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18. SUPPLEMENTARY NOTES

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Cargo loading adaptability	Transportability
Load distribution	Vehicle, wheeled
Physical characteristics	Vehicle, tracked

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Describes standard techniques for determining the center of gravity of heavy equipment including vehicles and large weapons. Covers suspension, reaction, and weighing methods. Includes procedures for calculating the combined center of gravity of two or more masses when attached to each other and considered a single unit. Discusses error factors and factors to be considered in selecting the appropriate method. Applies to wheeled and tracked vehicles, trailers, large weapons, construction equipment, and certain types of warehouse and shop equipment.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-101
*Test Operations Procedure 2-2-800 18 July 1980
AD No.

CENTER OF GRAVITY

Page

1. SCOPE. This TOP describes standard techniques for determining the center of gravity of heavy equipment including vehicles and large weapons. Also included is a procedure for calculating the combined center of gravity location of two or more masses when attached to each other and considered a single unit.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities. Overhead crane.

2.2 Instrumentation.

ITEM	MAXIMUM ERROR OF MEASUREMENT*
Platform scale	Accurate to ±0.5% of reading
Measuring tape	±2 mm
Weighing cell	±1% of reading
Transit or theodolite	±25 mm

*Values may be assumed to represent ±2 standard deviations; thus the stated tolerances should not be exceeded in more than 1 measurement out of 20.

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*This TOP supersedes TOP 2-2-800, 16 July 1974.

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3. PREPARATION FOR TEST.

3.1 Selection of Method. Before conducting a CG determination, consideration must be given the method to be used. Factors governing the selection are given below. The assumption is made that each method would be carried out with the same attention to procedure to eliminate gross errors.

a. Suspension Method. This method involves only the static suspension of the test item and no calculations are required to locate the CG.

b. Reaction Method. This method is used when the equipment required to determine the CG of a test item by the suspension method is of inadequate capacity to handle the weight of the test item, or when the design and/or configuration of the test item are such that it cannot be suspended.

c. Weighing Method. Only longitudinal and lateral CG locations are determined by this method. For tracked vehicles, only lateral CG's are obtainable by this method.

d. Combined CG Method. This method is used when the configuration of several attached masses makes it impossible or impractical to obtain the combined CG by one of the above empirical methods.

e. Analytical Method. This method may be used for items whose geometries are relatively simple and whose mass densities are uniform. This method generally involves nothing more than measuring and weighing and the application of simple mathematics.

3.2 Test Preparation.

a. Fully service the test item with fuel, oil, and water as required and install its auxiliary equipment (weapons, ammunition, communications equipment - as required). At the discretion of the test director, the full-load condition of cargo- and personnel-carrying vehicles may be used (simulated only) for CG determination.

b. After servicing and loading, determine the weight of the test item.

c. Lay out reference points and guidelines to establish the ultimate orientation of the test item and, when applicable, the transit (or theodolite) location. When used, the transit is positioned at an effective distance from, and with its line of sight perpendicular to, a plane through the longitudinal axis of the test item.

d. An overhead crane, if required for the selected procedure, is positioned over the test item.

e. Attach a marking panel for inscribing line projections to the side of the test item.

3.3 Data Required.

a. Nomenclature, serial number, and model number of the test item.

b. Weight of the test item.

4. TEST CONTROLS.

Develop suitable checklists and data sheets to assure all events take place in proper sequence and all data are recorded.

5. PERFORMANCE TESTS.

5.1 Suspension Method. The suspension method is based on the fact that a vertical line through the point of suspension will pass through the mass center of a freely suspended body.

5.1.1 Method. Suspend the test item by cables of unequal length fastened to lifting attachments at each end of the unit and hanging freely from the hook of a shop crane (Figure 1). The cable lengths selected determine the suspension angle (45° is optimum). A vertical line projected from the center of the load hook pivot will pass through the CG. This line is projected by transit to the marking panel on the test item where it is inscribed. The vertical plane of the test item longitudinal axis must be normal to the vertical plane described by the transit sighting scope.

Repeat the operation with the suspension cables interchanged to determine the CG in the horizontal and vertical direction (intersection of the two projected lines). Inscribing the intersecting lines on a marking panel projects the center of gravity to a vertical plane at the side of the item. The distances between the point of intersection (CG) and the horizontal and vertical reference lines are measured. Reference lines are located from reference points on the test item. When the item is a vehicle, the center of a wheel (or sprocket) is the usual reference point for longitudinal and vertical measurements. To determine the lateral CG, the weighing method is used (Paragraph 5.3).

There are three error factors that should be considered:

First, when the test item is a vehicle, consideration should be given to the fact that most vehicles have a spring suspension system. In a normal position on the ground the vehicle weight compresses the springs. When the vehicle is suspended from a crane, the springs are stretched. This could alter the weight distribution of the vehicle and affect the location of the CG.

Second, the angle of suspension will cause the shifting of fluids (fuel, oil, water, etc.) within a vehicle causing a difference in weight distribution.

Third, when any shift in the distribution of weight can have an appreciable effect on the location of the CG, blocking or other methods (e.g., tying the springs) of minimizing variations must be considered, but the weight of the blocks must be minimized and taken into consideration.

Figure 1. Determining the Center of Gravity of a Tank by the Suspension Method.

5.1.2 Data Required. Horizontal and vertical distances between the CG marking and the reference points, if on a vehicle (usually the centerline of sprocket and wheel).

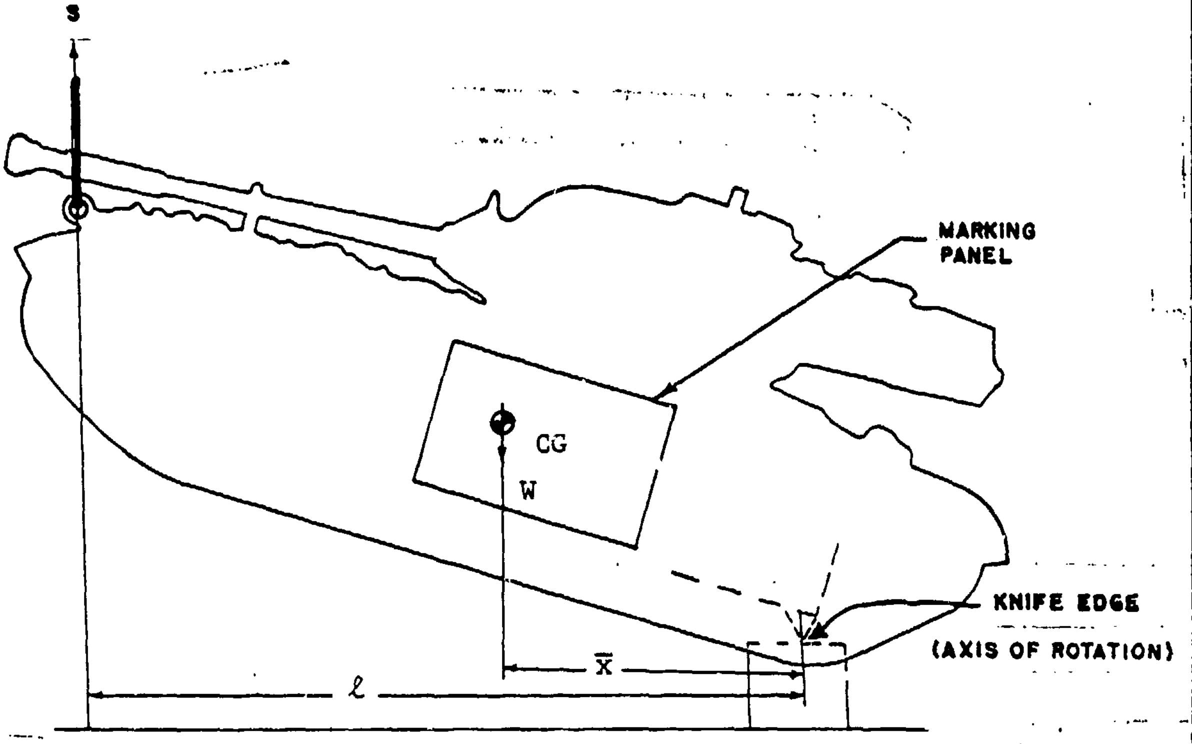
5.2 Reaction Method. The reaction method is based on the fact that when a body is a static equilibrium, the sum of the moments about an axis of rotation is zero.

5.2.1 Method. To provide an axis of rotation, attach a knife edge to the underside of the test item at one end (Figure 2). If the CG determination is to be made for wheeled vehicles or skid-mounted items, the axle, wheels, or skid (as appropriate) may be used as the axis of rotation instead of the knife edge. The other end of the test item is suspended by crane through a weighing cell so that the test item pivots about the axis of rotation. A suspension angle of 45° is optimum. While suspended on the axis of rotation, the test item must be free from motion and the lifting force must act in a vertical direction. The distance between the axis of rotation and the CG is determined by the equation presented in Figure 2. Values for ℓ, s, and w are obtained by measurement. With the values for s, ℓ, and w known (or measured) the value for $\overline{X}$ can be computed. A vertical line is projected at the computed distance ($\overline{X}$) from the axis of rotation to the marking panel on the test item where it is inscribed. Projection is made by transit or plumb bob. If the transit is used, the vertical plane of the test item longitudinal axis must be normal to the vertical plane described by the transit sighting scope. The reaction method is usually not used for tracked vehicles.

By reversing the suspension device and the axis of rotation so that the test item pivots about an axis of rotation at its opposite end, take moments about this second axis, solve the equation, and inscribe a second line which intersects the first. The point of intersection locates the CG horizontally and vertically. Inscribing the intersecting lines on a marking panel projects the CG to a vertical plane at the side of the item. The distances between the point of intersection (CG) and the horizontal and vertical reference lines are measured. Reference lines are located (by transit or plumb bob) from reference points on the test item which have been predetermined and set forth in the test directive or test plan for a particular test item. The method for locating lateral CG is the weighing method (Paragraph 5.3).

It should be noted at this point that the same result can be obtained, through similar calculations, if the weight reaction under the knife edge is measured (utilizing a calibrated platform scale instead of the vertical lifting force(s)) while the opposite end of the test item is suspended.

The error factors discussed for the suspension method are also true for the reaction method. In addition, the reaction method depends upon the solution of an equation in which quantitative measurements must be made. Measurements of the horizontal distances to projected lines, in particular, provide chances for error. Care must be taken to be sure that such measurements are on a horizontal plane.



To locate the center of gravity, moments are taken about the axis of rotation, then:

$s\ell - \bar{X}W = 0$

or $\bar{X}W = s\ell$

or $\bar{X} = \frac{s\ell}{W}$

where:

s = Force required to suspend test item

ℓ = Horizontal distance between axis of rotation and line of action of lifting force

$\bar{X}$ = Horizontal distance between axis of rotation and CG

W = Weight of test item

NOTE: The weight of a body acts through its CG.

Figure 2. Reaction Method for Determining Center of Gravity. (Wide Application Does not Usually Include Tracked Vehicles.)

5.2.2 Data Required.

a. Force required to suspend each end of the test item when the other end is on knife edge.

b. Horizontal distance between the axis of rotation and a vertical line through the lifting force.

c. Weight of test item.

5.3 Weighing Method. The weighing method, like the reaction method, is based on the fact that when a body is in static equilibrium, the sum of the moments about an axis of rotation is zero.

5.3.1 Method. In the weighing method, however, do not pivot the test item about the axis of rotation in a vertical direction, therefore, there is no determination of the vertical component of the CG. The weighing method of determining the longitudinal CG location of a vehicle is illustrated in Figure 3. The lateral CG can be determined by positioning the vehicle so that two side wheels are supported by the scale platform and the other two side wheels are supported by the floor. The method may be applied to any item as long as the points of support (rear and front wheels in contact with floor and scale platform) are pivotal points. Pivotal points for items without wheels can be provided through the use of round metal pipes or rods as support points. The CG location is determined by the equation in Figure 3. Values for s, ℓ, and w are obtained by measurement and are recorded. These values are then substituted in the equation and the CG location ($\bar{X}$) computed.

The weighing method depends upon the solution of an equation in which quantitative measurements must be made. Measurements of the horizontal distances to projected lines, in particular, provide chances for error. Care must be taken to be sure that such measurements are on a horizontal plane.

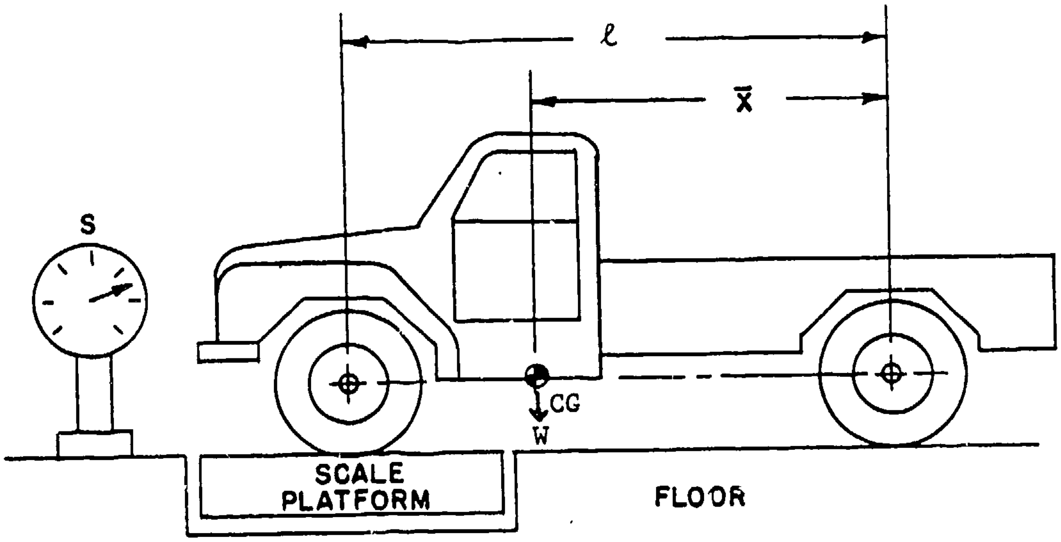
5.3.2 Data Required.

a. Forces required to support each portion of test item.

b. Horizontal distances between pivotal points (e.g., distance between centerlines of tracks on tracked vehicles).

c. Weight of test item.

d. Vehicle loading conditions.



To locate the center of gravity, moments are taken about the axis of rotation, then:

$s\ell - \bar{X}W =$

or $\bar{X}W = s\ell$

or $\bar{X} = \frac{s\ell}{W}$

where:

s = Force required to support test item.

ℓ = Horizontal distance between pivotal points.

$\bar{X}$ = Horizontal distance between axis of rotation and CG

W = Weight of test item.

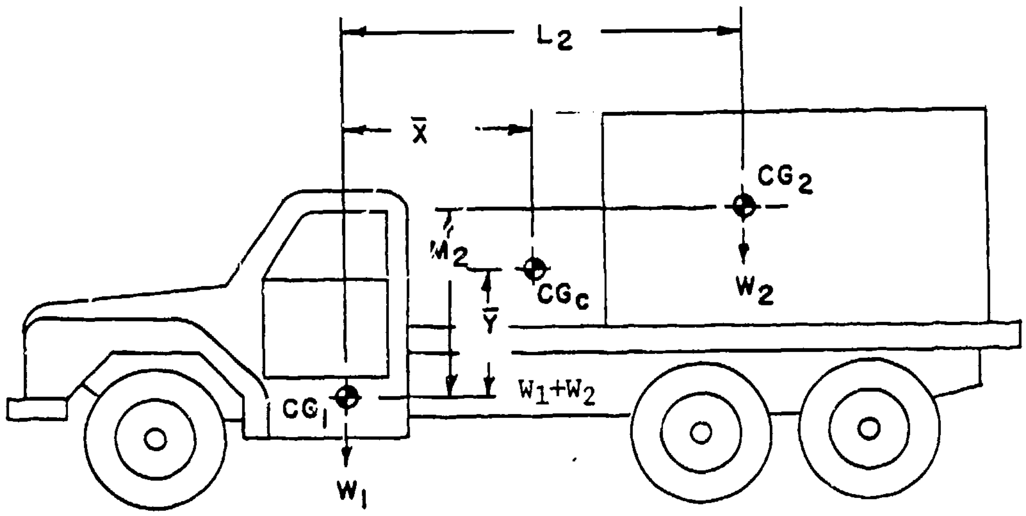
NOTE: The weight of a body acts through its CG.

Figure 3. Weighing Method for Determining Horizontal Center of Gravity.

5.4 Combined CG.

5.4.1 Method.

a. Two Centers of Gravity. The combined CG of two masses for which CG has previously been determined individually (e.g., a prime mover carrying a shelter or another item of equipment) can be located by balancing moments about a known CG as shown in Figure 4.



CG_1 = Prime mover center of gravity
CG_2 = Payload center of gravity
CG_c = Combined center of gravity of prime mover with payload

To locate the horizontal component of the combined CG, moments are taken about CG_1:

$W_2(L_2) = \overline{X}(W_1 + W_2)$ where:

$$\overline{X} = \frac{W_2(L_2)}{(W_1 + W_2)}$$

W_2 = Weight of payload

L_2 = Horizontal distance between CG_1 and CG_2

$\overline{X}$ = Horizontal distance between CG_1 and CG_c

W_1 = Weight of prime mover

To locate the vertical component of the combined CG, moments are again taken about CG_1:

$W_2(M_2) = \overline{Y}(W_1 + W_2)$ where:

$$\overline{Y} = \frac{W_2(M_2)}{(W_1 + W_2)}$$

M_2 = Vertical distance between CG_1 and CG_2

$\overline{Y}$ = Vertical distance between CG_1 and CG_c

Location of the lateral component is determined in a similar manner.

Figure 4. Method of Calculating Combined Center of Gravity.

b. Three or More Centers of Gravity. To combine three or more centers of gravity, the same approach as above of balancing moments about a known CG is used (Figure 4). However, the moment involving the combined CG (i.e., $\overline{X}(W_1 + W_2 + W_3 + $ -----) must be balanced on the other side of the equation with the sum of all the moments to all the other centers of gravity. To combine three centers of gravity horizontally, the following equation is applicable:

$$W_3(L_3) + W_2(L_2) = \overline{X}\ (W_1 + W_2 + W_3)$$

c. Error Factors. The error involved in this calculation depends upon the accuracy achieved in determining the individual CG locations.

5.4.2 Data Required. Not applicable.

6. DATA REDUCTION AND PRESENTATION. Determine the distances between the CG and the reference points using the data from Paragraphs 5.1.2, 5.2.2, and 5.3.2, as applicable, and using the formulas shown in Figures 2 and 3.

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