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NAVAL APPLICATIONS: TEN ALGORITHMS FOR THE HEWLETT-PACKARD HP-6--ETC(U)
FEB 79 R H SHUDDE
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NAVAL APPLICATIONS:
TEN ALGORITHMS FOR THE HEWLETT-PACKARD
HP-67 AND HP-97 CALCULATORS

edited by
R. H. Shudde

February 1979

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NAVAL POSTGRADUATE SCHOOL
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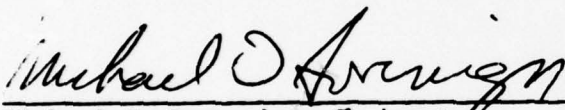
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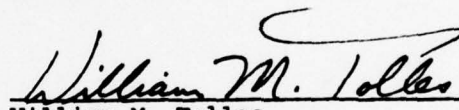
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NAVAL APPLICATIONS:
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edited by
R. H. Shudde

February 1979

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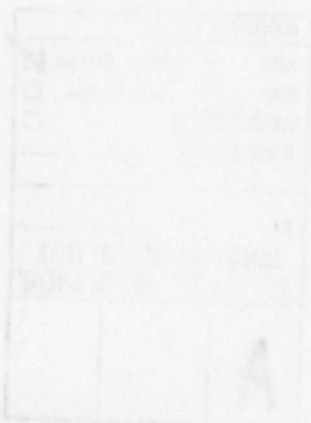
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ABSTRACT

Ten algorithms pertaining to underwater acoustics, target motion analysis, P-3 mission planning, flight crew management, and naval gunfire support conversions are presented along with programs for Hewlett-Packard HP-67 and HP-97 programmable calculators.



I. INTRODUCTION

This report contains a collection of programs which were submitted by officers in partial fulfillment of the requirements of the course Tactical Design and Analysis (OA 4658) conducted at the Naval Postgraduate School during the period of October through December 1978.

All programs were listed using an HP-97 with HP-97 key codes. The corresponding HP-67 key codes may be found on pages 324 through 331 of the "HP-67 Owner's Handbook and Programming Guide."

II. ACTIVE SONAR ACQUISITION by Mr. R. F. Fish and LT M. H. Trent

A. Problem Statement

A sonar at a depth (SD) has the possibility of detecting a target at a depth TD at a slant range r' . Detection can only occur if the target lies within the beam pattern and the signal excess is at least equal to the detection threshold. Whether or not the system is noise or reverberation limited depends on the geometry and doppler frequency shift. The problem is to determine the acquisition range of the sonar with various geometries and acoustic parameters.

B. Operational Analysis

The analysis uses a 0 dB detection threshold because of the limited number of storage registers (26) and program steps (224) in the calculator.

In using the program it should be noted that calculations do not include the effect of shadow zones. Acquisition ranges computed must be considered with this in mind. In addition, once the target and surface signals are outside the beam pattern (± 3 db) they are assumed to abruptly disappear respectively. The analysis also assumes the water is deep with no bottom effects.

Considering the above caveats the source and target can be placed as desired in the medium and the appropriate sonar equation parameters will be computed. In doing so, several tests will be made to determine which equations will be used.

The program will terminate before acquisition if one of the following occurs:

Slant range

$$r' < 0,$$

Angle-to-target

$$\theta_1 > \phi/2 + \gamma, \text{ or } \theta_1 > \phi/2 - \gamma \text{ (if target is below source),}$$

Angle-to-surface at r'

$$\theta_2 > \phi/2 + \gamma,$$

where

γ = pitch angle range.

These terminations and signal excess $SE \geq 0$ will finish with a "1" printed as an output at the end of the calculations.

After calculation of the surface reverberation level, RL_s , there is a program stop where the appropriate correction can be input for off-axis transmission and reception. The same event occurs when SE is calculated so that the sonar equation can be corrected.

The output listing is as follows:

<u>Doppler</u>	<u>No Doppler</u>
r'	r'
θ_1	θ_1
θ_2	θ_2
TL	TL
NL_s	RL_s displays but not printed
SE	Total of $RL_s + RL_v + NL_s$ combined and SE

C. Computational Algorithm

1. Input

- Sound speed, c (m/sec)
- Listening time between transmit pulses, t (sec)
- Source depth, SD (m)
- Target depth, TD (m)
- Horizontal (and vertical) half-beam width, $\phi/2$ (degrees)
- Sonar pitch angle, γ (degrees)
- Mixed layer depth, D (meters)
- Absorption coefficient, α (dB/meter)
- Frequency, f (kHz)
- Sea state, S.S.
- Column scattering coefficient, S_c
- Constant, 10
- Sonar self-noise level, NL_s (dB)
- Target strength, TS (dB)
- Range decrement (meters)
- [Pulse length, τ (sec) $\times \phi$ (radians)] $\div 2$
- Surface scattering coefficient, S_s (dB)
- Sonar source level, SL (dB)

2. For doppler set Flag 0; for no doppler clear Flag 0.

3. Output

r' , θ_1 , θ_2 , TL , RL_s , RL_v , total level, SE. For doppler, RL_s , RL_v , and total level are included in NL_s .

D. HP-67/97 Calculator Program

1. User Instructions

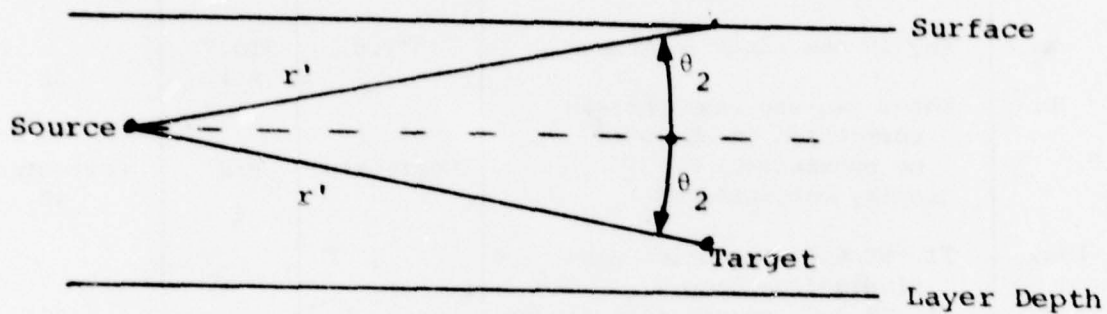
Step	Instruction	Input	Key(s)	Output
1.	Enter program card			
2.	Enter data in primary stage:			
a.	Sound speed (m/sec)	c	STO 0	
b.	Listening time (sec)	t	STO 1	
c.	Source depth (m)	SD	STO 3	
d.	Target depth (m)	TD	STO 4	
e.	Half-beam width (deg)	$\phi/2$	STO 7	
f.	Sonar pitch angle (deg)	γ	STO 8	
g.	Mixed layer depth (m)	D	STO A	
h.	Absorption coefficient (dB/m)	a	STO B	
i.	Frequency (kHz)	f	STO C	
j.	Sea state	S.S.	STO D	
k.	Source level (db)	SL	h STI	
3.	Enter data in secondary storage:*		P $\leftrightarrow$ S	
a.	Column scattering coefficient	S_C	STO 0	
b.	Constant	10	STO 2	
c.	Sonar self-noise level	NL_S	STO 3	
d.	Target strength	TS	STO 4	
e.	Range decrement (m)	r.d.	STO 5	
f.	$[\tau(\text{sec}) \times \phi(\text{radians})]/2$	$\tau\phi/2$	STO 6	
g.	Surface scattering coefficient	S_S	STO 8	
4.	Primary/Secondary exchange*		P $\leftrightarrow$ S	
5.	Doppler or No doppler		SF 0 CF 0	doppler no doppler
6.	Start computations	--	A	See Step 7
7.	Printed output:			
a.	Slant range			r'
b.	Angle-to-target			θ_1
c.	Angle-to-surface at range r'			θ_2
d.	Transmission Loss			TL
e.	If Flag 2 is set, self-noise is printed.			NL_S

Step	Instruction	Input	Key(s)	Output
8.	If Flag 2 is set, go to Step 9. Otherwise:			
a.	Display surface reverberation level			RL_s
b.	Enter two-way beam pattern correction in db (0 if no correction) Print total corrected level.	Correction	R/S	Total RL_s
9.	Stop and display SE. To change range decrement, execute Step a. Otherwise go to Step b.			SE
a.	Key in new range decrement	r.d.	STO 5 R ↓	SE
b.	Enter two-way beam pattern correction in db (0 if no correction) Display corrected SE	Correction	R/S	Corrected SE
10a.	If $SE < 0$, execution continues from Step 7.			
b.	If $SE \geq 0$, termination occurs			1.00

* The primary and secondary registers must be exchanged before (Step 3) and after (Step 4) entering data into the secondary storage registers.

2. Sample Problems

- a. Sonar and target are in the mixed layer in a "doppler" situation, so that acquisition is noise limited by NL_s (Figure 1).



Source depth = 30 meters
Target depth = 60 meters
Mixed Layer depth = 75 meters

FIGURE 1. Geometry of Sample Problem 1.

Input.

R0: 1500 m/sec	S0: -50 dB
R1: 6.7 sec	S2: 10
R3: 30m	S3: 65 dB re 1 μ Pa
R4: 60m	S4: 10 dB
R7: 10°	S5: 500 m (initial range decrement)
R8: 5°	S6: .17°sec
RA: 75m	S8: -30 dB
RB: .00328 dB/m	
RC: 25 kHz	
RD: 2	
RI: 227 dB re 1 μ Pa @ 1 m	

Set Flag 0. No corrections are made to SE.

Output

The results are shown on the Sample Problem output.

At acquisition

$r' = 3650$ meters

$\theta_1 = .47$

$\theta_2 = .47$

TL = 85.9 dB (layer)

NL_s = 65 dB re 1 μ Pa

SE = .21 dB

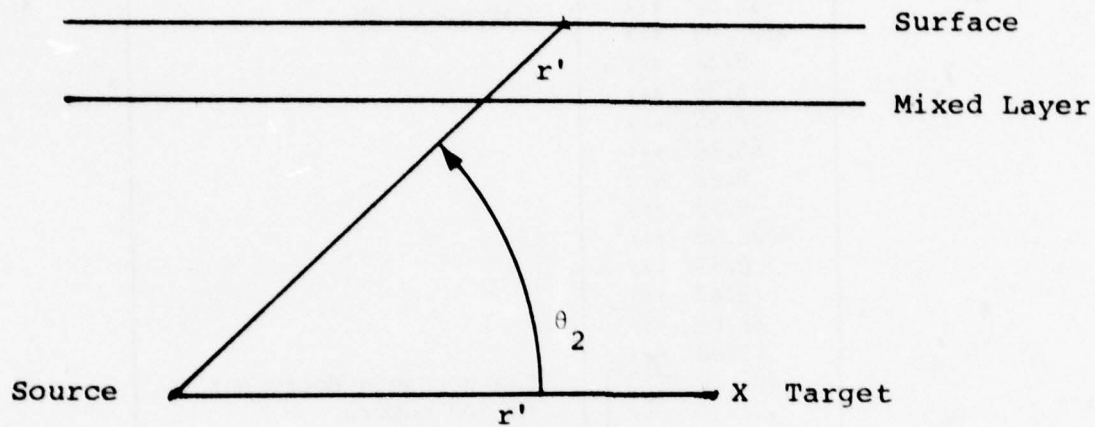
1500.00 ST00	} Primary Storage Registers
6.70 ST01	
30.00 ST02	
60.00 ST03	
10.00 ST04	
5.00 ST05	
75.00 ST06	
.00328 ST07	
25.00 ST08	
2.00 ST09	
227.00 ST10	} Secondary Storage Registers
F25	
-50.00 ST00	
10.00 ST01	
65.00 ST02	
10.00 ST03	
500.00 ST04	
.17 ST05	
-30.00 ST06	
F25	

SAMPLE PROBLEM 1. Input Data

	SFO	Set for doppler
	GSEA	Start
5025.00	***	r'
0.34	***	θ_1
0.34	***	θ_2
93.76	***	TL
65.00	***	RL _s
0.00	R/S	Correction to SE
-15.52	***	Corrected SE
4525.00	***	
0.38	***	
0.38	***	
90.95	***	
65.00	***	
0.00	R/S	
-9.90	***	
4025.00	***	
0.43	***	
0.43	***	
88.09	***	
65.00	***	
300.00	ST05]	Change range decrement
	RL]	to 300 meters
0.00	R/S	
-4.17	***	
3725.00	***	
0.46	***	
0.46	***	
86.34	***	
65.00	***	
50.00	ST05]	Change range decrement
	RL]	
0.00	R/S	
-0.67	***	
3675.00	***	
0.47	***	
0.47	***	
86.04	***	
65.00	***	
25.00	ST05]	Change range decrement
	RL]	
0.00	R/S	
-0.09	***	
3650.00	***	r'
0.47	***	θ_1
0.47	***	θ_2
85.90	***	TL (layer)
65.00	***	NL _s
0.00	R/S	
0.21	***	SE = 0.21
1.00		Terminate

SAMPLE PROBLEM 2. Output

- b. Sample Problems 2 and 3. The sonar and target configuration are shown in Figure 2.



Source depth = 600 meters
Target depth = 600 meters
Mixed Layer depth = 75 meters

FIGURE 2. Geometry of Sample Problems 2 and 3.

Input for Problems 2 and 3:

Same as for Problem 1 except

R3: 600 meters

Flag 0: set for problem 2;
clear for problem 3

R4: 600 meters

R8: 0°

0 entered as correction factors to RL_s and SE.

Output for Problem 2:

$r' = 4125$ meters

$\theta_1 = 0^\circ$

$\theta_2 = 8.36^\circ$

SE = .32 dB

Sonar acquired the target at about 4125 meters.

Output for Problem 3:

$r' = 3025$ meters

$\theta_1 = 0^\circ$

$\theta_2 = 11.44^\circ$

SE = 0.85 dB

Sonar acquired at 3025 meters.

	SFO	
	GSEA	
5025.00	***	
0.00	***	
6.86	***	
90.50	***	
65.00	***	
0.00	R/S	
-9.01	***	
4525.00	***	
0.00	***	
7.62	***	
87.95	***	
65.00	***	
100.00	ST05	Change range decrement to 100 meters
	R4	
0.00	R/S	
-3.91	***	
4425.00	***	
0.00	***	
7.79	***	
87.43	***	
65.00	***	
0.00	R/S	
-2.86	***	
4325.00	***	
0.00	***	
7.97	***	
86.91	***	
65.00	***	
0.00	R/S	
-1.81	***	
4225.00	***	
0.00	***	
8.16	***	
86.37	***	
65.00	***	
0.00	R/S	
-0.75	***	
4125.00	***	r'
0.00	***	θ_1
8.36	***	θ_2
85.84	***	TL
65.00	***	NL _s
0.00	R/S	
0.32	***	SE
1.00		Terminate

SAMPLE PROBLEM 2. Output

	CF0	No doppler
	GSEA	Start
5025.00	***	r'
0.00	***	θ_1
6.86	***	θ_2
90.50	***	TL
77.07	***	RLS
0.00	R/S	No correction to RL_s
77.37	***	Total RL_s
0.00	R/S	No correction to SE
-21.38	***	Corrected SE
4525.00	***	
0.00	***	
7.62	***	
87.95	***	
81.71	***	
0.00	R/S	
81.85	***	
0.00	R/S	
-20.76	***	
4025.00	***	
0.00	***	
8.57	***	
85.30	***	
86.52	***	
0.00	R/S	
86.59	***	
0.00	R/S	
-20.19	***	
3525.00	***	
0.00	***	
9.80	***	
82.51	***	
91.53	***	
0.00	R/S	
91.58	***	
0.00	R/S	
-19.59	***	
3025.00	***	r'
0.00	***	θ_1
11.44	***	θ_2
79.54	***	
77.08	***	
0.85	***	
0.00	R/S	
0.85	***	SE
1.00		Termination

SAMPLE PROBLEM 3. Output

3. Program Storage Allocations and Program Listings

Registers

R0: c (m/sec)	S0: S_c (dB)
R1: t (sec) and SL - 2TL + 10 log r'	S1: RL_v (dB)
R2: R_{max} and r'	S2: 10
R3: SD (m)	S3: NL (dB _{relμPa})
R4: TD (m)	S4: TS (dB)
R5: θ_1 (deg)	S5: Range decrement (m) (500 m default)
R6: θ_2 (deg)	S6: τ (sec) $\times \phi/2$ (AD)
R7: $\phi/2$ (deg)	S7: 10 log($\phi\tau c/2$)
R8: γ (deg)	S8: S_s (dB)
R9: $\phi/2 + \gamma$ (deg)	S9: RL_s (dB)
RA: D (meters)	
RB: α (dB/meter)	
RC: f (kHz)	
RD: S.S.	
RE: TL (dB)	
RI: SL (dB _{relμPa} @ 1m) or consistent with NL	

Initial Flag Status and Use:

0: ON for doppler, OFF for no doppler	1, 2, 3: OFF, unused
--	----------------------

User control keys:

A: Start program

a:

B:

b:

C:

c:

D:

d:

E:

e:

001	*LBLA	21 11	038	X>Y?	16-34	075	X>Y?	16-34
002	RCL0	36 00	039	GT00	22 00	076	GT06	22 00
003	RCL1	36 01	040	*LBL1	21 01	077	L06	16 32
004	X	-35	041	RCL7	36 07	078	1	01
005	2	02	042	RCL8	36 08	079	0	00
006	÷	-24	043	-	-45	080	X	-55
007	ST02	35 02	044	RCL5	36 05	081	RCL2	36 02
008	*LBLB	21 12	045	X>Y?	16-34	082	L06	16 32
009	RCL2	36 02	046	GT00	22 00	083	1	01
010	X<0?	16-45	047	RCLW	36 11	084	0	00
011	GT00	22 00	048	RCL3	36 03	085	X	-35
012	PRTX	-14	049	X>Y?	16-34	086	+	-55
013	1/X	52	050	GT06	22 06	087	RCLF	36 12
014	RCL3	36 03	051	X=?	-41	088	RCL2	36 02
015	RCL4	36 04	052	RCL4	36 04	089	X	-35
016	-	-45	053	X>Y?	16-34	090	+	-55
017	ABS	16 31	054	GT06	22 06	091	RCLC	36 12
018	X	-35	055	RCL3	36 03	092	1/X	54
019	SIN ⁻¹	16 41	056	RCL4	36 04	093	RCLD	36 14
020	ST05	35 05	057	X=?	16-35	094	X	-35
021	PRTX	-14	058	X=?	-41	095	1	01
022	RCL3	36 03	059	CHS	-22	096	.	-02
023	RCL2	36 02	060	RCLW	36 11	097	0	00
024	÷	-24	061	+	-55	098	4	04
025	SIN ⁻¹	16 41	062	X=0?	16-43	099	X	-35
026	ST06	35 06	063	GT06	22 06	100	RCL2	36 02
027	PRTX	-14	064	1/X	52	101	X	-35
028	RCL7	36 07	065	RCLA	36 11	102	RCLA	36 11
029	RCL8	36 08	066	X2	53	103	1/X	54
030	+	-55	067	X	-35	104	8	03
031	ST09	35 09	068	1/X	54	105	4	04
032	RCL4	36 04	069	1	01	106	0	00
033	RCL3	36 03	070	0	00	107	X	-35
034	X=?	15-35	071	5	05	108	÷	-24
035	GT01	22 01	072	X	-35	109	+	-55
036	RCL9	36 09	073	RCL2	36 02	110	ST0E	35 15
037	RCL5	36 05	074	X=?	-41	111	GT0C	22 13

112	*LEL6	21 06	149	GT0E	22 15	187	+	-55
113	RCL2	36 02	150	RCL9	36 09	188	P+S	16-51
114	LOG	16 32	151	RCL6	36 06	189	*LELE	21 15
115	2	02	152	XVY?	16-34	190	P+S	16-51
116	0	00	153	GT00	22 14	191	RCL3	36 02
117	x	-35	154	RCL1	36 01	192	RCL2	36 02
118	RCL6	36 12	155	P+S	16-51	193	+	-24
119	RCL2	36 02	156	RCL7	36 07	194	RCL2	36 02
120	x	-35	157	+	-55	195	X+Y	-41
121	+	-55	158	RCL8	36 08	196	Y*	31
122	STOE	35 15	159	+	-55	197	+	-55
123	*LELC	21 13	160	ST09	35 09	198	LOG	16 32
124	FRTX	-14	161	R/S	51	199	RCL2	36 02
125	RCL1	36 46	162	-	-45	200	x	-55
126	RCL2	36 15	163	GT0A	22 16 11	201	FRTX	-14
127	2	02	164	*LELD	21 14	202	CHS	-22
128	x	-35	165	P+S	16-51	203	RCL1	36 46
129	-	-45	166	0	00	204	+	-55
130	RCL2	36 02	167	ST09	35 09	205	RCL2	36 15
131	LOG	16 32	168	*LELA	21 16 11	206	2	02
132	1	01	169	RCL0	36 00	207	x	-35
133	0	00	170	RCL7	36 07	208	-	-45
134	x	-35	171	+	-55	209	RCL4	36 04
135	+	-55	172	P+S	16-51	210	+	-55
136	ST01	35 01	173	RCL1	36 01	211	R/S	51
137	RCL0	36 00	174	+	-55	212	-	-45
138	P+S	16-51	175	P+S	16-51	213	FRTX	-14
139	RCL6	36 06	176	ST01	35 01	214	X/00	16-45
140	x	-35	177	RCL2	36 02	215	GT09	22 09
141	LOG	16 32	178	RCL9	36 09	216	*LEL0	21 00
142	1	01	179	RCL2	36 02	217	1	01
143	0	00	180	+	-24	218	FRTX	-14
144	ST02	35 02	181	Y*	31	219	PTM	24
145	x	-35	182	RCL2	36 02	220	*LEL9	21 09
146	ST07	35 07	183	RCL1	36 01	221	RCL5	36 05
147	P+S	16-51	184	RCL2	36 02	222	P+S	16-51
148	F09	16 23 02	185	+	-24	223	ST-2	35-45 02
			186	Y*	51	224	GT0E	22 12

E. Computational Analysis

The active sonar equation is

$$SL - 2TL + TS - (NL - DI) \geq DT ,$$

NL_s
 RL

where

SL = source level for the sonar (dB_{relμPa} @ 1m),

TL = transmission loss (dB),

(NL-DI) = ambient noise term which is neglected due to
a higher NL_s or RL ,

RL = reverberation level (dB)

DT = system detection threshold (0dB assumed),

TS = target strength (dB),

and NL_s = Self-noise (dB_{relμPa}).

The only terms not known in the equation, TL and RL_s , are calculated at various ranges (decrements) until the signal excess (SE) $\geq$ DT(0).

The TL is calculated for two conditions:

a. When both source and target are in the layer (Reference 1)

$$TL = 10 \log r_t + 10 \log r' + \alpha r' + \frac{br'}{rs} ,$$

where

$$r_t = 105 \sqrt{\frac{D^2}{D - z_s}} \text{ is the transition range (meters),}$$

α = absorption (dB/meters),

$b = 1.04 \times SS \times \sqrt{f}$ bounce factor (dB/bounce) valid
between (3-25 kHz) (3-14 dB/bounce),

$$r_s = 840 \sqrt{D},$$

z_s = larger of source or receiver depths (meters),

and D = layer thickness (meters).

b. When both source and target are not in the layer the TL is

$$TL = 20 \log r' + \alpha r' \quad (\text{for } r' < r_t \text{ also when in layer}).$$

After using the proper TL formula it must be decided whether or not there is sufficient doppler to be able to disregard reverberation (i.e., RL_s and RL_v). If there is enough doppler then the NL_s term dominates and the sonar equation can be solved. If there is no doppler the appropriate reverberation must be considered and combined with NL_s . Then the sonar equation can be solved. By successive decrements of r' , there may be a point where $SE \geq DT$ and thus detection has occurred.

The reverberation equations are (Reference 2),

$$RL_s = SL - 2TL + 10 \log r' + S_s + 10 \log \left(\frac{\phi C I}{2} \right),$$

where

S_s = surface scattering parameter (dB) for the particular conditions (wind speed, grazing angle),

ϕ = sonar horizontal beam width (radians),

c = wave propagation time

and τ = transmit pulse width (seconds);

and

$$RL_v = SL - 2TL + 10 \log r' + S_c + 10 \log \left(\frac{\phi c \tau}{2} \right),$$

where

S_c = column scattering coefficient (dB) for the particular environmental conditions.

At each range decrement θ_1 and θ_2 are calculated to determine if they are inside the beam pattern. If θ_1 is not, acquisition cannot occur. If θ_2 is not, then RL_s is not important. The formulae for these quantities are (Figure 3):

$$\theta_1 = \sin^{-1} \left| \frac{SD - TD}{r'} \right| \quad \text{and} \quad \theta_2 = \sin^{-1} \frac{SD}{r'},$$

where

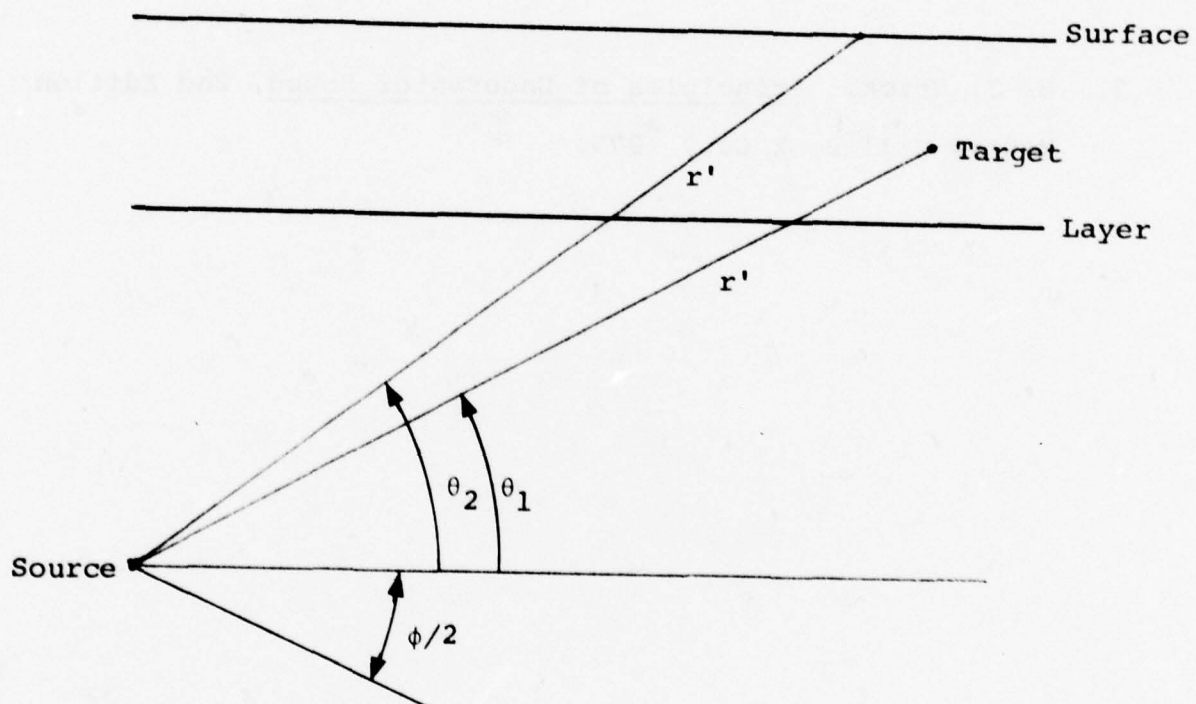
SD = source depth,

and TD = target depth.

In addition, depending on the values of these angles, corrections can be made to the RL_s and sonar equation to compensate for off-axis (beam pattern) transmission and reception.

To get an initial value of $r' = R_{\max}$ the equation

$R_{\max} = ct/2$ is used where t = the sonar "listening" time or time between successive pulse transmission.



- ϕ = sonar beam pattern (3dB points)
- θ_1 = angle to target at range r'
- θ_2 = angle to surface at range r'
- r' = slant range
- D = layer depth

FIGURE 3. Source and Target Geometry

F. References

1. A. B. Coppens and J. V. Sanders, "An Introduction to the Sonar Equations with Applications," Technical Report NPS-61Sd76071, July 1976, Naval Postgraduate School, Monterey, CA 93940.
2. R. J. Urick, Principles of Underwater Sound, 2nd Edition McGraw-Hill Book Co., 1975.

III. THREE ENGINE AVAILABLE RANGE REMAINING: P-3(B) AIRCRAFT
CONFIGURATION "B" by LT R. J. Knight

A. Problem Statement

Aircraft total fuel remaining, outside air temperature, and aircraft altitude data are available. Determine the aircraft's available range remaining.

This program allows a pilot or copilot to rapidly and efficiently provide a quick estimate of available range remaining in an emergency situation (three engine flight).

B. Operational Analysis

The aircraft's available range remaining can be extracted from the table listed on pages 12-189 of the P-3(B) aircraft NATOPS manual.

C. Computational Algorithm

1. Input fuel remaining (pounds).
2. Input outside temperature (°C).
3. Input altitude (feet)
4. Calculate the three-engine available range remaining.

D. HP-67/97 Calculator Program
 1. User Instructions

Step	Instruction	Input	Key(s)	Output
1.	Load program magnetic card side #1 and side #2			0.000000000
2.	Input fuel remaining,* press enter	pounds	ENT	pounds
3.	Input outside air temperature for specific altitude press enter	°C	ENT	°C
4.	Input altitude	feet	A	feet
5.	Press A to calculate the three engine available range remaining			range in NM

* Note: Fuel remaining must be entered as #10,000, #20,000, #30,000, #40,000 or #50,000. "Error" will display otherwise.

2. Sample Problem

Calculate the three-engine available range remaining if the remaining fuel is 10,000 pounds, the outside temperature is 11°C, and the altitude is 2000 feet. (ANSWER: 295 n.mi.)

10000. ENT
 11. ENT
 2000. GSEA
 295. ##

D. HP-67/97 Calculator Program

1. User Instructions

Step	Instruction	Input	Key(s)	Output
1.	Load program magnetic card side #1 and side #2			0.000000000
2.	Input fuel remaining,* press enter	pounds	ENT	pounds
3.	Input outside air temperature for specific altitude press enter	°C	ENT	°C
4.	Input altitude	feet		feet
5.	Press A to calculate the three engine available range remaining		A	range in NM

* Note: Fuel remaining must be entered as #10,000, #20,000, #30,000, #40,000 or #50,000. "Error" will display otherwise.

2. Sample Problem

Calculate the three-engine available range remaining if the remaining fuel is 10,000 pounds, the outside temperature is 11°C, and the altitude is 2000 feet. (ANSWER: 295 n.mi.)

```
10000. ENT↑
11. ENT↑
2000. GSEA
295. ***
```

3. Program Storage Allocation, Permanent Data, and
Program Listing

Registers:

R0: a_0	S0:	A: Fuel
R1: b_0	S1:	B: Altitude
R2: a_1	S2:	C: Temperature
R3: b_1	S3:	D: Temperature deviation
R4: a_2	S4:	E: Uncorrected range.
R5: b_2	S5:	
R6: a_3	S6:	
R7: b_3	S7:	
R8: a_4	S8:	
R9: b_4	S9:	

Flags: OFF, unused.

User Control Keys:

A: Compute	a.
B:	b:
C:	c:
D:	d:
E:	e:

Permanent Data

The following permanent data are stored in the primary storage registers R0 through R9.

-34302.26904	0
122.9065370	1
-35846.62839	2
43.18615709	3
-36857.62093	4
27.00641670	5
-38068.60561	6
20.18918143	7
-39482.60271	8
16.50293201	9

Program Listing

001 *LELH	21 11	START	058 RCL4	36 04	COMPUTE RANGE
002 STOB	35 12	STO ALTITUDE	059 RCL6	36 12	W/O TEMP CORRECTION
003 R4	-31		060 RCL6	36 06	F = 40,000 lbs
004 STOC	35 13	STO TEMP	061 -	-45	
005 R4	-31		062 RCL7	36 07	
006 STON	35 11	STO FUEL	063 +	-24	
007 EEX	-23		064 STOE	35 15	
008 4	04	TEST FUEL	065 GTDe	22 16 15	
009 +	-24	= 10,000 lbs?	066 *LBL5	21 05	COMPUTE RANGE
010 1	01		067 RCL8	36 12	W/O TEMP CORRECTION
011 -	-45		068 RCL8	36 08	F = 50,000 lbs
012 X=0?	16-43		069 -	-45	
013 GT01	22 01		070 RCL9	36 03	
014 1	01	TEST FUEL	071 +	-24	
015 -	-45	= 20,000 lbs?	072 STOE	35 15	
016 X=0?	16-43		073 *LBL6	21 16 15	
017 GT02	22 02		074 RCL8	36 12	COMPUTE TEMP
018 1	01	TEST FUEL	075 EEX	-23	CORRECTION
019 -	-45	= 30,000 lbs?	076 3	03	
020 X=0?	16-43		077 +	-24	
021 GT03	22 03		078 2	02	
022 1	01	TEST FUEL	079 CHS	-22	
023 -	-45	= 40,000 lbs	080 X	-35	
024 X=0?	16-43		081 1	01	
025 GT04	22 04		082 5	05	
026 1	01	TEST FUEL	083 +	-55	
027 -	-45	= 50,000 lbs	084 RCLC	36 13	
028 X=0?	16-43		085 -	-45	
029 ST05	22 05		086 STOD	35 14	
030 XZY	-41	TEST FUEL	087 X=0?	16-42	IF TEMP = STD
031 0	00	> 50,000 lbs	088 GT04	22 16 14	DISPLAY RANGE
032 +	-24		089 RCL6	36 15	
033 *LBL1	21 01	COMPUTE RANGE	090 DSP0	-63 00	
034 RCLB	36 12	W/O TEMP CORRECTION	091 RTN	24	
035 RCL0	36 00	F = 10,000 lbs	092 *LBL4	21 16 14	
036 -	-45		093 .	-62	
037 RCL1	36 01		094 0	00	TEMP ≠ STD
038 +	-24		095 0	00	DISPLAY RANGE
039 STOE	35 15		096 2	02	
040 GT0e	22 16 15		097 X	-35	
041 *LBL2	21 02	COMPUTE RANGE	098 RCL6	36 15	
042 RCLB	36 12	W/O TEMP CORRECTION	099 X	-35	
043 RCL2	36 02	F = 20,000 lbs	100 CHS	-22	
044 -	-45		101 RCL6	36 15	
045 RCL3	36 03		102 +	-55	
046 +	-24		103 DSP0	-63 00	
047 STOE	35 15		104 R/S	51	END
048 GT0e	22 16 15				
049 *LBL3	21 03	COMPUTE RANGE			
050 RCLB	36 12	W/O TEMP CORRECTION			
051 RCL4	36 04	F = 30,000 lbs			
052 -	-45				
053 RCL5	36 05				
054 +	-24				
055 STOE	35 15				
056 GT0e	22 16 15				
057 *LBL4	21 04				

E. Mathematical Analysis

A linear curve fit was performed using the HP-67/97 standard pack SD-03A program. Five "fits" were performed. For a constant fuel weight, X represented the range and Y represented the altitude. Resulting outputs provided the following:

<u>Fuel (pounds)</u>	<u>R²</u>	<u>a</u>	<u>b</u>
10,000	.998615613	-34,302.26904	122.9065370
20,000	.998739204	-35,846.62839	43.18615709
30,000	.999756772	-36,857.62093	27.00641670
40,000	.999823326	-38,068.60561	20.18918143
50,000	.999802631	-39,482.60271	16.50293201

For a constant fuel the range X could be obtained as follows:

$$X = \frac{Y - a}{b}$$

or

$$\text{Range} = \frac{\text{altitude} - \text{intercept (constant fuel)}}{\text{slope (constant fuel)}}$$

Temperature correction:

increase range 1% per 5°C above standard

decrease range 1% per 5°C below standard.

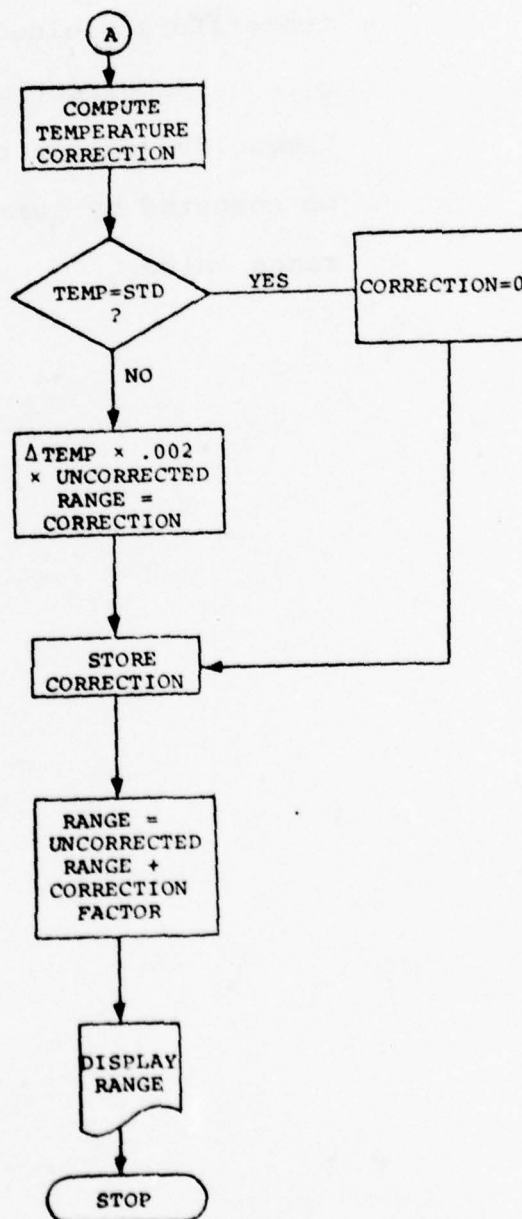
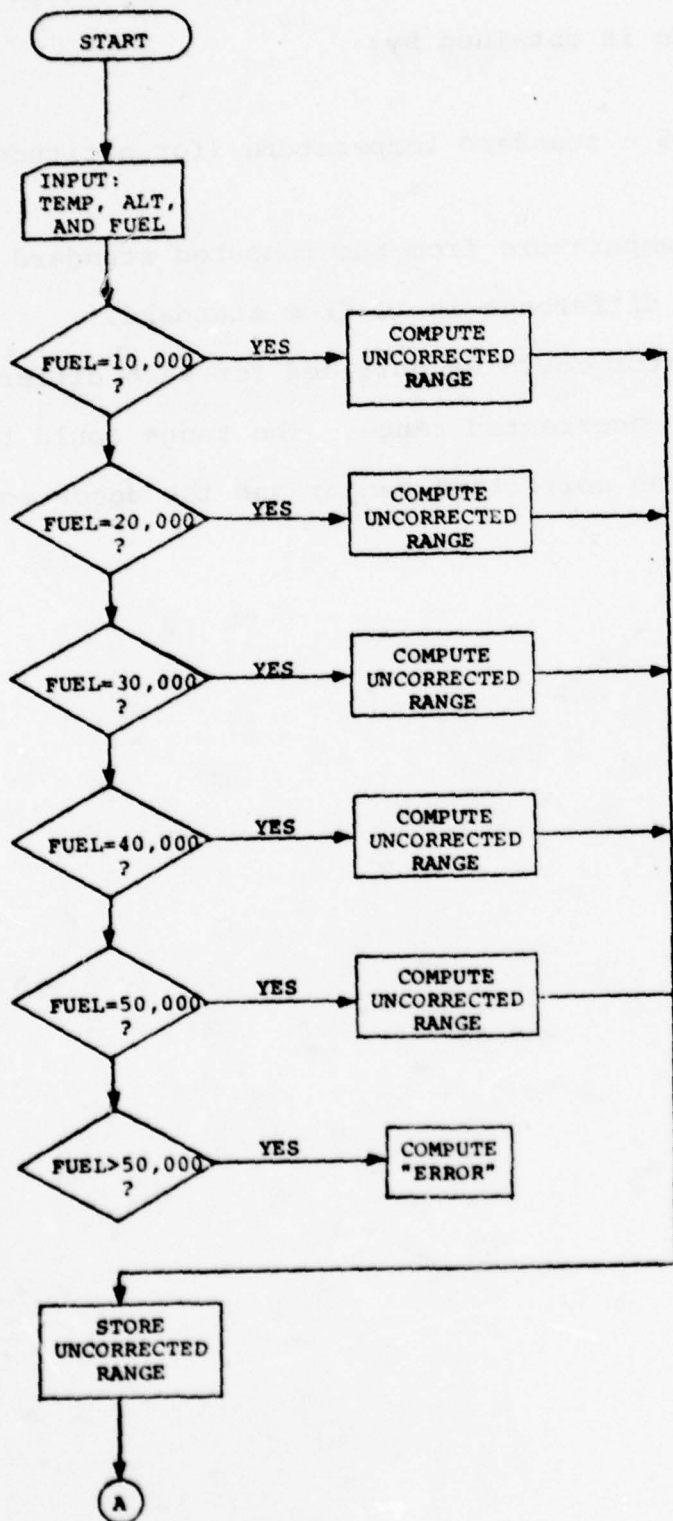
Based on a lapse rate of $-2^{\circ}/1000\text{ft}$ the standard temperature for a specified altitude is obtained by:

$$-2 \times \frac{\text{altitude}}{1000} + 15 = \text{standard temperature (for altitude)}$$

Subtracting the input temperature from the computed standard temperature yielded the difference in $^{\circ}\text{C}$ from standard.

A correction factor could be obtained for each difference times $.002/\text{degree}$ times uncorrected range. The range could then be computed by summing the correction factor and the uncorrected range value.

F. Program Flowchart



IV. MISSION PLANNING: P-3(B) AIRCRAFT CONFIGURATION "B"

LT M. D. Thomas.

A. Problem Statement

In order to carry out the various operational missions assigned the P3-B Aircraft, effective utilization of the platform is essential. All aspects of the mission must be carefully planned. Fuel planning directly influences endurance and the effectiveness of the mission. The NATOPS manual provides charts for this purpose. Two vital charts for planning are:

1. four engine maximum range operating table; used in proceeding to the operational area.
2. three engine loiter operating table; used while onstation for minimum fuel consumption.

The pilot or flight engineer enters with the aircraft's altitude and gross weight and finds the correct indicated airspeed (IAS) to fly.

This program is a user's program in that it translates these two charts onto an HP-67/97 magnetic card and allows calculation of IAS without the charts. Most missions are flown in configuration 'B' therefore the program presented here is for that case.

B. Operational Analysis

None.

C. Computational Algorithm

1. Enter altitude and gross weight in packed form: AAAAA.WWWW where AAAAA denotes the altitude in feet, and WWWW is the gross weight divided by 100,000. The leading zeroes, if any, in the value of WWW must be entered. For example, 18,000 feet and 76,500 pounds are entered as AAAAA = 18,000 and WWWW = 0765, that is 18,000.0765.
2. Compute the maximum range IAS or the three-engine loiter IAS.

D. HP-67/97 Calculator Program

1. User Instructions

Step	Instruction	Input	Key(s)	Output
1.	Enter program card			
2.	Enter altitude and gross weight. G.W. must be at least a three digit number. Compute four engine max range IAS.	ALT.GW	A	IAS (max range)
3a.	Enter altitude and gross weight. G.W. must be at least a three digit number. Compute three engine loiter range IAS	ALT.GW	B	IAS (Loiter)
b.	Optional: Compute the four engine max range IAS without re-entering the altitude and weight		R/S	IAS (max temp)

2. Sample Problems

		A <u>Max Range IAS</u>	B <u>Loiter IAS</u>
1.	130,000 lbs at 18,000 ft 18000.130	252	220
2.	86,000 lbs at 6,000 ft 6000.086*	241	175
3.	76,500 lbs at 10,000 ft 10000.0765	232	165
4.	50,000 lbs at 3,000 ft 3000.050	Error	Error
5.	130,000 lbs at 30,000 ft 30000.130	Error	Error

* Gross weight must be at least a three digit number (IE)

130,000	.130
76,000	.076
82,500	.0825

3. Program Storage Allocation and Listing

Registers

R0: altitude	S0:	RA:
R1: max range constant	S1:	:
R2: loiter airspeeds	S2:	:
:	:	RE:
R9:	S9:	RI:

Initial Flag Status and Use:

0: OFF, unused	2: OFF, unused
1. OFF, unused	3: OFF, unused.

User Control Keys:

A: Compute four engine IAS	a:
B: Compute three engine IAS	b:
C:	c:
D:	d:
E:	e:

001	*LEL4	21 11	038	5	05	COMPUTE MAX RANGE IAS	
002	D550	-63 00	039	XZY?	16-35		
003	ENT4	-21	040	6386	23 06		
004	INT	16 34	041	RCL0	36 00		
005	ST00	35 00	042	RCL1	36 01		
006	R4	-31	043	EEX	-23		
007	FRC	16 44	044	X	05		
008	EEX	-23	045	-	-35		
009	3	03	046	-	-45		
010	X	-35	047	EEX	-23		
011	2	02	048	3	03	CONDITIONAL TEST OF GROSS WEIGHT CATEGORY INCREMENTS CONSTANTS	
012	.	-62	049	÷	-24		
013	7	07	050	CHS	-22		
014	ST01	35 01	051	RTN	24		
015	XZY	-41	052	*LEL4	21 04		
016	2	02	053	XZY?	16-35		
017	2	02	054	GT01	22 01		
018	0	00	055	.	-62		
019	ST02	35 02	056	0	00		
020	R4	-31	057	3	03		
021	1	01	058	ST-1	35-45 01	CONDITIONAL TEST OF GROSS WEIGHT CATEGORY INCREMENTS CONSTANTS	
022	2	02	059	R4	-31		
023	7	07	060	5	05		
024	.	-62	061	ST-2	35-45 02		
025	5	05	062	-	-45		
026	GT04	22 04	063	GT05	22 05		
027	*LEL5	21 12	064	RTN	24		
028	6386	23 11	065	*LEL5	21 05		
029	RCL2	36 02	066	XZY?	16-35		
030	RTN	24	067	GT01	22 01		
031	*LEL1	21 01	068	.	-62	CONDITIONAL TEST OF GROSS WEIGHT CATEGORY INCREMENTS CONSTANTS	
032	6387	23 07	069	0	00		
033	R4	-31	070	2	02		
034	1	01	071	ST-1	35-45 01		
035	1	01	072	R4	-31		
036	7	07	073	5	05		
037	.	-62	074	ST-2	35-45 02		
UNPACK ALTITUDE AND GROSS WEIGHT						COMPUTE MAX RANGE IAS	
STORE MAX RANGE CONSTANT							
STORE LOITER CONSTANT							
SET INITIAL GROSS WEIGHT BRACKET							
COMPUTE LOITER IAS							
CHECK ALTITUDE RESTRICTIONS							

075	-	-45	
076	GT04	22 04	
077	RTN	24	
078	*LBL5	21 06	
079	RCL0	36 00	
080	2	02	
081	8	08	
082	EEA	-23	
083	3	03	
084	X>Y0	16-34	
085	RTN	24	
086	X<Y	-41	
087	FTX	-14	
088	GT0C	22 13	
089	*LBL7	21 07	
090	R4	-31	
091	7	07	
092	2	02	
093	.	-62	
094	5	05	
095	X>Y0	16-35	
096	RTN	24	
097	X<Y	-41	
098	PTX	-14	
099	GT0C	22 13	
100	RTN	24	
101	R/S	51	

CHECKS ALTITUDE IF ILLEGAL,
ERROR DISPLAY

CHECKS GROSS WEIGHT CATEGORY
IF ILLEGAL, ERROR DISPLAY

E. Computational Analysis

Using the HP-67 standard curve fitting program, a good linear fit was obtained on the four engine maximum range data. There is a linear relationship between altitude and indicated airspeed for each gross weight category. The coefficient of determination was equal to 1.00 in all cases, indicating a good fit. The following equations were used; loiter airspeeds are constant for each category.

<u>G.W. (1000 lbs)</u>	<u>Max range IAS</u>	<u>Loiter IAS</u>
132.5-127.5	$y = 270 - x/1000$	220
127.5-122.5	$y = 267 - x/1000$	215
122.5-117.5	$y = 265 - x/1000$	210
117.5-112.5	$y = 262 - x/1000$	205
112.5-107.5	$y = 260 - x/1000$	200
107.5-102.5	$y = 257 - x/1000$	195
102.5- 97.5	$y = 255 - x/1000$	190
97.5- 92.5	$y = 252 - x/1000$	185
92.5- 87.5	$y = 250 - x/1000$	180
87.5- 82.5	$y = 247 - x/1000$	175
82.5- 77.5	$y = 245 - x/1000$	170
77.5- 72.5	$y = 242 - x/1000$	165

x = altitude in feet and y = maximum range IAS.

V. USER-CONTROLLED SIMULATION OF APPROACH AND LANDING FOR
THE P-3 AIRCRAFT by LT J. Aiken

A. Problem Statement

This program simulates an aircraft approach and landing. Specifically, it is a time-step simulation of the final five miles of a precision approach for a Lockheed P-3 ORION aircraft. The simulation is user-controlled which allows the user to act as pilot and make the decisions which control the movement of the airplane during its final approach phase. The purpose of the program is to simulate accurately the flight of the aircraft and display to the operator his rate of movement and position resulting from his manipulation of the controls.

B. Operation Analysis

Relevant information on the airfield is as follows:

Runway	8000 ft (length 200 ft (width) 180 degrees magnetic heading SEA LEVEL elevation
Approach	TOUCHDOWN POINT 1000ft beyond approach threshold GLIDE SLOPE 2.83 degrees 2 min 18 sec time required at 135 kts ground speed FINAL APPROACH FIX: 5 miles, 1500ft (starting point)

The aircraft weighs 90,000 lbs with approach speeds 135/121 kts (approach flaps/land flaps). Note however that no provision is made for changing the gear/flap configuration so it is essentially an "approach-flap" landing. The simulation starts with the aircraft in motion: 1500 feet MSL, 135 kts IAS, 650 ft/min descent rate, landing gear down and approach flaps. The simulation allows the user to select horsepower settings, nose attitude, heading, wind direction, wind velocity, and time interval. At the end of a time interval the simulation is halted and the critical flight information is displayed to the operator, allowing him to alter controlling parameters and continue the flight. The simulation continues in this manner until the aircraft lands. Vital landing parameters are displayed and the simulation is complete. The simulation realistically responds to control changes provided the aircraft is flown in a somewhat reasonable fashion. Extreme deviations and maneuvers other than those required during an approach are not designed into the program.

C. Computational Algorithm

1. Initialize the aircraft at the starting point.
2. Input time step, wind direction and wind velocity.
3. Input horsepower, nose attitude, heading, and number of time steps desired.
4. Compute course deviation.
5. Compute horizontal acceleration.
6. Compute vertical acceleration.
7. Compute final velocity and average vertical velocity.
8. Compute altitude.
9. Compute final and average horizontal velocity.
10. Compute distance remaining based on ground speed.
11. Compute glide slope height and deviation from glide slope.
12. Check altitude less than 0.
13. DSZ (number of time steps is the counter) GTO 4 above.
14. Display approach parameters after completing desired time steps.
15. Display landing parameters upon landing.
16. Clear primary and secondary registers, GTO 1 for new problem.

D. HP-67 Calculator Program

1. User Instructions

Step	Instruction	Input	Key(s)	Output
1.	Enter program card			
2.	Clear primary and secondary registers			
3.	Initialize		f e	30384
4.	Enter time step	seconds	STO C	
5.	Enter wind direction	degrees	STO D	
6.	Enter wind velocity	knots	STO E	
7.	Enter horsepower	HP	A	HP
8.	Enter nose attitude	+ degrees	B	Nose attitude
9.	Enter heading	degress	C	Heading
10.	Enter number of time steps	integer	D	flashing
	<u>Output</u>			
	Altitude. Airspeed (Packed)			Alt. airspeed
	Descent rate (ft/min)		R/S	Descent rate
	Above (+) or below (-) glide slope		R/S	Feet hi/lo
	Distance to go Airborne (miles) Landed (feet)		R/S	+ Distance to go
	Right (+) or left (-) of of course		R/S	ft right/left
11.	If altitude GT zero go to Step 4; make new entries only if change desired. Step 10 must be re-entered.			

2. Sample Problem

Input							Output					
Time Step	Wind Direction	Wind Velocity	Horsepower	Nose Attitude	Heading	Steps	Altitude	Airspeed	Descent Rate	Above/Below Glide Slope	Distance To Go	Right/Left of Course
20	210	20	800	1.5	185	1	1295	133	-570	-1	4.4	63
					183	1	1108	132	-552	2.4	3.7	-34
					184	1	922	132	-560	6.9	3.1	-51
					185	1	732	132	-580	6.3	2.4	11
					184	1	538	132	-584	1.6	1.8	-6
10			790		184	1	441	132	-575	0	1.5	-14
					184.8	1	346	132	-574	-1	1.2	9
					184.3	1	252	131	-555	-1	.85	13
5			700	3.5	184	1	205	129	-559	-1	.7	8
					4	1	159	127	-552	-2	.5	4
					184.1	1	113	127	-552	-2	.4	2
					4.3	1	67	127	-547	-3	.24	-2
					4.8	1	22	126	-538	-3	.08	-7
2					6	1	4	126	-530	-3	.02	-8
					8	1	0	125	-516	-2	40	-22

Sample Problem Keystroke Sequence

GSBa	-580.08 ***
30384.00 ***	R/S
20.00 STOC	6.33 ***
210.00 STOC	R/S
20.00 STOE	2.44 ***
600.00 GSEA	R/S
1.50 GSBE	11.46 ***
185.00 GSBC	184.00 GSBC
1.00 GSBD	1.00 GSBD
1295.132 ***	536.132 ***
R/S	R/S
-570.00 ***	-584.02 ***
R/S	R/S
-1.02 ***	1.61 ***
R/S	R/S
4.35 ***	1.80 ***
R/S	R/S
62.92 ***	-5.66 ***
183.00 GSBC	10.00 STOC
1.00 GSBD	790.00 GSEA
1108.132 ***	184.00 GSBC
R/S	1.00 GSBD
-552.00 ***	441.132 ***
R/S	R/S
2.42 ***	-575.41 ***
R/S	R/S
3.71 ***	-0.35 ***
R/S	R/S
-34.34 ***	1.49 ***
790.00 GSEA	R/S
184.00 GSBC	-14.22 ***
1.00 GSBD	184.00 GSBC
922.132 ***	1.00 GSBD
R/S	346.132 ***
-560.40 ***	R/S
R/S	-573.69 ***
6.89 ***	R/S
R/S	-1.40 ***
3.08 ***	R/S
R/S	1.17 ***
-51.46 ***	R/S
775.00 GSEA	9.24 ***
185.00 GSBC	795.00 GSEA
1.00 GSBD	2.00 GSBE
732.132 ***	184.30 GSBC
R/S	1.00 GSBD
	252.131 ***

Sample Problem Keystroke Sequence (cont.)

	R/S		1.00 GSEC
-555.34	***	67.127	***
	R/S		R/S
-1.25	***	-546.74	***
	R/S		R/S
0.85	***	-2.72	***
	R/S		R/S
12.69	***	0.24	***
5.00 STOC			R/S
700.00 GSEA		-2.43	***
3.50 GSEE		4.00 GSEE	
184.00 GSEC		1.00 GSEC	
1.00 GSEC		22.126	***
205.129	***		R/S
	R/S	-538.29	***
-559.51	***		R/S
	R/S	-2.76	***
-1.27	***		R/S
	R/S	0.08	***
0.69	***		R/S
	R/S	-6.71	***
8.41	***	2.00 STOC	
4.00 GSEE		6.00 GSEE	
1.00 GSEC		1.00 GSEC	
159.127	***	4.126	***
	R/S		R/S
-552.84	***	-530.41	***
	R/S		R/S
-1.85	***	-2.61	***
	R/S		R/S
0.54	***	0.02	***
	R/S		R/S
4.13	***	-8.42	***
184.10 GSEC		8.00 GSEE	
1.00 GSEC		182.50 GSEC	
113.127	***	1.00 GSEC	
	R/S	0.125	***
-551.51	***		R/S
	R/S	-516.64	***
-2.35	***		R/S
	R/S	-2.24	***
0.39	***		R/S
	R/S	40.50	***
1.85	***		R/S
4.30 GSEE		-22.16	***
184.00 GSEC			

3. Program Storage Allocations and Program Listing

Registers:

R0: Right/left of course	S1: Horizontal force
R1: Horsepower	S2: Vertical force
R2: Nose attitude	
R3: Horizontal velocity	
R4: Vertical velocity	
R5: Altitude	
R6: Horizontal acceleration	
R7: Vertical acceleration	
R8: Distance remaining	
R9: Glide Slope Altitude	
RA: DELH	
RB: Heading	
RC: Time step	
RD: Wind direction	
RE: Wind velocity	
RI: Number of time steps	

Initial Flag Status:

0: OFF, Unused	2: OFF, Set ON upon landing
1: OFF, Unused	3: OFF, Unused

User Control Keys:

A: Horsepower	a:
B: Nose attitude	b:
C: Heading	c:
D: Time steps, start computation	d:
E:	e: Initialize

001	*LBLW	21 11	INPUT HORSEPOWER NOSE ATTITUDE HEADING	061	G8B1	23 01	COMPUTE
002	ST01	35 01		062	ST06	35 06	HORIZONTAL ACCEL
003	R/S	51		063	G8B2	23 02	COMPUTE
004	*LELB	21 12		064	ST07	35 07	VERTICAL ACCEL
005	ST02	35 02		065	RCL4	36 04	COMPUTE VERTICAL VELOCITY
006	R/S	51		066	RCL7	36 07	
007	*LBLC	21 13		067	RCL0	36 13	
008	ST08	35 12		068	X	-35	
009	R/S	51		069	ST+4	35-55 04	COMPUTE ALTITUDE
010	*LBLe	21 16 15		070	XZY	-41	
011	2	02	INITIALIZE SPEEDS ALTITUDE DISTANCE	071	RCL4	36 04	
012	2	02		072	+	-55	
013	8	03		073	2	02	COMPUTE HORIZONTAL VELOCITY
014	ST03	35 03		074	+	-24	
015	1	01		075	RCL0	36 13	
016	1	01		076	X	-35	
017	CHS	-22		077	ST+5	35-55 05	COMPUTE GROUND SPEED AND DISTANCE TO GO
018	ST04	35 04		078	RCL3	36 03	
019	1	01		079	RCL6	36 06	
020	5	05		080	RCL0	36 13	
021	0	00	COMPUTE DRIFT RATES AND COURSE DEVIATION	081	X	-35	COMPUTE GLIDE-SLOPE HEIGHT AND DEVIATION FROM GLIDE-SLOPE
022	0	00		082	ST+3	35-55 03	
023	ST05	35 05		083	XZY	-41	
024	3	03		084	RCL3	36 03	
025	0	00		085	+	-55	CHECK ALT < 0 LOOP CONTROL
026	3	03		086	2	02	
027	8	08		087	+	-24	
028	4	04		088	RCL0	36 14	
029	ST08	35 08		089	1	01	
030	R/S	51		090	8	08	
031	*LBLD	21 14	COMPUTE DRIFT RATES AND COURSE DEVIATION	091	0	00	COMPUTE GLIDE-SLOPE HEIGHT AND DEVIATION FROM GLIDE-SLOPE
032	ST01	35 45		092	-	-45	
033	*LELB	21 08		093	ABS	16 31	
034	RCLB	36 12		094	COS	42	
035	1	01		095	RCL5	36 15	CHECK ALT < 0 LOOP CONTROL
036	8	08		096	1	01	
037	0	00		097	.	-62	
038	-	-45		098	6	06	
039	SIN	41		099	9	09	
040	2	02		100	X	-35	
041	3	03	COMPUTE DRIFT RATES AND COURSE DEVIATION	101	X	-35	CHECK ALT < 0 LOOP CONTROL
042	0	00		102	-	-45	
043	X	-35		103	RCL0	36 13	
044	1	01		104	X	-35	
045	8	08		105	CHS	-22	CHECK ALT < 0 LOOP CONTROL
046	0	00		106	RCL8	36 08	
047	RCLD	36 14		107	+	-55	
048	-	-45		108	ST08	35 08	
049	SIN	41		109	.	-62	CHECK ALT < 0 LOOP CONTROL
050	RCL5	36 15		110	0	00	
051	1	01		111	4	04	
052	.	-62		112	9	09	
053	6	06	COMPUTE DRIFT RATES AND COURSE DEVIATION	113	X	-35	CHECK ALT < 0 LOOP CONTROL
054	9	09		114	ST09	35 09	
055	X	-35		115	CHS	-22	
056	X	-35		116	RCL5	36 05	
057	+	-55		117	+	-55	CHECK ALT < 0 LOOP CONTROL
058	RCL0	36 13		118	ST04	35 11	
059	X	-35		119	RCL5	36 05	
060	ST+0	35-55 00		120	X00	16-45	
				121	GT08	22 09	CHECK ALT < 0 LOOP CONTROL
				122	G8C1	16 25 46	
				123	GT08	22 08	CHECK ALT < 0 LOOP CONTROL

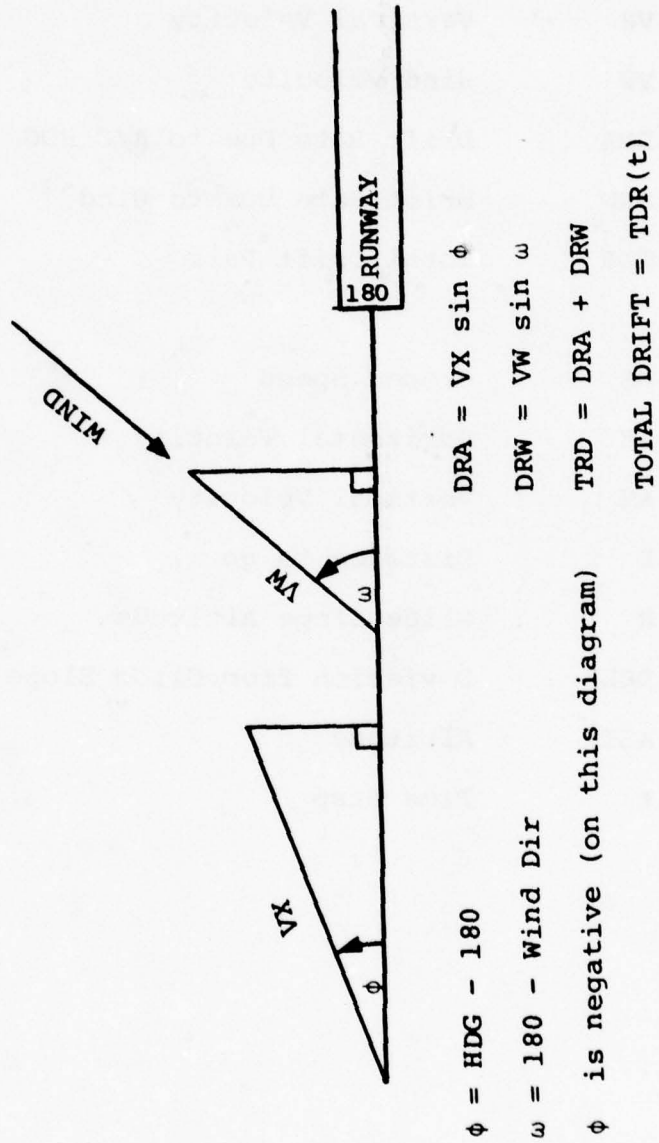
124	*LBL7	21 07		169	*LBL1	21 01	
125	RCL5	36 05		170	RCL2	36 02	
126	INT	16 34		171	.	-62	
127	RCL3	36 03		172	4	04	
128	1	01	ALTITUDE	173	CHS	-22	COMPUTE
129	6	06	DECIMAL	174	x	-35	
130	8	08	AIRSPEED	175	EEN	-23	HORIZONTAL
131	8	08	(PACKED)	176	3	03	
132	+	-24		177	CHS	-22	FORCE
133	+	-55		178	RCL1	36 01	
134	DSP3	-63 03		179	x	-35	
135	R/S	51		180	+	-55	
136	DSP2	-63 02		181	.	-62	
137	RCL4	36 04	RATE	182	4	04	
138	6	06	OF	183	-	-45	
139	0	00	DESCENT	184	F2S	16-51	
140	x	-35		185	RCL1	36 01	
141	R/S	51		186	XZY	-41	
142	RCL4	36 11	HIGH/LOW	187	STO1	35 01	COMPUTE
143	R/S	51		188	XZY	-41	
144	RCL8	36 08		189	-	-45	HORIZONTAL
145	F2P	16 23 02	DISTANCE TO GO	190	F2S	16-51	
146	STO5	22 05	(FEET IF	191	RCL6	36 06	ACCELERATION
147	6	06	LANDED)	192	5	05	
148	0	00		193	+	-24	
149	7	07		194	+	-55	
150	7	07		195	RTN	24	
151	+	-24		196	*LBL2	21 02	
152	*LBL5	21 05		197	.	-62	
153	R/S	51		198	0	00	
154	RCL0	36 00	LEFT/RIGHT	199	0	00	
155	R/S	51		200	1	01	
156	*LBL9	21 09		201	RCL1	36 01	COMPUTE
157	RCL8	36 08		202	x	-35	
158	RCL5	36 05	LANDED...	203	.	-62	VERTICAL
159	CHS	-22	ADJUST DISTANCE	204	8	08	
160	2	02	TO ZERO ALT.	205	-	-45	FORCE
161	0	00		206	RCL2	36 02	
162	x	-35		207	.	-62	
163	+	-55		208	0	00	
164	STO8	35 08		209	5	05	
165	0	00		210	x	-35	
166	STO5	35 05	SET ALT = 0	211	+	-55	
167	SF2	16 21 02	SET FLAG 2	212	F2S	16-51	
168	STO7	22 07		213	RCL2	36 02	
				214	XZY	-41	
				215	STO2	35 02	COMPUTE
				216	XZY	-41	
				217	-	-45	VERTICAL
				218	F2S	16-51	
				219	RCL7	36 07	ACCELERATION
				220	5	05	
				221	+	-24	
				222	+	-55	
				223	RTN	24	
				224	R/S	51	

E. Mathematical Analysis

The variable names used are:

VX	Horizontal Velocity
VY	Vertical Velocity
VW	Wind Velocity
DRA	Drift Rate Due to A/C HDG
DRW	Drift Rate Due to Wind
TDR	Total Drift Rate
GS	Ground Speed
AX	Horizontal Velocity
AY	Vertical Velocity
D	Distance to go
H	Glide Slope Altitude
DELH	Deviation from Glide Slope
ALT	Altitude
t	Time Step

COURSE DEVIATION COMPUTATION



DISTANCE, GROUNDSPED, GLIDE SLOPE

$$\text{Avg HOR Velocity} = \frac{1}{2} (VX_0 + VX_1) \quad (\text{for one time step})$$

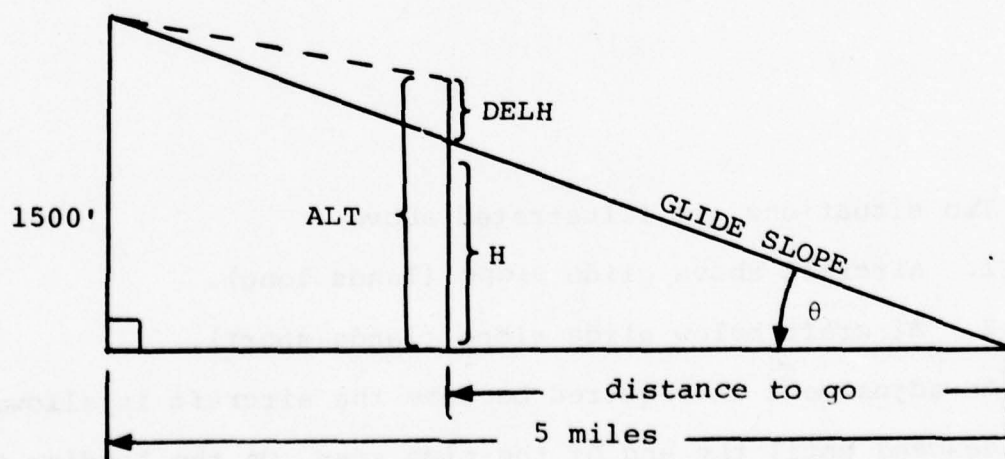
$$\text{Distance travelled} = GS(t)$$

$$GS = VX - VW \cos|\text{wind dir} - 180|$$

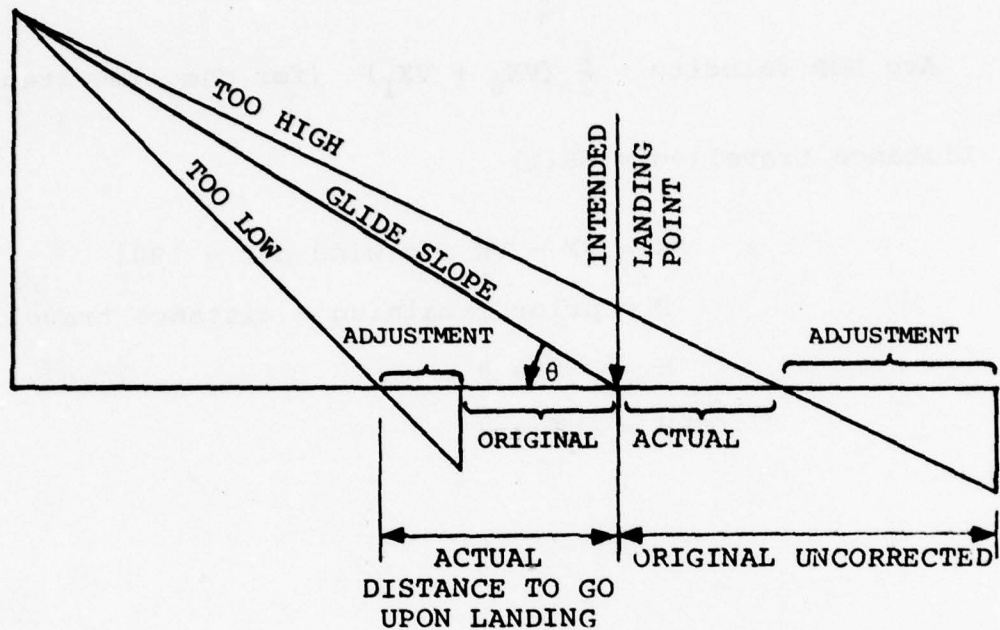
$$D = \text{prior remaining} - \text{distance travelled}$$

$$H = D \tan \theta$$

$$DELH = ALT - H$$



LANDING DISTANCE ADJUSTMENT



Two situations are illustrated above.

1. Aircraft above glide slope (lands long).
2. Aircraft below glide slope (lands short).

An adjustment is required because the aircraft is allowed to descend until the end of the time step. On the landing time step the aircraft will have descended below zero altitude.

The adjustment in either case is: $\text{adjustment} = H/(\tan \theta)$.

FORCES, ACCELERATIONS, AND VELOCITIES

$FX = - \theta + .001HP - .4$	$FX =$ horizontal force
$FY = .001HP - .8 + .05\theta$	$FY =$ vertical force
$AX' = (FX^1 - FX^0) + .2AX^0$	$\theta =$ nose attitude
$AY' = (FY^1 - FY^0) + .2AY^0$	Superscripts denote different time steps
$VX_1 = VX_0 + AX(t)$	Subscripts denote start and end of a time step.
$VY_1 = VY_0 + AY(t)$	

Although the author is not an aeronautical engineer, it was felt that his understanding of the basic laws of physics complemented by considerable pilot experience would serve sufficiently to accomplish the goals of this project. The formulae for force and acceleration were arrived at after testing several trial formulae on experienced P-3 pilots. The unanimous opinion was that the current program enables the simulation to closely model the actual flight characteristics of the aircraft.

VI. FLIGHT CREW MANAGEMENT USING THE HP-97 by LT Kenneth W. Peters

A. Problem Statement

A flight crew's most recent landing day and time is known. Using requirements for crew rest and postflight and preflight duration, compute when the flight crew will be available for take-off again. For planning and scheduling purposes, list crews in order of availability. For required onstation times compute takeoff, onstation, offstation and landing times for a given number of flights. Determine if flight crews will be available to meet this schedule.

B. Operational Analysis

When planning an operation requiring scheduling of several flight crews, crew availability must be considered. Accurate and easily understood crew records are necessary to meet both operational and safety requirements.

C. Computational Algorithm

1. Flight crew availability

- a. Enter required postflight to preflight crew rest time.
- b. Enter crew number and their most recent landing day and time.
- c. Compute the crew's earliest possible takeoff day and time using one hour for postflight and three hours for preflight.

2. List crews in order of availability
 - a. Enter number of flight crews = N.
 - b. Compare crew N availability with crew (N-1) availability. Store crew number and availability of crew which can take-off soonest. Compare this crew with crew (N-x), (x = 1,2,3,4,...,(N-1)), and store the crew which is available the soonest.
 - c. When most available crew has been determined, add 10,000 days to its takeoff availability date and increment counter.
 - d. Repeat Steps b and c until all crews have been listed, i.e. counter = N.
 - e. Restore crew availability data by subtracting 10,000 days from each crew's availability date.
3. Operational schedule.
 - a. Enter required number of flights from a particular base and the gap (+) desired for onstation coverage.
 - b. Compute takeoff day and time, onstation day and time, offstation day and time, and landing day and time.
 - c. Check number of flights versus counter. Repeat b as required.
 - d. Compare print-out of required takeoff times with crew availability listing (see Part 2 above).

D. HP-67/97 Calculator Program

1. User Instructions

Step	Instruction	Input	Key(s)	Output
1.	Enter program card			
2.	Compute flight crew availability			
a.	Enter crew rest time	HH.MM	fA	
b.	Enter crew rest data:			
	Crew #	$1 \leq \# \leq 19$	↑	
	Postflight time	HH.MM	↑	
	Preflight time	HH.MM	↑	
	Landing Julian day and time	DAY.HHMM	A	Crew # Availability DAY.HHM
	NOTE: If change in year will occur, Julian date can be entered as: YRDAY.HHMM			
3.	List crews in order of availability. Enter # of crews = N	$1 \leq N \leq 19$	B	Crew # Availability DAY.HHMM (repeated N times)
4.	Compute operational flight schedule			
a.	Enter # of flights and gap in onstation coverage: # of flights = N	$1 \leq N \leq 25$	↑	
	gap in coverage	HH.MM	fC	
b.	Compute schedule			
	onstation day and time	DAY.HHMM	↑	
	one-way transit time	HH.MM	↑	
	mission time	HH.MM	C	Flight # Takeoff DAY.HHMM Onsta DAY.HHMM Offsta DAY.HHMM Land DAY.HHMM
5.	(Optional) Store crew availability data on magnetic card: Set W/PRGM-RUN switch to RUN To reload data: Set W/PRGM-RUN switch to RUN and load data card obtained above		f W/DATA	

2. Sample Problem

a. Input the following data:

Crew rest = 15 hours

<u>Crew #</u>	<u>Postflight</u>	<u>Preflight</u>	<u>Landing</u>
1	1	3	2.2330
2	1	3	1.1200
3	1	3	2.1800
4	1	3	1.1532

b. Compute crew availability.

Answer:

<u>Crew #</u>	<u>Availability</u>
1	3.1830
2	2.0700
3	3.1300
4	2.1032

c. Input the following crew status:

<u>Crew #</u>	<u>(in) Register #</u>	<u>Availability</u>
1	1	3.1830
2	2	2.0700
3	3	3.1300
4	4	2.1032
5	5	2.0958
6	6	2.2020
7	7	3.1930
8	8	5.0730
9	9	4.0930
10	10	6.0430
11	11	4.0345
12	12	2.0730
13	13	8.0130
14	14	5.0315
15	15	3.0545
16	16	3.1300
17	17	9.0955
18	18	2.1030

d. Output listing of crews in order of availability.

Answer: 2, 12, 5, 18, 4, 6, 15, 3, 16, 1, 7, 11, 9,
14, 8, 10, 13, 17.

e. Develop an operational flight schedule consisting of six (6) flights with a zero (0) gap in onstation coverage. The first onstation time is 2.1830, it takes one (1) hour and fifty (50) minutes for a one-way transit, and a flight from this base has nine (9) hours of total mission time.

Answer:

<u>Flight #</u>	<u>Takeoff</u>	<u>Onsta</u>	<u>Offsta</u>	<u>Land</u>
1	2.1640	2.1830	2.2350	3.0140
2	2.2200	2.2350	3.0510	3.0700
3	3.0320	3.0510	3.1030	3.1220
4	3.0840	3.1030	3.1550	3.1740
5	3.1400	3.1550	3.2110	3.2300
6	3.1920	3.2110	4.0230	4.0420

f. Develop an operational flight schedule consisting of two (2) flights with a two (2) hour gap in onstation coverage. The first onstation time is 2.1830, with the same transit and mission time as in (e).

Answer:

<u>Flight #</u>	<u>Takeoff</u>	<u>Onsta</u>	<u>Offsta</u>	<u>Land</u>
1	2.1640	2.1830	2.2350	3.0140
2	3.0000	3.0150	3.0710	3.0900

- g. Develop an operational flight schedule with the same parameters as in (f), except with a negative two (-2) hour gap in onstation coverage.

Answer:

<u>Flight #</u>	<u>Takeoff</u>	<u>Onsta</u>	<u>Offsta</u>	<u>Land</u>
1	2.1640	2.1830	2.2350	3.0140
2	2.2100	2.2250	3.0410	3.0600

- h. With one flight from Base A with the first onstation time as above and one flight from Base B to the same operational area, compute the flight schedule. One-way transit time from Base B is two (2) hours, but mission time is now ten (10) hours. Zero (0) gap in coverage is desired.

Answer:

<u>Flight #</u>	<u>Takeoff</u>	<u>Onsta</u>	<u>Offsta</u>	<u>Land</u>
1	2.1640	2.1830	2.2350	3.0140
2	2.2120	2.2350	3.0450	3.0720

- i. With four (4) flight crews with crew availability as follows:

<u>Crew #</u>	<u>Availability</u>
1	3.1830
2	2.0700
3	3.1300
4	3.1700

determine if they are available to meet an operational flight schedule with the following conditions:

4 flights

2 hour gap in onstation coverage

3.0100 is the first onstation time

1 hour and 30 minute one-way transit

10 hour mission time

Answer: No, a crew is not available to meet the second scheduled takeoff time.

Examples a, b

15.0000 GSEA
1.0000 ENT?
1.0000 ENT?
3.0000 ENT?
2.2330 GSEA
1. ***
3.1830 ***
2.0000 ENT?
1.0000 ENT?
3.0000 ENT?
1.1200 GSEA
2. ***
2.0700 ***

3.0000 ENT?
1.0000 ENT?
3.0000 ENT?
2.1800 GSEA
3. ***
3.1300 ***
4.0000 ENT?
1.0000 ENT?
3.0000 ENT?
1.1532 GSEA
4. ***
2.1032 ***

Examples c, d

18.0000 GSEA	15. ***	9. ***
2. ***	3.0545 ***	4.0930 ***
2.0700 ***		
	3. ***	14. ***
12. ***	3.1300 ***	5.0315 ***
2.0730 ***		
	16. ***	6. ***
5. ***	3.1300 ***	5.0730 ***
2.0958 ***		
	1. ***	10. ***
18. ***	3.1830 ***	6.0430 ***
2.1030 ***		
	7. ***	13. ***
4. ***	3.1930 ***	8.0130 ***
2.1032 ***		
	11. ***	17. ***
6. ***	4.0345 ***	9.0955 ***
2.2020 ***		

Example e

6.0000	ENT:
0.0000	GSEC
2.1830	ENT:
1.5000	ENT:
9.0000	GSEC
1.00000000	***
2.1640	***
2.1830	***
2.2350	***
3.0140	***
2.00000000	***
2.2200	***
2.2350	***
3.0510	***
3.0700	***
3.00000000	***
3.0320	***
3.0510	***
3.1030	***
3.1220	***
4.00000000	***
3.0840	***
3.1030	***
3.1550	***
3.1740	***
5.00000000	***
3.1400	***
3.1550	***
3.2110	***
3.2300	***
6.00000000	***
3.1920	***
3.2110	***
4.0230	***
4.0420	***

Example f

2.0000	ENT:
2.0000	GSEC
2.1830	ENT:
1.5000	ENT:
9.0000	GSEC
1.00000000	***
2.1640	***
2.1830	***
2.2350	***
3.0140	***
2.00000000	***
3.0000	***
3.0150	***
3.0710	***
3.0900	***

Example g

2.0000	ENT:
-1.0000	GSEC
2.1830	ENT:
1.5000	ENT:
9.0000	GSEC
1.00000000	***
2.1640	***
2.1830	***
2.2350	***
3.0140	***
2.00000000	***
2.2100	***
2.2250	***
3.0410	***
3.0600	***

Example h

```
1.0000 ENT:  
0.0000 GSEC  
  
3.1830 ENT:  
1.5000 ENT:  
9.0000 GSEC  
1.00000000 ***  
2.1640 ***  
2.1630 ***  
2.2350 ***  
3.0140 ***  
  
1.0000 ENT:  
0.0000 GSEC  
  
2.2350 ENT:  
2.3000 ENT:  
10.0000 GSEC  
1.00000000 ***  
2.2120 ***  
2.2350 ***  
3.0450 ***  
3.0720 ***
```

Example i

```
4.0000 GSEC  
2. ***  
2.0700 ***  
  
3. ***  
3.1300 ***  
  
4. ***  
3.1700 ***  
  
1. ***  
3.1830 ***
```

```
4.0000 ENT:  
2.0000 GSEC  
3.0100 ENT:  
1.3000 ENT:  
10.0000 GSEC  
1.00000000 ***  
2.2330 ***  
3.0100 ***  
3.0800 ***  
3.0930 ***  
  
2.00000000 ***  
3.0830 ***  
3.1000 ***  
3.1700 ***  
3.1830 ***  
  
3.00000000 ***  
3.1730 ***  
3.1900 ***  
4.0200 ***  
4.0330 ***  
  
4.00000000 ***  
4.0230 ***  
4.0400 ***  
4.1100 ***  
4.1230 ***
```

3. Program Storage Allocation and Listing

Registers:

R0: Crew rest	S0: Crew 10 availability
R1: Crew 1 availability	S1: Crew 11 availability
R2: Crew 2 availability	S2: Crew 12 availability
R3: Crew 3 availability	S3: Crew 13 availability
R4: Crew 4 availability	S4: Crew 14 availability
R5: Crew 5 availability	S5: Crew 15 availability
R6: Crew 6 availability	S6: Crew 16 availability
R7: Crew 7 availability	S7: Crew 17 availability
R8: Crew 8 availability	S8: Crew 18 availability
R9: Crew 9 availability	S9: Crew 19 availability
RA: Landing data; # of crews	
RB: First onsta time; crew #; takeoff time	
RC: Mission time; flight counter	
RD: Gap between onstation periods; ith availability	
RE: Flight counter; crew counter; one-way transit	

Initial Flag Status and Use

0: Unused	2: OFF, day correction
1: Unused	d: OFF, hour correction

User Controlled Keys

A: Crew # ↑, postflight ↑, preflight ↑, land ⇒ compute availability	
B: crew # ↑; compute listing	
C: onsta ↑, one-way transit ↑, mission time ⇒ flight schedule	
D: unused	
E: unused	
a: crew rest	d: unused
b: unused	e: unused
c: flight ↑, gap	

001	*LELC	21 16 13	Input and Store # of flights and desired gap
002	STOD	35 14	
003	R4	-31	
004	STOW	35 11	
005	RTN	24	
006	*LELC	21 13	
007	CF2	16 22 02	Compute flight schedule
008	CF3	16 22 03	Input and store onstation day and time
009	STOC	35 13	Input and store one-way transit time
010	R4	-31	Input and store total mission time
011	STOE	35 15	
012	R4	-31	
013	STOB	35 12	
014	GSBO	23 00	
015	RCLE	36 15	Unpack ddd.hhmm to hh.mm
016	CHS	-22	
017	HMS+	16-55	Compute takeoff time
018	XK0?	16-45	Check for time greater than 24 hours
019	GSBe	23 16 15	
020	EEX	-23	
021	2	02	
022	+	-24	
023	RCLB	36 12	
024	INT	16 34	
025	F3?	16 23 03	
026	GSBd	23 16 14	
027	+	-55	Takeoff ddd.hhmm
028	STOB	35 12	
029	1	01	
030	*LBL9	21 09	
031	STOI	35 46	-----
032	DSP8	-63 00	Start loop
033	PRTX	-14	Print flight #
034	RCLB	36 12	
035	F2?	16 23 02	
036	GSB2	23 02	
037	DSF4	-63 04	
038	FRTX	-14	Print takeoff ddd.hhmm
039	STOB	35 12	
040	STOO	35 00	
041	GSBO	23 00	
042	RCLE	36 15	
043	HMS+	16-55	Compute and print onstation ddd.hhmm
044	GSBO	23 14	
045	GSBE	23 15	
046	GSBO	23 00	
047	RCLE	36 15	
048	RCLE	36 15	
049	HMS+	16-55	
050	CHS	-22	
051	RCLC	36 13	
052	HMS+	16-55	Compute and print offstation ddd.hhmm
053	HMS+	16-55	
054	GSBO	23 14	
055	GSBE	23 15	
056	GSBO	23 00	
057	RCLE	36 15	
058	HMS+	16-55	Compute and print landing ddd.hhmm
059	GSBO	23 14	
060	GSBE	23 15	
061	SPC	16-11	

062	RCLB	36 12
063	GSB0	23 00
064	RCLC	36 10
065	HMS+	16-55
066	RCLD	36 15
067	RCLD	36 15
068	HMS+	16-55
069	CHS	-22
070	HMS+	16-55
071	RCLD	36 14
072	HMS+	16-55
073	GSB0	23 14
074	RCLB	36 12
075	INT	16 34
076	+	-55
077	STOB	35 12
078	RCLA	36 11
079	1	01
080	+	-55
081	1	01
082	RCLI	36 45
083	+	-55
084	X=Y?	16-33
085	R/S	51
086	GT09	22 09
087	*LBLD	21 14
088	2	02
089	4	04
090	X<Y?	16-35
091	GSB8	23 06
092	X<Y	-41
093	EEX	-22
094	2	02
095	÷	-24
096	RTN	24
097	*LBL8	21 06
098	CHS	-22
099	HMS+	16-55
100	SF2	16 21 02
101	X<Y	-41
102	RTN	24
103	*LBL5	21 15
104	RCL0	36 00
105	INT	16 34
106	F2?	16 23 02
107	GSB2	23 02
108	+	-55
109	PRTX	-14
110	STOB	35 00
111	RTN	24
112	*LBL2	21 02
113	1	01
114	+	-55
115	RTN	24
116	*LBL0	21 00
117	FPC	16 44
118	EEX	-22
119	2	02
120	x	-35

Compute next takeoff ddd.hhmm

Increase counter

Check for exit from loop

Subroutine to correct for time greater
than 24 hours

Subroutine to correct time

Output subroutine
Print onstation, offstation, and land

Subroutine to correct date

Subroutine to change .hhmm to hh.mm

121	PTN	24	Subroutine to correct for negative time
122	*LELe	21 16 15	
123	2	02	
124	4	04	
125	HMS+	16-55	
126	SFS	16 21 03	
127	RTN	24	
128	*LELd	21 16 14	
129	1	01	Subroutine to correct date
130	-	-45	
131	RTN	24	
132	*LELa	21 16 11	Store crew postflight to preflight rest time
133	ST00	35 00	
134	CF2	16 22 02	
135	RTN	24	
136	*LELA	21 11	
137	ST0A	35 11	Compute crew's earliest possible takeoff
138	Rf	16-31	Store latest landing: ddd.hhmm
139	ST0I	35 46	Store crew #
140	Rf	-31	
141	FRC	16 44	
142	EEX	-23	
143	2	02	
144	x	-35	
145	HMS+	16-55	
146	HMS+	16-55	
147	RCL0	36 00	
148	HMS+	16-55	Compute crew I's takeoff availability
149	GSBD	23 14	
150	ST0i	35 45	
151	RCLA	36 11	
152	INT	16 34	
153	F2? 16	23 02	
154	GSB2	23 02	
155	ST+i 35	-55 45	
156	RCLi	36 46	
157	DSP0	-63 00	
158	FRTX	-14	Print crew #
159	PCLi	36 45	
160	DSP4	-63 04	
161	PRTY	-14	Print crew's ddd.hhmm takeoff availability
162	SPC	16-11	
163	RTN	24	

164	*LBL6	21 12	List flight crews in order of availability
165	STOA	35 11	Store # of crews = N
166	0	00	Zero counter
167	STOC	35 13	
168	*LBL7	21 07	
169	RCLA	36 11	Begin loop
170	STOI	35 46	
171	STOB	35 12	
172	RCLi	36 45	Recall crew # N availability
173	STOD	35 14	
174	*LBL6	21 16 12	
175	DSZI	16 25 46	Recall crew # N-1 availability
176	GT01	22 01	
177	GT04	22 04	
178	*LBL1	21 01	
179	RCLD	36 14	Compare availability
180	RCLi	36 45	
181	X=Y?	16-34	
182	GSB3	23 03	
183	STOD	35 14	Store earliest ddd.hhmm
184	RCLi	36 46	
185	STOB	35 12	
186	GT06	22 16 12	
187	*LBL3	21 03	
188	X=Y	-41	Swap registers
189	STOD	35 14	
190	GT06	22 16 12	
191	*LBL4	21 04	
192	RCLB	36 12	Output routine
193	DSP0	-63 00	Print crew #
194	PRTX	-14	
195	STOI	35 46	
196	DSP4	-63 04	
197	RCLi	36 45	Print crew availability ddd.hhmm
198	PRTX	-14	
199	SPC	16-11	
200	SPC	16-11	
201	SPC	16-11	
202	SPC	16-11	
203	EEX	-23	
204	4	04	
205	ST+i	35-55 45	Add 1000 to day--i.e. create an artificially large date
206	1	01	
207	RCLC	36 13	
208	+	-55	
209	STOC	35 13	
210	RCLA	36 11	
211	X=Y?	16-33	Check for end of loop
212	GT05	22 05	
213	GT07	22 07	
214	*LBL5	21 05	
215	STOI	35 46	
216	*LBL6	21 06	
217	EEX	-23	
218	4	04	Subtract 10,000 from date--i.e. correct artificially
219	ST-i	35-45 45	
220	DSZI	16 25 46	
221	GT06	22 06	
222	R/S	51	

VII. TARGET MOTION ANALYSIS (TMA) OF A BEARINGS-ONLY TARGET
FROM A MOVING PLATFORM by LT P. W. Marzluff and
LT R. C. Pilcher

A. Problem Statement

Bearings to a target either stationary or moving with constant course and speed are available from a non-stationary tracking platform. Determine the target's range, course and speed.

B. Operational Analysis

The four bearing TMA technique used in this program requires a minimum of four target bearing observations taken during a minimum of two tracking legs. A target bearing observation must be made and entered for the time corresponding to the initiation of own ship course or speed change. Exact target bearing observations of 090° and 270° require the addition of 0.1° to the observed value to avoid infinite computational values. When the tracking problem carries into a new day, the previous day's time scale must be continued (i.e. a time of 0010 on the second day must be entered as 2410).

Own ship and target information is entered on card 1. Estimation of target parameters begins on card 1 and is completed on card 2. Entering supplemental target or own ship information and generating a new estimate again requires the use of card 1 and then card 2.

The accuracy of the estimates are dependent on the accuracy of the inputs, principally the target bearing, the magnitude

of course or speed change, and the number of observations made. For a more complete examination of the character of the estimates, see Reference 1.

C. Computational Algorithm

1. Input own ship's course and speed. Calculate and store velocity components.
2. Input time, t_i , and observed target bearing, B_i . Calculate elapsed time since the first observation, Δt_i , and $\tan B_i$. Calculate and store the matrix values.
3. When own ship changes course or speed enter t_i and B_i observed at the time the course or speed change was made. Enter new own ship course and speed prior to entering the next bearing observation.
4. When at least four target bearing observations have been entered (bearings taken on a minimum of two tracking legs), estimation of target range, course, and speed can be made.
5. Additional target and own ship information can be entered and new estimates made.

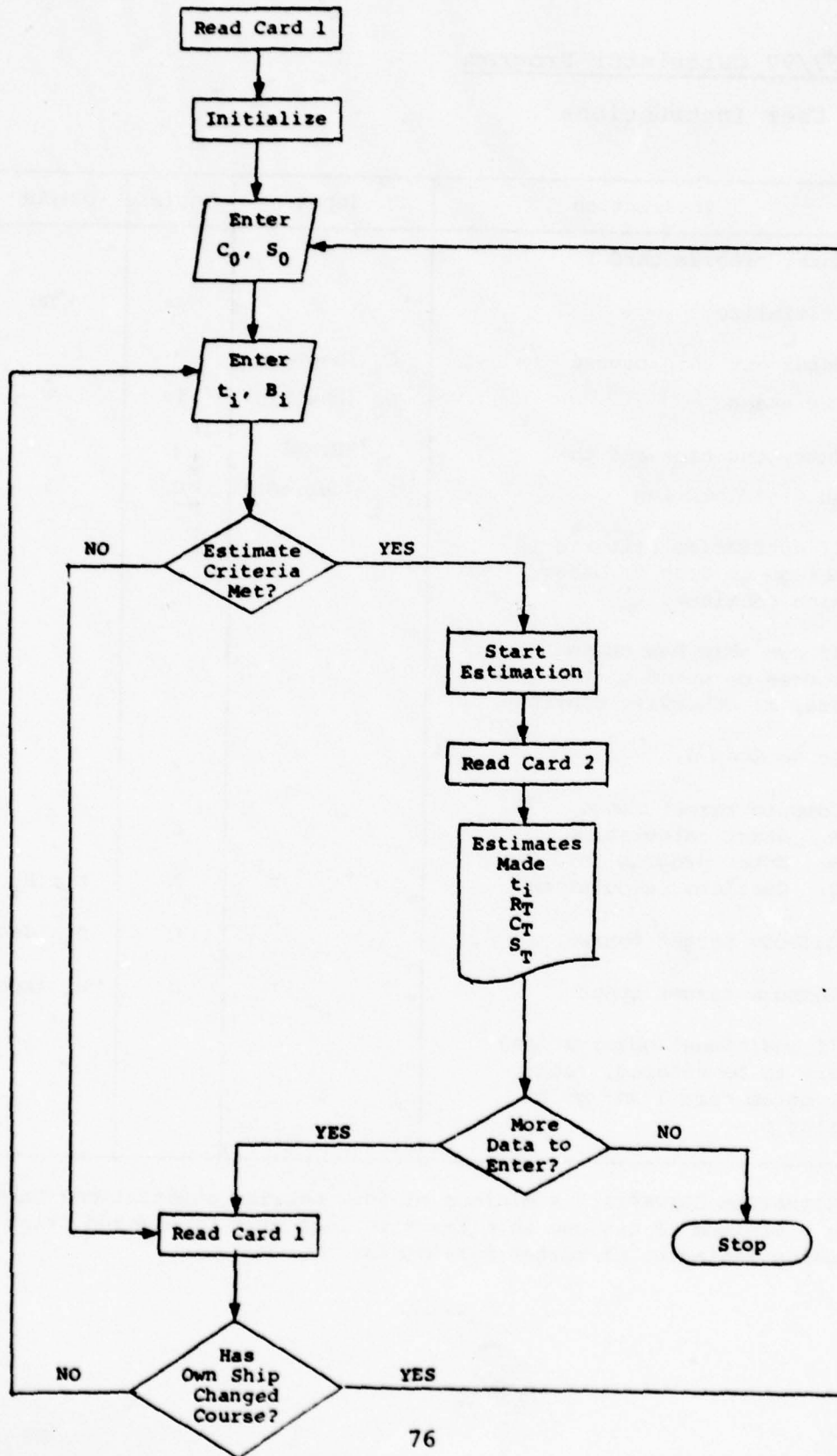
D. HP-67/97 Calculator Program

1. User Instructions

Step	Instruction	Input	Key(s)	Output
1.	Enter program card 1			
2.	Initialize		fe	0.00
3.	Enter own ship course and speed	C_0 (degrees) S_0 (knots)	$\uparrow$ fa	$\dot{W}$
4.	Enter the time and the observed bearing	t_i (HH.MM) B_i (degrees)	$\uparrow$ C	i
5.	If estimation criteria is met go to Step 8; other- wise continue.			
6.	If own ship has changed course or speed go to Step 3; otherwise continue.			
7.	Go to Step 4.			
8.	Compute target range A. Start calculation B. Enter program Card 2 C. Continue calculation		E A	$t_i; R_T$ (yds)
9.	Compute target course		C	C_T (degrees)
10.	Compute target speed		E	S_T (knots)
11.	If additional observations are to be entered, read program card 1 and go to Step 6.			.

NOTE: ESTIMATION CRITERIA: A minimum of four bearing observations taken on a minimum of two own ship tracking legs must be entered prior to making estimates of target parameters.

User Instructions Flowchart



2. Sample Problems

a. Exact Bearing Information.

Own ship tracks on course 000° at 15 knots for 10 minutes and turns to 057° at 15 knots. Three bearing observations are made on the first leg, with the fourth observation made on the second leg. Exact bearing information is assumed available. The contact is tracked as follows:

<u>Time</u>	<u>Bearing</u>
1000	150.0
1005	148.2
1010	146.9
1020	154.7

Estimate the target's range, course and speed at time 1020.

(Answers: 12,920 yds, 045° , and 10.0 knots.)

The following additional observations are made:

<u>Time</u>	<u>Bearing</u>
1025	158.8
1030	163.0
1035	167.2

Estimate the target's range, course and speed at time 1035.

(Answers: 12540 yds, 045° , 10.0 knots.)

CARD 1 card	GSBa	Initialize
	000.00 ENT: 15.00 GSbC	Own ship's course and speed
	10.00 ENT: 150.00 GSbC	Observation #1 time and bearing
	10.05 ENT: 148.20 GSbC	Observation #2 time and bearing
	10.10 ENT: 146.90 GSbC	Observation #3 time and bearing
	057.00 ENT: 15.00 GSbC	New own ship course and speed
	10.20 ENT: 154.70 GSbC	Observation #4 time and bearing
	GSbE	Start estimation
CARD 2	GSbA	Continue estimation
	10.20 *** 12901.01 ***	Time of estimate Estimated target range in yards
	GSbC 48.37 ***	Estimated target course in degrees
	GSbE 9.86 ***	Estimated target speed in knots
CARD 1	10.25 ENT: 158.80 GSbC	Observation #5 time and bearing
	10.30 ENT: 163.00 GSbC	Observation #6 time and bearing
	10.35 ENT: 167.20 GSbC	Observation #7 time and bearing
	GSbE	Start estimation
CARD 2	GSbA	Continue estimation
	10.35 *** 12540.49 ***	Time of revised estimate Revised estimated target range
	GSbC 46.22 ***	Revised estimated target course
	GSbE 9.95 ***	Revised estimated target speed

b. Inaccurate Bearing Information

Own ship tracks on course 000° at 15 knots for 10 minutes and turns to 056° at 15 knots. Three bearing observations are made on the first leg, with the fourth observation made on the second leg. The true target bearings have been altered by normal random variable with mean zero and variance 0.5 degrees squared. The contact is tracked as follows:

<u>Time</u>	<u>Bearing</u>
1000	150.0
1005	148.7
1010	146.0
1020	155.2

Estimate the target's range, course and speed at time 1020.

(Answers: 12,920 yds, 045° , and 10.0 knots.)

The following additional observations are made:

<u>Time</u>	<u>Bearing</u>
1025	159.7
1030	163.0
1035	166.4

Estimate the target's range, course and speed at time 1035.

(Answers: 12,740 yds, 045° , and 10.0 knots.)

CARD 1	GSSE	Initialize
	000.00 ENT: 15.00 GSSE	Own ship's course and speed
	10.00 ENT: 150.00 GSSE	Observation #1 time and bearing
	10.05 ENT: 148.70 GSSE	Observation #2 time and bearing
	10.10 ENT: 146.00 GSSE	Observation #3 time and bearing
	056.00 ENT: 15.00 GSSE	New own ship course and speed
	10.20 ENT: 155.20 GSSE	Observation #4 time and bearing
	GSSE	Start estimation
CARD 2	GSBA 10.20 *** 5757.14 ***	Continue estimation Time of estimate Estimated target range in yards
	GSBC 338.26 ***	Estimated target course in degrees
	GSBE 83.67 ***	Estimated target speed in knots
CARD 1	10.25 ENT: 159.70 GSSE	Observation #5 time and bearing
	10.30 ENT: 163.00 GSSE	Observation #6 time and bearing
	10.35 ENT: 166.40 GSSE	Observation #7 time and bearing
	GSSE	Start estimation
CARD 2	GSBA 10.35 *** 12945.90 ***	Continue estimation Time of revised estimate Revised estimated target range
	GSBC 68.64 ***	Revised estimated target course
	GSBE 9.87 ***	Revised estimated target speed

3. Program Storage Allocation and Listing

Registers

R0: t_1	S0: PS1; PS3; PS10
R1: $\Sigma W_i - \Sigma Z_i \tan B_i$	S1: $\Sigma \Delta t_i \tan^2 B_i$
R2: $-\Sigma W_i \tan B_i + \Sigma Z_i \tan^2 B_i$	S2: $\Sigma \Delta t_i^2 \tan^2 B_i$
R3: $\Sigma W_i \Delta t_i - \Sigma Z_i \Delta t_i \tan B_i$	S3: $-\Sigma \Delta t_i^2 \tan B_i$
R4: $-\Sigma W_i \Delta t_i \tan B_i + \Sigma Z_i \Delta t_i \tan^2 B_i$	S4: $\Sigma \Delta t_i$
R5: t_{i-1}	S5: $\Sigma \Delta t_i^2$
R6: t_i	S6: $\Sigma \tan B_i$
R7: W_i	S7: $\Sigma \tan^2 B_i$
R8: Z_i	S8: $\Sigma \Delta t_i \tan B_i$
R9: PS11; PS12; $\hat{v}$; Δt_i	S9: $i = N$
RA: $\hat{W}$	
RB: $\hat{Z}$	
RC: Δt_i ; PS4; $\hat{u}$	
RD: $\tan B_i$; PS7; $\hat{v}$	
RE: $Z_i \tan B_i$; PS13; $\hat{X}_1$	
RI: i ; PS2; PS5; PS6; PS8; PS9; $\hat{Y}_1$	

NOTE: All summations are over the range of $i = 1, \dots, N$.

PS denotes 'partial-sum'.

Initial Flag Status and Use:

0: OFF, Unused

2: OFF, Unused

1: OFF, Used

3: OFF, Used

User Control Keys; Card 1:

A:

a: $C_0 \uparrow S_0 \rightarrow$

B:

b:

C: $t_i \uparrow B_i \rightarrow$

c:

D:

d:

E: Start $\rightarrow$

e: Initialize $\rightarrow$

User Control Keys; Card 2:

A: $\rightarrow t_i; \hat{R}_{Ti}$

a:

B:

b:

C: $\rightarrow \hat{C}_T$

c:

D:

d:

E: $\rightarrow \hat{S}_{Ti}$

e:

Card 1

001	*LBL1	21 01	Stores initial time, t_1 , for further use
002	ST00	35 00	
003	ST05	35 05	
004	RTN	24	
005	*LBL2	21 16 15	Initialization
006	CLRG	16-53	
007	P2S	16-51	
008	CLRG	16-53	
009	CLX	-51	
010	SF2	16 21 02	
011	RTN	24	
012	*LBL3	21 16 11	Calculates and stores own ship velocity components
013	→R	44	
014	ST08	35 12	
015	R4	-31	
016	ST0A	35 11	
017	RTN	24	
018	*LBLC	21 17	Input observation and bearing
019	TAN	43	
020	ST0D	35 14	Fills the matrix values
021	X2Y	-41	
022	HMS+	16 36	
023	ST06	35 06	
024	F2?	16 23 02	Branches to store initial time
025	G8B1	23 01	
026	RCL0	36 00	
027	-	-45	
028	ST0C	35 13	
029	Σ+	56	
030	ST0I	35 46	
031	R4	-31	
032	RCLC	36 13	
033	X2	53	
034	X	-35	
035	P2S	16-51	
036	ST-3	35-45 03	
037	RCLD	36 14	
038	X	-35	
039	ST+2	35-55 02	
040	RCLC	36 13	
041	RCLD	36 14	
042	X2	53	
043	X	-35	
044	ST+1	35-55 01	
045	P2S	16-51	
046	RCL6	36 06	
047	RCL5	36 05	
048	-	-45	
049	ENT↑	-21	
050	ENT↑	-21	

Card 1

051	RCLW	36 11	
052	^	-35	
053	ST+7	35-55 07	
054	R4	-31	
055	RCLB	36 12	
056	x	-35	
057	ST+8	35-55 08	
058	RCL6	36 06	
059	ST05	35 05	
060	RCL7	36 07	
061	ST+1	35-55 01	
062	RCLD	36 14	
063	x	-35	
064	ST-2	35-45 02	
065	RCLC	36 13	
066	x	-35	
067	ST-4	35-45 04	
068	RCL7	36 07	
069	RCLC	36 13	
070	x	-35	
071	ST+3	35-55 03	
072	RCL8	36 08	
073	RCLD	36 14	
074	x	-35	
075	ST0E	35 15	
076	ST-1	35-45 01	
077	RCLD	36 14	
078	x	-35	
079	ST+2	35-55 02	
080	RCLC	36 13	
081	x	-35	
082	ST+4	35-55 04	
083	RCL6	36 15	
084	RCLC	36 13	
085	x	-35	
086	ST-3	35-45 03	
087	RCLI	36 46	
088	RTN	24	
089	*LBLE	21 15	Start estimate calculations
090	P2S	16-51	
091	1	01	Changes the sign of two matrix elements
092	CHS	-22	
093	STx6	35-35 06	
094	STx8	35-35 08	
095	RCL8	36 08	
096	RCL7	36 07	(Partial sums stored throughout; PS)
097	x	-35	
098	RCL6	36 06	
099	RCL1	36 01	
100	x	-35	

Card 1

101	-	-45
102	RCL4	36 04
103	X ²	53
104	RCL9	36 09
105	RCL5	36 05
106	X	-35
107	-	-45
108	X	-35
109	ST00	35 00
110	RCL6	36 06
111	RCL4	36 04
112	X	-35
113	RCL9	36 09
114	RCL8	36 08
115	X	-35
116	-	-45
117	RCL8	36 08
118	X ²	53
119	RCL6	36 06
120	RCL3	36 03
121	X	-35
122	-	-45
123	X	-35
124	ST-0	35-45 00
125	RCL6	36 06
126	X ²	53
127	RCL9	36 09
128	RCL7	36 07
129	X	-35
130	-	-45
131	RCL8	36 08
132	P ² S	16-51
133	RCL3	36 03
134	X	-35
135	RCL4	36 04
136	P ² S	16-51
137	RCL4	36 04
138	X	-35
139	-	-45
140	X	-35
141	ST01	35 46
142	RCL8	36 08
143	X ²	53
144	RCL4	36 04
145	RCL1	36 01
146	X	-35
147	-	-45
148	RCL6	36 06
149	P ² S	16-51
150	RCL1	36 01

Card 1

151	X	-35
152	RCL2	36 02
153	P2S	16-51
154	RCL9	36 05
155	X	-35
156	-	-45
157	X	-35
158	RCL1	36 46
159	-	-45
160	STOC	35 13
161	RCL0	36 00
162	X	-35
163	P2S	16-51
164	STO9	35 09
165	P2S	16-51
166	RCL6	36 06
167	X2	53
168	RCL9	36 09
169	RCL7	36 07
170	X	-35
171	-	-45
172	RCL8	36 08
173	RCL5	36 05
174	X	-35
175	RCL4	36 04
176	RCL3	36 03
177	X	-35
178	-	-45
179	X	-35
180	STOI	35 46
181	RCL8	36 08
182	X2	53
183	RCL4	36 04
184	RCL1	36 01
185	X	-35
186	-	-45
187	RCL6	36 06
188	RCL4	36 04
189	X	-35
190	RCL9	36 09
191	RCL8	36 08
192	X	-35
193	-	-45
194	X	-35
195	RCL1	36 46
196	-	-45
197	STOD	35 14
198	RCL6	36 06
199	RCL4	36 04
200	X	-35

Card 1

201	RCL9	36 05
202	RCL8	36 08
203	X	-35
204	-	-45
205	RCL8	36 08
206	P2S	16-51
207	RCL2	36 02
208	X	-35
209	RCL4	36 04
210	P2S	16-51
211	RCL6	36 06
212	X	-35
213	-	-45
214	X	-35
215	STOI	35 46
216	RCL8	36 08
217	RCL7	36 07
218	X	-35
219	RCL6	36 06
220	RCL1	36 01
221	X	-35
222	-	-45
223	R/S	51

Card 2

			Calculation of estimates
001	#LELH	21 11	
002	RCL4	36 04	
003	P2S	16-51	
004	RCL1	36 01	
005	X	-35	
006	RCL3	36 03	
007	P2S	16-51	
008	RCL9	36 03	
009	X	-35	
010	-	-45	
011	X	-35	
012	RCL1	36 46	
013	-	-45	
014	RCL0	36 14	
015	X	-35	
016	P2S	16-51	
017	RCL9	36 03	
018	X2Y	-41	
019	-	-45	
020	ST09	35 03	
021	P2S	16-51	
022	RCL6	36 06	
023	X2	53	
024	RCL9	36 03	
025	RCL7	36 07	
026	X	-35	
027	-	-45	
028	RCL8	36 03	
029	RCL3	36 03	
030	X	-35	
031	RCL4	36 04	
032	RCL2	36 02	
033	X	-35	
034	-	-45	
035	X	-35	
036	ST01	35 46	
037	RCL8	36 03	
038	X2	53	
039	RCL4	36 04	
040	RCL1	36 01	
041	X	-35	
042	-	-45	
043	RCL6	36 06	
044	RCL8	36 03	
045	X	-35	
046	RCL9	36 03	
047	RCL1	36 01	
048	X	-35	
049	-	-45	
050	X	-35	

Card 2

051	RCL1	36 46	
052	-	-45	
053	STOE	35 15	
054	RCL0	36 00	
055	x	-35	
056	ST00	35 00	
057	RCL6	36 06	
058	RCL4	36 04	
059	x	-35	
060	RCL9	36 09	
061	RCL8	36 08	
062	x	-35	
063	-	-45	
064	RCL8	36 08	
065	RCL1	36 01	
066	x	-35	
067	RCL6	36 06	
068	RCL2	36 02	
069	x	-35	
070	-	-45	
071	x	-35	
072	ST01	35 46	
073	RCL8	36 08	
074	RCL7	36 07	
075	x	-35	
076	RCL6	36 06	
077	RCL1	36 01	
078	x	-35	
079	-	-45	
080	RCL4	36 04	
081	RCL8	36 08	
082	x	-35	
083	RCL9	36 09	
084	RCL3	36 03	
085	x	-35	
086	-	-45	
087	x	-35	
088	RCL1	36 46	
089	-	-45	
090	RCLD	36 14	
091	x	-35	
092	RCL0	36 00	
093	XZY	-41	
094	-	-45	
095	P2S	16-51	
096	RCL9	36 09	
097	XZY	-41	
098	÷	-24	
099	ST09	35 09	^
100	RCLF	36 15	v

Card 2

101	X	-35	
102	RCLC	36 13	
103	XZY	-41	
104	-	-45	
105	RCLD	36 14	
106	÷	-24	$\hat{u}$
107	STOC	35 13	
108	RCL9	36 09	
109	STOD	35 14	
110	P2S	16-51	
111	RCL6	36 06	
112	RCL8	36 08	
113	X	-35	
114	RCL9	36 09	
115	RCL1	36 01	
116	X	-35	
117	-	-45	
118	X	-35	
119	CHS	-22	
120	RCL6	36 06	
121	RCL4	36 04	
122	X	-35	
123	RCL9	36 09	
124	RCL8	36 08	
125	X	-35	
126	-	-45	
127	RCLC	36 13	
128	X	-35	
129	-	-45	
130	RCL6	36 06	
131	P2S	16-51	
132	RCL1	36 01	
133	X	-35	
134	RCL2	36 02	
135	P2S	16-51	
136	RCL9	36 09	
137	X	-35	
138	-	-45	
139	+	-55	
140	RCL6	36 06	
141	X2	53	
142	RCL9	36 09	
143	RCL7	36 07	
144	X	-35	
145	-	-45	
146	÷	-24	$\hat{y}_1$
147	STOI	35 46	
148	P2S	16-51	
149	RCL1	36 01	
150	P2S	16-51	

Card 2

151	RCL8	36 08	
152	RCLD	36 14	
153	x	-35	
154	-	-45	
155	RCL4	36 04	
156	RCLC	36 13	
157	x	-35	
158	-	-45	
159	RCL6	36 06	
160	RCLI	36 46	
161	x	-35	
162	-	-45	
163	RCL9	36 09	
164	÷	-24	$\hat{x}_1$
165	STOE	35 15	
166	1	01	Change sign of two matrix elements
167	CHS	-22	
168	STX6	35-35 05	
169	STX8	35-35 08	
170	P2S	16-51	
171	RCL6	36 06	
172	+HMS	16 35	t_i
173	FRTX	-14	
174	RCL6	36 06	
175	RCL0	36 00	
176	-	-45	
177	STO9	35 09	
178	RCLC	36 13	
179	x	-35	
180	RCL6	36 15	
181	+	-55	
182	RCL7	36 07	
183	-	-45	
184	X2	53	
185	RCL9	36 09	
186	RCLD	36 14	
187	x	-35	
188	RCLI	36 46	
189	+	-55	
190	RCL8	36 08	
191	-	-45	
192	X2	53	
193	+	-55	
194	JX	54	$\hat{R}_T = ((X_1 + u, t_i - W_i)^2 + (Y_1 + v, t_i - Z_i)^2)^{1/2}$
195	2	02	(in nautical miles)
196	EEY	-23	
197	3	03	
198	x	-35	$\hat{R}_T$ in yards
199	FRTX	-14	
200	SF1	16 21 01	

Card 2

201	RTN	24	
202	*LBLC	21 13	
203	PCLC	36 13	
204	PCLD	36 14	
205	+F	34	
206	XZY	-41	
207	X00?	16-45	
208	GEB2	23 02	
209	PRTX	-14	$\hat{C}_T$
210	CF1	16 22 01	
211	RTN	24	
212	*LBL2	21 02	
213	3	03	
214	6	06	
215	0	00	
216	+	-55	
217	RTN	24	
218	*LBLE	21 15	
219	F1?	16 23 01	
220	GT09	22 09	
221	R↓	-31	
222	PRTX	-14	$\hat{S}_T$
223	SPC	16-11	
224	RTN	24	

AD-A068 633

NAVAL POSTGRADUATE SCHOOL MONTEREY CALIF

F/G 9/2

NAVAL APPLICATIONS: TEN ALGORITHMS FOR THE HEWLETT-PACKARD HP-6--ETC(U)

FEB 79 R H SHUDDE

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2 OF 2

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E. Mathematical Analysis

a. Assumptions

All calculations use a rectangular coordinate system as defined below. Additionally it is assumed the following quantities are accurately known (although the accuracy of the observed bearing varies):

- (1) time
- (2) target bearings
- (3) observer course and speed
- (4) observer initial position.

b. Symbology

- (1) Observer
 - (a) W: East-West position
 - (b) Z: North-South position
 - (c) (W_i, Z_i) : position at ith observation.
- (2) Target
 - (a) X: East-West position
 - (b) Y: North-South position
 - (c) (X_i, Y_i) : position at ith observation
 - (d) u: East-West velocity component
 - (e) v: North-South velocity component.
- (3) Other
 - (a) B_i : measured bearing from observer to target at the ith observation.
 - (b) t_i : time of the ith observation
 - (c) Δt_i : elapsed time between ith and first observation.
 - (d) $i = 1$ is the initial observation.

c. Development

The geometry for a two leg TMA is shown in Figure 1.

The target motion/position at any time can be described in terms of its initial position (X_1, Y_1) , and its velocity components $(u$ and $v)$, which are unknown and the elapsed time, Δt_i , which is known by: $X_i = X_1 + u\Delta t_i$ and $Y_i = Y_1 + v\Delta t_i$. Knowledge of the target bearing leads to the following:

$$\tan B_i = \frac{X_i - W_i}{Y_i - Z_i} = \frac{X_1 + u\Delta t_i - W_i}{Y_1 + v\Delta t_i - Z_i}$$

or

$$X_1 - Y_1 \tan B_i + u\Delta t_i - v\Delta t_i \tan B_i = W_i - Z_i \tan B_i \quad (1)$$

Equation (1) has four known variables $(W_i, Z_i, \Delta t_i, B_i)$ and the four unknown target variables (X_1, Y_1, u, v) . Define estimates for the four unknowns as $\hat{X}_1, \hat{Y}_1, \hat{u}$, and $\hat{v}$ and define an error, e_i , that represents the errors due to the use of estimates in Equation (1) at each observation:

$$e_i = \hat{X}_1 - \hat{Y}_1 \tan B_i + \hat{u}\Delta t_i - \hat{v}\Delta t_i \tan B_i - W_i + Z_i \tan B_i.$$

The least squares estimates of the variables X_1, Y_1, u and v are those values which minimize the expression

$$\sum_{i=1}^n e_i^2 = E(X_1, Y_1, u, v)$$

where n is the number of observations.

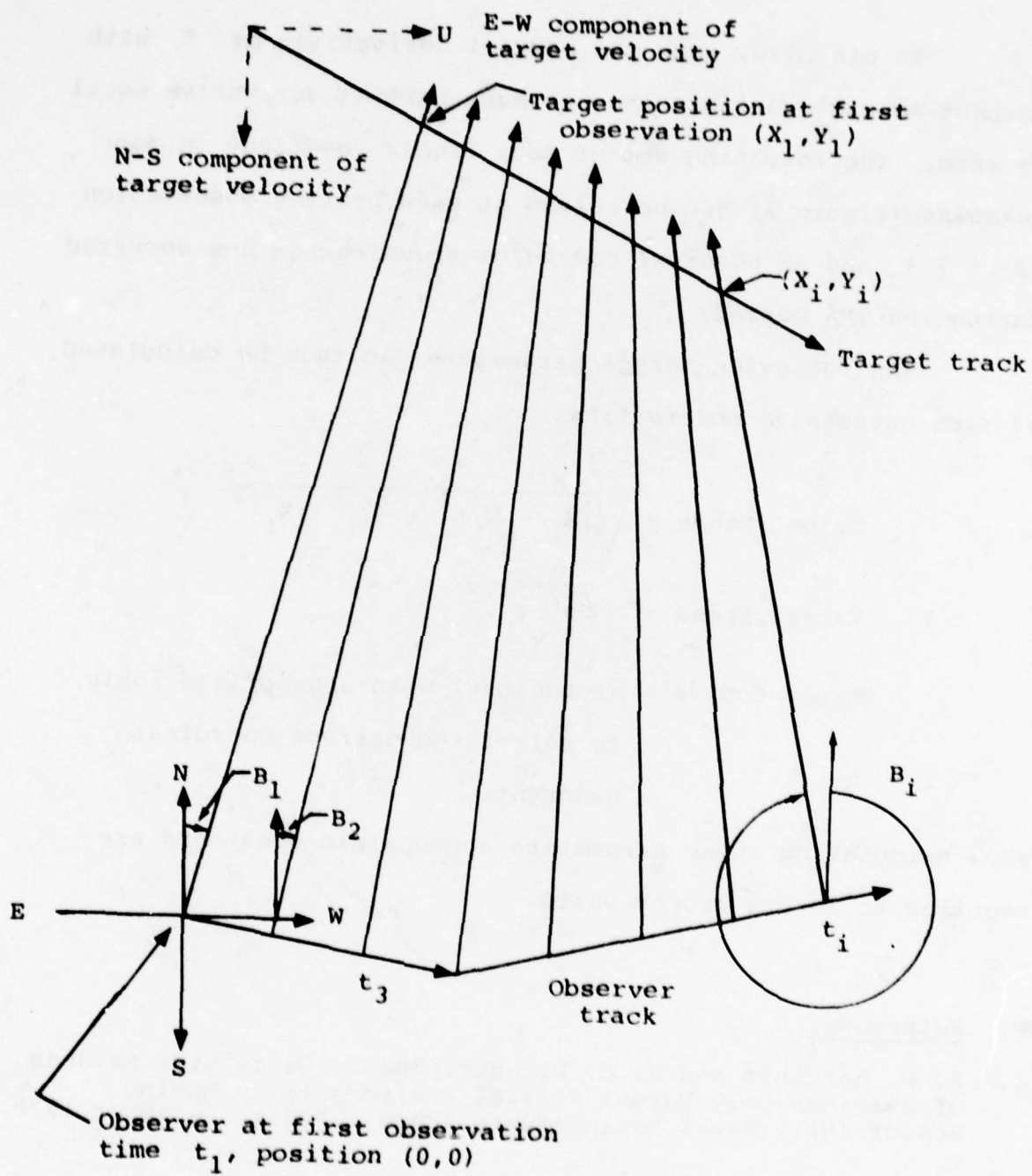


FIGURE 1. TMA Geometry

To minimize, take the partial derivatives of E with respect to each variable and set each partial derivative equal to zero. The resulting set of four linear equations in four unknowns (Figure 2) can be solved at each bearing observation if $i \geq 4$ and an observer course or speed change has occurred during the TMA period.

The following target parameters can then be calculated at each successive observation:

$$\text{Target Range} = \sqrt{(\hat{X}_i - W_i)^2 + (\hat{Y}_i - Z_i)^2}$$

$$\text{Target Speed} = \sqrt{\hat{u}^2 + \hat{v}^2}$$

Target Course = $\arctan(\hat{u}/\hat{v})$ with appropriate logic to select the correct coordinate quadrant.

When calculating these parameters appropriate constants are required to insure proper units.

F. Reference.

1. P. W. Marzluff and R. C. Pilcher, "Basic Calculator Methods of Bearings-Only Target Motives Analyses for a Moving Sensor (U). Naval Postgraduate School Thesis, December 1978.

FOUR BEARING TMA NORMAL EQUATIONS

$$\begin{bmatrix}
 -\sum_{i=1}^n \tan B_i & -\sum_{i=1}^n \Delta t_i & -\sum_{i=1}^n \Delta t_i \tan B_i & \sum_{i=1}^n W_i - \sum_{i=1}^n Z_i \tan B_i \\
 -\sum_{i=1}^n \tan B_i & -\sum_{i=1}^n \Delta t_i \tan^2 B_i & -\sum_{i=1}^n \Delta t_i \tan^2 B_i & -\sum_{i=1}^n W_i \tan B_i + \sum_{i=1}^n Z_i \tan^2 B_i \\
 \sum_{i=1}^n \Delta t_i & -\sum_{i=1}^n \Delta t_i^2 & -\sum_{i=1}^n \Delta t_i^2 \tan B_i & \sum_{i=1}^n W_i \Delta t_i - \sum_{i=1}^n Z_i \Delta t_i \tan B_i \\
 -\sum_{i=1}^n \Delta t_i \tan B_i & -\sum_{i=1}^n \Delta t_i^2 \tan^2 B_i & -\sum_{i=1}^n \Delta t_i^2 \tan^2 B_i & -\sum_{i=1}^n W_i \Delta t_i \tan B_i + \sum_{i=1}^n Z_i \Delta t_i \tan^2 B_i
 \end{bmatrix}
 \begin{bmatrix}
 \hat{X}_1 \\
 \hat{Y}_1 \\
 \hat{u} \\
 \hat{v}
 \end{bmatrix}$$

FIGURE 2

VIII. NAVAL GUNFIRE SUPPORT GRID SPOT CONVERSIONS, TRUE WIND,
AND TIME OF FLIGHT/MAXIMUM ORDINATE COMPUTATIONS FOR
5-INCH/54 PROJECTILE by LT Keith P. Curtis

A. Problem Statement

The success of Naval Gunfire Support operations in the Combat Information Center (CIC) is a function of rapid information processing and relay. Specifically, substantial error can be introduced by inaccurate grid spot conversions and to a lesser degree by improper computations of true wind. Also, commencement of a fire mission can be delayed waiting for Time of Flight (TOF) and/or Maximum Ordinate (Max Ord) information.

The inherent error of rapid calculations can be minimized by the use of the handheld programmable calculator. This paper addresses the use of the Hewlett Packard HP-67 to perform grid-spot conversions; compute true wind, TOF, and Max Ord.

B. Operational Analysis

The objective of this program is to provide a one-card program to accommodate the following:

1. Correct for magnetic variance for a geographic area.
2. Accept the Observer Target Line (OTL) in either mils magnetic or degree magnetic.
3. Perform precise grid spot conversion.
4. Provide Time of Flight information.

5. Provide Maximum Ordinate information.
6. Compute true wind.

C. Computational Algorithm

1. Enter magnetic variance.
2. Enter OTL either in mils magnetic or degree magnetic.
3. Enter observer "spots": left-right, add-drop (in yards).
4. Convert spots to East-West, North-South.
5. Enter range of shot and compute TOF and max ord.
6. Enter own ship course and speed, and relative wind to compute true wind.
7. Repeat Steps 3 through 6 as necessary.

D. HP-67 Calculator Program

1. User Instructions

Step	Instruction	Input	Key(s)	Output
1.	Read program card (both sides)			
2.	Enter magnetic variation (+ for East, - for West). If no variation is entered, 0 is used.	mag.var.	f b	
3.	Enter Observer Target Line in either:			
a.	degrees magnetic, or		A	OTL °T
b.	mils magnetic		f a	OTL °T
4 a.	Enter Left/Right spot (- for left, + for right)	L/R	↑	
b.	Enter Add/Drop spot (- for drop, + for add)	A/D	B	
c.	Display E/W spot (+ E, - W)			E/W spot
d.	Display N/S spot (+ N, - S)			N/S spot
	Optional: Recover the E/W spot		h x $\frac{+}{-}$ y	E/W spot
e.	Repeat Step 4 as required until OTL changes			
5.	Compute TOF and max ord			
a.	Enter target range, display:	range	C	
b.	Time of Flight			TOF
c.	Max Ord			Max ord
	Optimal: Recover TOF		h R ↑	
6.	Compute true wind.			
a.	Enter own ship's course and speed in the form SS.CCC where SS is the speed in integer knots and CCC is a three-digit course	SS.CCC	↑	
b.	Enter relative wind	SS.CCC	D	
c.	True wind is displayed			SS.CCC

Note: Use of the keys C or D do not require an OTL input.

2. Sample Problem

Own ship:	035T 12KTS
Relative wind:	225R 6KTS
Magnetic variance:	7E
OTL:	1930 mils mag
Spot:	Left 250, Drop 150
Range:	9600 yds

West 27, North 290

TOF: 16 seconds

Max Ord: 1050ft

True Wind: 230T 17KTS

7. GS66
1930. GS66
116. ***
-250. ENT†
-150. GS66
-27. ***
290. ***

9600. GS66
16. ***
1050. ***

12.035 ENT†
6.225 GS66
17.238 ***

3. Program Storage Allocation and Listings

Registers

R0:	OTL °T	S0:		RA:	$\log_{10}$ range
R1:		S1:		RB:	Ship's heading
R2:		S2:		RC:	L-R spot
R3:		S3:		RD:	A-D spot
R4:	TOF/	S4:	ΣX	RE:	
R5:	Max Ord	S5:		RI:	Control
	Coeff				
R6:		S6:	ΣY		
R7:		S7:			
R8:		S8:			
R9:	mag.var.	S9:			

Initial Flag Status and Use

0:	OFF, Unused	2:	OFF, Unused
1:	OFF, Unused	3:	OFF, Unused

User Control Keys

A:	OTL (degrees)	a:	OTL (mils)
B:	L-R spot, A-D spot	b:	mag.var.
C:	Range	c:	
D:	O/S c/S rel wind	d:	
E:		e:	

0.00000000	0
0.77750000	1
2.16600000	2
-0.20710000	3
0.26170000	4
0.07210000	5
0.10530000	6
0.85050000	7
0.28310000	8
0.00000000	9
0.00000000	A
0.00000000	B
0.00000000	C
0.00000000	D
0.00000000	E
0.00000000	F

COEFFICIENTS FOR MAX ORD/TOF EQNS

PRESTORED DATA

001	*LBLb	21	16	12	
002	DSP0	-63	00		
003	ST09	35	09		
004	R/S		51		
005	*LBLa	21	16	11	
006	.	-62			
007	0	00			
008	5	05			
009	6	06			
010	2	02			
011	5	05			
012	x	-35			
013	*LBLA	21	11		
014	DSP0	-63	00		
015	RCL5	36	00		
016	+	-55			
017	XK00	16-45			
018	GSBe	23	16	15	
019	ST00	35	00		
020	R/S		51		
021	*LBLB	21	12		
022	DSP0	-63	00		
023	XZY	-41			
024	+P	34			
025	XZY	-41			
026	RCL0	36	00		
027	-	-45			
028	XZY	-41			
029	+R	44			
030	PRTX	-14			
031	XZY	-41			
032	R/S		51		

STORE
MAG VAR
CONVERT MILS
TO DEGREES
CONVERT OTL
TO TRUE BRG
CONVERT OBSERVER
GRID SPOTS TO
E-W, N-S SPOTS

033	*LBLC	21	12		
034	DSP0	-63	00		
035	EEX	-23			
036	3	03			
037	+	-24			
038	LOB	16	32		
039	ST04	35	11		
040	RCL6	36	06		
041	RCL7	36	07		
042	RCL8	36	08		
043	RCLA	36	11		
044	x	-35			
045	+	-55			
046	RCLA	36	11		
047	x	-35			
048	+	-55			
049	10x	16	33		
050	PRTX	-14			
051	4	04			
052	ST01	35	46		
053	RCL5	36	05		
054	*LELc	21	16	12	
055	RCLA	36	11		
056	x	-35			
057	RCL1	36	45		
058	+	-55			
059	DSZI	16	25	46	
060	ST0c	22	16	12	
061	10x	16	33		
062	R/S		51		
063	*LBLD	21	14		
064	DSP0	-63	00		
065	P/S	16-51			
066	CLRG	16-53			
067	P/S	16-51			
068	XZY	-41			
069	GSB4	23	16	14	
070	2-	16	56		
071	R+	16-31			
072	RCLB	36	12		
073	+	-55			
074	GSB4	23	16	14	
075	2+	56			
076	RCL2	36	56		
077	+P	34			
078	RND	16	24		
079	INT	16	34		
080	XZY	-41			
081	XK00	16-45			
082	GSBe	23	16	15	
083	EEX	-23			
084	3	03			
085	+	-24			
086	+	-55			
087	DSP3	-63	03		
088	R/S		51		

COMPUTE TIME OF FLIGHT

COMPUTE MAX ORDNATE

COMPUTE TRUE WIND

089	*LBLd	21	16	14
090	INT		16	34
091	LSTX		16	63
092	FRC		16	44
093	STOB		35	12
094	EEX			-23
095	3			03
096	x			-35
097	X2Y			-41
098	+R			44
099	RTN			24
100	*LBLe	21	16	15
101	3			03
102	6			06
103	0			00
104	+			-55
105	RTN			24
106	R/S			51

E. Geometric/Mathematical Analysis

1. Grid-Spot Conversion

The conversion of grid spots oriented to an Observer Target Line to an East-West, North-South orientation for input to a shipboard GFCS can be accomplished by a rotation of the OTL counterclockwise to 000 degree True after the OTL has been corrected to true bearing (Figure 1).

The rotation formulas are

$$\begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} x' \\ y' \end{bmatrix},$$

or

$$x' = x \cos \theta + y \sin \theta \quad \text{and} \quad y' = -x \sin \theta + y \cos \theta,$$

where

$$\theta = \text{OTL } ^\circ \text{T}$$

$$x = \text{L/R Spot,}$$

$$y = \text{A/D Spot,}$$

$$x' = \text{E-W Spot,}$$

$$y' = \text{N-S Spot}$$

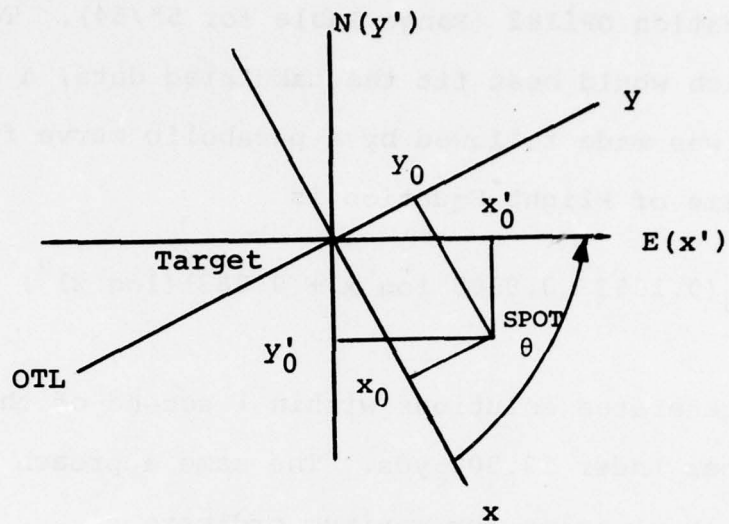


FIGURE 1: Rotation Geometry

2. TOF and Maximum Ordinate

This information is tabulated for the 5"/54 Projectile in BuOrd Publication OP1182 (Range Table for 5"/54). To find an equation which would best fit the tabulated data, a log transformation was made followed by a parabolic curve fit.

The time of Flight Equation is

$$f(x) = 10^{(0.1083 + 0.8505 \log x + 0.2831(\log x)^2)}$$

This equation generates solutions within 1 second of the tabulated values for ranges under 22,000 yds. The same approach was made in determining an equation for maximum ordinate.

The Maximum Ordinate Equation is

$$f(x) = 10^{(0.7775 + 2.1666 \log x - 0.2071(\log x)^2 + 0.2617(\log x)^3 + 0.0721(\log x)^4)}$$

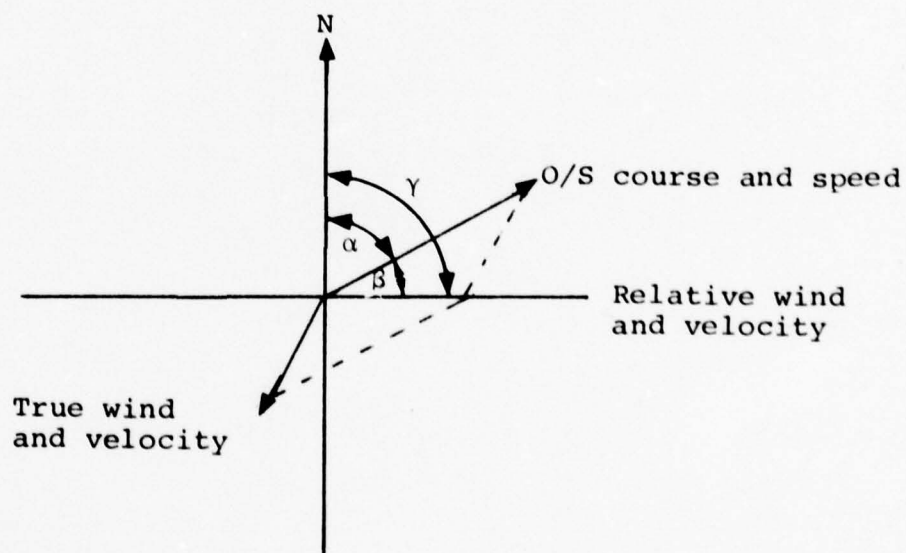
This equation generates solutions within 55ft of the tabulated values for ranges less than 19,000 yds. (Within 10ft for range less than 13,000 yds, and with 1 ft for ranges less than 7000 yds.)

The algorithm uses a nested polynomial to preserve accuracy in the calculation of the exponent. For example, Time of Flight is computed as follows:

$$f(x) = 10^{((0.2831 \log x + 0.8505) \log x + 0.1083)}$$

3. True Wind.

This computation is simple vector arithmetic. Relative wind is converted to Apparent wind by adding the ship's heading to the relative bearing, then converted to rectangular coordinates. Own ship's course and speed are then converted to rectangular coordinates and subtracted from apparent wind vector. The result is true wind which is converted to polar coordinates (Figure 2).



α = ship's heading

β = relative wind bearing

γ = apparent wind bearing

FIGURE 2. Wind vectors

IX. NORMAL MODE THEORY by LT J. M. Stone

A. Problem Statement

This program determines the number of normal modes that will propagate in a given ocean model. The ocean model must have either a rigid bottom or pressure release bottom. Also provided with each mode is the cutoff frequency (f_c), group velocity (C_g), and phase velocity (C_p). The user provides the speed of sound in water in m/sec (C_0), water depth in m(d), and frequency of the source in Hz(f).

B. Operational Analysis

None.

C. Computational Algorithm

Not submitted.

D. HP-67/07 Calculator Program

1. User Instructions

Step	Instruction	Input	Key(s)	Output
1.	Read program card			
2.	Initialize		f e	1.00
3.a.	Sound velocity (m/sec)	C ₀	↑	
b.	Water depth (m)	d	↑	
c.	Source frequency (Hz)	f		
4.	Bottom type: Either			
a.	Rigid Bottom, or	none	A	
b.	Pressure release bottom		B	
5.	Output sequence			
a.	Mode number			n
b.	Cutoff frequency for mode n			f _C
c.	Group velocity for mode n			C _g
d.	Phase velocity for mode n			C _p
e.	Display mode number			n
6.	Continue from Step 4a or 4b depending upon original bottom type. This process continues until the highest mode that will propagate for the given conditions has been displayed when [A] or [B] is pressed and the next mode will not propagate then the program displays the mode number of the last mode that will propagate.			

2. Sample Problems

Example 1.

$$C_0 = 1500 \text{ m/sec}$$

Rigid bottom

$$d = 15 \text{ m}$$

$$f = 150 \text{ Hz}$$

GSBe	Initializes Program
1500.00 ENT	
15.00 ENT	
150.00 GSBe	
1.00 ***	Flashes mode number (n)
25.00 ***	Flashes f_C for $n = 1$
1479.02 ***	Flashes C_g for $n = 1$
1521.28 ***	Flashes C_p for $n = 1$ (Stops, displaying mode no.)
GSBe	
2.00 ***	Flashes n
75.00 ***	Flashes f_C for $n = 2$
1299.04 ***	Flashes C_g for $n = 2$
1732.05 ***	Flashes C_p for $n = 2$ (Stops, displaying mode no.)
GSBe	
3.00 ***	Flashes n
125.00 ***	Flashes f_C for $n = 3$
829.16 ***	Flashes C_g for $n = 3$
2713.60 ***	Flashes C_p for $n = 3$ (Stops, displaying mode no.)
GSBe	
3.00 ***	Mode 4 will not propagate under
GSBe	these conditions so regardless of how many times A
3.00 ***	is pressed, mode 3 is displayed.

Example 2:

$C_0 = 1500$ m/sec

Pressure Release Bottom

$d = 15$ m

$f = 150$ Hz

GSBe	Initializes Program
1500.00 ENT1	
15.00 ENT1	
150.00 GSEB	
1.00 ***	Flashes mode no.
50.00 ***	Flashes f_C for mode 1
1414.21 ***	Flashes C_g for mode 1
1590.95 ***	Flashes C_p for mode 1 (Stops, displaying mode no.)
GSBe	
2.00 ***	Flashes mode no.
100.00 ***	Flashes f_C for mode 2
1118.03 ***	Flashes C_g for mode 2
2012.46 ***	Flashes C_p for mode 2 (Stops, displaying mode no.)
GSBe	
2.00 ***	Only two modes will propagate
GSBe	
2.00 ***	

NOTE: If such conditions exist such that no modes will propagate, 0.00 is displayed.

The program stops between modes and requires the user to initiate the next mode in order to allow the user sufficient time to write down the information presented.

3. Program Storage Allocations and Program Listing

Registers:

R0: f	S0:	RA:
R1: d	S1:	RB:
R2: C_0	S2:	RC:
R3: n	S3:	RD:
R4: f_C	S4:	RE:
R5: $\sqrt{1 - (f_C/f)^2}$	S5:	RI:
R6:	S6:	
R7:	S7:	
R8:	S8:	
R9:	S9:	

Initial Flag Status and Uses

0: OFF, Unused	2: OFF, Unused
1: OFF, Unused	3: OFF, Unused

User Control Keys

A: Rigid Bottom	a:
B: Pressure Release Bottom	b:
C:	c:
D:	d:
E:	e:

001	*LBL	21 16 15	Initializes Program
002	1	01	
003	ST03	35 03	n = 1
004	SF2	16 21 02	Controls storage of inputs on first pass
005	R/S	51	Input parameters at this stop
006	*LBLA	21 11	Case I--Rigid Bottom
007	F2?	16 23 02	
008	GSB1	23 01	Stores inputs on first pass
009	RCL3	36 03	
010	.	-62	
011	5	05	
012	x	-35	
013	.	-62	
014	2	02	Calculates f_C
015	5	05	$f_C = \frac{C_0(2n-1)}{4d}$
016	-	-45	
017	RCL2	36 02	
018	x	-35	
019	RCL1	36 01	
020	÷	-24	
021	RCL0	36 00	
022	X=Y	-41	
023	X=Y?	16-32	Is $f_C > f$
024	X=Y?	16-34	
025	ST04	22 04	Yes--display last mode # and stop
026	ST04	35 04	No--continue
027	RCL3	36 03	
028	PRTX	-14	Flash new mode #
029	RCL4	36 04	
030	PRTX	-14	Flash f_C
031	GSB2	23 02	Computes C_g and C_p
032	*LBL3	21 03	Increments mode no. for next iteration
033	1	01	
034	ST+3	35-55 03	
035	RCL3	36 03	
036	1	01	
037	-	-45	
038	R/S	51	Stops, displays mode # of run just completed
039	*LBLB	21 12	Case II--Pressure Release Bottom
040	F2?	16 23 02	
041	GSB1	23 01	Stores inputs on first pass
042	RCL3	36 03	
043	RCL2	36 02	
044	x	-35	Calculates f_C
045	RCL1	36 01	$f_C = \frac{C_0(2n)}{4d}$
046	÷	-24	
047	2	02	
048	÷	-24	
049	RCL0	36 00	

050	XZY	-41
051	X*Y?	16-32
052	X*Y?	16-34
053	GT04	22 04
054	ST04	35 04
055	RCL3	36 03
056	PRTX	-14
057	RCL4	36 04
058	PRTX	-14
059	GSB2	23 02
060	GT03	22 03
061	*LBL1	21 01
062	ST00	35 00
063	R↓	-31
064	ST01	35 01
065	R↓	-31
066	ST02	35 02
067	RTN	24
068	*LBL2	21 02
069	RCL4	36 04
070	RCL0	36 00
071	÷	-24
072	X²	53
073	CHS	-22
074	1	01
075	+	-55
076	JX	54
077	ST05	35 05
078	RCL2	36 02
079	x	-35
080	PRTX	-14
081	RCL2	36 02
082	RCL5	36 05
083	÷	-24
084	PRTX	-14
085	RTN	24
086	*LBL4	21 04
087	RCL3	36 03
088	1	01
089	-	-45
090	R/S	51

Is $f_C \geq f$
 Display last mode no.
 Yes--and stop
 No--continue

Flash new mode no.

Flash f_C
 Computes C_g and C_p increments mode # for next iteration
 Subroutine 1--Stores inputs on first pass only

Subroutine 2--Calculates C_g and C_p

$$C_g = C_0 \sqrt{1 - (f_C/f)^2}$$

$$C_p = C_0 / \sqrt{1 - (f_C/f)^2}$$

Flash C_p

Allows the last mode number to be displayed after each iteration

E. Mathematical Analysis

Consider a shallow water ocean model with depth d . According to Normal Mode Theory the sound pressure at any point can be determined by the solution of the wave equation and is given by

$$p_n = A_n \sin K_{nz} z \exp[i(\omega t - K_{nz} x)]$$

Sound will propagate at different angles and this is what gives rise to the various modes. As θ , in Figure 1 approaches zero, the sound will not propagate because it is merely bouncing up and down off the surface and bottom (no x-direction of travel). This determines the cutoff frequency for mode n .

The cutoff frequency is dependent upon the boundary conditions at the surface and bottom because the solution of the wave equation is dependent upon the boundary conditions. The surface is always considered to be a pressure release boundary. As the mode number increases the cutoff frequency for that mode is higher also. When the cutoff frequency exceeds the frequency of the source then that mode will not propagate, nor will higher modes.

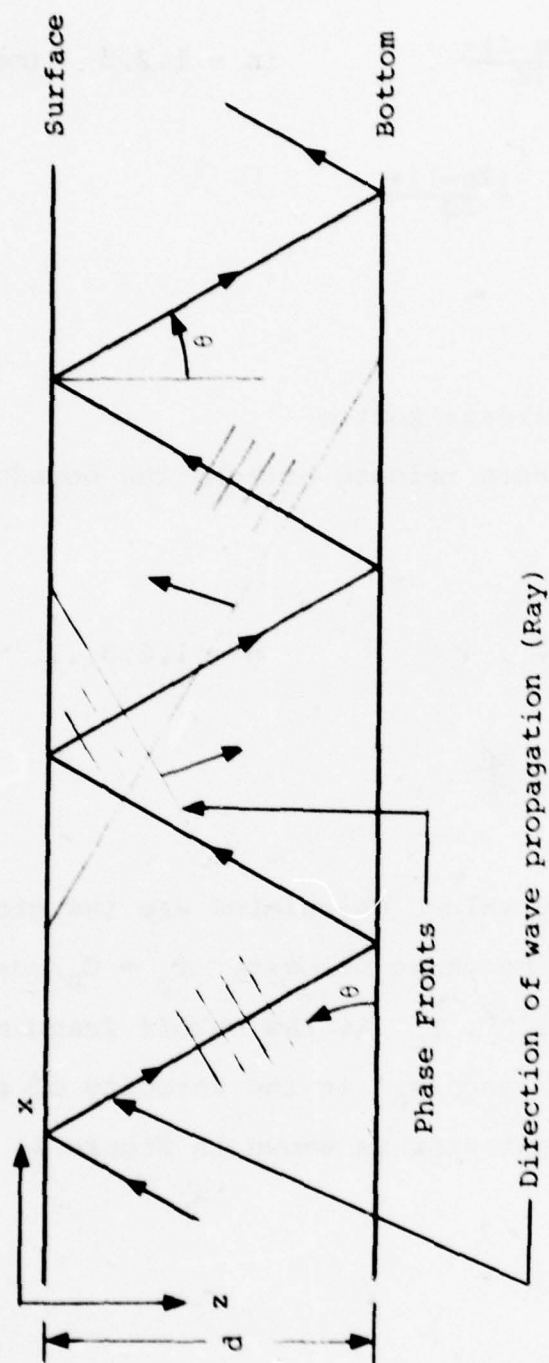


FIGURE 1. Wave Propagation Geometry

Case I: Rigid Bottom

For the rigid bottom, the boundary condition yields a

$$K_{nz} = \frac{(2n-1)\pi}{2d}, \quad n = 1, 2, 3 \quad (\text{mode } \#)$$

and

$$f_C = \frac{C_0}{2} \frac{(2n-1)\pi}{2d}.$$

Case II: Pressure Release Bottom

For the pressure release bottom, the boundary condition yields

$$K_{nz} = \frac{n\pi}{d}, \quad n = 1, 2, 3, \dots \quad (\text{mode } \#)$$

and

$$f_C = \frac{C_0}{2\pi} \frac{n\pi}{d}.$$

The remaining values calculated are the group velocity $C_g = C_0 \cos \phi$ and the phase velocity $C_p = C_0 / \cos \phi$, where $\cos \phi = [1 - (f_C/f)^2]^{1/2}$, f_C is the cutoff frequency, f is the source frequency, and C_0 is the velocity of sound. The geometry of these quantities is shown in Figure 2.

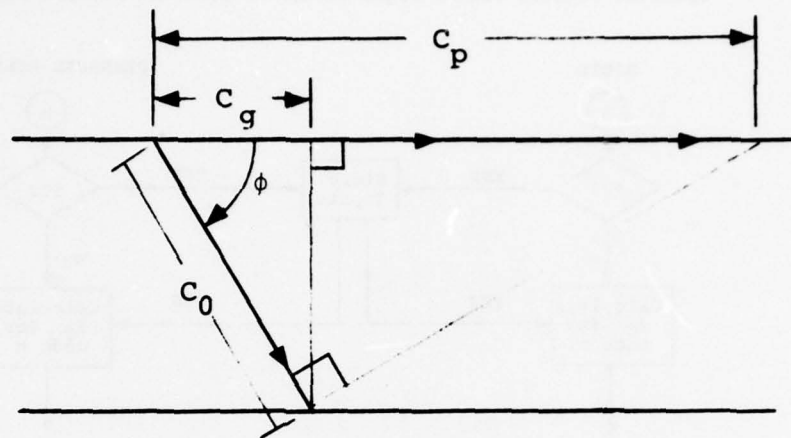
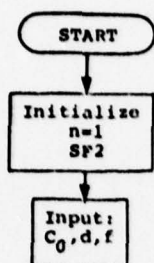
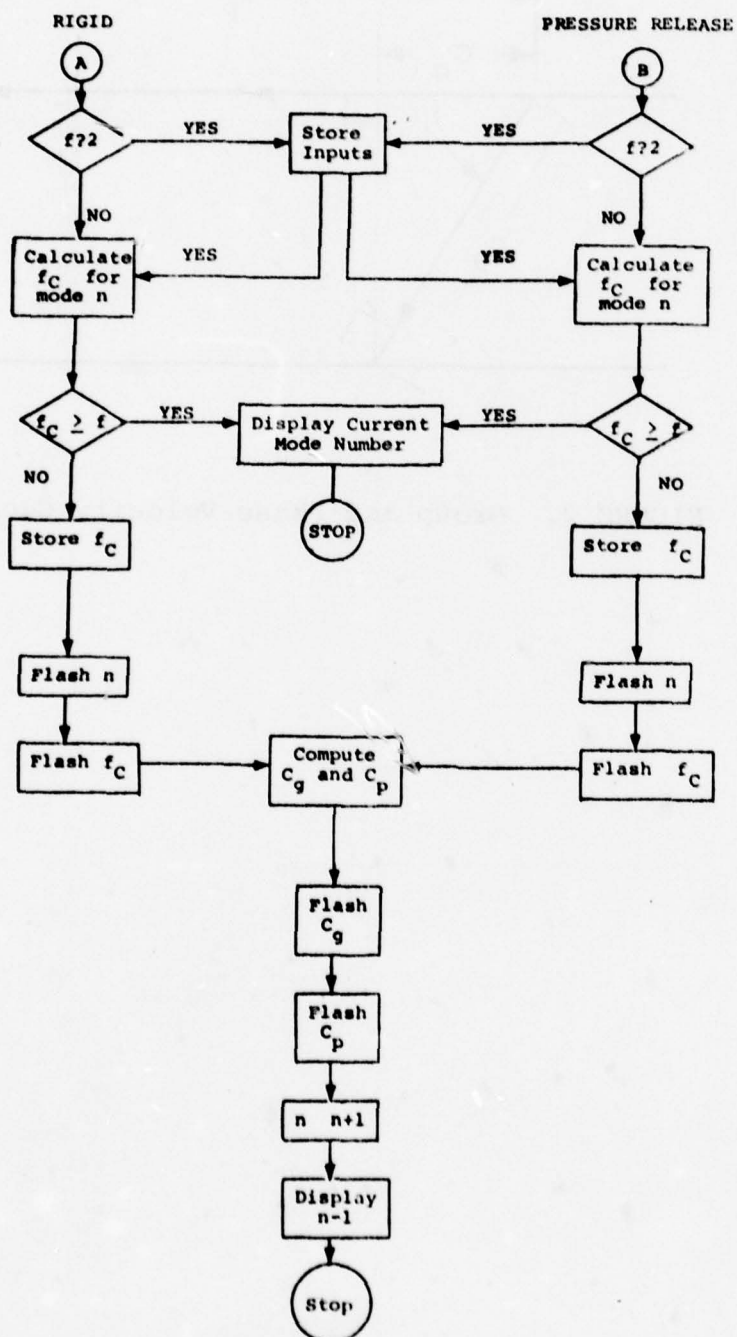


FIGURE 2. Group and Phase Velocity Geometry



Operator selects either rigid bottom or pressure release bottom



X. NORMAL MODE TRANSMISSION LOSSES by LT Michael D. Clary

A. Problem Statement

As an alternative to Ray Theory, the use of Normal Mode Theory provides a more exact approach to the solution of transmission loss problems. Given source frequency and depth, range to and depth of receiver, and modal values for the speed of sound and the absorption coefficient, the program user may either specify the effective pressure amplitude of the source at one meter and solve for modal effective pressure amplitudes and the resulting transmission losses, or if the modal pressures are input, the value of the one meter effective source pressure amplitude can be obtained.

B. Operational Analysis

Since this program is used primarily as a theoretical problem solver based on give data, no operational analysis is provided.

C. Computational Algorithm HP-67

1. Input source frequency, depth, receiver depth, effective pressure amplitude at 1 meter (source) or effective pressure amplitude of given model.
2. Input absorption coefficient for given mode, range between source and receiver, and speed of sound for the mode.
3. Compute sums required for transmission loss equation.
4. Compute and output coherent and/or incoherent transmission losses.

D. HP-67 Calculator Program

1. User Instructions

Step	Instruction	Input	Keys(s)	Output
1.	Load side one and two of program card			
2.	Program the eigenfunction for $z_n(z)$, $z_n(z_0)$ at LBL3 in the W/PGRM MODE. (Assume value of z and z_0 will be in the x-register upon initialization of each computation.) The last two program steps must be STO(i), h RTN. Return calculator to RUN MODE			
3.	Enter computational values			
a.	frequency of source in Hz	f	ENTER	f
b.	depth of source in meters	z_0	ENTER	z_0
c.	depth of receiver in meters	z	ENTER	z
d.	effective pressure amplitude at 1 m in μPa or effective pressure amplitude of given value	$P(1)$ $- P_n $	A A	f f
	enter as $- P_n $			
e.	absorption coefficient for the mode	α_n	ENTER	α_n
f.	range from source in meters	r	ENTER	
g.	speed of sound for the mode in meters/sec	C_n	B	$ P_n $ or $P(1)$
	Output will be either the mode value for the effective pressure amplitude or the value of the effective pressure amplitude at 1 m. All values are in μPa .			

Step	Instruction	Input	Key(s)	Output
4.	Sum the values of $P_n \sin(2\pi f_r)/C_n$ and $P_n \cos(2\pi f_r)/C_n$		C	n
5.	Sum the value of P_n^2		D	P_n^2
6.	Return to Step 2 for additional mode computations. Information for Steps 3a, b, c and d need not be re-entered. If all mode computations are completed, go to 7.			
7.	Compute transmission loss (in dB) for coherence for incoherence	f	E e	T.L. T.L.
8.	For new case go to Step 1			

2. Sample Problem

For a nearly isovelocity layer of water 50 m deep overlying a silt bottom rich in decaying organic matter, the following are found to be good approximate values for a source frequency of 50 Hz:

n	$Z_n(z)$	c_n	f_n (cutoff)	α_n
1	$0.2 \sin(0.050z)$	1550m/s	25 Hz	$1 \times 10^{-4}/m$
2	$0.2 \sin(0.105z)$	1630	33	2×10^{-4}
3	$0.2 \sin(0.189z)$	2110	45	4×10^{-4}
4	not excited	---	55	---

- a. Evaluate the effective amplitudes $|P_n|$ at a receiver at a range of 2 km and at a depth of 20 m. Determine both transmission loss values.

SOLUTION: (given that the source is at a depth of 50m)

1. Enter first eigenfunction $Z_n(z)$ under label 3.
Value of z (or z_0) will be in the X-register.
2. Enter f , z_0 , z and $P(1) = 10^7 \mu\text{Pa}$ for $n = 1$ and compute P_1 .
3. After recording value P_1 , sum the values for transmission loss calculations.
4. Repeat Steps 1-3 for all necessary values of n (three for the given example).
5. When all P_n 's have been obtained, calculate transmission loss, both coherent and incoherent cases.
6. Numerical answers:

$$P_1 = 2.05 \times 10^4 \mu\text{Pa}$$

$$|P_1| = 2.05 \times 10^4 \mu\text{Pa}$$

$$P_2 = -2.54 \times 10^4 \mu\text{Pa}$$

$$|P_2| = 2.54 \times 10^4 \mu\text{Pa}$$

$$P_3 = 0.39 \times 10^3 \mu\text{Pa}$$

$$|P_3| = 0.39 \times 10^4 \mu\text{Pa}$$

$$\text{TL}(\text{coherence}) = 53 \text{ dB}$$

$$\text{TL}(\text{incoherence}) = 50 \text{ dB}$$

Keystroke Sequence for Sample Problem a.

		GT03			2.-04 ENT1
092	*LBL3	21 03			2.+03 ENT1
093	.	-62			1630. GSEB
094	0	00			2.54+04 ***
095	5	05			GSEC
096	X	-35			2.00+00 ***
097	SIN	41			GSED
098	.	-62			6.44+00 ***
099	2	02			GT03
100	X	-35			092 *LBL3 21 03
101	STO1	35 45			093 . -62
102	RTN	24			094 1 01
	50.00 ENT1				095 8 06
	50.00 ENT1				096 9 09
	20.00 ENT1				097 X -35
	1.+07 GSEA				098 SIN 41
	50.00 ***				099 . -62
	1.-04 ENT1				100 2 02
	2.+03 ENT1				101 X -35
	1550.00 GSEB				102 STO1 35 45
	2.05+04 ***				103 RTN 24
	GSEC				4.-04 ENT1
	1.00+00 ***				2.+03 ENT1
	GSED				2110. GSEB
	4.22+08 ***				3.92+02 ***
	GT03				GSEC
092	*LBL3	21 03			3.00+00 ***
093	.	-62			GSEC
094	1	01			1.54+05 ***
095	0	00			GSEE
096	5	05			53. ***
097	X	-35			GSEe
098	SIN	41			50. ***
099	.	-62			
100	2	02			
101	X	-35			
102	STO1	35 45			
103	RTN	24			

b. Using the same table values and the computed values for each P_n , verify that the value for $P(1)$ is in fact $10^7 \mu\text{Pa}$.

1. Enter first eigenfunction $Z_n(z)$ under label 3.
2. Enter computational values for $n = 1$ and compute $P(1)$.
Note that the values of P_n must be entered as the negative value of the absolute.
3. Calculate $P(1)$. Repeat Steps 1-3 for each value of n .
4. Numerical answers:

$$|P_1| = 2.05 \times 10^4 \mu\text{Pa} \quad P(1) = 9.98 \times 10^6 \approx 10^7 \mu\text{Pa}$$

$$|P_2| = 2.54 \times 10^4 \mu\text{Pa} \quad P(1) = 10^7 \mu\text{Pa}$$

$$|P_3| = 0.39 \times 10^3 \mu\text{Pa} \quad P(1) = 9.94 \times 10^6 \approx 10^7 \mu\text{Pa}$$

Keystroke Sequence for Sample Problem b.

```

GT03
50.00 ENT1
50.00 ENT1
20.00 ENT1
-2.05+04 GSEA
1.-04 ENT1
2.+03 ENT1
1550.00 GSEE
9.98+06 ***
GT03
50. ENT1
50. ENT1
20. ENT1
-2.54+04 GSEA
2.-04 ENT1
2.+03 ENT1
1650. GSEE
1.00+07 ***
GT03
50. ENT1
50. ENT1
20. ENT1
-0.39+03 GSEA
4.-04 ENT1
2.+03 ENT1
2110. GSEE
9.94+06 ***

```

3. Program Storage Allocation and Program Listing

Registers:

R0: f	S0: ΣP_n^2
R1: z_0	S1:
R2: z	S2:
R3: C_n	S3:
R4: a_n	S4: $\Sigma \sin(2\pi f_r)/C_n$
R5: r	S5:
R6: $P(1)$ or $- P_n $	S6: $\Sigma \cos(2\pi f_r)/C_n$
R7:	S7: $\Sigma \cos^2(2\pi f_r)/C_n$
R8:	S8: $\Sigma [\sin(2\pi f_r)/C_n][\cos(2\pi f_r)/C_n]$
R9:	S9: n
RA: P_n or $P(1)$	
RB: $(2\pi f_r)/C_n$ and $\cos(2\pi f_r)/C_n$	
RC: $\sin(2\pi f_r)/C_n$	
RD: Coherent TL	
RE: Incoherent TL	
RI: Scratch	

Initial Flag Status and Use: OFF, Unused

Trig Mode: RAD

User Control Keys:

A: $f \uparrow z_0 \uparrow z \uparrow P(1) \text{ or } -|P_n|$ a:

B: $\alpha_n \uparrow r \uparrow C_n \rightarrow P_n \text{ or } P(1)$ b:

C: $\text{Sum sin, cos}(2\pi f_r)/C_n$ c:

D: $\text{Sum } P_n^2$ d:

E: $\rightarrow$ Coherent TL e: $\rightarrow$ Incoherent TL

001	*LELA	21 11
002	RAD	16-23
003	CLRG	16-53
004	P2S	16-51
005	CLRG	16-53
006	ST06	35 06
007	R4	-31
008	ST02	35 02
009	R4	-31
010	ST01	35 01
011	R4	-31
012	ST00	35 00
013	RTN	24
014	*LBL6	21 12
015	ST03	35 03
016	R4	-31
017	ST05	35 05
018	R4	-31
019	ST04	35 04
020	RCL6	36 06
021	X00?	16-45
022	GT01	22 01
023	1	01
024	ST09	35 09
025	*LBL2	21 02
026	7	07
027	ST01	35 46
028	RCL1	36 01
029	GSB3	23 03
030	8	08
031	ST01	35 46
032	RCL2	36 02
033	GSB3	23 03
034	RCL9	36 09
035	X00?	16-45
036	RTN	24
037	*LBL4	21 04
038	RCL7	36 07
039	RCL5	36 05
040	/X	54
041	÷	-24
042	RCL8	36 08
043	x	-35
044	RCL3	36 03
045	RCL0	36 00
046	÷	-24
047	/X	54
048	x	-35
049	RCL6	36 06
050	x	-35
051	RCL4	36 04
052	RCL5	36 05
053	x	-35
054	CHS	-22
055	e*	33
056	x	-35
057	ST0A	35 11

Enter values for f , Z_0 , Z , and either $P(1)$ or $-|P_n|$. Clears all registers, sets radian mode.

Enter values for α_n , r , and c_n

Determine calculations required.

1 is stored in R_9 if P_n is being calculated

Set up storage for $Z_n (Z_0)$ and $Z_n (z)$; branches to user-defined function to compute

Returns to Label 1 for calculations of $P(1)$

Compute P_n .

*Note that $|P_n|$ is stored in Register A,

$|P_n|$ is displayed upon completion.

058	SCI	-12	
059	ABS	16 31	
060	RTN	24	
061	*LBL1	21 01	
062	CHS	-22	Stores in $ P_n $ in R_6 .
063	STO6	35 06	-1 stores in R_9 to indicate that $P(1)$
064	1	01	is being calculated.
065	CHS	-22	Calculate $Z_n(z_0)$, $Z_n(z)$
066	STO9	35 09	
067	GSB2	23 02	
068	RCL5	36 05	
069	JX	54	
070	RCL6	36 06	
071	X	-35	
072	RCL3	36 03	
073	RCL0	36 00	
074	÷	-24	
075	JX	54	
076	÷	-24	
077	RCL7	36 07	
078	÷	-24	Compute $P(1)$
079	RCL8	36 08	
080	÷	-24	
081	RCL4	36 04	
082	RCL5	36 05	
083	X	-35	
084	CHS	-22	
085	e ^x	33	
086	÷	-24	
087	X<0?	16-45	
088	CHS	-22	
089	STOA	35 11	
090	SCI	-12	
091	RTN	24	
092	*LBL3	21 03	User-defined label to compute
093	STOI	35 45	$Z_n(z_0)$ and $Z_n(z)$.
094	RTN	24	
095	*LBLC	21 13	
096	RCL5	36 05	
097	RCL0	36 00	
098	X	-35	
099	PI	16-24	
100	2	02	
101	X	-35	
102	X	-35	
103	RCL3	36 03	Sums and stores the sine and cosine of
104	÷	-24	$\frac{2\pi f_r}{C_n}$
105	STOB	35 12	
106	SIN	41	
107	STOC	35 13	
108	RCLB	36 12	
109	COS	42	
110	STOB	35 12	
111	RCLA	36 11	for use in calculations of T.L. (coherent)
112	X	-35	
113	RCLC	36 13	
114	RCLA	36 11	

115	x	-35	
116	Σ+	56	
117	RTN	24	
118	*LBLD	21 14	
119	RCLA	36 11	
120	X²	53	
121	PZS	16-51	Computes P_n^2
122	ST+0	35-55 00	
123	PZS	16-51	
124	RTN	24	
125	*LBLD	21 15	
126	PZS	16-51	
127	RCLA	36 04	
128	X²	53	
129	RCL6	36 06	
130	X²	53	
131	+	-55	
132	JX	54	
133	PZS	16-51	
134	RCL6	36 06	Computes T.L. assuming coherence.
135	÷	-24	
136	LOG	16 32	
137	2	02	
138	0	00	
139	x	-35	
140	CHS	-22	
141	FIX	-11	
142	DSP0	-63 00	
143	ST00	35 14	
144	RTN	24	
145	*LBLD	21 16 15	
146	PZS	16-51	
147	RCL0	36 00	
148	PZS	16-51	
149	JX	54	
150	RCL6	36 06	
151	÷	-24	
152	LOG	16 32	Computes T.L. assuming incoherence.
153	2	02	
154	0	00	
155	x	-35	
156	CHS	-22	
157	FIX	-11	
158	DSP0	-63 00	
159	ST0E	35 15	
160	RTN	24	
161	R/S	51	

E. Mathematical Analysis

The following four formulas are the basis for the mathematical computations (Ref. 1).

$$1. \quad P_n = P(1) \sqrt{\frac{C_n}{f}} \frac{z_n(z_0)}{\sqrt{r}} z_n(z) \exp(-\alpha_n r)$$

$$2. \quad P(1) = \frac{P_n \sqrt{r}}{\sqrt{(C_n/f)} z_n(z_0) z_n(z) \exp(-\alpha_n r)}$$

3. Coherent transmission loss

$$TL = -20 \log \left[\left[\left(\sum P_n \sin \frac{2f_r}{C_n} \right)^2 + \left(\sum P_n \cos \frac{2f_r}{C_n} \right)^2 \right]^{1/2} / P(1) \right]$$

4. Incoherent transmission loss

$$TL = -20 \log \left[(\sum P_n^2)^{1/2} / P(1) \right]$$

F. Reference

1. A. B. Coppens and J. V. Sanders, "An Introduction to the Sonar Equations with Applications," Technical Report NPS-61Sd76071, July 1976, Naval Postgraduate School, Monterey, CA 93940

XI. GOLDEN SECTION SEARCH by LT J. K. McDermott

A. Problem Statement

The minimum value of a unimodal function of one variable, $f(x)$, for a specified interval is determined by utilizing Golden Section Search Techniques, i.e.

$$\begin{array}{ll}\text{Minimize} & f(x) \\ \text{Subject to} & x \in I\end{array}$$

where $I = [a, b]$ is a closed interval in E_1 space.

B. Operational Analysis

Golden Section Search is a specific type of interval of uncertainty (IOU) method of single variable optimization which requires the selection of a specific interval. Once the interval has been selected, the program locates the value of x which will minimize a unimodal function $f(x)$ being evaluated within this specific interval. If a different interval is selected, a different x with a correspondingly different minimum functional value may be obtained.

Golden Section Search locates a local minimum and not the global minimum. A function which is not unimodal over the specific interval may produce an x value which does not provide the minimum (global) functional value within the interval. The behavior for non-unimodal functions is not predictable.

The functions which may be evaluated are limited to some degree by (i) the number of program steps available for user supplied function program listing (139-224), (ii) functions of one variable preferably unimodal over the IOU to avoid ambiguity, and (iii) user's programming capability and imagination.

Golden Section Search was originally suggested by J. Kiefer, "Sequential Minimax Search for a Maximum," Proc. Amer. Math. Soc., 4, no. 3, June 1953, pp. 502-506. The name traces back to Euclid's discovery that it is possible to divide any given line segment into two parts such that the ratio of the whole to the larger part equals the ratio of the larger part to the smaller. The division of a line in this manner came to be known as the Golden Section, both because it has several rather interesting geometric and numerical properties and because the proportions of the two parts seem pleasing to the eye.

The author (programmer) is indebted to Professor J. K. Hartman of the Naval Postgraduate School whose lectures and class notes form the bases of this HP-67/97 calculator program.

C. Computational Algorithm

Basic IOU Algorithm Structure (GSS)

1. Given initial IOU $I = [a, b]$ and function $f(x)$. Let K be a function evaluation, iteration counter.
2. Compute initial X_1 as

$$X_1 = a + \sigma(b-a) \text{ with } \sigma = (3 - \sqrt{5})/2$$

Set $I_1 = 1$ and $K = 2$.

3. At iteration K , interval I_{K-1} resulting from previous iteration contains best point (one producing smaller function value) thus far and its relative position is σ or $1-\sigma$. Place new point (X_K) symmetrically:

$$X_K = \text{ENDL} + \text{ENDR} - X_{\text{OLD}}$$

where $I_{K-1} = [\text{ENDL}, \text{ENDR}]$ and X_{OLD} provided the smaller function value between previous two evaluated points.

4. Compute $f(X_K)$.
5. Shorten IOU to $I_K \subset I_{K-1}$ with length $L_K < L_{K-1}$ from information $f(X_K)$ provides. Set $K = K+1$ and go to step 3 for the next iteration.

STOPPING RULE:

Stop when either $K = \text{NMAX}$ (present number of function iterations) or when $L_K \leq \text{RIOU}$ (preset required interval of uncertainty length).

HP-67 Computational Algorithm

1. Input user supplied function program listing in available program steps 139 through 224.
2. Input left endpoint of interval of uncertainty (ENDL).
3. Input right endpoint of interval of uncertainty (ENDR).
4. Input required length of the final interval of uncertainty (RIOU).
5. Input maximum number of function evaluations desired (NMAX)
6. Output final interval of uncertainty [ENDL,ENDR].
7. Output minimum (local) function value in interval.
8. Output X value that produces minimum function value.

D. HP-67/97 Calculator Program

1. User Instructions

Step	Instruction	Input	Key(s)	Output
1.	Enter program card			
2.	Select GTO f e		GTO f e	
3.	Slide W/PRGM-RUN switch to W/PRGM	User supplied function program		
4.	Slide W/PRGM-RUN switch to RUN			
5.	Enter left endpoint of interval of uncertainty	ENDL	A	ENDL
6.	Enter right endpoint of interval of uncertainty	ENDL	B	ENDR
7.	Enter required length of interval of uncertainty	RIOU	C	RIOU
8.	Enter maximum number of function evaluations to be performed	NMAX	D	NMAX
9.	Compute final interval of uncertainty, minimum function value, and corresponding X value	NONE	E	
	ENDL displayed when computation complete			ENDL
10.	Press R/S to display ENDR			ENDR
11.	Press R/S again to display f(X)			f(X)
12.	Press R/S once more to display X			X
13.	To repeat program press f CLREG and go to Step 5		f CL REG	

2. Sample Problem

- a. minimize $f(x) = |x^2 - 16|$
 subject to $x \in I_0$

$I_0 = [1, 16]$, RIOU = 0.01, NMAX = 25.

SOLUTION: [3.99560, 4.00240] in 17 function evaluations

Function Value = 0.00162

Minimum Point $x = 3.99980$

User Supplied Program Listing

139	*LBLE	21	16	15	670e
140	ROLE		36	15	
141	N²			53	
142	1			01	
143	6			06	
144	-			-45	
145	ABS	16	31		
146	RTN		24		
147	R/S		51		

Recalls x from Register E.

Function value is left in the display (x-register).

1.00	6S66
16.00	6S66
.01	6SEC
25.00	6S60
	6S6E
3.99560	***
	R/S
4.00240	***
	R/S
0.00162	***
	R/S
3.99980	***

NOTE: First load provided program (with RUN position).
Select GTO f e. Move switch to W/PRGM. Enter user
supplied program for function. Move switch to run
position. Enter input and compute.

b.

$$\text{Minimize } f(x) = 20 - x + \frac{1}{(16-x)}$$

Subject to $x \in I_0$

$$I_0 = [10, 15.9], \text{RIOU} = 0.01, \text{NMAX} = 25$$

SOLUTION: [14.99555, 15.00255] in 15 function evaluations

Function Value = 6.00000

Minimum Point $x = 14.99823$

User Supplied Program Listing

		GTOe	
139	*LBL e	21 16 15	
140	2	02	
141	8	00	
142	ROLE	36 15	Recall x from Register E.
143	-	-45	
144	1	01	Result is left in x-register
145	6	06	
146	ROLE	36 15	
147	-	-45	
148	1/X	52	
149	+	-55	
150	RTN	24	
151	R/S	51	
		10.00 GS6A	
		15.90 GS6B	
		.01 GS6C	
		25.00 GS6D	
		GS6E	
		14.99555 ***	
		R/S	
		15.00255 ***	
		R/S	
		6.00000 ***	
		R/S	
		14.99623 ***	

NOTE: First load provided program with switch in RUN position.
 Select GTO f e. Move switch to W/PRGM. Enter user
 supplied program for function. Move switch to RUN
 position. Enter input and compute.

c. minimize $f(x) = \frac{x}{2} + \sin(\frac{\pi x}{2})$ (x in radians)

subject to $x \in I_0$

$I_0 = [0, 10]$, $RIOU = 0.01$, $NMAX = 25$.

SOLUTION: [2.79094, 2.79827] in 16 function evaluations

Function value = 0.44890	} local minimum (x = 0.0 is global)
Minimum point x = 2.79373	

posit

3. Program Storage Allocation

Registers:

R0: function counter	S0:	RA:
R1: ENDL	S1:	RB:
R2: ENDR	S2:	BC:
R3: RIOU	S3:	RD:
R4: NMAX	S4:	RE: Current X
R5: X_1	S5:	RI: 4 (decrement)
R6: X_2	S6:	
R7: F_1	S7:	
R8: F_2	S8:	
R9: not used	S9:	

NOTE: User supplied function can utilize sixteen registers.

Initial Flag Status and Use:

0: OFF, Unused	2: OFF, Unused
1: OFF, Unused	3: OFF, Unused

User Control Keys

A: Left endpoint (ENDL)	a:
B: Right endpoint (ENDR)	b:
C: Required interval of uncertainty (RIOU)	c:
D: Maximum function iterations (NMAX)	d:
E: Compute	e: User defined function

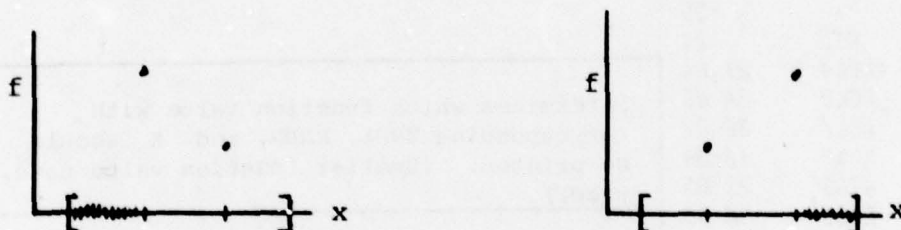
001	*LBLA	21 11	Input:
002	ST01	35 01	Left endpoint
003	RTN	24	Right endpoint
004	*LBLB	21 12	Required interval of uncertainty
005	ST02	35 02	Maximum number of function evaluations
006	RTN	24	(ENDL, ENDR, RIOU, NMAX)
007	*LBLC	21 13	
008	ST03	35 03	
009	RTN	24	
010	*LBLD	21 14	
011	ST04	35 04	
012	3	03	
013	ENT↑	-21	Calculate Sigma
014	5	05	
015	JX	54	$\sigma = \frac{(3 - \sqrt{5})}{2}$
016	-	-45	
017	2	02	
018	÷	-24	
019	RCL2	36 02	
020	RCL1	36 01	Calculate initial x_1
021	-	-45	
022	x	-35	$x_1 = ENDL + \sigma(ENDR - ENDL)$
023	RCL1	36 01	
024	+	-55	
025	ST05	35 05	
026	0	00	
027	ST00	35 00	Initialize counters
028	4	04	Set up display
029	ST01	35 45	Require radian calculations
030	RCL4	36 04	
031	DSF5	-63 05	
032	RAD	-16-22	
033	RTN	24	
034	*LBLB	21 15	
035	RCL5	36 05	
036	RCL1	36 01	
037	-	-45	Calculate initial x_2
038	RCL2	36 02	
039	XZY	-41	
040	-	-45	
041	ST06	35 06	
042	GSB1	23 01	Obtain initial function values
043	GSB8	23 08	(F_1 and F_2) from initial x_1 and x_2 .
044	GSB2	23 02	
045	GSB8	23 08	

046	*LBLa	21 16 11	Determine larger function value. If F_1
047	RCL8	36 08	larger go to branch two, otherwise go to
048	RCL7	36 07	branch one.
049	X>Y?	16-34	
050	GT03	22 03	
051	RCL6	36 06	X_2 becomes right endpoint of interval of
052	ST02	35 02	uncertainty
053	RCL1	36 01	
054	-	-45	
055	RCL3	36 03	Compare $IOU < RIOU?$
056	X=Y	-41	If yes, print out final results
057	X<Y?	16-35	
058	GT04	22 04	
059	RCL5	36 05	Old X_1 becomes X_2
060	ST06	35 06	Old F_1 becomes F_2
061	RCL7	36 07	
062	ST08	35 08	
063	GSB6	23 06	Determines new $X = (X_1)$ and store.
064	ST05	35 05	
065	RCL4	36 04	
066	RCL0	36 00	Has NMAX been exceeded? If yes, print error.
067	X>Y?	16-34	
068	GT00	22 00	
069	GSB1	23 01	Calculate F_1 and return to compare new
070	GSB8	23 08	values of F_1 and F_2 .
071	GT0a	22 16 11	
072	*LBL3	21 03	
073	RCL2	36 02	X_1 becomes left endpoint of interval
074	RCL5	36 05	of uncertainty
075	ST01	35 01	
076	-	-45	
077	RCL3	36 03	Compare $IOU < RIOU?$
078	X=Y	-41	If yes, print out final results
079	X<Y?	16-35	
080	GT04	22 04	
081	RCL6	36 06	Old X_2 becomes X_1
082	ST05	35 05	Old F_2 becomes F_1
083	RCL8	36 08	
084	ST07	35 07	
085	GSB6	23 06	Determines new $X = (X_2)$ and store.
086	ST06	35 06	
087	RCL4	36 04	
088	RCL0	36 00	Has NMAX been exceeded?
089	X>Y?	16-34	If yes, print error.
090	GT00	22 00	

091	GSB2	23 02	Calculate F_2 and return to compare new values of F_1 and F_2	↓
092	GSB8	23 08		↓
093	GT0a	22 16 11		
094	*LBL8	21 08		
095	1	01	Increments function counter for determination of NMAX exceeded.	
096	ST+0	35-55 00		
097	RTN	24		
098	*LBL6	21 06		
099	RCL2	36 02	Determines new X (X_1 or X_2 depending on which branch subroutine called from)	
100	RCL5	36 05		
101	-	-45		
102	RCL1	36 01		
103	+	-55		
104	RTN	24		
105	*LBL4	21 04		
106	RCL8	36 08	Determines which function value with corresponding ENDL, ENDR, and X should be printed. (Smaller function value used.)	
107	RCL7	36 07		
108	XY?	16-34		
109	GT05	22 05		
110	RCL5	36 05		
111	RCL7	36 07	Sets up stack for printout if F_1 small value.	
112	RCL2	36 02		
113	RCL1	36 01		
114	GT07	22 07		
115	*LBL5	21 05		
116	RCL6	36 06	Sets up stack for printout if F_2 smaller value	
117	RCL8	36 08		
118	RCL2	36 02		
119	RCL1	36 01		
120	*LBL7	21 07		
121	R/S	51		
122	R4	-31		
123	DSZ1	16 25 46	Prints out final results.	
124	GT07	22 07		
125	GT00	22 00		
126	RTN	24		
127	*LBL1	21 01		
128	RCL5	36 05		
129	STOE	35 15		
130	GSBe	23 16 15	F_1 Routine	
131	STO7	35 07		
132	RTN	24		
133	*LBL2	21 02		
134	RCL6	36 06		
135	STOE	35 15	F_2 Routine	
136	GSBe	23 16 15		
137	STO8	35 08		
138	RTN	24		
139	*LBLc	21 16 15		
140	RTN	24	Use defined function	
141	R/S	51		

E. Mathematical Analysis

For each X the function $f(X)$ is evaluated. By comparing two function values F_1 and F_2 the interval of uncertainty can be reduced as follows:



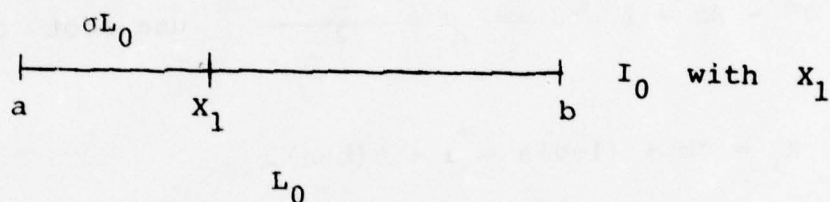
The placement of the X 's is determined by the Golden Section Search Technique utilizing the "Golden Ratio." Placement of the first X (X_1) determines the placement of all other X 's since all remaining points are placed symmetrically with respect to each point remaining in successive intervals of uncertainty.

In order to ensure that each IOU length is predictively independent of the function $f(x)$, X_1 and X_2 are placed symmetrically in the IOU. When the IOU is reduced, the new shorter IOU still contains the best point thus far achieved, so selecting a new X point will allow further reduction. (New X for each iteration.)

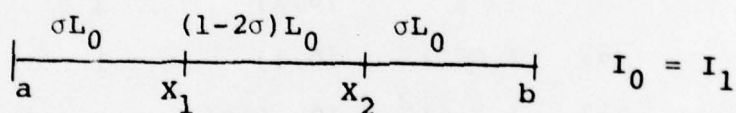
Golden Section Search selects X_1 to satisfy:

The relative position of the X points in the remaining IOU is the same at each iteration.

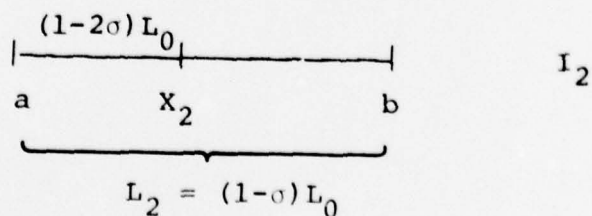
Explanation:



$I_1 = I_0$ since no reduction with one point. Relative position of X_1 in I_1 is $GL_0/L_0 = \sigma$. Now place X_2 symmetrically



Suppose $f(X_2) < f(X_1)$ and reduce IOU accordingly



Relative position of X_2 is

$$\frac{(1 - 2\sigma)L_0}{(1 - \sigma)L_0} = \frac{1 - 2\sigma}{1 - \sigma}$$

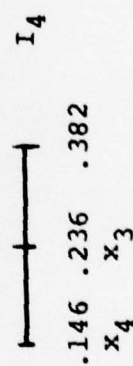
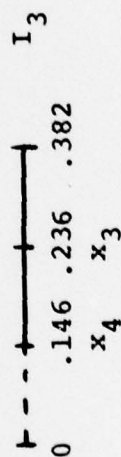
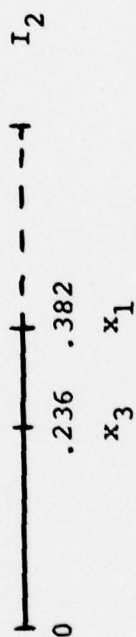
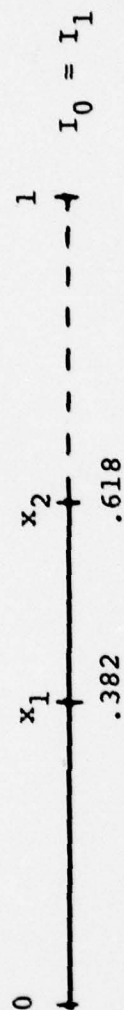
$$\sigma = \frac{1 - 2\sigma}{1 - \sigma} \implies \text{"relative position same at each iteration"}$$

$$\sigma^2 - 3\sigma + 1 = 0 \implies \sigma = \frac{3 \pm \sqrt{5}}{2} \quad \text{use root } \sigma = \frac{3 - \sqrt{5}}{2}$$

Choose $x_1 = \sigma b + (1 - \sigma)a = a + \sigma(b - a)$.

Example: $n = 4$, $f(x) = (x - .303)^2$, $I_0 = [0, 1]$.

K	I_{K-1}	x_K	$f(x_K)$	I_K	L_K
0	--	--	--	$[0, 1]$	1
1	$[0, 1]$	.382	$(.079)^2$	$[0, 1]$	1
2	$[0, 1]$	.618	$(.315)^2$	$[0, .618]$	$.618 = (1 - \sigma)$
3	$[0, .618]$	.236	$(.067)^2$	$[0, .382]$	$.382 = (1 - \sigma)^2$
4	$[0, .382]$	.146	$(.157)^2$	$[\cdot 146, .382]$	$.236 = (1 - \sigma)^3$



FINAL ANSWER: x_3 (OPTIMAL) $e[.146, .382]$;

$x_3 = .236$ is best point evaluated thus far.

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