# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE *(DD-MM-YYYY)* | 2. REPORT TYPE | 3. DATES COVERED *(From - To)* |
|---|---|---|
| 09-11-2009 | Final | |

**4. TITLE AND SUBTITLE**
Test Operations Procedure (TOP) 3-2-836 (2.1.2)
Combat Vehicle Fire Control Systems - Gun/Sight Synchronization

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHORS**

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
US Army Aberdeen Test Center (TEDT-AT-AD)
400 Colleran Road
Aberdeen Proving Ground, MD 21005-5059

**8. PERFORMING ORGANIZATION REPORT NUMBER**
TOP 3-2-836 (2.1.2)

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Test Business Management Division (TEDT-TMB)
US Army Developmental Test Command
314 Longs Corner Road
Aberdeen Proving Ground, MD 21005-5055

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
Same as item 8

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution unlimited.

**13. SUPPLEMENTARY NOTES**
Defense Technical Information Center (DTIC), AD No.:
This TOP supersedes ITOP 3-2-836 (2.1.2), dated 31 March 1987

**14. ABSTRACT**
This TOP describes tests for measuring and evaluating the capability of vehicle-mounted main-gun sighting systems; particularly those systems located apart from the gun mount, to maintain the prescribed azimuth and elevation relationship with the gun-bore axis for all positions of gun elevation and depression.

The reader is referred to TOP 3-2-836 (0) Combat Vehicle Fire Control Systems - Overview Document or International Test Operations Procedure (ITOP) 3-2-836 (0) Combat Vehicle Fire Control Systems - Overview Document.

**15. SUBJECT TERMS**

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | B. ABSTRACT | C. THIS PAGE | | | 19b. TELEPHONE NUMBER *(include area code)* |
| Unclassified | Unclassified | Unclassified | SAR | 24 | |

**Standard Form 298** (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure (TOP) 3-2-836 (2.1.2) 09 November 2009

# COMBAT VEHICLE FIRE CONTROL SYSTEMS GUN/SIGHT SYNCHRONIZATION



*This TOP supersedes ITOP 3-2-836 (2.1.2), dated 31 March 1987.

Approved for public release, distribution unlimited.

1. SCOPE.

This TOP describes tests for measuring and evaluating the capability of vehicle-mounted main-gun sighting systems; particularly those systems located apart from the gun mount, to maintain the prescribed azimuth and elevation relationship with the gun-bore axis for all positions of gun elevation and depression.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities. (For slope method)

| Item | Requirements |
|---|---|
| Test slope | To position the vehicle for simulation of full elevation and depression angles in 5° increments at a stationary gridboard. |
| Mounting hardware (e.g., V-block) | To facilitate mounting or installation of measurement devices (e.g., reference telescope). |
| Gridboard | Panel with grid spacing marked to permit location of aiming points within 0.1 mrad* for distance deployed from the gun. |

2.2 Instrumentation.

| Devices for Measuring | Permissible Error of Measurement** |
|---|---|
| Angular deviation of line of sight (LOS) of the vehicle sighting devices and the bore axis (e.g., with a telescope at muzzle or breech for slope method OR with a collimator at the gun for the collimator method) | 0.1 mrad |
| Angular elevation of gun (e.g., gunner's quadrant) | 0.5° |
| Cant angle of gun | 1 mrad |

*The preferred unit for angular measurement is the radian. Milliradian (mil) or degree units may be used when required; units of measure must be identified.

**The permissible error of measurement (instrumentation) is the two-sigma value for a normal distribution; thus, the stated errors should not be exceeded in more than 1 measurement of 20.

## 3. REQUIRED TEST CONDITIONS.

### 3.1 Inspection and Servicing.

a. Ensure that all required system maintenance is performed in accordance with applicable Technical Manuals, Lubrication Orders, or other guidance documents.

b. Ensure that:

(1) All operating systems are up to proper speeds (gyroscopes), and all systems are at normal operating temperatures (electro-optical and mechanical).

(2) The torque friction and backlash at the turret and gun coupling locations are within specified values. If the torque friction and backlash are within specification but not optimal, do not optimize. The test should be conducted within the specification range.

(3) The gun balance complies with specified values as applicable. Provide weight compensation for any installed instrumentation to maintain proper balance as necessary.

### 3.2 Stowage.

a. Stow the test vehicle with the required complement of ammunition (actual or simulated) and all items of on-equipment materiel (actual or simulated) to provide the moment of inertia and center of gravity of a combat loaded vehicle.

b. Attach all equipment (or simulant) to the gun that is normally attached during combat, e.g., searchlight, telescope, coaxial machinegun, machinegun ammunition belt, ballistic shield.

c. Load a dummy round of ammunition (one that simulates the primary round carried by the vehicle) in the gun during all non-firing stabilization system tests.

### 3.3 Safety.

Safety procedures pertinent to the test area and test vehicle should be adhered to at all times. The following procedures should be considered:

a. Inspect the system for safety hazards before testing, and continually monitor the system for hazards during testing.

b. Use experienced vehicle operators who have received training on the test system.

c. Ensure that adequate protective clothing and equipment is worn**,** e.g., helmets, safety shoes, eye and ear protection.

3.4 Slope Method.

3.4.1 Facilities.

Synchronization data can be adversely influenced by excessive gun cant and, the combination of sight-to-gun parallax and insufficient gridboard and boresighting ranges. Care should be taken to minimize the effects of these parameters. A complete explanation of the geometric complexities and dependency of the associated parameters and of corrective calculations for cant is presented in Appendices A through D. Controlling the parameters of gun cant and gridboard and boresight ranges by proper preparation of the test facilities is advised. The following procedure minimizes undesirable influences to preclude corrective calculations.

a. Determine the maximum sight-to-gun parallax (sight to gun offset), from engineering drawings or by direct measurement. Choose the value that is the largest linear distance regardless of axis. Call this maximum sight-to-gun parallax ‘b’.

b. Determine the maximum sight-to-gun reference telescope parallax (sight to reference telescope offset), from engineering drawings or by direct measurement. Choose the value that is the largest linear distance regardless of axis. Call this maximum sight-to-gun reference telescope parallax‘d’.

c. Using Figure 1, the parallax distance b, the minimum boresight range, $R_{J_{min}}$ (based on facility capability) and the maximum distance the tank will travel from its initial position, $s_{max}$ (based on facility capability) determine the minimum gridboard distance, $R_{G_{min}}$ that must be maintained to minimize parallax induced errors.

$s_{max}$ is based on change in the range (slant range) to the gridboard, lateral displacement is not important.

Example: The sight is 1 and 0.5 meter to the left and below the gun respectively for the combat vehicle under test. Figure 1 is entered from the lower right side at a value of ‘b’ equal to 1 meter. The test facility has boresight targets at 1000 and 1200 meters. Proceed up from the parallax gun-sight axis until the 1000-meter $R_{J_{min}}$ line is intersected. The test facility design requires the combat vehicle to move a maximum of 15 meters when measuring the full range of gun elevations (backing up a slope or moving from a forward to a backward sloped ramp). Proceed left from the 1000-meter $R_{J_{min}}$ line to intersect the 15-meter $s_{max}$ line. Then proceed down to the $R_{G_{min}}$ axis and determine the minimum gridboard distance required to control parallax induced errors to a negligible level, 300 meters.

(1) Actual gridboard distance $R_G$, considering scintillation effects.

(2) Cant angle limit $K_L$.

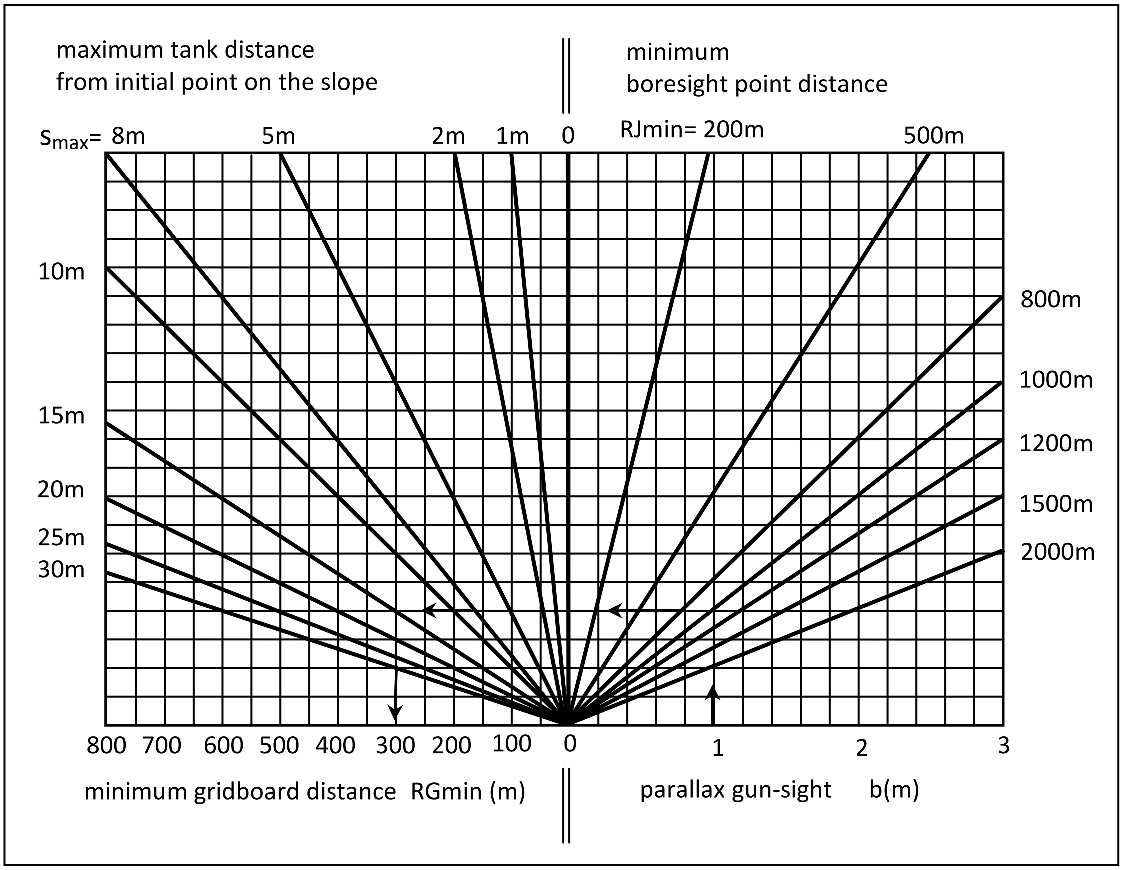



Figure 1. Determination of minimum gridboard distance.

d. Select a gridboard distance $R_G$, larger than $R_{G_{min}}$ that can be accommodated by the facility.

e. Using Figure 2, the actual gridboard distance $R_G$, and the parallax distance d, determine the cant limit $K_L$ that must be maintained to minimize gun cant induced errors.

Continuing the example from above, an actual gridboard distance of 500 meters is chosen (greater than $R_{G_{min}}$ = 300 meters). Physical measurements on the combat vehicle under test indicate that the gun reference telescope is 0.3 and 1.5 meters left and above the sight, respectively. Enter Figure 2 on the selected gridboard distance axis at 500 meters, proceed down to intersect with a‘d’ value of 1.5 meters. Proceed to the right and determine a maximum gun cant limit of 15 mrad required to control parallax induced errors to a negligible level.

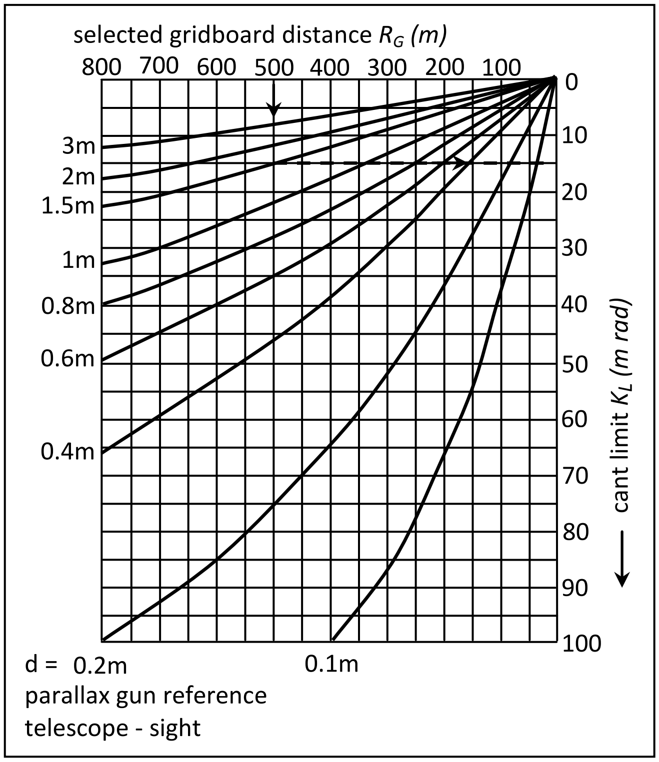



Figure 2. Determination of maximum gun cant limit.

f. Mount a calibrated gridboard in a vertical position, plumb, level, and perpendicular to the LOS at the selected distance $R_G$.

g. Select a test site for vehicle position that will minimize cant angle. For cant angles equal to or less than $K_L$ corrective calculations are not necessary. For cant angles greater than $K_L$, see Appendix A.

3.4.2 Instrumentation.

The specific instrumentation referenced in this TOP is considered typical. Equivalent measuring devices may be used.

a. Attach a telescope to the gun mount and align it with the mount to serve as a basic reference for all synchronization measurements. Telescope rigidity and repeatability are obtained by mounting (bolting or welding) a machined V-block to the mount as illustrated in Figure 3. The V-block mounting permits the telescope to be removed as necessary without compromising the reference base.

b. Prepare for and install, as necessary, mounting hardware to facilitate the use of telescopes at the muzzle or breech as bore-alignment references (Figure 4). The type of fire control system, physical limitations of test hardware and instrumentation, and objectives of the particular test determine what type or types of bore-alignment references should be used. Available muzzle scopes and breach scopes are acceptable as long as the permissible error of measurement is achieved.

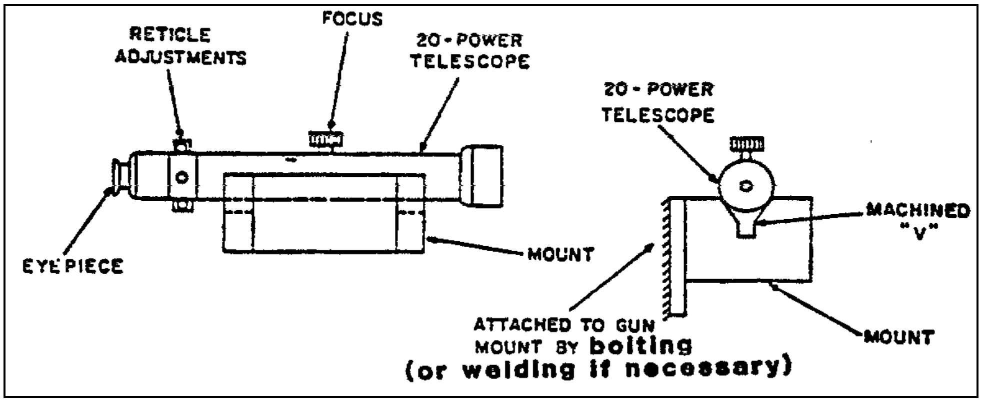



Figure 3. Reference telescope in V-block mount.

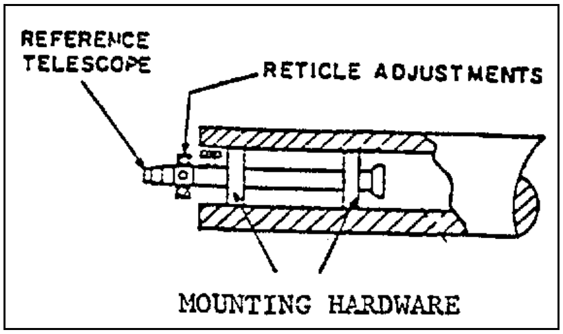



Figure 4. Reference telescope in bore mount.

3.4.3 <u>Test Controls</u>.

a. Obtain all measurements under similar conditions (air temperature, solar loading, prevailing atmospheric conditions, etc.).

b. Conduct initial alignment at minimum attainable temperature difference between vehicle interior surface and exterior surface.

c. Ensure that the distribution of the mass associated with gun movement is realistic (e.g., by inserting a dummy round).

3.5 <u>Collimator Method</u>.

3.5.1 <u>Facilities</u>.

Level test site.

3.5.2 Instrumentation.

a. Using appropriate mounting hardware, mount a collimator so that it moves in direct correlation with the gun (preferably on the gun mantlet).

b. Align the collimator so that the sight-reticle position can be read throughout the full range of gun elevation.

3.5.3 Test Controls.

a. Obtain all measurements under similar conditions (air temperature, solar loading, prevailing atmospheric conditions, etc.).

b. Conduct initial alignment at minimum attainable temperature difference between vehicle interior surface and the exterior surface. Slight mechanical changes on the collimator mounting (e.g., expansion due to temperature change) can affect collimator position and bias the data. Care must be taken that the required angular tolerance is not exceeded.

c. Ensure that the distribution of the mass associated with gun movement is realistic (e.g., by inserting a dummy round).

4. TEST PROCEDURES.

4.1 Slope Method.

a. Position the test vehicle as level as possible at the top of the test slope (Figure 5.), or at the base of a ramp.

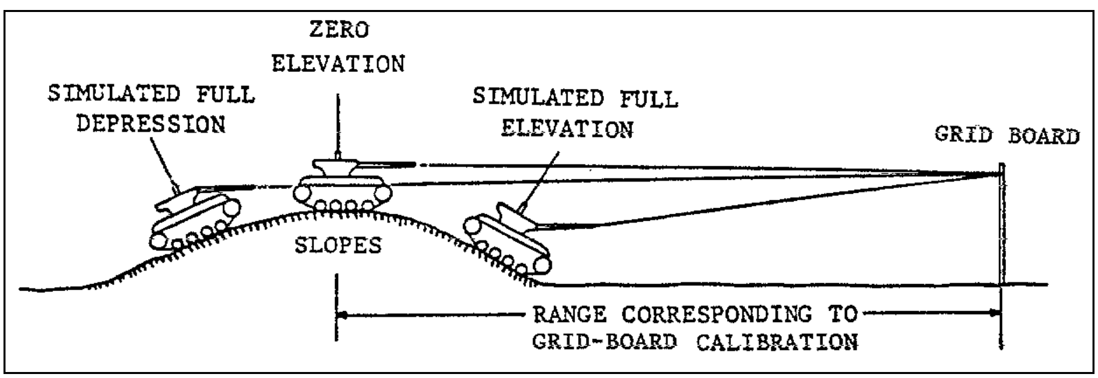
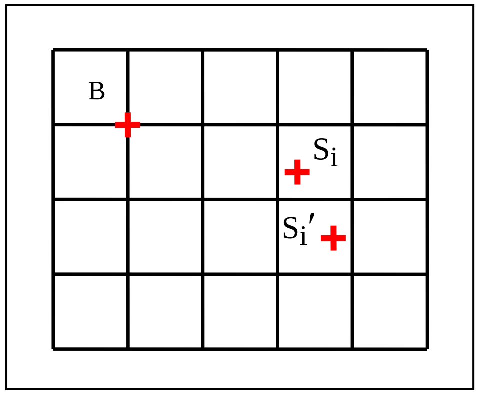



Figure 5. Test slope operation.

b. Boresight at a range in accordance with paragraph 3.4.1. The alignment angle between sight and gun (boresight mode or zeroed ballistic computer) must be maintained throughout the test.

c. Select an aim point B (Figure 6) on the gridboard to use throughout the remainder of testing. Select either a sight reticle or reference telescope reticle to lay on point B.




B = aiming point.
$S_i$ = e.g., sight reticle position, lay direction.
$S_i'$ = e.g., sight reticle position, lay direction.

Figure 6. Example of typical gridboard readings.

d. Using the same reticle as in paragraph 4.1c, re-lay on point B from high to low, right to left. Point $S_i$ in Figure 6 represents the reticle position(s) of the remaining sighting device(s) (e.g., main sight).

e. Repeat paragraph 4.1d, but lay from low to high, left to right (Figure 6, point $S_i'$). Differences from the readings recorded in paragraph 4.1d are measures of overall (system) backlash.

f. By changing the position of the tank on the slope or the ramp, the angle of elevation between gun and hull is changed in increments of 5° within the full operating range (e.g., -10 to +20°). Generally the positions of points $S_i$ and $S_i'$ will change with reference to their initial positions (0° elevation). The different readings $S_i$ and $S_i'$ resulting from this are identified by the index i (i = 0, 1, 2 ...) where i is an index for the gun elevation (Figure 6).

g. The reticle positions ($S_i$ and $S_i'$), the elevation angle (angle between gun and hull) and the gun cant angle must be recorded for each hull position (corresponding to the elevation angle).

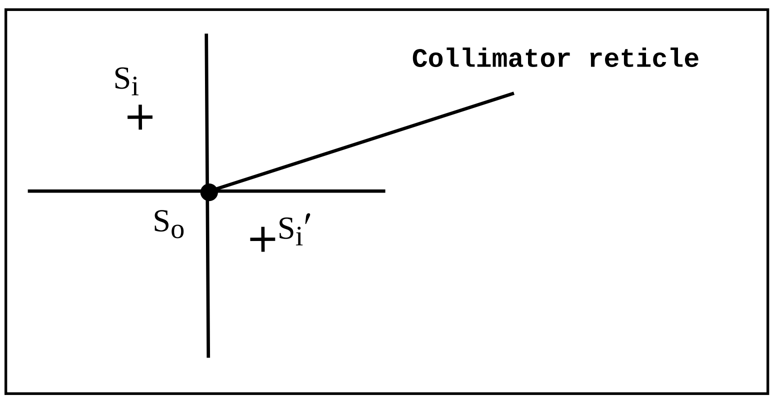
4.2 Collimator Method.

a. Position the tank on a level surface.

b. Switch to boresighting mode or zero the computer output if a different mode is used.

c. After laying the gun from top right to initial elevation (e.g., 0°), align the collimator in such a way that the reticle of the collimator and the reticle of the sighting device to be measured (e.g., main sight) coincide. This initial sight reticle position ($S_o$) is the reference point for measuring synchronization errors.

d. For this test, change the gun elevation in increments of 5° over the full operating range (e.g., -10 to +20°) while maintaining the same hull to turret offset angle. When positioning the gun on the desired elevation, lay from top right ($S_i$ in Figure 7) and from bottom left ($S_i'$ in Figure 7). The deviations of the sight reticle from the collimator axis will be recorded ($S_i$ and Si') for each gun elevation. Differences from the readings recorded ($S_i$ and Si') are measures of overall (system) backlash. The different readings $S_i$ and $S_i'$ resulting from this are identified by the index i (i = 0, 1, 2 ...), where i is an index for the gun elevation.




$S_o$ = initial position of sight reticle.
$S_i$ = position of sight reticle after laying from top right.
$S_i'$ = position of sight reticle after laying from bottom left.

Figure 7. Collimator field-of-view (FOV).

e. The reticle positions ($S_i$ and $S_i'$), the elevation angle (angle between gun and hull) and the gun cant angle must be recorded for each hull position (corresponding to the elevation angle).

## 5. DATA REQUIRED.

Record the following data:

a. Reticle positions of each incremental angle of gun elevation.

b. Reticle adjustment control readings (e.g., knob readings).

c. Elevation angle (angle between gun and hull).

d. Gun cant angle (angle between trunnion axis and earth horizontal).

e. Actual gridboard and boresight ranges.

f. Distance and direction tank moved from initial position (component movement along gun axis for slope method).

g. Identification of each test participant.

h. Model and serial numbers of sighting system and vehicle.

## 6. PRESENTATION OF DATA.

a. Calculate the system backlash for each gun elevation angle by calculating the difference between the values $S_i$ and $S_i'$ ($S_i$ - $S_i'$) for i = 0, 1... number of measurements. Present an average and one standard deviation value.

b. As a reference point for the calculation of synchronization error, select a point, $S_o$, for a specific gun elevation angle (e.g., 0°), then calculate $S_i$ - $S_o$ for i = 1, 2... number of measurements.

(1) For cant angles ≤ $K_L$, the differences directly represent the synchronization error.

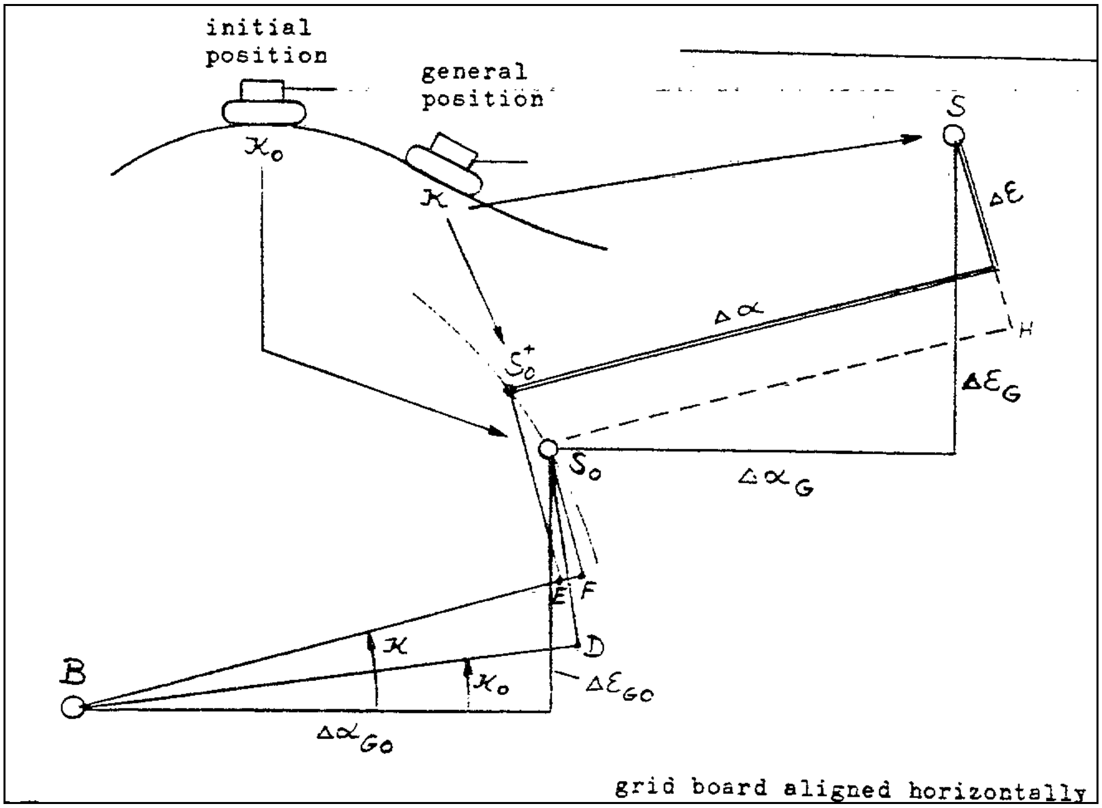
(2) For cant angles > $K_L$, the synchronization error is to be calculated with formula 1, Appendix A, when using the slope method.

c. Present the results of the synchronization error (paragraph 6b) and the system backlash (paragraph 6a) together with the gun elevation angle in a table, for comparison with tolerances established in requirements documents.

d. Graph the synchronization error (paragraph 6b) versus gun elevation angle. On the graph present the average and one standard deviation backlash value (paragraph 6a).

# APPENDIX A. INFLUENCE OF CANT ON THE SYNCHRONIZATION ERROR DETERMINATION IN THE SLOPE OR CRANE METHOD

The reading points and distances on the gridboard for the horizontal and canted gun coordinate systems are shown in Figure A-1.




KEY: B marked gridboard point for the gun reference telescope.

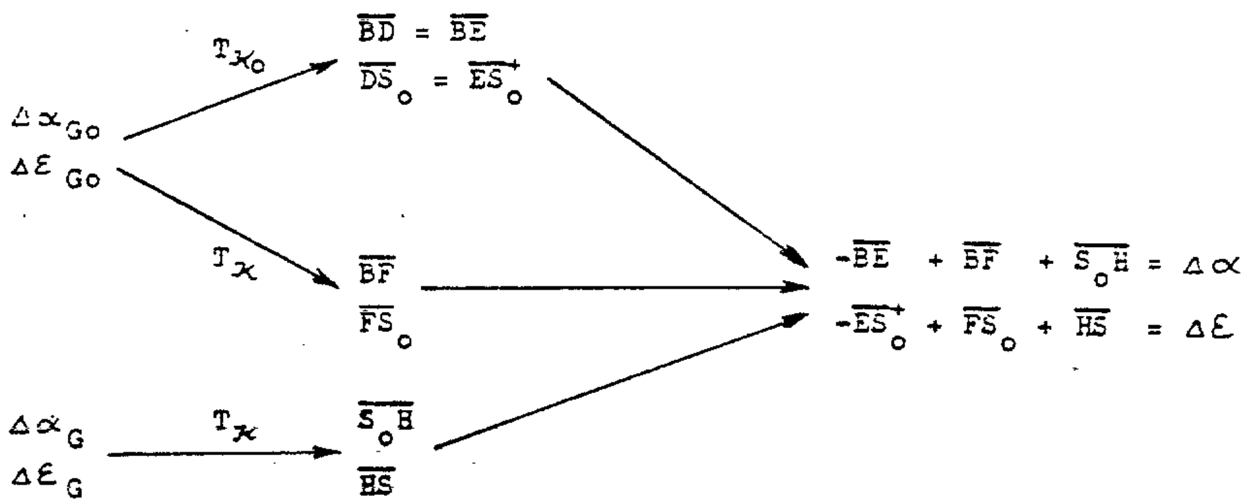
$S_o$..........LOS point for the initial position of the tank ($K_o$).
$S_o^+$.........Theoretical, nonreadable point, resulting from $S_o$ due to a change in cant K - $K_o$.
S...........LOS point for a general tank position (K).
o...........(Index) initial position, e.g., on top of the hill.
G..........(Index) gridboard.
$\Delta\alpha$, $\Delta\varepsilon$..................................Synchronization errors.
$\Delta\alpha_{Go}$, $\Delta\varepsilon_{Go}$, $\Delta\alpha_G$, $\Delta\varepsilon_G$.........Gridboard readings.

Only B, $S_o$, S are points that can be observed.

Figure A-1. Gridboard.

In spite of all efforts to level the hill during its construction, let the gun be canted by $K_o$ (measurement of K about the gun axis, counterclockwise is positive, in firing direction) in the initial position on the tank on top of the hill. In this position the boresighting is performed and the gun reference telescope is then aligned at point B marked on the gridboard, and finally the angles $\Delta\alpha_{Go}$ and $\Delta\varepsilon_{Go}$ between point B and the LOS point $S_o$ are noted. For the initial position the synchronization errors $\Delta\alpha$, $\Delta\varepsilon$ are defined to be zero.

For any other position on the slope (hill) angle K will assume a random value which is generally different from $K_o$. Thus the initial point of the LOS, $S_o$, has rotated to position $S_o^+$. The latter, however, cannot be observed. The synchronization errors $\Delta\alpha$ and $\Delta\varepsilon$ extend between $S_o^+$ and S and not between $S_o$ and S, and are derived as follows:




T = the transformation of coordinates.
x = u cos K + v sin K.
y = v cos K - u sin K.

Transformation $T_{K_o}$ is analogous with $K_o$ instead of K.

From the above scheme the synchronization errors in the gun coordinate system are as follows:

$$\Delta\alpha = \Delta\alpha_G \cos K + \Delta\varepsilon_G \sin K + \Delta\alpha_{Go}(\cos K - \cos K_o) + \Delta\varepsilon_{Go}(\sin K - \sin K_o)$$
$$\Delta\varepsilon = \Delta\varepsilon_G \cos K - \Delta\alpha_G \sin K + \Delta\varepsilon_{Go}(\cos K - \cos K_o) - \Delta\alpha_{Go}(\sin K - \sin K_o)$$

Formula (1)

## APPENDIX B. LIMITS OF CANT ANGLES IN THE SLOPE OR CRANE METHOD

For small cant angles K (about the gun axis), formula (1) needs not be considered, and thus permitting the following approximations (Figure A-1):

$$\Delta\alpha \approx \Delta\alpha_G$$

$$\Delta\varepsilon \approx \Delta\varepsilon_G$$

From this the following synchronization errors result:

$$\delta\Delta\alpha = \Delta\alpha_G - \Delta\alpha$$

$$= \Delta\alpha_G (1 - \cos K) - \Delta\varepsilon_G \sin K - \Delta\alpha_{Go} (\cos K - \cos K_o) +$$
$$- \Delta\varepsilon_{Go} (\sin K - \sin K_o)$$

$$\delta\Delta\varepsilon = \Delta\varepsilon_G - \Delta\varepsilon$$

$$= \Delta\varepsilon_G (1 - \cos K) + \Delta\alpha_G \sin K - \Delta\varepsilon_{Go}(\cos K - \sin K_o) +$$
$$+ \Delta\alpha_{Go}(\sin K - \sin K_o).$$

Since K is small, the following approximations will suffice to determine the K limit:

$$\delta\Delta\alpha \approx -(\Delta\varepsilon_{Go} + \Delta\varepsilon_G)K + \Delta\varepsilon_{Go}K_o$$

$$\delta\Delta\varepsilon \approx (\Delta\alpha_{Go} + \Delta\alpha_G)K - \Delta\alpha_{Go}K_o$$

K and $K_o$ have the same limit $K_1$ (1 = limit) in common. With the transition:

$$\begin{array}{lll} \alpha \text{ - equation: } -K = K_o & \searrow & \\ & & K_1 \\ \varepsilon \text{ - equation: } \phantom{-}K = -K_o & \nearrow & \end{array}$$

the last equations change into:

$$\delta\Delta\alpha_{tol} = (2\Delta\varepsilon_{Gomax} + \Delta\varepsilon_{Gmax})K_1$$

$$\delta\Delta\varepsilon_{tol} = (2\Delta\alpha_{Gomax} + \Delta\alpha_{Gmax})K_1.$$

The $2\sigma$ value of the basic angular tolerance is considered a reasonable value for still acceptable errors when measuring synchronization errors, therefore

$$\delta\Delta\alpha_{tol} = \delta\Delta\varepsilon_{tol} \equiv 2\sigma = 0.1 \text{ mrad.}$$

Maximum values for the synchronization errors are layed down in the relevant specifications. For turret-type battle tanks these values normally do not exceed 0.5 mrad, hence

$$\Delta\alpha_{Gmax} = \Delta\varepsilon_{Gmax} \equiv 0.5 \text{ mrad.}$$

$\Delta\alpha_{Go}$ and $\Delta\varepsilon_{Go}$ are angular components belonging to the gridboard distance $\overline{BS}_o$ (index o: slope or crane initial position and bore-sighting, see App A.) Figure B-1 shows that

$$\overline{BS}_{o\,\max} = d \text{ (Resulting parallax distance with the components } d_\alpha, d_\varepsilon)$$

$$\Delta\alpha_{Go} = \frac{d_\alpha}{R_G} \leqq \frac{d_{\alpha\,\max}}{R_G} = \frac{d}{R_G} = \Delta\alpha_{Go\,\max}$$

$$\Delta\varepsilon_{Go} = \frac{d_\varepsilon}{R_G} \leqq \frac{d_{\varepsilon\,\max}}{R_G} = \frac{d}{R_G} = \Delta\varepsilon_{Go\,\max}\,.$$

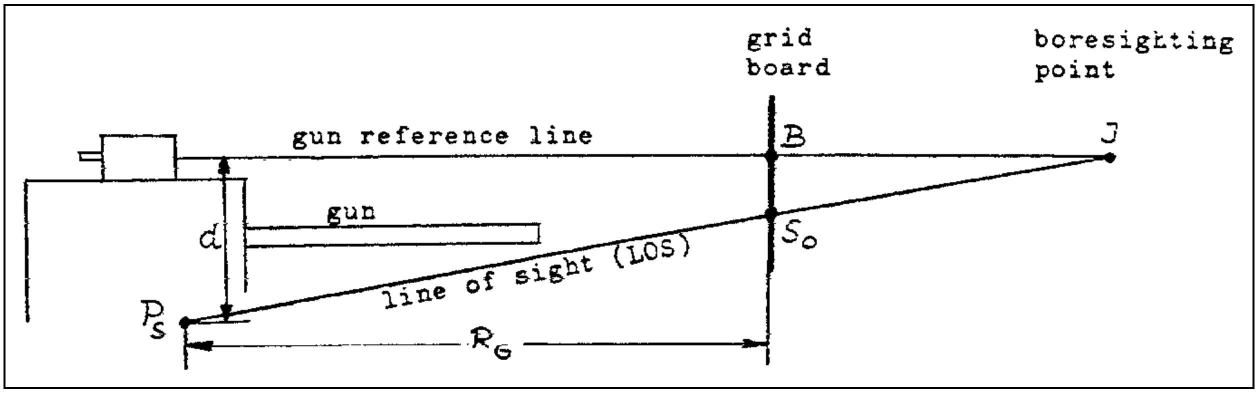



Figure B-1. Geometry of boresighting.

From this the following cant angle limit is obtained:

$$\boxed{K_1 = \frac{1}{\frac{2d}{R_G}\,10^4 + 5}} \qquad K \leqq K_1 : \begin{cases}\Delta\alpha = \Delta\alpha_G \\ \Delta\varepsilon = \Delta\varepsilon_G\end{cases}$$

Formula (2)

$$K > K_1 : \left.\begin{cases}\Delta\alpha = \Delta\alpha(K) \\ \Delta\varepsilon = \Delta\varepsilon(K)\end{cases}\right\} \text{Formula (1), Appendix A.}$$

# APPENDIX C. GRIDBOARD READING ERRORS DUE TO A CHANGE OF TANK POSITION ON THE SLOPE

While the collimator (paragraph 4.2) in the capacity of goniometer permits direct measurement (as is desired) of the deviation angles within the gun coordinate system, the deviation angles of synchronization (synchronization errors) are measured indirectly by way of length (grid spacing), when using a gridboard. If the calibration of angles for the grid spaces has been carried out at a defined tank position on the slope (typically on top of the hill = initial position), a gridboard reading from any other position will be erroneous. In order to avoid a recalibration for each position, the conditions giving still acceptable calibration errors are determined as follows:

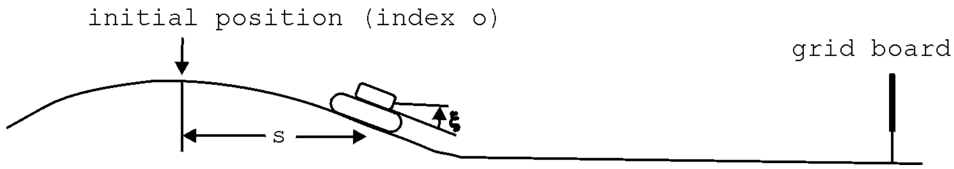



Figure C-1. Variation of the elevation angle ξ caused by a change of the tank position on the slope.

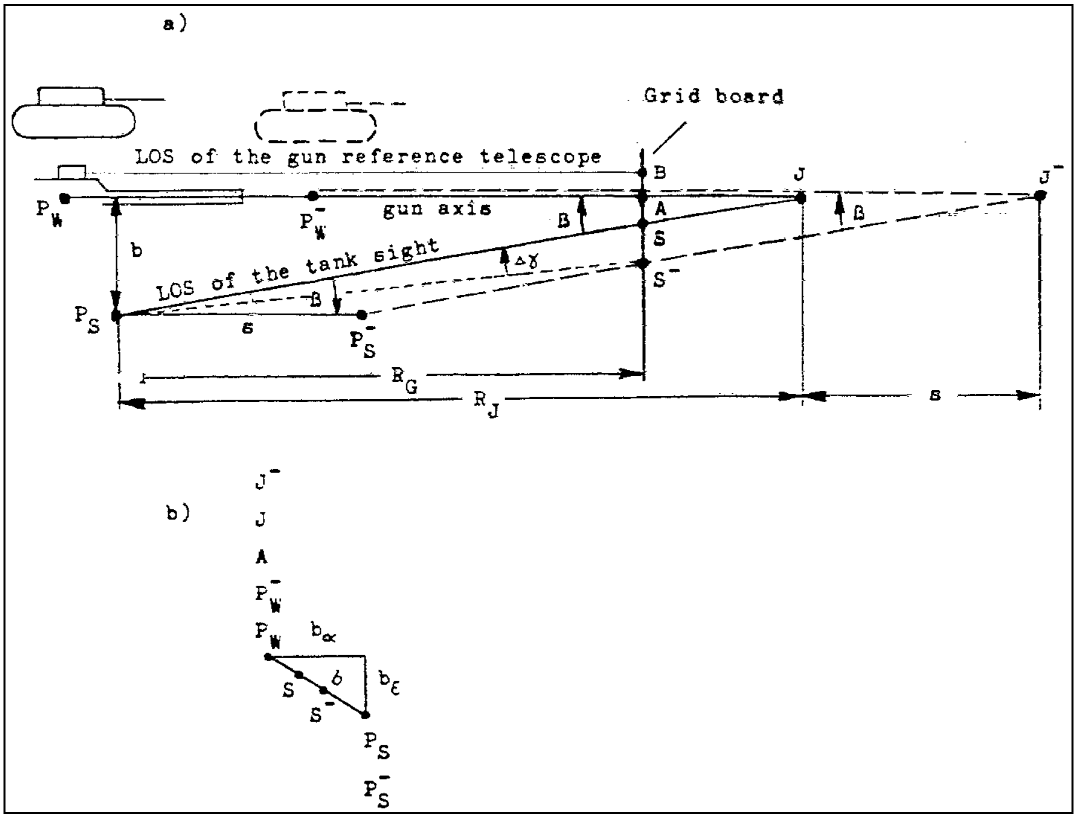
As has been verified by a check calculation, translatory changes of position perpendicular to the LOS can be ignored for the gridboard calibration. However, changes of the tank-to-gridboard are more critical, and their effects are investigated by means of Figure C-2.

After the tank has moved along the gun axis by the distance s as shown in Figure C-2 the gridboard reading $\overline{BS}$ is transformed into $\overline{BS}$ (provided the parallax angle β remains unchanged). $\overline{SS}$ represents the reading error caused by the change of position and corresponds to the angular error$\Delta\gamma$. $\Delta\gamma$ must be kept so small that the basic angular tolerance ($2\sigma = 0.l$ mrad) is not substantially exceeded.

$$\Delta\gamma = \frac{\overline{SS}}{R_G} = \frac{s \tan B}{R_G} = \frac{sb}{R_G R_J}.$$

With $\Delta\gamma \longrightarrow \Delta\gamma_{tol}$ (acceptable error) and $s \longrightarrow s_{max}$(maximum distance) the above formula changes into the following inequality:

$$\boxed{R_J \geqq \frac{b \;\; s_{\max}}{R_G \;\; \Delta\gamma_{tol}}} \qquad \text{Formula (3)}$$




KEY: $P_W$ Gun rotation point (W = Weapon).

$P_S$ Tank sight rotation point.

b Distance of the gun and sight rotation points perpendicular to gun axis.

J Boresighting point of gun and sight.

A Intersection point of the gun axis with the gridboard.

B Intersection point of the LOS of the gun reference telescope with the gridboard, marked on the gridboard.

S Intersection point of the LOS of tank sight under test with the gridboard (point to be read).

$R_G$ Gridboard distance from initial position of tank.

$R_J$ Distance between the boresighting point and the initial position of the tank.

\- Identifies points after tank movement by the distance a.

$\beta$ Parallax angle (geometric resultant).

$\Delta\gamma$ Reading angle error due to change of tank position by the distance s (geometric resultant).

Figure C-2. Gridboard calibration errors due to the components of the tank movement along the gun axis. The figure shows the resulting angular geometry along the gun axis and perpendicular to the gun axis.

$\Delta\gamma$ is a systematic error that together with the random error produces the resultant error of the gridboard reading.

The random error consists of two statistically independent errors;

1. Error when aligning the gun reference telescope to point B marked on the gridboard.

2. Error when reading the LOS point $S^-$ off the gridboard.

These single errors include the basic angular tolerance of $2\sigma = 0.1$ mrad so that the resulting random error then amounts to $2\sigma_{B,S^-} = \sqrt{2}\ 0.1$ mrad. Figure C-3 illustrates these errors.

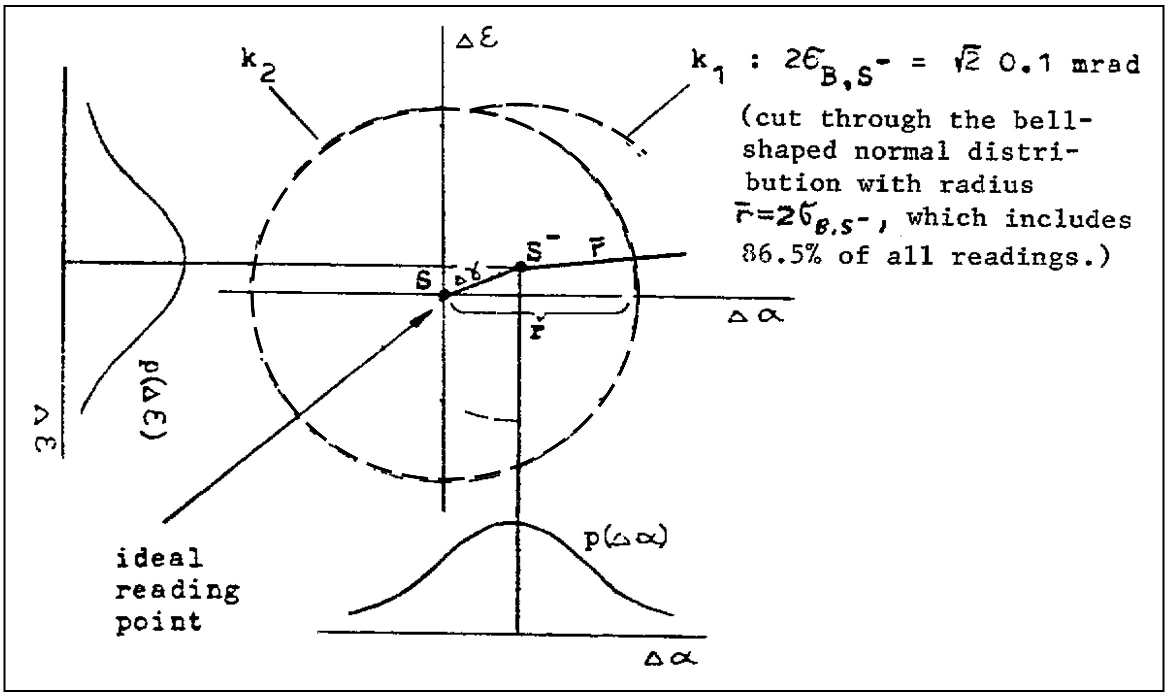



Figure C-3. Circles or error tolerances on the gridboard used as a basis for the following table.

Circle $k_1$, which is displaced by $\Delta\gamma$ from the origin of coordinates (ideal reading point S on the gridboard), represents the random errors when determining point $S^-$. Circle $k_1$ includes $P = 1 - e^{-2}$ i.e. 86.5 percent of all readings. Systematic error $\Delta\gamma$ and $k_1$ are associated with the dashed circle $k_2$ extending centrically around S, which is kept large enough to also include exactly 86.5 percent of all readings. Circle $k_2$ with its radius r represents the tolerance limit of the resulting reading errors.

If $\Delta\gamma$ is increased from zero upward (with $k_1$ remaining constant), circle $k_2$ and thus r, will also increase. The following table shows the interrelation between r and$\Delta\gamma$.

| $\Delta\gamma$ mrad | 0 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 |
|---|---|---|---|---|---|---|---|---|---|
| $r / 2\sigma_{B,S^-}$ (–) | 1 | 1.007 | 1.021 | 1.045 | 1.075 | 1.117 | 1.169 | 1.227 | 1.285 |

$r / 2\sigma_{B,S^-}$ values were obtained using a Monte Carlo method. For a specified $\Delta\gamma$, r was varied until 86.5 percent of the distribution of readings are contained in a circle $k_2$ of radius r centered at S. The procedure is repeated for other selected values of $\Delta\gamma$, giving the table of $\Delta\gamma$ and $r / 2\sigma_{B,S^-}$.

This table aids in selecting an allowable value for $\Delta\gamma$ that $k_2$ is only slightly greater than $k_1$ and the permissible error of measurement (0.1 mrad) is not significantly exceeded. The table shows that with $\Delta\gamma$ = 0.05 mrad, $k_2$ is only 12 percent larger than $k_1$ representing a still acceptable value. $\Delta\gamma_{to1}$ = 0.05 mrad.

Thus the inequality for $R_J$ (formula (3)) changes into

$$\boxed{R_J \geqq \frac{\overline{2\ 10^4\ b\ s_{max}}}{R_G}} \quad \text{Formula (4)}$$

Example: With b = lm, $s_{max}$ = 25 m, $R_G$ = 500 m, the value obtained for $R_J \geqq$ 1000 m.

APPENDIX D. PARAMETER DETERMINATION

The parameters (influencing the synchronization errors), discussed in paragraph 3.4.1.a through c, are determined one by one by means of a diagram, Figure 1 (paragraph 3.4.1c) or Figure D-1 in this appendix, in a certain sequence. The diagram is completely applicable for the slope method; however, the lower part applies for the crane method only.

Formula (4) and (2) form the basis for the diagram. Formula (4) in a rewritten form reads as follows:

$$\frac{R_G}{s_{\max}} \geqq \frac{2\ 10^4\ b}{R_J} \ .$$

From this equation it follows that

$$\frac{R_{G\ \min}}{s_{\max}} = \frac{2\ 10^4\ b}{R_{J\ \min}} \ . \ \text{formula (5)}$$

The right side of formula (5)

$$y_r = \frac{2\ 10^4}{R_{J\ \min}}\ b$$

describes a family of straight lines over the parallax distance b (gun - sight, see Figure C-2) with the minimum boresighting distance $R_{Jmin}$ as a parameter (see Figure D-1 upper right).

The left side of formula (5)

$$y_l = \frac{1}{s_{\max}}\ R_{G\ \min}$$

describes a family of straight lines over the minimum gridboard distance $R_{Gmin}$ with the maximum distance of slope movement $s_{max}$ as a parameter (Figure D-l upper left).

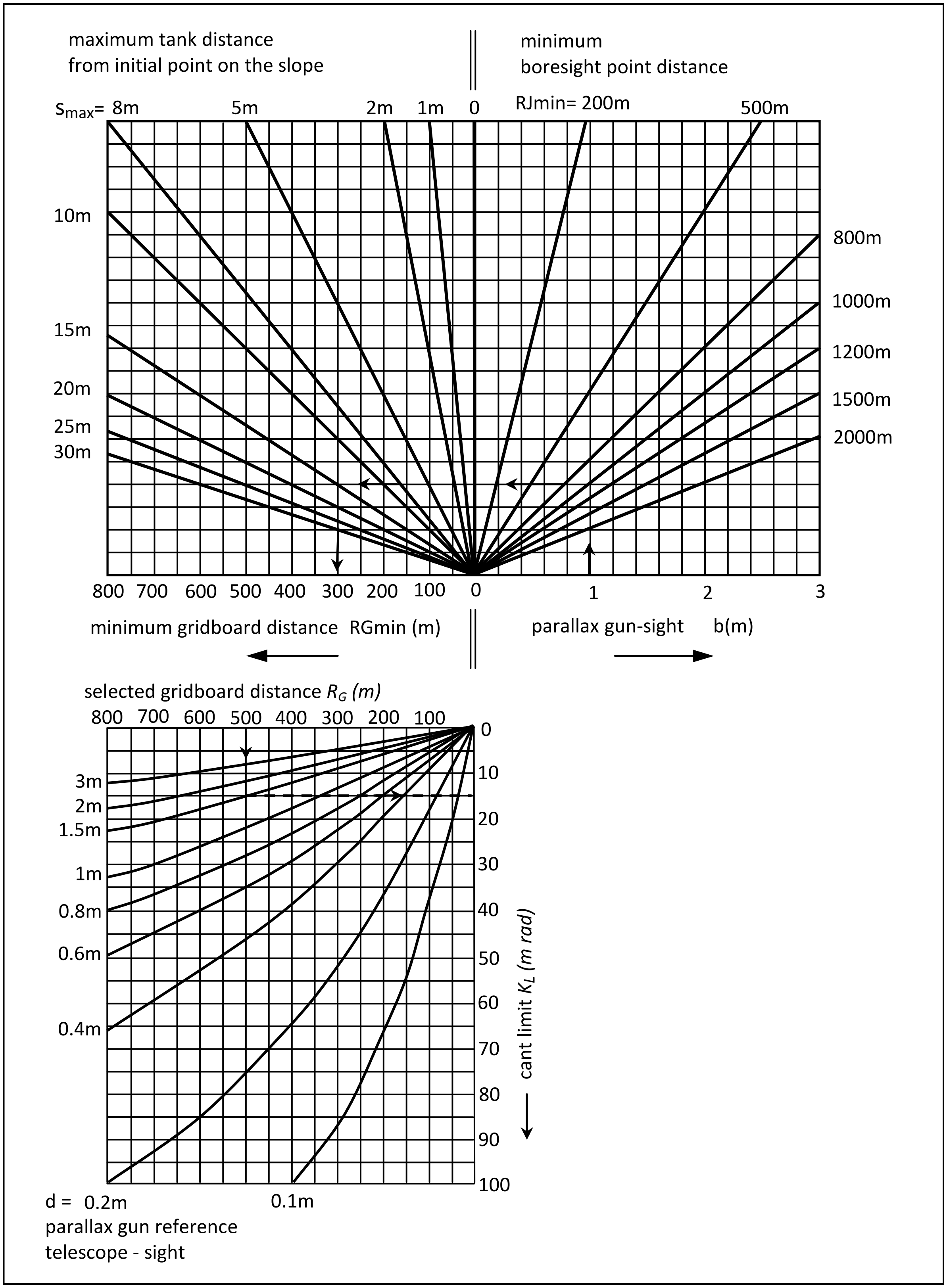



Figure D-1. Determination of parameters for the gun/sight synchronization test.

Finally, Formula (2) results in the family of curves of the cant angle limit $K_1$ ($R_G$,d) over the selected gridboard distance $R_G$, with the parallax distance d (gun reference telescope - sight (Figure B-1) as a parameter (Figure. D-1, lower left).

The parameter diagram is passed through counter-clock-wise (dotted line with direction arrows) thus determining all test parameters in the following sequence:

$$b \longrightarrow R_{Jmin} \longrightarrow smax \longrightarrow R_{Gmin} \longrightarrow R_G \longrightarrow d \longrightarrow K_l$$

where the gridboard distance $R_G$ (according to the test conditions) can be chosen within the limits

$$R_{G\,\mathrm{min}} \leqq R_G \leqq R_{G\,\mathrm{max}}.$$

The maximum gridboard distance $R_{Gmax}$ depends on the scintillation effects of air, normally

$$R_{G\,\mathrm{max}} = 500\ m.$$

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division (TEDT-TMB), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: Close combat Systems Division (AT-FPC), US Army Aberdeen Test Center, 400 Colleran Road, Aberdeen Proving Ground, MD 21005-5059. Additional copies can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Road, Suite 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.