040	-	51	Compute r		$X > y$	32 81	if $\theta > 360^\circ$ $\theta - 360^\circ \rightarrow \theta$		
	RCL 4	34 04			CLX	44			
	X	71			-	51			
	STO B	33 08			STO C	33 13			
	R $\downarrow$	35 53		100	RCL B	34 12			
	2	02			-X-	31 84			
	+	81			$X \neq y$	35 52			
	TAN	31 64			RTN	35 22			
	DEG	35 41			LBL B	31 25 12			
	1	01			CF3	35 61 03			
050	RCL 3	34 03	Compute v		7	07	Enter data		
	+	61			STI	35 33			
	1	01			0	00			
	RCL 3	34 03			-2-	31 84			
	-	51		110	MERGE	32 41			
	+	81			PAUSE	35 72			
	$\sqrt{x}$	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	R_1	USED	
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
	P_2	T_2	e_2	a_2	ω_2	i_2	R_2	USED	
A	t		B	p		C	θ		I

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[illegible]

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 $(\alpha_0, \delta_0) \rightarrow (\alpha_{50}, \delta_{50}) \rightarrow (l, b)$
 4. Converts galactic coordinates to equatorial coordinates for any epoch by $(l, b) \rightarrow (\alpha_{50}, \delta_{50}) \rightarrow (\alpha, \delta)$
- 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 . $0^\circ \leq l < 360^\circ$, $0^h \leq \alpha < 24^h$.
- 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.

This program has been verified only with respect to the numerical example given in Program Description II. User accepts and uses this program material AT HIS OWN RISK, in reliance solely upon his own inspection of the program material and without reliance upon any representation or description concerning the program material.

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Program Description II

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Sketch(es)

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

$$\alpha_{1855} = 12^h 52^m.8$$

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

What are its galactic coordinates?

Solution(s)	[f] [A]	1.0000	(Set NORND Flag)
	[f] [B]	1.0000	(Set PRECESS Flag)
	1855 [A] 1950 [B]	1950.0000	(IE and FE)
	28.4600 [ENTER] 12.5248	12.5248	$\delta_{1855}, \alpha_{1855}$
	[D]	58.1767	l (decimal deg)
Transform back to check results	[h] [x $\rightleftharpoons$ y]	87.9582	b (decimal deg)
	[f] [C], [h] [x $\rightleftharpoons$ y]	(interchange IE, FE, restore b iny, l in x)	
	[E]	12.5248	α_{1855}
	[h] [x $\rightleftharpoons$ y]	28.4560	δ_{1855} (NORND)

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

NO ROUND? PRECESS? IE $\Rightarrow$ FE IE $\rightarrow$ y, FE $\rightarrow$ x

IE FE $\delta_0 \uparrow \alpha_0 \rightarrow \delta, \alpha$ $\delta \uparrow \alpha \rightarrow b, l$ $b \uparrow l \rightarrow \delta, \alpha$

2

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 $\rightarrow$ y FE $\rightarrow$ x
3	Enter final epoch (when loaded FE = 1900.0)	FE (years)	B	IE $\rightarrow$ y FE $\rightarrow$ x
4	Process δ_0, α_0 to δ, α	$\delta_0 \uparrow \alpha_0$	C	$\delta \rightarrow$ y $\alpha \rightarrow$ 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 $\Rightarrow$ galactic conversion:			
5	Transform 1950.0 δ, α to b, l	$\delta_{1950} \uparrow \alpha_{1950}$	D	$b \rightarrow$ y $l \rightarrow$ x
6	Transform b, l to 1950.0 δ, α	$b \uparrow l$	E	$\delta_{1950} \rightarrow$ y $\alpha_{1950} \rightarrow$ x
	Optional:			
7	Change NO ROUND flag		f a	1 $\Rightarrow$ NO ROUND 0 $\Rightarrow$ ROUND
8	Change PRECESS flag		f b	1 $\Rightarrow$ PRECESS 0 $\Rightarrow$ NO PREC
9	Exchange IE, FE leaving x, y unchanged		f c	x, y unchanged
10	Display current IE, FE		f d	IE $\rightarrow$ y FE $\rightarrow$ 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	$b \rightarrow$ y $l \rightarrow$ 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	$b \uparrow l$	E	$\delta \rightarrow$ y $\alpha \rightarrow$ x
	For new case with same FE go to step 12E			
*	Optional - avoids rounding of intermediate results			

67 Program Listing I

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STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	A F LBLA	31 25 11	ENTER NEW IE (NIE)		+	61	
	1	01			RCL B	34 12	
	9	09			+	61	
	0	00		060	RCL 5	34 05	
	0	00			X	71	
	-	51			STO 1	33 01	$\theta \rightarrow 1$
	ENTER	41		d	g LBL d	32 25 14	IE $\rightarrow$ y, FE $\rightarrow$ x
	CHS	42			RCL 4	34 04	
	RCL 4	34 04			1	01	
010	+	61			9	09	
	STO +5	33 61 05	FE - NIE $\rightarrow$ 5		0	00	
	h R+	35 53			0	00	
	STO 4	33 04	NIE - 1900 $\rightarrow$ 4		+	61	
	GTO 1	22 01	GTO PREC CONST. SUB.	070	STO 3	33 03	
B	F LBL B	31 25 12	ENTER NEW FE (NFE)		RCL 5	34 05	
	1	01			+	61	
	9	09			RCL 3	34 03	
	0	00			h X $\rightarrow$ y	35 52	
	0	00			h RTN	35 22	
020	-	51		C	F LBL C	31 25 13	PRECES
	RCL 4	34 04			f GSB 5	31 22 05	$\rightarrow$ H, ROTATE
	-	51			f GSB 2	31 22 02	$\rightarrow$ H, MS, ROUND
	STO 5	33 05	NFE - IE $\rightarrow$ 5		h RTN	35 22	
1	F LBL 1	31 25 01	UPDATE PREC CONST.	080	5 F LBL 5	31 25 05	
	RCL 9	34 09			f H $\leftarrow$	31 74	Convert α, δ to decimal degrees
	RCL 5	34 05			1	01	
	X	71			5	05	
	RCL 8	34 08			X	71	
	+	61			h X $\rightarrow$ y	35 52	
030	RCL 5	34 05			f H $\leftarrow$	31 74	
	X	71		0	F LBL 0	31 25 00	Rotate sub.
	RCL 4	34 04			STO 3	33 03	
	RCL 7	34 07			h X $\rightarrow$ y	35 52	
	X	71		090	RCL 0	34 00	Rotate about z by 1st Euler angle
	+	61			+	61	
	RCL 6	34 06			h X $\rightarrow$ y	35 52	
	+	61			f COS	31 63	Convert to polar in x-z plane
	RCL 5	34 05			f R $\leftarrow$	31 72	
	X	71			RCL 3	34 03	
040	STO 0	33 00	$J_0 \rightarrow 0$		f SIN	31 62	
	RCL 5	34 05			g $\rightarrow$ P	32 72	
	g X ²	32 54			h X $\rightarrow$ y	35 52	rotate about y by 2nd Euler angle
	RCL A	34 11			RCL 1	34 01	
	X	71		100	-	51	
	+	61			h X $\rightarrow$ y	35 52	Convert to rect in x-z plane
	STO 2	33 02	$z \rightarrow 2$		f R $\leftarrow$	31 72	
	RCL E	34 15			g $\sin^{-1}$	32 62	
	RCL 5	34 05			STO 3	33 03	
	X	71			h R+	35 53	Convert to polar in x-y plane
050	RCL D	34 14			g $\rightarrow$ P	32 72	
	+	61			h X $\rightarrow$ y	35 52	
	RCL 5	34 05			RCL 2	34 02	Rotate about z by third Euler angle
	X	71			+	61	
	RCL 4	34 04		110	1	01	
	RCL C	34 13			0	00	
	X	71			8	08	

REGISTERS

0	1	2	3	4	5	6	7	8	9
J_0	θ	Z	used	IE - 1900	FE - IE	$6.40069444 \times 10^{-3}$	$3.87777778 \times 10^{-8}$	$8.38888889 \times 10^{-9}$	5.0×10^{-12}
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
167.75	62.6	-57	used						
A	B	C	D	E	F	G	H	I	J
2.19722222×10^0	$5.56856111 \times 10^{-3}$	$-2.36444444 \times 10^{-8}$	$-1.18333333 \times 10^{-8}$	$-1.16666667 \times 10^{-11}$					

67 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS	
	0	00			STO 4	33 04		
	+	61		170	n R4	35 53		
	3	03		6	f LBL 6	31 25 06	INVERT EULER ANGLES	
	6	06	GET		RCL 0	34 00		
	0	00	$0 \leq \alpha/R < 360$		CHS	42		
	$\div$	81			RCL 2	34 02		
	g FRAC	32 83			CHS	42		
120	3	03			STO 0	33 00		
	6	06			n R4	35 53		
	0	00			STO 2	33 02		
	X	71			CLX	44		
	RCL 3	34 03		180	RCL 1	34 01		
	n RTN	35 22			CHS	42		
2	f LBL 2	31 25 02	$\rightarrow$ H.M.S & ROUND SUB		STO 1	33 01		
	g $\rightarrow$ H.M.S	32 74	8 $\rightarrow$ H.M.S		n R4	35 53		
	n $\times \Rightarrow y$	35 52			n RTN	35 22		
	1	01		a	g LBL a	32 25 11	NO ROUND FLAG TOGGLE	
130	5	05			n F? 0	35 71 00		
	$\div$	81			GT0 3	22 03		
	g $\rightarrow$ H.M.S	32 74	$\alpha \rightarrow$ H.M.S		n SFO	35 51 00		
	n F? 0	35 71 00	CHECK FLAG		1	01		
	n RTN	35 22	SET $\Rightarrow$ NO ROUND	190	n RTN	35 22		
	f RND	31 24		3	f LBL 3	31 25 03		
	f H $\leftarrow$	31 74			n CFO	35 61 00		
	g $\rightarrow$ H.M.S	32 74			0	00		
	n $\times \Rightarrow y$	35 52	ROUND		n RTN	35 22		
	f RND	31 24		b	g LBL b	32 25 12	PRECESS FLAG TOGGLE	
140	f H $\leftarrow$	31 74			n F? 1	35 71 01		
	g $\rightarrow$ H.M.S	32 74			GT0 4	22 04		
	n $\times \Rightarrow y$	35 52			n SFI	35 51 01		
	n RTN	35 22			1	01		
D	f LBL D	31 25 14	EQUAT. $\rightarrow$ GAL.	200	n RTN	35 22		
	n F? 1	35 71 01	PRECESS FLAG?	4	f LBL 4	31 25 04		
	f GSB C	31 22 13	SET $\Rightarrow$ PRECESS		n CF 1	35 61 01		
	f P $\Rightarrow$ S	31 42	EULER ANGLES FOR CONV		0	00		
	f GSB S	31 22 05	$\rightarrow$ H.M.S, ROTATE		n RTN	35 22		
	n $\times \Rightarrow y$	35 52					CONTENTS OF DATA	
150	f P $\Rightarrow$ S	31 42	RESTORE REG'S				REGISTERS - TO BE	
	n RTN	35 22					STORED ON CONSTANTS	
E	f LBL E	31 25 15	GAL. $\rightarrow$ EQUAT.				CARD:	
	f P $\Rightarrow$ S	31 42	GET EULER ANGLES				0-5. 0.0	
	f GSB 6	31 22 06	INVERT FOR INVERSE TAN.	210			6. 6.400694444-3	
	n $\times \Rightarrow y$	35 52					7. 3.877777778-8	
	f GSB 0	31 22 00	ROTATE				8. 8.388888889-9	
	f GSB 2	31 22 02	$\rightarrow$ H.M.S + ROUND				9. 5.0-12	
	f GSB 6	31 22 06	REINVERT ANGLES				10. 167.75	
	f P $\Rightarrow$ S	31 42	RESTORE REG'S				11. 62.6	
160	n F? 1	35 71 01	CHECK PRECESS FLAG				12. -57.0	
	f GSB C	31 22 13	SET $\Rightarrow$ PRECESS				13-19. 0.0	
	n RTN	35 22					20. 2.197222222-8	
C	g LBL C	32 25 13	EXCHANGE IE, FE	220			21. 5.568561111-3	
	RCL 4	34 04					22. -2.369444444-8	
	RCL 5	34 05					23. -1.183333333-8	
	CHS	42					24. -1.166666667-11	
	STO 5	33 05					25. 0.0	
	-	51						
LABELS				FLAGS		SET STATUS		
A ENTER IE	B ENTER FE	C PRECESS	D EQU $\rightarrow$ GAL	E GAL $\rightarrow$ EQU	0 0 $\Rightarrow$ ROUND 1 $\Rightarrow$ NO ROUND	FLAGS		DISP
a NO ROUND FLAG TOGGLE	b PRECESS FLAG TOGGLE	c IE $\Rightarrow$ FE	d FE $\Rightarrow$ X, IE $\Rightarrow$ Y	e	1 0 $\Rightarrow$ NO PRECESS 1 $\Rightarrow$ PRECESS	ON OFF	TRIG	FIX ☒
0 ROTATES	1 COMPUTES PREC. EULER ANGLES	2 H $\rightarrow$ H.M.S + ROUND	3 CF 0	4 CF 1	2	0 ☐ ☒	DEG ☒	SCI ☐
5 H.M.S $\rightarrow$ H + ROTATE	6 INVERTS EULER ANGLES	7	8	9	3	1 ☐ ☒	GRAD ☐	ENG ☐
						2 ☐ ☐	RAD ☐	n <u>4</u>
						3 ☐ ☐		

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 eccentricity, 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 T r is the focal radius, and a is the semi-major axis. a is computed by

$$(4) a = \left[\frac{\mu T^2}{4\pi^2} \right]^{1/3} \text{ and}$$

(5) $r = \frac{a(1-e^2)}{1+e \cos v}$ where v 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

$\mu = GM$ where G is the Constant of Universal Gravitation 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 = $v = \sqrt{\mu \left(\frac{2}{r} - \frac{1}{a} \right)}$ and
Path Angle to the local vertical = $\beta_v = \sin^{-1} \left[\frac{\mu a(1-e^2)}{rv} \right]^{1/2}$

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 Δv must be replaced in R_4 , since it has been reduced through successive divisions by a factor of 5⁴ in step 117. For Key C operation, the original value of Δv 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.

This program has been verified only with respect to the numerical example given in Program Description II. User accepts and uses this program material AT HIS OWN RISK, in reliance solely upon his own inspection of the program material and without reliance upon any representation or description concerning the program material.

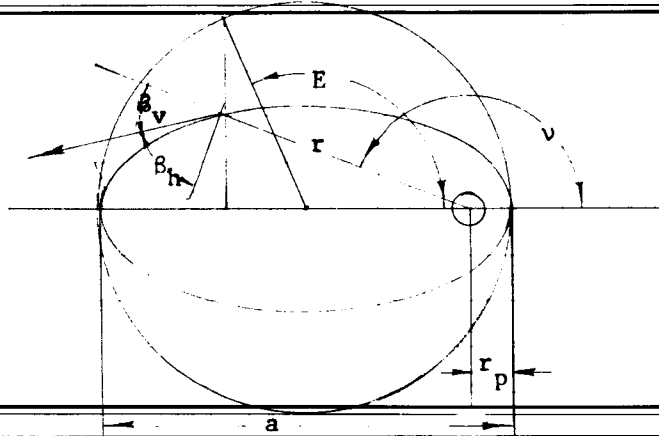
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The inverse process for equation (1) is another matter. The equation cannot be solved explicitly. It must be solved through a matter of successive approximations or iterations. We wish to solve for the true anomaly given a particular time for the body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

We start by entering a trial value of v and computing the time. If this time is less than the desired time, we augment the original value of v by Δv a sufficient number of times until the calculated time is greater than the true time. The value of v_x is then decreased by Δv and a smaller Δv established, say 1/5 th Δv . The iteration is then performed until the computed time is again greater than the true time, and the process is repeated with ever smaller Δv '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:

- The GMT when the true anomaly is 40°
- The velocity in the orbit at that time of a).
- The focal distance (focal radius) at the above time.
- The path angle to the vertical at the above time.
- The true anomaly at a GMT of 1900:26 in the same orbit.
- 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, $3 \times 60 \times 60 = 10800$ 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_4 . Key E gives 81.918° for the value of β_v for part d).

Place 20 for Δv in R_4 . Place the new time of 19.0026 in R_9 . Let us place 0.0001 (or 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° 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 $^\circ$ as the value of v 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



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 v in display, for which the time is desired.	v		
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
	R/S computes the path angle to the horizontal		R/S	β vert. β horiz.
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 between the true and the calculated times is less than one second.			
9	Place a trial value of the true anomaly in the display.	trial v		
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 v 's, expressed in seconds) and stop when the difference is less than the value placed in R_7 . Displayed is the corresponding value of v in decimal $^\circ$.		C	successive Δt 's and final value of v 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 v ($v + \Delta v$) in R_1 , the focal radius r , in R_2 , the eccentricity in R_C , the value of n in R_3 and Δv in R_4 .			
	See page 3a for additional information			

Some experience is needed in choosing the initial value of v and Δv . Generally Δv will be less than v 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 Δv should be considerably less than v so that upon the first iteration, the value of $v + \Delta v$ is not greater than 360 degrees. If the time, (in R_0) is close to the periapsis time (say $T/4$ or less) then one should start with a relatively small v (say 60 degrees) and a large Δv , say 90 degrees. Care should be taken to see that the initial $v + \Delta v$ does not equal 180 degrees, (for instance 120° and 60°) An error will then result. Simple start with a slightly different v or Δv (say 120 degrees and 59 degrees).

One can always start, in a completely unknown situation, with a small v and Δv , say 5 or 10 degrees, and 10 degrees for Δv , 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 v and Δv .

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

67Program Listing I

KEPLER'S EQUATION									
STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS		
001	f-LBL-A	31-25-11			g-RAD	32-73			
	1	01			h - π	35-73			
	RCL-B	34-12			g-x y	32-81			
	g - x^2	32-54		060	GTO-1	22-01			
	RCL-A	34-11			GTO-2	22-02			
	x	71			f-LBL-1	31-25-01			
	h - π^2	35-73			h-down	35-53			
	g - x^2	32-54			h-down	35-53			
	4	04			GTO-3	33-03			
010	x	71			f-LBL-3	31-25-03			
	./.	81	computes a		f-sine	31-62	At in sec.		
	h-x/y	35-52			RCL-C	34-13			
	3	03			x	71			
	./.	81		070	-	51			
	h - y^x	35-63			RCL-3	34-03			
	STO-0	33-00			./.	81			
	RCL-C	34-13			h-pause	35-72			
	h- x/y	35-52			h-deg	35-41			
	./.	81			RCL-E	34-15			
	-	51			./.	81			
020	STO-C	33-13	computes e		g-hms	32-74	At in dec. hrs.		
	h - π	35-73			RCL-D	34-14	At in hms		
	2	02	computes n		h-hms+	35-83	t		
	x	71		080	h-RTN	35-22	time after periapsis		
	RCL-B	34-12			f-LBL-2	31-25-02			
	./.	81			h- x/y	35-52			
	STO-3	33-03			CLX	44			
	h - RTN	35-22			2	02			
	f-LBL-B	31-25-12			x	71			
030	STO-1	33-01			h- x/y	35-52			
	1	01			-	51			
	h- x/y	35-52			ENT	41			
	1	01	INITIALIZATION Place v in x		GTO-3	22-03			
	RCL-C	34-13		090	f-LBL-C	31-25-13			
	g - x^2	32-54			f-GSB-B	31-22-12			
	-	51			STO-8	33-08			
	RCL-0	34-00			RCL-9	34-09			
	x	71			g x y	32-81			
	h- x/y	35-52			GTO-4	22-04			
040	f -cos	31-63			GTO-5	22-05			
	RCL-C	34-13			f-LBL-4	31-25-04			
	x	71			RCL-1	34-01			
	1	01	computes r		RCL-4	34-04			
	+	61		100	+				
	./.	81			GTO-C	22-13			
	STO - 2	33-02			f-LBL-5	31-25-05			
	RCL-0	34-00			RCL-8	34-08			
	./.	81			RCL-9	34-09			
	-	51			CHS	42			
050	RCL-C	34-13			h-hms+	35-83			
	./.	81			h-ABS	35-64			
	h-RAD	35-42			RCL-7	34-07			
	g - cos	32-63	computes E		RCL-7	32-71			
	ENT	41		110	g -x y	22-06			
	ENT	41			GTO-6	22-06			
	RCL-1	34-01			GTO-7	22-07			
					f-LBL-6	31-25-06			
REGISTERS									
0 a Km	1 v	2 r km	3 n	4 Δv	5	6	7 Δt diff.	8 $t_{(last)}$	9 t_x
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
A μ km ³ /sec ²	B T seconds	C r_p km (prog)	D t_p	E 3600	I				

STEP	KEY ENTRY
------	-----------

[illegible]

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 $\dot{\mathbf{r}}_1(\frac{dx}{dt}, \frac{dy}{dt}, \frac{dz}{dt})$ at time t_1 . Let $k = \text{gravitation constant } (L^{3/2} T^{-1} \text{ units})$; $\mu = \text{normalized mass}$. Then compute $\gamma = k(t_2 - t_1)$; $r_i = \sqrt{\mathbf{r}_i \cdot \mathbf{r}_i}$ $i=1, 2$; $\cos(\psi_2 - \psi_1) = (\mathbf{r}_1 \cdot \mathbf{r}_2) / (r_1 r_2)$; $\beta = \frac{r_1 + r_2}{4 \sqrt{r_1 r_2} \cos(\frac{\psi_2 - \psi_1}{2})} - \frac{1}{2}$; and
$$m = \frac{\mu \gamma^2}{[2 \sqrt{r_1 r_2} \cos(\frac{\psi_2 - \psi_1}{2})]^3}.$$

Then set $y=1$ and loop through the following equations until y remains unchanged: $x = m/y^2 - \beta$; $\cos(\frac{E_2 - E_1}{2}) = 1 - 2x$; $\sin(\frac{E_2 - E_1}{2}) = \sqrt{4x(1-x)}$; $X = [(E_2 - E_1) - \sin(\frac{E_2 - E_1}{2})] / \sin^3(\frac{E_2 - E_1}{2})$; and $y = 1 + X(\beta + x)$. When y has stabilized, compute: $a^{1/2} = \gamma \sqrt{\mu} / [2y \sqrt{r_1 r_2} \cos(\frac{\psi_2 - \psi_1}{2}) \sin(\frac{E_2 - E_1}{2})]$; $f = 1 - \frac{G}{\mu} [1 - \cos(E_2 - E_1)]$; $a = \gamma - a^{3/2} [(E_2 - E_1) - \sin(E_2 - E_1)] / \mu$; $f' = f/k$, and finally, $\dot{\mathbf{r}}_1 = \frac{\mathbf{r}_2 - f \mathbf{r}_1}{f'}$. The orbital elements of the body

at time t_1 are considered 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.

This program has been verified only with respect to the numerical example given in Program Description II. User accepts and uses this program material AT HIS OWN RISK, in reliance solely upon his own inspection of the program material and without reliance upon any representation or description concerning the program material.

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Program Description II

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Sketch(es)

Sample Problem(s) Given the following data: $k = 0.07436574$ (e.r.)³/min,
 $\mu = 1.0$ e.m. and $r_1 = (2.460609, 2.040523, 0.143819)$ e.r. at
 $t_1 = 0$ min, and $r_2 = (1.988041, 2.503334, 0.314554)$ e.r. at
 $t_2 = 15.0395328$ minutes, compute r_1 at $t_1 = 0$ min.

Input:

1.0000 ENT1
 .07436574 G5BA
 0.00000000 ENT1
 .14381900 ENT1
 2.04052300 ENT1
 2.46060900 G5BB
 15.03953280 ENT1
 .31455400 ENT1
 2.50333400 ENT1
 1.98804100 G5BC

Solution(s)

G5BE

Output:

Stack

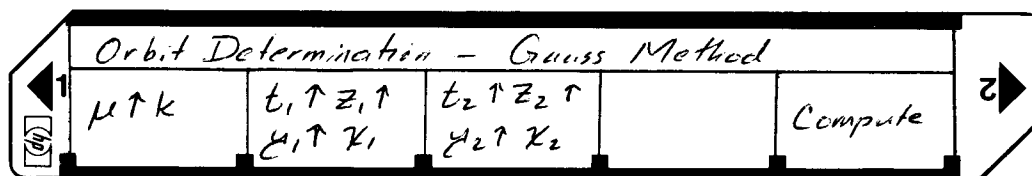
contents

0.00000000+00 T ← r_{enre}
 1.160747099-02 Z ← $\dot{z}$
 3.356191327-02 Y ← $\dot{y}$
 -2.850818940-02 X ← $\dot{x}$

Reference(s)

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

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program card.		☐	☐	
2	Enter normalized mass	μ	☐	☐	
	Enter gravitational constant	k	☐	☐	
3	Enter reference point: time	t_1	☐	☐	
	r_1 components	z_1	☐	☐	
		y_1	☐	☐	
		x_1	☐	☐	
4	Enter second point time	t_2	☐	☐	
	r_2 components	z_2	☐	☐	
		y_2	☐	☐	
		x_2	☐	☐	
5	Compute		☐	☐	
6	Output is automatically printed on the HP-97 (ignore T-register)		☐	☐	
7	On the HP-67, roll the stack down to obtain r_1 .		☐	☐	$\dot{x}_1$
	x_1 is in the X-register		☐	☐	$\dot{y}_1$
	y_1 " " " Y-register		☐	☐	$\dot{z}_1$
	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

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STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	Store μ & k	057	RCL7	36 27	$v_2 - v_1$
002	STOA	35 11		058	$\div$	-24	
003	R4	-31		059	COS ⁻¹	16 42	
004	STOB	35 12		060	2	02	
005	R/S	51		061	$\div$	-24	
006	*LBLB	21 12	Store r_1 & t_1	062	COS	42	$\cos(\frac{v_2 - v_1}{2})$
007	STO1	35 01		063	RCL0	36 00	
008	R4	-31		064	RCL7	36 07	
009	STO2	35 02		065	x	-35	
010	R4	-31		066	JX	54	
011	STO3	35 03	Store r_2 & t_2	067	x	-35	$\sqrt{r_1 r_2} \cos(\frac{v_2 - v_1}{2})$
012	R4	-31		068	STOE	35 15	
013	STOC	35 13		069	RCL0	36 00	
014	R/S	51		070	RCL7	36 07	
015	*LBLC	21 13		071	+	-55	
016	STO4	35 04	Store r_1 & t_2	072	RCL1	36 15	l
017	R4	-31		073	$\div$	-24	
018	STO5	35 05		074	4	04	
019	R4	-31		075	$\div$	-24	
020	STO6	35 06		076	.	-62	
021	R4	-31	Compute: r	077	5	05	M
022	STOD	35 14		078	-	-45	
023	R/S	51		079	RCLD	36 14	
024	*LBLD	21 15		080	X ²	53	
025	RAD	16-22		081	RCLB	36 12	Exchange P & S registers
026	RCLD	36 14	r_1	082	x	-35	
027	RCLC	36 13		083	RCL1	36 15	
028	-	-45		084	2	02	
029	RCLA	36 11		085	x	-35	
030	x	-35	r_2	086	3	03	Store m & l
031	STOD	35 14		087	Y ^x	31	
032	RCL1	36 01		088	$\div$	-24	
033	RCL2	36 02		089	P2S	16-51	
034	+P	34		090	STO0	35 00	Initialize γ Loop
035	RCL3	36 03	r_1, r_2	091	R4	-31	
036	+P	34		092	STO1	35 01	
037	STO0	35 00		093	1	01	
038	RCL4	36 04		094	STO2	35 02	
039	RCL5	36 05	r_1, r_2	095	*LBL9	21 09	X
040	+P	34		096	RCL2	36 02	
041	RCL6	36 06		097	X ²	53	
042	+P	34		098	1/X	52	
043	STO7	35 07		099	RCL0	36 00	$\sin(\frac{E_2 - E_1}{2})$
044	RCL1	36 01	r_1, r_2	100	x	-35	
045	RCL4	36 04		101	RCL1	36 01	
046	x	-35		102	-	-45	
047	RCL2	36 02		103	STO4	35 04	
048	RCL5	36 05	r_1, r_2	104	4	04	$\sin(\frac{E_2 - E_1}{2})$
049	x	-35		105	x	-35	
050	+	-55		106	1	01	
051	RCL3	36 03		107	RCL4	36 04	
052	RCL6	36 06		108	-	-45	
053	x	-35	r_1, r_2	109	x	-35	$\sin(\frac{E_2 - E_1}{2})$
054	+	-55		110	JX	54	
055	RCL0	36 00		111	STO5	35 05	
056	$\div$	-24		112	1	01	

REGISTERS

0	r_1	1	r_2	2	γ	3	z_1	4	z_2	5	γ_2	6	z_2	7	r_2	8	$a^{3/2}$	9	$E_2 - E_1$
S0	m	S1	l	S2	γ	S3		S4	X	S5	$\sin(\frac{E_2 - E_1}{2})$	S6	$E_2 - E_1$	S7		S8		S9	
A	k		B	μ		C	t_1		D	t_2 & r		E	Used & C/S/k		I	f			

97 Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
113	RCL4	36 04		169	1	01	
114	2	02		170	-	-45	
115	x	-35		171	x	-35	
116	-	-45	$\cos\left(\frac{E_2 - E_1}{2}\right)$	172	1	01	
117	+P	34		173	+	-55	
118	X $\leftrightarrow$ Y	-41		174	STOI	35 46	ξ
119	2	02		175	RCL9	36 09	
120	x	-35		176	SIN	41	
121	STO6	35 06	$(E_2 - E_1)$	177	LSTX	16-63	
122	ENT1	-21		178	-	-45	
123	SIN	41		179	RCL8	36 08	
124	-	-45		180	x	-35	
125	RCL5	36 05		181	RCLB	36 12	
126	3	03		182	JX	54	
127	Y*	31		183	=	-24	
128	=	-24	X	184	RCLD	36 14	
129	RCL1	36 01		185	+	-55	ε
130	RCL4	36 04		186	RCLA	36 11	
131	+	-55		187	=	-24	$\varepsilon' = \varepsilon/k$
132	x	-35		188	STOE	35 15	
133	1	01		189	DSP9	-63 09	
134	+	-55	New value of ε	190	RCL4	36 04	
135	RCL2	36 02		191	RCL1	36 01	
136	X $\leftrightarrow$ Y	-41		192	GSB8	23 08	$\dot{x}_i$
137	STO2	35 02		193	STO4	35 04	
138	=	-24	Test for	194	RCL5	36 05	
139	1	01	convergence	195	RCL2	36 02	
140	-	-45		196	GSB8	23 08	
141	FIX	-11		197	STO5	35 05	
142	DSP9	-63 09		198	RCL6	36 06	
143	RND	16 24		199	RCL3	36 03	
144	X $\neq$ 0?	16-42	Loop if not	200	GSB8	23 08	
145	STO9	22 09	converged	201	STO6	35 06	$\dot{z}_i$
146	RCLD	36 14		202	0	00	
147	RCLB	36 12		203	X $\leftrightarrow$ Y	-41	
148	JX	54		204	RCL5	36 05	
149	x	-35	$\sqrt{\mu}$	205	RCL4	36 04	
150	2	02		206	PRST	16-14	Print stack
151	=	-24		207	R/S	51	
152	RCL2	36 02		208	GT00	22 00	Error display
153	=	-24		209	*LBL8	21 08	Subroutine
154	RCLC	36 15		210	SCI	-12	
155	=	-24		211	RCLI	36 46	
156	RCL5	36 05	$a^{1/2}$	212	x	-35	$\dot{r}_i = \frac{r_2 - \sum r_i}{\varepsilon'}$
157	=	-24		213	-	-45	
158	RCL6	36 06		214	RCLC	36 15	
159	P $\leftrightarrow$ S	16-51	Exchange P & S	215	=	-24	
160	STO9	35 09	$E_2 - E_1$	216	RTN	24	
161	X $\leftrightarrow$ Y	-41		217	R/S	51	
162	STO8	35 08	$a^{1/2}$				
163	X $\neq$	53	a				
164	STX8	35-35 08	$a^{3/2}$				
165	RCL0	36 00					
166	=	-24					
167	RCL9	36 09					
168	COS	42					

LABELS					FLAGS	SET STATUS		
A Input	B $r_1 \& t_1$	C $r_2 \& t_2$	D	E Compute	0	FLAGS	TRIG	DISP
a	b	c	d	e	1	ON OFF		
0 Error	1	2	3	4	2	0 ☐ ☒	DEG ☐	FIX ☒
5	6	7	8 ☒	9 Loop	3	1 ☐ ☒	GRAD ☒	SCI ☐
						2 ☐ ☒	RAD ☐	ENG ☐
						3 ☐ ☒		n ☒

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