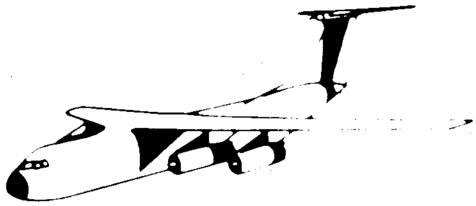

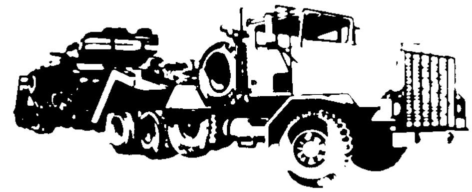

TR 88-V5-02
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TRANSPORTABILITY ENGINEERING ANALYSIS

CROSSED VERSUS NEAR-SIDE TIEDOWN CHAINS/WIRE ROPES FOR RAIL TRANSPORT

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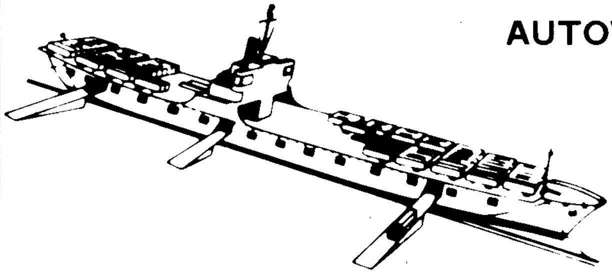

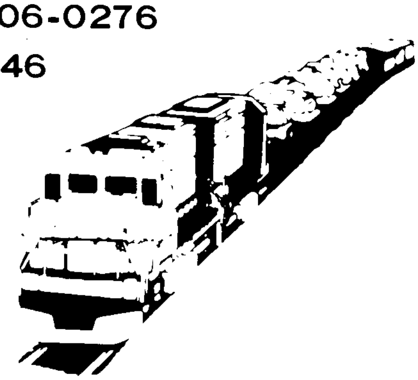

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I. EXECUTIVE SUMMARY

For rail transport, near-side tiedowns are better than crossed tiedowns. Near-side tiedowns should be used in all cases unless specific published figures direct that tiedowns be crossed. (Crossed tiedowns are presently used for rail transport in Europe.) The analysis shows that, at impact, the force in the tiedowns is much higher if the tiedowns are crossed than it would be if they go to the near side. In the case of a 5-ton truck on a typical flatcar, the force in the tiedowns would be 26 percent higher in crossed tiedowns than in near-side tiedowns. That additional load could cause the tiedowns to fail. Even if an item of equipment is secured on a flatcar equipped with chain tiedowns and center rails, the chains should not be crossed. Enough lateral restraint will be provided by friction, rubrails, and the tiedowns.

II. INTRODUCTION

This analysis supports our position that chain/wire rope tiedowns on railcars be straight from the tiedown provisions to the near side of the railcar, rather than crossed from the tiedown provisions to the far side of the railcar.

The Training and Doctrine Command (TRADOC) had been training people to cross all tiedowns. (Crossed tiedowns are presently used on railroads in Europe.)

This analysis considers near-side and crossed tiedowns for longitudinal and lateral restraint. Because near-side tiedowns provide better vertical restraint than crossed tiedowns, vertical restraint will not be analyzed, since it would be similar to the longitudinal restraint analysis and the required vertical restraint is less than the required longitudinal restraint.

Throughout this analysis, "near-side" will mean "straight from a tiedown provision on a vehicle to the nearest side or chain tiedown rail of the railcar." "Crossed" will mean "from a tiedown provision on a vehicle to the far side of the railcar so that a pair of tiedowns would cross each other."

Rail tiedowns should be at 45° from the car deck to the tiedown when viewed from the side of the railcar; therefore, the longitudinal distance along the flatcar deck from the vehicle's tiedown provisions to the stake pocket will equal the height of the tiedown provision above the railcar deck.

III. GENERAL CASE

First, we will consider, as a general case, the M923A1 5-ton truck (figs 1 and 2). Rule 13 of Section No. 1, General Rules Governing the Loading of Commodities on Open Top Cars (GROTC), published by the Association of American Railroads (AAR), states that the longitudinal restraint should be three times the object's weight (3 g's) and the lateral restraint should be two times the object's weight (2 g's) (app A).

A. LONGITUDINAL RESTRAINT

The weight of the truck is 32,175 pounds and the required restraint is three times the truck's weight. Thus, (3)(32,175) = 96,525 pounds. Two tiedowns are effective at each end of the vehicle, so the longitudinal restraint required from each tiedown is:

$$\frac{96,525}{2} = 48,263 \text{ pounds.}$$

Because of the nature of tiedown materials, usually chain or wire rope, the force the tiedown exerts is always tension in the direction of the tiedown. That force can be considered to be composed of component forces acting in three mutually perpendicular directions oriented such that one is longitudinal, one is lateral, and one is vertical (fig 3). The force in the tiedown due to a 3-g impact (longitudinal force) is equal to the share of the longitudinal force for the tiedown divided by the cosine of angle "A." The trigonometric functions can be calculated from the known geometry of the truck and flatcar. In figure 3, "e" is the adjacent side and "k" is the hypotenuse of a right triangle containing angle A. The cosine of an angle is the length of the adjacent side divided by the length of the hypotenuse; therefore, cosA = e/k. The length of e is given in figures 1 and 2. It is the same as the vertical distance from the flatcar deck to the tiedown provision. The length of k may be found using the Pythagorean theorem:

$$e^2+f^2 = d^2$$

$$d^2+h^2 = k^2$$

$$e^2+f^2+h^2 = k^2$$

$$k = \sqrt{e^2+f^2+h^2}$$

$$\text{therefore,} \quad \cos A = \frac{e}{\sqrt{e^2+f^2+h^2}} .$$

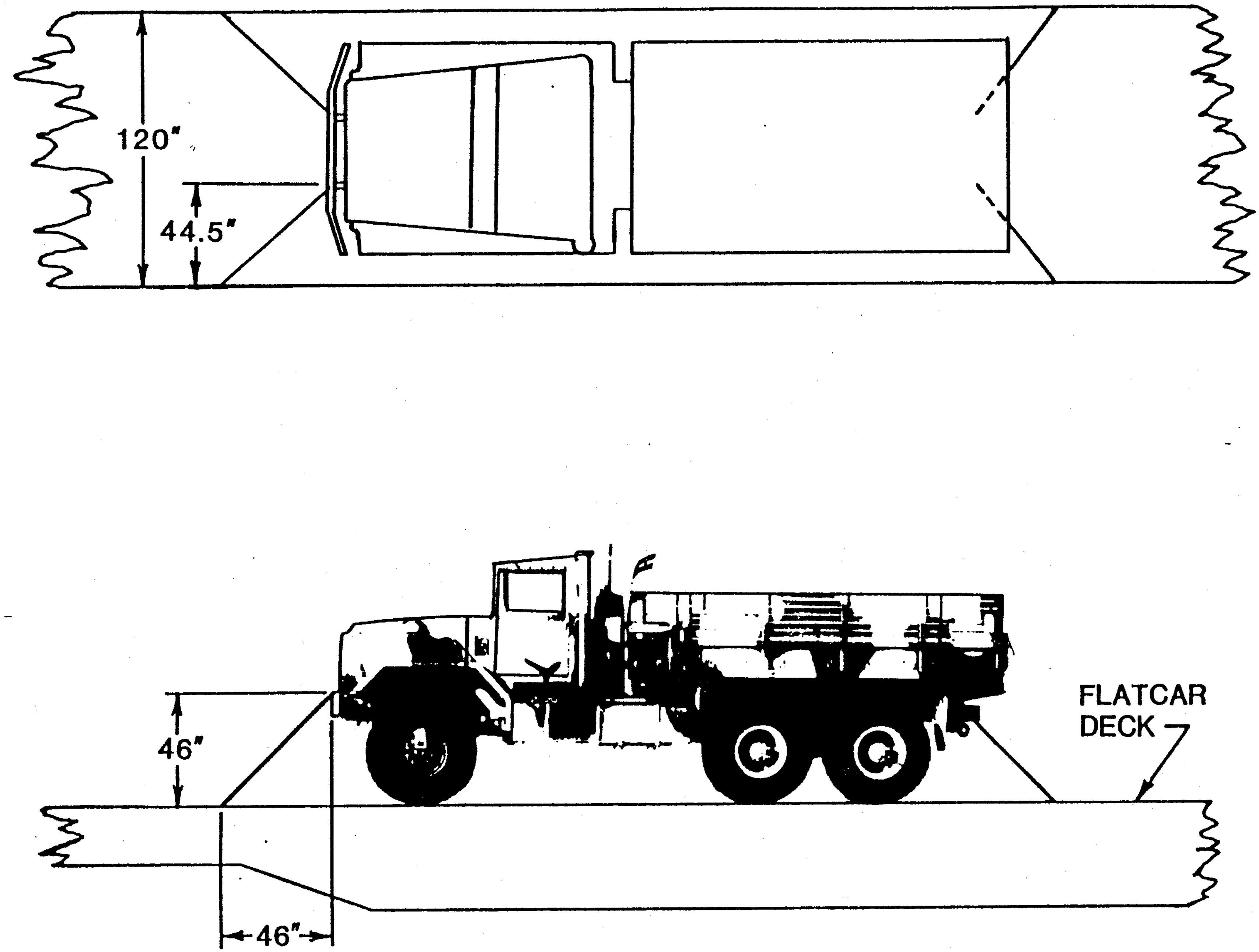

Figure 1. Five-ton truck, tiedowns to near side.
(NOTE: All dimensions are typical.)

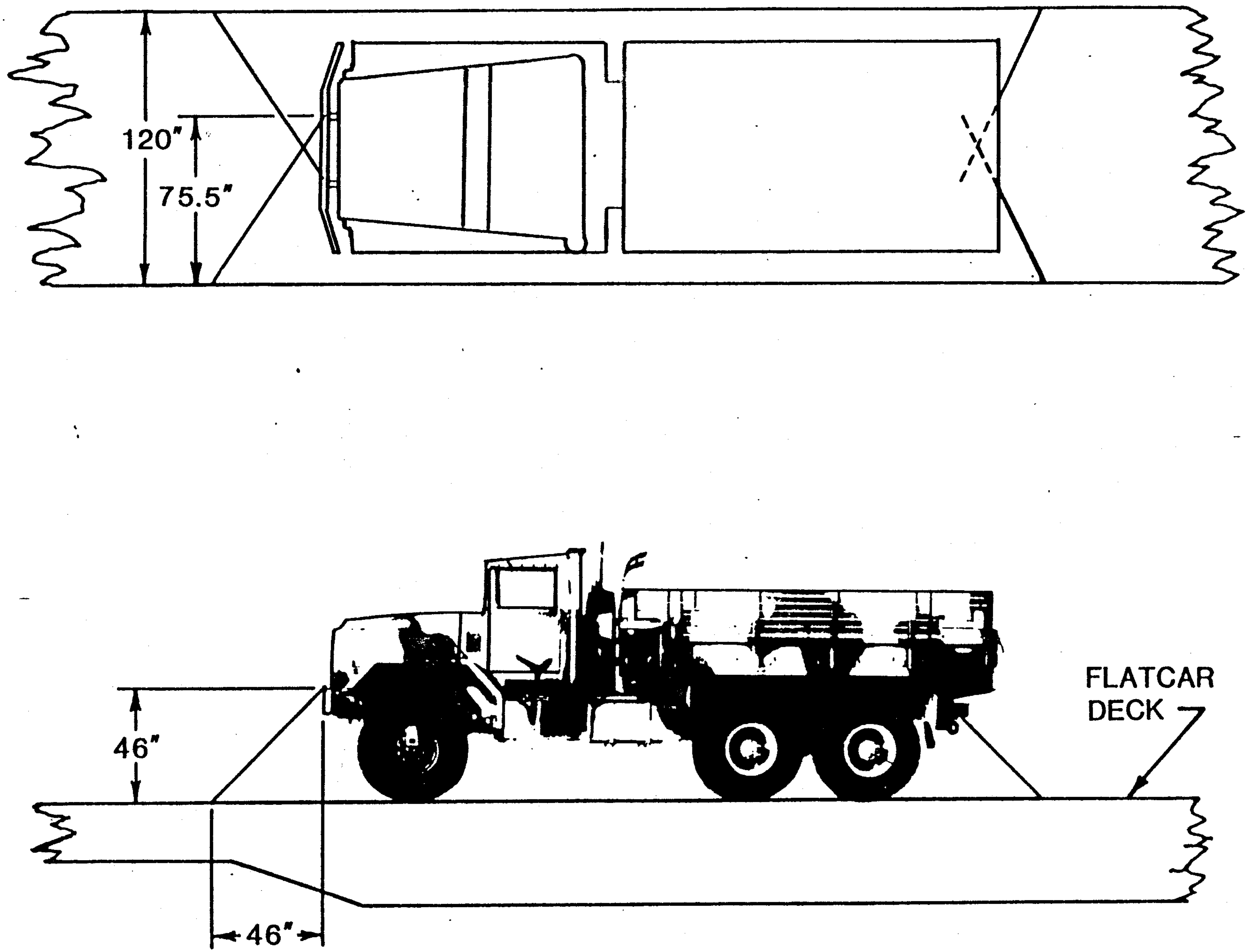

Figure 2. Five-ton truck, tiedowns crossed.
(NOTE: All dimensions are typical.)

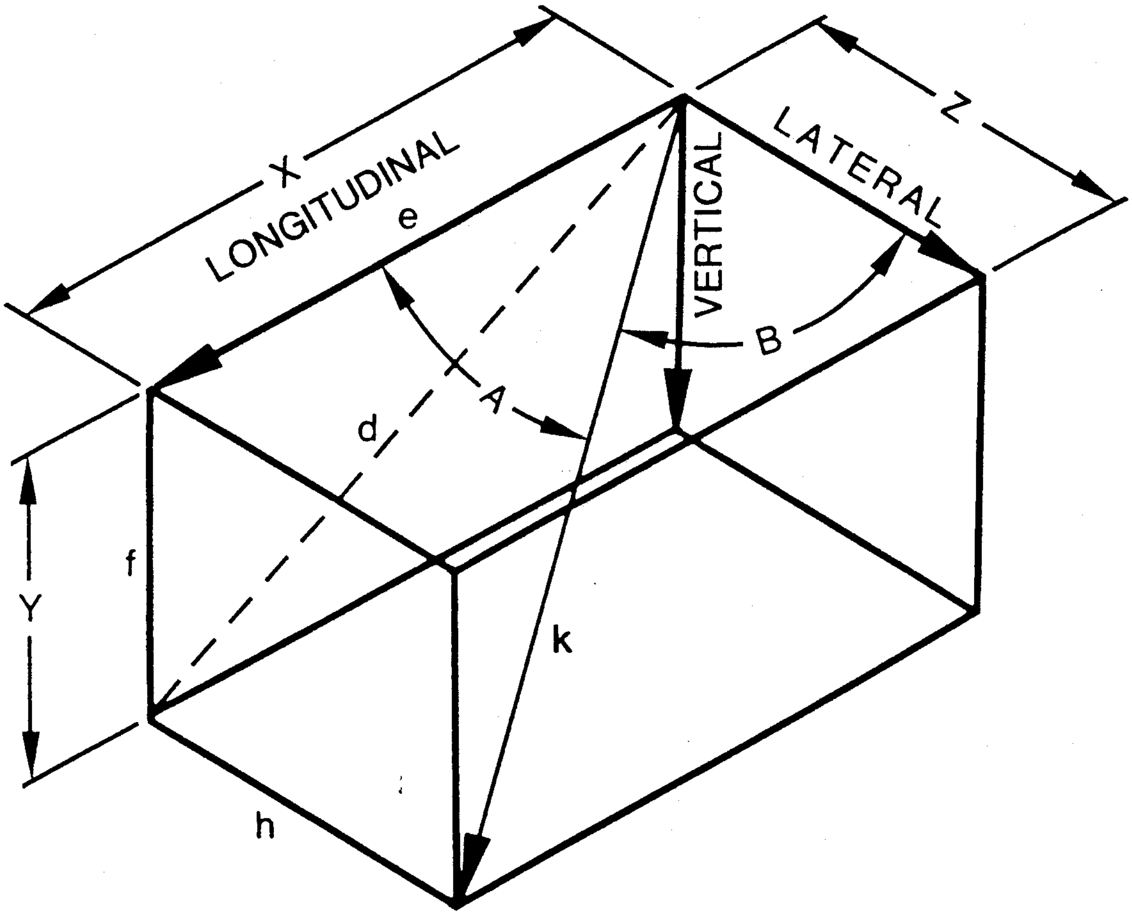

Figure 3. Force directions.

Longitudinal restraint required	=	48,263	pounds
e	=	46	inches
f	=	46	inches
Near-side h	=	44.5	inches
Crossed h	=	75.5	inches

For near-side tiedowns:

$$\frac{48{,}263}{\cos A_1} = \frac{48{,}263}{\frac{e}{k}}$$

$$= \frac{48{,}263}{\left[\frac{e}{\sqrt{e^2+f^2+h^2}}\right]}$$

$$= \frac{48{,}263}{\left[\frac{46}{\sqrt{46^2+46^2+44.5^2}}\right]}$$

$$= \frac{48{,}263}{0.5836}$$

$$= \underline{\underline{82{,}695 \text{ pounds} \quad \text{near-side}}}$$

For crossed tiedowns:

$$\frac{48{,}263}{\cos A_2} = \frac{48{,}263}{\frac{e}{k}}$$

$$= \frac{48{,}263}{\left[\frac{e}{\sqrt{e^2+f^2+h^2}}\right]}$$

$$= \frac{48{,}263}{\left[\dfrac{46}{\sqrt{46^2+46^2+75.5^2}}\right]}$$

$$= \frac{48{,}263}{0.4616}$$

$$= \underline{\underline{104{,}564 \text{ pounds} \quad \text{crossed}}}$$

The increase in the force due to changing from near-side tiedowns to crossed tiedowns is: 104,564 - 82,695 = 21,869 pounds, which can be expressed as:

$$\frac{21{,}869}{82{,}695} = 26.4\% \text{ increase.}$$

B. LATERAL RESTRAINT

From the GROTC, the lateral restraint must be two times the object's weight: (2)(32,175) = 64,350 pounds. Two tiedowns are effective at each side of the vehicle, so the lateral restraint required from each tiedown is:

$$\frac{64{,}350}{2} = 32{,}175 \text{ pounds.}$$

The force in the tiedown from a 2-g lateral force is equal to the share of the lateral force for the tiedown divided by the cosine of angle "B" (fig 3):

Lateral restraint required =	32,175	pounds
e =	46	inches
f =	46	inches
Near-side h =	44.5	inches

For near-side tiedowns:

$$\frac{32{,}175}{\cos B_1} = \frac{32{,}175}{\frac{h}{k}}$$

$$= \frac{32{,}175}{\left[\dfrac{h}{\sqrt{e^2+f^2+h^2}}\right]}$$

$$= \frac{32{,}175}{\left[\dfrac{44.5}{\sqrt{46^2+46^2+44.5^2}}\right]}$$

$$= \frac{32{,}175}{0.5646}$$

$$= \underline{\underline{56{,}988 \text{ pounds} \quad \text{near-side}}}$$

As can be seen, the force in the tiedown from a 2-g lateral force (56,988 pounds) is smaller for the near-side tiedown than the force for a 3-g longitudinal force (82,695 pounds). That indicates that, if the tiedown is strong enough for the expected longitudinal forces, it will also have ample strength for the lateral loads. Another way to look at the lateral restraint is to find the lateral force component associated with the force in the tiedown due to the longitudinal force: (82,695)cosB = (82,695)(0.5646) = 46,689 pounds for one tiedown. While the tiedowns at only one end of the vehicle would be loaded by a longitudinal force, the two tiedowns on one side of the vehicle are available to resist lateral forces.

$$\frac{93{,}378}{32{,}175} = 2.9 \text{ times the weight of the vehicle.}$$

Therefore, a near-side tiedown that will provide the 3-g longitudinal restraint will provide a 2.9-g lateral restraint.

IV. SPECIAL CASE

Now, we will consider a special case, where near-side tiedowns are parallel (fig 4). That can occur on chain-tiedown flatcars on which the center tiedown rails have the same spacing as the tiedown provisions on the 5-ton truck.

A. LONGITUDINAL RESTRAINT

The force in the chain due to a 3-g longitudinal force is:

Longitudinal restraint required	=	48,263 pounds
e	=	46 inches
f	=	46 inches
Near-side h	=	0 inches
Crossed h	=	31 inches

For near-side tiedowns:

$$\frac{48{,}263}{\cos A_3} = \frac{48{,}263}{\frac{e}{k}}$$

$$= \frac{48{,}263}{\left[\frac{e}{\sqrt{e^2+f^2+h^2}}\right]}$$

$$= \frac{48{,}263}{\left[\frac{46}{\sqrt{46^2+46^2+0^2}}\right]}$$

$$= \frac{48{,}263}{0.7071}$$

$$= \underline{\underline{68{,}254 \text{ pounds} \quad \text{near-side}}}$$

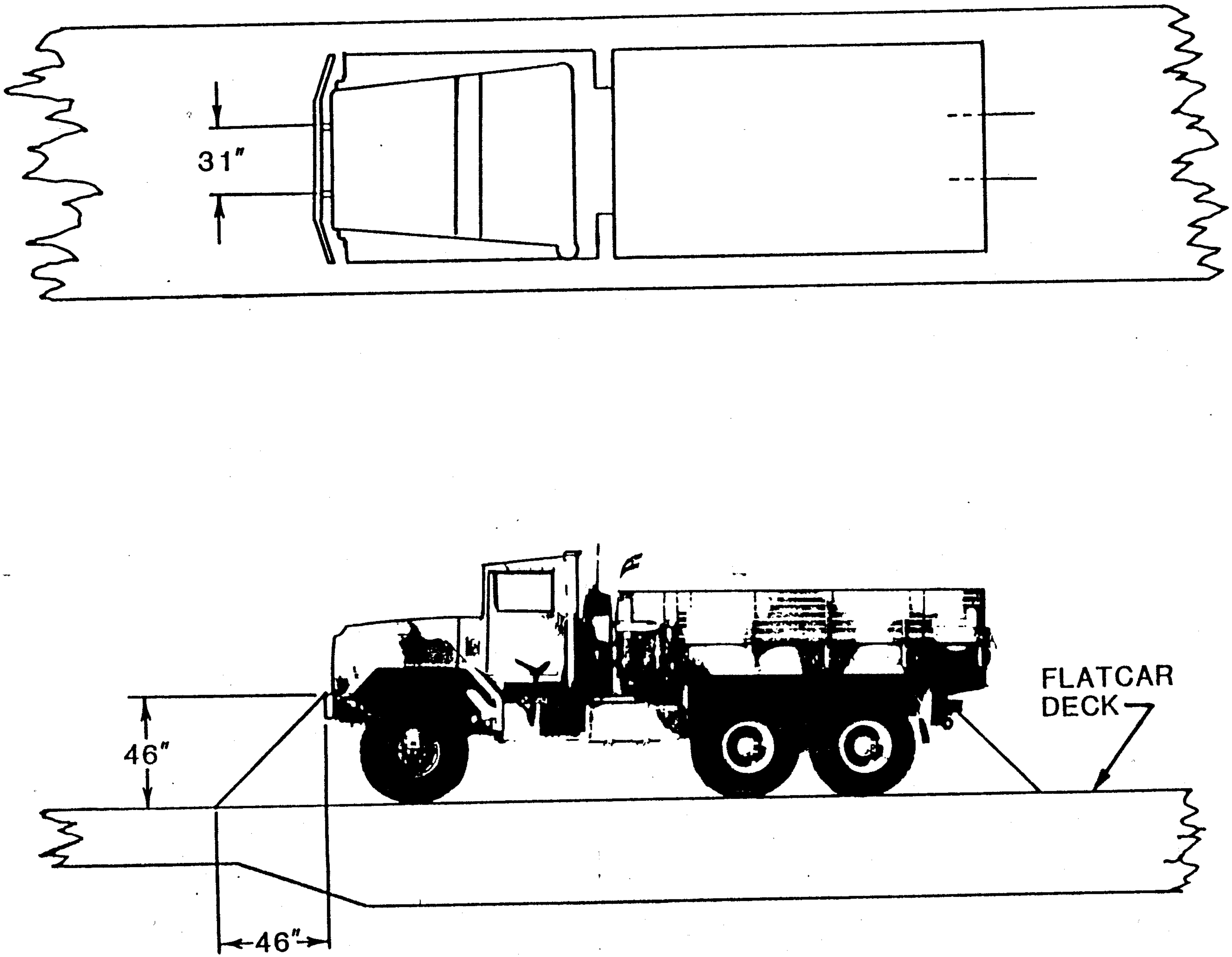

Figure 4. Five-ton truck, tiedowns to near side, center chain-tiedown rails.
(NOTE: all dimensions are typical.)

For crossed tiedowns (fig 5):

$$\frac{48,263}{\cos A_4} = \frac{48,263}{\frac{e}{k}}$$

$$= \frac{48,263}{\left[\frac{e}{\sqrt{e^2+f^2+h^2}}\right]}$$

$$= \frac{48,263}{\left[\frac{46}{\sqrt{46^2+46^2+31^2}}\right]}$$

$$= \frac{48,263}{0.6383}$$

$$= \underline{\underline{75,608 \text{ pounds crossed}}}$$

The calculations clearly show that the force in the crossed chains is significantly higher than that in the near-side chains.

B. LATERAL RESTRAINT

When the chains are precisely horizontal (fig 4), as viewed from the top of the railcar, the tiedowns provide no direct lateral restraint. As the vehicle slips in the lateral direction, all four chains begin to provide lateral restraint. For example, consider a side slip of 4 inches using the lateral restraint associated with the force in the chains due to the longitudinal restraint for near-side tiedowns.

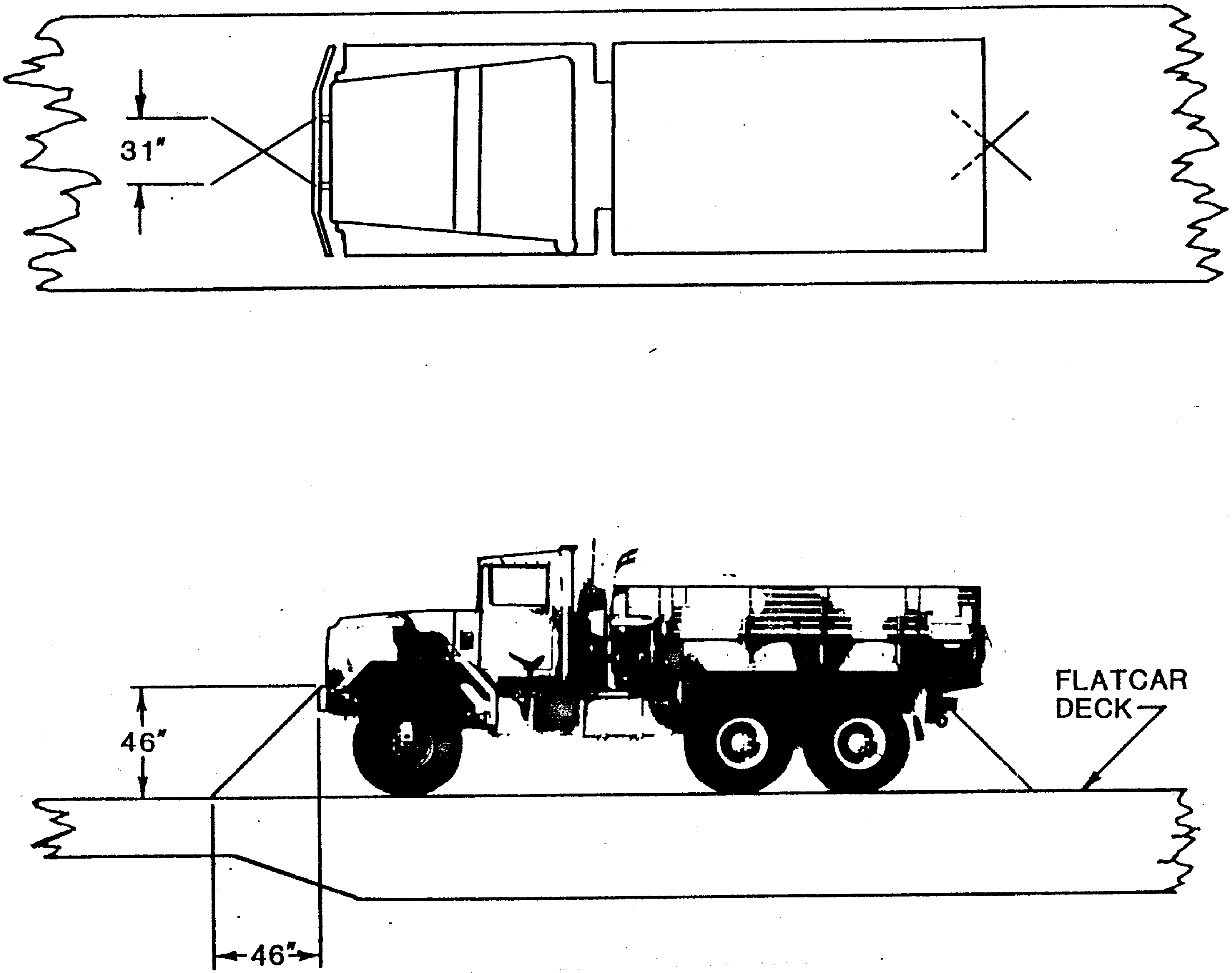

Figure 5. Five-ton truck, tiedowns crossed, center chain tiedown rails.
(NOTE: All dimensions are typical.)

Tiedown strength required for longitudinal restraint = 68,254 pounds
Number of tiedowns available = 4
e = 46 inches
f = 46 inches
h = 4 inches

$$(68{,}254)(\cos B_3)(4) = 273{,}016(h/k)$$

$$= 273{,}016\left[\frac{h}{\sqrt{e^2+f^2+h^2}}\right]$$

$$= 273{,}016\left[\frac{4}{\sqrt{46^2+46^2+4^2}}\right]$$

$$= 273{,}016\ (.06137)$$

$$= \underline{\underline{16{,}755 \text{ pounds;}}}$$

$$\frac{16{,}755}{68{,}254} = 24.5\%$$

Thus, the tiedowns will provide 25 percent of the 2-g lateral restraint requirement with a 4-inch side slip. Most chain tiedown flatcars have rubrails that will prevent excessive lateral movement of vehicles and provide adequate lateral restraint. The approved figure 88-B in Section No. 6, Rules Governing the Loading of Department of Defense Materiel on Open Top Cars (RGDOD) is similar to this case and is accepted without question by railroad mechanical inspectors.

V. ADDITIONAL CONSIDERATIONS

Rule 15, paragraph 8.4, of the GROTC states: "chains used for the securement of commodities subject to rolling should be applied in such a manner as to provide the greatest restraint against longitudinal movement." That implies that chains should be to the near side of a flatcar (app B).

Friction between tires or tracks and the railcar deck provides additional lateral restraint.

Most figures in the RGDOD require side blocking of wheels or tracks, which provides considerable lateral restraint.

Crossing of tiedowns not only results in a higher stress in the tiedown, it also induces a higher stress in the tiedown provisions. If the tiedown provision deforms, it has failed and is no longer safe to use.

The railroad inspector still has the final word on loading if a specific figure is not used.

VI. CONCLUSION

As a general rule, secure tiedowns to the near side of a railcar. Do not cross the tiedowns.

VII. RECOMMENDATION

MTMCTEA recommends that no rail tiedown be crossed unless a specific figure in the AAR loading rules clearly requires the tiedowns to be crossed.

Rule 12. Partial Loading or Unloading.

(a) Partial unloading of a load from a car is not recommended. In the event that a load is partially unloaded, the remainder of the load on the car must comply with or be arranged to comply with an existing figure or the General Rules before further movement.

Rule 13. Load Restraint Values For General Rule Loads.

(a) When a specific figure is not involved and when an object or load is secured using applicable securement details listed in General Rules 1-21 inclusive, it is recommended the following load restraint values, longitudinally, latitudinally and vertically, be observed:

Longitudinally—total load restraint, in each direction, should equal 3 times object weight.
Latitudinally —total load restraint, in each direction, should equal 2 times object weight.
Vertically —total load restraint should equal 2 times object weight.

(b) These restraint values do not apply to pivoted bolster loads.

Rule 15 (cont)

b. Binders must be compatible with the size of chain with which they are to be used.

5.8 Binders must be equipped with two grabhooks except when chain assemblies contain grabhooks intended to shorten chains.

5.9 The welding of binders to chain is prohibited except in the manufacturing process. Binders may be attached to chain using a repair type connecting link of the type in Fig. 1 of this rule, which has equivalent strength of chain.

5.10 Binders of a style which could open during transit must have the operating handle wired or otherwise secured to prevent undesired opening.

6. Chain Attachment

6.1 Welding of chains directly to the car is prohibited.

6.2 Permanent attachment of chains to car stake pockets is not encouraged. Stake pockets purpose is defeated when chains are permanently attached therein.

6.3 Attachment of chain to welded anchors is permitted provided attachment has sufficient lineal inches of weld to provide a rated strength equal to 125% of the ultimate failure rating for the chain.

6.4 Use of U-bolt cable clamps as a means of securing chains to car which meet ASTM specifications is permissible. For 3/8 inch high test and alloy chain use 1/2 inch U-bolt cable clamp having 32,500 lb. minimum breaking strength. For 1/2 inch high test and alloy chain use 5/8 inch U-bolt cable clamp having 50,000 lb. minimum breaking strength.

6.5 Whenever possible, chains should pass around or through stake pockets with the grabhook engaging the chain. (See Fig. 4)

7. Chain Repairs

7.1 Repairs to chains must be made using a repair device of the illustrated type (See Fig. 1) which is rated by the manufacturer to equal the type of chain in which it is used. Repair links made by the following manufacturers are acceptable; Crosby Company (LOK A LOY), Campbell Chain Company (QUICK A LOY), Dominion Chain Company, Ltd. (KUPLEX CHAIN JOINER), Columbus McKinnon (HAMMERLOCK), Dominion Chain Company (ACCOLOY), Acco Industries, Inc. (Kuplok Mechanical Coupling Link). Locate repair links where they will not impair the use of corner protectors, tensioning devices, locking devices or other features of the chain assemblies.

7.2 Repairing of chains by welding is prohibited.

7.3 Use of missing link type connecting links (See Fig. 2), lap links, and cold shuts is prohibited.

7.4 The tieing of chains for any purpose is prohibited.

7.5 The use of bolts to repair broken chains or to secure ends of chains when hooks are missing is prohibited.

8. Application of Chains

8.1 A sufficient number of chains will be used to safely restrain the lading. The chain's rated working load limit will be the restraining capacity used in determining the number of chains required.

8.2 Except as specifically provided in figures, the number of chains required will be determined using the following basic formula:

$$\text{Chains Required} = \frac{\text{Weight of Lading}}{\text{Working Load Limit}}$$

with a minimum of three chains used.

This formula is applicable to flat loaded commodities not subject to rolling. When the commodity is subject to rolling, the following general formula applies:

$$\text{Chains Required} = \frac{\text{Weight of Lading}}{\text{Working Load Limit}} \times 2$$

with a minimum of four chains used, two in each direction.

8.3 Chains used in the securement of flat loaded commodities will be applied over the top of the load, and will be at an approximate right angle (90°) angle to the side of the car whenever possible, except when method of chain application is prescribed in a specific figure.

8.4 Chains used for the securement of commodities subject to rolling should be applied in such a manner as to provide the greatest restraint against longitudinal movement.

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