

MOT. Body one minute 15' X cos LAT, x sin LAT  
0-90 200-250  
10-150 180-250  
190-270 190-250  
230-300 20-260

MANUAL OF OPERATING INSTRUCTIONS  
for  
**COMPUTER, AIR NAVIGATION, BOMBING**  
**TYPE CPU-48 P (VAID)**

With trigonometrical (circular slide rule) solution of the radar fixed reference bombing problem, including direct and offset sighting procedures, for bomber aircraft.

With additional trigonometrical (circular slide rule) solutions of the optical, "Last Resort," fixed VRM (non synchronous) and timing methods for determining the bomb release point emergency conditions, for bomber aircraft.

With additional trigonometrical (circular slide rule) solutions of the BNS (synchronous) offset component determination problem for bomber aircraft and distance/course solutions for all aircraft.

With additional trigonometrical (circular slide rule) and vectoral (plotting disc) solutions of various dead reckoning and celestial navigation problems, including a one-minute combined celestial motion solution, for all aircraft.

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NOTE:

The final version of this Instruction Manual will include 28 pages of illustrations of the examples which are mentioned in the text, illustrated examples of Figures 17, 29 and 30, the GHA of Aries Table and the Table of Supplementary Stars.

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## SECTION I

## INTRODUCTION/BIBLIOGRAPHY

1. This handbook is issued to provide the basic instructions for using the CPU-48/P. It contains a complete description and instructions with examples to illustrate some of the various methods that are available for employing the equipment. Only the principal procedures are presented; it is anticipated that the user will discover additional techniques as he becomes operationally familiar with the computer. While examples are not provided for all types of aircraft, the user should be aware that the same principals are applicable to all aircraft which possess similar bombing and navigation systems, e.g., B-47 (MA-7A) and early B-52 (MA-6A).

2. The following texts/sources were used to verify the methods and data outlined in this handbook:

USAF Manual 51-40

H. O. No. 9 (Bowditch), U.S. Hydrographic Office.

H. O. No. 211 (Ageton), U.S. Hydrographic Office.

H. O. No. 249, Epoch 1965.0, U.S. Hydrographic Office.

Strategic Air Command (USAF) Manual No. 55-10.

"Air Navigation", P.V.H. Weems

"An Introduction to Air Navigation" Harry C. Carver

"Mathematics of Air and Marine Navigation", A.D. Bardley

"Plans and Spherical Trigonometry", Wm. C. Brenke

"Mathematical Tables", H. B. Dwight, D. Sc.

Letter, U.S. Naval Observatory, 27 Nov. 62, Mr. E.W. Woodward

## SECTION II

## PURPOSE

1. The primary purpose of the CPU-48/P computer is to provide a rapid, accurate and reliable means of solving the bombing and navigation problems by use of a fixed radar reference when the synchronous radar method cannot be employed because of electronic or mechanical malfunctions or for any other reason. Additionally, the computer is designed to provide assistance to planners, navigators, pilots and other crew members in rapidly and accurately solving all other recognized phases of the alternate (emergency) bombing problem, including release by timing (DR), optical fixed angle, and "Last Resort" (pilot sighting from a fixed reference). Further, it affords a valuable tool in solving the navigation problem, particularly by celestial means. Finally various trigonometric and geometrical formulae required for the solution of certain additional bombing and navigation problems may be readily solved by use of the CPU-48/P computer. These include procedure turns, acceleration adjustments (Coriolis and heading/velocity wander), target timing wind/ground speed, fixed reference bombing by offset sighting, offset component computations for BNS (Synchronous) bombing and vector distance and course computations. It should be noted that a knowledge of trigonometry is not prerequisite to utilize the trigonometric scales of this computer.

## SECTION III

## GENERAL DESCRIPTION

1. The CPU-48/P is a multipurpose bombing/navigation computer. The front side will be referred to as the slide-rule side, and is essentially a series of circular slide rules, each of which is capable of producing precision computational results. The side consists of two discs, one stationary and the other rotatable, and a movable transparent arm on which has been etched a cursor hairline. Colorcoded scales are provided, with functions as described below. The front side is intended primarily for use in solving the alternate (emergency) bombing problem, but possesses numerous additional functions.
2. The reverse side, referred to as the plotting or grid side, consists of a rotatable, transparent plotting disc integral with a graduated compass rose, a fixed rectangular grid, and a movable (transparent) partial arm on which has been etched a cursor hairline. Two scales, utilized in celestial computations, are printed on the under side of the plotting face. The rectangular grid printed on the base disc, under the plotting face, is divided into equal squares, with each fifth line being accentuated. Various scales and a fixed compass rose are provided on the grid and will be described subsequently. The primary purpose of the grid side is to provide accurate celestial navigation computations and plotting solutions.

## SECTION IV

## IDENTIFICATION OF THE SLIDE RULE SCALES (Figure 1)

1. ALTITUDE, RANGE, (1000 ft.). This YELLOW (outermost) scale on the fixed disc, referred to as the ALTITUDE scale, is used in solving various problems involving altitude or range in feet. It has a direct relationship with the white RANGE NM scale immediately below which makes it possible to obtain simultaneous readouts in terms of both feet and nautical miles (1,000 feet=.16458 NM). It is a repeated logarithmic scale and is calibrated in feet. The indicated increments may be divided or multiplied as desired in increments of 10; for example, the number 10, which normally represents 10,000 feet, may also be used to represent such values as 100 feet, 100,000 feet, etc.
2. RANGE, NM. This WHITE scale, located on the fixed disc immediately inside the altitude scale, is a repeated logarithmic scale and is calibrated in nautical mile increments. It is used in solving various dead reckoning problems involving distance, speed and horizontal range, being functionally similar to the MILES scale of the MB-4A type computer. It is also used in solving mathematical and trigonometric formulae. It bears a direct relationship with the altitude scale directly above (1NM = 6,076 feet), which makes it possible to obtain simultaneous readouts in terms of both feet and nautical miles. The indicated increments may be divided or multiplied as required in increments of 10; for example, the number 10, which normally represents

10 nautical miles, may also be used to represent such values as 1 NM, 100 NM, etc. Pertinent symbols on this scale include the following:

- a. W/C arrow (26.25), used in Wander and Coriolis computations.
- b. "P" arrow (95), used in computing procedure turns.
- c.  $\pi$  (3.1416), used in geometric solutions involving area, radius, etc.
- d.  $2\pi$ (6.283), used in geometric solutions involving area, radius, etc.
- e.  $\textcircled{10}$ , used in multiplication and division (arithmetical) functions.

3. TIME. This WHITE (outermost) scale on the rotatable disc is logarithmically calibrated in time increments and is used in solving various dead reckoning problems, being functionally similar to the MINUTES scale of the MB-4A type computer. The primary differences from the MB-4A are that the CPU-48/P Scale is not continuous and that hours are not indicated. The indicated increments of 2 thru 20 may be divided or multiplied as required in increments of 10; for example, the number 10, which normally represents 10 minutes, may also be used to represent such values as 1 minute, 100 minutes, etc. The scale may also be used to represent seconds, as desired or required; additionally, it may be used in solving various mathematical and trigonometric formulae. Pertinent symbols on this scale include the following:

- a. SEC arrow (3.6). Used in time computations involving seconds.
- b. Speed arrow (6.0). Used in time computations involving minutes.
- c. "8" arrow. Used in procedure turn computations.
- d.  $\textcircled{10}$  used in multiplication and division (arithmetical) functions.

4. COSINE. This GREEN (outermost) scale on the rotatable disc is a pure cosine scale, calibrated in degrees from  $0^\circ$  (RANGE arrow) counter-clockwise to  $83^\circ$ . It is used in solving the radar fixed angle problem as well as in various other trigonometric problems involving the cosine function. The scale may be also adapted to solving formulae involving the secant function.

5. COTANGENT. This YELLOW (innermost) scale on the rotatable disc is a pure cotangent scale, calibrated in degrees from  $5^\circ$  counterclockwise to  $83^\circ$ . The value  $45^\circ$  is represented by the RANGE arrow. The scale is used in solving the Last Resort, optical and radar fixed angle bombing problems as well as in various other trigonometric problems involving the cotangent function. It may also be adapted for use in solving trigonometric problems involving the tangent function by computing and using the co-degree ( $90^\circ$  minus the desired degree value).



6. SINE. This BLUE (intermediate) scale on the rotatable disc is a pure sine scale, calibrated in degrees from  $0.6^\circ$  clockwise to  $90^\circ$  (RANGE arrow). It is used in solving the computation of the "Wander" and "Coriolis" adjustment problems and may also be used in solving various other trigonometric problems involving the sine function. That portion of the sine scale from  $0.6^\circ$  to  $7^\circ$  may be adapted for use in solving the cosing and cotangent functions for values of  $0.6^\circ$  thru  $5^\circ$  and  $83^\circ$  thru  $89.4^\circ$  and for tangent functions for increments from  $0.6^\circ$  to  $7^\circ$  and from  $85^\circ$  thru  $89.4^\circ$  with no appreciable loss of accuracy. The scale may also be adapted to solving formulae involving the cosecant function.

7. Last Resort (B-47 in GREEN and B-52 in YELLOW). These scales and curves, located within the inner perimeter, are designed to permit a simple one-step solution of the Last Resort (visual sighting angle for B-47 and B-52 Aircraft. The entering arguments are pressure altitude (scales calibrated in 2,000' increments), Mach (.05 increments) and gross weight (10,000 pound increments for B-47, 20,000 pound increments for B-52). The solution is read on the applicable sighting angle scale (calibrated in  $.5^\circ$  increments).

8. RANGE Arrow. Used in computing ranges and in various other trigonometrical computations. It represents  $0^\circ$  on the cosine scale,  $45^\circ$  on the cotangent/tangent scales and  $90^\circ$  on the sine scale.

9. Transparent Cursor Arm. A rotatable arm on which is etched a hairline cursor; it is used to facilitate precision alignment of the various scales. Normally, the cursor arm will retain its position against the outer disc when the inner disc is rotated under it; should there be any tendency to movement, the cursor should be held in position with one hand while rotating the inner disc with the other hand.

## SECTION V

### INSTRUCTIONS FOR CIRCULAR SLIDE RULE SIDE

1. Dead Reckoning (DR). All DR (time/distance) problems may be solved quickly and accurately on the CPU-48/P. The method of solution is basically similar to that employed on the MB-4A type computer and will be readily apparent to the user. The (black) arrow at 6.0 is the familiar "Speed" arrow and should be used when time increments of minutes are involved; the small black arrow at 3.6 is the "SEC" arrow and should be used when time increments of seconds are involved.

a. Example #1:

(1) Given: Ground Speed (GS) = 582 knots; time = 53 minutes.

(2) Find: Distance traveled.

(3) Solution: Set speed arrow to 582; read distance = 514 NM on the RANGE NM scale above 53 on the TIME scale.

b. Example #2:

(1) Given: Distance traveled = 514 NM; time = 53 minutes

(2) Find: Ground Speed in knots (GSK).

(3) Solution: Set 53 on the TIME scale under 514 on the RANGE NM scale; read GSK = 582 knots on the RANGE NM scale above the speed arrow.

c. Example #3:

(1) Given: Ground Speed = 349 knots; distance to go = 15NM.

(2) Find: Time to go in seconds.

(3) Solution: Set SEC arrow to 349; read time = 155" on the TIME scale under 15 on the RANGE NM scale.

2. Multiplication and Division.

a. Multiplication and Division.

(1) Required: Multiply 97 by 6.5

(2) Solution: Set 10 on the TIME scale under 97 on the RANGE NM scale; read the product, 630.5 on the RANGE NM scale above 65 on the TIME scale.

b. Division Example.

(1) Required: Divide 630.5 by 6.5

(2) Solution: Set 6.5 on the TIME scale under 630.5 on the RANGE NM scale; read the quotient, 97 on the RANGE NM scale over 10 on the TIME scale.

3. Feet/Nautical Miles Conversion.

a. To convert feet to nautical miles (NM), set the cursor over thousands of feet on the yellow ALTITUDE scale; read NM under the cursor on the white RANGE NM scale. Reverse procedure to convert nautical miles to feet. Example: 6.33 NM = 38,500 feet.

b. To convert knots to feet per second (fps), set the SEC arrow to the desired knots value on the RANGE NM scale; place the cursor over 10 on the TIME scale; read fps under the cursor on the ALTITUDE scale. Example: 510 knots = 861 fps. Nautical miles per second (NMS) is read under the cursor on the RANGE NM scale (.142 NMS in this example). To find the trail equivalent for a given speed the time condition (as may be required in determining the Q/DBW adjustment), set the SEC arrow to the true air speed in knots on the RANGE NM scale; place the cursor over the time value in seconds (ATF) on the TIME scale; read the equivalent trail value under the cursor (in feet on the ALTITUDE scale or in NM on the RANGE NM scale). Example: 510 knots @ 3.25 seconds = .46 NM or 2,800 feet.

NOTE: All references and primary solutions in the instructions which follow will be in terms of nautical miles, using the RANGE NM scale. Trail in feet should normally be converted to NM by this method when using these solutions, unless the computation is specifically desired or required to be in feet (in which case the reading in feet may be obtained by setting the cursor over the NM reading on the RANGE NM scale and reading the solution in thousands of feet under the cursor on the ALTITUDE scale.)

#### 4. Alternate (Emergency) Bombing Problem Solutions (Direct Sighting).

a. General. The CPU-48/P computer is capable of providing highly accurate solutions to the various alternate bombing problems, including Last Resort (pilot sighting), optical fixed angle, radar fixed reference (to be referred to hereafter as radar fixed angle) and timing from a pre-selected reference point to release. Wherever possible, the basic problem should be precomputed prior to the initiation of the bomb run and refined as close as practicable to release.

b. Ground Speed Determination. In those cases where the synchronous features of the BNS (bombing and navigation system) are lost and DOPPLER is inoperative or not available, it may be necessary to compute ground speed by optical or radar timing in order to insure the accomplishment of accurate non-synchronous bombing. The computation may be accomplished on either the slide rule or the plotting side. If the selected timing point is not on track, the target timing procedure, utilizing the plotting side computation (Section VII, Paragraph 2), is preferred; however, the slide rule side may, if desired, be used in such event by using the offset correction procedure described in Paragraph 5 below. If the selected timing point is essentially on track, the slide rule side may be used as follows:

(1) Accurately time the apparent travel of the point (in seconds) between two optical fixed angles or radar fixed range marks (FRM). At high or medium bombing altitudes, the target or

aiming point may and should be used for this purpose on the bomb run unless briefed pre-release maneuvers preclude maintaining a "straight-in" track; in the latter event, determine ground speed prior to the maneuvers. If possible, try to have the aircraft on, or very nearly on, the same track during the timing sequence as is planned for the bomb run.

(2) Compute horizontal range (HR) traveled during the timing period and ground speed as follows:

(a) Fixed Optical Sighting Angle ( $SA^\circ$ ) Method.

1. Set the cursor over the altitude above the sighting point (in thousands of feet) on the yellow ALTITUDE scale.

2. Holding the Cursor Arm firmly in place against the outer disc (HINT: Push arm toward you from rear of computer, exerting pressure on partial arm; release when disc is positioned), rotate the inner disc until the first sighting angle used in the timing sequence is under the cursor on the Yellow TANGENT scale. Read and record HR in NM opposite the RANGE arrow. SUGGESTION: This procedure of determining HR may also be used to facilitate accurate visual navigation.

3. Repeat process for the second sighting angle.

4. Subtract Step 3 from Step 2 ( $HR_1 - HR_2$ ); remainder is distance traveled during the timing period. NOTE: If the second sighting angle is a negative value (behind the aircraft)  $HR_2$  must be added to  $HR_1$ .

5. Set time in seconds (recorded at the end of the timing period) on the TIME scale against distance traveled in NM on the RANGE NM scale; read GSK on the RANGE NM scale above the SEC arrow.

6. Example

a. Given: 1st  $SA^\circ = 70^\circ$ ; 2nd  $SA^\circ = 45^\circ$ ;  
altitude above sighting point = 39,400'; time = 75 seconds.

b. Solution:  $HR_1 = 17.8$  NM;  $HR_2 = 6.5$  NM;  
 $HR_1 - HR_2 = 11.3$  NM; Set 75 on the TIME scale under 11.3 on the RANGE NM scale; read GS = 540 knots on the RANGE NM scale opposite the SEC arrow.

(b) Radar Fixed Angle Method.

1. Set the RANGE arrow to the first indicated fixed range mark (FRM) value on the RANGE NM scale. For ASQ-38, set

the RANGE arrow to the adjusted FRM value, if known; if this value is unknown, subtract .2 NM from indicated FRM value, e.g., if the indicated FRM value is 20 NM, set RANGE arrow to 19.8 NM.

2. Set the cursor over the altitude above the sighting point (in thousands of feet) on the yellow ALTITUDE scale; note the degree value under the cursor on the green COSINE scale.

3. Holding the cursor firmly in place against the outer disc, rotate the inner disc until the degree value noted on the COSINE scale appears under the cursor on the yellow COTANGENT scale.

4. Read and record HR in nautical miles opposite the RANGE arrow. NOTE: If the degree value on the green COSINE scale is greater than  $83^\circ$ , assume slant range (SR) equals horizontal (ground) range (HR); this will usually occur most frequently at low flight altitudes and/or when using large FRM values.

5. Repeat process for second FRM.

6. Subtract Step 5 from Step 4 ( $HR_1 - HR_2$ ); remainder is distance traveled during timing period. NOTE: If the second FRM used in the timing sequence is behind the aircraft, you must add  $HR_1$  to  $HR_2$ .

7. On the CPU-48/p, set time in seconds on time SCALE under distance in NM (Step 6); on RANGE scale; read GSK on the RANGE NM scale opposite the SEC arrow.

8. Example

a. Given: ASQ-38 BNS (FRM error unknown);  
1st FRM = 60NM (assume 59.8 NM adjusted value); 2nd FRM = 20NM  
(assume 19.8 NM adjusted value); altitude above target = 39,400';  
from 1st to 2nd FRM is 273°;

b. Solution:  $HR_1 = 59.8$  NM; (COSINE degree value is greater than  $83^\circ$ );  $HR_2 = 18.8$  NM (COSINE reading =  $71^\circ$ );  $HR_1 - HR_2 = 41.0$  NM; GS = 540 K.

c. Radar Fixed Angle Bombing (Direct).

(1) Set RANGE arrow to the desired FRM (from which the release timing sequence is to be initiated). For ASQ-38 BNS, set RANGE arrow to the adjusted FRM value (subtract .2 NM from the indicated value if the FRM error is unknown).

(2) Set the Cursor over the altitude above target (in thousands of feet) on the yellow ALTITUDE scale. Note the degree value under the cursor on the green COSINE scale.

(3) Holding the cursor firmly in place against the outer disc, rotate the inner disc until the degree value noted on the green COSINE scale is under the cursor on the yellow COTANGENT scale.

(4) Read HR in nautical miles opposite the RANGE arrow.

(5) Add trail in NM. Sum is  $HR_t$ . NOTE: This step may be performed mathematically or directly upon the CPU-48/P computer by increasing HR an amount equal to trail, using the cursor to assist the counting process; retain the cursor over  $HR_t$ .

(6) Set the SEC arrow under best known ground speed in knots.

(7) Read Time-to-Impact (TI) in seconds on the TIME scale beneath  $HR_t$  (under the cursor) on the RANGE NM scale.

(8) Subtract AIF in seconds to get Time-to-Release (TTR) in seconds (from the instant of target/FRM coincidence).

(9) Example

(a) Given: ASQ-38 BNS; ATF = 56.7"; Trail = 15,200'; GS = 540 K; Release Altitude = 39,400' above target; FRM = 10NM (assume 9.8 NM adjusted value).

(b) Solution: Trail = 2.5 NM; COSINE reading = 48.75°; HR = 7.4 NM;  $HR_t = 7.4 + 2.5 = 9.9$  NM; TI = 66"; TTR = 66 - 56.7 = 9.3".

d. Last Resort (Pilot) Bombing - Direct Sighting. (B-47/52).

(1) Compute Last Resort Sighting Angle ( $SA^\circ$ ). This is a one-step computation. Choosing applicable scale (B-47 or B-52), set the center line so that pressure altitude scale (along lower center line) and Mach number curve intersect; interpolate visually to desired accuracy. Maintaining setting, read sighting angle on S.A. scale (along upper center line) over bomb run gross weight curve; interpolate visually to desired accuracy (tick marks furnished each .5°, making interpolation possible to accuracy of .25° or better.)

(2) Find HR and  $HR_t$ .

(a) Place the cursor over release altitude above target in thousands of feet on the yellow ALTITUDE scale.

(b) Rotate the inner disc (holding cursor firmly in place against outer disc) until the Last Resort  $SA^\circ$  appears under the cursor on the yellow COTANGENT scale.

(c) Read HR in NM on the RANGE NM scale opposite the RANGE arrow. This is the horizontal range subtended by the Last

Resort sighting angle at bombing altitude (this procedure may be used to facilitate accurate visual navigation, if desired).

(d) Add trail in NM.  $S_{\text{up}}$  is  $HR_t$ . NOTE: This step may be performed mathematically or directly upon the CPU-48/P computer by increasing HR an amount equal to trail, using the cursor to assist the counting process; retain the cursor over  $HR_t$ .

(3) Find TI and TTR: Same as for radar fixed angle method above.

(4) Example

(a) Given: B-52 airplane; pressure altitude = 42,500'; Mach = 0.82; gross weight = 287,000 pounds; ATF = 56.7"; Trail = 15,200'; GS = 540 K; release altitude above target = 39,400'.

(b) Solution:  $SA^\circ = 65.8^\circ$ ; HR = 14.4 NM; Trail = 2.5NM;  $HR_t = 14.4 + 2.5 = 16.9$  NM; TI = 113"; TTR = 113 - 56.7 = 56.3".

e. Optical Fixed Angle Bombing (Direct Sighting, Standard Method).

(1) Determine Whole Range (WR). Set the SEC arrow to best known ground speed in knots. Read Whole Range (WR) in NM on the RANGE NM scale over ATF in seconds. (If Whole Range (WR) in feet is desired set cursor over ATF on the time scale and read WR in feet under cursor on ALTITUDE scale).

(2) Determine Actual Range (AR). Subtract trail from WR ( $AR=WR-L$ ) in NM. NOTE: This step may be performed mathematically or directly upon the computer by decreasing WR an amount equal to trail, using the cursor to assist the counting process; retain cursor over AR.

(3) Determine Dropping Angle ( $DA^\circ$ ).

(a) Set the RANGE Arrow to AR in NM on the RANGE NM scale.

(b) Holding the inner disc firmly in position, set the cursor over altitude above target on the yellow ALTITUDE scale. Read  $DA^\circ$  on the yellow COTANGENT scale under the cursor.

(4) Example

(a) Given: ATF = 56.7"; Trail = 15,200'; GS = 540 K; release altitude above target = 39,400'.

(b) Solution: Trail = 2.5 NM; WR = 8.5 NM; AR = 8.5 - 2.5 = 6.0 NM;  $DA^\circ = 42.8^\circ$ .

## f. Optical Fixed Angle Bombing (Direct Sighting, TTR Method).

(1) General. It may sometimes be advantageous to determine the release point optically by the time-to-release (TTR) method. The principle is identical to the Last Resort method, i.e., a timing sequence is initiated from a fixed sighting angle of greater value than the actual dropping angle. The primary advantage of this technique is that neither the actual range nor the dropping angle need be re-computed should the bomb-run ground speed change significantly from the planned ground speed. Additionally, it permits an excellent in-flight cross-check to be made on the accuracy of the Last Resort method.

## (2) Methods.

(a) 45° Method. In most instances, the dropping angle will be found to be less than 45°. An angle of 45° subtends a horizontal range equal to altitude above the sighting point. Thus, HR = bombing altitude. To compute TTR from the 45° sighting angle, simply add trail in feet to the release altitude above the sighting point; convert to HR in nautical miles on the CPU-48/P computer. To use the method in flight, preset 45.0° into the optics and initiate the timing sequence when the optical reticle (rate hair) and the target are coincident. Release the bomb at termination of TTR as determined on the CPU-48/P computer, using the best known ground speed. The 45° method will provide adequate accuracy for most optical fixed angle releases and is both flexible and readily computable on short notice. Example: Release altitude above target = 48,000'; trail = 28,000'; ATF = 75°; GS = 450K; HR = 48,000';  $HR_t = 48,000' + 28,000' = 76,000' = 12.5 \text{ NM}$ ; TI from 45° = 100" (computed on CPU-48/P); TTR from 45° = 100" = 75" = 25".

(b) Optical/Last Resort Method. Preset optics to the same sighting angle as computed for Last Resort. Optical TTR will be identical to the Last Resort TTR.

(c) Additional TTR Methods. Should, for any reason, a sighting angle other than 45° or the Last Resort sighting angle be desired or required, the following sighting angles provide a simple solution of HR in nautical miles (these may be memorized or recorded, or may be recalled when desired on the CPU-48/P

1. 31.3°. Sighting altitude in thousands of feet divided by ten = HR in NM (Example: If altitude above the sighting point is 32,000 feet, HR, or horizontal distance from point, is 3.2NM).

2. 50.5°. Twice the sighting altitude in thousands of feet divided by ten = HR in NM (Example: If altitude above the sighting point is 32,000 feet, HR is 6.4 NM).

3. 80.7°. Sighting altitude in thousands of feet = HR in NM (Example: If altitude above the sighting point is 32,000 feet, HR is 32NM).



## g. Low Altitude Fixed Angle Optical Bombing.

(1) General. The procedure for determining the optical dropping angle for very low altitude bombing is similar to that used in high altitude bombing. In some instances, however, the dropping angle may be greater than can be accommodated on the yellow COTANGENT scale (i.e., in excess of  $83^\circ$ ). In such event, the degree values on the Blue SINE scale may be used to determine the dropping angle without appreciable loss of accuracy. Convert the degree value as read from the Blue SINE scale to a dropping angle by subtracting the indicated value from  $90^\circ$ . NOTE: When using the periscopic sextant to determine the release point at very low bombing altitudes, use the value as read directly from the Blue SINE scale to preset as a depression angle (negative value) into the sextant; if the depression angle exceeds  $7^\circ$ , use the yellow COTANGENT scale for slightly increased accuracy, converting the indicated COTANGENT degree value to a depression angle by subtracting this value from  $90^\circ$ . CAUTION: Because of the relatively large ranging error which results from even minor computational errors or failures to maintain altitude when releasing free fall bombs at very low levels, use extreme care in both computing the dropping angle and in bomb run execution.

## (2) Example:

(a) Given: ATF = 4.1"; Trail = 140 feet; GS = 494 Knots; bombing altitude = 340 feet above target.

(b) Solution: Trail = .023 NM; WR = .563 NM; AR = .563 - .023 = .54 NM; DA $^\circ$  =  $83.9^\circ$ . NOTE: Set cursor over 35 on the yellow ALTITUDE scale; set RANGE arrow to 54; read depression angle =  $6.1^\circ$  on Blue SINE scale; DA $^\circ$  =  $90^\circ - 6.1^\circ = 83.9^\circ$ .

5. Alternate (Emergency) Bombing Problem Solution (Offset Sighting),

a. General. In many instances, it is possible to improve alternate (emergency) bombing accuracy by making use of an offset aiming point (OAP), particularly when the target is a "No Show" type. If a usable OAP can be found on or very near the planned inbound track (or extension of that track), the adjustment to the basic sighting/timing data is relatively simple. Should, however, the offset point be located an appreciable distance off-track, an additional correction may be required: this correction can be computed quickly and accurately on the CPU-48/P. The relative bearing (RB) of the OAP from the airplane at release may also be computed on the CPU-48/P.

b. Computation. Select an OAP (of suitable radar and/or visual significance) on or near the planned inbound track (or extension of this track). Measure and record the range offset component (RO), i.e., the range distance (over or short) that the OAP is from the target (parallel to the planned track) in NM. If the OAP is an appreciable distance right or left of the planned true course, compute an additional range adjustment as outlined below. Compute TTR or DA<sup>0</sup> and release RB as follows:

(1) Radar Fixed Angle/Last Resort.

(a) Measure and record the OAP/course offset, CO, in NM, i.e., the perpendicular distance that the OAP is off-course (left or right). NOTE: This distance can in no case be greater than HR and should preferably be considerably less.

(b) Compute HR on the CPU-48/P (as previously described)

(c) Compute HR<sub>c</sub> on the CPU-48/P.

1. Set the RANGE arrow to HR

2. Set cursor over CO in NM on the RANGE NM scale.

3. Note the corresponding degree value under the cursor on the green COSINE scale. Read and record RBO of OAP from airplane track at final sighting on Blue SINE scale.

4. Holding the cursor firmly in place against the outer disc, rotate the inner disc until the degree value noted on the green COSINE scale (previous step) is under the cursor on the Yellow COTANGENT scale.

5. Read and record HR<sub>c</sub> (i.e., HR adjusted for the offcourse sighting), on the RANGE NM scale above the RANGE arrow.

(d) Apply RO algebraically to HR<sub>c</sub> to determine OHR (i.e., off-set horizontal range). RULE: If OAP is short of target, add RO to HR<sub>c</sub>. Subtract if OAP is beyond target.

(e) Add Trail in NM. Sum is OHR<sub>t</sub> (i.e., offset horizontal range adjusted for Trail).

(f) Compute TTR in seconds on the CPU-48/P as previously described, substituting OHR<sub>t</sub> for HR<sub>t</sub>.

(g) Complete OAP/RB computation:

1.  $RB^{\circ}$  is right if OAP is right of course;  $RB^{\circ}$  is left if OAP is left of course. This is the relative bearing from true course, as determined in Step 5b(1)(c) above; drift correction must be added or subtracted to obtain RB from the heading mark (radar fixed angle), or aircraft longitudinal axis (Last Resort).

2. If OAP is to left, subtract minus drift correction, add plus drift correction. If OAP is to right, add minus drift correction, subtract plus drift corrections. Resulting figure is  $RB^{\circ}$  from aircraft heading. For radar fixed angle bombing, set the rotatable cursor (on the radar scope) to this value; OAP should intersect the cursor and FRM at final sighting (at start of timing sequence).

(h) Example:

1. Given: B-47 airplane (MA-7A BNS); ATF = 66"; Trail = 22,500' (3.7 NM); GS = 400 K; pressure altitude = 42,300'; release altitude above OAP = 40,300'; Mach = .81; GW = 125,000 pounds; drift correction = +2° (airplane is drifting left, crabbing to right); OAP is 7.9 NM over (this is RO) and 3.9 NM to the left (this is CO). Find TTR from the 15NM FRM/OAP coincidence and from the Last Resort sighting of the OAP; find RB for both modes. (CAUTION: The 1st 5 NM FRM will not be displayed on the radar scope at this altitude).

2. Radar Fixed Angle Solution : COSINE  
 reading = 63.9°; HR = 13.5 NM; HR<sub>C</sub> = 13.0 NM; OHR = 13.0 - 7.9 = 5.1 NM;  
 OHR<sub>T</sub> = 5.1 + 3.7 = 8.8 NM; TI = 79.2"; TTR = 79.2 - 66 = 13.2"; RB to  
 OAP = 17° left of track; RB from heading marker = 17° + 2° = 19° (left).

3. Last Resort Solution : SA° =  
 73.8°; HR = 22.9 NM; HR<sub>C</sub> = 22.6 NM; OHR = 22.6 - 7.9 = 14.7 NM; OHR<sub>T</sub> =  
 14.7 + 3.7 = 18.4 NM; TI = 165.5 "; TTR = 165.5 - 66 = 99.5"; RB from  
 track = 10° (left); RB from aircraft longitudinal axis = 10° + 2° =  
 12° (left).

(2) Optical Fixed Angle (Standard Method).

(a) Measure and record OAP/course perpendicular distance in NM (CO), i.e., the distance that OAP is off track (left or right), and range offset (RO) in NM, i.e., the range distance (over or short) that the OAP is from the target (parallel to track).

(b) Compute Actual Range (AR) as previously described.

(c) Apply RO algebraically to AR; resulting figure is OAR (offset Actual Range). RULE: If OAP is short of target, subtract RO from AR; if OAP is beyond (over) target, add RO to AR. NOTE: If RO is more than AR distance short of target, the dropping angle will necessarily be a negative value (behind the aircraft).

(d) Compute OAR (Offset Actual Range adjusted for off-course sighting).

1. Set RANGE arrow to OAR in NM on RANGE NM scale.
2. Set cursor over CO in NM on RANGE NM scale.
3. Note degree value under cursor on yellow

COTANGENT scale.

4. Holding cursor firmly in place against outer disc, rotate the inner disc until the degree value noted on the yellow COTANGENT scale, appears under the cursor on the green COSINE scale. Read and record  $OAR_C$ , on the RANGE NM scale opposite the RANGE arrow.

(e) Compute Offset Dropping Angle ( $ODA^\circ$ ).

1. Set RANGE arrow to  $OAR_C$ ; set cursor over altitude above OAP in thousands of feet on the yellow ALTITUDE scale.
2. Read  $ODA^\circ$  under cursor on the yellow COTANGENT scale. REMEMBER: IF RO is more than AR distance short of target, the  $ODA^\circ$  will be behind the aircraft (negative value).

(f) Compute RB. Same procedures as for Last Resort and Radar Fixed Angle, above, substituting  $OAR_C$  for HR.

(g) Example ;

1. Given: ATF = 56.7"; Trail = 15,200' (2.5 NM); GS = 540 K; release altitude above OAP = 40,000'; Drift Correction =  $-9^\circ$  (airplane is drifting to right, crabbing to left, i.e., is decreasing heading); OAP is 7.9 NM over (this is RO) and 3.9 NM to the left (this is CO) of the extended track. Find  $ODA^\circ$  and RB at release.

2. Solution: WR = 8.5 NM; AR = 6.0 NM; OAR = 6.0 + 7.9 = 13.9 NM;  $OAR_C$  = 14.4 NM;  $ODA^\circ$  =  $65.5^\circ$ ; RB from Track =  $16^\circ$  (left); RB from airplane heading =  $15^\circ - 9^\circ = 7^\circ$  (left).

(3) Optical Fixed Angle (TR Method). Solution is same as for Last Resort, Paragraph 4d(2) above, substituting the desired  $SA^\circ$  for the Last Resort  $SA^\circ$ .

#### 6. Variable Range Mark (VRM) Non-Synchronous Bombing.

a. Because of malfunction of the automatic drive feature of the variable range mark (VRM), it may not be possible to operate the BNS in the synchronous mode. Occasionally, the VRM may still be capable of being displayed on the radar scope and may be set to a desired value through operation of the range dials or through the fixed angle feature of the optics. If the altitude tie-in has not malfunctioned, the display

will remain a ~~true~~ ground presentation; in such event, the VRM may be set to the computed actual range value through manipulation of the range dials; or the dropping angle may be set into the optics, which will provide a ground range value display of VRM equal to AR. The requisite computations have been previously described in the discussion on optical fixed angle bombing. For offset bombing, set the offset actual range or offset dropping angle (ODA<sup>o</sup>). RESTRICTION: Because of the criticality of the ground range to slant range conversion when very short actual ranges are involved, the method described in this paragraph should not be attempted when AR or OAR is less than approximately one-half of the altitude; otherwise, serious ranging errors may result.

b. If the altitude feed-in to the BNS has malfunctioned, the VRM will revert to a slant range function (same as the FRMs). In such event, it will be necessary to either set the dropping angle (DA<sup>o</sup>) or offset dropping angle (ODA<sup>o</sup>) into the optics, or to convert actual range to a slant range value in order to set the VRM correctly. This is essentially a reversal of the method previously discussed in paragraph 5 above, and may be computed on the CPU-48/P as follows (first two steps are same as for optical fixed angle method):

(1) Set RANGE arrow to AR (or OAR if accomplishing offset bombing) in NM on the RANGE NM scale.

(2) Set the cursor over release altitude above the aiming point (in thousands of feet) on the yellow altitude scale.

(3) Note the degree value (DA<sup>o</sup>) under the cursor on the yellow COTANGENT scale.

(4) Holding the cursor firmly in place against the outer disc, rotate the inner disc until the degree value noted above is under the cursor on the green COSINE scale. Read SR (slant range) in NM on the RANGE NM scale opposite the RANGE arrow. NOTE: For ASQ-38 BNS, add the FRM error, if known (if unknown, add .2NM) to the indicated slant range value.

(5) Example; NOTE: Range and dropping angle data as computed for the optical fixed angle method may be used for the fixed VRM method):

(a) Given: ASQ-38 BNS; FRM error = .2 NM; ATF = 56.7"; Trail = 15,200'; GS = 540 K; release altitude above target = 39,400'. Find release slant range and dropping angle.

(b) Solution: Trail = 2.5 NM; AR = 6.0 NM; release slant range = 8.8 NM; release slant range (adjusted for ASQ-38 BNS) = 8.8 + 0.2 = 9.0 NM; DA<sup>o</sup> = 42.8<sup>o</sup>.

#### 7. Timing Runs, (Trail-Plot Method).

a. This procedure permits a relatively simple way of determining the release point when release must be made by pure dead reckoning (DR), i.e., all BNS equipment has malfunctioned and Last Resort cannot be

accomplished because of visibility conditions in the target area. The main advantage of the system is that actual range (AR) need not be computed nor plotted at any time; further, the basic ETA to the release point can be quickly and accurately refined whenever new fixing information is procured prior to release.

b. Procedure.

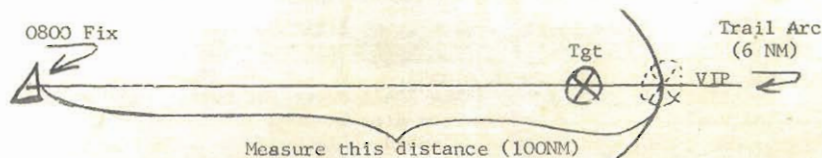
(1) Preflight. On the bomb run chart, inscribe an arc trail distance in NM beyond the target. This trail arc should extend approximately  $60^{\circ}$  on either side of the extended track.

(2) Inflight. Extend the best known track through the target to the trail arc. The intersection of track and the trail arc is the virtual impact point (VIP).

(3) Compute ETA from last known position to <sup>THE</sup> VIP.

(4) Subtract ATF; remainder is ETA to release. Update this ETA if and when new fixing and/or ground speed data is obtained prior to release.

c. Illustration: Trail Plot Method (not to scale):



Trail = 36,500' (6NM); ATF = 80" (1'20"); GS = 480K  
 Distance to VIP at 0800 fix = 100NM; Time = 12½'  
 ETA to VIP = 0812:30  
 Less ATF - 1:20  
 ETA to Release = 0811:10

d. Timing Initiation Point (TIP). If a TIP can be located short of the release point and on or very near track, a refinement of the above procedure is possible. In such event, plan to fly directly over the TIP (if possible); determine the moment of overflight by optical means ( $SA^{\circ} = 0^{\circ}$ ), if equipment and visibility permit, and initiate the timing sequence. If a TIP cannot be found on or near track and/or if non-optical sighting methods are necessary, treat the TIP as a long range OAP and compute the TTR by one or more of the procedures discussed in paragraph 5 above. NOTE: (highway, river, railroad, etc.) which intersects track at approximately  $90^{\circ}$  may be considered.

### 8. Crosstrail Computation (Non-Synchronous Bombing).

a. Set RANGE arrow to trail in NM on RANGE NM scale (or set to Trail in feet on ALTITUDE scale, using cursor to assist alignment).

b. Read crosstrail in NM on the RANGE NM scale (or cross trail in feet on ALTITUDE scale) above drift correction in degrees on the **Blue** SINE scale. Adjust aiming into the direction of the cross-wind (move aircraft same direction as drift correction, or crab, i.e., aim left if sign of drift correction is minus).

c. Example:

(1) Given: Trail = 15,200'. (2.5NM); drift correction =  $-9^{\circ}$  (airplane is crabbing to the left).

(2) Solution: Crosstrail aiming adjustment = .39 NM (2,370') to the left.

(BNS Precomputation form in blank, Figure 17.)

### 9. Procedure Turn Computation (Time/Distance Back, Time Saved).

a. General. In order to roll out precisely on the desired track, it is necessary to begin the turn short of the plotted turn point. This may be computed in terms of either time or distance, as preferred. The advantage of using the time computation is that it is not necessary to know or apply ground speed -- time back will always be the same, regardless of ground speed, for any given turn type (number of minutes required to turn  $360^{\circ}$ ) and degree of turn. Time gained in executing the procedure turn can also be computed; this computation is also independent of ground speed. Distance back, if desired, can be found by converting time to distance on the **CFU-48/P** utilizing computed time back and best known ground speed. In those cases where the plotted turn point is to be made good (overflow), the computation described below may be used to determine the amount of displacement from the plotted track (after rollout) and the time lost by this procedure.

b. Procedure.

(1) Set 10 under the "P" arrow (at 95 on the RANGE NM scale.)

(2) Place the cursor over procedure turn type (number of minutes required for  $360^{\circ}$  turn) on the TIME scale. Time back in seconds for a  $90^{\circ}$  turn can be read on the RANGE NM scale under the cursor.

(3) Holding cursor firmly in place against the outer disc rotate inner disc until the RANGE arrow is under the cursor. The RANGE arrow represents a  $90^{\circ}$  turn. For turns other than  $90^{\circ}$ , utilize the **Yellow** COTANGENT scale as follows:

(a) Let the RANGE arrow represent a  $90^\circ$  turn.

(b) Let each degree increment on the yellow COTANGENT scale be equal to two degrees of turn. Turns of less than  $90^\circ$  are to the left of the RANGE arrow in decreasing order from  $90^\circ$  (increasing order on the COTANGENT Scale). Turns greater than  $90^\circ$  are to the right of the RANGE arrow in increasing order from  $90^\circ$  (decreasing order on the COTANGENT SCALE). For example:  $80^\circ$  turn =  $50^\circ$  on the COTANGENT scale;  $70^\circ$  turn =  $55^\circ$  on the COTANGENT scale;  $100^\circ$  turn =  $40^\circ$  on the COTANGENT scale, etc.

(4) Set the cursor over the converted turn value on the COTANGENT scale; read time back (in seconds) to start procedure turn under the cursor on the RANGE NM scale.

(5) To find time saved in the procedure turn, hold the cursor firmly against the outer disc (over the time back value determined in the previous step); rotate the inner disc until the RANGE arrow is displaced to the opposite side of the cursor by an amount equal to the converted degree value on the COTANGENT scale. For example: for a  $70^\circ$  turn ( $20^\circ$  less than  $90^\circ$  which equates to  $10^\circ$  converted value) the converted COTANGENT scale value for the time back computation is  $55^\circ$  ( $10^\circ$  left of the RANGE arrow); for the time gained computation, the converted COTANGENT scale value is  $35^\circ$  ( $10^\circ$  right of the RANGE arrow). Read time saved (in seconds) in the turn on the RANGE NM scale over "8", (small arrow) on the TDM scale. Subtract this value from the ETA to the next action point.

(6) If it is desired to find distance back, set the SEC arrow under ground speed in knots on the RANGE NM scale; read distance back in NM on the RANGE NM scale above time back in seconds on the time scale.

(7) Example:

(a) Given: Six minute procedure turn ( $1^\circ$ /second turn rate); amount of turn ( $TH_1$  to  $TH_2$ ) =  $85^\circ$ ; ground speed = 484K.

(b) Find: Time and distance back to start turn and time saved in turn.

(c) Solution: Converted COTANGENT turn value =  $47\frac{1}{2}^\circ$  (use for time back solution); displaced COTANGENT value (use for time saved solution) =  $42\frac{1}{2}^\circ$ ; time back = 52"; time saved = 20" (subtract from ETA to next action point); distance back = 7 NM.



10. TRIGONOMETRIC FUNCTIONSa. General.

Within minor limitations the natural trigonometric functions of sine, cosine, tangent and cotangent may be read directly on the CPU-48. Additionally, the natural trigonometric values of secant and cosecant may be derived from the computer, even though scales are not specifically provided for these functions. Mathematical formulae involving multiplication or division of these functions may also be solved quickly and accurately without recourse to outside aids. All of the navigational and bombing computational procedures described in this handbook make use of the trigonometric functions of the CPU-48/P even though the basic formula may not be described in all cases.

b. Natural Trigonometric Functions.

(1) For all precision computations of sine, cosine, tangent and cotangent, set the RANGE arrow to 1.0. Read the natural trigonometric value on the RANGE NM scale opposite the desired degree increment on the applicable degrees scale (inner disc). Use the cursor to assist alignment where necessary. All values to the left of the RANGE arrow are less than 1.0. All values to the right of the RANGE arrow are greater than 1.0. Thus, all sine and cosine values are less than 1.0; cotangent values for degree increments greater than  $45^\circ$  are less than 1.0; cotangent values for degree increments less than  $45^\circ$  are greater than 1.0. Tangent values for degree increments greater than  $45^\circ$  are greater than 1.0; tangent values for degree increments less than  $45^\circ$  are less than 1.0.

(2) Sine Function ( $.6^\circ - 90^\circ$ )

(a) Read the sine value on the RANGE NM scale opposite the desired degree increment on the **Blue** SINE scale.

(b) Example: Sine  $32^\circ = .788$ .

(c) Limitation: Cannot be used to obtain exact values of fractional degree increments less than  $0.6^\circ$ . To obtain a close approximation of the actual value, set 10 on the TIME scale to the one degree sine value (.01745). Read the trigonometric value on the RANGE NM scale above the fractional degree value displayed on the TIME scale. For example, the sine of  $.25^\circ = .00436$ . NOTE: The sine of  $0^\circ$  is zero (C,C).

(3) Cosine function. ( $0^\circ - 89.4^\circ$ )

(a) Read the cosine value on the RANGE NM scale opposite the desired degree increment on the green COSINE scale.

(b) Example: Cosine  $38^\circ = .788$ .

(c) Limitations: Cannot be used for direct readout of values for degree increments in excess of  $83^\circ$ . To determine values between  $83^\circ$  and  $89.4^\circ$ , first compute the co-degree ( $90^\circ$  minus the desired degree value); read the COSINE value on the RANGE NM scale

opposite the co-degree value on the **Blue SINE** scale. For example, the cosine of  $84^\circ$  is the same as the sine of  $6^\circ$ , i.e., .1045. To obtain the value for fractional degree increments greater than  $89.4^\circ$ , compute the co-degree and use the procedure described above for obtaining sine values of fractional degree increments less than 0.6. For example, the cosine of  $89.75^\circ = .00436$ . NOTE: The cosine of  $90^\circ$  is zero (0.0)

(4) Tangent Functions. ( $0.6^\circ - 89.4^\circ$ ).

(a) Compute the co-degree ( $90^\circ$  minus the desired degree value). Read the tangent value on the RANGE NM scale opposite the co-degree value on the **yellow** COTANGENT scale.

(b) Example:  $\text{Tangent } 38.25^\circ = \text{Cotangent } 51.75^\circ = .788$ .

(c) Limitations: Cannot compute exact values for degree increments less than  $7^\circ$  or greater than  $85^\circ$ . However, since sine and tangent values for degree increments less than  $7^\circ$  are virtually identical, a close approximation of the actual value for these degree values can be obtained by reading the value on the RANGE NM scale opposite the desired degree increment on the SINE scale. For example: the tangent of  $3^\circ = \text{Sine } 3^\circ = .0523$ . If the tangent values for degree increments greater than  $85^\circ$  are desired, use the following procedures; compute the co-degree ( $90^\circ$  minus the desired degree value); set the cursor over 1.0 on the RANGE NM scale; retaining the arm in position against the outer disc, rotate the inner disc until the desired co-degree value on the **Blue SINE** scale appears under the cursor; read the tangent value opposite the RANGE arrow (this will be a close approximation of the actual tangent value). For example, the tangent of  $87^\circ = 19.2$ . NOTE: The tangent of  $0^\circ$  is 0.0, the tangent of  $90^\circ$  is infinity.

(5) Cotangent function. ( $0.6^\circ - 89.4^\circ$ )

(a) Read the cotangent value on the RANGE NM scale opposite the desired degree increment on the **yellow** COTANGENT scale.

(b) Example:  $\text{Cotangent } 51.75^\circ = .788$ .

(c) Limitations: Cannot compute exact values for degree increments greater than  $83^\circ$  or less than  $5^\circ$ . However, since sine values for degree increments less than  $7^\circ$  are virtually identical to cotangent values greater than  $83^\circ$ , a close approximation of the actual cotangent values for degree increments greater than  $83^\circ$  can be obtained by computing the co-degree ( $90^\circ$  minus desired degree) and reading the trigonometric value on the RANGE NM scale opposite the co-degree increment on the **Blue SINE** scale.

For example: The cotangent of  $87^\circ = \text{Sine } 3^\circ = .0523$ . If the cotangent values for degree increments less than  $5^\circ$  are desired, use the following procedure: Set the cursor over 1.0 on the RANGE NM scale; retaining the arm in position against the outer disc, rotate the inner disc until the desired degree value on the **Blue** SINE scale appears under the cursor; read the cotangent value opposite the RANGE arrow (this will be a close approximation of the actual cotangent value). For example: the cotangent of  $3^\circ = 19.2$ . NOTE: The cotangent of  $0^\circ$  is infinity; the cotangent of  $90^\circ$  is zero (0.0).

(6) Secant Function ( $0^\circ - 89.4^\circ$ ).

(a) Set the desired degree increment on the green COSINE scale directly under 1.0 on the RANGE NM scale. Read the secant value on the RANGE NM scale opposite the RANGE arrow. All values will be greater than 1.0 (the secant value for  $0^\circ$  is 1.0). For secant values of degree increments in excess of  $83^\circ$ , compute the co-degree ( $90^\circ$  minus the desired degree) and utilize the **Blue** SINE scale, i.e., set the co-degree increment on the SINE scale under 1.0 on the RANGE NM scale (use the cursor to assist alignment) read the secant value on the RANGE NM scale opposite the RANGE arrow.

(b) EXAMPLE: Secant  $85.2^\circ = 11.95$ .

(7) Cosecant Function ( $0.6^\circ - 90^\circ$ )

(a) Set the desired degree value on the **Blue** SINE scale directly under 1.0 on the RANGE NM scale (use the cursor to assist alignment). Read the cosecant value on the RANGE NM scale opposite the RANGE arrow. All values will be greater than 1.0 (the cosecant value of  $90^\circ$  is 1.0).

(b) Natural Trigonometric Functions

c. Trigonometric Formulae

(1) General. Mathematical formulae, involving division or multiplication of trigonometric functions (sine, cosine, tangent and cotangent) may be solved directly on the CPU-48/P.

Note: The Coriolis Solution is an example. (see Section VII, paragraph 1e), the formula for which is: Coriolis Correction on NM = GSK times .02625 times Sine Latitude. For examples of some fairly complex formulae, see paragraph 13c, Great Circle Solution. REMEMBER: the RANGE arrow serves the same purpose in division and multiplication of Trigonometric functions as 10 does in arithmetical functions.

(2) Multiplication Procedures (Sine, Cosine, Tangent and Cotangent).

Set the RANGE arrow to the desired mathematical value on the RANGE NM scale. Read the product on the RANGE scale opposite the desired degree value on the appropriate trigonometric scale (inner disc). The process is the same as described in subparagraph b above, except that the Range arrow is set to the exact value of the number to be multiplied rather than to 1.0. In all cases, the product will be less than the value of the multiplier if the product is read to the left of the RANGE arrow; it will be greater than the value of the multiplier if the product is read to the right of the RANGE arrow.

## (a) Example:

1. Solve formula: Precession = 15.04 x Sine Latitude.  
(Precession is earth rate per hour; assume latitude is 37° North).

2. Solution: Set RANGE arrow to 15.04; set cursor over 37° on **Blue** SINE scale; read **P** = 9.05° per hour (under cursor on RANGE N.M. scale).

## (3) Division Procedures.

## (a) Division of a mathematical value by a trigonometric function.

1. Set the desired degree increment on the appropriate trigonometric scale (inner disc) under the desired value on the RANGE NM scale, using the cursor to assist alignment where necessary. For tangent computations, compute the co-degree and use the COTANGENT scale. Read the quotient on the RANGE NM scale opposite the RANGE arrow.

## 2. Example:

a. Solve formula:  $9.05 \div \tan 31^\circ$ .

b. Solution: Co-degree  $31^\circ = 59^\circ$ . **Set 59° on yellow** COTANGENT scale under 9.05 on RANGE NM scale; read quotient, 15.04 above RANGE arrow.

(b) Division of a trigonometric function by a mathematical value.

1. Compute the natural trigonometric function (Paragraph 9 above).

2. Place cursor over the natural trigonometric value on the RANGE NM scale. Retaining cursor in position against outer disc, rotate inner disc until divisor on TIME scale is under cursor. Read quotient on the RANGE NM scale opposite **10** on TIME scale.

## 3. Example:

a. Solve Formula: Cosine  $53^\circ \div 15.04$ .

b. Solution: Set RANGE arrow to 1.0. Place cursor over  $53^\circ$  on green COSINE scale. Holding arm firmly in place against outer disc, rotate inner disc until 15.04 on TIME scale is under cursor. Read quotient, 0.4 on RANGE NM scale opposite  $\textcircled{10}$  on TIME scale.

(4) Secant/Cosecant Functions. The procedures for multiplication and division of the secant and cosecant functions vary only slightly with those described above for sine, cosine, tangent and cotangent.

(a) Example Number 1. Find the product of secant  $47.5^\circ$ , times cotangent  $31^\circ$ .

1. Set  $47.5^\circ$  on the COSINE scale under 1.0 on the RANGE NM scale.

2. Set cursor over  $31^\circ$  on the COTANGENT scale. Read the product, 2.46, on the RANGE NM Scale under the cursor.

(b) Example Number 2. Find the quotient of cosecant  $30^\circ$  divided by 9.05.

1. Set  $30^\circ$  on the SINE scale under 1.0 on the RANGE NM scale (use cursor to assist alignment). Set cursor over RANGE arrow while retaining inner disc in position.

2. Retaining cursor in position, rotate inner disc until 9.05 on the TIME scale is under the cursor.

3. Read the quotient, .22, on the RANGE NM scale opposite  $\textcircled{10}$  on the TIME scale."

#### 11. Geometric Functions.

a. General. The constant values of  $\pi$  and  $2\pi$  are inscribed at their mathematical values of 3.1416 and 6.283, respectively, on the RANGE NM scale. These constants may be found useful in solving certain geometrical problems. For example, to find the area of a circle, we use the formula  $A = \pi r^2$ , where A is area,  $\pi = 3.1416$  and r is radius. To solve, set  $\textcircled{10}$  under  $\pi$  and place the cursor over the r value (on the TIME scale); retaining cursor in position against the outer disc, rotate inner disc until  $\textcircled{10}$  is under cursor; read A on the RANGE NM scale over the r value.

b. Example Number 1:

(1) Problem: Find the area of a circle whose diameter is 28.6 feet (remember, radius =  $\frac{1}{2}$  diameter).

(2) Solution: Radius = 14.3 feet; Area = 642 square feet.

c. Example Number 2:

(1) Problem: Find the no-wind radius of turn for an airplane flying at a true airspeed of 562 knots, executing an eight minute turn.

(2) Solution: Radius = Circumference  $\frac{v}{2\pi}$ . The circumference is the air distance the airplane will fly in eight minutes at 562 knots. Solve on CPU-48 Set speed arrow to 562; place cursor over 8 on TIME scale; holding cursor in place against outer disc, set 10 on inner disc under 277. Read no-wind radius of turn = 12 NM (under cursor on TIME scale).

12. BNS (Synchronous) Offset Component Solution.

a. Determine the difference in latitude (DIFF LAT) and longitude (DIFF LONG) between the target and the OAP (to the nearest tenth of a second of arc, 1", (if possible). Convert differences in minutes and seconds to seconds (multiply minutes by .60 and add the odd seconds).

b. Determine the approximate mid-latitude between the target and the OAP. Normally, the mid-latitude can be interpolated by estimate to sufficient accuracy so that the validity of the offset solution will not be materially affected. However, if extreme accuracy is desired, the precise mid-latitude may be found by adding one-half of DIFF LAT to the lesser of the two latitudes.

c. To find the N-S offset, set the CPU-48/P speed arrow (6.0) to DIFF LAT in seconds of arc on the RANGE NM scale; place the cursor over 10 on the TIME scale; read the N-S offset component distance in feet under the cursor on the ALTITUDE scale. (NOTE: To help determine the decimal point, remember that one second of latitude is equal to slightly more than 100 feet. If offset distance in NM is desired, read this value under the cursor on the RANGE NM scale.

d. To find the E-W offset, set the CPU-48/P speed arrow (6.0) to DIFF LONG in seconds of arc on the RANGE NM scale; place the cursor over 10 on the TIME scale. Retain the cursor in position against the outer disc, rotate the inner disc until the RANGE arrow is under the cursor; place the cursor over mid-latitude on the green COSINE scale; read the E-W offset component distance in feet under the cursor on the ALTITUDE scale. (NOTE: To help determine the decimal point, remember that a second of longitude is equal to a second of latitude, or slightly more than 100 feet, at the equator; at 60° latitude, 1" longitude =  $\frac{1}{2}$ " latitude, or about 50 feet). If offset distance in NM is desired, read under the cursor on the RANGE NM scale.

e. Example:

(1) Given:

(a) Target = 39° 22' 18.6" N, 83° 15' 18.7" W.

$$(b) \text{ DAP} = 39^{\circ} 18' 22.5'' \text{ N}, 83^{\circ} 17' 22.5'' \text{ W.}$$

(2) Solution:

(a) DIFF LAT:

$$\begin{array}{r} 39^{\circ} 22' 18.6'' \text{ N (TGT)} \\ -39^{\circ} 18' 22.5'' \text{ N (DAP)} \\ \hline 3' 56.1'' = (3 \times 60) + 56.1 = 236.1'' \end{array}$$

(b) Mid LAT =  $39^{\circ} 20'$  (approximately).

(c) DIFF LONG:

$$\begin{array}{r} 83^{\circ} 17' 22.5'' \text{ W (DAP)} \\ -83^{\circ} 15' 18.7'' \text{ W (TGT)} \\ \hline 2' 03.8'' = (2 \times 60) + 03.8 = 123.8'' \end{array}$$

(d) N-S Offset **CFU-48/P** = 23,900' S. (Direction is SOUTH because DAP is south of target).

(e) E-W Offset **CFU-48/P** = 9,700' W. (Direction is WEST because DAP is west of target).

### 13. Distance and Course Solutions.

a. General. It may sometimes be advantageous or necessary to determine the course and distance between two geographical points without plotting or measuring on a navigational chart. In those instances where a slaved heading reference is to be used to establish aircraft heading, the airplane will fly a Mercator course (rhumb line); however, the plotted course on the ON, JN or GN chart, being Lambert Conformal projections, approximates a great circle; there will be a discrepancy between the plotted route and the actual flight path and it would therefore be desirable to determine the latter data to enhance planning accuracy. In some cases it may be desirable to compute the great circle course and distance more accurately than can be determined by measuring on the navigational chart. **CFU-48/P** provides an accurate and relatively simple "middle latitude" course and distance solution (which closely approximates the Mercator solution) and a precise great circle solution.

b. Mercator (Middle Latitude) Solution. The distance and course determined by **CFU-48** method are extremely close approximations of the data which will be found by measuring on a Mercator projection navigational chart. The discrepancy is virtually indeterminable unless the distance is unusually great, the direction of flight is intercardinal and part or all of the course is in the higher latitudes. (For example, the error for a flight between Paris and New York is less than ten nautical miles). This small disadvantage will in most cases be more than compensated by the comparative ease of **CFU-48** solution versus the difficulty of measuring the distance with any degree of precision under such conditions. For convenience, the "middle latitude" method will be referred to as the

Mercator solution in the balance of this discussion. CPU-48/P computational procedure for Mercator distance and course is similar to the BNS (Synchronous) offset component solution, Paragraph 12, above, except that the components are employed in terms of nautical miles rather than feet and are resolved to a single distance.

(1) Determine the difference in latitude (DIFF LAT) and longitude (DIFF LONG) between departure and destination to the nearest minute of arc. Convert these differences in degrees and minutes to minutes only (multiply the degrees by 60 and add the odd minutes). NOTE: Both points must lie on the same side of the equator if an accurate solution is to be obtained.

(2) Determine the approximate mid-latitude (Mid LAT) between departure and destination. For short distances, the mid-latitude can be interpolated by estimate to sufficient accuracy. However, for longer legs, determine Mid LAT by adding one-half of DIFF LAT to the lesser of the two latitudes.

(3) Find DIFF LAT in NM; this is the same as DIFF LAT in minutes of arc.

(4) Find DIFF LONG in NM. Set the RANGE arrow to DIFF LONG in minutes of arc on the RANGE NM scale; place the cursor over Mid-LAT on the green COSINE scale. Read DIFF LONG in NM under the cursor on the RANGE NM scale. NOTE: To help determine the decimal point, remember that a minute of longitude at the equator equals one NM; at 60° latitude, 1' longitude =  $\frac{1}{2}$  NM.

(5) To find Mercator distance, set the RANGE arrow to DIFF LONG in NM (E-W component) on the RANGE NM scale; place the cursor over DIFF LAT in NM (N-S component). Note the degree value displayed under the cursor on yellow COTANGENT scale. This is the basic Mercator course (COT°).

(6) Retaining the cursor in position against the outer disc, rotate the inner disc until the cotangent degree value noted above appears under the cursor on the green COSINE scale; read Mercator distance in NM between departure and destination opposite the RANGE arrow on the RANGE NM scale.

(7) To find the Mercator course in degrees, utilize the cotangent degree value found in step (5), above, in accordance with the following table: (NOTE: COT° = Cotangent degree value)

<u>Component Direction of DESTINATION from DEPARTURE</u>	<u>Mercator Course</u>
NE	COT° (no correction)
NW	360° - COT°
SE	180° - COT°
SW	180° + COT°



## c. Great Circle Solution.

(1) General. The Lambert Conformal and Stereographic projections normally used for air navigation provide practical great circle accuracy for short and medium distances. However, unacceptable course and distance errors may be expected when long legs are to be flown and the flight direction is other than predominantly north-south. This is particularly true when part or all of the plotted course lies in latitudes other than that on which the meridian convergence for the navigational chart is based. For example; the mid-latitude GNC is based on a meridian convergence of .78535 corresponding to a latitude of  $51^{\circ}45'$ . The more easterly or westerly the flight path and the further the course is removed from the convergence latitude, the greater will be the discrepancy from a true great circle. Quite possibly, it may appear to the navigator that his airplane is drifting off-course, whereas no deviation may exist at all; unnecessary and incorrect alteration could conceivably result. A gnomonic projection portrays the great circle path with truth, but it is not very convenient to measure angles and distances on this chart. The great circle problem may be solved by spherical trigonometry or by Ageton (HD 211), but the first method is complicated and the requisite formulae not generally known to the average navigator, while the tables and forms for the latter method may not always be available.

(2) The **CFU-48/P** Solution. The great circle solution available on the **CFU-48/P** is considerably less difficult and complicated than the mathematical methods and, being based on trigonometric principles, is precise. It is not particularly recommended for short legs as the information may more easily be determined by measurement or by utilizing the **CFU-48/P** Mercator solution; the error incurred by either method in such cases is not significant. Also, the great circle readouts for short distances may prove awkward to interpolate with accuracy on the circular slide-rule. However, the advantage of the **CFU-48/P** method will become readily apparent when long distances are involved.

## (3) Great Circle Distance.

(a) The basic trigonometric formula for computing great circle distance is:

$$\text{COS } D^{\circ} = (\text{SINE } L_1 \times \text{SINE } L_2) + (\text{COS } L_1 \times \text{COS } L_2 \times \text{COS DIFF LONG}^{\circ})$$

where  $D^{\circ}$  = great circle distance in degree of arc,  $L_1$  = departure latitude,  $L_2$  = destination latitude, and  $\text{DIFF LONG}^{\circ}$  = longitude difference between departure and destination in degrees. (This formula should be used when both latitudes are on the same side of the equator and the difference in longitude does not exceed  $90^{\circ}$ . For other situations, see sub-paragraph (c), below).

## (b) Solution.

1. Determine  $\text{DIFF LONG}^{\circ}$  between departure and destination (in degrees of arc).

- scale.
2. Set RANGE Arrow to 1.0; place cursor over  $L_1$  on SINE scale.
  3. Retaining cursor in position, rotate inner disc until RANGE arrow is under cursor.
  4. Place cursor over  $L_2$  on SINE scale; read product under cursor on RANGE NM scale; record.
  5. Set RANGE arrow to 1.0; place cursor over  $L_1$  on COSINE scale.
  6. Retaining cursor in position, rotate inner disc until RANGE arrow is under cursor.
  7. Place cursor over  $L_2$  on COSINE scale; retaining cursor in that position, rotate inner disc until RANGE arrow is under the cursor.
  8. Place cursor over DIFF LONG<sup>o</sup> on COSINE scale; read product under cursor on RANGE NM scale; record.
  9. Add steps 4 and 8; record sum.
  10. Place RANGE arrow to 1.0; place cursor over sum determined in previous step; read  $D^o$  (distance in degrees of arc) under cursor on COSINE scale; record.
  11. Multiply  $D^o$  by 60 to obtain great circle distance in NM.

(c) Special cases. When  $L_1$  and  $L_2$  lie on opposite sides of the equator, or when DIFF LONG<sup>o</sup> exceeds 90<sup>o</sup>, the basic distance formula requires modification. The mechanics of solution are essentially the same as just described, above.

1. Formula to be used when  $L_1$  and  $L_2$  have opposite signs:

$$\cos D^o = (\cos L_1 \times \cos L_2 \times \cos \text{DIFF LONG}^o) - (\sin L_1 \times \sin L_2)$$

2. Formula to be used when DIFF LONG<sup>o</sup> exceeds 90<sup>o</sup>:

$$\cos D^o = (\sin L_1 \times \sin L_2) - (\cos L_1 \times \cos L_2 \times \sin [\text{DIFF LONG}^o - 90^o])$$

Note: If the second factor in the above formula is a larger value than the first, it indicates that  $D^o$  is in excess of 90<sup>o</sup> (great circle distance is more than 5,400 NM). In such event, subtract the first factor from the second and locate residual  $D^o$  on the SINE scale. ADD 90<sup>o</sup> to residual  $D^o$  to obtain total  $D^o$ ; multiply total  $D^o$  by 60 to obtain great circle distance in NM.

#### (4) Great Circle Course Solution (precision method)

(a) The basic trigonometric formula for computing great circle course is:

$$\cos C^o = \frac{(\sin L_2) - (\sin L_1 \times \cos D^o)}{(\cos L_1 \times \sin D^o)}$$

where  $G^{\circ}$  = Basic great circle course in degrees (other factors as previously described)

(b) Solution.

1. Set RANGE arrow to 1.0; place cursor over  $L_2$  on SINE scale; read SINE under cursor on RANGE NM scale; record.
2. Retain RANGE arrow at 1.0; place cursor over  $L_1$  on SINE scale.
3. Retaining cursor in position, rotate inner disc until RANGE arrow is under cursor.
4. Place cursor over  $D^{\circ}$  (as determined in Distance solution, above) on the COSINE scale; read product under cursor on the RANGE NM scale; record.
5. Subtract step 4 from step 1; record difference (NOTE: If step 1 is larger value than step 4, subtract step 1 from step 4).
6. Set RANGE arrow to 1.0; place cursor over  $L_1$  on COSINE scale.
7. Retaining cursor in position, rotate inner disc until RANGE arrow is under cursor.
8. Place cursor over  $D^{\circ}$  on SINE scale; read product under cursor on RANGE NM scale; record.
9. Place cursor over difference determined in step 5, above; retaining cursor in position, rotate inner disc until product obtained in step 8 above, is under cursor on the TIME scale.
10. Place cursor over 10 on the TIME scale; read quotient under the cursor on the RANGE NM scale.
11. Retaining cursor in position, set the RANGE arrow to 1.0; read  $G^{\circ}$  (the basic great circle course in degrees) under the cursor on the COSINE scale.  $G^{\circ}$  as read on the CFU-48/P will always be  $90^{\circ}$  or less. The easiest way to convert this value to the true great circle course is to measure the approximate value on a Lambert Conformal, stereographic or gnomonic projection and compare with CFU-48 reading; the  $G^{\circ}$  value may then be applied to  $360^{\circ}$  or  $180^{\circ}$  (if necessary) to derive the true great circle course. The experienced navigator will have no difficulty in converting the CFU-48/P reading to the true great circle value, even when it is not feasible to make an approximate measurement; for the lesser experienced navigator a few basic rules may be of assistance:
  - a. If destination is north and east of departure,  $G^{\circ}$  will always equal the true great circle course (no conversion is necessary).
  - b. If destination is north and west of departure, true great circle course =  $360^{\circ} - G^{\circ}$ .

c. If destination is south and east of departure, the initial great circle course will either be equal to  $G^\circ$  or to  $180^\circ - G^\circ$ . It is not possible to offer positive guidance in this case, since the initial great circle course always bends toward the pole. When destination is predominantly southward of departure, the  $180^\circ - G^\circ$  rule applies; in other cases it generally is advisable to first obtain an approximate measurement or determine the approximate angle by the method described in sub-paragraph (5), below.

d. If destination is south and west of departure, the initial great circle course will either be equal to  $360^\circ - G^\circ$  or to  $180^\circ + G^\circ$ . This situation is similar to that discussed in the previous sub-paragraph; if destination is predominantly southward of departure, the  $180^\circ + G^\circ$  rule applies. In other cases, the guidance offered in the previous paragraph is applicable.

12. Special Case. If the second factor ( $\text{SINE } L_1 \times \text{COS } D^\circ$ ) in the great circle course formula, above, is larger in value than the first factor, ( $\text{SINE } L_2$ ), subtract the first factor from the second.

(5) Great Circle Solution (optional method).

(a) General. This procedure, which is applicable to short or medium distances only, requires that the Mercator course first be determined (by measuring on a Mercator projection or at mid-course on a Lambert Conformal, or by the slide rule method described in sub-paragraph b, above). An adjustment is then determined and applied as discussed below to arrive at the approximate initial great circle course.

1. Set the RANGE arrow to  $\frac{1}{2}$  DIFF LONG $^\circ$  (half of the difference of longitude in degrees) on the RANGE NM scale.

2. Place the cursor over mid-latitude on the SINE scale.

3. Read the course correction in degrees under the cursor on the RANGE NM scale.

4. If the Mercator course direction is EASTWARD ( $001^\circ - 179^\circ$ ), SUBTRACT the correction from the Mercator course; if the Mercator course direction is WESTWARD ( $181^\circ - 359^\circ$ ), ADD the correction to the Mercator course. The resulting figure is a practical approximation of the Initial great circle course, which may be used in lieu of the precision method when the distance is not excessive.

NOTE: The method described above may be used to convert great circle radio bearings to Mercator bearings. Apply the correction to the observed bearing as follows: SUBTRACT the correction from the observed bearing if the aircraft is EAST of the station; ADD the correction to the observed bearing if the aircraft is WEST of the station. The adjusted bearing may now be plotted accurately on a Mercator projection. These rules are applicable to the northern hemisphere; reverse for southern hemisphere."

(6) Determining the Vertex. When a gnomonic projection is not available to determine the great circle flight path, the **CFP-48/P** may be used to find the vertex (point of highest latitude) between departure and destination in order to more accurately duplicate the great circle course on the JN or GN chart. Two formulae are provided, the first to determine the latitude of the vertex, the second to find the longitude.

- (a) Latitude of the Vertex ( $L_V$ ):

$$\cos L_V = \sin G^\circ \times \cos L_1$$

- (b) Longitude of the Vertex ( $LONG_V$ ) from departure:

$$\cot LONG_V = \cot (90^\circ - G^\circ) \times \sin L_1$$

NOTE: Plot  $LONG_V$  from departure towards destination.

(7) Determining intermediate points. If a slaved heading reference is to be used to establish aircraft heading, a true great circle course cannot be made good; it can be approximated, however, by flying a series of rhumb lines. If a gnomonic projection is not available to extract the desired points along the great circle course (for establishing the individual rhumb lines), the points may be determined on the **CFP-48/P** as follows:

- (a) Determine the vertex.

(b) Divide the distances between departure and vertex, and between vertex and destination, into the desired number of segments.

(c) If the great circle course is predominantly east-west, arbitrarily select the longitude of the points and the longitude differences between the points; determine the latitude of each point on the **CFP-48/P** by formula:  $\cot (90^\circ - L_m) = \cot (90^\circ - L_1) \times \cos \text{DIFF LONG}_m$ . (Where  $L_m$  = latitude of the selected point, and  $\text{DIFF LONG}_m$  = difference of longitude [in degrees] between the points).

(d) If the great circle course is predominantly north-south, arbitrarily select the latitude of the points; find the longitude difference between the points by formula:  $\cos \text{DIFF LONG}_m = \cot (90^\circ - L_m) \times \cot L_V$ .

(e) Determine the great circle course for each leg segment. The simplest way to do this is to measure the angle on the JN or GN chart, (the error for short distances is negligible) or by applying the great circle formula previously described.

(8) Optional great circle formulae: The great circle course and distance problem may be solved by formulae other than described above. These formulae, along with a complete discussion of the great circle solution, are provided in Carver's excellent treatise, "An Introduction to Air Navigation". H.O. No. 9 (Bowditch), H.O. No 211 (Ageton) and most standard textbooks on spherical trigonometry also contain additional formulae and information that will prove of

value to the serious student of air navigation.

d. EXAMPLE: Find the Mercator and great circle courses and distances for a flight between Pittsburgh, Pa., and Marrakech, Morocco; also, the vertex of the great circle flight path. The heading is to be established and maintained by an unslaved heading reference to permit continuous great circle flight. The coordinates of Pittsburgh are  $40^{\circ} 26' N$ ,  $79^{\circ} 57' W$ ; the coordinates of Marrakech are  $31^{\circ} 39' N$ ,  $8^{\circ} 02' W$ .

(1) Mercator CPU-48/P Solution:

(a) DIFF LAT

$$\begin{array}{r} 40^{\circ} 26' N \text{ (Dept)} \\ -31^{\circ} 39' N \text{ (Dest)} \\ \hline 8^{\circ} 47' \times 60 = 527' = 527 \text{ NM (south)} \end{array}$$

(b) DIFF LONG

$$\begin{array}{r} 79^{\circ} 57' W \text{ (Dept)} \\ -8^{\circ} 02' W \text{ (Dest)} \\ \hline 71^{\circ} 55' \times 60 = 4315' \text{ (east)} \end{array}$$

(c) Mid LAT =  $\frac{1}{2} (40-26 + 31-39) = 36^{\circ} 02\frac{1}{2}' N$

(d) DIFF LONG in NM CPU-48/P

$$\text{COS } 36^{\circ} 02\frac{1}{2}' \times 4315' = 3490 \text{ NM}$$

(e) COI CPU-48/P =  $81.4^{\circ}$

(f) Mercator CPU-48/P Distance = 3530 NM

(g) Mercator CPU-48/P Course =  $180^{\circ} - 81.4^{\circ} = \underline{98.6^{\circ}}$  (destination is SE of departure)

NOTE: If the cotangent value on the CPU-48/P exceeds  $83^{\circ}$ , assume sine and cotangent to be equal values; use the Blue SINE scale ( $0.6^{\circ} - 7^{\circ}$ ) and convert to a cotangent value by subtracting the indicated sine value from  $90^{\circ}$ . If the cotangent value on the CPU-48/P is less than  $5^{\circ}$ , reverse the setting process, i.e., set the RANGE arrow to DIFF LAT in NM (N-S component) and place the cursor over DIFF LONG in NM (E-W component); use the SINE scale ( $0.6^{\circ} - 5^{\circ}$ ) and assume the indicated sine value to be identical to the cotangent value (do NOT subtract the value from  $90^{\circ}$ ).

(2) Great Circle Solution:

(a)  $L_1 = 40^{\circ} 26' N$ ;  $L_2 = 31^{\circ} 39' N$

(b) DIFF LONG

$$\begin{array}{r} 79^{\circ} 57' \text{ W} \\ - 8^{\circ} 02' \text{ W} \\ \hline 71^{\circ} 55' \end{array}$$

(c) $\text{SINE } L_1 \times \text{SINE } L_2$	= .340
(d) $\text{COS } L_1 \times \text{COS } L_2 \times \text{COS DIFF LONG}^{\circ}$	= <u>+ .200</u>
(e) Sum	= .540
(f) $D^{\circ} (\text{Cos } .539)$	= $57.3^{\circ}$
(g) Great Circle Distance ( $57.3 \times 60$ )	= <u>3,438 NM</u>
(h) $\text{SINE } L_2$	= .525
(i) $\text{SINE } L_1 \times \text{COS } D^{\circ}$	= <u>- .351</u>
(j) Remainder	= .174
(k) $\text{COS } L_1 \times \text{SINE } D^{\circ}$	= .641
(l) $.174 \div .641$	= .271
(m) $C^{\circ} (\text{Cos } .271)$	= $74.25^{\circ}$
(n) Initial great circle course	= <u><math>74.25^{\circ}</math></u>
(o) Vertex (Lat)	= <u><math>42.9^{\circ} \text{ N}</math></u>
(p) Vertex (Longitude difference from departure)	= $23.4^{\circ}$
(q) Vertex (Longitude) = $79^{\circ} 57' - 23^{\circ} 24'$	= <u><math>56^{\circ} 33' \text{ W}</math></u>

NOTE: For purpose of comparison, the following is presented:

Ageton (HO 211) Great Circle Distance	= $3,437\frac{1}{2}$ NM
Ageton (HO 211) Great Circle Initial Course	= $74.35^{\circ}$
Ageton (HO 211) Vertex (Lat)	= $42^{\circ} 52' \text{ W}$
Ageton (HO 211) Vertex (Longitude)	= $56^{\circ} 36\frac{1}{2}' \text{ W}$
Measured Great Circle Distance (GNC)	= $3,412 \text{ NM}^*$
Measured Great Circle Course (GNC)	= $70^{\circ}$
Measured Vertex (Lat)	= $43^{\circ} 55' \text{ N}$
Measured Vertex (Long)	= $54^{\circ} 00' \text{ W}$

\*NOTE: The measured great circle distance is apparently less than the actual great circle distance. This is obviously impossible; the aircraft would actually fly a slightly longer distance than the great circle distance

if it were to follow the measured route, since it deviates from a true great circle. This discrepancy is due to inherent inaccuracies of the projection (the chart is truly correct only at the latitude upon which the convergence angle is based). As a result of this situation, the crew will have less fuel reserve than planned and the ETA will be a few minutes in error; the problem will be compounded if the navigator attempts to establish a great circle track and is not aware of this phenomenon; as he corrects the aircraft to make good the plotted course, the total flight distance will be further increased. While the discrepancy in the above example is not particularly serious, longer legs would create a marked difference between the true great circle course and distance and the measured data."

#### 14. Off-Course Correction

a. Application. This procedure may find application in certain practical navigational situation, e.g., when the navigator finds himself off-course and the fix and next action point lie on different charts, making it unwieldy to draw in a new course, or during severe turbulent conditions in low altitude flight when the ordinary mechanics of plotting become extremely difficult to accomplish.

b. Assumption. The off-course correction procedure is based on the assumption that a change in heading produces the same change in track. This assumption is precisely true under no-wind conditions only, whenever a wind exists, any change in heading results in a change in drift effect of the wind. However, when the corrections are relatively small, or when the wind effect is negligible, as in most low altitude flight conditions, the assumption may be considered substantially correct. When the corrections are large and a strong wind prevails, the procedure may still be employed to provide the approximate course correction, with refinements being made at such time as the aircraft position and the next action point lie on a common chart.

#### c. Procedure.

(1) Set the RANGE arrow to NM flown (from the last known position to the fix) on the RANGE NM scale.

(2) Set the cursor over NM off-course on the RANGE NM scale.

(3) Read the compass correction to parallel course under the cursor on the **Blue** SINE scale.

(4) Holding the cursor in position against the outer disc, rotate the inner disc until the RANGE arrow points to distance to go in NM on the RANGE NM scale. Read the additional course correction under the cursor on the **Blue** SINE scale.

(5) Add the two course corrections (Steps 3 and 4). The sum is the total compass correction necessary to converge on the next action point.

#### d. Example:

(1) Given: The navigator of an airplane flying on a true heading of



340° obtains a fix and finds his position to be 456 NM from departure and 36 NM to the right of his intended track. What is the correction and true heading to parallel the original course? What is the total correction and true heading necessary to converge on destination which lies 258 NM ahead?

(2) Solution:

(a) Correction to parallel course =  $4\frac{1}{2}^{\circ}$  (to the left); true heading to parallel course =  $340^{\circ} - 4\frac{1}{2}^{\circ} = 335\frac{1}{2}^{\circ}$ .

(b) Additional correction to converge on destination =  $8^{\circ}$  (to the left); total correction to converge on destination =  $4\frac{1}{2}^{\circ} + 8^{\circ} = 12\frac{1}{2}^{\circ}$  (to the left); true heading to converge on destination =  $340^{\circ} - 12\frac{1}{2}^{\circ} = 327\frac{1}{2}^{\circ}$ .

e. Rapid Return to Track. In some instances it is desirable to return the aircraft to its intended track as rapidly as possible by executing a large arbitrary turn in the direction of the plotted course. When this is to be done, it is necessary to know how long to hold the corrective heading until the original course has been intercepted. The computation may be accomplished quite simply on the **CFU-48/P**

(1) Determine the compass correction to parallel course as described in Paragraphs c(1), (2) and (3) above.

(2) Holding the cursor in position against the outer disc, (cursor over distance off-course on the RANGE NM scale), rotate the inner disc until the desired additional heading correction in degrees appears under the cursor on the **Blue SINE** scale. Read distance to go to intended track (in NM) opposite the RANGE arrow on the RANGE NM scale.

(3) Convert distance to time on the **CFU-48/P** (normal DR solution), using the best known inbound ground speed.

(4) Add the two compass corrections (Steps 1 and 2). The sum is the total compass correction necessary to converge on intended track.

f. Example:

(1) Given: The navigator of an airplane flying on a true heading of 340° obtains a fix and finds his position to be 456 NM from departure and 36 NM to the right of his intended track. He desires to return rapidly to the original course and plans on a turn of 60° to the left. His approximate inbound ground speed will be 500 knots. What is the total compass correction, true heading, distance and time to converge on course?

(2) Solution:

(a) Correction to parallel course =  $4\frac{1}{2}^{\circ}$  (to the left).

(b) Total compass correction =  $60^{\circ} + 4\frac{1}{2}^{\circ} = 64\frac{1}{2}^{\circ}$  (to the left).

(c) True heading =  $340^{\circ} - 64\frac{1}{2}^{\circ} = 275\frac{1}{2}^{\circ}$ .

(d) Distance to go =  $41\frac{1}{2}$  NM.

(e) Time to intersect course = 5.0 minutes.

NOTE: Variations of the above procedure are possible and may prove useful. For example: the navigator might desire to correct the airplane heading back to the intended track immediately upon ascertaining his position. In such event, compute the correction to parallel course as soon as the arbitrary correction is called to the pilot; subtract the heading correction to parallel course from the arbitrary heading correction; using the difference between the two figures, compute the distance to go on the CPU-48/P and convert to time. In the above example, if this procedure were used, the true heading would be  $340^\circ - 60^\circ = 280^\circ$ ; distance to go would be 44 NM (CPU-48/P setting on the SINE scale is  $60^\circ - 42^\circ = 552^\circ$ ); time to go (assuming ground speed of 500 knots) is 5.3 minutes.

## SECTION VI

## IDENTIFICATION OF THE PLOTTING (GRID) SIDE SCALES (FIGURE 2)

1. The Transparent Plotting Disc

a. 360° Compass Rose. This compass rose (YELLOW background), provided around the outer circumference of the transparent (rotatable) plotting disc, just inside the WHITE compass rose of the fixed disc, is used in conjunction with the fixed compass rose in the computation of celestial motion, periscopic sextant relative bearing, true heading, plotting of LOPs, target timing wind, etc.

b. Motion of the Body Scale. This is a cosine incremented latitude scale, originating at the grommet (representing 90° latitude) and extending towards 270° on the compass rose. It is used in determining the one-minute motion of the body (M/B) adjustment for celestial navigation.

c. Polaris Azimuth Scale. This is a latitude incremented scale (0°-75°) extending towards 29.85° on the compass rose. It is used in the computation of the true azimuth of Polaris. The symbol "Q", located at the outermost portion of this scale, is used in determining the "Q" adjustment of Polaris. The Polaris values have been validated for Epoch 1965.0; they are intended for use primarily in conjunction with the HO-249 solution and may be used without tangible error through 1969.

2. The Fixed Disc.

a. 360° Compass Rose. This compass rose (WHITE background), provided around the outer circumference of the fixed disc, is used in conjunction with the rotatable compass rose in the computation of celestial motion, periscopic sextant relative bearing, true heading, plotting of LOPs, target timing wind, etc.

b. Plotting Grid. The plotting grid is provided on a WHITE background at a scale of approximately 1:2,000,000 (about the same as the JN navigation charts). Each fifth line is accented (printed slightly darker and wider). It is used in conjunction with the various scales overprinted upon it in the determination of celestial motion, acceleration adjustments, plotting of LOPs, resolving of fixes, target timing winds, etc. The overprinted scales are as follows:

(1) Motion Scales. These scales (YELLOW background) printed vertically above and below the grommet in all four quadrants and numbered from 2 through 16, are used primarily in the computation of celestial motion and acceleration adjustments. For guidance, the signs of the adjustments, applicable to the Hc method, are printed in all four quadrants (YELLOW background).

(2) Plotting "Q" Scales. These scales, printed vertically above and below the grommet in increments of ten (from 10 through 80), and horizontally left and right of the grommet in increments of twenty (20 through 80), are used in the plotting of LOPs, in the computation of the Polaris "Q" correction, in converting nautical

miles to minutes of arc, and in obtaining target timing winds.

(3) Polaris Azimuth Scale. This scale (GREEN background), printed horizontally to the immediate right and left of the grommet, is used in conjunction with the Polaris Latitude Scale of the transparent plotting disc in determining the true azimuth of Polaris. The center of the grommet represents  $360.0^{\circ}$  ( $000.0^{\circ}$ ). The other indicated values are to be interpreted as follows;  $7^{\circ} = 357.0^{\circ}$ ;  $8^{\circ} = 358.0^{\circ}$ ;  $9^{\circ} = 359.0^{\circ}$ ;  $1^{\circ} = 001.0^{\circ}$ ;  $2^{\circ} = 002.0^{\circ}$ ;  $3^{\circ} = 003.0^{\circ}$ . Each small square of the grid represents one tenth of a degree ( $0.1^{\circ}$ ) of azimuth.

(4) GSK Scale. This ground speed in knots scale, printed vertically directly below the grommet towards  $180^{\circ}$  on the fixed compass rose, is calibrated in increments of twenty knots, from 100 through 1,000 knots, and is used in determining the motion of the observer (M/O).

3. The Cursor. This is a rotatable partial arm, on which has been etched a hair-line cursor. It is intended to facilitate reading of the compass roses. The abbreviation "SRB" refers to readings on the outer (WHITE) compass rose; the abbreviation (TH) refers to readings on the inner (YELLOW) compass rose.

## SECTION VII

### INSTRUCTIONS FOR PLOTTING (GRID) SIDE

#### 1. Celestial Navigation.

a. General. The grid side of the CPU-48/P is designed to assist in the rapid and accurate computation of celestial motions, periscopic sextant relative bearing, true heading, corrected celestial azimuth, Polaris "Q" adjustment/azimuth, and acceleration adjustments. In addition, LOPs may be plotted, fixes resolved into ranges and bearings, or directly into geographical coordinates, and latitude/longitude adjustments computed for updating the BNS present position counters.

NOTE: The CPU-48/P Computer is designed to provide adjustment values which are applicable to the computed altitude (HC). If it is desired to apply adjustments to the observed (sextant) altitude (HO), simply reverse the signs as indicated upon the face of the grid.

#### b. Celestial Motions (One Minute). (Figure 29).

(1) General. The two celestial motions, motion of the observer (M/O) and the motion of the body (M/B), for one minute of time, may be computed separately or (in most cases) as a single, combined one minute motion. Either method may be used, depending upon conditions and/or individual preference.

NOTE: The transparent plotting face is constructed to accommodate inscribing and/or plotting with a pencil. The face may be cleaned easily with an ordinary eraser for subsequent use, and periodically with soap and water.

(2) Motion of the Observer (M/O) and Motion of the Body (M/B) Computation.

(a) Set the best known true course under the index.

(b) Inscribe a mark on the ground speed scale (GSK) over the best known ground speed in knots.

(c) Rotate the plotting face until the true azimuth ( $Z_n$ ) of the body (tabulated or computed for the time of fix) is under the index; read all corrections above and below the horizontal center line which runs through the grommet. Obtain reading to desired accuracy, using the unit scales (numbered from 2 through 16); each small square is equal to .2 (two tenths) minutes of arc; interpolation to the nearest .1 minute of arc may be accomplished visually. If the mark is above the horizontal line running through the grommet, the sign of the correction is plus when adjusting the HC. If the mark is below the horizontal line running through the grommet, the sign of the correction is minus when adjusting the HC. The signs are applicable to "early" observations (i.e., observations made before fix time); reverse sign for "late" observations (i.e., observations made after fix time).

1. Motion of the Observer (M/O): Extract the one minute motion adjustment from the M/O mark made in step (b) above; record on the celestial precomputation form (Figure 29).

2. Motion of the Body (M/B): Extract the one minute motion adjustment from the DR latitude on the M/B scale; record on the celestial precomputation form.

3. Add the two motion adjustments algebraically to determine the combined one minute motion adjustment.

(3) Combined Motion. In most instances (except for essentially eastward flight direction at high ground speed), it is possible to determine a combined one minute motion adjustment directly from the CPU-48/P grid. To do this, set the best known true course on the compass rose of the plotting face under the fixed index. Measure the motion of the observer adjustment with dividers (from the grommet to the best known ground speed on the GSK scale). Plot this distance vertically downward from the DR latitude on the M/B scale and inscribe a mark at that point. Rotate the plotting face until the azimuth ( $Z_n$ ) of the body is under the index. Extract the combined one minute motion adjustment from the inscribed mark. Record on the celestial computation form. Repeat for each body.

(4) Multiply the one minute combined motion factor by the number of minutes which are scheduled between the mid-observation time and the fix time. Reverse the sign of the adjustment if

observation is to be later than the scheduled fix time. Record on the celestial precomputation form.

c. Periscopic Sextant Relative Bearing (SRB), True Heading (TH), and Azimuth (Zn) Computation. See Figure 29.

(1) General. The 360° compass roses on the two discs make it convenient to compute the periscopic sextant relative bearing (SRB), the true heading (TH) from an observed sextant relative bearing (SRB), and (if desired), the corrected body azimuth (Zn) for the time of observation. The SRB method permits rapid azimuthal orientation of the observed bodies without re-setting the azimuth dial between observations. The dial is set to 000.0° and is not changed at any time. The celestial observer locates the body by pre-setting the HC, adjusted for motion, refraction, personal/sextant errors and (for the moon) parallax/semi-diameter, and rotating the sextant azimuthally until the precomputed SRB appears under the vertical crosshair on the azimuth scale across the bottom of the field of vision.

(a) SRB Computation. Set Zn of the body to be observed under the index of the CPU-48/P. Read SRB on the fixed (WHITE) compass rose opposite the best known true heading on the YELLOW (inner) compass rose of the transparent (rotatable) face. Use the etched cursor on the partial arm to facilitate alignment and reading.

HINT: The SRB computations may be made in conjunction with the motion computations so that separate settings need not be made.

(b) True Heading Computation. Set Zn of the observed body under the index. Read the true heading on the white compass rose of the plotting face opposite the observed sextant relative bearing (SRB) on the fixed (WHITE) compass rose. Use the etched cursor on the partial arm to facilitate alignment and reading. For increased accuracy, the true heading check should be made as close to fix time as is practicable. (Polaris is an exception.)

(c) Azimuth Correction Computation. This is a rarely used procedure but may prove useful in isolated instances. To accomplish this computation it is essential that true heading be accurately known. If it is desired to correct the tabulated Zn to the time of the observation, it is recommended that Polaris (if available) be observed and a precise true heading established prior to using this method for other bodies. To compute the corrected azimuth on the CPU-48/P, set true heading on the yellow compass rose of the plotting face opposite the observed sextant relative bearing (SRB) on the fixed (white) compass rose. Read corrected Zn under the index. Use the etched cursor on the partial arm to facilitate alignment and reading.

NOTE: It should be realized that correcting the azimuth to the time of the observation will rarely provide significant increased positional accuracy when using standard celestial fixing methods, unless the assumed position is considerably removed from the actual position. The technique should be used with discretion, and only when TH is precisely known.

REMEMBER: Zn is always read under the index; SRB (or SRB.) is always read on the fixed (white) compass rose (outer ring); TH is always read on the yellow compass rose of the plotting face. For guidance, the TH/SRB relationship is inscribed on the partial arm.

d. Polaris Computations. See Figure 29

(1) Set the LHA of Airies under the index.

(2) Read the true azimuth (Zn) of Polaris left or right of the vertical center line running through the grommet, using DR latitude on the Polaris latitude (short) scale on the plotting face and the green azimuth scale on the grid. The three numbered degrees to the immediate left of the grommet, 7°, 8° and 9°, represent 357°, 358° and 359° respectively. The three numbered degrees to the immediate right of the grommet, 1°, 2° and 3°, represent 001°, 002° and 003° respectively. The grommet represents 360° (000°). Each small square of the grid represents .1.

(3) Read the Polaris "Q" correction at the dot in the middle of the "Q" (at the outer extremity of the Polaris latitude scale on the plotting face), using the "ten" numbered scale (each small square of the grid represents one minute of arc); read above and below the horizontal center line running through the grommet. Above the grommet is plus when applying the "Q" correction to the basic Polaris HC (the basic HC of Polaris is equal to the latitude of the assumed position). Below the grommet is minus. Reverse the signs when using the latitude method (Polaris HO plus or minus "Q" = Latitude).

e. Coriolis Computations (Slide Rule Side)

NOTE: It is recommended that celestial observations be accomplished with the heading reference placed in an unslaved configuration in order to improve accuracy and to negate the requirement for computing rhumb line correction. If it is necessary to accomplish the observations with a slaved heading reference, military users are advised to extract the combined Coriolis and rhumb line correction from the tables furnished in AFM 51-40. For a slide rule solution of rhumb line correction, see sub-paragraph (7), below.

(1) Set 10 under the "W/C" arrow (26.25).

(2) Set cursor over DR ground speed in knots on the TIME scale.

NOTE: If it is planned to compute heading (wander) acceleration adjustments, the basic wander factor may be read under the cursor on the Range NM scale and recorded at this time for later use (See paragraph f, below).

(3) Retaining cursor in position against the outer disc, rotate inner disc until RANGE arrow is under cursor.

(4) Read Coriolis correction in NM under the cursor on the white RANGE NM scale over DR latitude on the blue SINE scale. Apply correction to the assumed position or to the celestial fix (to right, perpendicular to track, in northern hemisphere; reverse rule for southern hemisphere).

(5) Example:

(a) Given: GS = 514 K; DR Latitude =  $45^{\circ}$  N.

(b) Solution: Wander Factor = 13.5; Coriolis Correction =  $9\frac{1}{2}$  NM (right).

(6) For computation and application of Coriolis correction when using the MD-1 automatic astro compass, solve from the "MD-1 Residual Coriolis Adj - NM" graph, Figure 30.

(7) Rhumb Line Correction (circular slide rule).

(a) If observations are to be made when the airplane is being steered by a slaved heading reference, it will be necessary to apply rhumb line acceleration correction in addition to Coriolis. The precise correction may be computed on CPU-48/P, if desired, by solving the formula:

$$R = .146 \times (\text{GSK} \div 100)^2 \times \text{Sine of Track Angle} \times \text{Co-tangent of Co-latitude.}$$

(b) CPU-48/P solution follows:

1. Set  $\textcircled{10}$  under .146 on the RANGE NM scale; set cursor over ground speed in knots on the TIME scale. Retaining cursor in position, rotate the inner disc until  $\textcircled{10}$  is under cursor; again, set cursor over ground speed in knots on the TIME scale.

2. Retaining cursor in position, rotate inner disc until RANGE arrow is under cursor; set cursor over track angle in degrees on SINE scale. NOTE: If track is greater than  $90^{\circ}$ , resolve as follows: If between  $90^{\circ}$  and  $180^{\circ}$ , subtract track from  $180^{\circ}$ ; if between  $180^{\circ}$  and  $270^{\circ}$ , subtract  $180^{\circ}$  from track; if between  $270^{\circ}$  and  $360^{\circ}$ , subtract track from 360.

3. Retaining cursor in position, rotate inner disc until RANGE arrow is again under cursor; set cursor over co-latitude ( $90^{\circ}$  - latitude) on COTANGENT scale. Read rhumb line correction in NM on RANGE NM scale (under cursor).

4. If track is EASTWARD ( $001^{\circ}$  -  $179^{\circ}$ ), ADD rhumb line correction to Coriolis; SUBTRACT if track is WESTWARD ( $181^{\circ}$  -  $359^{\circ}$ ).

5. EXAMPLE:

a. Given: GS = 514 K; DR Lat =  $53^{\circ}$  N;  
Track =  $246^{\circ}$ . Find rhumb line correction and combined Coriolis/rhumb line correction.



b. Solution: Co-Lat =  $90^{\circ} - 53^{\circ} = 37^{\circ}$ ;  
 Resolved Track =  $246^{\circ} - 180^{\circ} = 66^{\circ}$ ; Coriolis correction = 10.7 NM (right);  
 rhumb line correction = -4.5 NM; Combined Coriolis/rhumb line  
 correction =  $10.7 - 4.5 = 6.2$  NM (right).

f. Random Acceleration Adjustments.

(1) General. If the airplane track (relative to a straight line as perceived in space) changes while a celestial observation is being made with a bubble sextant, an acceleration will be experienced upon the bubble, causing it to be displaced from the true vertical. Similarly, any deviation of ground speed during the observation cycle will induce an acceleration upon the bubble. The resulting observation will be in error by an amount proportional to the amount of change of track, the airplane's ground speed (for track acceleration), the amount of ground speed change (for ground speed acceleration) and the relative bearing of the body. The Coriolis and rhumb line phenomena discussed in the preceding sub-paragraph are two types of track acceleration. A third type is caused by the airplane deviating from the planned track, due to such factors as steering inaccuracies (human or autopilot), gyro drift (if using a deslaved heading reference); changing magnetic variation (if using a slaved heading reference and automatic magnetic variation computing equipment is not available), or sudden wind shifts. Ground speed acceleration is induced by airspeed deviation during the celestial observation or by wind shifts. The track and ground speed accelerations are collectively referred to as random accelerations; their effects must be considered when precision celestial navigation is desired.

(a) Heading Acceleration ("Wander"). Normally, only heading change is considered when determining track acceleration (although the track change may occasionally be determined with reasonable accuracy on some aircraft by observing the Doppler drift indicator). For practicality, any small change of heading is considered to exert an identical influence upon track. This acceleration, the effect of which is most pronounced during "beam" or course line observations, will be referred to as heading acceleration, or "wander". It should be noted that an observed heading change during a celestial observation is not necessarily the actual heading acceleration.

1. If a deslaved heading reference is used during the observation (which is the preferred mode of many present day navigators), the true heading (and track) should change (since the airplane is describing a great circle flight path), unless flight direction is directly north-south (or east-west along the equator). The amount of required heading change during the observation, to be referred to as  $\Delta TH$  (Delta True Heading), is readily computable on the circular slide rule of the CPU-48/P.  $\Delta TH$  must be applied to the observed heading change to find the actual heading acceleration. A simple procedure of precomputing this data will be discussed subsequently.

2. If a slaved heading reference is used during the observation, and automatic magnetic variation feed-in equipment (Mag Var cam) to the navigation computer is installed and operable, the airplane will attempt to hold a constant true heading; the acceleration due to flying a curved path will, in this case, have already been computed and applied in the rhumb line adjustment so that any observed heading change may be considered to be heading acceleration. If automatic mag. var. compensatory equipment is not available, the navigator must determine the amount of magnetic variation change and apply it to the observed heading change; this is normally quite difficult to do with any degree of accuracy and is seldom a practical procedure.

(b) Velocity Acceleration. A change of ground speed during a celestial observation, the effect of which is most noticeable on "speed line" observations, will be referred to as "Velocity Acceleration". Normally, a change of true air speed reading may be considered to be synonymous to ground speed change; however, for aircraft so equipped, the acceleration may be determined directly from the Doppler ground speed indicator.

(c) The CPU-48/P random acceleration computational method is unique in that the navigator need not concern himself as to whether the celestial body is "ahead", "behind" or "abeam"; the relative bearing is determined automatically in the CPU-48/P process. Further, the acceleration adjustment factors may be obtained at the same time as the motion adjustment readouts (see sub-paragraph b, above), thus eliminating additional settings.

## (2) Precomputations.

(a)  $\Delta$  TH Computation (Slide Rule Side). NOTE: This procedure is intended for use when a slaved heading reference is employed during the celestial observation period.

1. Set the SEC arrow to GSK (ground speed in knots) on the RANGE  $\overline{NM}$  scale.

2. Place the cursor over the planned time duration of the observation in minutes on the TIME scale.

3. Retaining the cursor in position, rotate the inner disc until mid-latitude on the COSINE scale is under the cursor. (Technically, this is the latitude of the airplane at mid-observation time; for practicality, however, the DR latitude for fix time may be used for all observations of the fix.)

4. Place the cursor over mid-latitude on the SINE scale (same latitude value as used in previous step).

5. Retaining the cursor in position, rotate the inner disc until the RANGE arrow is under the cursor.

6. Place the cursor over relative track angle on the SINE scale; read  $\Delta$ TH in tenths of a degree under the cursor on the RANGE NM scale; round off to the nearest .1° (NOTE: To determine the relative track angle when track is less than 360° or more than 90°, observe the following rules: If DR track is between 90° and 180°, subtract track from 180°; if DR track is between 180° and 270°, subtract 180° from track; if DR track is between 270° and 360°, subtract track from 360°).

7. If flight direction is EASTWARD (001° - 179°), the sign of  $\Delta$ TH is plus (true heading is increasing); if flight direction is WESTWARD (181° - 359°), the sign of  $\Delta$ TH is minus (true heading is decreasing). These rules are for northern hemisphere; reverse for south latitude.

8. Apply  $\Delta$ TH algebraically to each initial heading reading (i.e., the reading made at the start of each celestial observation) and record the adjusted initial heading in the box provided on the celestial computation form. The adjusted initial heading represents the heading value which will exist at the end of the observation cycle if no heading acceleration occurs; a comparison of this value with the terminal heading reading will therefore reveal the actual heading acceleration. The balance of the heading acceleration computation will be discussed subsequently.

#### 9. Example.

a. Given: GS=495K; Planned duration of observation = 2 Minutes; DR Latitude = 63°N; DR Track = 112°; Initial TH reading (at start of observation) = 110.5°; Terminal TH reading (at end of observation) = 111.2°.

b. Solution: Relative track angle =  $180^\circ - 112^\circ = 68^\circ$ ;  $\Delta$ TH =  $+ .5^\circ$  (sign is plus because flight direction is eastward); Adjusted initial TH =  $110.5^\circ + .5^\circ = 111.0^\circ$ ; Acceleration =  $111.2^\circ - 111.0^\circ = +.2^\circ$  (sign is plus because heading has increased).

#### (b) Acceleration Computations.

1. Slide Rule Side. Set 10 on the TIME scale under the "W/C" arrow (26.25) on the RANGE NM scale. Read the basic heading "wander" factor (WF) on the RANGE NM scale opposite DR ground speed in knots on the TIME scale. This factor is valid for a two minute observation. (NOTE: The WF value for a two minute observation is the same as the readout obtained when solving the first factor of the Coriolis computation, sub-paragraph e, above, and may be recorded at that time for use in the heading wander computation.)

2. Plotting (Grid) Side. (NOTE: The following may be accomplished at the same time as the motion computation, paragraph 1b, above).

a. Set DR track under the index

b. Inscribe a mark (label "W") on the horizontal line, right from the grommet towards 90° on the fixed compass rose at a value equivalent to the basic WF as computed in the previous step, utilizing the "units" scale (each small square = .2), i.e., the same scale as is used for motion computations.

c. Inscribe a mark, "V", with the apex over 1.5 (i.e.,  $7\frac{1}{2}$  small squares) on the "units" scale (same scale as is used for motion computations), upwards from the grommet toward the index. This is the basic velocity acceleration factor VF, for one knot of ground speed increase during a two minute celestial observation. NOTE: If preferred (to increase ease of reading), the "V" mark may be inscribed at 15 on the motion scale (or 75 on the plotting scale); if this technique is used, divide the extracted VF value, step d, below, by ten.

d. Set body Zn under the index. Read the wander factor (WF) value at the "W" mark. Read the velocity acceleration (VF) factor value at the apex of the "V" mark. The values and signs of these factors are determined in the same manner as the motion values, i.e., if the mark is above the horizontal line running through the grommet, the sign is plus; if below the grommet, the sign is minus.

e. Record the WF and VF values and signs in the appropriate boxes of the celestial computation form. The recorded WF value represents the adjustment required to counter the effect of one degree of increased heading acceleration (right wander) during a two minute observation. The VF value represents the adjustment required to counter one knot of ground speed increase during a two minute observation. (NOTE: If one minute observations are to be made, double the values of WF and VF as read from the CPU-48/P; if thirty second ( $\frac{1}{2}$  minute) observations are to be made, quadruple these values.

### (3) Post-Computations.

(a) Heading Wander. Read heading at the start of the observation (to the nearest .1° if possible); apply  $\Delta$  TH algebraically and record adjusted initial TH; record heading at the termination of the celestial observation (to the nearest .1°, if possible); subtract algebraically the initial heading from the terminal heading and record the difference (Wander). If the terminal heading is a greater value than the initial heading, the sign is plus; if the terminal heading is a lesser value than the initial heading, the sign is minus.

(b) Velocity Acceleration. Record Doppler ground speed at the start and at the termination of the celestial observation (to the nearest knot). The true airspeed readings may be substituted, if Doppler is not available, without significantly degrading accuracy. Subtract algebraically the initial velocity from the terminal velocity and record the difference (V ACCEL). If the terminal velocity is a greater value than the initial velocity, the sign is plus; if the terminal velocity is a lesser value than the initial velocity, the sign is minus.

(c) Multiply WF and Wander Algebraically and record the product to the nearest whole number in the W ADJ block of the celestial precomputation form. If both signs are the same, the sign of W ADJ is plus; if the signs are different, the sign of W ADJ is minus.

(d) Multiply VF and V ACCEL algebraically and record product to the nearest whole number in the V ADJ block of the celestial precomputation form. If both signs are the same, the sign of V ADJ is plus; if the signs are different, the sign of V ADJ is minus.

(e) Apply W ADJ and V ADJ to the  $H_c$ , utilizing the appropriate post adjustment boxes of the celestial precomputation form.

(4) Example: See Figure 29 for blank computation sheet.

g. Plotting LOPs and Resolving the Fix.

(1) The grid is constructed on approximately the same scale as the JN chart, i.e., 1:2,000,000.

(2) The Grommet represents the assumed position.

(3) Set body Zn under the index; plot "toward" intercepts vertically upward from the grommet intercept distance toward the index; plot "away" intercepts vertically downward from the grommet intercept distance away from the index. Use the "tens" numbered scale, with each small square representing one NM. If the intercepts are unusually large, use the units scale times ten, with each small square representing two NM. If the intercepts are unusually small, it may be desirable to let each large square represent one NM; some increase of accuracy may be anticipated if this is done. Construct a perpendicular at the end of the intercept distance; use a straight edge, or draw freehand, utilizing the parallel horizontal lines on the grid face for guidance.

(4) Repeat process until all LOPs are plotted.

(5) Resolve fix center.

h. Plotting the Fix.

(1) Range and Bearing Plotting Method. If the fix is to be plotted on the navigation chart as a range and bearing from the assumed position, rotate the plotting face until the center of the resolved fix is in direct line between the grommet and the index, along the vertical line running through the grommet. Read the fix bearing in degrees under the index and the range in NM from the grommet upward to the center of the resolved fix, using the same scale as was used to plot the LOPs (normally the "tens" scale). Plot this range and bearing on the chart from the assumed position. If the assumed position has been pre-adjusted on the chart, for Coriolis and precession/nutation effects, no further adjustment of the fix is necessary.

NOTE: If it is preferred to adjust the resolved fix on the CPU-48/P grid for Coriolis and precession/nutation effects, set the best known track under the index; move the fix center  $90^\circ$  to the right or left (as required) for Coriolis effect using the same scale as was used to plot the LOPs. Next, set the azimuth of the tabulated precession/nutation correction (HO-249, Vol I, Table 5), under the index and move the fix vertically upward from the resolved fix center the number of nautical miles tabulated for the precession/nutation correction. Rotate the plotting face until the adjusted fix is between the grommet and the index. Obtain the range and bearing as previously described and plot on the navigational chart from the uncorrected assumed position.

(2) Nautical Mile Plotting Method

(a) Set  $360^\circ$  under the index.

(b) Note the number of nautical miles of latitude and longitude difference between the resolved fix center and the grommet. (Use the same scale as was used in plotting the LOPs). Plot these differences on the chart from the assumed position. If the assumed position has been pre-adjusted on the chart for Coriolis and precession/nutation effects, no further adjustment of the fix is necessary. If the assumed position has not been pre-adjusted for these effects, it is recommended that the resolved fix center be adjusted on the CPU-48/P grid, using the procedure described in previous paragraph.

NOTE: When  $360^\circ$  is set under the index, the CPU-48/P will be north oriented. Thus, if the fix falls in the upper left (northwest) quadrant of the CPU-48/P grid, the charted fix must be plotted north and west of the assumed position.

(3) Coordinate Conversion Method

(a) Set  $360^\circ$  under the index. The CPU-48/P is now oriented to true north, with the grommet representing the assumed position.

(b) Read the latitude adjustment in minutes of arc (using the same scale as was used to plot the LOPs) from the position of the resolved fix center; record in the CPU-48/P latitude adjust block on the celestial precomputation form. If the fix is above the horizontal line running through the grommet, record adjustment as North; if below the grommet, record as South.

(c) To find the longitude correction in minutes of arc, note the number of nautical miles the fix lies to the right or left of the vertical center line running through the grommet. Rotate the plotting face until fix latitude in degrees is under the index. Find the point along the M/B latitude scale line which intersects the longitude in nautical miles correction, measuring left from the vertical center line (using the same scale as was used in plotting the LOPs); mark this point. Rotate the plotting face until  $360^\circ$  is again under index. Read the number of minutes of longitude correction from the grommet left to the mark made on the M/B latitude scale line. Record in the CPU-48/P longitude adjust block on the celestial pre-computation form. If the fix is left of the vertical line running

through the grommet, record correction as West; if the right of the grommet, record as East.

NOTE: If preferred, the slide rule side may be used to convert nautical miles to minutes of arc. The method is slightly more accurate than the plotting method and may prove somewhat faster in practice. To use, set fix latitude on the green COSINE scale under longitude adjustment in NM on the RANGE NM scale; read longitude adjustment in minutes of arc on the RANGE NM scale opposite the RANGE arrow. If the adjustment is more than 60 minutes of arc, convert to degrees and minutes (divide by 60 to obtain degrees and retain the remainder as minutes).

(d) Apply corrections to the coordinates of the assumed position to determine the celestial fix coordinates. Utilize blocks provided on celestial precomputation form. If the direction of the correction is the same as the assumed position coordinate, add the correction; subtract if different.

NOTE: If the assumed position has been pre-adjusted for Coriolis and precession/nutation effect, apply the corrections to the coordinates of the adjusted assumed position; otherwise adjust fix for these effects and apply corrections to coordinates of the uncorrected assumed position.

#### (4) Present Position (PP) Adjustment Method

(a) Record the PP coordinates at fix time; utilize the "PP counters" blocks provided on the celestial precomputation form.

(b) Subtract (algebraically) the PP coordinates from the celestial fix coordinates. The difference is the PP adjust. Correct the PP counters as soon as feasible.

NOTE: Various methods for adjusting the PP counters are available and may be utilized as desired or required by command or unit policy.

#### (5) MD-1 PP Adjustment Method. Figure 30.

(a) The present position counter readings represent both the DR and the assumed positions. The MD-1 provides a "running" readout of the intercepts which in turn indicate the BNS present position error (except for refraction and residual Coriolis effects). Intercept values other than zero represent PP error. Time is of no particular significance in the celestial fixing problem. Likewise, the PP error (difference between the PP counter readings and the celestial fix coordinates) is a running error; therefore, time required to determine this error and adjust the PP counters is not critical.

(b) Observe and record the extremes of the intercept readings. Determine the intercept average, utilizing the blocks provided in the MD-1 Celestial Computation Form, Figure 30. Apply refraction correction as required (note that the sign of the refraction correction depends upon the direction of the intercept; when the intercept average is zero, the sign of the refraction correction is plus,

and the intercept is plotted away).

(c) Plot the intercepts on the ~~map~~<sup>cpu-48/p</sup> and resolve the fix, using the procedure described above. Adjust the fix for residual Coriolis (Figure 30) if necessary. Determine the celestial fix coordinates by any of the methods previously described. REMEMBER: The ~~map~~<sup>cpu-48/p</sup> grommet always represents the uncorrected PP counter reading.

(d) Determine the PP counter adjustment utilizing the blocks provided in the MD-1 Celestial Computation Form, Figure 30.

(e) Adjust the PP counters at the earliest convenient moment. Various methods for adjusting the counters are available and may be utilized as desired or required by command or unit policy.

(6) Air Plot Wind Determination. Figure 28 If desired, the celestial wind may be determined on the ~~map~~<sup>cpu-48/p</sup> grid. This is accomplished as follows:

(a) Determine the coordinates of the air position at fix time (if the present position counters are being used to maintain air position, simply read and record the coordinates at fix time). Plot on chart. Measure range and bearing (or NM N-S/E-W) from assumed position.

(b) Plot the air position on the ~~map~~<sup>cpu-48/p</sup> grid relative to the grommet/assumed position using either the range and bearing or the nautical mile method. Set 360° under the index to secure north orientation, if using nautical mile procedure.

(c) After the celestial fix has been resolved, rotate the plotting face until the air position and the celestial fix are aligned vertically, with the air position on top. Read wind direction under the index. Measure the velocity component and convert to an hourly basis on the slide rule side.

i. Special Motion of the Body Correction for the Moon. If, when observing the moon, the observation time differs appreciably from the fix time and increased accuracy is desired, multiply the M/B adjustment as extracted from the ~~map~~<sup>cpu-48/p</sup> by the factor .93 (use slide rule side). The product is the lunar M/B adjustment.

NOTE: Because of its rapid change of declination and non-standard body motion, it is recommended that the moon be observed as close to the fix time as possible. Apply parallax and semi-diameter corrections in accordance with the guidance furnished on the celestial precomputation form, Figure 29.

#### j. Example.

(1) Given: DR latitude = 44-53N; DR longitude = 91-31W;  
Time of Fix = 0910 7 Oct 1963; GHA of Aries = 152-47; DR GS = 514 K;  
DR Track = 035°; DR TH: 038°; Bodies = Procyon, Polaris and Hamal;  
Scheduled Observation Times = 0907, 0910, 0913. Adjustments to be applied to  $H_0$ ; HO-249, Vol I, Epoch 1965.0 used to compute  $H_0$ , Zn and



(2) Solution: See celestial precomputation form, Figure 29.

k. GHA of Airies Table for Years 1963-1969, Figure 31. <sup>(omitted)</sup> This table is provided for the convenience of the navigator and may be used as desired in lieu of an air almanac. It is valid through 31 Dec. 1969.

1. <sup>(omitted)</sup> Supplementary Stars. A table of Supplementary Stars (epoch 1965.0) Figure 32, is provided to permit the navigator to utilize additional bodies when planning celestial fixes. These bodies may be freely integrated with bodies tabulated in HO-249, Vol I, or employed separately. Adjust the assumed position or fix for precession/nutation in accordance with Table 5, HO-249, Vol I, Epoch 1965.0, to obtain accurate LOP data for the years 1963-1969.

## 2. Target Timing Winds.

a. General. When synchronous or Doppler Winds cannot be obtained, it will be necessary to compute wind by the best backup means available. One of the better alternate methods is the target timing method, which can be profitably employed so long as a radar picture is maintained and at least one usable return can be tracked on the scope. It may be also employed with optical fixes. Two or more fixes, separated by a reasonable time interval, are required.

b. If altitude inputs continue to function and the radar VRM is maintained and can be set, the ranges may be plotted as ground ranges without conversion. However, if the altitude input and/or VRM have malfunctioned, it will be necessary to convert the slant range readings to ground (horizontal) range (HR), using the procedure described in Section IV, Paragraph 4b(2)(b).

### c. Example,

(1) Possibly the easiest way to explain the target timing wind computation on the ~~form~~ is to work through a practical example. In this sample problem, <sup>example</sup> it is assumed that both the stabilization and the VRM have malfunctioned so that the radar scope is oriented to aircraft heading (relative bearing display) and all measured ranges are slant ranges (FRMs). Further, assume MA-7A BNS (no FRM adjustment required). A return is tracked at the following relative bearings and slant ranges. (NOTE: Optical fixes may be computed and plotted in lieu of radar fixes, if desired or required:)

- (a) #1 =  $14^{\circ}/60$  NM.
- (b) #2 =  $17^{\circ}/40$  NM.
- (c) #3 =  $28^{\circ}/20$  NM.
- (d) #4 =  $134^{\circ}/10$  NM.

(2) Additional data: TH =  $46^{\circ}$ ; TAS = 468 K; time from first to last fix = 7'35" (455"); altitude above sighting point = 36,000 feet.

(3) Find: True bearings and ground ranges; GSK; distance tracked; wind direction and velocity.

(4) Solution:

(a) True bearings and ground ranges (REMEMBER:  $TB=RB+TH$ ):

1. #1 =  $14^{\circ} + 46^{\circ} = 60^{\circ}/60$  NM.

2. #2 =  $17^{\circ} + 46^{\circ} = 63^{\circ}/40$  NM.

3. #3 =  $28^{\circ} + 46^{\circ} = 74^{\circ}/19$  NM.

4. #4 =  $134^{\circ} + 46^{\circ} = 180^{\circ}/8$  NM.

NOTE: RB may be converted to TB on the <sup>CPU-48/p</sup> ~~MB-4A~~, if desired, by setting RB under the index; read TB on the ~~MB-4A~~ (inner) ring opposite TH on the ~~MB-4A~~ (outer) ring.  
WRITE

(b) Procedures:

1. Plot the fixes on the grid side of the <sup>CPU-48/p</sup> ~~MB-4A~~, setting TB at the index and plotting the ground ranges from the grommet toward the index, using the "tens" scale. The first fix is plotted with  $60^{\circ}$  under the index, 60 NM toward the grommet; the second fix is plotted with  $63^{\circ}$  under the index, 40 NM toward the grommet; etc., until all fixes are plotted.

2. Line up the fixes vertically, first fix at top; read Track =  $54^{\circ}$  under index.

3. Measure the distance between the first and last fixes. Read distance =  $64\frac{1}{2}$  NM (this is the ground speed component).

4. Turn to the circular slide rule side. Set time run (455") on the TIME scale under GS component ( $64\frac{1}{2}$  NM) on the RANGE NM scale. Read GS = 511 knots on the RANGE NM scale over the SEC arrow on the TIME scale.

5. At this point, all the information necessary to solve the wind problem (TH, TC, TAS, GS) has been obtained. The wind triangle may now be solved quite simply on the MB-4A type computer. However, the problem may be solved on the ~~MB-4A~~, if preferred, by continuing as described below, in the following steps:

a. Set the SEC arrow to TAS (468 K); read the TAS component (59 NM) on the RANGE NM scale above time run (455") on the TIME scale.

b. Now turn back to the grid side. Set TH =  $46^{\circ}$  under the index. Measure up 59 NM from the grommet toward the index and inscribe a mark at this point.

c. Set Track =  $54^{\circ}$  under the index; from the mark made in the previous step, plot the GS component ( $64\frac{1}{2}$  NM) vertically downward. Mark the end of this component (label "0"). What you are doing here is establishing the wind triangle.

d. Rotate "0" until it is exactly between the grommet and the index. Read the wind direction ( $288^{\circ}$ ) under the index and wind component velocity (10) from the grommet upward to the "0" mark.

e. Back to the circular slide rule side. Set 455" on the TIME scale under the wind component velocity, 10, on the RANGE NM scale. Read the wind velocity, 79 knots, above the SEC arrow. So there you have the wind;  $288^{\circ}/79$  knots.

c. Summary:

(1) Plot the fixes as you get them. Convert to TB if scope is not north oriented. Convert slant range to ground range when necessary (usually not required for the longer ranges). A minimum of two fixes are required; however, three or more fixes will provide improved track accuracy.

(2) Line up the fixes vertically (average them out if they won't make a straight line). Read track under index. Measure distance run (GS component) and compute GS on the slide rule side.

(3) Compute and plot the TH/TAS component for time run.

(4) Set up the wind triangle by plotting the GS component down from the end of the heading component. Line up the end of this line, "0", between the index and the grommet.

(5) Read wind direction and component velocity; convert to an hourly increment on the slide rule side.

3. Geometric Functions (not illustrated). If two sides and the included angle of any triangle are known, whether or not the triangle is a right triangle, the third side may be found by plotting on the grid. The procedure is as follows:

a. Set the index to  $360^{\circ}$ ; inscribe a mark between the grommet and the index corresponding to the value of one of the two known sides (use the most convenient scale).

b. Set the index to the value of the included angle; inscribe a mark between the grommet and the index corresponding to the value of the second known side, using the same scale as in step a, above.

c. Measure the distance between the two inscribed marks. Find the value of the third side by either of the two following methods:

(1) Counting method. Rotate the face until the two marks lie on the same horizontal or vertical plane. Count the number of grid lines between the marks. This is the value of the third side.

(2) Divider method. Arc off the distance (with dividers) between the two inscribed marks. Place this distance along any convenient horizontal or vertical scale (use the same scale as was used for plotting the points); read value of the third side.

d. Example

(1) Given: The known sides of a triangle are 53 NM and 71 NM, respectively; the included angle is  $115^{\circ}$ . Find the third side.

(2) Solution: The value of the third side is  $104\frac{1}{2}$  NM.



CELESTIAL COMPUTATION											SHEET NO.		
NAVIGATOR											HO - 249		
STAR SELECTION BY AZIMUTH			TH/GH	O	FIX TIME			DATE (#)		ALT MSL (1000 FT.)			
			TC/GC	O	BODY								
			GS	K	BASE GHA								
			CORIOLIS OR COR/RH L	R	L	CORR							
			PREC/NUT	NM	O	SHA(+)							
			DR LAT	N	S	GHA							
			DR LONG	W	E	ASSUM -W LONG +E							
MOTION ADJUSTMENTS	MOTION OBSERVER	+	+	+	+	+	LHA						
	MOTION BODY	-	-	-	-	-	ASSUM LAT	O	H	S			
	COMBINED 1 MIN ADJ	+	+	+	+	+	DEC	N	N	N	N	N	
	X TIME DIFF (FIX/PL OBS)	E	E	E	E	E	PLANNED OBS TIME						
MOTION ADJUSTMENTS	TOTAL MOT. ADJUST.	-	-	-	-	-	ACTUAL OBS TIME						
	MOON	PX	-	-	-	-	TAB H <sub>c</sub>						
	REFR	+	+	+	+	+	CORR <sup>D</sup> DEC	+	+	+	+	+	
MISC ADJ	PERS/SEXT	-	-	-	-	-	H <sub>c</sub>						
	TOTAL ADJ →	+	+	+	+	+	TOTAL → ADJ	+	+	+	+	+	
W/V ACCELERATION ADJUSTMENTS	INITIAL HEADING	0	0	0	0	0	ADJ H <sub>c</sub> (Set)						
	TH	+	+	+	+	+	HOFF TIME MOT ADJ (PL/ACT)	+	+	+	+	+	
	ADJ INIT HEADING	0	0	0	0	0	ACCEL W ADJ V	+	+	+	+	+	
	TERMINAL HEADING	0	0	0	0	0	POST ADJ H <sub>c</sub>						
	WANDER	+	+	+	+	+	H <sub>0</sub>						
	X WF	+	+	+	+	+	INTERCEPT	T	T	T	T	T	
	W ADJ	+	+	+	+	+	Zn	0	0	0	0	0	
	INITIAL VELOCITY (K)						CONV HW ANGLE -E	0	0	0	0	0	
	TERMINAL VELOCITY (K)						GRID Zn	0	0	0	0	0	
	V ACCEL (K)	+	+	+	+	+	SRB (Set)						
X VF	+	+	+	+	+	SRB <sub>0</sub> (Observed)							
V ADJ	+	+	+	+	+	TH/GH							
REFRACTION TABLE (Condensed)			ASSUM COORD	N	W	CEL FIX COORD	N	W	ADJ FIX TIME	E			
R	ALTITUDE MSL (Thousands of Feet)			ADJ	+	N	PP COUNTERS (-)	N	E	TIME ADJ	E		
	0	10	20	30	40	50				L			
	1	6.30	5.50	4.60	3.60	2.60	1.70						
2	3.30	2.60	1.90	1.40	90	-60							
3	2.10	1.60	1.20	80	50	2-40							
	1.60	1.20	80	60	3-10	1-30	CEL FIX COORD	N	W	LONG ADJ	E, 0, W		
							PP ADJ	+	N	+	W		
								-	S	-	E		
											Early = Eset (15'/Min)		

FIGURE 29. CELESTIAL PRECOMPUTATION,  
(PERISCOPIC SEXTANT)  
sliderulemuseum.com

CELESTIAL COMPUTATION: MD-1 AUTOMATIC ASTRO COMPASS										SHEET NO.		
NAVIGATOR					DATE (#)			FIX TIME				
PRESENT POSITION		LAT		LONG		TH/GH		W/V		TAS		DISTANCE
COUNTERS		-		+		RUN		K		K		NM
PRES. POSN ADJUST		+		-		TC/GC		W/V		TH/GH		MM
CEL. FIX COORD		-		-		TO RUN		GS		DISTANCE		TIME
CEL. FIX COORD		-		-		GS		K		NM		ETA
BODY	#1	#2	#3	TAS	K	ALTY MSL						
SHA	°	STAR DATA PANEL	°	STAR DATA PANEL	°	STAR DATA PANEL	SUN #1					
DEC	°	N	°	N	°	N	SUN #2					
MAX	T	A	T	A	T	A	SUN #3					
MIN	T	A	T	A	T	A	SUM					
INT. AVG	T	A	T	A	T	A	INT. AVG					
REFR. CORR. *	-	+	-	+	-	+	REFR. CORR.	Y-				
INT.	T	A	T	A	T	A	INT.					
Zn							Zn					
CONV.	+W	-E	+W	-E	+W	-E	CONV.	+W				
GRID Zn							GRID Zn					
PRESENT POSITION ADJUSTED TO THE FIX POSITION												
NORTH LATITUDE				SOUTH LATITUDE								
WEST-LONG		EAST-LONG		WEST-LONG		EAST-LONG						
N		N		N		N						
+		+		+		+						
-		-		-		-						
+		+		+		+						
-		-		-		-						
<p>These diagrams indicate the signs of adjustments to the present position counters for correcting them to the fix position. The cross at the center represents the present position counter values. With the fix falling in one of the quadrants, the signs in that quadrant indicate the directions that present position latitude and longitude adjustments are made to move present position to the fix. The signs apply to latitude and longitude adjustments respectively.</p> <p>EXAMPLE: Flight is in NORTH latitude and EAST longitude.  Present position recorded at fix time: 54-15 N 170-20 E  Latitude/Longitude adjustment: + 5 N -17 E  Celestial Fix (at fix time) is in NW Quad: 54-20 N 170-03 E  (Increase PP Lat by 5'; Decrease PP Long by 17')</p>												
RESIDUAL CORIOLIS ADJUSTMENT												
DR LAT	°	N	PRESENT GS	K	ADJUST FIX OR ASSUMED POSITION	NM	R	PRESENT TC	°			
		S				L						
<div style="display: flex; justify-content: space-between;"> <div style="width: 60%;"> <p>MD-1 RESIDUAL CORIOLIS ADJ. - NM</p> <p>GROUND SPEED KNOTS</p> <p>RESIDUAL ADJ. - NM</p> <p>LEFT RIGHT</p> <p>In North Lat, apply adjustment to fix or assumed position to LEFT if entry is from left (GS less than 450K); apply to RIGHT if entry is from right (GS more than 450K). Reverse rule for South Lat.  EXAMPLE: GS = 525K; Lat = 50° North.  Fix Adj. = 1/2 NM to right.</p> </div> <div style="width: 35%; font-size: small;"> <p>GROUND SPEED KNOTS</p> <p>RESIDUAL ADJ. - NM</p> <p>LEFT RIGHT</p> <p>In North Lat, apply adjustment to fix or assumed position to LEFT if entry is from left (GS less than 450K); apply to RIGHT if entry is from right (GS more than 450K). Reverse rule for South Lat.  EXAMPLE: GS = 525K; Lat = 50° North.  Fix Adj. = 1/2 NM to right.</p> </div> </div>												

\*If intercept is zero (0), sign of refraction correction is PLUS and the intercept is plotted AWAY.

FIGURE 30. CELESTIAL PRECOMPUTATION,  
(MD-1 AUTOMATIC ASTRO COMPASS)

Figure 34-1GLOSSARY OF NAVIGATION/BOMBING ABBREVIATIONS

ALT	- Altitude.
AR	- Actual Range. AR = WR - TRAIL.
ATA	- Actual Time of Arrival.
ATF	- Actual Time of Fall (BNS Ballistic Setting, normally but not necessarily identical to TTD).
BNS	- Bombing and Navigation System.
BRL	- Bomb Release Line or Locus (used interchangeably).
BW*	- Ballistic Wind (a fictitious wind, being the weighted average of all the winds which act upon a gravity weapon during its trajectory).
CO	- Course Offset Component Distance, i.e., the perpendicular distance of the OAP from true course (track) or extended true course (track).
COORD	- Coordinates (Geographical or Grid).
DA or DA <sup>o</sup>	- Dropping Angle.
DBW	- Differential Ballistic Wind (the vectoral difference between the wind existing at release altitude, WA, and the ballistic wind, BW).
DEC	- Declination.
DGZ	- Designated Ground Zero.
DR	- Dead Reckoning.
ETA	- Estimated Time of Arrival.
FRM	- Fixed Range Mark (slant range value).
GC	- Grid Course.
GH	- Grid Heading.
GHA	- Greenwich Hour Angle.
GS	- Ground Speed.
GSK	- Ground Speed in Knots.
G Zn	- Grid Azimuth



Figure 34-2

- $H_C$  - Computed Altitude (normally, as tabulated in HO-249).
- $H_O$  - Observed Altitude (assumed to be same as  $H_S$ , sextant altitude in this text).
- HO-MO-TO - A coined guide-word to remind the navigator that when the  $H_O$  is more (greater value) than the  $H_C$ , the intercept is to be plotted toward the sub-point of the celestial body.
- HR - Horizontal Range (same as Ground Range).
- $HR_C$  - HR adjusted for CO (Off course sighting).
- $HR_t$  - HR adjusted for Trail (I.e., the ground distance of the airplane from the VIP at the instant of target sighting).  $HR + TRAIL = HR_t$ .
- IP - Initial Point.
- LR - Last Resort; an emergency bombing technique whereby the pilot determines the bomb release point by means of a pre-determined timing sequence initiated from a fixed angle visual sighting device; the actual angle is dependent upon aircraft (B-47 or B-52), pressure altitude, Mach and gross weight.
- LAT - Latitude.
- LONG - Longitude.
- LOP - Line of Position.
- M/B - Motion of the Body.
- M/H - Magnetic Heading.
- M/O - Motion of the Observer.
- MSL - Mean Sea Level.
- NM - Nautical Mile.
- OAP - Offset Aiming Point
- OAR - Offset Actual Range.  $OAR = AR + RO$ .
- $OAR_C$  -  $OAR$  adjusted for CO (off course sighting).
- ODA or  $ODA^\circ$  - Offset Dropping Angle.
- OHR - Offset Horizontal Range (ground range from the airplane to the target at the instant of OAP sighting).

Figure 34-3

OHR <sub>t</sub>	- OHR adjusted for trail, i.e., the ground distance of the airplane from the VIP at the instant of OAP sighting).
PP	- Present Position.
PX	- Parallax (applicable to Lunar sightings, primarily).
RB or RB <sup>o</sup>	- Relative Bearing.
RO	- Range Offset component distance, i.e., the range distance of the OAP, parallel to track, to the target.
SA or SA <sup>o</sup>	- Sighting Angle.
SEC	- Seconds.
SD	- Semi-Diameter (applicable to Lunar sightings, primarily).
SHA	- Siderial Hour Angle.
SP	- Sighting Point.
SRB	- Sextant Relative Bearing (periscopic sextant).
SRB <sub>o</sub>	- Observed SRB.
TAS	- True Air Speed (in knots unless otherwise specified).
TB	- True Bearing.
TC	- True Course.
TI	- Time-to-Impact, i.e., the time in seconds from the of target/or OAP sighting to weapon impact and/or burst.
TGT	- Target.
TH	- True Heading.
TIL	- Timing Initiation Line.
TIP	- Timing Initiation Point.
TR	- Track .
TTD	- Time-to-detonation, i.e., the time in seconds from the instant of weapons release to detonation (normally, but not necessarily, the same as ATF).

Figure 34-4

- TTR - Time-to-Release, i.e., the time from the instant of target or OAP sighting to release.
- V - Velocity.
- VF - Velocity Factor (for one knot of increased GS or TAS during a celestial observation).
- VIP - Virtual Impact Point, i.e., a fictitious point located trail distance beyond the target along the extension of the release track; used in emergency (alternate) bombing solutions.
- W - Wander (amount of heading wander during the celestial observation).
- WA - Wind at altitude, i.e., the wind existing at release altitude, used automatically by the BNS or manually by the navigator to determine the airplane bomb run heading, drift correction, crosstrail and release point.
- W/C - Wander/Coriolos constant (26.25)
- WF - Wander Factor (for one degree of right heading wander during a celestial observation).
- WR - Whole Range.  $WR = ATF \times GS$  in Ft/sec.
- Zn - Azimuth (celestial).

