IDENTIFICATION OF SHOCK AND VIBRATION FACTORS IMPACTING ON CARGO BEING TRANSPORTED ON HIGH SPEED LANDING CRAFT AND DESIGN OF A TEST PROGRAM FOR PACKAGING AND TIE-DOWN SYSTEMS EVALUATION

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CHAPTER I

BACKGROUND AND STUDY OBJECTIVES

NAVSHIPS is engaged in developing a new system to improve the effectiveness of future amphibious assault operations. This advanced development program, the Amphibious Assault Landing Craft Program (S14-17), calls for the defining, developing, and testing a new set of landing craft that will provide system performance improvement and operational flexibility. To provide this flexibility the craft will operate at higher speeds than present craft.

Recognizing that these operational conditions produced by the increased speed of such landing craft, the environment, will plan unique requirements on the packaging and tiedowns or the material to be transported, NAVSHIPS has requested that NAVSUP support the program efforts. It has requested that this support be given in the designing and testing of support equipment to insure that the material the new craft will be transporting will arrive at its destination in good condition, and ready for use.

In order for the supply support equipment to be evaluated and tested properly, the influence of environmental and operational systems factors imparted to the cargo being transported from the supply ship to the beach must be defined. This report contains a definition study having seven objectives:

1. It establishes on a preliminary basis the loadings ("load factors") imparted to the cargo being transported on the landing craft under specific conditions of sea state, speed, cargo load (tonnage) and load distribution.

2. It establishes variations in the impact and acceleration loadings for the landing craft operating under the specified conditions.

The force loads imparted to the cargo establish the criteria vital to the evaluation and design of the supply logistics support equipment, that is, cargo tie-down systems, and materials packaging and packing. Additional criteria must be established to set the objectives for selecting or designing adequate tie-down and packaging concepts. This report

3. establishes those criteria to be considered in designing the tie-down equipment suitable for each operational situation, and
4. presents recommendations for a test program designed for the empirical evaluation of cargo tie-down systems for contemplated assault landing crafts.

For the test program, requirements in the following areas are specified:

5. the types of materials handling equipment that should be tested to determine which, if any, best suits the operations requirements and any new design,
6. the levels and mix of cargo tonnage and the commodities to be included in the test program
7. some suggestions for potential redesign requirements for existing tie-down systems utilized in cargo transport from the mother ship to the beach and the development of new systems.

Thus, this study has sought to identify the factors that will constrain the design of new, and the use of existing, logistics support equipments in the NAVSHIPS Amphibious Assault

Landing Craft Program. Additionally, the study results should assist in shaping final ship design and packaging modes. Further, this report will serve as a basis for a test program to determine the manner and extent to which the identified environmental and operational factors will constrain the Assault Landing Craft Program. The format of the report is discussed in the following paragraphs.

In Chapter II the steps involved in each phase of cargo movement from point of rest in the mother ship to point of rest on the beach, as well as the types of supply logistics support equipment required in each step, are identified. Flow charts are presented.

Chapter III contains a definition of the operational and environmental factors influencing cargo movement activity for four (4) different support vessels supplying each of two (2) types of landing craft, looking at three (3) sizes of each craft. The maximum, or worst, load factor is considered in each of the following situations:

(a) the loading of cargo into the landing craft from the supply vessel assuming an out of phase motion of the supply vessel and the landing craft while the cargo is being lowered into positions at maximum speed.

(b) The transport of the cargo to the beach in four conditions of landing assault craft loading at the worst condition of operation (at the maximum speed in head or following seas).

(c) In a broaching situation to the point of ninety degrees roll.

(d) The grounding of the landing craft on the beach and any possible problems of high loading in the surf.

A definition of the highest loadings that can occur in the operation of the landing craft over their range of speeds and in sea states ranging from sea state 2 to sea state 5 is provided.

Finally, the following factors and criteria necessary for test program development are defined.

- The criteria necessary to define effective tie.down systems and changes in materials packaging are established.
- Any non-load factors considered desirable are also noted.

Chapter IV reviews the data on the shock and vibration environment of transportation modes and systems now in use. Also reviewed are present military tie-down and packaging systems used for vehicle and cargo during movement by air, highway, rail, and ship. Existing logistics support equipment systems are discussed from both positive holding (tension) and shock attenuation viewpoints. Reference is made to the lack of data comparable to that developed in Chapter III for the proposed new landing craft environment.

In Chapter V a representative list of commodities to be included in the test program is suggested. Vehicle and cargo tie-down systems, materials packaging, and possible new systems to be included in the test program are recommended. Test design, methods, equipment, and evaluation criteria are also specified.

CHAPTER II

CARGO FLOW AND EQUIPMENT USED IN AMPHIBIOUS ASSAULT OPERATIONS

The amphibious assault cargo logistics flow consists of the flow of all materials and supplies from the port of embarkation (POE) to the land transport system in the amphibious objective area (AOA). The specific section of this logistic supply chain under analysis in this study is the flow of cargo from the supply ship in the amphibious staging area to the AOA. This section of the logistics supply chain will be broken down into several different phases to facilitate the analysis of potentially severe cargo handling or transporting problems. Only those problem areas where cargo damage is likely to occur will be investigated. The type of cargo flow and the equipment necessary for that flow will be defined.

The cargo flows through five stations in the supply logistics operation starting from the supply ships in the staging area to the amphibious objective area on the beachhead. These stations are as follows:

Station (1). Supply ship - ready for horizontal flow
Station (2). Supply ship - ready for vertical flow
Station (3). Supply ship - ready for off-loading to landing craft
Station (4). Landing craft - ready for off-loading to AOA
Station (5). Amphibious objective area - beachhead.

Each of these five stations is connected with four different cargo handling phases and one transportation phase. The four cargo handling phases are:

Cargo handling phase (a)	Horizontal flow - Supply ship
Cargo handling phase (b)	Vertical flow - Supply ship
Cargo handling phase (c)	Off-loading - Supply ship
Cargo handling phase (d)	Off-loading - Landing craft

The transportation phase and the most important new regime in amphibious assault is the high speed landing craft transport of materials and supplies from the amphibious staging area to the ACA. Currently under evaluation are two design types of high speed landing craft; a planing hull design, and an air cushion design. For each of these two design types three load carrying capacities were considered at 30,000 pounds, 125,000 pounds, and 320,000 pounds. This study will look at these two types, the planing hull and air cushion designs operating at their design speed of 22 knots and 50 knots respectively in sea state three (3) and at reduced speeds in sea state five (5).

This supply logistics flow can be represented as shown in figure I-1. The supply flow can recycle from station (2) to station (1) several times before reaching station (3). In some operations the flow will not enter the high speed transport phase but will be accomplished by conventional landing craft or helicopter. In many operations the flow will pass through several cargo handling phases and two stations when the cargo is moved vertically up and out of the supply ship and off-loaded into the landing craft by one piece of cargo handling equipment.

In the cargo logistics flow, the major problem areas where significant damage occurs are:

- the vertical movement of the cargo out of the supply ship
- the off-loading of the cargo into the landing craft
- the ship to shore transport of the cargo by the landing craft
- the off-loading at the AOA

Damage of the cargo occurs in all of these operational phases due to broken bonds on the cargo pallets, the impacting of the cargo on the supply ship's side or the landing craft's cargo box, the dynamic motions of the high speed landing craft and impact loads during the vertical movement of the cargo out of the supply ships or the landing craft.

The cargo flow is accomplished by many different pieces of cargo handling equipment. The following is a phase breakdown of this equipment.

Cargo handling phase (a) Horizontal flow

The horizontal movement of cargo in the supply ship is accomplished by conveyor, fork lift, or pallet transporter from the place of stowage (station (1)) to the area where it can commence its vertical movement (station (2)). The load limits on these cargo handling systems are:

- Conveyor: usually limited to a single 40" x 48" pallet loaded to 43" max and weighing 4,000 pounds
- Pallet transporter: weight limited at 3,000, 4,000 and 6,000 pounds
- Fork lift: weight limited at 3,000, 4,000, and 6,000 pounds.

Cargo handling phase (b) Vertical flow

The vertical movement of cargo up and out of the supply ship to a position where it can be off-loaded into the landing craft is accomplished by elevator, conveyor, monorail crane, or cargo booms from its position ready for vertical movement (station (2)) to station (3) ready for off-loading. The load limits on these cargo handling systems are:

-Elevator: approximately 17'10" x 7'11" x 7'0" with weight limit of 16,000 pounds

-Vertical conveyor: limited to 48" x 54" x 56" volume and a weight of 4,000 pounds

-Monorail crane: two hoists per crane with a capacity of 4,000 pounds

-Cargo lifts: weight limited at 3, 5, 10, 15, 30, 35, 45, or 60 tons. Most cargo holds are equipped with a small 10 ton boom and a large 30 to 60 ton boom.

Cargo handling phase (c) Off-loading-supply ship

This phase of cargo movement takes place from the point where the cargo leaves the hold and starts its movement toward the landing craft. This movement can be over the side of the supply ship or into the open well inside the supply ship. This cargo movement is handled by monorail cranes or cargo lifts. The specific limits of these pieces of equipment are as described before. The cargo lifts can be of the yard and stay type, or of the jib crane type for heavier loads.

This cargo movement phase is finished when the cargo is positioned in the landing craft.

Transportation Phase

This phase of cargo flow takes the cargo from the supply ship amphibious staging area to the AOA. For the purpose of this study only the two high speed landing craft will be considered, although this phase can be accomplished by conventional landing craft or by helicopter. The three different load capacities and two types of high speed landing craft design are analyzed for their impact and vibration loadings during transit.

Cargo handling phase (d) Off-loading landing craft

The landing craft is unloaded at the beachhead by the short cargo handling equipment carried in during the amphibious landing. This equipment includes all terrain fork lift, mobile truck and crawler cranes, and various sizes of trucks. Causeway and portable harbors are also utilized. The operational limitations on this equipment are:

Fork lifts - RT class- 3,000, 6,000, and 10,000 pounds

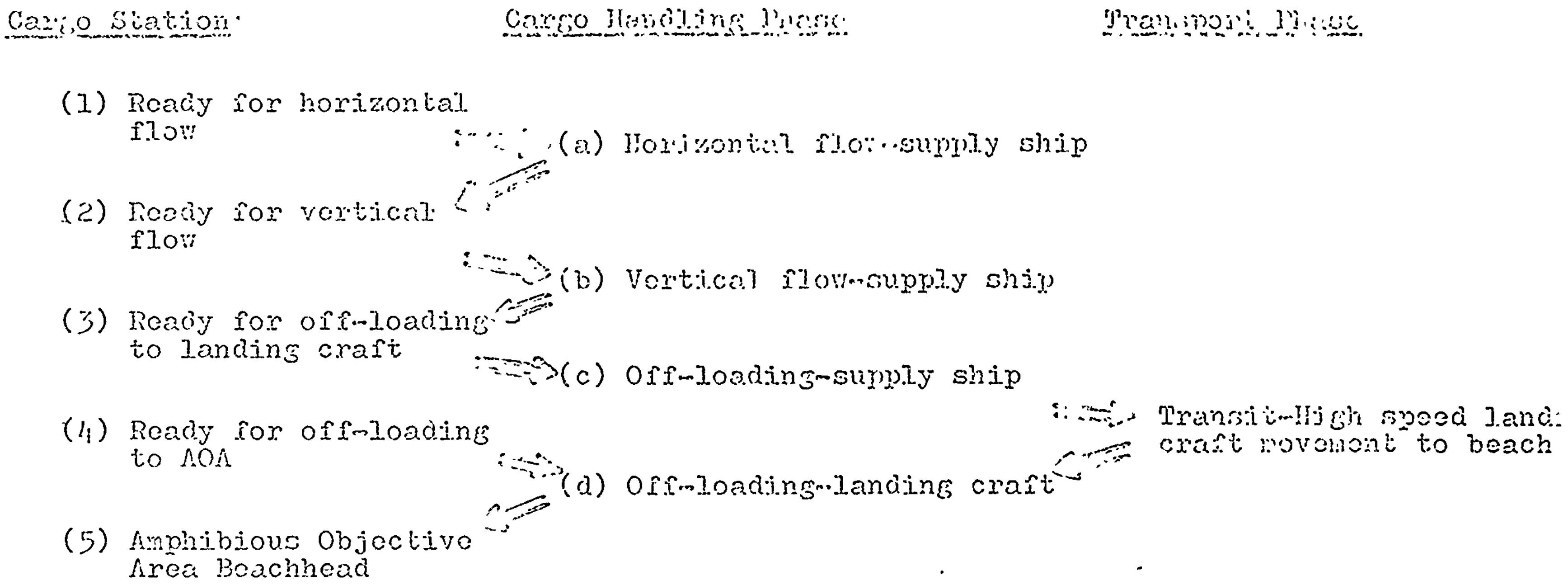
Fork lifts - TD 15 - 20,111 pounds

Truck cranes M-60 - 6,000 pounds
Bay city - 25,000 pounds

Trucks - 2 1/2 tons to 5 tons

This cargo logistic flow breakdown forms the basis of the operational phase analysis to evaluate the effectiveness of the materials packaging and cargo tie-down procedures for the new high-speed amphibious operation.

Cargo Logistic Flow Diagram



(Figure II-1)

CHAPTER III

OPERATIONS AND ENVIRONMENTAL FACTORS CHARACTERISTIC OF PROPOSED NEW HIGH SPEED LANDING CRAFT

III-1. Introduction. Dynamic Loading of Amphibious Assault Cargo

The operational and environmental factors which influence the cargo movement activity from the supply ships in the Amphibious Staging Area (ASA) to the beach in the Amphibious Objective Area (AOA) result primarily from the operation of the supply system, the high speed landing crafts and the supply ships in the physical environment of the landing zone. The major difference in the operation analysed in this report from past landing operations is the employment of high speed assault landings taking place from the ASA beyond the horizon. Thus, the dynamics of these new landing craft create additional design criteria on the materials packaging and tie-down systems. These new high speed landing craft subject the assault support cargo to new and different types of loadings.

Two types of loads are encountered in all physical systems. These are vibratory loads, an acceleration loading on the system having more than occasional occurrence, and impact or shock loads, an acceleration loading of short duration and individual form occurring much less frequently than the time duration of the function of the system. The vibratory loadings usually have a dominant frequency or frequency range while the shock or impact load will have a broader frequency range with a dominant frequency set by the structure of the object impacted. The structure of the cargo will have little effect on the frequency of the vibratory loadings. A typical vibratory loading is the wave encounter force of the landing craft meeting the waves. An impact loading is the landing on a particularly steep wave from an almost airborne position. The vibratory load is continuous while the impact or shock load is unique in its existence.

In the amphibious assault landing from the ASA to the AOA, there are three phases of the operation which can result in damaged cargo due to the dynamic motions of the supply ship and the landing craft.

- The <u>first phase</u> is phase (c) the off-loading of the supply ship placing the cargo into the landing craft. This phase of the operation can occur at the side of the supply ship as with the AKA's or in the cargo well of the LHA. In both areas of loading, the wave motion can be extremely hazardous to the off-loading operation. With the ACV, the off-loading operation can be completed with the craft stationed on the ramp at the end of the well, thus eliminating this particular problem. The planing craft is not as adaptable in its operation.
- The <u>second phase</u> is the transition phase from the supply ship in the ASA to the beach in the AOA. This phase of operation results in long time durations of

vibratory acceleration loadings along with the probable occurrence of impact loads. Both the ACV and the planing hull designs encounter these operational conditions. The third phase is the off-loading phase (d) of the landing craft at the beach in the AOA. The ACV in this case can leave the water and position itself on solid ground before off-loading commences while the planing craft must remain in the water, possibly in dangerous surf conditions.

In the first phase there are two impact and shock load situations which must be considered. The first is the impact of the cargo unit or pallet with the side of the supply ship due to the pendulum action of the cargo slung on the cargo boom as the ship rolls. The second is the impact of the cargo unit or pallet with the cargo deck of the landing craft as it heaves, pitches and rolls alongside the supply ship.

The transition phase of the assault landing operation has five individual sources of dynamic motion which can place vibratory loadings and impact loads on the contents of the cargo.

First, there is the heave and pitch accelerations of the dynamic motions of the landing craft operating at high speed in waves. This motion results in large vertical accelerations on the cargo, in particular the cargo in the bow of the craft, and smaller horizontal longitudinal accelerations.

Secondly, there is the wave impact of the landing craft with steep waves. This impact or shock loading can be quite high if it results from an airborne flight path into the next wave encountered.

Thirdly, one phenomenon which more than any has plagued the landing operation in the past and will continue to do so even with these two new design types of landing craft is the broaching of the landing craft in waves and surf. This particular problem takes on new dimensions with the higher running speeds of these new craft. The danger of a high speed broach is quite real. Assuring that the landing craft survives the high speed broach and remains in an upright position depends greatly on the holding power of the tie-down system in preventing the cargo from shifting.

The fourth possible dynamic action the landing craft can undergo is a high speed grounding. This would be a problem for the planing hull design if it encountered a submerged reef or sand bar during a high speed approach to the beach. The resulting deceleration of the landing craft places horizontal acceleration loads of long time duration on the cargo and its tie-down system.

The fifth possible vibration load found in the high speed landing craft operational systems is the propulsor and engine induced vibration. These two subsystems can generate in some of the poorer designs vibratory loads capable of being considered significant in packaging and tie-down systems design. The loads in these cases will be of a much higher frequency than all the other loads discussed.

The off-loading of the landing craft at the beach will be hindered by the same type of cargo impact problems as is encountered during the off-loading of the supply ship. In most cases, the worst loadings will be encountered during the off-loading of the supply ship in the ASA, and any load encountered off-loading at the beach in the AOA will be less than the off-loading shipside.

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The analysis which follows on each of these potentially damaging operational situations will calculate the worst possible condition which could occur if the dynamic motion were unrestrained. The resulting dynamic load will define the upper limit of the loading envelope for the design of packaging and tie-down systems for the amphibious assault operation.

III-2. High Speed Wave-Induced Motion Loads

The landing craft are designed to operate at full design speed in sea state two or at a speed of 22 knots in sea state five. This condition is used since it represents the maximum wave induced motions encountered. The amphibious operations would not be started in sea states greater than sea state five; thus, this is the upper limit of the motions evaluation in this study.

The landing craft are subjected to two types of dynamic loadings during their movement from the ASA to the AOA. The first and most frequent is the vibratory loading experiences as they encounter the waves. The second type of loading is also due to wave encounter but here the loading is very short and severe, taking the form of an impact or shock load. This section of the report will discuss the motions loadings and Section V will discuss the wave impact loads.

The two most widely differing modes of operation are those of head seas wave encounter and following seas wave encounter. As one would expect, the frequency of the wave encounter is much greater in head seas. The frequency of encounter can be calculated assuming the waves are in deep water and are travelling at speeds given by the first equation in Appendix VI towards or away from the landing craft. The frequency of encounter for the sea states two to sea states five, for the head and following seas cases frequencies range from 0.76 cps to 0.18 cps for landing craft speeds of 22 knots and from 1.05 cps to 0.62 cps for landing craft speeds of 50 knots. Hence in the most extreme case, that of an operation from over the horizon 30 nautical miles seaward, the cyclical loading of the cargo on board the landing craft can undergo as many as 4000 load cycles during the 30 nautical mile trip to the beach in the AOA. This value is for the head seas encountered during a 22 knot per hour trip over the 30 nautical miles. If the trip is made at 50 knots, the number of encounters will drop to 2280 load cycles. Both these values will be less if the waves are travelling toward the AOA and the landing craft only encounters following seas.

The acceleration loading which the cargo must endure during its transport from the ASA to the AOA will depend on a number of factors. These are:

a. The sea state encountered in the operations area
b. The dominant direction of this sea state
c. The speed of the landing craft
d. The load trim of the landing craft
e. The location of the cargo in the cargo well of the landing craft
f. The skill of craft handling of each individual operator.

At times the craft's loading will not be ideal and the trim of the landing craft will vary. The sea state and its dominant wave direction will not be under anyone's control. The speed of the craft will in most cases be pushed to the limit of the craft's operator's endurance, not to say anything of the cargo's endurance.

The motion acceleration loadings anticipated during the operations will be worst for the head seas encounter case. Both the level of acceleration loading and the frequency of encounter will be highest. The values for these loadings are given in more complete form in Appendix A, but representative values are listed here. A short discussion of the reported motions for the ACV's as tested at Naval Ship Research and Development Center is given in Appendix A.

Hence the range of cyclic loading is 0----5000 cycles per cargo trip.

The maximum range of g loadings for the wave motions

for the ACV's: 0----4.5 g's bow accelerations
for the Planing Craft: 0----7 g's bow accelerations

for the maximum in 100 wave encounters.

The average acceleration loadings for the entire 5000 cycles and the values at which the cargo should be tested for fatigue are as follows:

for the ACV's: Sustained acceleration load level = 1.9 g's for 5000 cycles.

for the Planing Craft: Sustained acceleration load level = 3.1 g's for 5000 cycles.

Hence the cargo tie downs and packaging must be capable of withstanding 3.1 g's sustained over 5000 cycles and high motion loads of up to 7 g's of bow acceleration.

III-3. Broach and Roll Condition

Amphibious operations are most hazardous when the dominant wave motion is onshore and the sea state is large enough to generate a surf zone. When landing craft navigate in the surf zone, there is always considerable danger in losing control of the landing craft and broaching. In the event that this does occur and the landing craft remains afloat upright, it is desirable to hold the cargo in position in the cargo well of the landing craft so that the center of gravity of the craft will not change. The lashing or tie-down system must be able to withstand both the acceleration loading due to the fast broaching yaw, the acceleration due to the rolling of the landing craft to approximately sixty degrees (approximate roll limit before overturn) and the transferal of the entire weight of the cargo to the lashing and tie-down gear. The combination of these three loadings makes up the maximum loading to be experienced in this case.

The angular motion of any body results in an acceleration which can be defined in radial and transverse components as:

$$a = (\ddot{r} - r\omega_r^2)i_r + (r\dot{\omega}_r + 2\dot{r}\omega_r)i_\theta$$

where a = acceleration
r = radius from point of rotation on landing craft
$\dot{r}$ = velocity of radius vector
$\ddot{r}$ = acceleration of radius vector
ω_r = angular velocity
$\dot{\omega}_r$ = angular acceleration
i_r and i_θ are unit vectors in the radial and tangential direction.

For the broach and roll condition, the only significant term in the above equation is the $r\omega_r^2$ term. Hence the acceleration is;

$$a = -r\omega_r^2 \quad \text{in the radial direction.}$$

When a landing craft undergoes a <u>fast</u> broach and roll, the complete motion can happen in about one second. Using a value for ω_r = 1 radian/sec for the broach and 1 radian/sec for the yaw, the two accelerations are found:

$$a_{ROLL} = 1 \times r_{ROLL} \quad ft/sec^2$$

$$a_{YAW} = 1 \times r_{YAW} \quad ft/sec^2$$

For a cargo unit or pallet positioned at the corner of the landing craft well, the values of r_{ROLL} and r_{YAW} are respectively 17 feet and 70 feet. These values are for the largest planing craft. The acceleration load is the vector addition of the two acceleration components:

$$a_{ROLL} = 17 \; ft/sec^2$$

$$a_{YAW} = 70 \; ft/sec^2$$

Combined acceleration load is 72 ft/sec^2 or approximately 2.25 g's. This load must be taken by the tie-down system along with the entire weight of the cargo, be it 2, 5, 10, 30 or 70 tons.

Hence for the broach and roll condition, the cargo tie-down system must be capable of supporting the entire weight of the cargo from one side and be able to withstand a loading of up to 2.25 g's for a range of time duration of approximately one second to four seconds. The acceleration diagonally is a vectored force operating on the cargo of the landing craft.

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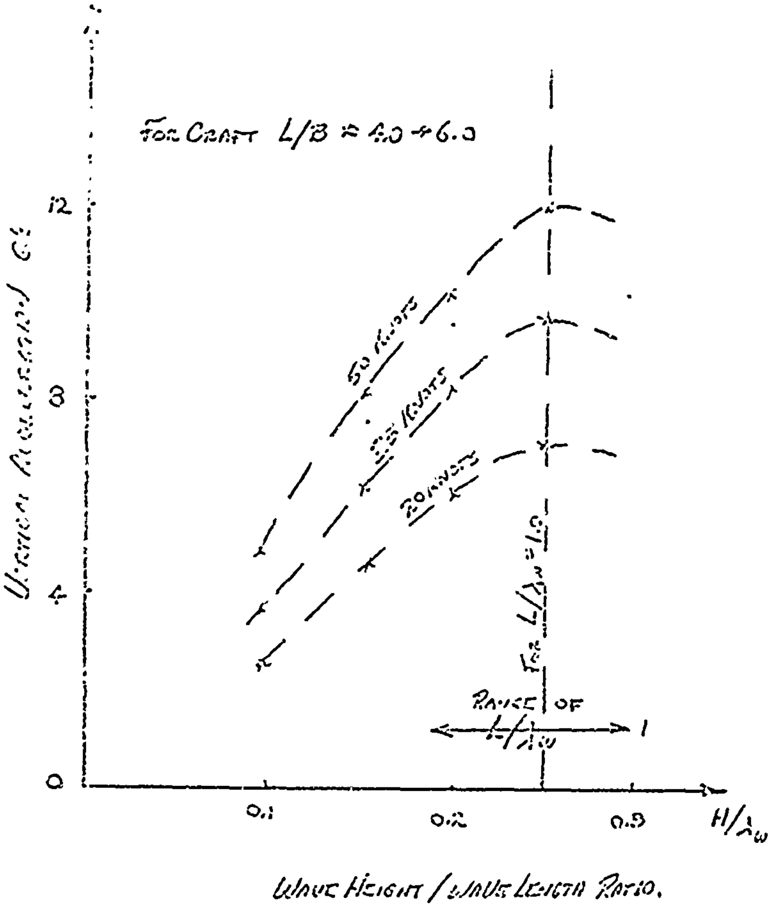
III-4. Dynamic Loading of Amphibious Assault Cargo: Wave Compact Loads on High Speed Planing Hulls.

The forward bluff bows of these new high speed landing are very prone to high speed bow impacts, in particular, in following seas where a high overall running speed can be sustained. When a bow impact occurs, the pitch angle of the landing craft moves down and the craft attempts to submerge its bow in the wave crest. This dynamic motion creates a large acceleration (really a deceleration of the craft) loading directed perpendicular to the plan of contact. The effect of this action is to subject the craft and its cargo to a horizontal and vertical acceleration loading originating at the bow.

The magnitude of these values are essential in evaluating the materials packaging and tie-down systems. The orientation of these loads can vary from entirely horizontal to a loading which is directed within thirty degrees of the vertical. The value of the loading can be read from the acceleration chart shown in the following figure.



This chart has been developed from data found in NACA reports reference, 13, 14, 15, and 16.

The values of acceleration can be read from the graph for the respective sea-state, speed, and craft length to wave length ratio. This graph shows that the impact loads can be as great as 12 g's from the L/λ_w = 1.0 case when the wave height to wave length ratio is approximately 25. The orientation of this vector can be completely horizontal or as much as within 30 degrees of the vertical on the landing craft. The 12 g acceleration load can then be directed so that 6 g's are horizontal and 10.4 g's vertical. These loadings can have a time duration up to 0.4 seconds.

III-5. High Speed Grounding

The planing hull landing craft may encounter difficulties in an amphibious assault operation if the approach to the beach is obstructed by shoals and reefs. The danger here is that of a high speed grounding. Assuming a 35 knot speed capability and a grounding that would simulate a level submerged shoal or reef which would not severely damage the bottom but would bring the landing craft to a halt in less than 30 feet, the horizontal deceleration loading and the time duration are approximately:

Acceleration loading = 2.0 g's (in deceleration)
Duration = 1.0 second

The planing hull could encounter a much higher acceleration loading in a proportionally shorter time duration but the limit would be reached very shortly where the craft would sustain too much bottom damage to be of any use after. Hence the cargo would be lost.

The dynamics of high speed grounding should bring to bear on the cargo a range of acceleration loads from zero to 2.5 g's with time durations as long as 2.5 seconds. The dominant direction of this force is horizontal, or the lateral direction relative to the cargo units or pallets.

III-6. Propulsor Vibration

One other type of vibration loading the cargo must experience is the vibration induced in the landing craft hull structure by the water jets which propel the planing hull landing craft and the air screws which propel the air cushion vehicle. Hull vibrations and hence vibrations of the cargo well deck and the cargo will occur at the natural frequencies of the hull structure and at the rotating frequencies of the propulsors and their driving machinery.

The vibrations of the hull's structure are laborious to calculate and would only register vibratory forces in the lower frequency range where the wave encounter frequencies dominate. The overall effect of these hull modes of vibration would not be significant alongside the wave encounter vibratory forces. The more significant vibratory forces are those of the propulsors themselves. These are the blade natural frequencies found at the operating RPM or a multiple of this value depending on the number of propulsor blades and the dynamic relationship between the propulsor and the structure of the vehicle.

The ACV is propelled by tandem shrouded air screws mounted aft outboard of the cargo well. The load level of the vibratory force set up by the operation of the air screws will be in the range of 0.6 g to 1.1 g's over a frequency range from 100 cps to over 660 cps (ref. 4,5). The distribution of the g level over this range will be a level distribution with high peaked loadings occurring at various specific frequencies depending on the natural frequencies of components of the landing craft. The packaging, packing and tie-down system should be able to adequately handle a 1.0 g loading of frequency from 100 cps to 600 cps.

The planing craft is propelled by water jet mounted in the stern of the landing craft. The vibratory loads encountered in this craft will be at the frequency level of the shaft rotation or at a multiple of this value given by the number of impeller blades and their influence on the hull structure. Shaft rotation for the water jet propelled planing craft will be as high as several thousand revolutions per minute. The planing hull landing craft will have propulsor excited vibrations of up to a maximum of 0.3 g over the frequency range found in water jets.

The vibratory force set up by the propulsion machining can be in the low frequency range for reciprocating engines or in the higher frequency range for gas turbines. The only significant vibratory forces would result from the operation of the reciprocating engine and would again be in the same frequency range as that of the propulsors.

The design criteria for the tie-down and packaging systems should be capable of absorbing the one half to one g loadings with over the frequency range of from 20 to 600 cycles per second.

III-7. Off-Loading of Landing Craft at the Beach

The two landing craft directly involved in this study find different unloading situations when they reach the beach. The ACV is unloaded on the beach itself, having negotiated the surf and the slope of the beach up to the high water mark or the berm of the beach. The planing craft landing craft is different in its operation in that it cannot leave the water to unload and hence must risk damage and broaching in the surf or breaking waves.

The planing craft will be grounded in the surf zone or inshore of this zone. The condition of onshore wave movement will create the high amplitude waves which characterize all surf zones. The wave height in the surf zone depends greatly upon the bottom geometry of the foreshore and the texture of the bottom material. Under optimal conditions the amplitude of the breaking wave can be two to two and one half times the dominant wave height in deep water. The increased wave amplitude concentrates the wave's energy into a shorter wave and forces a vertical motion of the landing craft during its unloading operation. This motion is very complicated and can best be determined by making some very limiting assumptions. The motion of the landing craft in this case cannot be greater than the wave amplitude in the surf zone so this value can be used as an upper limit. The maximum wave amplitude encountered in the surf zone over 100 wave encounters would be:

Surf Factor [H_{100} wave encounters = 4.56 x 3.9 = 17.8 feet]
(double amplitude)

The double amplitude highest wave found in 100 encounters in sea state 5 gives a good measure of the largest wave supposedly encountered in the surf zone. Surf waves are approximately 2.0 to 2.5 times the amplitude of average waves and this gives for sea state 5, wave double amplitudes in the surf zone of from 13.8 feet to 17.3 feet. Any pounding of the landing craft on the bottom in the surf zone would present only lower acceleration levels where structural damage of the hull did not occur. Cargo damage will be dominantly in off-loading under these conditions.

The danger of damaging the cargo during the unloading operation in the surf zone comes from pitching and heaving of the landing craft up so that the well deck of the landing craft impacts with the cargo after it has been lifted from its stowed position on the well deck. The heave motion in this case is much faster than the heave motion encountered when the landing craft is being loaded alongside the supply ship. The period of motion in the surf zone is shorter and the heave velocity much higher due to the higher wave amplitude in the surf zone. The velocity of heave in this case can be as large as 4.0 to 5.0 feet per second. The impact of the cargo well deck on the cargo at this speed, assuming zero hook velocity in the unloading operation, is still not as significantly large as the case of the shipside loading.

Hence the design of materials packaging and the packing of contents is adequate to protect the cargo during the beach unloading when it is designed to accommodate the worst unloading condition encountered alongside the supply ship.

CHAPTER IV

LOAD AND ENVIRONMENTAL FACTORS INVOLVED IN THE DEFINITION AND DETERMINATION OF AN EFFECTIVE TIE-DOWN AND MATERIALS PACKAGING SYSTEM FOR AMPHIBIOUS OPERATIONS

The previous section of this report has presented the range and nature of the damaging dynamic vibration and shock or impact loads which could possible act on the amphibious assault cargo during a high-speed landing operation. These loads have been defined by their acceleration magnitude and frequency range. These dynamic loads have also been defined as to their orientation with respect to the cargo unit or palletized load. In addition, the time duation of the vibration or shock load has been approximated. These loads cover the loading of the landing craft and its unloading at the beach along with the loads encountered in the transitional stage from the supply ship to the shore.

Since these loads are a very important part of the evaluation and design of the packaging and tie-down systems, the following table of values is given:

Table IV-1: Dynamic Load Factors for the Amphibious Assault Program

Operational Phase	Source	Type of Load	Magnitude and Frequency	Orientation	Duration
Off-loading supply ship	Ship side impact	Shock	30 g's loading at 15-20 cps.	Transverse on cargo	0.005-0.01 sec.
	Cargo well impact	Shock	25 g's loading at 10-15 cps.	Vertical on cargo	Same as above
Transport of cargo to shore by high speed landing craft	Wave motion	Vibration	3.5 g's 0-5000 cycles approx. 1 cps. peaks-7 g's	Predominantly vertical Small amount horizontal	1/2 hr.--1→1/2 hr.
	Broaching	Rapid angular acceleration	2.5 g's		1→4 secs.
	Wave impact	Shock	Up to 12 g's	Horizontal and vertical	0.005→0.0 sec.
	Bottom grounding	Shock	1.3 g's	Horizontal	0→2-1/2 secs.
	Propeller vibration	Vibration	1/2 g planing craft 0--700 cps. 1.0 g havercraft	Vertical	Time of operation
Off-loading of landing craft	Heaving pitching craft in surf	Shock	Lower than previous off-loading	Vertical	

These load factors as outlined in figure III-1 are important in the design and selection of the materials packaging and tie-down systems for the following reasons:

1. The lateral impact of the cargo with the side of the supply ship can generate accelerations of 30 g's which can damage the contents of the cargo unit, pallet or container. The impact of a vehicle with the side of the supply ship could easily make the vehicle inoperative.

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Further damage to the cargo unit or pallet can occur if the lateral impact breaks or damages the integrity of the cargo load so that the cargo is lost or the contents are exposed to further damages. The occurrence of this impact will be random in nature depending on the pendulum action of the cargo on the cargo booms subject to the roll motion of the supply ship.

2. The cargo well impact generates the largest acceleration loading on the cargo if all dynamic motions involved in this phase of the unloading operation combine to produce the maximum descent velocity for the cargo. This loading can range to a high acceleration loading of from 20.0 to 50.0 g's if the cargo pallet and landing craft cargo-well deck deflect less than one quarter of an inch. The loading here will be predominantly in the vertical direction with a majority of the initial contacts being made by the edge or corner of the cargo unit or pallet. In this particular loading case, the loading of wheeled vehicles with their spring suspensions will help reduce the loading by absorbing some of the descent motion and impact before the vehicle is at rest. The most damaging situations are the rapid descent and contact of pallets, cargo units and unsprung vehicles with the cargo-well deck resulting in little deflection of the deck and accordingly very high loadings. The energy content of

V-2. Packaging and Packing of Military Supplies and Equipment -- Current Practice

Ample general documentation exists of current military procedures standards and tests for the packaging packing[1,2,3], unit loading[4,5],palletization,[4,5] containerization[4], cushioning[6,7,8] blocking[8] bracing[8], anchoring[8] of military supplies and equipment. Further for most classes of military commodities specific packaging and packing standards exist. Test procedures for evaluating package design and structure are also specified[1,9,10].

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[1] Defense Supply Agency,"Preservation Packaging, and Packing of Military Supplies and Equipment."Packing Volume II.. DSAM 4125.2, October 9, 1967

[2] United States Army Materiel Command, Engineering Design Handbook, Packaging and Pack Engineering. AMCP 706-121, October, 1964.

[3] Departments of the Air Force, The Army, and the Navy, and Defense Supply Agency. Packaging and Materials Handling. "Packaging and Handling of Dangerous Materials for Transportation by Military Aircraft" AFM 71-4, May 29, 1968.

[4] Department of Defense, Military Standard, Palletized and Containerized Unit Loads 40" x 48" Pallets, Skids, Runners, or Pallet-Type Base. MIL-STD-147B. April 30, 1968.

[5] Emberger, C. Shrink Wrapping. Sup. 0442, June 24, 1970

[6] Department of Defense, Mustin, G. (special consultant) Theory and Practice of Cushion Design, SVM-2. May 1, 1968.

[7] Department of Defense. Military Stardarization Handbook Package Cushioning Design, MIL-HDBK-304. November 25, 1964

[8] Department of Defense, Military Standard, "Cushioning, Anchoring, Bracking, Blocking, and Waterproofing; with appropriate Test Methods", MIL-STD-1186. October 28, 1963.

[9] Joint Military Packaging Training Center. "Testing Equipment for Packaging Training", JMPTC BKLT 110, September 1968.

[10] See Appendix C.

horizontal and vertical directions will give lateral and vertical loads of 5.6 g's and 4.2 g's respectively.

3. The planing craft is very susceptible to high speed bottom grounding during its approach to the beach. If a sand bar or coral reef were encountered while the craft were at high speed, large horizontal and vertical acceleration can be experienced. The case of large vertical accelerations is not so applicable since considerable damage would be experienced by the bottom structure of the landing craft before acceleration loading reached the magnitude of the vertical impact loadings which occur during the loading operation. The horizontal acceleration is most important, since it can be as high as 2 g's for a time duration of 2 seconds. This is a large lateral loading of <u>longer</u> time duration than is encountered in the other dynamic motion cases.

The ACV and the planing hull landing craft are not without vibrations from the propulsion engines and the propulsors. The ACV, will have the vibration from the turbines or reciprocating engines and the vibration from the air-screw thrusters. Of the two sources, the air screw will generate the larger vibratory forces of approximately 1 g loading with a frequency range from 100 cycles per second to 600 cycles depending on the operating speed of the craft. The planing hull will experience vibratory forces from its propulsor and small loadings but of higher frequency from the engines. The level of this loading depends greatly on the design of the craft but can range from 0.1 g's to 0.3 g's with a range of frequencies from 1000 cps to 6000 cps.

The last dynamic motion encountered by the cargo in its transport from the supply ship in the ASA to the beachhead in the AOA is a vertical impact loading during the off-loading of the landing craft onto the beach. If a surf is running the landing craft will tend to heave as the surf runs by the craft. This type of motion is only involved in the planing hull case since the ACV will leave thewater completely to unload on the beach. This dynamic loading will be no more severe than the off-loading from the supply ship to the landing craft case.

These dynamic loads that the cargo must withstand during an amphibious operation must be absorbed as they have been defined by the cargo or the packaging and tie-down system must be capable of altering these maximum loads to a lower more acceptable level. Hence any future materials packaging and tie-down system must be subjected to these loads without experiencing contents damage before the system is deemed acceptable in handling the possible environmental forces and conditions with a degree of confidence of over 98 percent.

Design Criteria of the Cargo Tie-Down Systems

The cargo tie-down system must be designed to meet the following requirements:

1. Positive positioning of the cargo unit or pallet in the cargo well. The tie-down system must be able to maintain the cargo in place during the exposure of the landing craft to vibrations and horizontal and vertical

impacts. Deck implaced restrainer may be necessary.

2. Retain the cargo in the craft and maintain integrity of load during the broach conditions.
3. The tie-down system must be designed to always maintain a specified level of loading.
4. The cargo tie-down system must prevent the build-up of lateral static loads on the cargo.
5. The lashing system will be universal for unit loads, pallets and vehicles.
6. The lashing gear must be capable of withstanding the sustaned 3 g loadings for 5000 cycles at 1 cps and the maximum g landings of 12 g's for (5) occurrences per trip to shore.

Criteria for the Design of Materials Packaging Systems

1. The package must be designed to absorb the maximum vibration loads encountered during the one-way transition of the cargo the the AOA. The packaging must take this loading for the time duration of this in transit phase of the operation.
2. The packaging material must be capable of absorbing lateral impacts and still maintain the package's integrity.
3. The materials packaging must cushion the cargo from damage due to vibration or shock loads subjected to the cargo through the packing and packaging.
4. The packaging material must also absorb all vertical

shock and impact loads, protect the cargo and remain intact.

5. The packaging material must be capable of becoming salt-water soaked and still perform its function.
6. The cargo units or loaded pallets must be capable of withstanding both horizontal dynamic loads and static loads from stacking and shifting cargo.
7. The pallet design must have a natural frequency well outside of the range of operating frequencies, and where possible below the range of operating frequencies.
8. Maximum acceleration loading protection must be assured in all cases of items with high natural frequencies since the damage of items with high natural frequencies is directly proportional to the maximum acceleration.
9. Package integrity is maintained with damage to 30 percent of the packaging.
10. The contents of a unit load or palletized load must be secured by the packaging system in such a manner as to reduce the working of the various components of that load.

Other Factors in the Materials Packaging and Tie-Down System Design

1. The material packaging and tie-down systems designs should account for the corrosiveness of the salt water environment.
2. The design should register levels of confidence for the strength of the packaging and tie-down items after various stages of fatigue and random impact loading.

CHAPTER V

REVIEW OF SHOCK AND VIBRATION CHARACTERISTICS OF EXISTING TRANSPORTATION ENVIRONMENTS AND REVIEW OF PRESENT AND PROPOSED TIE-DOWN AND MILITARY PACKAGING SYSTEMS

V-1. Data on Shock and Vibration Environment of Presently Used Transporations Modes

Packaging, packing and tie-down systems now in regular use for ship, rail, aircraft and truck cargo movement have been developed in general practice to the point where they will withstand the shock and vibration environment characteristic of these modes[1,2,3,4,5]. This general use environment then provides a performance baseline against which existing packaging and tie-down systems have been "tested".

Selected tables of this data are reproduced in Appendix B. Selected data in graphic form are reproduced below.

In evaluating this "use-test" data several points should be borne in mind.

First, the exact results measurements of shock and vibration in transportation modes are highly dependent on the precise manner in which the measurement is made. Thus, for example,

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[1] Harris, C. and C. Crede. Shock and Vibration Handbook 1961, McGraw-Hill, Inc.

[2] Department of the Army Technical Bulletin, TB 55-100 April 17, 1964: "Transportability Criteria and Shock and Vibration.

[3] Department of Defense. Military Standard Mechanical Vibrations of Shipborad Equipment. MIL-STD-167B(Ships) August 11, 1969.

[4] Department of Defense Research and Engineering. Index to the Shock and Vibration Bulletins. February, 1968

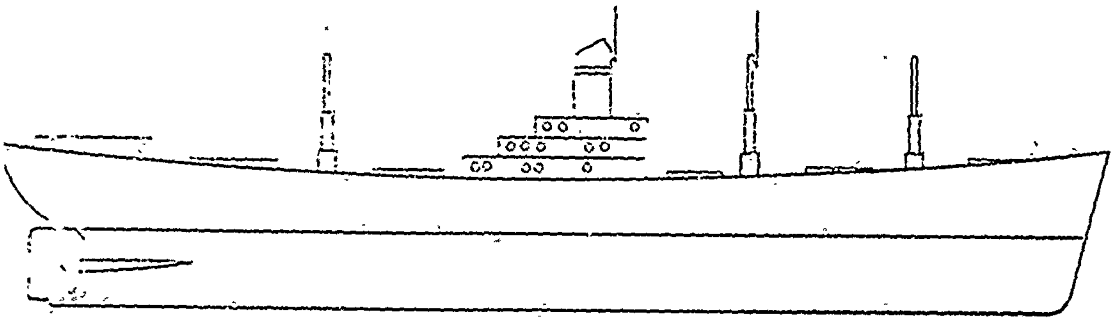
[5] See data in Appendix B.

readings on a recording accelerometer placed on a flatbed truck are dependent on where in the truck the instrument is placed. Further, whether a package tied down to the truck experiences the same g - loadings is highly dependent on such factors as how tightly it is tied down, whether the tie downs have any "give" under shock loads, whether it is on a pallet, whether it is stacked on the top of or under other packages, and so on.

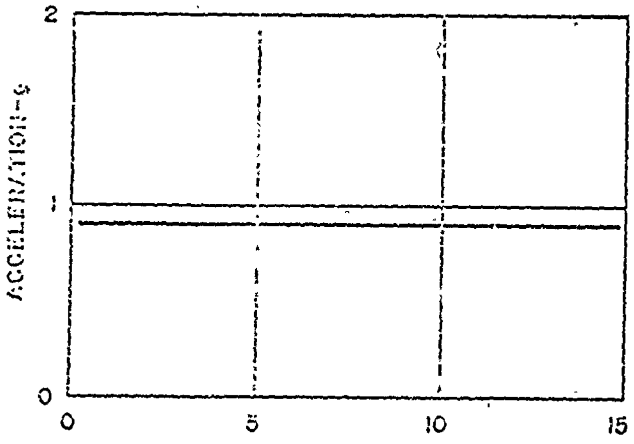
Second, this use-test data should be compared, where possible, with g - load test data on packaging and tie-down systems gathered under laboratory test conditions. As discussed in following sections, existing testing procedures for packaging and tie-down systems do not provide impact and vibration test data in a form useful for accurate comparison (i.e. g-loadings). Ideally, such test data should provide for any item or level-A packaged commodity (a) the minimum single impact g-loading at which the item package is damaged, (b) the minimum single impact g-loading at which the contents are damaged, (c) the minimum multiple impact (e.g. 5000 cycles) g-loading at which the item or package is damaged, (d) the minimum multiple impact (e.g. 5000 cycles) g-loading at which the contents is damaged, and (c) similar data for each tie-down sytem, including strength, fatigue characteristics and shock load strength. As will be seen in the reviews which follow, existing test procedures for items, packages, or tie-down systems do not provide this kind of data.

Third, it can be assumed that, in general, many existing tie-down systems have been shown through general use to be capable of repeated usage without failure under the shock and vibration conditions characteristic of the transportation in mode in which they are now employed. Further, it can be assumed that a typical item or level-A packaged commodity when tied down in the military specified manner will withstand a total transit and handling experience which might involve for example rail and truck transportation within the U.S., ship or air transportation to another point on the earth and subsequent boat, assault craft, truck and rail movement. Current practice thus indicates that, under transportation environments encountered in today's normal movemet of military supplies and equipment, packaging and tie-down systems now in use will at least meet the performance criteria (a) the package is held on the vehicle, (b) the pack or pallet is held together, and (c) the package contents are adequately protected from damage.

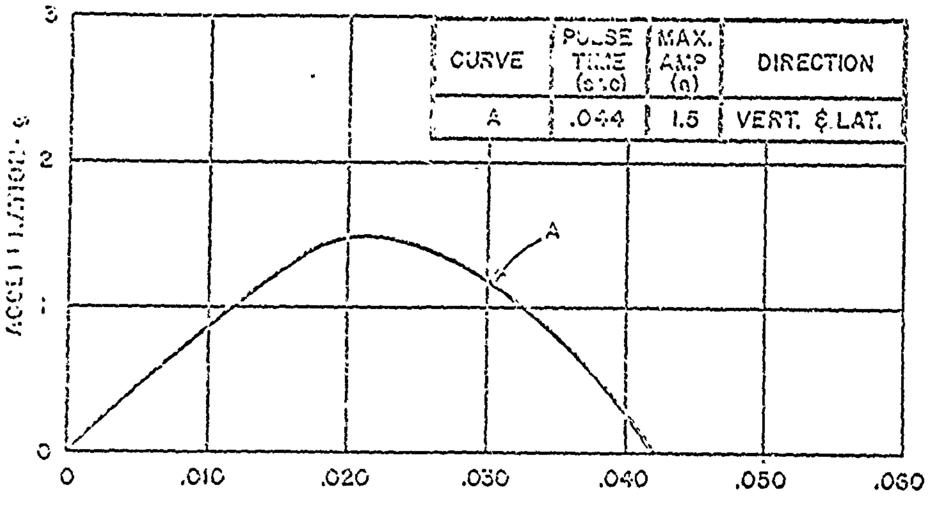
Reference to the mode data above (Figs V-1 to V-4) makes clear the varied character (in terms of frequency and intensity) of the shock and vibration use-test experience. That data should be thought of in terms of the calculated data for the proposed new landing craft presented earlier. The reader will recall that data included for each craft type and size in each



SCHEMATIC (C-2 CLASS)



-VIBRATION, VERTICAL & LATERAL-



CURVE	PULSE TIME (sec)	MAX. AMP (g)	DIRECTION
A	.044	1.5	VERT. & LAT.

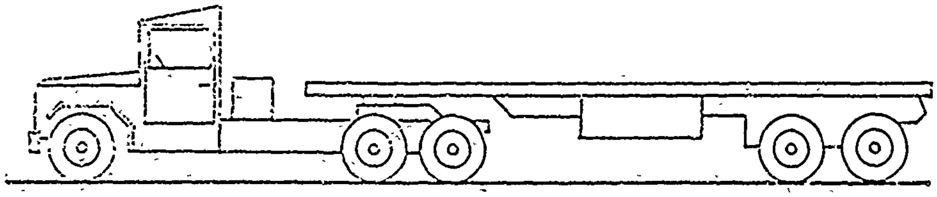
-SHOCK-

CARGO ENVIRONMENTS FOR SEA TRANSPORT

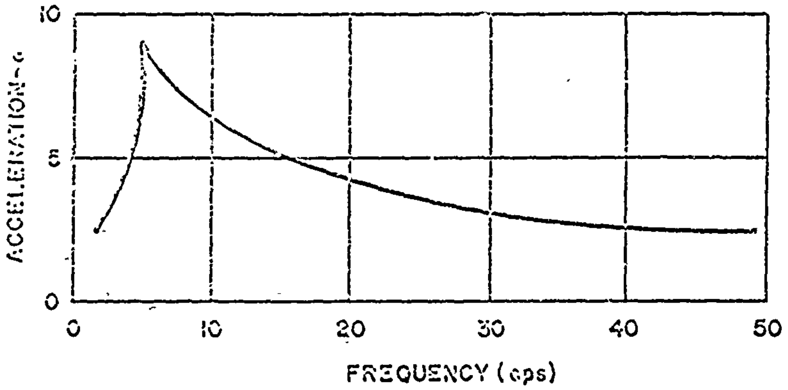
Fig. V-1

Source: Fig. V-1 -- V-4, see footnote 2

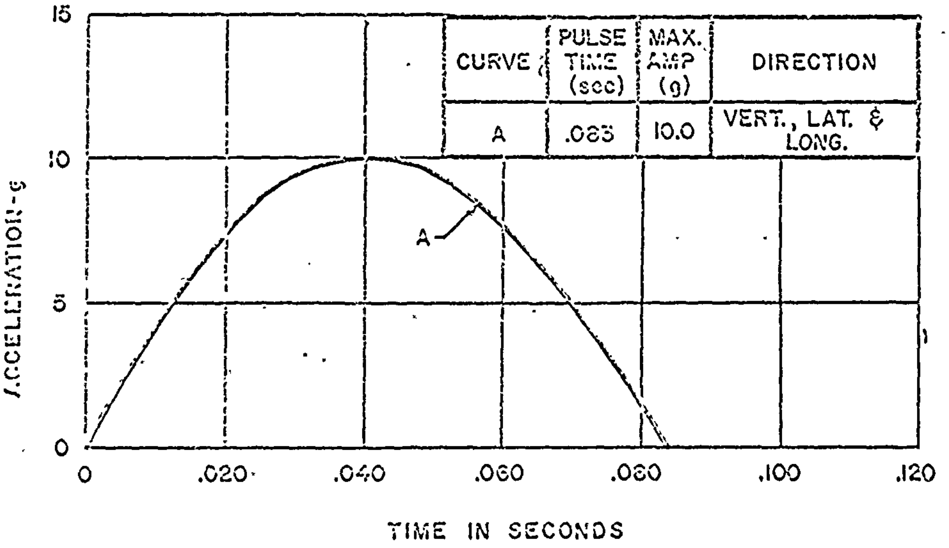
University Consultants, Inc.



SCHEMATIC



– VIBRATION, VERTICAL –

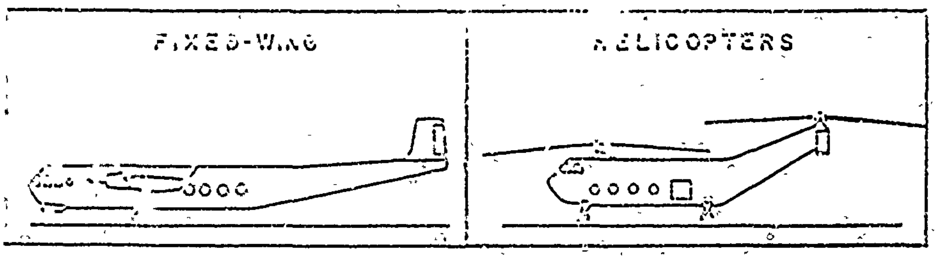


CURVE	PULSE TIME (sec)	MAX. AMP (g)	DIRECTION
A	.083	10.0	VERT., LAT. & LONG.

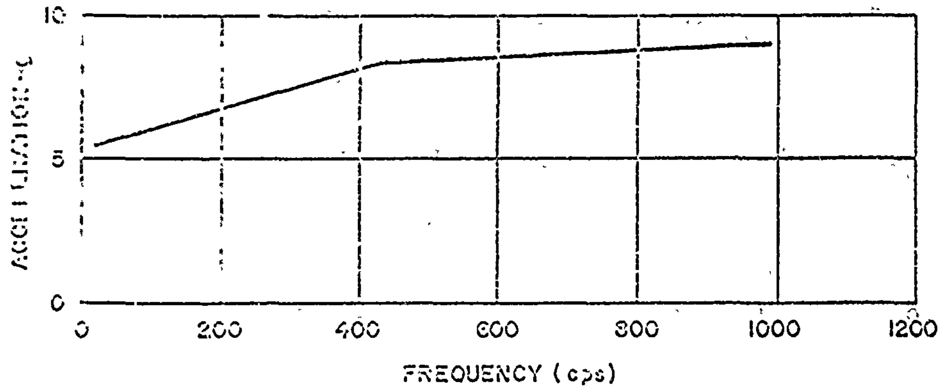
– S H O C K –

CARGO ENVIRONMENTS FOR HIGHWAY TRANSPORT

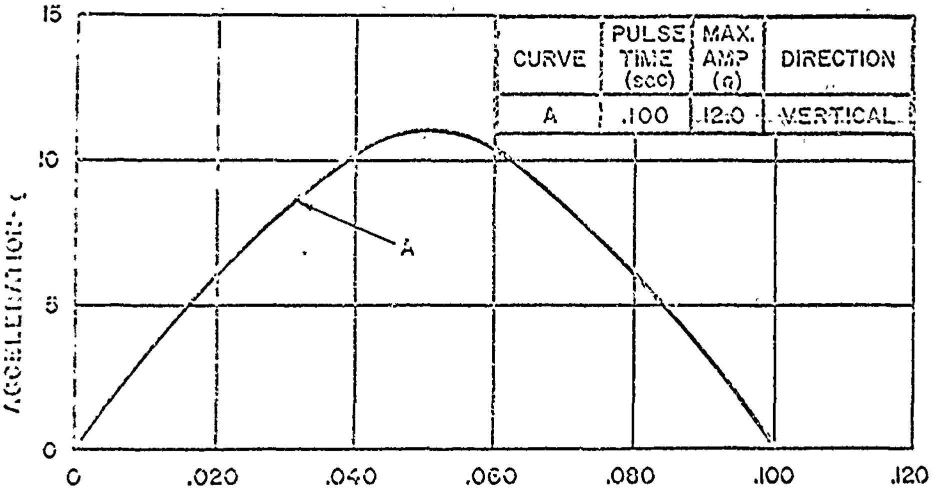
Fig. V-2



SCHEMATIC



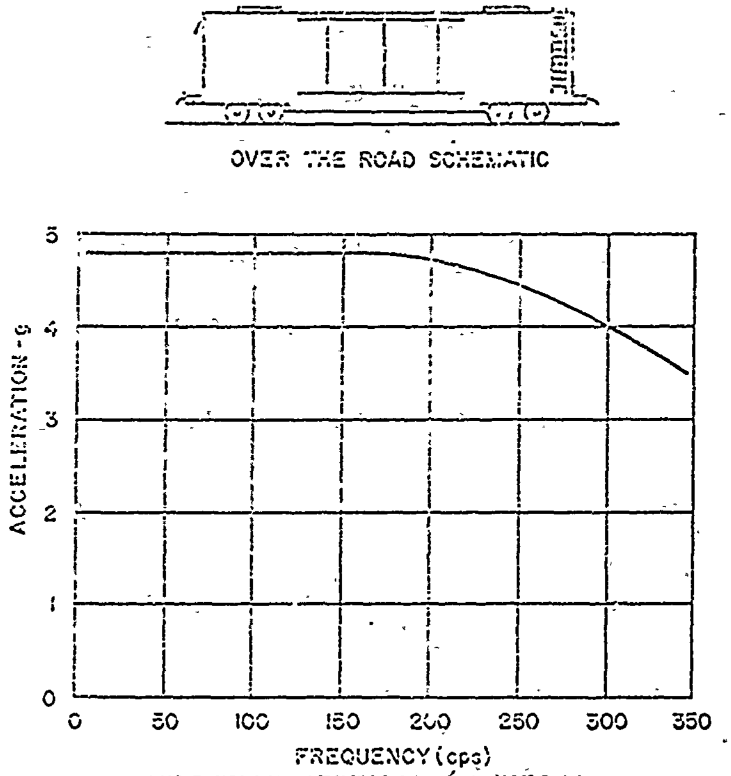
— VIBRATION, VERTICAL - LATERAL - LONGITUDINAL —



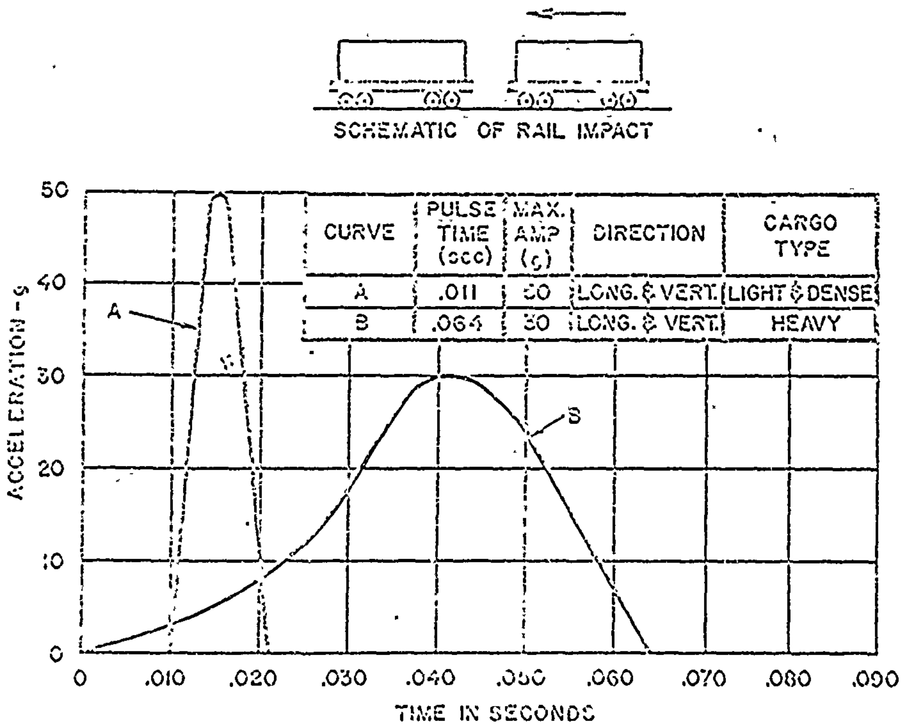
-SHOCK-

CARGO ENVIRONMENTS FOR AIR TRANSPORT

Fig. V-3



- VIBRATION, VERTICAL & LATERAL -



CURVE	PULSE TIME (sec)	MAX. AMP (g)	DIRECTION	CARGO TYPE
A	.011	50	LONG. & VERT.	LIGHT & DENSE
B	.064	30	LONG. & VERT.	HEAVY

- SHOCK -

CARGO ENVIRONMENTS FOR RAIL TRANSPORT

Fig. V-4

selected sea state data on the intensity and frequency distribution of impacts as the craft made its journey from the ASA to the AOA.

4,

V-2. Packaging and Packing of Military Supplies and Equipment -- Current Practice

Ample general documentation exists of current military procedures standards and tests for the packaging packing[1,2,3], unit loading[4,5],palletization,[4,5] containerization[4], cushioning[6,7,8] blocking[8] bracing[8], anchoring[8] of military supplies and equipment. Further for most classes of military commodities specific packaging and packing standards exist. Test procedures for evaluating package design and structure are also specified[1,9,10].

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[1] Defense Supply Agency,"Preservation Packaging, and Packing of Military Supplies and Equipment."Packing Volume II.. DSAM 4125.2, October 9, 1967

[2] United States Army Materiel Command, Engineering Design Handbook, Packaging and Pack Engineering. AMCP 706-121, October, 1964.

[3] Departments of the Air Force, The Army, and the Navy, and Defense Supply Agency. Packaging and Materials Handling. "Packaging and Handling of Dangerous Materials for Transportation by Military Aircraft" AFM 71-4, May 29, 1968.

[4] Department of Defense, Military Standard, Palletized and Containerized Unit Loads 40" x 48" Pallets, Skids, Runners, or Pallet-Type Base. MIL-STD-147B. April 30, 1968.

[5] Emberger, C. Shrink Wrapping. Sup. 0442, June 24, 1970

[6] Department of Defense, Mustin, G. (special consultant) Theory and Practice of Cushion Design, SVM-2. May 1, 1968.

[7] Department of Defense. Military Standarization Handbook Package Cushioning Design, MIL-HDBK-304. November 25, 1964

[8] Department of Defense, Military Standard, "Cushioning, Anchoring, Bracking, Blocking, and Waterproofing; with appropriate Test Methods", MIL-STD-1186. October 28, 1963.

[9] Joint Military Packaging Training Center. "Testing Equipment for Packaging Training", JMPTC BKLT 110, September 1968.

[10] See Appendix C.

Packaging is specified in three levels A,B,C. Level A packaging is that designed to meet the most severe transportation and storage conditions, and it is the only level which need concern u here. Level A packaging is defined as:

> "Level A, Military Pack: The degree of packing which will afford adequate protection during shipment, handling, indeterminate storage, and worldwide distribution."

Test procedures now employed are described in Appendix B.

It is important to note that the criteria for level A packaging design do not specify performance standards with respect to either minimum single impact g-load which must be withstood without damage to package or to package contents, or minimum multiple impact g-load which must be withstood without package or contents damage. The same holds true for packed and palletized cargo units. Qualitative test procedures and qualitative instructions for package construction are specified, but data so obtained cannot easily be translated into the kind of g-loading data needed for evaluation of package performance in the new shock and vibration environments of proposed high speed landing craft.

In the ideal case, the kind of data needed for the test program prescribed herein would be of the form described below. Since it does not now exist, it is recommended in Chapter V that the test program include testing of packaged commodities.

FORM OF IDEAL PRESCRIPTIVE DATA FOR LEVEL A PACKAGING DESIGN

Military Standard Packaged Item or Commodity or Tie-down System	Minimum Single Impact g-load without Damage to Contents or to Item Being Tested	Minimum Single Impact g-load without Damage to Packaging or Tie-down System	Minimum Multiple Impact g-load 5,000 cycles without Damage to Contents of Package or to Item Being Tested	Minimum Multiple Impact g-load 5,000 cycles without Damage to Packaging or Tie-down System	Minimum Vibration Load Intensity without Damage to Contents of Package or to Item Being Tested at Selected Frequencies, e.g., Propeller Vibration	Minimum Constant Tension Load Without Damage	Minimum Co stant Comp sion Load out Damage
____							
____							
____							
____							

V-3. Tie-Down Systems -- Current Practice

Tie-down systems are used to secure and prevent shifting of cargo while in movement between two points via surface, air and maritime transporation or any combination thereof. Use of tie-down systems prevents or minimizes damage to or loss of the cargo being moved and the vehicle(s) transporting it. Such systems range from the carefully designed to the "hit-or-miss" categories.

This section, and its supporting appendices, describe tie-down systems currently in use and, to the extent possible, those currently under development. This section also presents recommendations regarding tie-down systems to be included in a test program prescribed in Chapter V developed to evaluation of materials packaging and cargo tie-downs for the new high speed landing craft.

This section will be devoted to discussions of tie-down systems specifically employed in rail, truck, air and water transport. State-of-the-art information will be presented, and developmental efforts will be discussed.

I. Existing Tie-Down Systems

A. Truck Tie-Down Systems.

Tie-down systems used in the movement of cargo by trucks over the U.S. highway network fall into the "hit-or-miss" category that is, tie-down systems used on trucks are left to the discretion and experience of the individual driving the vehicle. Insofar as could be determined through investigation and inquiries, no industry-wide standards have been developed; and, consequently, tie-down systems in use for securing of the same commodities or different trucks range fron the sophisticated to the very simple. As might be expected, no testing of tie-down systems employed by trucking companies of significance to this study have been performed.

B. Rail Tie-Down Systems

The railroad industry, through its association, the American Association of Railroads (AAR), establishes rules governing the loading of commodities on open top cars--cars on which tie-down systems are extensively employed. These rules are promulgated by the Operations and Maintenance Department, Mechanical Division, AAR. These rules are published in a continually--updated AAR publication entitled General Rules Governing the Loading of Commodities on Open Top Cars.

As stated in the Rules:

> "These rules have been formulated for the purpose of providing uniform, safe and economical methods of loading in open top cars, and the material specified in these rules for securing the loads are minimum requirements. All of the General Rules and the requirements for blocking and securing of loads as outlined under the individual figures are mandatory and must be used unless their omission is specified in the individual figures ...[1]

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[1] See General Rules Governing the Loading of Commodities On open Top Cars, "Preface", p. 4

The AAR rules categories as presented in the General Rules manual are as follows:

(1) General Rules (Applicible to Sections 1 to 7)[2]

(2) Steel Products, Including Pipe.

(3) Load Grading, Road Making and Farm Equipment Machinery

(4) Miscellaneous Commodities, Including Machinery

(5) Forest Products

(6) Department of Defence Material

(7) Trailers

A review of the General Rules Manual shows that tie-down systems prescribed therein are commodity-oriented, (e.g. Ingots, Rails, Road Roller, Logs, etc.) and that each system, though possibly having a commonality of many elements, differ in some detail from the others. A closer examination of the tie-down systems depicted in the General Rules shows that they have as a major element either steel bands, wire, wire rope and/or cable, rods and bolts, chain or flat bars and plates, or some combination thereof. The system may be "quick tie-down" or require lengthy preparation. Steel bands used in tie-down systems are used once and then discarded; wire, wire rope/cable, chains, etc., may be used one or more times.

The AAR rules are not inviolate. They are subject to amendments, revisions or additions. This is clearly spelled

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[2] When the dimensions and kind of materials to be used for securing the load are not specified in Sections 2 to 7, General Rules Section 1, which are to be carefully observed in connection with all loading, will govern

out in the AAR manual, with the mechanism for such changes providing the foundation for the industry and Department of Defense (DoD) test programs for tie-down systems. The AAR manual states:

> "Shippers desiring to deviate from the AAR Open Top Loading Rules, or desiring approval of a method not now covered by these rules, must submit to the Secretary, Mechanical Division, [AAR], or the Chairman, Committee on Loading Rules ... drawings ... giving plans), end and side views, with all items of securement identified ....
>
> "On receipt of any submission ... the matter will be transmitted to the Committee on Loading Rules for their review and comments after which the issurance of experimental load cords will be dependent on the decisions rendered by this Committee.
>
> "Shipper, after having received authority for experimental shipments [will conduct experimental load tests and maintain proper records for submission to the Committee. The Committee upon review of the records of the experimental load tests will determine if the proposed change will become part of the General Rules.][3]

Discussions with AAR personnel clearly emphasized that the test program engaged in was a "destructive" type program' that is, the proposed rule change was in many cases actually tried in practice to determine if it is effective.

Unlike shippers of commerical cargo who work directly with the AAR re rule changes, shippers of DoD material desiring such changes must submit such proposals to the U.S. Army Transportation Engineering Agency (TEA), Military Traffic Management ard Terminal Service, Fort Eustis, Virginia through appropriate

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[3] Supra, footnote 1, pp. 15-17.

channels of the AAR. TEA evalueates such proposals using its facilities and works in conjunction with the AAR in implementing rule changes that it deems practicable.

C. Maritime Tie-Down Systems

The leading manufacturers of tie-down equipments and systems include Peck and Hale, Inc., West Sayville, New York, Aeroquip, Jackson, Michigan and Eastern Roadacraft, Easton, Pennsylvania. Maritime tie-down equipments are designed into systems for the various customers. No single tie-down system is available that can be used by all shipping companies, although the systems designed for use by the various companies are primarily composed of off-the-shelf items. The dominant factors necessitating individually designed systems are the . type of lashing gear to be used, the difference in vessel characteristics, ship loading standards and the nature of the packaging of the goods being transported. As is stated in the Peck and Hale Brochure for Lashing Systems For Containers, RO/RO, Vehicles and Heavy Lifts:[4]

"The design of lashings for deck-storage of containers cannot be determined by any empirical formula. Quite apart from the type of lashing gear and associated hardware, the

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[4] See Appendix D,"Systems Design Capability" Section of Lashing Systems , Peck and Hale, Inc.

lashing system will depend upon many other factors which influence an adequate securing plan and contain stow; --

--The strength and construction of the containers,

--The G.M. of the vessel,

--Ship's speed,

--roll characteristics,

--The nature of the container landings

--height of stock

will all serve to affect the design of the lashing system."

Schematics accompanying the above-quoted statement indicate the diversity of tie-down systems that are in use for securing of containers of like dimensions.

Lashing gear manufactured by Peck and Hale, Inc., has traditionally relied upon the use of cable. One primary reason for use of cable is the ability of the user to rapidly discern whether the cable can be used for the subsequent voyage or if repalcement is required. (This is done by running a cloth over the cable to see if any broken strands or unravelling has occurred during prior usage.) Peck and Hale further indicated that the use of cable in tie-down systems is prevalent throughout the maritime industry. However, Aeroquip has proposed and engineered an advanced method (designated the "Advanced Shipboard Chain Tensioner System") for securing vehicles and other equipment aboard ship. This system physically differs from Peck and Hale gear in several respects: its use of chain rather than cable and, further, of energy-absorbing pre-tension and tension load cells that " . . . permit the secured 'cargo' to live with the motion of the ship even under shock conditions."[5]

It should be emphasized that commercial maritime tie-down systems are designed to be able to meet cargo weight requirements. That is, systems are usually designed to restrain a particular load[6] of x pounds rather than to withstand the shock and impact loads occurring during cargo movement although the systems will also withstand the shock and impact loads in a normal situation. These programs to determine shock and impact strengths of maritime tie-down systems are rare. No concentrated testing has been, or is being, performed by manufacturers, and that testing performed is inappropriate to determine suitability of existing tie-down systems to the proposed advanced landing craft. However, test programs have been conducted in cooperation with DoD to obtain information relating to specific problems. An illustration of such a test program in whick Peck and Hale is involved is the Grade A Shock Tests Program being conducted at the San Francisco Navy Yard, Hunter's Point. This program is being performed in support of the CVAN program and has as one of its goals the testing of securing systems for weapons, etc., to be used in the CVAN. This test program is a "destructive" program, and is still in progress.

Inquiries were made of the Military Sealift Command and various shipping companies regarding any test programs of tie-down systems performed by them. In each instance it was learned that the equipment manufacturer and/or test agencies of the DoD

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[5] See Appendix D, Advanced Ship Chain Tensioner System, "Description," Bulletin 5045A, June 1970, Aeroquip.

[6] e.g., pallet container, vehicle, etc.

were relied upon to provide tie-down systems adequate to the shippers' requirements.

5 Because tie-down system manufacturers focus primarily upon developing equipment capable of restraining cargo in forms of weight limitations--with an inherent ability to withstand normal minimum shock and impact loads--the test program derived as a result of this study must be designed so as to produce systems capable of meeting the unique shock and vibration loadings created by the proposed high speed landing craft weight limitations.

D. Air Tie-Down Systems

Air tie-down systems in use currently are, like maritime systems, designed to meet the specific maximum environmental and operational conditions that exist for the vehicle in which they are employed. The systems are easy to handle rapidly, with tie-down fittings being integral segments of the aircraft structure. These fittings have rated capacities, that is, ultimate rated strength values. For example, the C-141A has available for use fittings having rated ultimate strength values of 10,000 and 25,000 pounds.[7]

For each major aircraft design the military has developed general rules for determining the number and positioning the elements of the tie-down system to be used. These rules are predicted upon minimum restraint forces developed for each aircraft type; and, as used, permit determination of the number tie-down restraints required for the cargo being transported, (The minimum restraint forces are force levels, expressed in units of the force of gravity, that the tie-down system must be capable of withstanding. They are developed for each aircraft type and are expressed in terms of forward, aft, lateral and vertical forces.) These are, however, specific tie-down procedures that have been developed for certain items or combinations of items.[8]

As in the case of the rail and truck industries, a variety of tie-down devices are employed in restraining air cargo. The most commonly used for military purposes are the D-1, C-2, MB-1, MB-2, A-1A and MC-1, with cargo freedom nets also used to secure

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[7] See Appendix D, T.O. 1-C-141A-9, Cargo Loading, USAF Series C-141A Aircraft, AF 33(657)-8835, AF 33(657)14885, 6 April 1967 paragraphs 2-70 to 2-85.

[8] Ibid. See Section VIB through Section VIF.

and restrain cargo. (Similar items are also used for commercial purposes.) The D-1, C-2, MB-1 and MB-2 tie-down devices both require the use of chain; the A-1A and MC-1 devices, web straps. (Any of these devices can be used in conjunction with cargo tie-down nets.)[9]

Replies to inquiries regarding testing of tie-down systems revealed that DoD conducts a continuing program, aimed at updating general and specific rules already developed for existing aircraft types and to develop rules to be applied to new aircraft.[10]

Little information was available regarding tie-down systems in commercial usage or commercial test programs. However, as most air cargo aircraft in commercial usage are of military design origin, it is believed that the systems employed by DoD and commercial carriers are analagous and that commercial carriers look to military test programs. Discussions with tie-down systems manufacturers and TEA and review of available literature support this belief.

II. Review of Proposed Tie-Down Systems

In brief, it can be said that few "tie-down systems of the future" are on the drawing boards or under development by manufacturers of such systems. Manufacturers in general do not engage in advance design of new systems but rather await the statement of specific requirements before assembling the required systems. Essentially, new systems are made up of elements of

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[9] See Appendix B-4, Preparation of Freight for Air Shipment, December 1969, DSAM, 4145.7, TM38-236, NAVAIR15-01-3, AFP 71-8, MCO P4030. 30A, Section 1-19.

[10] See Appendix D, Military Specification, Air Transportability Requirements, General Specification for, Mil-A-8421C (USAF) 14 August, 1969.

old systems reconfigured to meet the new requirements. Manufacturers recognize the desirability of improving existing systems and equipments and developing new systems and equipments but "in the absence of sufficient capital resources" are unable to engage in long-range planning and design efforts.

Efforts devoted to changes in systems and equipments are primarily those in which the federal government, e.g., DoD, is the major participant. For example, several manufacturers' tie-down equipments are participating with the Department of the Navy in performance of the Grade A Shock Test Program, at the San Francisco Navy Yard.

In essence, the number of manufacturers of tie-down systems and equipments is small and the companies themselves are generally small. The focus of the manufacturers is first upon manufacture of the requisite system components (e.g., tie-down fittings; lashings -- cable, wire, chain, etc.; tensioners; etc.) and then upon their assembly into systems capable of meeting specified requirements. Design efforts are subservient to manufacturing efforts.

CHAPTER VI

RECOMMENDATIONS FOR A TEST PROGRAM

6

The major point that this study emphasizes is the insufficient data for both the design testing and usage of packaging and tie-down systems for use in the new amphibious assault land craft. Although there are many data available on various modes of transportation, they are inappropriate for this application. It is with this awareness that the following recommendations are made for the future testing and design of packing, materials packaging and tie-down or lasting systems. The following recommendations are offered in the form of the outline

(1) Commodities to be tested

(2) Packaging to be tested

(3) Tie-Down Systems to be tested

(4) New systems and concepts recommended for further investigations

(5) Test equipment recommendation

(6) Test Design, Methods and Evaluation Criteria

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VI-1. REPRESENTATIVE LIST OF COMMODITIES TO BE INCLUDED IN TEST PROGRAM

Origin

An amphibious assault may include virtually any combination of Fleet Marine Force Units. Thus the list below was derived from a complete review of Fleet Marine Force Tables of Equipment now in effect.[1]

Criteria for Selection of Items to be Tested

Representativeness: Items from each major group of commodity which might be carried aboard a landing craft were selected. Further, in some cases, notably vehicles and electronic gear, more than one form of a given item is included when those forms are judged to have potentially different shocks and vibration sensitivity. Items which were judged to be highly shock insensitive (e.g., an entrenching tool) were omitted.

Quality: Emphasis has been given in the selection of items in a given class which are needed in large quantity for the Marine Force Unit's effective operation.

Criticality: Emphasis has been given to selecting those items judged to be more critical to the effective performance of a unit's military function.

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[1] The tables of equipment are listed in "Index to Fleet Marine Force Tables of Equipment", A04G/mlc, 24 June 1970.

Marine Corps Review: The following list includes revisions requested by the Marine Corps after review of the preliminary list.

List of Suggested Commodities to be Tested

Electronic, Electrical and Communication Gear

Battery Charger PP-3240A/U
Control Radio Set, AN/GRA-39
Radio Set, AN/GRC-125
Radio Set, AN/MRC-83, Truck Mounted
Radio Set, AN/PRC-77
Generator Set 30 KW, 60 HZ, Trailer Mtd.
Radiac Set, AN/PDR-27-J
Telephone Set, TA-312/PT
Telephone Set, TA-1/PT
Teletypewriter set, AN/TGC-14A-V
Converter, Telegraph-telephone signal TH-85/U
Switchboard SB-22
Radio Set AN/MRC-109
Radio Terminal Set - AN/PCC-1
Radio Terminal Set - AN/MRC-135

Vehicles

Trailer, Cargo, 1 1/2 Ton, 2-Wheel, M105A2
    -L 166 W 83 H 98 INS -
Truck, Platform, Utility, 1/27 4x4, M274A2
    -L 119 W 49 H 43 INS -
Trailer, Tank, Water, 400 Gal., M149
    -L 161 W 83 H 77 INS-
Truck, Cargo, 5 ton, 6x6, M54A2C, W/O Winch
    W/PTO -L 313 W 98 H 118 INS-
Truck, tank, fuel servicing, 1200 Fal., 2 1/2 ton, 6x6, M49A2C
Truck, Ambulance, 1/4 T, 4x4, M718
    -L 150 W63 H 71 INS-
Trailer, Amphib. Cargo, 1/4 ton, 2 Wheel, M416
    -L 109 W 61 H 42 INS-
Truck, Utility, 1/4 ton, 4x4, M1[illegible] A1
    -L 132 W 63 H 71 INS-
Chassis Trailer, 3 1/2 ton, 2 wheel, M-353
Truck, Cargo, 2 1/2 ton, M35A2C W/OW, W/E
    -L 262 W 96 H 115 INS-
Truck Firefighting, 1/4 ton, 4x4, MOD 3088-1
    -L 150 W 61 H 71 INS-
Crane, Truck Mounted 15 Ton
Crane, Shovel, Koehring Model 2N
MIL STD Air Conditioner - MAC 6V20

Truck, Wrecker, 5 Ton, 6x6, M543A2
-L 310 W 97 H 86 INS-
Truck, Cargo, Articulated, 1 1/4 Ton, M561
Truck, Cargo, 4x4, 1 1/4 Ton, M715
Truck, Cargo, 4x4, 1 1/4 Ton, XM705
Carrier, Cargo, Amphibious, M 116A1, L 188 1/8
W 82 1/2, H 79 1/8 INS
Carrier, Cargo, Armor, Amphibious, M733
L 197 1/4 W 83 H 68 1/4 INS

Petroleum, Oil, Lubricants and Related Materials

Fuel Oil Diesel, M.l-F-16884, 55 gal. drum

Subsistence and Subsistence Related

Meal, Combat Individual, Ration, Operational "B" and Ration Supplement Pack
Food Container, Insulated, 5 Gal. CAP
Can, Water, Military, CAM type, 5 Gal.
Jug, Vacuum, 3 gal. CAP

Weapons/Ordnance Equipment

Launcher, Rocket, 3.5", M20A1B1 W/E
Submachine Gun, Cal. 45, M3A1, W/E
Launcher, Grenade, 40 MM, M79 W/E
Machine Gun, Cal. 50, Browning Ma, HB Flexible
Binoculars, 6x30, M 13A1, W/E
Telescope Observation, M49
Sniper Rifle, M40
Telescope, Battery Commander's, M65
Gunners Quadrant
Circle Aiming, M2
Howitzer, 105 mm, Towed, M101A1
Compass, M2
Computer, Gun Direction, M18

Ammunition

Fx, VT, M514A1E1
Fz, MT, M565
Fz, MTSQ, M564
LAW
Blasting Caps
Pyrotecnics
7.92 Ammo
155 mm Howitzer Powder
8" Howitzer, Powder
Mines

Miscellaneous

Saw Chain, One-Man Portable
Charge, Hydrogen Generator, ML-305A/TM
Pump Assembly, Expedient Refueler, Fuel Dispensing,
    Gasoline Driven, CAP 50GPM-81 TDH
Suit, Cooling, Toxicological Agents, Protective, Coveralls
Lantern, Kerosene
Lantern Set, Gasoline, Illuminating Equipment
Office Supply Set, Field, Typewriter 11 in.
Insect Repellant, 75% Diethyltoluamide, 2 oz. bottle,
    Personnel and Clothing application -DEET-
Tool bit, Mechanics
Extinguisher, Fire, Dry Chemical, CAP 4 lb.
Watch, Wrist, Complete
Ammonia Inhalant Solution, Aromatic -10 Amputer-
Decontaminating Apparatus, Power Driven, Skid-Mounted
    Multipurpose 500 Gal. M12A1
Decontaminating Agent STB
First Aid Kit, General Purpose
Calculator, Printing Double, Independent Registers Credit
    Balance, W/Automatic accumulation of total and memory
Accessory Outfit, Gasoline, Field Range, A Pack
Torch Outfit, Cutting and Welding
Compass, Magnetic, Unmounted Lensatic
Insecticide, 0.6% Pyrethrum Acrosol 12 oz. spray can

VI-2. Packaging to be Tested

Each item or commodity in the commodity list presented earlier should initially, for test program purposes, be packaged with military standard level A packaging as prescribed in the packaging standards for that item. Further, packages and item should be packed, unit loaded, palletized and containerized in accordance with the prescribed military standard procedures for that item. Thus the testing program will reveal those areas in which packaging, packing, unit loading, palletization and containerization procedures will need to be modified and strengthened.

VI-3. Recommendations: Tie-Down Systems for Test Program

In determining tie-down systems to be tested for their ability to meet environmental and operational conditions imposed by the proposed new landing craft, a series of major criteria must be considered and validated these include:

- --Ease and rapidity of handling
- --Ability to be used repeatedly (if possible, for the duration of the assault and support waves)
- --Flexibility, enabling a system, with minor adjustments, to be universally applicable to all cargo being transported.[1]
- --Ability to maintain cargo position integrity during movement from the ASA to the AOA.
- --Ease and rapidity of inspection
- --Positive-positioning ability
- --Ability to maintain constant tension on all system components.

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[1] It should be determined if cargo units can be configured so as to permit the desired flexibility to be achieved.

The review of existing tie-down systems indicates that there is an inadequate data base upon which to determine if they meet one or more of the foregoing criteria and that many of the existing systems will not meet many of the criteria list. For example, in preceeding sections of this study it has been pointed out that shock and vibration data developed in various test programs involving existing tie-down systems are not adequate to permit determination of the system to withstand repeated usage during which they will encounter the shock and vibration loadings calculated as being created by the proposed landing craft. Further, many systems patently are not designed for ease and rapidity of handling. Finally, there is no system that appears to meet the universality criteria or to approach it.

Thus, it is our recommendation that manufacturers of tie-down systems and equipments be an integral part of the testing team and that their role be in determining if a system capable of meeting the prescribed criteria is feasible and, then of designing the system or suitable alternative system(s).

VI-4. New Systems and Concepts Recommended for Further Investigation

It is recommended that in addition to testing existing packaging and tie-down systems, the proposed test program include the systems and concepts described below. Each of these proposals incorporates particular characteristics which would appear to be particularly appropriate to the shock and vibration environment of high speed landing craft.

VI-4-a. Energy Absorbing Pallets:

These might, for example, be injection molded of a resiliant plastic material in a standard size and shape. They should be able to deform or impact and then self-restore to their original shape and strength.

VI-4-b. Shock-Attenuating Tie-Down Mechanism:

Such a tie-down system should have the following characteristics: It should be able to maintain cargo position without shifting or movement under the highest shock loads anticipated in landing craft operation. It should be able to "give" so that impact loads can be dissipated in the tie-down spring rather than be directly transmitted to the cargo as is the case with rigid mounting.

VI-4-c. Shrink Wrapping of Unit Loads and Palletized Cargo:

This process should be tested to determine the appropriate strength wrapping plastic to be used in high speed landing craft applications.

VI-4-d. Nylon or Dacron Webbing and Topper:

Used extensively in air cargo tie-down and to a much lesser extent in shipping.These systems have advantages of light weight and ability to "give" and absorb part of the impacts received by cargo (nylon webbing is more resiliant than dacron in this regard).

VI-4-e. Quick Take-up Units:

Such units would remove any slack which might develop in the tie-downs and could insure a constant minimum tension on the tie-downs. This would minimize the likelihoodof cargo movement.

VI-5. Test Equipment Recommendations

The environmental loads imposed on the assault cargo (see Chapter IV) require a variety of tests to be performed over the range of frequencies comprising the environmental loading factors.

Specifically two test pieces of equipment should be utilized in the testing of the materials packaging and tie-down systems. The first is a heavy duty shaker capable of taking a fully loaded pallet or container and vibrating it through the range of vibratory forms given in Chapter IV. This particular testing will be to evaluate the packaging material, packing and unit restrainers.

The other type of test equipment required to adequately test the tie-down systems is a large mechanically driven testing platform to which the loaded pallet or unit cargo can be lashed and again tested over the range of load and vibration frequencies found in the environment. This machine would be ideal if the test bed were actually a full scale section of the landing crafts cargo well deck. The size of the loadings and the mass of the cargo pallet and deck structure will necessitate this testing machine to be quite massive with large energy supply.

The only other tests required are the drop-type of shock tests to evaluate the materials packaging and packing in its ability to meet the high 30g shock loads found in shipside impact or cargo well deck impact.

See the following attached list of existing testing equipment.

The material on this page and the succeeding 3 have been reproduced from the Department of Defense, Military Standardization Handbook Package Cushioning Design, MIL-HDBK-304. Nov. 25, 1964

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TESTING EQUIPMENT LIST

6.1.2.2.2 Vibration exciters.--The two types of vibration exciters that are used for tests of packaging materials are (1) the direct drive mechanical vibration machines and (2) the electrodynamic vibration machines.

6.1.2.2.2.1 Mechanically driven vibration machines.--One type of machine, utilizing the reaction principle, employs a set of unbalanced masses mounted on counter-rotating shafts. Machines of this type are capable of producing rectilinear motion involving peak accelerations up to 20 g over a frequency range of 8 to 100 c.p.s.

The cam-driven machine, which is most commonly used in packaging testing, consists essentially of a table driven by an electrical motor through a linkage system employing rotating cams or eccentrics (fig. 6-7). Machines of this type are capable of describing circular, rectilinear (unidirectional), or elliptical motion in the horizontal and vertical planes through a frequency range of 1 to 10 c.p.s. at 0 to 63 g (peak acceleration).

Both of these machines are relatively low in cost and are particularly adapted to production of low frequency motion having large amplitudes.

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From Department of Defense: Military Standardization Handbook Package Cushioning Design, MIL-HDBK-304. Nov. 25, 1964.

6.1.2.2.2.2 Electrodynamic vibration machines.--This type of vibration machine (fig. 6-8) uses the electrodynamic method of force generation. The force causing the motion is produced by the interaction of current flow in a driver coil and a strong magnetic field produced by an electromagnet. A mounting table that is rigidly attached to the driving coil is supported on the machine body by a system that allows movement of the table only in a plane normal to its surface. The exciting signal may be obtained from a sinusoidal signal generator, a random noise generator, or from a magnetic tape recording of an actual environmental condition. This input signal is amplified in electronic power amplifiers and applied to the driving coil. Frequency response compensation and cycling control circuits are necessary. For more detailed information on electrodynamic vibration systems, see reference (55).

Electrodynamic vibration machines are complex and costly but are capable of operating from about 5 to 3,000 c.p.s. or more, with displacement amplitudes up to 1 inch. Maximum accelerations as high as 125 g may be obtained.

From Department of Defense: Military Standardization Handbook Package Cushioning Design, MIL-HDBK-304. Noy. 25, 1964.

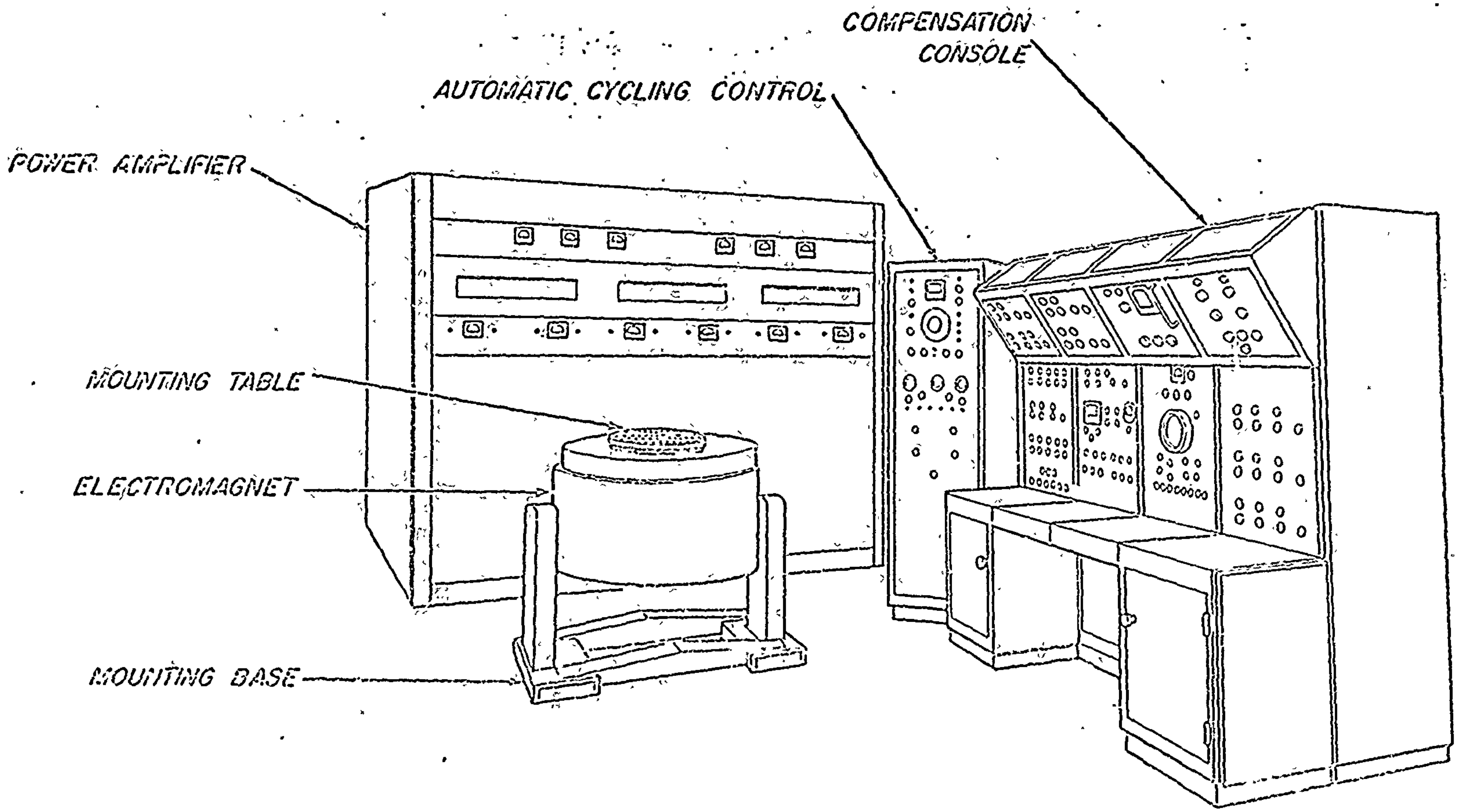

Figure 6-8.--Electrodynamic vibration testing machine and supplementary control equipment.

[illegible]

From Department of Defense: Military Standardization Handbook Package Cushioning Design, MIL-HDBK-304. Nov. 25, 1964.

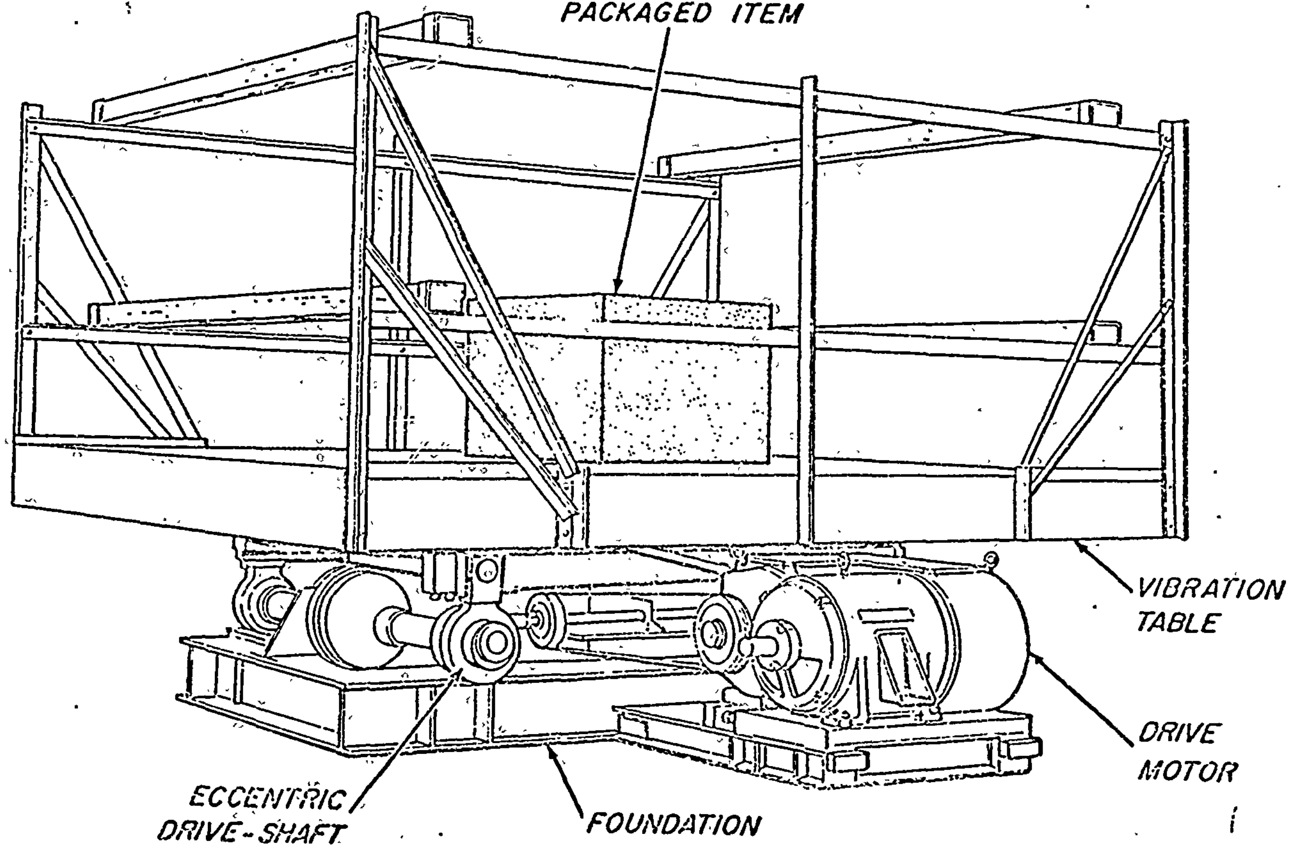

Figure 6-7.--Mechanically driven vibration testing machine.

(GI-122-451)

VI-6. Testing Design and Evaluation Criteria

The packaging and tie-down systems must be put through a series of tests which will completely simulate the damaging environmental load factors these systems must accommodate during the amphibious assault operation. The following criteria should be used:

1. Vibratory loading of the cargo unit or loaded pallet over the range of frequencies at the maximum sustained loading level for the maximum time duration plus the excursion to the peak loads. The packaging should then be stripped down for visual examination and determination of damage .
2. Shock loading of the cargo unit or pallet with the required acceleration loadings. Stripping down of packaging and examination for damage.
3. Complete testing of lashing or tie-down system on the heavy duty test bed covering the range frequencies and the range of g-loading at these frequencies.
4. Simulated horizontal and vertical shock or impact loadings on the cargo and its tie-down system for loading up to the maximum wave impace loading expected for the occurrence of 10 percent of the operational cycles considered for the life of the tie-down system.
5. Determine the degree of confidence of the structural strength of the tie-down system over a range of cyclical loadings of the design load from 0 to 200,000 cycles.

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6. All design criteria should have a factor of safety of 2 with higher factors used when necessary.
7. All systems must be rated and evaluated on the basis of those factors shown listed in Chapter IV and sections (11) and (12) of this chapter.
8. Specific attention should be focused upon the new systems and concepts suggested in section (IV) of this Chapter.
9. All tie-down systems surviving the 200,000 cycle level should be destructively tested to determine the remaining strength and verify the accuracy of the level of confidence figure.

The tests to be performed on the tie-down and packaging systems and the presentation of the test data are given in the following figure. The description of these tests and the test data in the chart are discussed thereafter.

It has not been within the scope of this study to review all testing facilities in the U.S. to assess their suitability for the proposed program. However, review of some test equipment and facilities supports the conclusion that, in order to test all the items listed in the commodity list presented earlier in this chapter, some modification of existing test equipment and/or construction of new test equipment may be required (e.g., large shaker tables exist but their frequency range of operation is usually much higher than that required here). Accordingly our tentative estimate, after brief discussion with one testing organization, is that the cost of testing the entire commodity list proposed would be in the vicinity of three to four million dollars.

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ITEM OR SYSTEM TESTED CHART

Load Factor	Descriptive Factor	Measure or Evaluation Factor	Load Factor Magnitude (Distribution Share)
General	Positive Positioning	Range of Lateral or Longitude Movement	Movement
	Constant Tension	Tension Load Maintenance	Tension Pull
	Maintenance of Cargo Integrity Unit	The Unit Load, Pallet, or Container did not Fall Apart	———
	Ease and Rapidity of Installing	Speed of Attachment and Detachment (Unit or System)	Attachment Detachment
	Flexibility	Number of Load Types the System Handles	———
	Inspectability	Time to Inspect and Accessability	———
	Corrosiveness	Salt-Water Resistance	———
Vibration	Low Freq. Horiz. Low Freq. Vert. High Freq. Horiz. High Freq. Vert.	1. Load Envelope Used in Test 2. Probability of Failure 3. Structural Fatigue	Random Loading: 2.5 g's Random Loading: 3.5 g's Random Loading:
Shock or Impact	Dominant Freq. Low Short Time Duration Long Time Duration	1. Load Envelope Used in Test 2. Probability of Failure 3. Structural Fatigue	Shock Load: 25 g's (15 cps Dominant Frequen Shock Load: 30 g's (Drop Test Equivalent) Quick Deceleration 2-5 g's with a Time Dura from 0-2 Seconds

NOTE: The maximum loading experienced in 100 cycles can be as high as 7.0 g's. Hence, thi value should be used in the random loading test frequency distribution in all test

Magnitude (Units)	Frequency Content	Time Duration	Data Display
Feet	—	—	Long. & Lateral From Median Pos. ± Ft.
Lbs.	—	—	Tension Range @ Constant Value ± Lbs.
—	—	—	Maintained or Not Maintained
Seconds	—	—	Time to Attach-- Time to Release
—	—	—	Number of Load Types
Seconds Percentage	—	—	Time to Inspect-- Percentage Accessible
—	—	—	Protected or Not Protected
Acceleration g's	0-2.0 cps	Up to 1-1/2 hr. times the No. of Useful Life Types of the Gear	1. Random Vibration Envelope 2. Probability of Failure vs. Failure Age 3. Log of Acc. Amplitude vs. Log of No. of Cycles
Acceleration g's	0-2.0 cps		
Acceleration g's	0-700 cps		
Acceleration g's	0-700 cps		
Acceleration g's	10-20 cps	5-10 Tests 0.0→0.01 sec.	1. Random Vibration Envelope 2. Probability of Failure vs. Failure Age 3. Log of Acc. Amplitude vs. Log of No. of Cycles
Acceleration g's	(Drop Test)	0-5 Tests	
Acceleration g's	0 cps zero frequency	0-5 Tests 0-2 secs.	

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ITEM OR SYSTEM TEST CHART

Load Factor - General

Positive Positioning -

- measure the range of lateral and longitudinal movement of the load when tied down on test-bed
- the measurements will be in feet and inches of movement from the initial tie-down position
- data presentation: ± ft. and inches from median position

Constant Tensioning -

- measure the constant tensioning and maintenance of tension of each tie-down design and configuration when the cargo unit or pallet is tied down on the test-bed
- the measurement will be in lbs. plus or minus over the initial tension value
- the data presentation: ± lbs. of tension about the given lbs. initial value

Maintenance of Cargo -

- the unit load, pallet or container does not fall apart, the cargo stays packaged together
- this test is qualitative; is, after the vibration and impact tests, the cargo still tied together in a unit

Ease and Rapidity of Installing -

- the speed of attachment and detachment of the tie-down system
- the measurement will be in seconds, the time to install one piece of tie-down equipment and the time for tie-down of the entire cargo unit
- the data presentation: time in seconds for set-up of unit and system, time in seconds for breakdown of unit and system

ITEM OR SYSTEM TEST CHART (Cont.)

Flexibility -

- the qualitative evaluation of the tie-down system in tying-down different types of loads
- how adaptable is each tie-down unit and/or system in holding different loads
- the data presentation: the measures will be qualitative and judge the relative flexibility of each type

Inspectability -

- the qualitative evaluation of the tie-down system relative to its inspectability should be a comparative appraisal of each unit on the job inspection properties
- the data presentation: relative appraisal of the instectability of each unit being tested

Corrosiveness -

- are there any ferrous metals in the tie-down unit or in the materials used in packaging
- is galvanic corrosion a problem
- the data presentation: yes or no to the corrosiveness, what strength factor must be assigned to the corrosion of the unit over its life

Load Factor - Vibratory

- the vibration test for each condition must be conducted in such a fashion so as to create a continuous envelope of acceleration versus frequency for the range of interest. The test acceleration spectrum must have the amplitude content to generate the required (1/100) encounter statistics.

ITEM OR SYSTEM TEST CHART (Cont.)

- the data presentation:
  - acceleration vs. frequency
  - probability of failure vs. failure age
  - log of acceleration amp. vs log of no. of cycles

Load Factor - Impact

- the impact or shock tests must generate the acceleration magnitude for the range of time duration indicated. The dominant frequency of the impact must be within the range of frequency indicated. This can be achieved by impacting against specific bed plates with the required frequency as its natural frequency
- the data presentation: the data will be given in the same form as for the vibration tests

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Appendix A

Background Data on Loading Craft Calculations

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Appendix A Background Data on Loading Craft Calculations

A-1 AALCP Craft Descriptions:

Craft Type	Designation	Craft Dimensions	Cargo Space	Payload (lbs.)
1. ACV	C-30-50	48'x30.5'x16'	37.5'x9.5'	30,000
2. Planing	P30-35	60'x14.5'x17.2'	47.5'x9.5'	30,000
3. Planing	P125-35	75'x22.5'x12'	45.9'x17'	125,000
4. ACV	C150-50	87.9'x47'x23'	66'x27.3'	150,000
5. ACV	C150-50	97.5'x48'x23.3'	66'x27.3'	150,000
6. Planing	P320-35	150'x30'x20'	100'x27.5'	320,000

Note:

--All ACV are assumed to have standard bottom and shirt configurations.

--All planing hulls are assumed to have the inverted V bottom, the angle of negative deadrise being no more than 10 degrees.

A-2 Deflection of the Ship Side:

The deflection of the shell of the supply ship to a concentrated load at the center of a panel in the side of the ship can be given by the following formula. The maximum deflection will be;

$$W = 4Pa^3/\pi^4 bK \qquad \text{(ref 17)}$$

Where $K = Et^3/12(1-\nu^2)$

and $E = 30 \times 10^6$ (Young's Modulus for Steel)

t = the plate thickness = 0.5 inches

= 0.03 (the Poisson ratio for steel)

P = the concentrated load

a = the short span across the side shell panel

= assumed value 3 feet

b = the long span along the side shell panel

= assumed value 12 feet.

ω = side shell deflection assuming a simply supported panel.

For a the cargo load, the concentrated load acting on the panel can be found from the equation:

(ref 2)

$$P = W_c + \sqrt{W_c^2 + \frac{kW_cV^2}{g}}$$

W_c = weight of cargo

k = side shell spring constant

V = velocity of impact = 10 ft/sec.

g = gravitational constant

Since the impact loading and the resulting acceleration will be worst for the lighter loads which deflect the side shell the least, a 2 ton load will be used as the envelope design criteria.

$$k = \frac{P}{\omega} = \pi^4 b\ K/4a^3$$

where $K = 2 \cdot x\ 10^4$ ft-lbs.

or k = 180,000 lbs/ft for the side shell panel.

Calculating the concentrated load;

$$P = 4000 \text{ lbs} + \sqrt{\frac{4000^2 + 160{,}000 \text{ x } 4000 \text{ x } 10\text{ft/sec}}{32.2}}$$

$$= 4000 \text{ lbs} + 14{,}700 \text{ lbs} = 18{,}700 \text{ lbs.}$$

The deflection of the side shell is for this load,

ω = <u>1.63 inches</u>

A-3 <u>Shock and Impact Load Calculations</u>

The equation of motion of a package item can be written as:

$$M\ddot{\delta} = -K'\delta + Mg$$

for a package being dropped at the moment of impact; where

M = the mass of the package

$\ddot{\delta}$ = the acceleration of the package on impact

K'= the spring constant of the outer packaging

g = the gravitational constant

Solving this equation as is given in (ref 4) pp. 41-5-7 the following equations are arrived at.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{g[(\ddot{\delta} g)\ \max - 1]^2}{2h}}\ \text{cps}$$

and $(\ddot{\delta} g)\ \max. \cong 2h/\delta \max$

The equations can be solved for the maximum acceleration of the impact and the natural dominant frequency

knowing the impact deflection and the speed of the impact or the equivalent drop height "h".

Using these equations for the deflect of 1.3 inches of the side shell panel and the input velocity of 10 ft/sec.

The g load will be approximately 30g's and the dominant natural frequency of the impact is 15-16 cps.

A-4 Supply-Ship Off-Load Lateral Impact

The first dynamic loading encountered in the amphibious movement of cargo is the problem of the cargo unit or palletized load striking the side of the supply ship. The impact of the cargo with the side of the supply ship results from the pendulum action of the cargo slung from the unloading boom or crane. The major component of the pendulum motion comes from the rolling of the supply ship. The magnitude of this pendulum action can be determined as follows. Typical roll periods for various supply ships are as follows:

Supply Ship	Roll Period
AKA 112	15.6 sec.
AKA 113	13.7 sec.
APA 248/249	12.6 sec.[1]

The values of 10 seconds roll period and 15 seconds roll period will be used to estimate the approximate magnitude of the impact on the side of the supply ship.

The angular velocity of the pendulum motion can be calculated from the formula:

$$\omega_R = \left(\frac{2\pi}{T}\right)\Theta$$

where Θ = maximum roll in radians

T = period of roll in seconds.

The roll velocity of the end of the boom is:

$$V_R = \omega_R r$$

where r = the radial distance from the center of floatation of the ship to the end of the boom.

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[1] Tech. Report H19-69. Final Report: Analysis of the Large Pallet Concept (S14-17) Amphibious Assault Landing Craft Program.. San Francisco Bay Naval Shipyard. 30 June 1969.

This roll velocity can be broken down into its two components, the horizontal velocity parallel to the water surface and the vertical velocity perpendicular to the water surface. Assuming the roll velocity of theship's side is small in comparison to the cargo's pendulum velocity, the following velocities for ship side impact are derived:

Roll period 10-15 seconds
Roll angle 5-10 degrees
Radial arm r = 100 feet.

$$\omega_R = \left(\frac{2\pi}{10}\right)(10)(.017) = 0.108$$

The horizontal and vertical velocity of this pendulum motion is:

$$V_{HORIZONTAL} = \frac{VCG}{r} \times V_R$$

$$V_{VERTICAL} = \frac{OCG}{r} \times V_R$$

where VCG = the vertical center of gravity of the cargo above the centerline

OCG = the outboard distance of the center of gravity of the cargo from the centerline of the ship.

These two velocities for the roll angles of 5 and 10 degrees are, assuming a 60 degree boom angle:

	V_H	V_V
10 degrees roll motion with a 10 second roll period	9.8 ft./sec.	4.60 ft./sec.

The values for r, OCG and VCG were scaled from the profile plan of the AKA with the heavy load booms directed outboard at 60 degree angle. The worst case was taken as the 10 degrees of roll motion and a 10 second roll period. The resulting velocities are quite high, in particular the horizontal component which would create a large g loading laterally on the cargo if the pendulum motion were unrestrained. The acceleration of this impact and the dominant frequency of the impact as given by the equations developed in Appendix A for [illegible] the loading acceleration and the deflection on the side shell of the ship are:

> Deflection of a ship-side shell panel due to a 2 ton cargo load impacting at 10 ft/sec. with the side of the ship is approximately 1.3 inches on a 3 foot by 12 foot shall panel.

The 2 ton cargo unit is used as the more extreme case since the acceleration of the cargo load increases with a decrease in deflection of the side shell upon impact. Thus, a 2 ton cargo load was taken as being representative of an upper limit on a design criterion envelope.

The acceleration and dominant natural frequency as calculated by the equations given in the Handbook of Shock and Vibrations and Appendix A are:

> The cargo unit or pallet acceleration load on impact with the side shell of the ship during an unrestrained impact can be as large as 30 g's with a dominant frequency of 15-16 cycles per second.

A-5 Cargo Impact with the Landing Craft Well Deck

The next damaging situation encountered by the cargo during its transport from the amphibious staging area to the amphibious objective area is the impact of the cargo with the cargo well deck. This situation can be a very severe situation if the supply ship is rolling toward the side the landing craft is on while descending at full speed and the landing craft is heaving and pitching upward at its maximum rate of movement. The combined motion in this case will present the most critical case to the safety of the cargo, the most dangerous in the damage and breakage of the cargo.

The motion of the supply ship that will predominantly affect the magnitude of the loading will be the rolling motion of the ship. The equation for vertical velocity component was given in section III-1 as:

$$V_N = \frac{OCG}{r} = V_R$$

where OCG = the horizontal distance from the centerline of the supply ship to the center of gravity of the cargo.

r = distance from the center of floatation to the most outboard pully on the jib boom.

V_R = roll velocity of the outboard pulley on the end of the jib boom.

V_N = velocity of the jib boom normal to the still water surface.

The motion of the cargo hook enters into the impacting of the cargo packages with the floor (deck) of the landing craft's cargo well in that the velocity of descent of the hook adds into the overall impact velocity. The hook velocities for various loads are as follows:[1]

Load in Tons	Velocity of Hook
0-2	5.58 ft./sec.
2-4.5	2.62 ft./sec.
4.5-15	0.67 ft./sec.
15-40	0.61 ft./sec.
40-70	0.39 ft./sec.

The variation of the descent speed with the load weight becomes important in the impact calculation. The interesting factor with this system of reducing the loading descent rate with the load weight is that the heavier loads can generate a greater displacement of the well deck both structurally through the deflection of the well deck structure and dynamically through the increased displacement of the landing craft. Thus, the heavier load will experience smaller accelerations through the lower descent speeds and through the greater displacement upon impact than will the lighter cargo pallets.

The landing craft when positioned alongside the supply ship such as the AKA experiences the full effect of the sea state in the amphibious staging area (ASA) while the landing craft being loaded in the well of supply ships like the LPD, LSD, and LHA will in most cases experience a much different sea state, in some cases much more severe. The problem of loading within these latter well-type ships is solved by mating the landing craft to the ship. The motions of the landing craft alongside the

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[1] Tech. Rep. H19-69. Final Report: Analysis of the Large Pallet Concept (S14-17) Amphibious Assault Landing Craft Program. San Francisco Bay Naval Shipyard. 30 June 1969.

supply ship will be taken as the worst condition experienced in the operation, assuming that for well operation of greater severity the landing craft can be mated to the supply ship before the loading takes place, thus eliminating the craft's motion and reducing the problem of cargo impact damage.

A landing craft or station for off-loading from the supply ship will be subjected to the prevailing sea state in the ASA. The landing craft will be at zero speed relative to the ground and the supply ship as well. Only in unusual circumstances will thesupply ship be moving through the water while the unloading operation is in progress. The motions of a landing craft ACV or planing) will be the most responsive for the conditions that the wavelength of the dominant wave structure is equal to the length of the landing craft. These conditions can be defined as follows:

When the $\frac{\lambda_c}{L_c} \approx 1.0 \rightarrow 1.1$ (range of values)

where λ_c = wavelength of the dominant wave structure present in the ASA (from crest to crest)

L_c = length on the waterline of the landing craft.

The motion of the landing craft will range from:

Heave of Craft (H_c) = $1.4 \rightarrow 2.2$ (range of values) times "heave amplitude" H_0 of the dominant waves, for the landing craft's heaving motion.

Pitch of Craft (Θ_c) $1.4 \rightarrow 1.6$ (range of values) times the "pitch angle" Θ_w of the waves, for the landing craft's pitching angle.

Assuming a sinusoidal wave form for these calculations to simplify the determination of the vertical heave and pitch motions, the following heave and pitch velocities can be encountered at the bow of the largest landing craft in sea-state 5. The motions of the largest landing craft, the 320,000 lb. design, are used in this calculation as being representative of the upper limit on the design envelope since in sea-state 5 the scale of landingcraft length to wavelength is approximately 1.0. The average wave heights are given in Appendix A for the range of sea-states from Beaufort 2 to Beaufort 5.

Using the equations for the greatest expected wave heights given in Appendix A, the following heave and pitch motions of the craft are found:

Landing Craft Maximum Heave Amplitude = 2.2 x 7.0 = 15.4 feet
at Zero Speed in SS 5

Landing Craft Maximum Pitch Amplitude = 1.6 x 4 degrees = 6.4 degrees
at Zero Speed in SS 5

The vertical motions of the landing craft due to the combined heave and pitch motions are as follows:

Maximum Heave Velocity = 6.0 ft./sec.

Maximum Pitch Velocity = 2.5 ft./sec.
at the Bow of the
Craft

Combining with these velocities the maximum hook velocity for a 2 ton cargo load and the vertical velocity component of the supply ship's roll induced motion, the maximum contact velocity of the cargo unit or palletized load is found:

Maximum conbined velocity = 18.68 ft./sec.

Calculating the contact load on the cargo well deck of the loading craft using the calculation for the 3 foot by 12 foot--1/2 inch thick panel in Appendix A but changing the impact velocity to 18.68 ft./sec. and leaving the spring constant at the spring stiffness for the steel plating on the cargo deck.

The concentrated contact load will be 19,000 lbs.

The cargo deck deflection due to this concentrated load can be as much as 1.75 inches deflection if the load strikes on one corner initially.

The acceleration loading on the cargo unit at this speed of impact and deflection will be 25 g's with a dominant frequency of from 12-15 cycles per second. The equations found in Appendix A were used to calculate this acceleration load and the frequency.

The cargo in the off-loading process can experience very large g loading if the pendulum motion induced by the roll of the supply ship or the rapid descent of the cargo onto the

A-6 Sea State Data: (partial listing) (ref. 3)

Beaufort Scale	Wave Period	Wave Height	Wind Speed
2	5.9 sec	1.3 m	5 Knots
3	6.0 "	1.5 m	9 "
4	6.1 "	1.7 m	12 "
5	6.6 "	2.1 m	18 "

Wave Velocity Equations:

(first order approximations)

Condition	Equation
Shallow water	$V_w = \sqrt{gh}$
Deep Water	$V_w = \sqrt{g\lambda w/_{2\pi}}$

where V_w = wave velocity

g = gravitational constant 32.2 ft/sec^2-lbs.

h = water depth in feet

λ_w = wave length in feet

π = 3.1416 constant

A-7 Statistical Wave Height and Amplitude Equations (ref 3)

Average apparent wave height:

$$\bar{h}_w = 2.5E = 1.77(2E)^{1/2}$$

Average amplitude wave,

$$\bar{\eta}_a = 1.25E = 0.886(2E)^{1/2}$$

One third highest wave height:

$$(h_w)_{1/3} = 4.06 = 2.83(2E)^{1/2}$$

One Tenth Highest wave height

$$(h_w)_{1/10} = 5.1E = 3.60(2E)^{1/2}$$

The greatest expected heights of waves in N encounters:

$N = 100$ $H_6 = 6.5E^{1/2} = 4.56(2E)^{1/2}$

$N = 1000$ $H_6 = 7.7E^{1/2} = 5.46(2E)^{1/2}$

$N = 10,000$ $H_6 = 8.9E^{1/2} = 6.28(2E)^{1/2}$

where E = area under the energy spectrum

h_w = wave height from crest to trough

H_6 = greatest expected wave in N encounters

A-8 Calculation of the Wave Length from Wave Period Data

Speed of a wave in deep water $V = \sqrt{gh_n/2\pi}$

$$\text{Period of wave} = \frac{L_w}{V_w} = \frac{L_w}{\sqrt{gL_n/2\pi}} = \sqrt{\frac{2\pi L_w}{g}}$$

$$\text{Length of wave} = L_w = \text{Period}\sqrt{2\pi/g}$$

Sea State Beaufort	Wave Period	Wave Height	Wave Length
2	5.9 sec	4.26 ft	79 ft
3	6.0 "	4.91 ft	81.5 ft
4	6.1 "	5.58 ft	84.0 ft
5	6.6 sec	6.9 ft	98.5 ft

The wave slopes can be calculated as:

$$\text{Wave Slope} = \tan\left(\frac{\text{wave Height}}{\text{wave Length}}\right)$$

Wave Slopes range from 4 to 6 degrees

Appendix B

Data on Shock and Vibration Characteristics of Ship, Rail, Air and Highway Transporation Modes

University Consultants, Inc.

CHAPTER 5

TRANSPORTATION ENVIRONMENTS

The most damaging environments encountered by packaged items during transportation are shock and vibration. The shocks and vibrations to be expected depend on the particular mode of transportation. The effect of these environments on the item being transported is further dependent upon the manner in which the item is packaged and the stowage technique used. Techniques used for protecting packaged items against the harmful effects of shock and vibration include: blocking and bracing; use of cushioning materials, either elastic (resilient) or nonelastic (crushable); and use of shock and vibration isolation systems.

5-1 SHOCK AND VIBRATION

Although shock and vibration are often treated as separate phenomena, the distinction between the two is not clear cut. The difference between transient shock motion and periodic vibration is fairly obvious; but the existence of any basic differences between shock and random vibration, which is not periodic, is much less obvious. However, shock may be considered as intermittent excitation and vibration as sustained excitation.

Vibrations and shocks will impose forces on and deform any flexible or elastic structure. The severity of the deformation depends upon the nature and intensity of the imposed force, and the geometrical configuration, total mass, internal mass distribution, stiffness distribution, and damping of the item or equipment.

5-1.1 VIBRATION

Vibration is an oscillation wherein the quantity is a parameter that defines the motion of a mechanical system. Vibration has also been described as the variation, usually with time, of the magnitude of a quantity with respect to a specified reference, when the magnitude is alternately greater and smaller than the reference.

Vibration may be periodic in nature, or it may be nonperiodic.

5-1.1.1 Periodic Vibration

The simplest form of periodic vibration is simple harmonic motion, which is motion that varies sinusoidally. Simple harmonic motion can be identified by any two of the four parameters: frequency, amplitude of excursion, velocity, and acceleration. Figure 5-1 shows the relationship between frequency, acceleration, and double amplitude, where double amplitude is the excursion from one extreme of harmonic motion to the other. From the illustration it can be seen that if double amplitude remains constant, the acceleration increases as the square of the increase in frequency. Likewise, increasing the excursion while the frequency remains constant results in a proportionately higher acceleration.

Any periodic motion can be considered as consisting of motions at one or more frequencies, with the motion at each frequency being harmonic. A periodic, or steady-state, vibration can be completely defined by designating the frequency, or frequencies, the maximum value of the harmonic variable at each frequency, and the phase relationships that exist between the component harmonic motions. The harmonic variable may be expressed in terms of displacement, velocity, or acceleration.

5-1.1.2 Nonperiodic Vibration

There are two types of nonperiodic vibration: random and white-noise. They differ from one another, although the two terms are often used synonymously. Random vibration differs from steady-state vibration in that the amplitudes at the component frequencies vary randomly with respect to time, and therefore cannot be predicted. White-noise vibration has no defined component frequencies, and both frequencies and amplitudes may vary randomly with time. (Ref. 1).

5-1.1.3 Resonance

The response of a structure to shock and vibration is determined largely by the excitation

Source: Packaging and Pack Engineering, AMCP 706-121, October, 1964

frequency and the resonance characteristics of the structure. Resonance affects the magnitude of the applied load and its transmission characteristics. Any shock or vibration at the resonant frequency is amplified in force, resulting in an increased chance for damage.

The ratio of the output vibration amplitude to the applied vibration amplitude is the transmissibility. Transmissibility can be considered a magnification factor, and is greatest at resonance. It decreases down to unity below resonance, and can become less than unity above resonance.

5-1.2 SHOCK

Shock connotes impact, collision, or blow, usually caused by physical contact. It denotes a rapid change of load, or a rapid change of acceleration with a resultant change of load.

A shock motion cannot be defined by assigning numerical values to established parameters; it can only be defined by describing the history of a significant parameter such as acceleration, velocity, or displacement. The time duration of a shock pulse is important, since it helps in determining the way in which an object will react to that pulse.

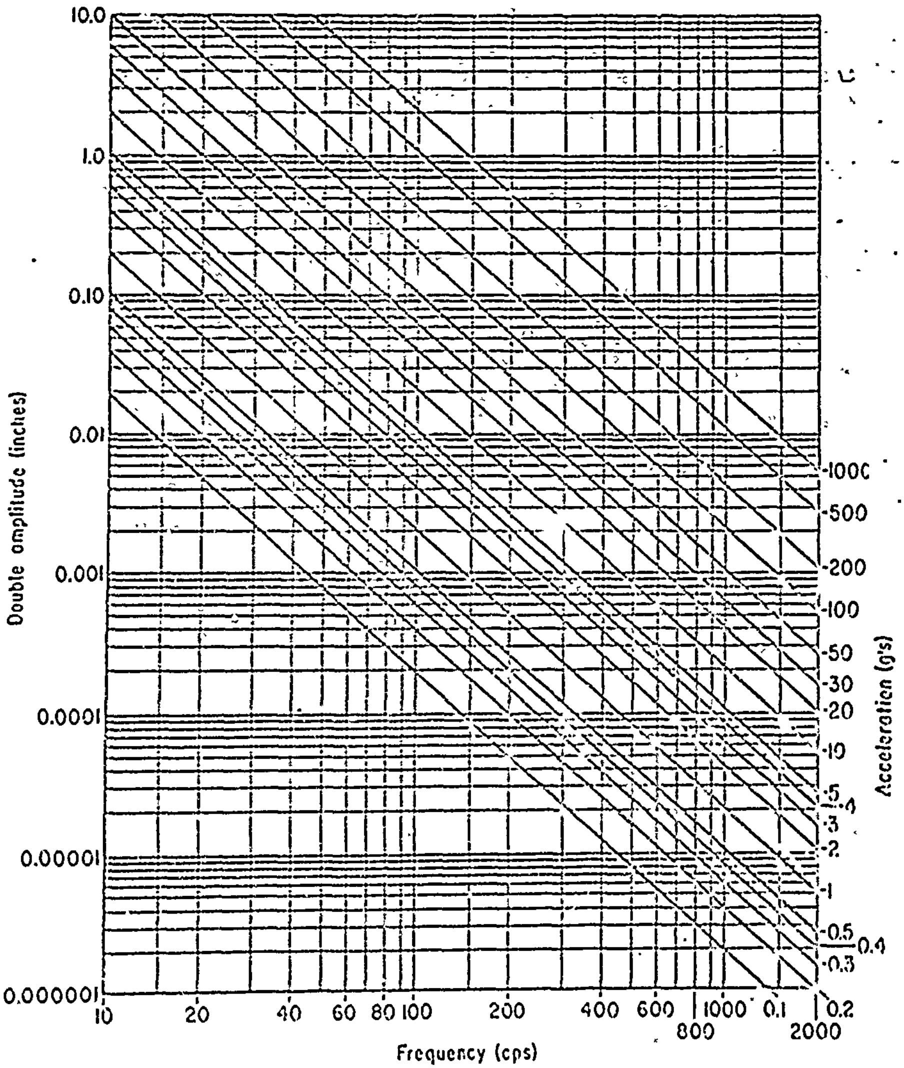


Figure 5-1. Relationship Between Frequency, Acceleration, and Double Amplitude (Ref. 7)

Source: Packaging and Pack Engineering, AMCP 706-121, October, 1964

3

Although theoretically an equation might be written for a particular shock motion, actual shock motions are usually complex, and the customary method of describing the time function of the motion is graphical (Figure 5-2). There are an infinite number of possible shock motions, since the motion may vary in pulse shape, time duration, and peak acceleration. (Refs. 1 and 2).

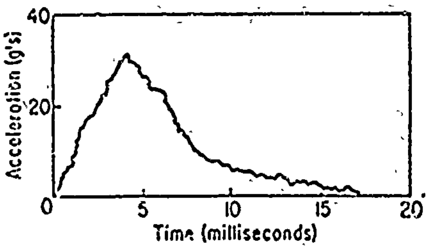


Figure 5-2. Plot of Typical Shock Motion

5-2 TRANSPORTATION SHOCK AND VIBRATION

Data on the actual shock and vibration environment likely to be encountered during the various modes of transportation are presented in the following paragraphs. Some of the data given are relative in nature, but are nevertheless useful in damage prevention.

5-2.1 TRUCK TRANSPORT

Vibration frequencies in motor trucks are dependent upon the natural frequency of the unsprung mass on the tires, the natural frequency of the spring system, and the natural frequencies of the body structure. The vibration amplitudes are dependent upon road conditions and the speed of travel. Intermittent road shocks of high magnitude can occur, with resultant extreme truck-body displacements. These large displacements may result in a severe shock environment for unlashed cargo as it bounces about the truck floor. Vibrations caused by the truck engine and transmission system are relatively insignificant in the cargo area. (Ref. 1).

The predominant natural frequencies of various military transport vehicles, as measured in the cargo space, are given in Table 5-1. Figure 5-3 presents vibration data measured in the cargo spaces of trucks and trailers, and Table 5-2 shows the accelerations of the cargo in a 2-1/4-ton, M-104 trailer combination during operation over various terrain.

TABLE 5-1. PREDOMINANT FREQUENCIES MEASURED IN CARGO SPACES OF VARIOUS MILITARY TRANSPORT VEHICLES (Ref. 1)

Type of Vehicle	Direction of Acceleration	Predominant Frequencies (cps)		
		Springs	Tires	Body
Truck (2-1/2 tons)	Vertical	2 to 4	8 to 13	70 to 180
	Longitudinal	-	10 to 20	70 to 100
	Lateral	2	10 to 20	100 to 200
Truck (3/4 ton)	Vertical	2 to 3	5 to 10	60 to 110
	Longitudinal	-	-	70 to 100
	Lateral	-	-	60 to 70
Trailer (1 ton)	Vertical	3 to 5	8 to 10	50 to 100
	Longitudinal	-	-	50 to 100
	Lateral	2	-	50 to 120
M-14 Trailer	Vertical	1 to 4	7 to 10	50 to 70
	Longitudinal	3 to 4	8 to 10	200 and greater
	Lateral	2 to 4	-	-
M1, 2T Trailer	Vertical	2.5 to 5	7.75 to 10.5	100 to 150

Source: Packaging and Pack Engineering, AMCP 706-121, October, 1964

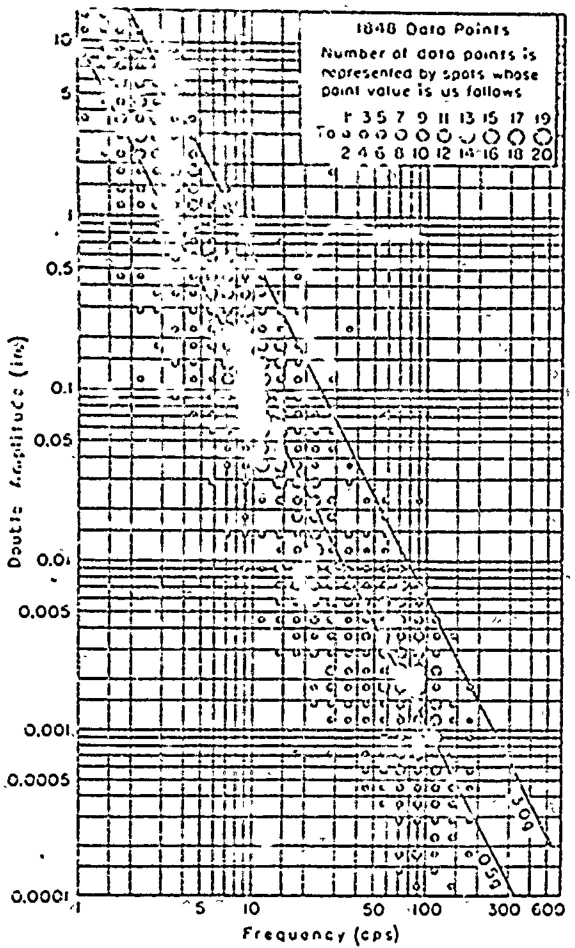


Figure 5-3. Truck Transportation Vibration Data (Ref. 2)

5-2.2 RAIL TRANSPORT

Vibrations in moving freight cars arise from track and wheel irregularities, and occur principally in the lateral and vertical directions. The exciting frequencies caused by rail joints and wheel imbalance vary from 0 to 13 cycles per second. Railroad car structural-frame frequency is usually in the range of 50 to 65 cycles per second. Shock and transient vibrations during coupling and during starting and stopping are generally considered to be the most damaging phases of rail shipment.

Figure 5-4 presents data on the number of occurrences of shocks of various levels recorded on the floor of a freight car during a 700-mile trip. The data are divided into shock ranges and direction. For each direction and within each shock range, the shocks are plotted against the speed range during which they occurred. Table 5-3 shows the percentage of travel time in each speed range during the 700-mile trip. The time durations of the shock impulses, while not measured accurately, were estimated to be between 10 and 50 milliseconds.

Figure 5-5 shows the velocity of impact during switching operations taken from a representative number of railroad yard operations. It can be seen that the mean speed of impact is about 7 miles per hour, which is well above the approximate 5 miles per hour limit for which the switching gear provides cushioning protection. Longitudinal accelerations of a freight car body that can be expected for impact speeds of 1 to 7 miles per hour are shown in Figure 5-6.

The method of bracing greatly affects the maximum acceleration of lading. This is shown in Table 5-4. Although a freely-floating lading is desirable, it is not practical since it requires large space for the movement of the load; furthermore, it does not provide protection against several successive impacts in the same direction. Controlled floating, in which movement is controlled by means of snubbers that center the

TABLE 5-2. CARGO ACCELERATION IN 2-1/4-TON TRUCK, M-104 TRAILER COMBINATION (Ref. 3)

Operation Over	Maximum Acceleration (g's)			
	Longitudinal	Lateral	Vertical	Vector Total
Sandy Beach	2. 5	1. 0	4. 5	5. 3
Ungraded Road (30 mph)	0. 5	1. 0	1. 5	1. 9
Graded Road (30 mph)	1. 0	0. 25	1. 0	1. 4

Source: Packaging and Pack Engineering, AMCP 706-121
October, 1964

TABLE 5-3. PERCENTAGE OF TRAVEL TIME vs SPEED RANGE FOR FIGURE 5-4

Speed Range (mph)	Travel and Recording Time (%)
0	9. 3
0-10	14. 3
10-20	9. 4
20-30	20. 3
30-40	21. 2
40-50	10. 8
50-60	6. 1
60-70	8. 3
over 70	0. 3

load after each impact, is the most practical. Figure 5-7 shows the comparative results for one such controlled-floating arrangement and a blocked arrangement. (Ref. 3).

5-2.3 AIR TRANSPORT

During air transport, the in-flight shock and vibration environment is generally not too severe. The loadings which are important are the dynamic loadings that occur during flight in rough air. These are differentiated from shock loadings in that they consist of fairly high magnitude accelerations imposed for a prolonged period of time. These accelerations can be as high as 2 to 3 g's during normal operation of large transport aircraft.

TABLE 5-4. RATIO OF LADING ACCELERATIONS : CAR ACCELERATIONS FOR DIFFERENT TYPES OF BRACING (Ref. 3)

Type of Bracing	Ratio: $\frac{\text{lading acceleration}}{\text{car acceleration}}$
Solid Bracing	1. 0
Controlled Floating	0. 6-0. 7
Free Floating	0. 1

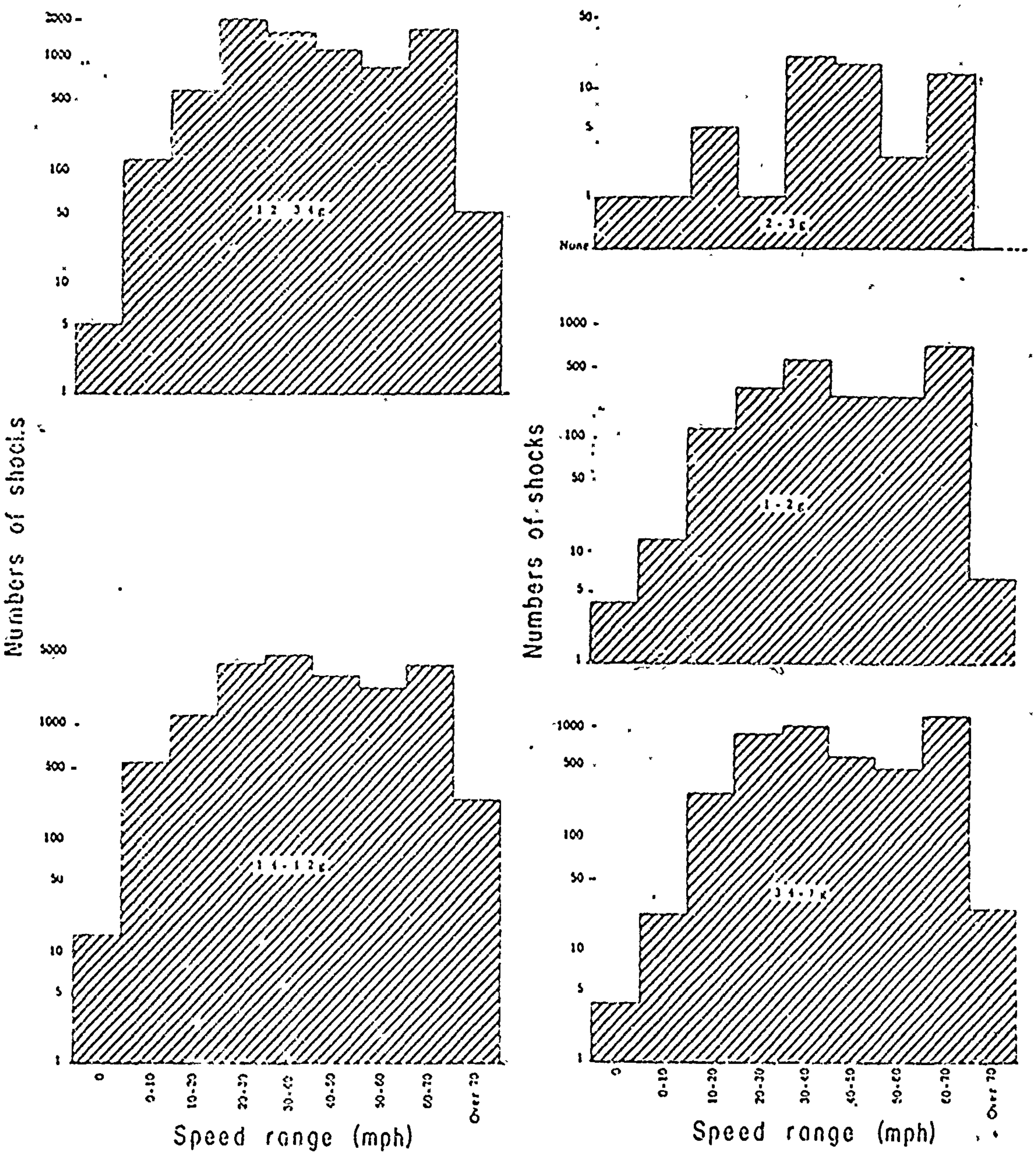
The most damaging conditions encountered during air shipment are the shocks resulting from handling operations. This is shown in Figure 5-8, which is a plot of the maximum shock recorded during a test shipment by a major airline. For the test, two impact recorders were placed in a wooden box, having a total weight of 73 pounds, and both longitudinal and vertical shocks were recorded.

5-2.4 SHIP TRANSPORT

The principal excitation forces for shipboard vibrations result from the ship structure interfering with the flow of water from the propellers, and from imbalance or misalignment of the propeller shaft system. The frequency range of the vibrations is about 5 to 25 cycles per second, with attendant accelerations reaching a maximum of about 1 g.

During normal service ship cargos do not experience shock loads of any significant magnitude, with the exception of the shocks that may occur during loading and unloading operations.

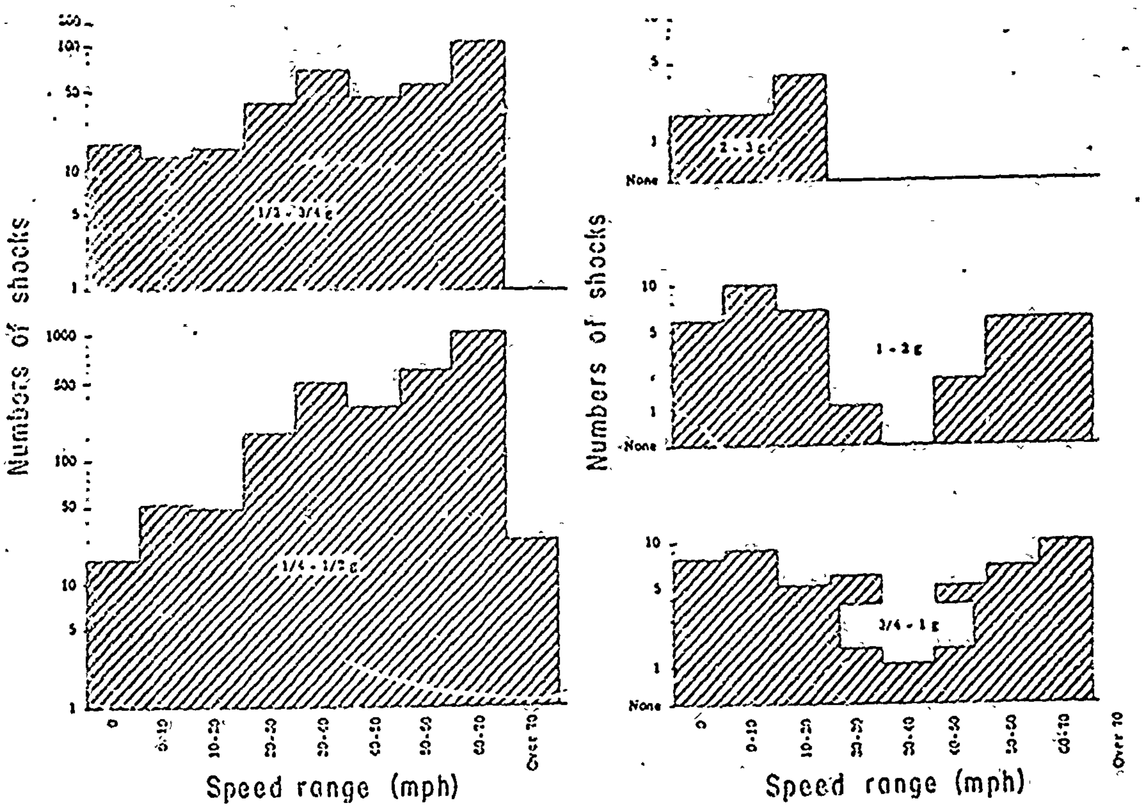
Source: Packaging and Pack Engineering, AMCP 706-121
October, 1964



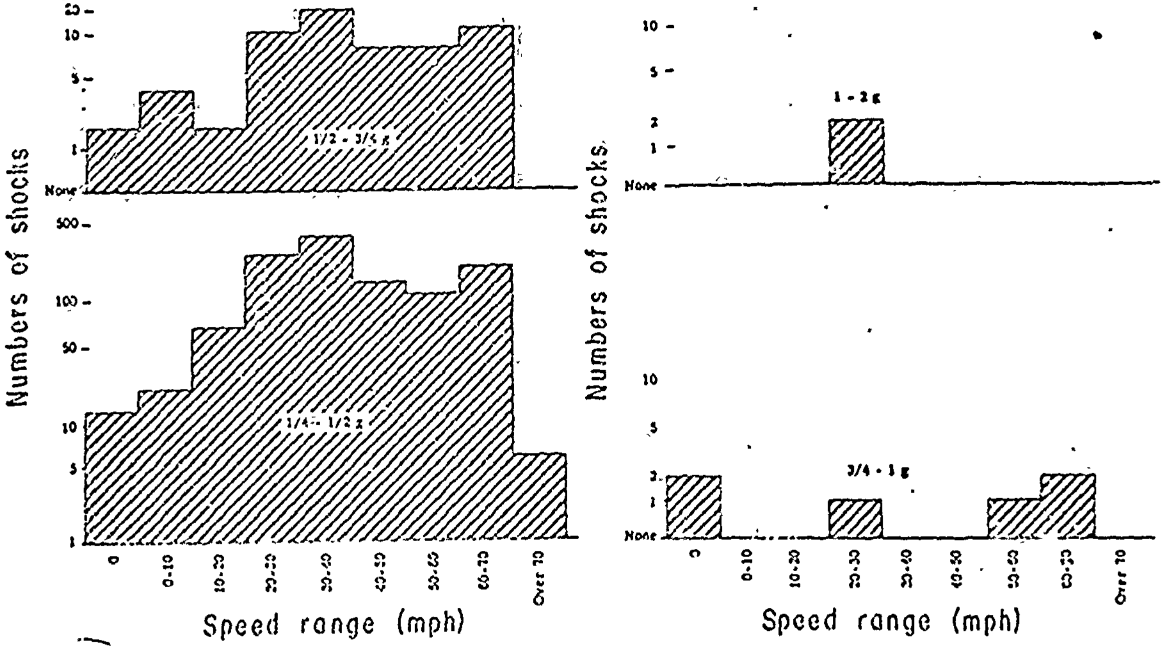
(a) VERTICAL SHOCKS MEASURED ON FREIGHT

Figure 5-4. Freight and Freight Car Shock Measurements (Ref. 1)

Source: <u>Packaging and Pack Engineering</u>, AMCP 706-121
October, 1964



(b) LONGITUDINAL SHOCKS MEASURED ON FREIGHT CAR FLOOR



(c) LATERAL SHOCKS RECORDED ON FREIGHT CAR FLOOR

Figure 5-4. Freight and Freight Car Shock Measurements (Ref. 1) (cont)

Source: <u>Packaging and Pack Engineering,</u> AMCP 706-121
October 1964

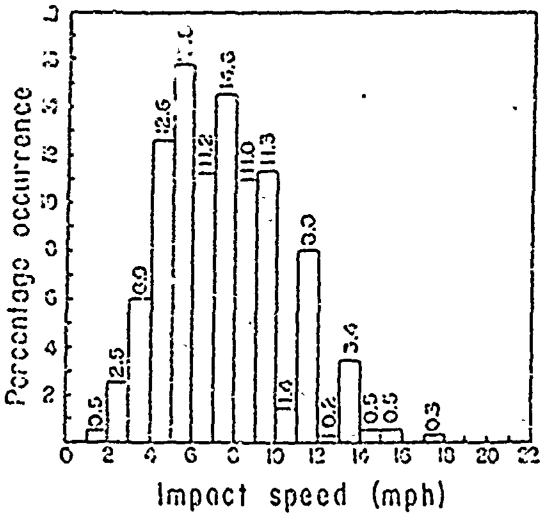


Figure 5-5. Impact Speed During Freight Car Switching Operations (Ref. 1)

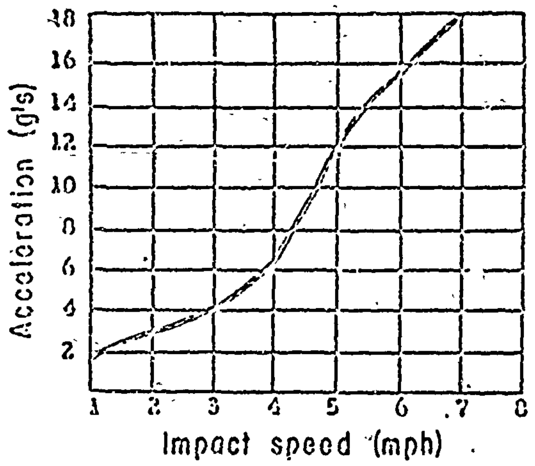


Figure 5-6. Maximum Longitudinal Acceleration of Freight Car Body vs Switching Impact Speed (Ref. 1)

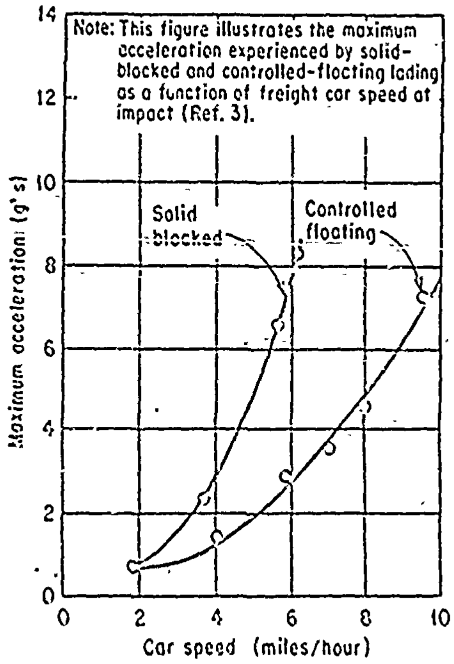


Figure 5-7. Acceleration Experienced by Solid-Blocked and Controlled-Floating Lading

Source: Packaging and Pack Engineering, AMCP 706-121 October, 1964

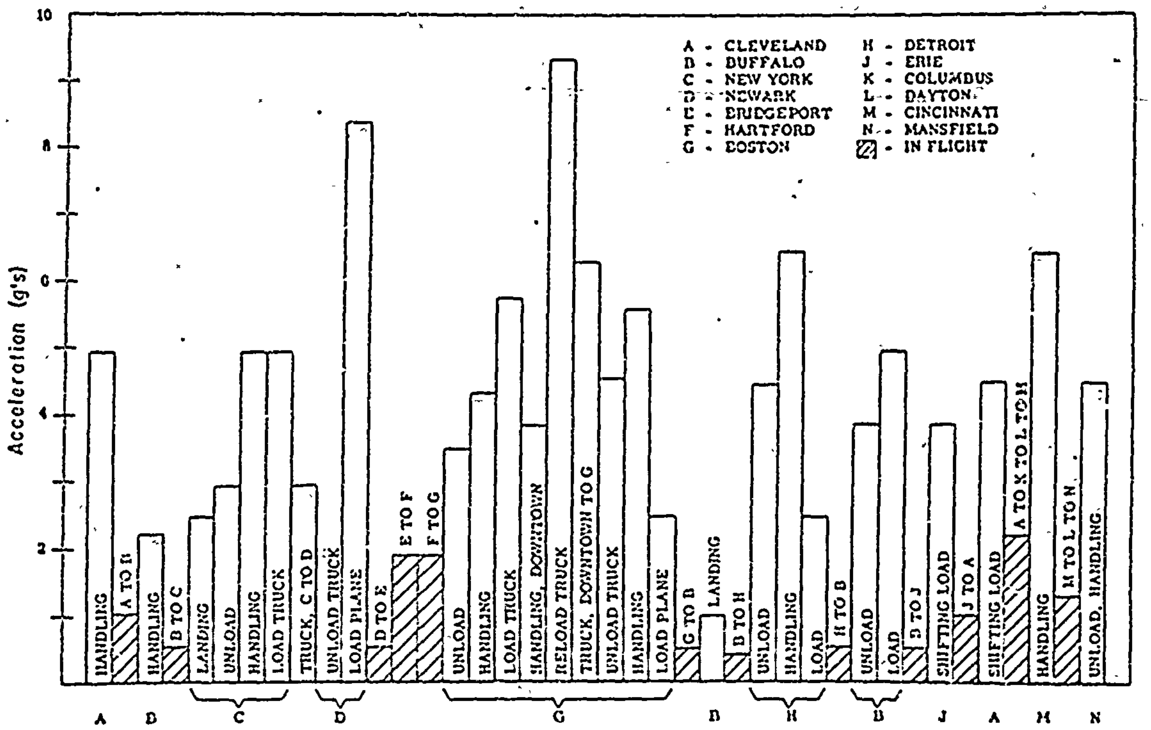


Figure 5-8. Maximum Shocks Recorded During Airline Test Shipment (Ref. 1)

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2. E.C. Theiss, et al., *Handbook of Environmental Engineering*, ASD TR 61-363, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, 1961.
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Source: Packaging and Pack Engineering, AMCP 706-121
October, 1964

The vibration frequencies encountered aboard ship vary from zero to approximately 33 hertz (Hz) (2000 cycles per minute (c.p.m.)). In some of the latest surface ships, frequencies of up to 50 Hz (3000 c.p.m.) have been observed. The severity of vibration on a ship depends upon the type of ship, and location of equipment within the ship's structure.

5.1.3.3.3 Endurance test. The equipment shall be vibrated for a total period of at least 2 hours at the resonant frequencies chosen by the test engineer. If no resonance is observed, this test shall be performed at 50 Hz or at the upper frequency as specified in 5.1.3.3.4. The amplitudes of vibration shall be in accordance with table I and figure 1.

Table I - Vibratory displacement of environmental vibration.

Frequency range (Hz)	Table amplitude (inch)
4 to 15	0.030 ± 0.006
16 to 25	.020 ∓ .004
26 to 33	.010 ∓ .002
34 to 40	.005 ∓ .001
41 to 50	.003 ∓ .000 - .001

5.1.3.3.5 Endurance test for mast mounted equipment. Equipment intended for installation on masts, such as radar antennae and associated equipment, shall be designed for a static load of 2.5g (1.5g over gravity) in vertical and transverse (athwartship and longitudinal) directions, to compensate for the influence of rough weather. In addition, the equipment shall be vibrated for a total period of at least 2 hours, at the resonant frequencies chosen by the test engineer. If no resonance was observed, this test shall be performed at 33 Hz, unless excepted by 5.1.3.3.4. The amplitudes of vibration shall be in accordance with table II.

Table II - Vibratory displacement of environmental vibration for mast mounted equipment.

Frequency range (Hz)	Table amplitude (inch)
4 - 10	0.100 ± .010
11 - 15	.030 ∓ .006
16 - 25	.020 ∓ .004
26 - 33	.010 ∓ .002

5.4.1.1.2 Excessive longitudinal vibration. Excessive longitudinal vibration of the main propulsion system units occurs when the displacement amplitude is greater than that shown in table IV.

Table IV - Vibratory displacement of longitudinal vibration in main propulsion systems.

Frequency range (Hz)	Amplitude (Inch)
4 to 15	0.030 ± 0.006
16 to 25	.020 ∓ .004
26 to 33	.010 ∓ .002
34 to 40	.005 ∓ .001
41 to 50	.003 ∓ .0000 - .0001

Source: Military Standard Mechanical Vibrations of Shipboard Equipment, MIL-STD-167B (Ships) 11 August 1969

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A typical cab-behind-engine truck[7] of 144 in. wheel base and 27,000 lb loaded weight has a natural frequency in pitch of 4.4 cps (item 2 above) and a natural frequency in bounce of 3.4 cps. Both of these natural frequencies refer to vibration of the vehicle on the tires, i.e., the modes of vibration described above under item 1. Corresponding information for several classes of trucks and other vehicles is given in Tables 45.1 and 45.3.

Table 45.1. Typical Shock and Vibration Data for Tractor-Trailer Combination at Normal Operating Conditions

(After M. C. Kaye.[5]*)*

Component	Frequency, cps	Acceleration, g	
		Av.	Max.
Tractor:			
Front axle	8–9	2.5	5
Rear-axle bounce	9–10	2.5	5
Rear axle due to universal joint action	60–65	0.4 vert. 0.1 horiz.	0.6 vert. 0.3 horiz.
Trailer axle	14–15	1.5	3
Transmission	60–65	0.4 vert. 0.7 horiz.	0.6 vert. 1.8 horiz.
Tractor frame:			
(a) Pitch on tires only with rigid suspension springs	4–4.5	0.6	1.2
(b) Pitch with deflection of suspension springs and tires	2–2.5	0.4	0.7
(c) Frame flexure excited by pitch vibrations	6–10	0.15	0.45
(d) Frame flexure excited by engine vibration	60–100	0.07	0.25
Pitch of trailer frame with deflection of suspension springs and tires	2–4	0.1	0.3
Tractor cab, deck vibration	60–65	0.1	0.3
Short wheel-base tractor cab, fore-and-aft motion, driver's neck level:			
(a) Pitch on tires only with rigid suspension springs	4–4.5	0.2	0.4
(b) Pitch with deflection of suspension springs and tires	2–2.5	0.2	0.8
(c) Frame flexure due to pitch	9–10	0.1	0.3
Long wheel-base tractor cab, fore-and-aft motion, driver's neck level:			
(a) Pitch on tires only with rigid suspension springs	6–10	0.5	1.2
(b) Pitch with deflection of suspension springs and tires	2–2.5	0.05	0.1

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

The maximum acceleration in the cargo space of the truck for various effective static spring deflections is shown in Fig. 45.8. The effective static spring deflection is not the

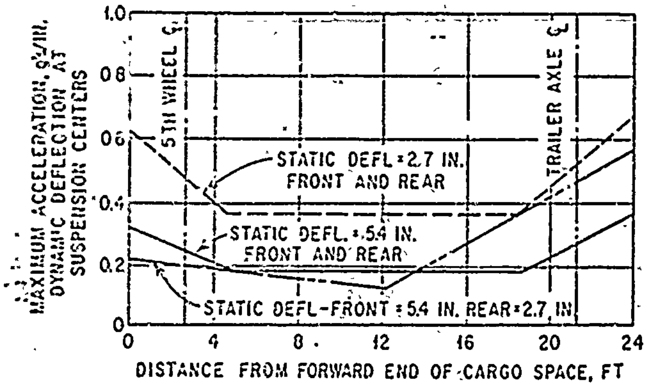

FIG. 45.9. Maximum acceleration at various points in the cargo space of a semitrailer per unit dynamic deflection at the suspension center. These values were computed for several effective static spring deflections of the trailer and tractor suspension springs and are based on unit dynamic deflection of the suspension springs.

change in height of the truck above the ground between the loaded and unloaded condition, but is computed by dividing the total load in pounds by the spring stiffness at the loaded condition; i.e., only in the special case of linear springs are the effective static deflection and the actual deflection equal. The acceleration values are computed for 1 in. dynamic deflection at the spring. For example, a deflection of 3 in. in actual service would result in an acceleration equal to three times the value indicated in Fig. 45.8. A similar graph, Fig. 45.9, shows the acceleration over the cargo space of a 24-ft trailer for various effective static spring deflections of the trailer and tractor suspension springs. The acceleration values also are based on unit dynamic spring deflection at the suspension centers.

Table 45.2. Acceleration at G ort Vehicles (2¼-Ton Truck, M-104 Trc and Road Test

(A. Pursifull.[8])

Type of action	Max. acceleration, g				Frequency, cps
	Longitudinal	Lateral	Vertical	Vector total, g	
Beaching	2.5	1.0	4.5	5.3	3.3
Ungraded road (30 mph)	0.5	1.0	1.5	1.9	
Graded road (30 mph)	1.0	0.25	1.0	1.4	

Table 45.3. Predominant Frequencies Measured in the Cargo Space of Various Military Transport Vehicles *

(After I. R. Ehrlich.[10])

Type of vehicle	Direction of acceleration	Predominant frequencies, cps		
		Body (sprung mass)	Vibration on tires	Resonant vibration of structural part of the body
Truck (2½ ton)	Vertical	2–4	8–13	70–180
	Longitudinal	...	10–20	70–100
	Lateral	2	10–20	100–200
Truck (¾ ton)	Vertical	2–3	5–10	60–110
	Longitudinal	...	...	70–100
	Lateral	...	...	60–70
Trailer (1 ton)	Vertical	3–5	8–10	50–100
	Longitudinal	...	...	50–100
	Lateral	2	...	50–120
M-14 trailer	Vertical	1–4	7–10	50–70
	Longitudinal	3–4	8–10	200
	Lateral	2–4	...	
M-1 trailer (2 ton)	Vertical	2.5–5	7.75–10.5	100–150

* These data were obtained for operation of the vehicles over rough roads at speeds above which damage to the vehicle and endangerment to the driver were probable.

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

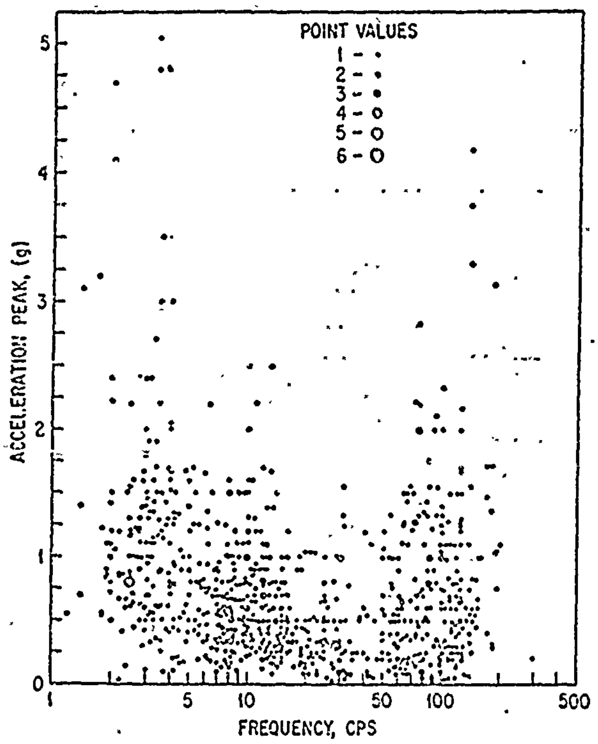

FIG. 45.22. Experimental values of acceleration in the cargo spaces of trucks and trailers. These data were obtained for operation of the vehicles over rough roads at speeds at which damage to the vehicle and endangerment to the driver were possible. The sizes of the dots represent a variable number of test points as indicated. (*I. R. Ehrlich.*[10])

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

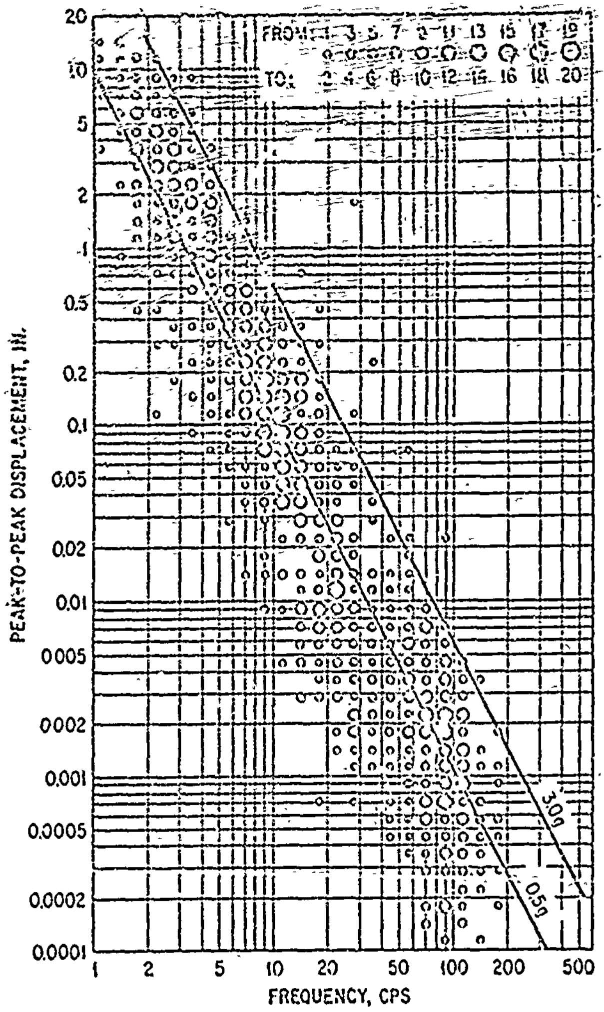

Fig. 45.23. Vibration conditions in the cargo spaces of trucks and trailers and on vehicle body appendages. Operating conditions are similar to those described with reference to Fig. 45.22. The data represent 1848 test points obtained on nine vehicles. The number of points in adjacent squares is represented by centrally located solid circles whose point values are indicated in the inset. (*I. R. Ehrlich.*[10])

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

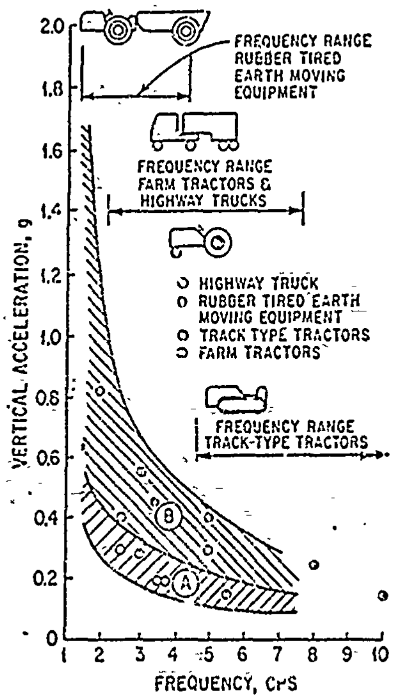

FIG. 45.24. Average acceleration measured under operational conditions for commercial and military vehicles. Zone A includes vehicle accelerations typical of highway conditions for trucks and haul conditions for rubber-tired earth-moving equipment and for cultivation and plowing by farm tractors; Zone B includes vehicle operations typical of off-highway operations for trucks and field operations for rubber-tired earth-moving equipment, and mowing and disc harrowing for farm tractors. (*I. R. Ehrlich.*[10])

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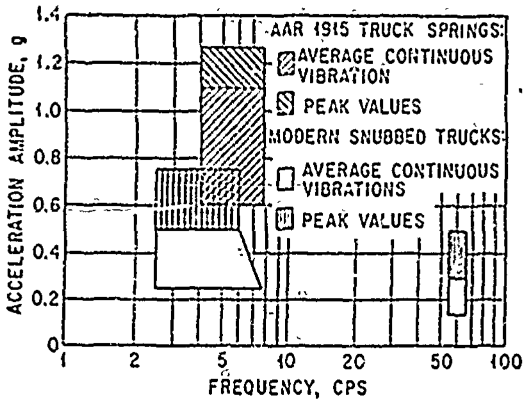

FIG. 45.33. Ranges of predominant frequencies and corresponding acceleration amplitudes in railroad freight cars. The diagonally crosshatched areas refer to cars equipped with AAR 1915 truck springs; blank and vertically crosshatched areas refer to modern trucks with snubbers.

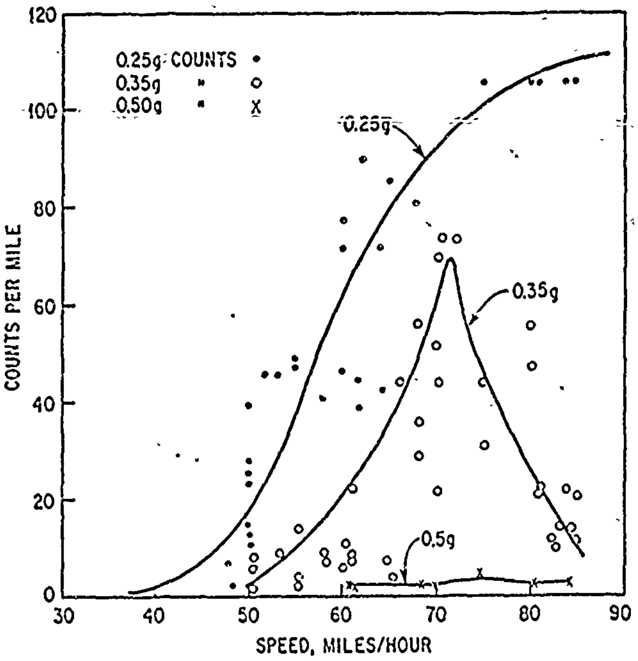

FIG. 45.34. Curves showing number of "counts per mile" (i.e., acceleration peaks) at acceleration levels of 0.25g, 0.35g, and 0.50g as a function of car speed. The data are for a car having springs with $3^{11}/_{16}$ in. maximum deflection and a total load of 104,000 lb on the rail.

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

SHOCK

SOURCES OF SHOCK

Shocks are imposed on railroad freight cars as a result of impacts during switching operations. Severe impacts occur infrequently during the period of a shipment. This is illustrated by Figs. 45.37 and 45.38 which show the distribution of recorded impact speeds in railroad yards.[19, 20]

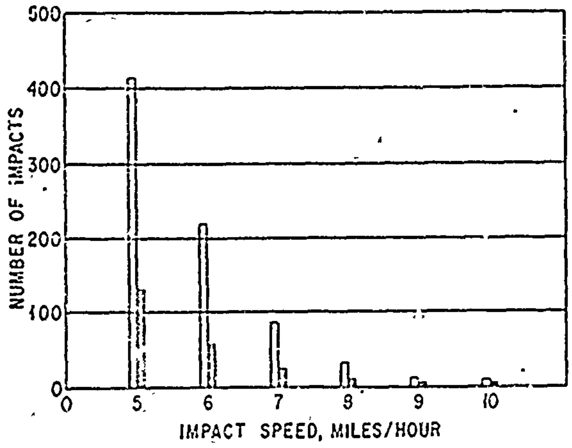

FIG. 45.37. Distribution of impact speed of 1,568 cars in yard and road service during a period of three months. Number of impacts in yard service is indicated by open bars and in road service by solid bars.

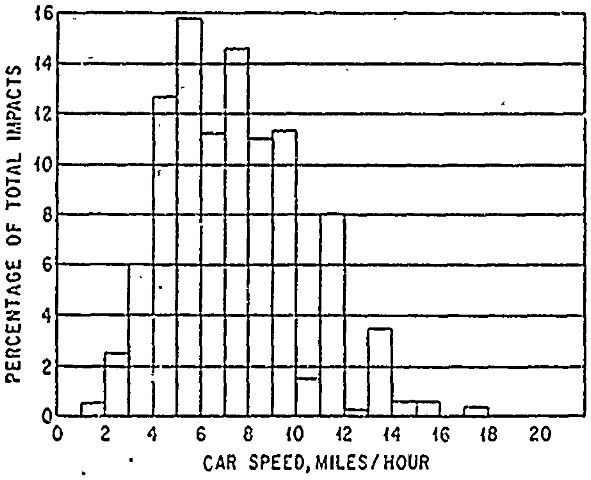

FIG. 45.38. Distribution of impact speeds during switching in the Chicago area in the winter of 1949–1950. A total of 555 impacts are included in the distribution.

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

Records on underway tests should be of sufficient length so that at least a dozen cycles of the lowest frequency vibration appear in the record.* The amplitudes of motion at each frequency of vibration should be reported for the interval when the over-all vibration motion is largest at a particular test condition. In this way data from different tests or for different ships are more comparable. Amplitude values vary during steady-state test runs for a number of reasons—phasing of blades of multipropeller ships, small propeller speed variations, and response of the ship to waves. Data also should be obtained during hard turns (full rudder over and full speed) and during crashback maneuvers (i.e., rapid change from hard ahead at full speed to hard astern at a speed dependent upon the power of the backing engine).

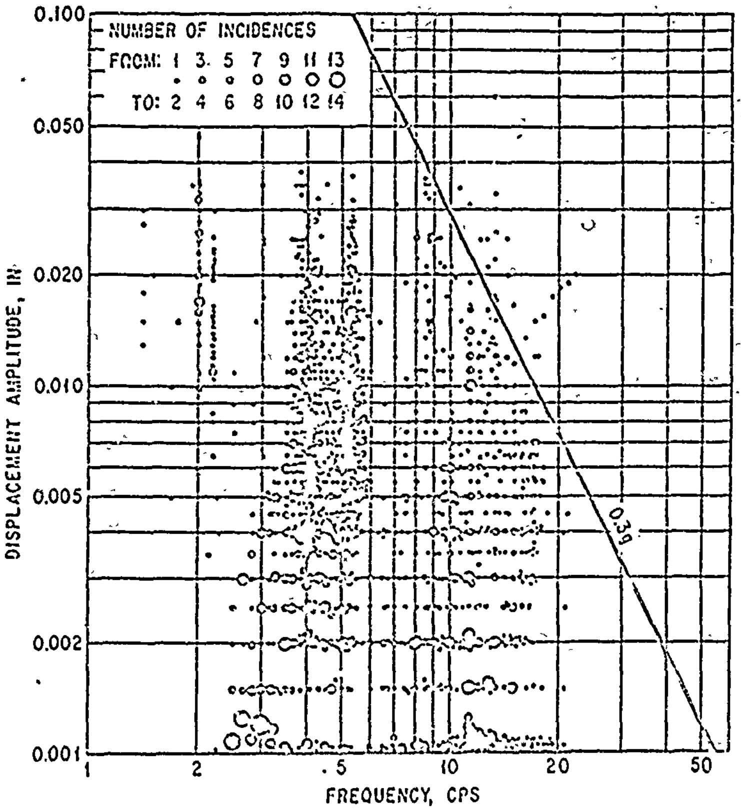

Fig. 46.2. Vertical and athwartship hull and deck vibrations for various ships (predominantly destroyers).[10]

To reduce the cost of the test, it is convenient to solicit the aid of ship personnel to check whether there is apparent excessive vibration of local structure, machinery, and equipment. The items reported as apparently vibrating excessively may be checked later by the test personnel with hand-held portable vibrographs at the speeds where the apparently excessive vibrations are most pronounced.

Vertical and athwartship measurements should be made near the after perpendicular †

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* A preliminary study indicates that many more cycles are necessary to forecast statistically the maximum values that might be obtained over fairly long running time under substantially the same test conditions.[1]

† *After perpendicular* is the vertical line at the aftermost point of the intersection of the ship afterbody (hull) with the water surface when the ship is at design draft. *Forward perpendicular* is similarly defined.

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

at the fantail (stern) on all such tests. These measurements also should be made at the bow near the forward perpendicular. Bow measurements can be used to verify modes of vibration of the hull.

Normally, records obtained on underway hull vibration tests are analyzed for vibratory amplitudes at first-order (shaft-speed) frequencies and propeller-blade frequencies.[9] The records also may be analyzed for hull natural frequencies, independent of ship speed. The vibrations at these resonant frequencies usually are excited by ocean waves, but they may be excited even in almost calm seas if the propeller shaft or propeller-blade frequencies are quite close to hull natural frequencies.

Underway vibration tests on a large number of commercial and naval ships of many types and classes (including aircraft carriers, cruisers, destroyers, submarines, auxiliary ships, and commercial-type ships such as cargo carriers, ore carriers, and tankers) have resulted in criteria of satisfactorily low levels of vibration which are achievable. Maximum vibratory hull displacement amplitudes less than 0.010 in. at shaft or propeller-blade frequencies are considered excellent while those less than 0.020 in. are considered satisfactory. For displacement amplitudes in excess of 0.020 in., remedial measures such as changes in propellers, straightening propeller blades, balancing shafts, or changing flow lines to the propellers often are undertaken.

Figure 46.2 shows a summary indicating the frequencies at which various values of displacement amplitudes have occurred on quite a few ships of a number of types (preponderantly destroyers[19]). Data are plotted for a number of speeds. The values are those only for straight runs and give a rough indication of the ranges of amplitudes at various frequencies (in the lower frequency range) of environmental vibration on ships. Maximum displacement amplitudes for a number of types of ships are given in Table 46.1 together with frequencies and orders (shaft speed, blade frequency, double-blade

Table 46.1. Typical Vibration Data Obtained on Several Classes of Ships

Kind of ship	Location	Shaft speed, rpm	Vertical vibration		Location	Shaft speed, rpm	Athwartship vibration	
			Frequency, cpm	Displacement amplitude, in.			Frequency, cpm	Displacement amplitude, in.
Ammunition ship, maritime hull No. MC1575 (four-bladed propeller)	Stern	95 45	95 * 105–110 ‡	0.014 0.013	Stern	40	40 *	0.025
Refrigeration ship, maritime hull No. MA36 (four-bladed propeller)	Stern	100	400 †	0.018	Stern	37	148 †	0.019
Icebreaker (two three-bladed propellers)	Stern	95	285 †	0.040				
Destroyer (two three-bladed propellers)					Stern	180 240	540 † 240 *	0.007 0.028
Destroyer (two four-bladed propellers)	Stern	220 310 240 60	74 ‡ 310 * 960 † 461 §	0.180 0.021 0.004 0.002	Stern	300 123 310	120 ‡ 123 * 1,300 †	0.134 0.033 0.003
Aircraft carrier (four five-bladed propellers)	Stern Island	160 153 153 150	160 * 765 † 153 * 750 †	0.008 0.005 0.003 0.002	Stern Island	165 165 115	165 * 825 † 575 †	0.010 0.003 0.002
Heavy cruiser (two four-bladed propellers)	Stern	330 250	60 ‡ 1,120 *	0.009 0.002	Stern	300 300	90 ‡ 1,200 †	0.017 0.002

Note: Shaft rpm nominal.
* shaft frequency.
† blade frequency.
‡ hull natural frequency.
§ double blade frequency.

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

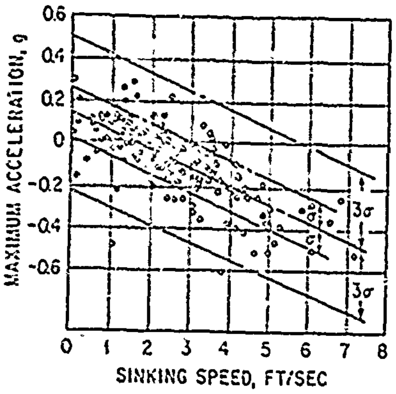

FIG. 47.6. Maximum acceleration (with reference to 1g gravitational acceleration) measured at the center-of-gravity of an aircraft as a function of its downward velocity (sinking speed). The standard deviation σ is 0.12g; thus, 68 per cent of all observations fall within 0.12g of the mean and 99.7 per cent fall within 0.36g of the mean. (*After J. J. Saunders and G. F. Piper.*[9])

sec, as shown in the curve, is typical. Vibration modes with frequencies ranging from approximately 1 to 4 cps are excited, with dynamic magnification factors of 1.5 to 2.0, when a complex airplane structure is subjected to this type of input.[5] Airframe structure and equipment components must be designed to withstand the load and acceleration amplitudes imposed during this condition.

Landing Impact. The landing operation begins with the airplane in a steep glide on final approach with the throttles retarded. Upon nearing the ground, the glide is broken or flattened out to reduce both the rate of descent and the forward velocity—thus minimizing the landing impact loads and reducing the landing roll-out. The rate of descent (*sinking speed*) of the aircraft at the time of the landing impact is the controlling parameter for landing loads. At the instant of landing, the theoretical value of the sinking speed is $v \sin \theta$, where v is the corresponding velocity of the airplane along the glide path and θ is the angle between the horizontal and the glide path. This value is affected by the aerodynamic ground effect, the wind, the technique of the pilot, and the lift-drag characteristics and wing loading of the aircraft. Therefore values of sinking speed encountered during operations are distributed statistically.

A maximum value of sinking speed for cargo airplanes of 7.23 ft/sec, a minimum value of 0.05 ft/sec, a mean value of 2.55 ft/sec, and a standard deviation about the mean of 1.40 ft/sec were observed for 187 landings.[5] Under the assumption that at the instant of initial ground contact the pitching accelerations of the airplane are small, the observed accelerations can be assumed to be the accelerations of the airplane's center-of-gravity. Figure 47.6 shows the relation of observed accelerations to sinking speed; downward acceleration is considered negative and upward acceleration (deceleration) is considered positive. The central line through the data points is a line of best fit determined by the method of least squares, and the bands of width σ represent a standard error estimate indicating the degree of scatter.

Measurements of maximum vertical acceleration during landing at various positions

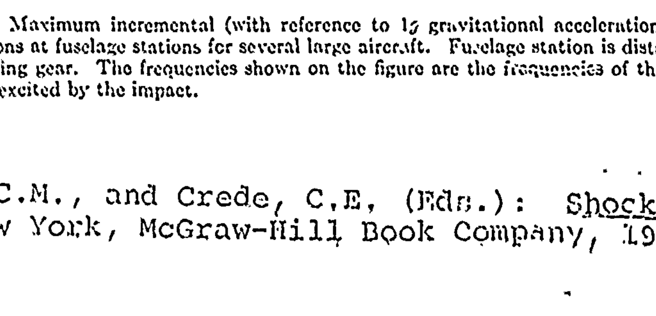

FIG. 47.7. Maximum incremental (with reference to 1g gravitational acceleration) landing accelerations at fuselage stations for several large aircraft. Fuselage station is distance from main landing gear. The frequencies shown on the figure are the frequencies of the fuselage vibration excited by the impact.

From Harris, C.M., and Crede, C.E, (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

The values denoted by the crosses in Fig. 47.30 are above 10*g* acceleration and at frequencies higher than 60 cps. These vibrations are due exclusively to gunfire. They may be considered to be transient since the duration of gunfire is small compared to the duration of the steady-state vibration. However, for long bursts of firing, i.e., 15 to 30 rounds or more, single machine-gun vibration shows definite periodicities, the fundamental corresponding to the firing rate of the gun. Multiple gun installations also may produce a nonperiodic steady-state vibration due to varying phase between gun cycles (see *Gun Firing* in this chapter and in Chap. 48). Gunfire may produce either transient or steady-state vibration depending upon the number of rounds fired.

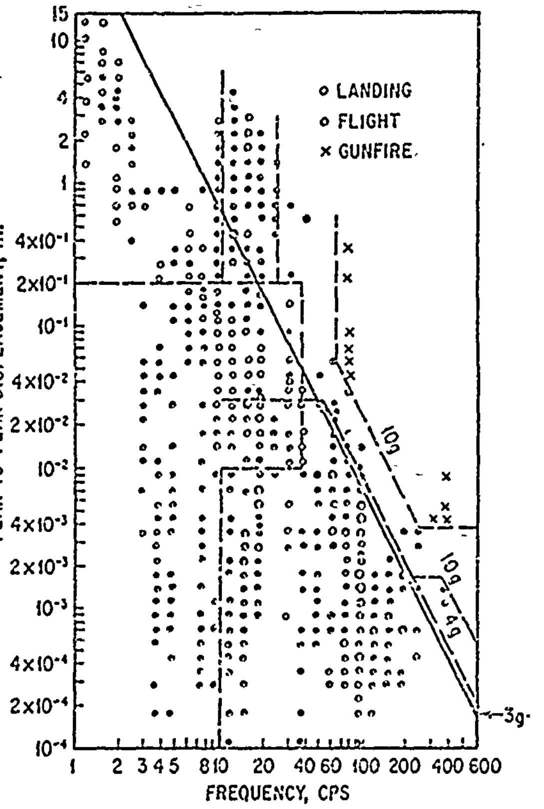

FIG. 47.30. Vibratory displacements and frequencies in jet-engine aircraft during flight, landing, and gunfire. A multiplicity of data is indicated by larger dots. The envelopes shown in dotted lines group together data from common sources. (*After E. Klein, R. S. Ayre, and I. Vigness.*[51])

The remaining portion of Fig. 47.30 is approximately the region lying below 0.03-in. peak-to-peak displacement from 10 to 50 cps and continuing at a constant acceleration amplitude of 4*g* to 500 cps. The points in this region represent steady-state vibration, principally in the fuselage, of jet-engine aircraft in the normal flight conditions,[52] i.e., climb, cruise, descent. Figure 47.31 shows vibration data for additional jet-engine aircraft (fighters); these data are consistent with the data of Fig. 47.30 for steady-state vibration of the fuselage in that the points fall below 0.03-in. peak-to-peak displacement and 4*g* acceleration amplitude. Similar results are obtained by similar analysis of vibration for reciprocating engine aircraft.[51]

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

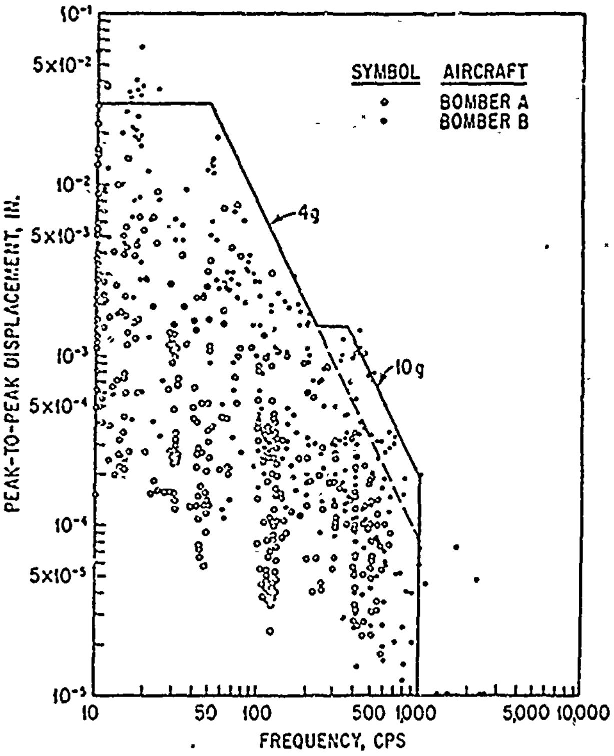

FIG. 47.33. Steady-state vibration at fuselage locations of jet-bomber aircraft during normal flight. Vertical, lateral and longitudinal directions are combined. Data are based on measurements on two aircraft. (*After E. J. Lunney and C. E. Crede.*[62])

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

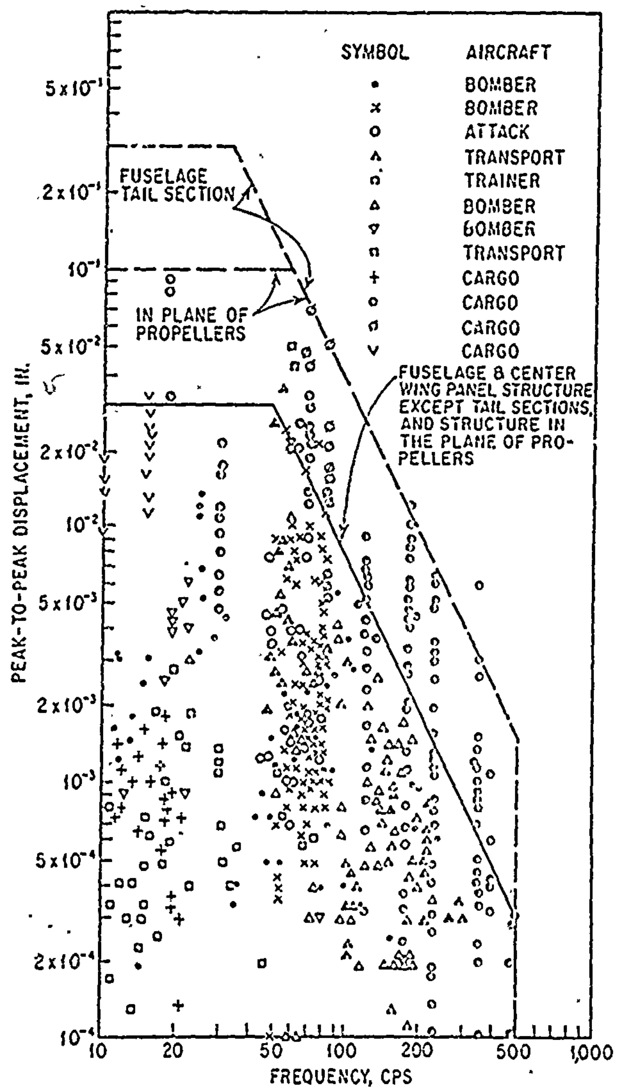

FIG. 47.36. Vibration envelopes for steady-state vibration of fuselages and empennages of reciprocating-engine aircraft, based on measurements on 12 aircraft. Vertical, lateral, and longitudinal directions are combined. (*After E. J. Lunney and C. E. Crede.*[52])

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

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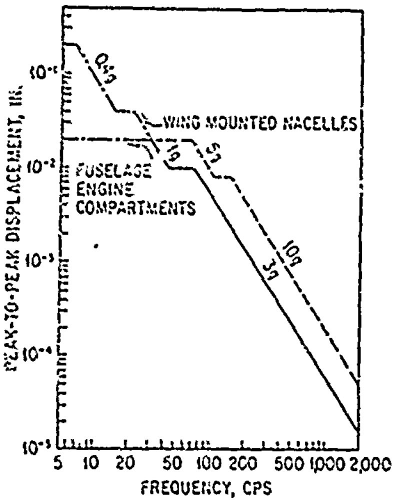

FIG. 47.38. Vibration envelope for engine compartments and nacelles in reciprocating (solid line) and turbojet-engine aircraft, (dotted line) based on measurements in seven aircraft.

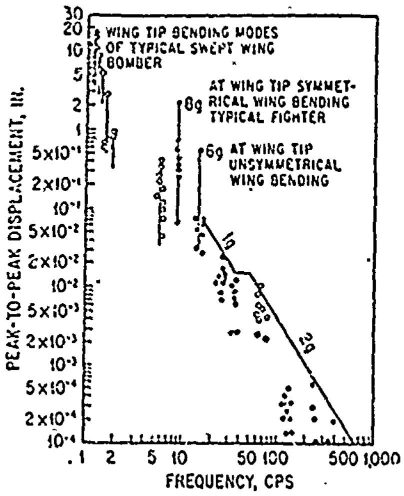

FIG. 47.39. Vibration envelope for outer wing panels and wing tip panels on reciprocating and turbojet engine aircraft, based on measurements on three aircraft. The vertical lines indicate the natural frequencies of the wings.

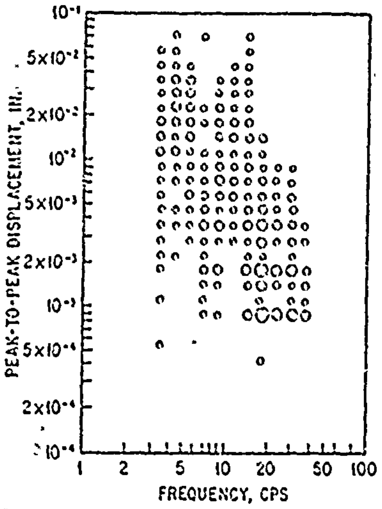

FIG. 47.40. Vibratory displacement and frequency measured in a helicopter. The large dots indicate a multiplicity of measurements. (*After R. E. Barbiere and W. Hall.*[53])

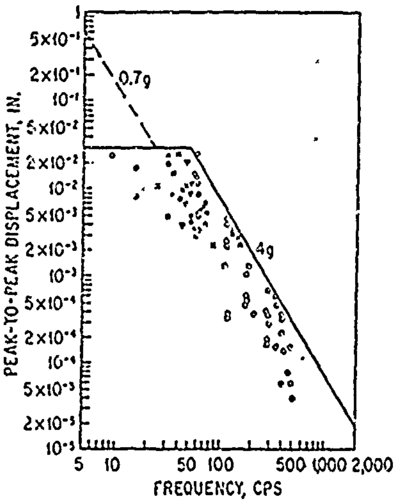

FIG. 47.41. Displacement and frequency data for vibration on cargo deck in cargo aircraft, based upon measurements in five aircraft. The solid envelope bounds the data for steady-state vibration; the dotted envelope refers to maximum expected transient vibration.

From Harris, C.M., and Crede, C.E. (Eds.): Shock and Vibration Handbook. New York, McGraw-Hill Book Company, 1961.

Appendix C

Test Procedures for Military Packaging

University Consultants, Inc.

The Source for pages C-1 through C-9 is : Preservation, Packaging, and Packing of Military Supplies and Equipment - Packing (Volume 2) , DSAM 4145.2, Vol. II, TM38-230-2, NAVAIR 15-01-2, AFM 71-4 and MCOP 4030.21A.

1-24. Testing of Packs

a. Purpose of Testing. The purpose of testing is to prove the adequacy of packaging and packing requirements and the workmanship of fabrication. Testing may be performed in the research and development phase or by tests at the operational level. Since containers in the storage and shipment cycle are subjected to various and constantly changing storage and shipping hazards, it is difficult to develop complete data for their design by merely observing the containers in service. Examinations of failures will reveal the weaknesses and suggest the specific principles of design to overcome such failures. Since service tests are not performed under controlled conditions, laboratory tests are necessary to simulate field hazards. Each test is designed to reproduce one or more of the stresses encountered in the field. During the test cycles the sequence of failures can be observed, classified, and the weaknesses from which the failures result determined. By means of such tests any number of containers can, in turn, be subjected to exactly the same actions, thus providing the data necessary to produce balanced construction and workmanship. In the following pages are described a number of methods that have been devised for subjecting containers to hazards similar to those encountered in the field. Both laboratory and field testing are necessary since there are certain conditions inherent in each method of testing that cannot be duplicated in the other.

b. Types of Tests. Development and testing of packages and containers should be started as soon as possible after initiation of item development. Some of the tests most commonly used in proving design adequacy include the vibration, impact (incline, pendulum, free fall), cyclic exposure, and salt spray tests (fig. 1-4). One or more of these tests are usually applicable to the design of military packages and packs. In many cases the technical activity having design responsibility, has interval tests and procedures that are applicable to a specific design problem. The documents most

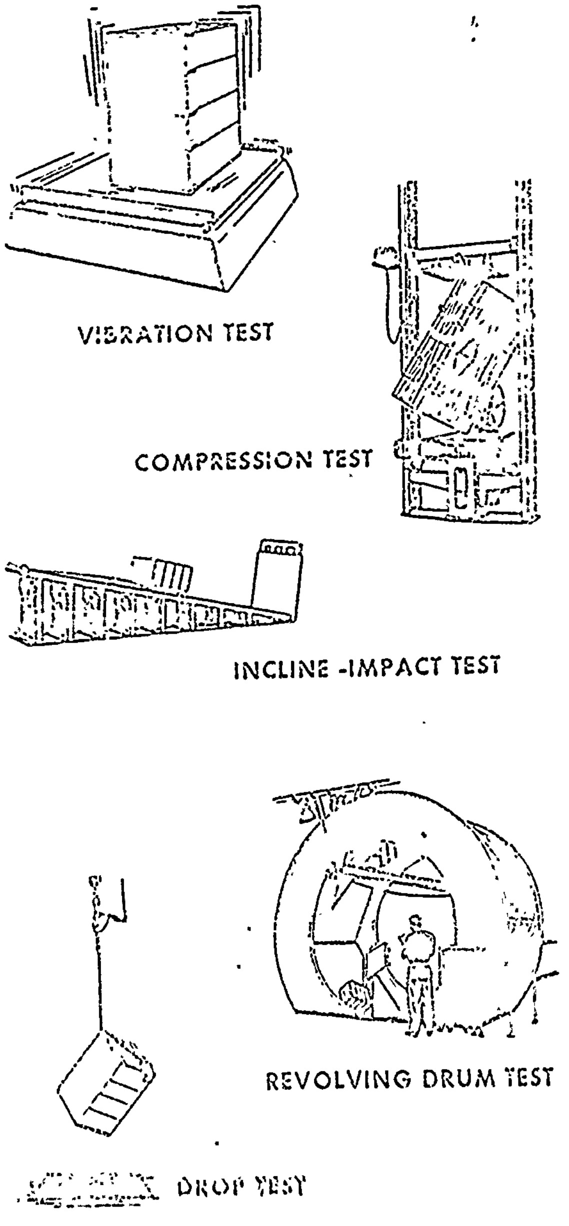

Figure 1-4. Examples of container tests.

From: Preservation, Packaging, and Packing of Military Supplies and Equipment - Packing. DSAM 4145.2, Vol. II, TM38-230-2, NAVAIR 15-01-2, AFP71-4 and MCOP 4030.21A.

generally used for test guidance are MIL-P-116, MIL-STD-1186, and FED-STD-101.

c. Testing of Packages (Unit and Intermediate Containers) (MIL-P-116). After an item has been packaged in accordance with one of the MIL-P-116 methods, tests are conducted to determine the effectiveness of the method. The types of tests conducted will depend on the particular method used and are also specified in MIL-P-116. The tests called for in MIL-P-116 are not all-inclusive, however, and additional or different tests are sometimes required. The types of tests specified in MIL-P-116 for proving the adequacy of unit protection are the quick-leak test, vacuum-retention test, rough handling test, cyclic exposure test, and the heat-seal test. See volume I for details.

d. Testing of Packs (Exterior Containers) (MIL-STD-1186). In addition to the tests of unit protection mentioned above, containers may be exposed to laboratory simulated environmental extremes. When packs prepared for shipment in accordance with the detailed requirements of MIL-STD-1186 are tested for any rough handling required by the specification, contract, or order, there should be no settlement or shifting of contents. Further, the testing should cause no damage to the contents and should not loosen, break, or displace the anchoring, blocking, or bracing. The testing should not render the interior containers, wraps, liners, barriers, or cushioning ineffectual in providing continued and adequate protection to the contents.

e. Types of Rough Handling Tests. The various types of rough handling tests include: Free-fall drop test; cornerwise drop test; pendulum-impact test; incline-impact test; edgewise drop test; vibration tests; and others. The particular tests employed usually depend upon the size and shape of the package. Completed packages as prepared for shipment are given a rough handling test when specified in a contract or order. When a rough handling test is required, it precedes applicable tests [illegible] to detect leaks and inadequate seals, or closures and preservative retention. Inspection and tests for leaks in barrier materials, seals and closures, and preservative retention, when required, are performed on the contained unit package(s), following the rough handling test, to determine existence or extent of detrimental effects. Unless a particular test is specified by the procuring agency, selection of the applicable rough handling test should be in accordance with (1) or (2), below, as applicable.

(1) *Packs not exceeding 200 pounds.* Packs not exceeding 200 pounds and with no dimension greater than 60 inches should be tested by the free-fall method, paragraph 1-24e(3), below, except that items having a net weight exceeding 100 pounds and which are secured to the base of the container, should be tested as indicated for packs exceeding 200 pounds.

(2) *Packs exceeding 200 pounds.* Packs exceeding 200 pounds or having any dimension greater than 60 inches should be tested first by the cornerwise-drop test, paragraph 1-24e(6), below, followed by either the pendulum-impact test, paragraph 1-24e-(7)(*a*), below, or the incline-impact test, paragraph 1-24e(7)(*b*), below. If the cornerwise-drop test is impractical because of the container size or shape, the edgewise-drop test, paragraph 1-24e(5), below, may be substituted.

(3) *Free-fall drop test* (fig. 1-41). The pack shall be tested in accordance with test method 216 of FED-STD-101.

(*a*) A drop tester is any suitable apparatus which will allow an absolutely free, unobstructed fall of the container at the orientation and the direction required. A lifting device that will not damage the container will be used and a level steel or cement surface to absorb all shock without displacement will be provided.

(*b*) The height from which the specimen should be dropped is dependent upon the weight, size, kind of container, and level of pack.

(*c*) This test is meant to simulate the fall of an item dropped by a man from a height he would normally use to lift and carry an item of that size.

(*d*) The container should be dropped cornerwise from a height of 30 inches onto a steel, concrete, or stone surface of sufficient mass to absorb the shock without deflection in such a manner that the corner of the container absorbs the full force of the fall (fig. 1-41). This test should be repeated until each of the eight corners of the container has received a fall. (The height of 30 inches refers to the distance from the steel, concrete, or stone surface to the nearest corner of the container when suspended prior to the fall.) The fall shall be a free-fall, in that no ropes or other suspending media are attached to the container during the fall. If the container is of the drum type, the top and bottom of the drum should be marked so that the circle of the top and bottom is quartered, and the test should be applied to each quartered section.

(4) *Revolving drum test* (fig. 1-40).

(*a*) The apparatus used for this test consists of either a 7- or 14-foot revolving drum hexagonally shaped.

(*b*) The revolving drum test is particularly useful for determining weaknesses and for comparing performance under rough handling of packages, containers, etc. It may be used as a comparison of containers and alternate containers or for comparing banded or nonbanded containers.

(5) *Edge-wise drop test* (fig. 1-42). The pack should be tested in accordance with test method 213 of FED-STD-101. The loaded container should be supported at one end of its base on a sill or block 5 inches in height and at right angles to the skids. The opposite end of the container should be allowed to fall freely from the specified height indicated for the weight in table 1-XI onto a steel, concrete, or stone surface of sufficient mass to absorb the shock without deflection (fig. 1-42). The test should be applied twice to opposite ends of the container. If the size of the container and the location of the center of gravity are such that the drop tests cannot be made from the prescribed height, the greatest attainable height should be the height of the drops.

(6) *Cornerwise-drop test* (fig. 1-43). The pack should be tested in accordance with test method 214 of FED-STD-101. The container should be supported at one corner of its base on a block 5 inches in height. A 12-inch block should be placed under the other corner of the same end of the container. The lowest point of the opposite end of the container should then be raised to a height indicated for the weight in table 1-XI and allowed to fall freely onto a steel, stone, or concrete surface of sufficient mass to absorb the shock without deflection.

(7) *Guided-impact test.* Packs having a gross weight exceeding 200 pounds or any dimension exceeding 60 inches, closed for shipment, should be subjected to one of the following guided-impact tests. A single impact should be applied to each side and end having a dimension less than 9.5 feet. The tests are intended to evaluate the ability of a packed item to withstand humping during rail shipment. The tests are not to be used for the purpose of evaluating the adequacy of the blocking, bracing, and tiedowns used to secure a load on or in a rail car.

From: Preservation, Packaging, and Packing of Military Supplies and Equipment - Packing. DSAM 4145.2, Vol. II, TM38-320-2, NAVAIR 15-01-2, AFP71-4 and MCOP 4030.21A.

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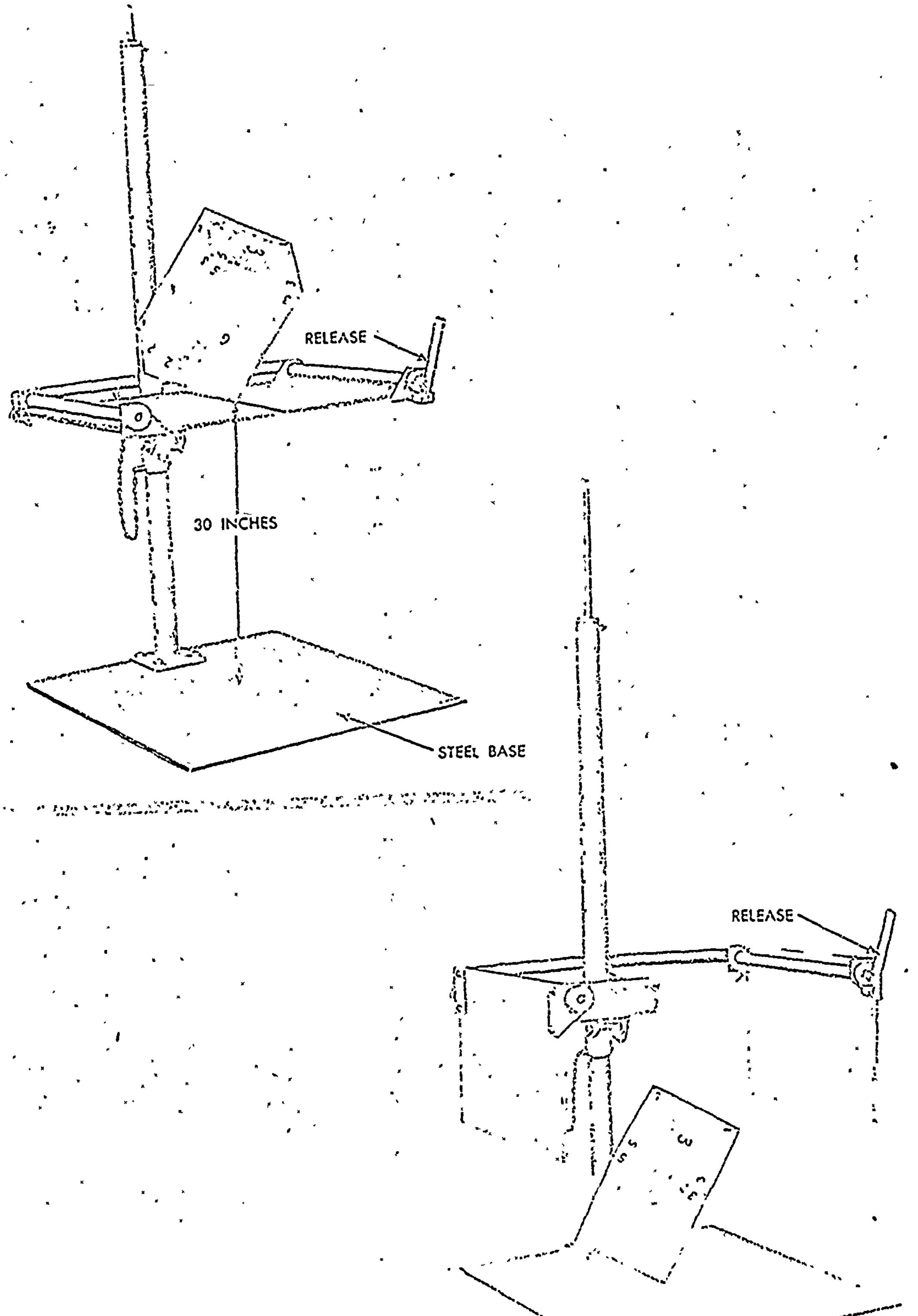

Figure [illegible]. Free fall drop tests

From: Preservation, Packaging, and Packing of Military Supplies and Equipment - Packing. DSAM 4145.2, Vol. II, TM38-320-2, NAVAIR 15-01-2, AFP71-4 and MCOP 4030.21A.

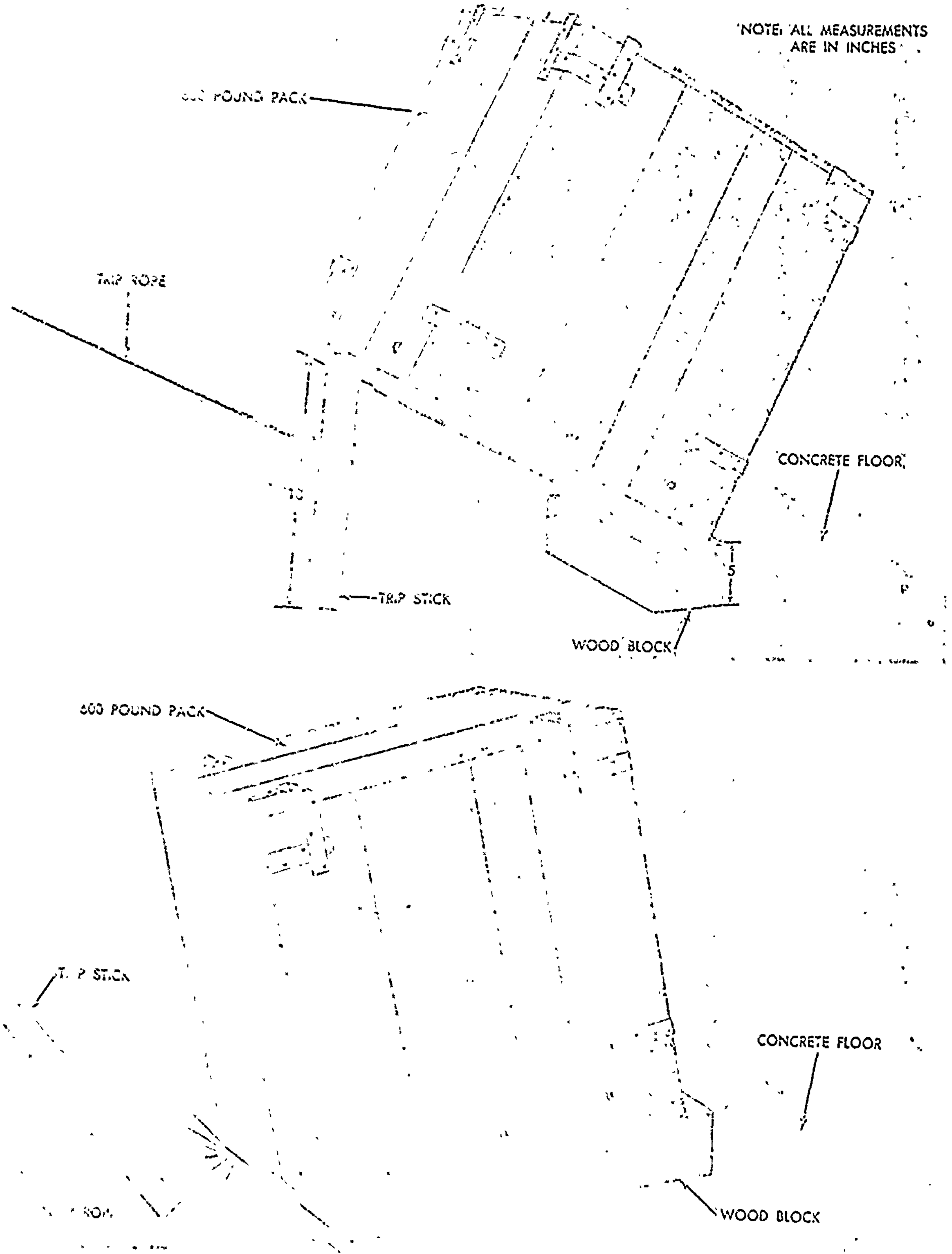

Figure [illegible]. Edgewise drop test.

From: Preservation, Packaging, and Packing of Military Supplies and Equipment - Packing. DSAM 4145.2, Vol. II, TM38-320-2, NAVAIR 15-01-2, AFP71-4 and MCOP 4030.21A.

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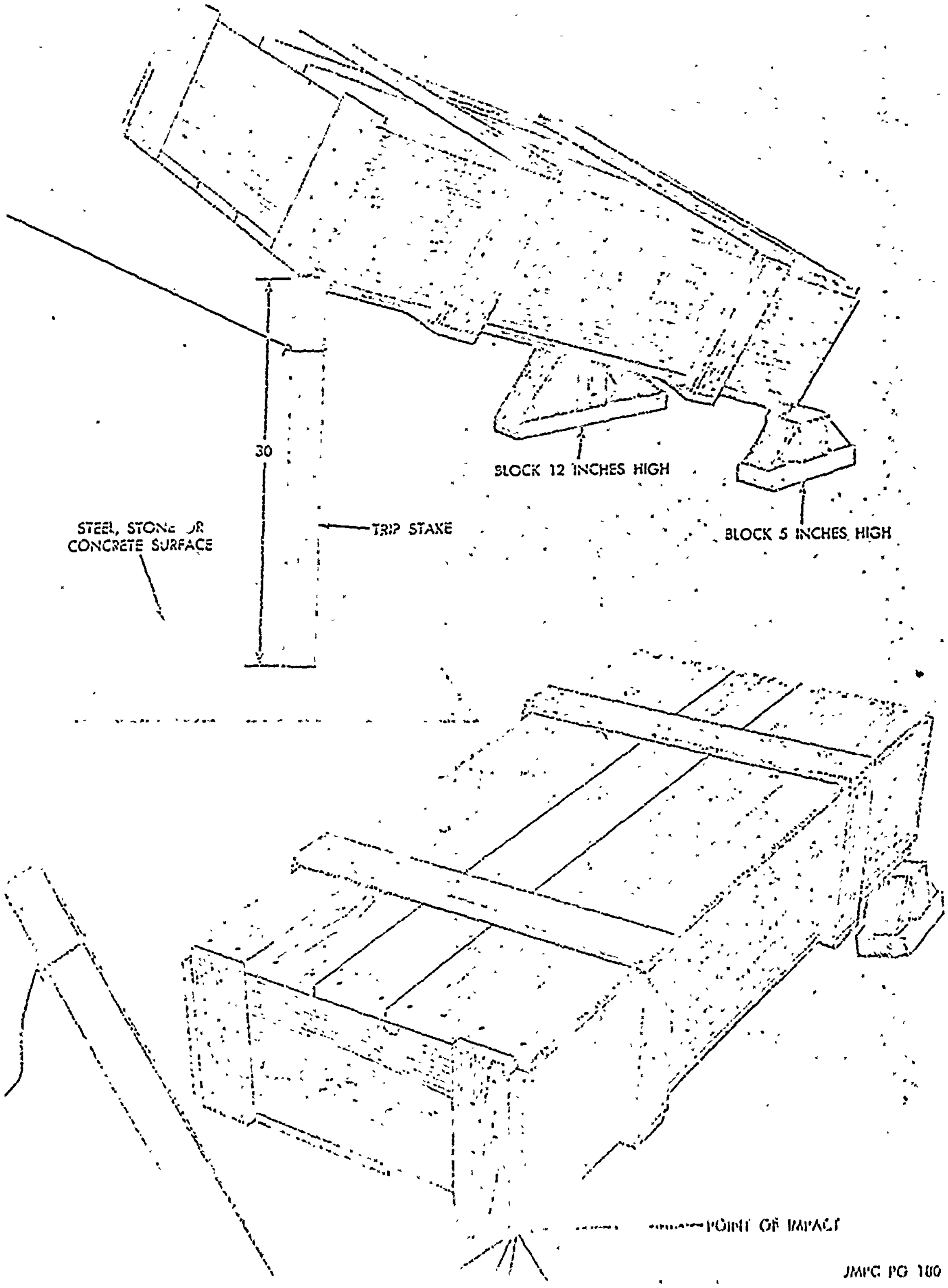

Figure 14-8. Cornerwise drop test.

From: Preservation, Packaging, and Packing of Military Supplies and Equipment - Packing. DSAM 4145.2, Vol. II, TM38-230-2, NAVAIR 15-01-2, AFM71-4 and MCOP 4030.21A.

(a) *Pendulum-impact test* (fig. 1–44). The pack should be tested in accordance with test method 212 of FED–STD–101. The container should be swung as a pendulum against a nominal 8 x 8 inch or larger timber resting horizontally on the floor and securely blocked and fastened to prevent any movement. The container should be suspended by ropes, chains, or cables so that its center of gravity will swing through an arc of 16-foot radius. When suspended, the base should be parallel to the floor, and it should clear the floor by 1 to 3 inches. The longitudinal axis of the container should be perpendicular to the length of the timber, and the end should rest lightly against it. The container should be pulled back from the timber until the center of gravity is raised by an amount indicated for the weight in table 1–XI, then released and allowed to swing freely against the timber. The opposite end also should be subjected to one impact.

(b) *Incline-impact test* (fig. 1–40). The pack should be tested in accordance with test method 211 of FED–STD–101.

1. This test simulates the abuses encountered by packages in freight cars or trucks when the vehicles are subjected to sudden starts and stops.

2. The pack, mounted on a movable platform dolly which rides on a plane inclined 10 degrees from the horizontal, is released from a known distance up the incline and permitted to strike against a fixed backstop at the bottom of the plane. The magnitude of impact shock is varied by using different release points.

(8) *Compression test* (fig. 1–40). This test is performed in accordance with ASTM D642–47 (Compression Test for Shipping Containers). The test provides for two procedures—Procedure A for measuring the ability of a container to resist external compressive loads applied to its faces, and Procedure B for measuring the ability of the container to resist external compressive loads applied to diagonally opposite edges or corners. These procedures are usually accomplished on containers without contents. They are suitable for testing boxes, crates, barrels, drums, kegs, and pails made of metal, wood, fiberboard, and combinations of these materials.

(9) *Vibration test* (fig. 1–40). The pack should be vibration tested in accordance with ASTM Designation D 999, Vibration Test for Shipping Containers, Procedure A or B, as specified. The duration of the vibration test should be as specified.

(*a*) The standard packaging laboratory vibration machine consists of a wooden table supported on two cross shafts, one near each end of the table. Each of the shafts carries two eccentrics which have a total amplitude of 1 inch. The speed or number of cycles per minute and the type of motion may be varied.

(*b*) Vibration frequently produces deterioration or partial crushing of the unit or interior packing which reduces resistance to other shocks, such as impact from dropping, jolting, or bumping. This test can disclose weakness in assembly of the packed item.

(*c*) Vibration tests simulate the forces and motions typical of railroad cars, motor trucks, air transportation, etc.

(10) *Simulated contents.* At the discretion of the procuring agency, simulated contents of the same dimensions, weight, and physical properties as the actual contents may be substituted in the tests described above. A shock-re-

From: Preservation, Packaging, and Packing of Military Supplies and Equipment - Packing. DSAM 4145.2, Vol. II, TM38-320-2, NAVAIR 15-01-2, AFP71-4 and MCOP 4030.21A.

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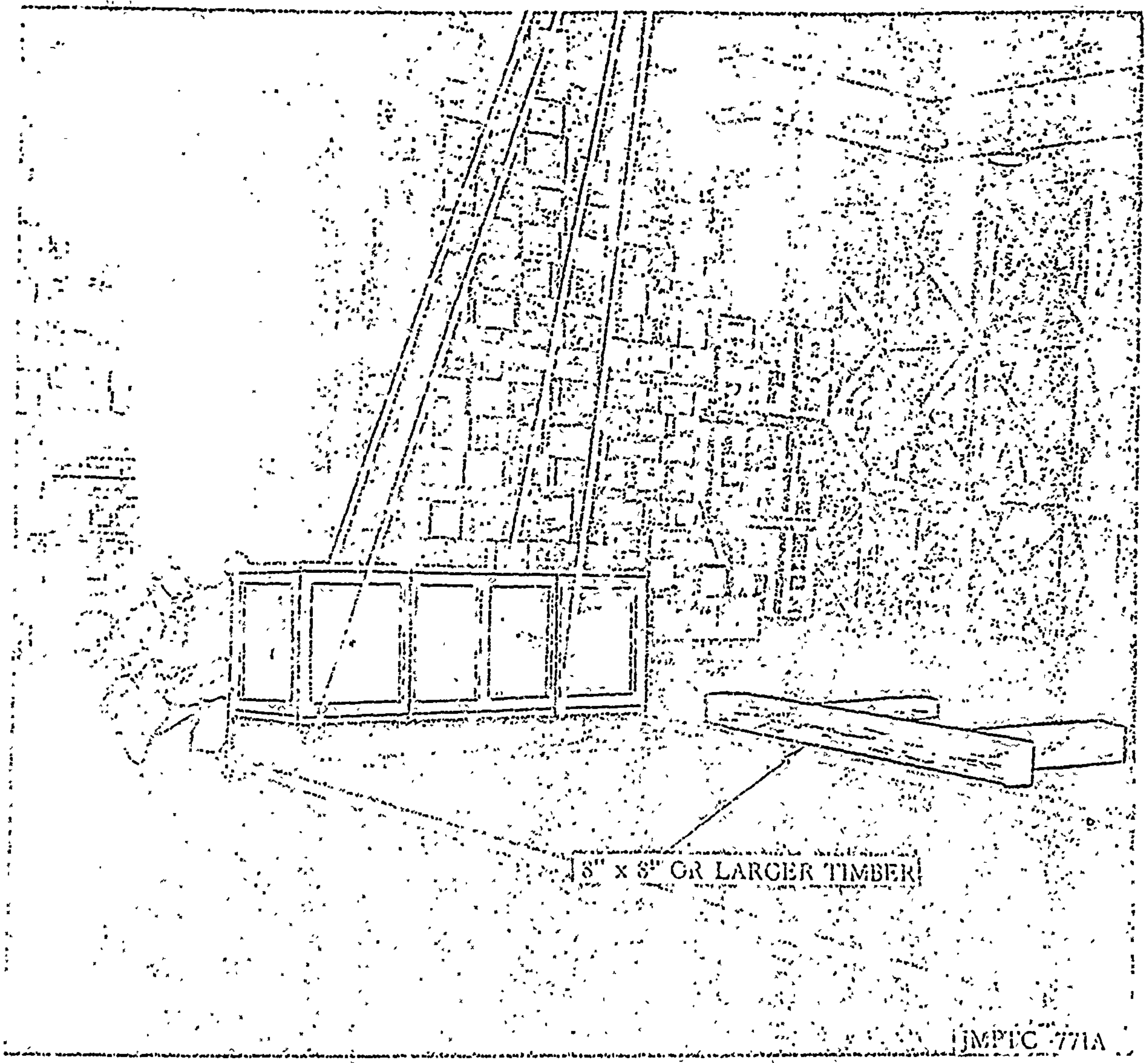

Figure 1-44. Pendulum-impact test.

cording instrument of an acceptable type should be appropriately installed within the shipping containers. This provision is intended to avoid unnecessary damage or complete destruction of valuable commodities and to avoid hazards to personnel conducting the tests.

(11) *Interpretation of results.* All materials and components comprising the method of preservation shall be free from damage or evidence of displacement which affects the utility of the method of preservation. The material used in the method of preservation should show no visible signs of damage. When specified, functional tests should be conducted on the preserved items or equipment to determine freedom from operational malfunction.

From: Preservation, Packaging, and Packing of Military Supplies and Equipment - Packing. DSAM 4145.2, Vol. II, TM38-320-2, NAVAIR 15-01-2, AFP71-4 and MCOP 4030.21A.

Table 1-XI. Graduated Drop and Impact Test Heights

Gross weight of container and contents	Edgewise-drop test (2 drops each end)	Cornerwise-drop test (2 drops on each of 2 diagonally opposite corners of bottom)	Impact test (1 impact on each of 2 opposite ends) use either test	
Pounds	Height of drop (inches)	Height of drop (inches)	Pendulum drop (inches	Incline impact (feet)
Through 250	30	30	14	7.0
Over 250 through 500	24	24	11	5.5
Over 500 through 1,000	18	18	8	4.0
Over 1,000	12	12	5	2.5

From: Preservation, Packaging, and Packing of Military Supplies and Equipment - Packing. DSAM 4145.2, Vol. II, TM38-320-2, NAVAIR 15-01-2, AFP71-4 and MCOP 4030.21A.

The Source for pages C-10 through C-45 : Military Standard Environmental Test Methods. MIL-STD-810B, 20 October, 1969.

METHOD 513.1

ACCELERATION

1. Purpose. - The acceleration test is performed to determine if equipment is constructed to withstand expected steady state stresses and to insure that performance degradations or malfunctions will not be produced by the simulated service acceleration environment other than gravity. Procedure I is the structural test and Procedure II is the operational test.

2. Apparatus. - Either of two facilities may be utilized for acceleration tests: a centrifuge, or a track and rocket sled facility. A centrifuge of adequate size is recommended for all structural and most operational tests because of the convenience and ease of control. However, the performance of space oriented equipment, such as gyros, space control platforms, etc., are difficult to test on a centrifuge, even when a counter-rotating fixture is employed. A rocket sled run is advantageous where strictly linear acceleration is required.

3. Procedures. - The test item shall be subjected to both the structural and the operational test, unless otherwise specified.

3.1 Mounting of test item. - Direction of forward acceleration is always considered to be the direction of the vehicle acceleration and equipment shall be oriented accordingly,using its normal mounting means. For centrifuges,the location of the test item (with reference to the G level established for the test) shall normally be determined by a measurement from the rotational center of the centrifuge to the geometric center of the test item. Should any point of the test item nearest the center of the centrifuge experience less than 90 percent of the specified G level, the test item shall be moved outward on a radius of the centrifuge or the speed of rotation shall be increased until not less than 90 percent of the specified G level is obtained. Caution: If the furthest end of the test item experiences more than 110 percent of the desired G level at the geometric center (while the nearest end experiences 90 percent or under), then the test item may be tested using a lower speed and a larger radius centrifuge arm. For large test specimens exceptions should be made to allow for maximum gradient based on the existing availability of large centrifuges in commercial or Government test facilities.

3.1.1 Test item orientation (centrifuge). - When a centrifuge is used to attain the required acceleration levels, the test item shall be oriented as follows:

Fore:	Front or forward end of test item shall face toward center of centrifuge.
Aft:	Reverse item 180 degrees from the "fore" position.
Up:	Top of specimen shall face toward center of centrifuge.
Down:	Reverse item 180 degrees from the "up" position.
Lateral:	Each side (right, left) in turn shall face toward center of centrifuge.

3.2 Test level determination. - The G level to be applied to the test item is contingent on two factors: The direction of forward acceleration level (A) of the vehicle, and the orientation of the test item within the vehicle.

Where: A = The highest possible known or unknown forward acceleration of a vehicle in which equipment is to be mounted. (A) shall never be less than one G level.

Instructions for selection of test levels for Procedure I from table 513.1-I, and for Procedure II from table 513.1-II are as follows:

Forward accel. of vehicle	Orientation of test item in vehicle	Test level
Known	Known	Substitute known acceleration A in forward acceleration column of appropriate vehicle category, and use given multiplying factors to attain test level for indicated directions.
Known	Unknown	Substitute known acceleration A in forward acceleration column of appropriate category, and use largest given multiplying factor to attain test level for all directions.
Unknown	Known	Select most probable level from those given in forward acceleration column of appropriate category, and use given multiplying factors to attain test level for required direction.
Unknown	Unknown	Select most probable level from those given in forward acceleration column of appropriate category, and use largest given multiplying factor to attain test level for all directions.

3.3 Procedure I. Structural test. - The test item shall be installed on the acceleration apparatus in accordance with section 3, General Requirements, paragraph 3.2.2, by its normal mounting means. The G level shall be determined in accordance with 3.2, and shall be applied while the test item is nonoperating.

3.3.1 Performance of test. - The G level determined for the test shall be applied along at least three mutually perpendicular axes in two opposite directions along each axis. The test time duration in each direction shall be at least 1 minute following centrifuge stabilization. On centrifuges, a test time of 1 minute is usually sufficient to determine structural soundness (proper operation); however, the test time may be increased. Test times for other apparatus will probably be shorter, depending upon the type of apparatus. At the conclusion of the test, the test item shall be operated and the results compared with the data obtained in accordance with section 3, General Requirements, paragraph 3.2.1. The test item shall then be inspected as specified in section 3, General Requirements, paragraph 3.2.4.

3.4 Procedure II. Operational test. - The test item shall be installed on the acceleration apparatus in accordance with section 3, General Requirements, paragraph 3.2.2, by its normal mounting means. The G level shall be determined in accordance with 3.2, and shall be applied while the test item is operating.

TABLE 513.1-I. G levels for structural test (Procedure I)

Vehicle category	Forward acceleration A 1/	Test level				
		Direction of vehicle acceleration (see figure 513.1-1)				
		Fore	Aft	Up	Down	Lateral (two directions)
Airplanes	2.0	1.5 x A	4.5 x A	6.75 x A	2.25 x A	3.0 x A
Helicopters	2.0	1.5 x A	1.5 x A	5.25 x A	2.25 x A	3.0 x A
Manned aerospace vehicles	6.0 to 12.0	1.5 x A	0.5 x A	2.25 x A	0.75 x A	1.0 x A
Air launched missiles	9.0 to 30.0	1.5 x A	0.5 x A	2.25 x A	0.75 x A	1.0 x A
Ground launched missiles	6.0 to 30.0	1.5 x A	0.5 x A	1.0 x A	1.0 x A	1.0 x A

1/ Levels in this column shall be used when forward acceleration is unknown. When the forward acceleration of the vehicle is known, that level shall be used for (A).

TABLE 513.1-II. G levels for operational test (Procedure II)

Vehicle category	Forward acceleration A 1/	Test level				
		Direction of vehicle acceleration (see figure 513.1-1)				
		Fore	Aft	Up	Down	Lateral (two directions)
Airplanes	2.0	1.0 x A	3.0 x A	4.5 x A	1.5 x A	2.0 x A
Helicoptors	2.0	1.0 x A	1.0 x A	3.5 x A	1.5 x A	2.0 x A
Manned aerospace vehicles	6.0 to 12.0	1.0 x A	0.33 x A	1.5 x A	0.5 x A	0.66 x A
Air launched missiles	9.0 to 30.0	1.0 x A	0.33 x A	1.5 x A	0.5 x A	0.66 x A
Ground launched missiles	6.0 to 30.0	1.0 x A	0.33 x A	0.66 x A	0.66 x A	0.66 x A

1/ Levels in this column shall be used when forward acceleration is unknown. When the forward acceleration of the vehicle is known, that level shall be used for (A).

3.4.1 Performance of test.- The G level determined for the test shall be applied along at least three mutually perpendicular axes in two opposite directions along each axis. The test time duration in each direction shall be at least 1 minute following centrifuge stabilization. A test time of 1 minute is usually sufficient to determine proper operation; however, the test time may be increased. This test time applies to centrifuge apparatus only. Other apparatus may require modification of the above test time duration. The test item shall be operated before, during and at the conclusion.. of each test, and the results compared with the data obtained in accordance with section 3, General Requirements, paragraph 3.2.1. The test item shall then be inspected as specified in section 3, General Requirements, paragraph 3.2.4.

4. Summary.- The following details shall be specified in the equipment specification or test plan.

- (a) Procedure number if both procedures are not required (see 3).
- (b) Pretest data required(section 3, General Requirements, paragraph 3.2.1).
- (c) Test level and test time (see 3.3 and 3.4).
- (d) Length of time required for operation and measurements.

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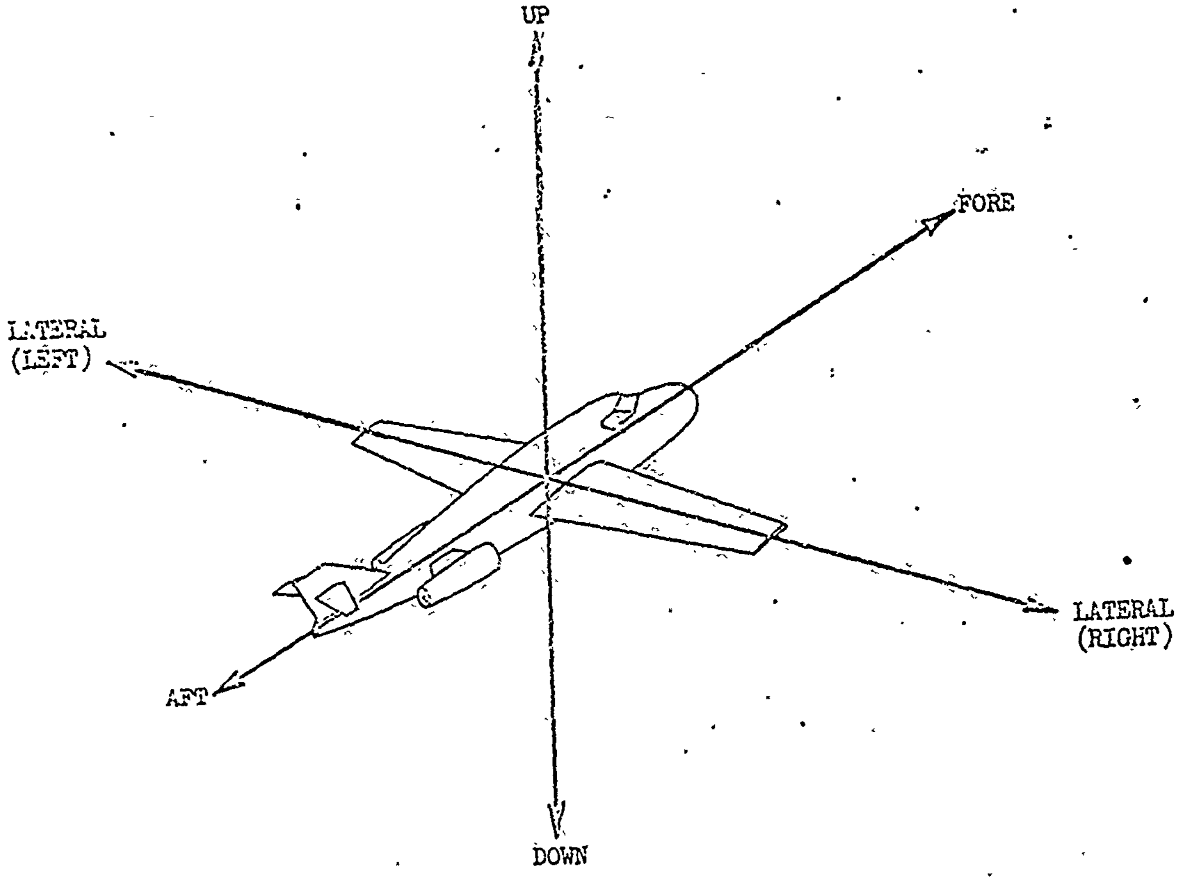

FIGURE 513.1-1. Direction of vehicle acceleration

METHOD 514.1

VIBRATION

1. Purpose. - The vibration test is performed to determine if equipment is constructed to withstand expected dynamic vibrational stresses and to insure that performance degradations or malfunctions will not be produced by the service vibration environment. Tests specified herein are established for equipment which may be used in a variety of military applications.

2. Apparatus. - Vibration equipment with required instrumentation.

3. General. - The vibration test charts, tables 514.1-I through 514.1-VII, provide a convenient means of summarizing test procedures to be specified in the equipment specification or test plan according to various military applications. Each table title refers to the applicable category of the equipment to be tested. The tables are divided into two major sections. Section A, "Test procedure and time schedule chart," specifies the tests to be imposed on the equipment and the test time schedule for each test. Section(s) B(C),"Curve selection chart," specifies the vibration test curves applicable to that particular equipment category and application. Guidance for selection of the vibration test for an item is as follows:

(a) Determine equipment category (or categories) in accordance with 3.1.

(b) Proceed to the applicable table corresponding to equipment category (a) through (h) or 4.17 for category (i) equipment. Select a procedure from the table based on the following equipment mounting configuration:

(1) Without vibration isolators

(2) With vibration isolators

(3) Tied down

(4) Loose

(c) For all procedures except IX, XI, and XIII, select the applicable test level curve(s) from tables 514.1-I through 514.1-VII in accordance with 3.3 based on:

(1) Listed selection criteria

(2) Detailed knowledge of the specific equipment environment

3.1 Equipment category. - For purposes of this test method, equipment is categorized according to the vehicle in which it will be installed or transported as follows:

CATEGORY

(a) Equipment installed in airplanes and helicopters (see table 514.1-I and figure 514.1-1)

(b) Equipment installed in airplanes, excluding helicopters (see table 514.1-II and figure 514.1-2)

(c) Equipment installed in helicopters (see table 514.1-III and figure 514.1-3)

(d) Equipment installed in air launched missiles (see table 514.1-IV and figure 514.1-4)

(e) Equipment installed in ground launched missiles (see table 514.1-V and figure 514.1-5)

(f) Equipment installed in ground vehicles (see table 514.1-VI and figure 514.1-6)

(g) Equipment transported by common carrier, land or air (see table 514.1-VII and figure 514.1-7)

(h) Ground equipment, excluding category f (for transportation test, see category g)

(i) Shipboard and amphibious equipment or when a ship is the common carrier (see 4.37)

3.2 Applicable tests. - For any given equipment category, all tests listed beside the selected procedure for the applicable equipment mounting configuration in tables 514.1-I through 514.1-VII shall be performed unless otherwise specified. For example, referring to table 514.1-IV section A, for testing equipment category (d) when Procedure III is selected, there are four parts with four different test levels indicated by the test curves. Tests indicated by "X" in all four parts shall be performed to evaluate equipment installed in an air launched missile for both the captive and flight phase.

3.3 Selection of test curves. - A curve shall be selected using tables 514.1-I through 514.1-VII or by making a detailed analysis of the expected vibration environment within the particular vehicle involved. A primary consideration is the equipment location with respect to predominant vibration sources such as high intensity noise of jet and rocket exhausts, aerodynamic excitation including atmospheric wind and turbulence, and unbalance of rotating parts. Additional factors to be considered shall include attenuation or amplification and filtering by structural members. Guidance for selecting vibration curves with respect to equipment location or application is given in section(s) B(C) of tables 514.1-I through 514.1-VII. Applicable test curves for each equipment category are shown on figures 514.1-1 through 514.1-7. In some instances, several curves are shown for one equipment category. When the equipment, due to its application, may be subjected to more than one level of particular type of vibration, the curve representing the most severe level shall be selected.

3.4 Examples of procedure selection. - The equipment specification or test plan shall identify which tests are to be imposed on the equipment by specifying the applicable procedure and test curve(s) when applicable. Tables 514.1-I through 514.1-VII and figures 514.1-1 through 514.1-7 are arranged to accommodate this identification.

3.4.1 Example No. 1. - Select the test conditions for equipment to be used in the following application.

Category: Equipment installed in airplane (jet engine at rear of fuselage)

Equipment location: Forward half of fuselage

Equipment mounting: On vibration isolated panel

Referring to table 514.1-II, the above identification specifies the following test conditions:

Procedure I

Part 1 (curve J)

Part 2 (curve AR)

Part 1 specifies a resonance search, resonance dwell and sinusoidal vibration cycling to the level of curve J from figure 514.1-2 within the time schedule specified for part 1 on table 514.1-II. Next, with vibration isolators removed in accordance with note 2, part 2 is performed the same as part 1 but to the test level of curve AR from figure 514.1-2 within the time schedule specified for part 2 from table 514.1-II.

3.4.2 Example No. 2. - Select the test conditions for equipment to be used in the following application:

Category: Equipment installed in air launched missile (missile thrust/weight ratio 15/1 and carried on airplane wing of jet airplane with wing mounted engines).

Equipment location: Equipment in missile booster section

Equipment mounting: Without vibration isolators (hard mounted)

Referring to table 514.1-IV, the above identification specifies the following test conditions:

Procedure II

Part 1 - Captive phase (curve H)

Part 2 - Flight phase (curve R)

Part 3 - Flight phase (curve AJ)

Part 1 specifies a resonance search, resonance dwell, and sinusoidal cycling to the level of curve H from figure 514.1-4 within the time schedule specified for part 1 of procedure II on table 514.1-IV. These tests are followed by part 2, a sinusoidal cycling test to the level of curve R from figure 514.1-4 within the time schedule specified for part 2 of procedure II on table 514.1-IV. Next, part 3, a random vibration test, shall be performed to the level of curve AJ from figure 514.1-4 within the time schedule specified for part 3 of procedure II on table 514.1-IV.

4. Test procedures. - The basis for selecting a test procedure (Procedure I through XII) for a particular equipment category shall be according to 3. A procedure consists of all tests indiated by an "X" under the "Applicable tests" column of tables 515.1-I through 514.1-VII to the right of the procedure number with the duration of the test as specified under the column entitled "Test time schedules (per axis)". The vibration environment, specified by the curve selected from tables 514.1-I through 514.1-VII in accordance with 3, shall be applied to each of the three mutually perpendicular axes of the test item. The entire sequence of tests may be accomplished for any one axis before changing to the next axis. The transverse motion at the input monitoring point(s) shall be minimized, and should be limited to 100 percent of the input motion except that reaction machines shall be balanced to reduce transverse motion +/-10 percent.

4.1 Test item operation. - Unless otherwise specified, the test item shall be operated during application of vibration (resonance search, resonance dwell, cycling, and random vibration) so that functional effects caused by these tests may be evaluated. When a test item performance test is required during vibration and the time required for the performance test is greater than the duration of the vibration test, the performance test shall be abbreviated accordingly. At the conclusion of the test, the test item shall be operated and the results shall be compared with the data obtained in accordance with section 3, General Requirements, paragraph 3.2.1. At the conclusion of each test, the test item then shall be inspected in accordance with section 3, General Requirements, paragraph 3.2.4.

4.2 Mounting techniques. - In accordance with section 3, General Requirements, paragraph 3.2.2, the test item shall be attached to the vibration exciter table by its normal mounting means or by means of a rigid fixture capable of transmitting the vibration conditions specified herein. Precautions shall be taken in the establishment of mechanical interfaces to minimize the introduction of undesirable responses in the test setup. Whenever possible, the test load shall be distributed uniformly on the vibration exciter table in order to minimize effects of unbalanced loads. Vibration amplitudes and frequencies shall be measured by techniques that will not significantly affect test item input control or response. The input control sensing device(s) shall be rigidly attached to the vibration table or to the intermediate structure, if used, at or as near as possible to the attachment point(s) of the test item.

4.3 Combined temperature-vibration test. - Tests shall be performed under room ambient conditions unless a high or low temperature vibration test is specified, in which case the temperature extremes and time duration also shall be specified.

4.4 Combined sinusoidal cycling and random vibration test. - The sinusoidal cycling and random vibration tests shall normally be performed separately. If analyses of actual or predicted data indicate a simultaneous sinusoidal and random vibration environment, the procedure for a combined test shall be specified.

4.5 Common test techniques. -

4.5.1 Sinusoidal vibration tests. - The vibration shall be applied along each of the three mutually perpendicular axes of the test item. The vibratory acceleration levels or double amplitudes of the specified test curve shall be maintained at the test item mounting points. When specified, for sinusoidal resonance search, resonance dwell, and cycling tests of items weighing more than 80 pounds mounted in airplanes, helicopters, and missiles, the vibratory accelerations shall be reduced +/-1 g for each 20 pound increment over 80 pounds. Acceleration derating shall apply only to the highest test level of the selected curve, but in no case shall the derated test level be less than 50 percent of the selected curve (see note 1 of applicable table 514.1-I through 514.1-V). For equipment weighing over 100 pounds and transported by aircraft, resonance search, resonance dwell, and cycling tests may be frequency and acceleration derated (see notes 1 and 2 of table 514.1-VII). When packaged items are always grouped together on mechanized loading platforms or pallets, acceleration and frequency derating may be based on the total load on the pallet. When the input vibration is measured at more than one control point, the control signal shall be the average of all the accelerometers unless otherwise specified. For massive test items, fixtures and large force exciters, it is recommended that the input control level be an average of at least three or more inputs.

4.5.1.1 Resonance search. - Resonant frequencies of the equipment shall be determined by varying the frequency of applied vibration slowly through the specified range at reduced test levels but with sufficient amplitude to excite the item. Sinusoidal resonance search may be preformed using the test level and cycling time specified for sinusoidal cycling test, provided the resonance search time is included in the required cycling test time of 4.5.1.3.

4.5.1.2 Resonance dwell. - The test item shall be vibrated along each axis at the most severe resonant frequencies determined in 4.5.1.1. Test levels, frequency ranges, and test times shall be in accordance with the applicable conditions from tables 514.1-I through 514.1-V and figures 514.1-1 through 514.1-7 for each equipment category. If more than four significant resonant frequencies are found for any one axis, the four

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most severe resonant frequencies shall be chosen for the dwell test. If a change in the resonant frequency occurs during the test, its time of occurrence shall be recorded and immediately the frequency shall be adjusted to maintain the peak resonance condition. The final resonant frequency shall be recorded.

4.5.1.3 Cycling. - The test item shall be vibrated along each axis in accordance with the applicable test levels, frequency range, and times from tables 514.1-I through 514.1-VII and figures 514.1-1 through 514.1-7. The frequency of applied vibration shall be swept over the specified range logarithmically in accordance with figure 514.1-10. The specified sweep time is that of an ascending plus a descending sweep and is twice the ascending sweep time shown on figure 514.1-10 for the specified range. Linear sweep rates may be substituted for the logarithmic sweep rate. When linear sweep rates are used, the total frequency range shall be divided into logarithmic frequency bands having similar time intervals such that each time interval is the time of ascending plus a descending sweep for the corresponding band. The sum of these time intervals shall equal the sweep time specified for the applicable frequency range. The linear sweep rate for each band is then determined by dividing each bandwidth in cps by one-half the sweep time in minutes for each band. The logarithmic frequency bands may be readily determined from figure 514.1-10. The frequency bands and linear sweep rates shown in table 514.1-IX shall be used for the 2 (or 5) to 500 cps and 5 to 2,000 cps frequency ranges. For test frequency ranges of 100 cps or less, no correction of the linear sweep rate is required.

4.5.2 Random vibration test. - The test item shall be subjected to random vibration along each of three mutually perpendicular axes according to one specified curve AE through AP from the applicable figure 514.1-4 or 514.1-5. Test times shall be according to the applicable schedule from tables 514.1-IV or 514.1-V. The instantaneous random vibration acceleration peaks may be limited to three times the rms acceleration level. The power spectral density of the test control signal shall not deviate from the specified requirements by more than +40, -30 percent (+/-1.5 dB) below 500 cps and +100, -50 percent (+/-3 dB) between 500 cps and 2,000 cps, except that deviations as large as +300, -75 percent (+/-6 dB) shall be allowed over a cumulative bandwidth of 100 cps, maximum, between 500 and 2,000 cps.

Tolerance levels in terms of dB are defined as:

$$dB = 10 \log_{10} \frac{W_1}{W_0}$$

Where W_1 = measured acceleration power spectral density in G^2/cps units. The term W_0 defines the specified level in G^2/cps units.

Confirmation of these tolerances shall be made by use of an analysis system providing statistical accuracies corresponding to a bandwidth-time constant product, BT = 50, minimum. Specific analyzer characteristics shall be as specified below or equivalent.

(a) On-line, contiguous filter, equalization/analysis system having a bandwidth = B = 50 cps, maximum.

(b) Swept frequency analysis systems characterized as follows:

1. Constant bandwidth analyzer.

   a. Filter bandwidth as follows:
      B = 20 cps, maximum between 20 to 200 cps
      B = 50 cps, maximum between 200 to 2,000 cps

   b. Analyzer averaging time = T = 2 RC = 1 second, minimum, where T = True averaging time and RC = analyzer time constant

   c. Analysis sweep rate (linear)=R= $\frac{B}{4RC}$ or $\frac{B^2}{8}$, (cps/second) maximum, whichever is smaller.

2. Constant percentage bandwidth analyzer.

   a. Filter bandwidth=pf_c=one-third octave maximum (.23 f_c) where p=percentage and f_c = analyzer center frequency.

   b. Analyzer averaging time=T= $\frac{50}{pf_c}$, minimum

   c. Analysis sweep rate (logarithmic)=R=$\frac{pf_c}{4RC}$ or $\frac{(pf_c)^2}{8}$ (cps/second), maximum, whichever is smaller.

(c) Digital power spectral density analysis system employing quantization techniques providing accuracies corresponding to the above approach.

The composite G-rms test level shall not be less than the value given on figure 514.1-4 or 514.1-5 for each test curve. Accelerometer(s) employed for test level control shall be mounted in accordance with 4.1. Where more than one accelerometer is employed for test level control, the power average of the several accelerometer signals shall be used as the test level signal control.

4.6 Procedure I. -

4.6.1 Part 1. - Proceed the same as in 4.5.1.1, 4.5.1.2, and 4.5.1.3. The test level shall be according to one specified curve C through H, J, L, M, Z, AS, or AT from figures 514.1-1, 514.1-2, or 514.1-3 as applicable for that equipment category. Test time schedules shall be as specified for part 1 of Procedure I in the applicable table.

4.6.2 Part 2. - Test items normally provided with vibration isolators shall be vibrated in accordance with 4.5.1.1, 4.5.1.2, and 4.5.1.3 with the vibration isolators removed but including any other required holding devices. The test level shall be according to one specified curve B or AR from figures 514.1-1, 514.1-2, or 514.1-3 as applicable for that equipment category. Test time schedules shall be as specified for part 2 of Procedure I in the applicable table.

4.7 Procedure II. -

4.7.1 Part 1. - Proceed the same as in 4.5.1.1, 4.5.1.2, and 4.5.1.3. The test level shall be according to one specified curve C, D, H, or J from figure 514.1-4. Test time schedules shall be as specified for part 1 of Procedure II as shown in table 514.1-IV.

4.7.2 Part 2. - Proceed the same as in 4.5.1.3. The test level shall be according to one specified curve P, Q, R, or S from figure 514.1-4. Test time schedules shall be as specified for part 2 of Procedure II as shown in table 514.1-IV.

4.7.3 Part 3. - Proceed the same as in 4.5.2. The test level shall be according to one specified curve AF through AK from figure 514.1-4. Test time schedules shall be as specified for part 3 of Procedure II as shown in table 514.1-IV.

4.8 Procedure III. -

4.8.1 Part 1. - Test items normally provided with vibration isolators shall be vibrated with the isolators in place as in 4.5.1.1, 4.5.1.2, and 4.5.1.3. The test level shall be according to one specified curve C, D, H, or J from figure 514.1-4. Test time schedules shall be as specified for part 1 of Procedure III as shown on figure 514.1-IV.

4.8.2 Part 2. - Test items normally provided with vibration isolators shall be vibrated in accordance with 4.5.1.1, 4.5.1.2, and 4.5.1.3 with the vibration isolators removed but including any other required holding devices. The test level shall be according to one specified curve B or AR from figure 514.1-4. Test time schedules shall be as specified for part 2 of Procedure III as shown in table 514.1-IV.

4.8.3 Part 3. - Next, vibration isolators shall be replaced and the test item vibrated again as in 4.5.1.3. The test level shall be in according to one specified curve P, Q, R, or S from figure 514.1-4. Test time schedules shall be as specified for part 3 of Procedure III as shown in table 514.1-IV.

4.8.4 Part 4. - With vibration isolators in place, proceed the same as in 4.5.2. The test level shall be according to one specified curve AF through AK from figure 514.1-4. Test time schedules shall be as specified for part 4 of Procedure III as shown in table 514.1-IV.

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4.9 Procedure IV. -

4.9.1 Part 1. - Proceed the same as in 4.5.1.1, 4.5.1.2, and 4.5.1.3. The test level shall be according to one specified curve B or AR from figure 514.1-4. Test time schedules shall be as specified for part 1 of Procedure IV as shown in table 514.1-IV.

4.9.2 Part 2. - Proceed the same as in 4.5.1.3. The test level shall be according to curve N from figure 514.1-4. Test time schedules shall be as specified for part 2 of Procedure IV as shown in table 514.1-IV.

4.9.3 Part 3. - Proceed the same as in 4.5.2. The test level shall be according to curve AE from figure 514.1-4. Test time schedules shall be as specified for part 3 of Procedure IV as shown in table 514.1-IV.

4.10 Procedure V. -

4.10.1 Part 1. - Proceed the same as in 4.5.1.3. The test level shall be according to one specified curve P through U from figure 514.1-5. Test time schedules shall be as specified for part 1 of Procedure V as shown in table 514.1-V.

4.10.2 Part 2. - Proceed the same as in 4.5.2. The test level shall be according to one specified curve AE through AP from figure 514.1-5. Test time schedules shall be as specified for part 2 of Procedure V as shown in table 514.1-V.

4.11 Procedure VI. -

4.11.1 Part 1. - Test items normally provided with vibration isolators shall be vibrated with the isolators in place as in 4.5.1.3. Test levels shall be according to one specified curve P through U from figure 514.1-5. Test time schedules shall be as specified for part 1 of Procedure VI as shown in table 514.1-V.

4.11.2 Part 2. - Test items normally provided with vibration isolators shall be vibrated in accordance with 4.5.1.3 with the vibration isolators removed but including any other required holding devices. Test levels shall be according to curve N from figure 514.1-5. Test time schedules shall be as specified for part 2 of Procedure VI as shown in table 514.1-V.

4.11.3 Part 3. - With vibration isolators in place, proceed the same as in 4.5.2. Test levels shall be according to one specified curve AE through AP from figure 514.1-5. Test time schedules shall be as specified for part 3 of Procedure VI a shown in table 514.1-V.

4.12 Procedure VII. -

4.12.1 Part 1. - Proceed the same as in 4.5.1.3. Test levels shall be according to curve N from figure 514.1-5. Test time schedules shall be as specified for part 1 of Procedure VII as shown in table 514.1-V.

4.12.1 Part 2. - Proceed the same as in 4.5.2. Test levels shall be according to curve AE from figure 514.1-5. Test time schedules shall be as specified for part 2 of Procedure VII as shown in table 514.1-V.

4.13 Procedure VIII. - Proceed the same as in 4.5.1.1, 4.5.1.2, and 4.5.1.3. Test levels shall be according to one specified curve V, W, or Y from figure 514.1-6. Test time schedules shall be as specified in Procedure VIII as shown in table 514.1-VI. Time schedule A shall be used for general tests when the vehicle (in which the equipment is to be mounted) or its mileage schedule is not known. Time schedule B is to be used for more realistic testing when the vehicle is known. When test item resonances below 5 cps are measured or expected the test curves shall be extended to 2 cps and the sweep time shall be 18 minutes (2-500-2 cps).

4.14 Procedure IX. -

4.14.1 Part 1. - Proceed the same as in 4.5.1.1. The test level shall be applied over a frequency range of 10 to 55 cps and at a vibratory displacement of not less than 0.030 inches, double amplitude. The vibratory frequency shall be changed in discrete steps of 1 cps and maintained at least 10 seconds at each frequency. Where possible, fixturing shall be such that resonances within the test item can be observed and measured. Subassemblies may be tested separately, provided they are secured to the vibration exciter in a manner similar to that used to mount them in the test item. Vibration isolators, if any, of the test item shall be blocked during the test. The test item shall have no resonances in the frequency range of 10 to 55 cps that exceed twice the amplitude of applied vibration. This criteria applies for equipment designed to operate with or without vibration isolators.

4.14.2 Part 2, bounce, vehicular. -

4.14.2.1 Apparatus. - A package tester capable of 1 inch (double amplitude) displacement and of suitable capacity for testing military equipment.

4.14.22 Test conditions. -

(a) Cover the test bed of the package tester with a panel of 1/2-inch plywood, with the grain parallel to the drive chain. Secure the plywood with sixpenny nails, with top of heads flush with, or slightly below the surface. Space nails at 6-inch intervals around all four edges. If the distance between either pair of fences is greater than 24 inches, the plywood shall also be nailed at 3-inch intervals in a 6-inch square at the center of the test area.

(b) Using suitable wooden fences, constrain the vehicular, or simulated, adapter plate to a horizontal motion of not more than 2 inches in any lateral direction.

4.14.2.3 Performance of test. -

Step 1 - Secure the test item to the vehicular, or simulated, adapter plate in accordance with section 3, General Requirements, paragraph 3.2.2, and place on the package tester with the constraints outlined in 4.14.2.2(b). If the test item weighs over 200 pounds, an approved simulated adapter plate shall be used.

Step 2 - Attach an accelerometer as close as possible to the point of test item attachment to record the shock transmitted to the test item.

Step 3 - Adjust the package tester, shafts in phase and table operating in a vertical linear mode, to a speed such that the average value of the random acceleration peaks shall be 7.5 +/-2.5 g's. Measure this input with an accurate measuring or recording system at the output of a band pass filter. The filter band pass shall be 0.2 to 100 cps and the attenuation slope shall be 12 to 18 dB per octave at the 3-dB down point. Due to the random nature of the input, pulses greater than 10 g's can be expected to occur, however, if they are infrequent, they need not be used in calculating the average. Perform the test for a total of 3 hours. At the end of each 3/4-hour period, rotate the adapter plate and test item 90 degrees each time in the same direction.

Step 4 - At the end of the 3-hour period, operate the test item and compare the results with the data obtained in accordance with section 3, General Requirements, paragraph 3.2.1. Then inspect the test item as specified in section 3, General Requirements, paragraph 3.2.4.

4.15 Procedure X. - Proceed the same as in 4.5.1.1, 4.5.1.2, and 4.5.1.3. The test level shall be according to specified curve(s) AV, AW, AX, AY, AA and AQ from figure 514.1-7 as applicable. Test time schedules shall be as specified for Procedure X as shown in table 514.1-VII. When test item resonances below 5 cps are measured or expected the test curves shall be extended to 2 cps.

4.16 Procedure XI. -

4.16.1 Part 1. - Proceed the same as in part 1 of Procedure IX.

4.16.2 Part 2, bounce, loose cargo. -

4.16.2.1 Purpose.- To determine that the equipment, as prepared for field use, shall be capable of withstanding the vibrations normally induced during transportation as loose cargo. Equipment in this class is normally transported in a shipping case, transit case, or combination case.

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4.16.2.2 Apparatus. - A package tester capable of 1 inch (double amplitude) displacement and of suitable capacity for testing military equipment.

4.16.2.3 Test conditions. - The test bed of the package tester shall be covered with a panel of 1/2-inch plywood, with the grain parallel to the drive chain. The plywood shall be secured with sixpenny nails, with top of heads flush with or slightly below the surface. Nails shall be spaced at 6-inch intervals around all four edges. If the distance between either pair of fences is greater than 24 inches, the plywood shall also be nailed at 3-inch intervals in a 6-inch square at the center of the test area. Using suitable wooden fences, constrain the test item to a horizontal motion of note more than 2 inches in a direction parallel to the axes of the shafts, a distance more than sufficient to insure the test item will not rebound from fence to fence.

4.16.2.4 Performance of test. - The test item, as secured in its shipping case, transit case, or combination case, or as otherwise prepared for field transportation, shall be placed on the package tester within the constraints outlined above. The package tester shall be operated in the synchronous mode with the shafts in phase. (In this mode any point on the bed of the package tester will move in a circular path in a vertical plane perpendicular to the axes of the shafts). The package tester shall be operated at 1-inch double amplitude and 284 rpm +/-2 rpm for a total of 3 hours. At the end of each 1/2-hour period, turn the test item to rest on a different face, so that at the end of the 3-hour period the test item will have rested on each of its six faces (top, bottom, sides, and ends). At the end of the 3-hour period, the test item shall be operated and the results compared with the data obtained in accordance with section 3, General Requirements, paragraph 3.2.1. The test item shall then be inspected as specified in section 3, General Requirements, paragraph 3.2.4. The package tester shall be operated in the vertical linear mode (straight up and down in the vertical plane) instead of in the synchronous mode when one of the following conditions occurs:

(a) Bouncing of the test item is very severe and presents a hazard to personnel.

(b) Forward and rear oscillations cannot be reduced. When operated in the vertical linear mode, wooden fences shall be placed on all four sides of the test item to constrain its motion to not more than 2 inches in either direction.

4.17 Procedure XII. - For shipboard and amphibious equipment or when a ship is the common carrier, the vibration test shall be in accordance with Type 1 of MIL-STD-167.

4.18 Procedure XIII. -

4.18.1 Part 1. - Proceed the same as in part 1 of Procedure IX.

4.18.2 Part 2, bounce, system shelter assemblage. -

4.18.2.1 Purpose. - To insure that the system shelter assemblage shall be capable of withstanding the vibrations normally induced during transportation. The system shelter assemblage may consist of equipment mounted in a truck or trailer, or equipment mounted in a shelter which is then mounted on a truck or trailer.

4.18.2.2 Performance of test. - The system shelter assemblage shall be driven five times over the sections of the Munson Test Course at the Aberdeen Proving Ground, Aberdeen, Maryland, or approved equal, in the following order and at the specified speeds. (See 4.1.)

Coarse washboard (6-inch waves spaced 72 inches apart)	5 mph
Belgian block	20 mph
Radial washboard (2-inch to 4-inch waves)	15 mph
Single corrugations (4-inch to 6-inch waves)	20 mph
Any short sections between the above sections	20 mph

5. Summary.- The following details shall be specified in the equipment specification or test plan:

(a) Procedure number (see 3).

(b) Pretest data required (section 3, General Requirements, paragraph 3.2.1).

(c) Curve selection (see 3.3).

(d) Acceleration or frequency derating of selected curve, if required (see 4.5.1).

(e) Nonoperation of equipment during test, if desired (see 4.1).

(f) Limitation of transverse motion (see 4).

(g) Temperature extremes and test time durations (see 4.3).

(h) Procedure for combining sinusoidal and random vibration, if applicable (see 4.4).

(i) Total vehicle mileage (see table 514.1-VI).

(j) Total land transportation mileage (see time schedule in table 514.1-VII).

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TABLE 514.1-I

A. Test procedure and time schedule chart for equipment installed in airplanes and helicopters – equipment category (a)

Equipment mounting configuration	Procedure number	Procedure part number	Applicable tests (see 4 for test procedures)			Test time schedule (per axis)				Curve (note 1)
								Sweep time		
			Resonance search (4.5.1.1)	Resonance dwell (4.5.1.2)	Sinusoidal cycling (4.5.1.3)	Dwell time at each resonance (4.5.1.2)	Sinusoidal cycling time (4.5.1.3)	5-500-5 cps	5-2000-5 cps	
Without vibration isolators	I	1	X	X	X	30 min	3-hrs-less dwell time	15 min	20 min	M,Z,AS,AT
With vibration isolators (note 2)	I	1	X	X	X	30 min	3-hrs-less dwell time	15 min	20 min	M,Z,AS,AT
		2	X	X	X	10 min	30 min	15 min	20 min	B,AR
Normally with vibration isolators but tested without isolators.	I	2	X	X	X	10 min	30 min	15 min	20 min.	B,AR

Note 1: For sinusoidal vibration resonance tests and cycling tests of items mounted in airplanes and helicopters and weighing more than 80 pounds, the vibratory accelerations shall be reduced by +/− 1 g for each 20-pound increment of weight over 80 pounds. However, the vibratory acceleration shall in no case be less than 50 percent of the specified curve level.

Note 2: Test items of equipment normally provided with vibration isolators first shall be tested with the isolators in place. (Part 1). The isolators then shall be removed, and the test item rigidly mounted and subjected to the test level indicated. (Part 2).

B. Curve selection chart for category (a) equipment

Selection criteria	Curve (for freq. to 500 cps)	Curve (for freq. to 2000 cps such as jet aircraft)
Equipment designed for both helicopter and airplane applications when the location in the airplane is in the forward half of fuselage or in wing areas of airplanes with engines at rear of fuselage.	M	AS
Equipment designed for both helicopter and airplane applications when the location in the airplane is in the rear half of the fuselage or in wing areas of airplanes with wing or front mounted engines or other equipment or engine locations not specifically mentioned for other curves.	Z	AT
Equipment installed on vibration isolated panels or racks when the panel or rack is not available for test or when the equipment is tested with isolators removed as specified by the applicable procedure.	B	AR

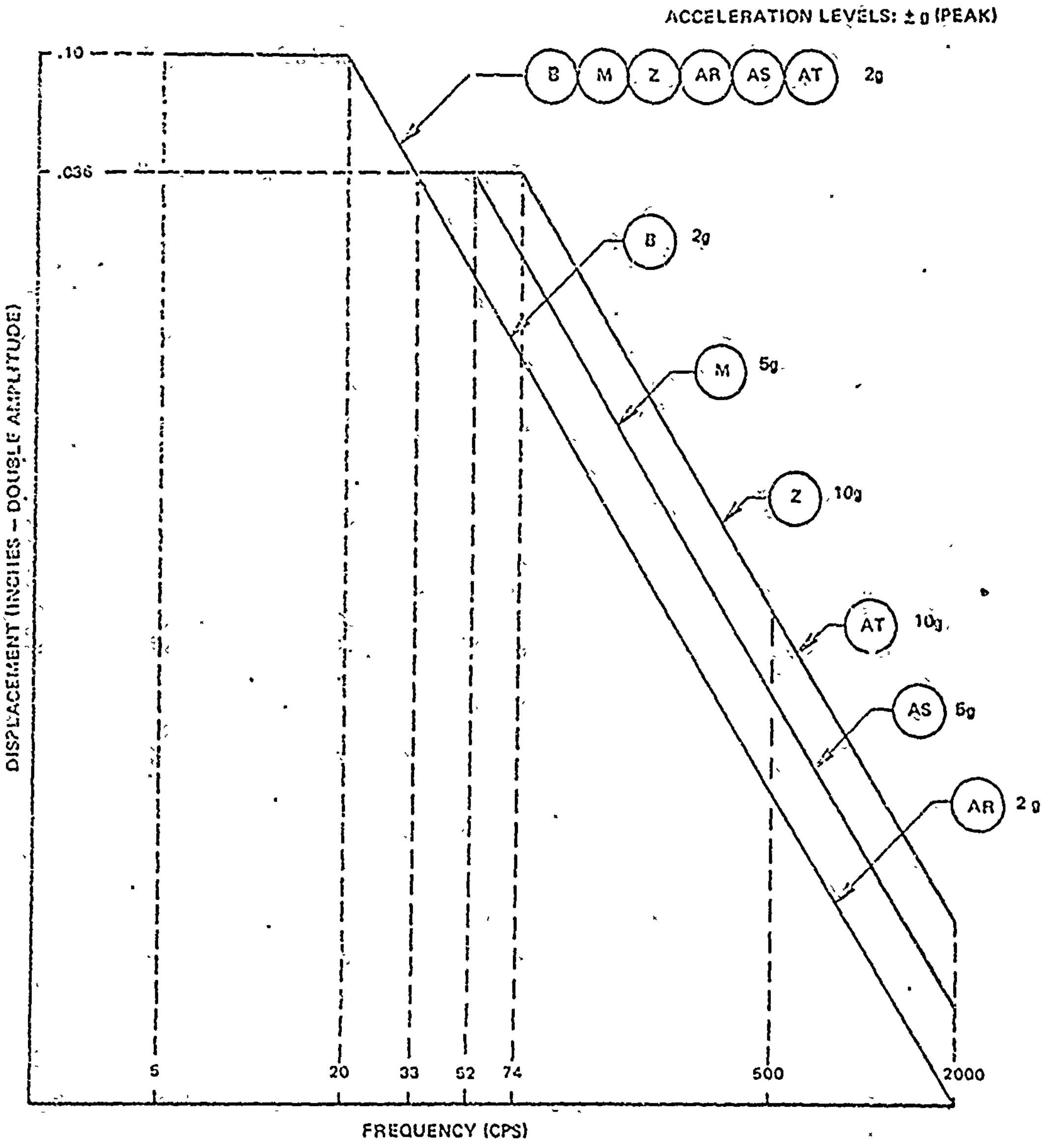

FIGURE 514.1–1. Vibration test curves for equipment installed in airplanes and helicopters – equipment category (a)

TABLE 514.1-II

A. Test procedure and time schedule chart for equipment installed in airplanes – equipment category (b).

Equipment mounting configuration	Procedure number	Procedure part number	Applicable tests (see 4 for test procedures)			Test time schedule (per axis)				Curve (note 1)
			Resonance search (4.5.1.1)	Resonance dwell (4.5.1.2)	Sinusoidal cycling (4.5.1.3)	Dwell time at each resonance (4.5.1.2)	Sinusoidal cycling time	Sweep time		
								5-500-5 cps	5-2000-5 cps	
Without vibration isolators	I	1	X	X	X	30 min	3 hrs-less dwell time	15 min	20 min	C,D,E,F, G,H,J,orL
With vibration isolators (note 2)	I	1	X	X	X	30 min	3 hrs-less dwell time	15 min	20min	C,D,E,F, G,J,H,orL
		2	X	X	X	10 min	30 min	15 min	20 min	B,AR
Normally with vibration isolators but tested without isolators	I	2	X	X	X	10 min	30 min	15 min	20 min	B,AR

Note 1: For sinusoidal vibration resonance tests and cycling tests of items mounted in airplanes and weighing more than 80 pounds, the vibratory accelerations shall be reduced by +/- .1 g for each 20-pound increment of weight over 80 pounds. However, the vibratory acceleration shall in no case be less than 50 percent of the specified curve level.

Note 2: Test items of equipment normally provided with vibration isolators first shall be tested with the isolators in place. (Part 1). The isolators then shall be removed, and test item rigidly mounted and subjected to the test level indicated. (Part 2).

B. Curve selection chart for category (b) equipment

Selection criteria	Curve (for freq. to 500 cps)	Curve (for freq. to 2000 cps such as jet aircraft)
Equipment installed on vibration isolated panels or racks when the panel or rack is not available for test or when the equipment is tested with isolators removed as specified by the applicable procedure.	B	AR
Equipment in forward half of fuselage or equipment in wing areas of airplanes with engines at rear of fuselage.	C	J
Equipment in rear half of fuselage or equipment in wing areas of airplanes with wing or front mounted engines or other equipment or engine locations not specifically mentioned for other curves	D	H
Equipment located in the engine compartments or pylons of airplanes	E	G
Equipment mounted directly on airplane engines	F	L

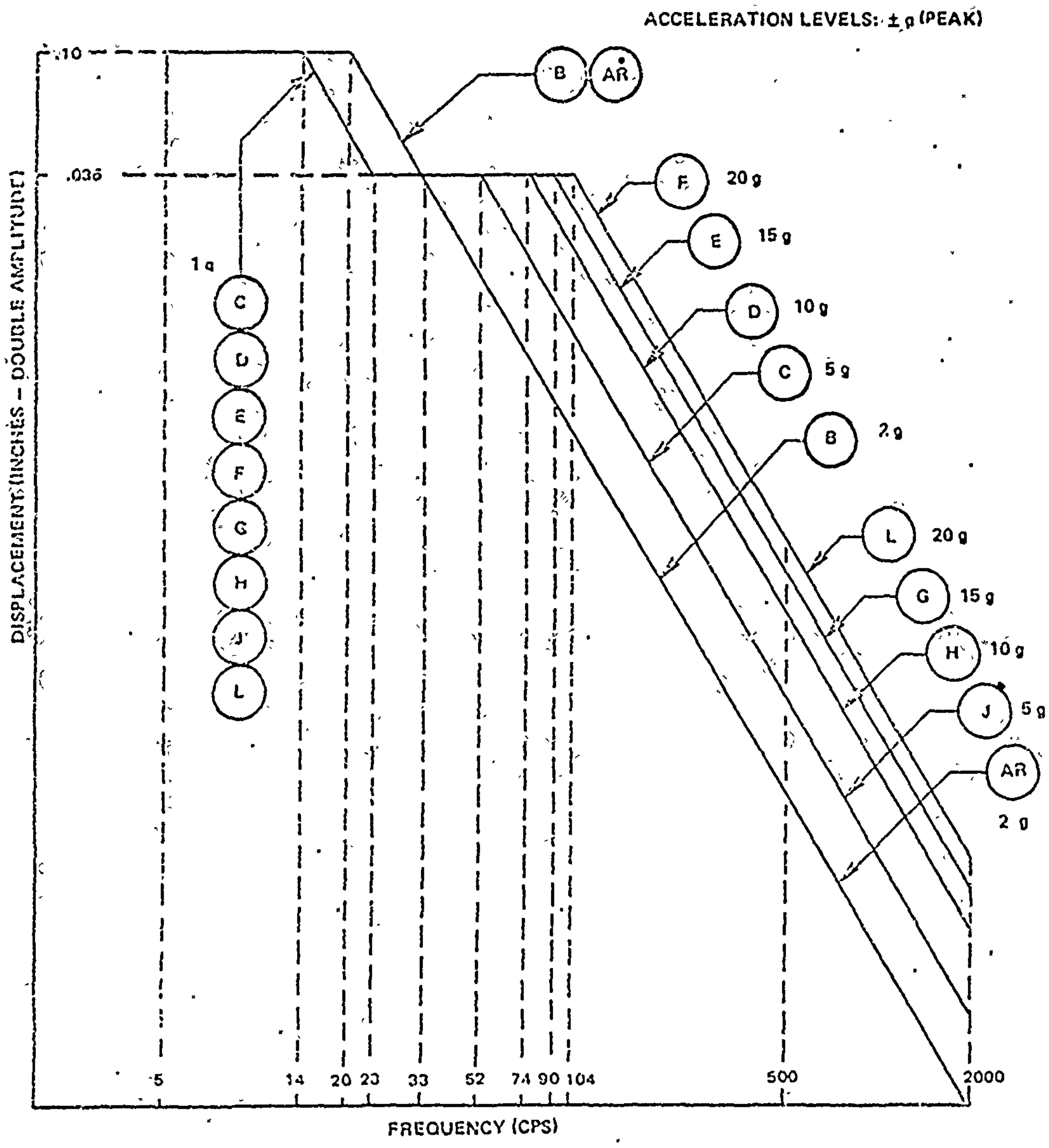

FIGURE 514.1–2. Vibration test curves for equipment installed in airplanes, excluding helicopters – equipment category (b)

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TABLE 514.1-III

A. Test procedure and time schedule chart for equipment installed in helicopters – equipment category (c)

Equipment mounting configuration	Procedure number	Procedure part number	Applicable Tests (see 4 for test procedures)			Test time schedule (per axis)			Curve (note 1)
			Resonance search (4.5.1.1)	Resonance dwell (4.5.1.2)	Sinusoidal cycling (4.5.1.3)	Dwell time at each resonance (4.5.1.2)	Sinusoidal cycling time (4.5.1.3)	Sweep time 5-500-5-cps	
Without vibration isolators	1	1	X	X	X	30 min	3 hrs-less dwell time	15 min	M
With vibration isolators (note 2)	1	1	X	X	X	30 min	3 hrs-less dwell time	15 min	M
		2	X	X	X	10 min	30 min	15 min	B
Normally with vibration isolators but tested without isolators	1	2	X	X	X	10 min	30 min	15 min	B

Note 1: For sinusoidal vibration resonance tests and cycling tests of items mounted in helicopters and weighing more than 80 pounds, the vibratory accelerations shall be reduced by +/- 1 g for each 20-pound increment of weight over 80 pounds. However, the vibratory acceleration shall in no case be less than 50 percent of the specified curve level.

Note 2: Test items of equipment normally provided with vibration isolators first shall be tested with the isolators in place. (Part 1). The isolators then shall be removed, and the test item rigidly mounted and subjected to the test level indicated. (Part 2)

B. Curve selection chart for category (c) equipment

Selection criteria	Curve
Equipment designed for helicopter applications only	M
Equipment installed on vibration isolated panels or racks when the panel or rack is not available for test or when the equipment is tested with the isolators removed as specified by the applicable procedure.	B

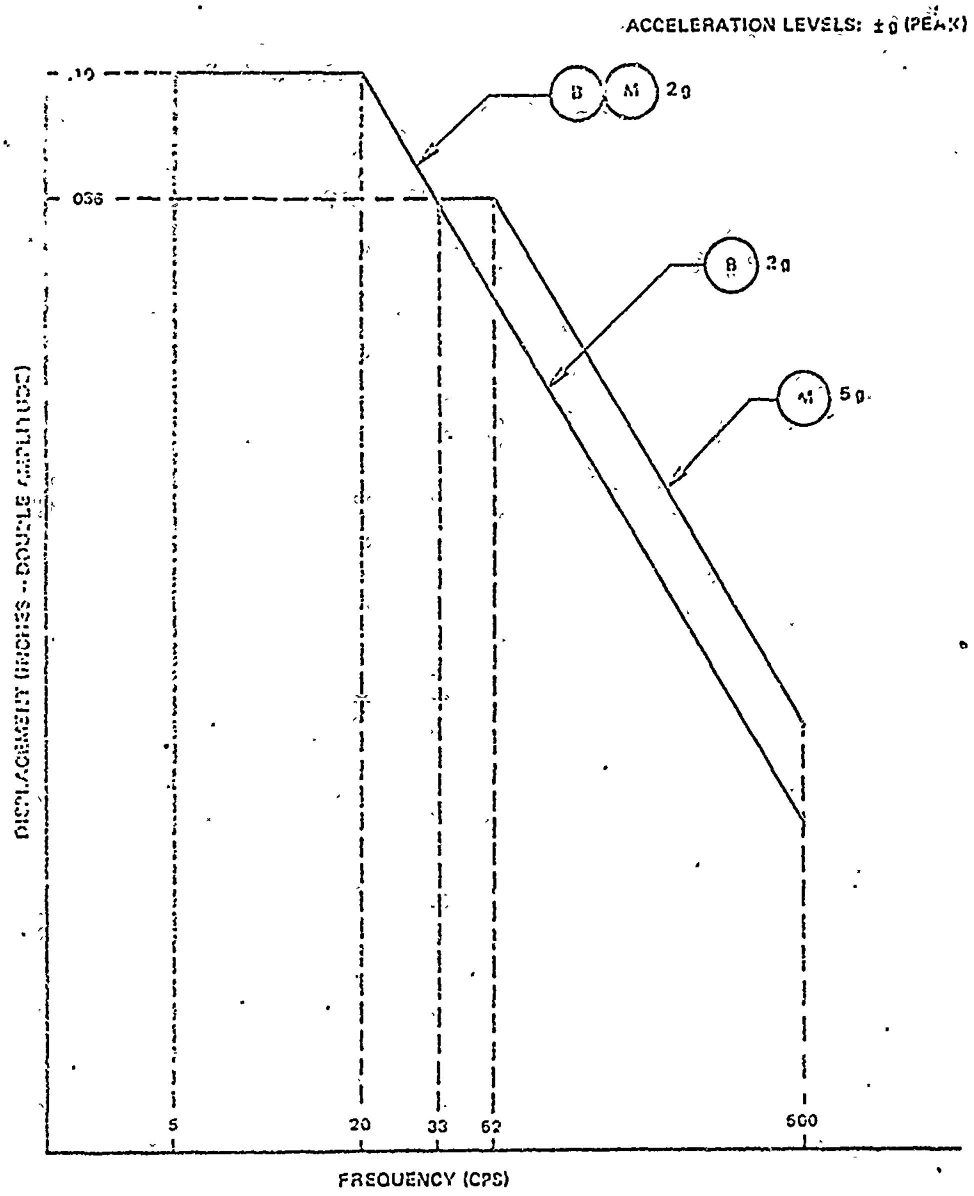

FIGURE 514.1–3. Vibration test curves for equipment installed in helicopters – equipment category (c)

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TABLE 514.1-IV

A. Test procedure and time schedule chart for equipment installed in air launched missiles – equipment category (d)

			Applicable tests (See 4 for test procedures)				Test time schedule (per axis)					
Equipment mounting configuration	Procedure number	Procedure part number	Resonance search (4.5.1.1)	Resonance dwell (4.5.1.2)	Sinusoidal cycling (4.5.1.3)	Random 4.5.2	Dwell time at each resonance (4.5.1.2)	Sinusoidal cycling time (4.5.1.3)	Sweep time 5-500-5 cps	Sweep time 5-2000-5 cps	Random time	Curve (note 1)
Without vibration isolators	II	1 (captive)	X	X	X		30 min	2 hrs-less dwell time	15 min	20 min		C,D,H,or J
		2(flight)			X			30 min	15 min	20 min		P,Q,R or S
		3(flight)				X					30 min	One of AF thru AK
With vibration isolators (note 2)	III	1 (captive)	X	X	X		30 min	2 hrs-less dwell time	15 min	20 min		C,D,H or J
		2 (captive)	X	X	X		10 min	30 min	15 min	20 min		B or AR
		3(flight)			X			30 min	15 min	20 min		P,Q,R or S
		4(flight)				X					30 min	One of AF thru AK
Normally with vibration isolators but tested without vibration isolators	IV	1 (captive	X	X	X		30 min	2 hrs-less dwell time	15 min	20 min		B or AR
		2(flight)			X			30 min	15 min	20 min		N
		3(flight)				X					30 min	AE

B. Curve selection chart for flight phase category (d) equipment

Equipment location by vehicle section	Approximate thrust to weight ratio or thrust in pounds	Vibration test curves	
		Sinusoidal	Random
Booster	20/1 or greater	S	AK
	5/1 thru 20/1	R	AJ
	5/1 or less	Q	AH
All except Booster	15/1 or greater	Q	AG
	Less than 15/1	P	AF

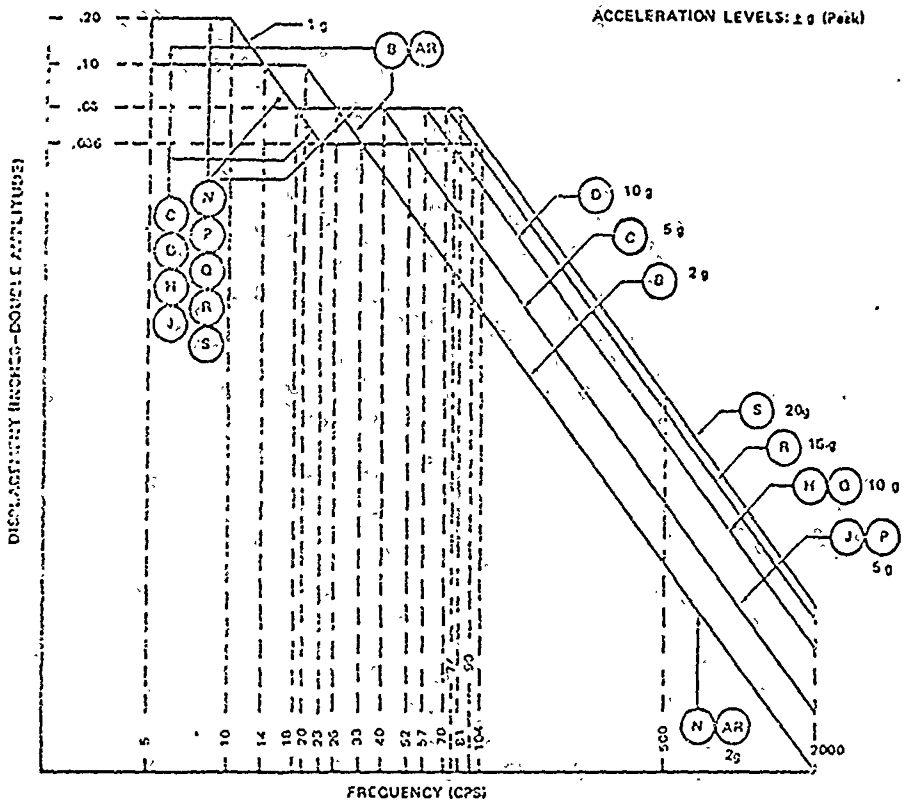
Note 1: For sinusoidal vibration resonance tests and cycling tests of items mounted in missiles and weighing more than 80 pounds, the vibratory acceleration shall be reduced by +/- 1 g for each 20-pound increment of weight over 80 pounds. However, the vibratory acceleration shall in no case be less than 50 percent of the specified curve level.

Note 2: Test items of equipment provided with vibration isolators first shall be tested with the isolators in place (Part 1). The isolators then shall be removed, and the test item rigidly mounted and subjected to the test level indicated. (Part 2). Isolators shall be replaced and the test item subjected to the test level indicated. (Parts 3 & 4)..

C. Curve selection chart for captive phase category (d) equipment

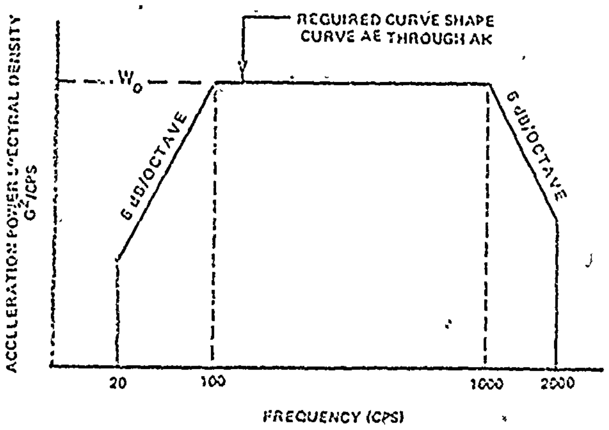
Selection criteria	Curve (for freq. to 500 cps)	Curve (for freq. to 2000 cps such as jet aircraft)
Equipment in missiles attached to wing of airplanes with engines in rear of fuselage	C	J
Equipment in missiles carried on airplane fuselage or attached to wing in airplanes with wing of front mounted engines	D	H
Equipment in missiles carried on airplanes or helicopters and installed on vibration isolated panels or racks when the panel or rack is not available for test or when the equipment is tested with isolators removed as specified by the applicable procedure	B	AR

SINUSOIDAL VIBRATION CURVES



RANDOM VIBRATION CURVES

RANDOM VIBRATION ENVELOPE



RANDOM VIBRATION TEST LEVELS

TEST CURVE	ACCELERATION POWER SPECTRAL DENSITY W_o (G2/CPS)	COMPOSITE G-RMS MINIMUM
AE	0.02	5.4
AF	0.04	7.6
AG	0.06	9.3
AH	0.10	12.0
AJ	0.20	16.9
AK	0.30	20.7

NOTE: COMPOSITE G-rms = $\left[\int_{f_1}^{f_2} W(f)df\right]^{1/2}$

WHERE f_1 AND f_2 ARE THE LOWER AND UPPER TEST FREQUENCY LIMITS, RESPECTIVELY. W(f) IS THE ACCELERATION POWER SPECTRAL DENSITY IN G²/CPS UNITS.

FIGURE 514.1–4. Vibration test curves for equipment installed in air launched missiles – equipment category (d)

TABLE 514.1-V

A. Test procedure and time schedule chart for equipment installed in ground launched missiles – equipment category (c)

Equipment mounting configuration	Procedure number	Procedure part number	Applicable tests (see 4 for test procedures)		Test time schedule (per axis)			Curve (note 1)
			Sinusoidal cycling (4.5.1.3)	Random (4.5.2)	Sinusoidal cycling time (4.5.1.3)	Sweep time 5-2000-5 cps	Random time	
Without vibration isolators	V	1	X		30 min	20 min		One of P thru U
		2		X			30 min	One of AE thru AP
With vibration isolators. (note 2)	VI	1	X		30 min	20 min		One of P thru U
		2	X		30 min	20 min		N
		3		X			30 min	One of AE thru AP
Normally with vib. isolators but tested without isolators.	VII	1	X		30 min	20 min		N
		2		X			30 min	AE

Note 1: For sinusoidal vibration resonance tests and cycling tests of items mounted in missiles and weighing more than 80 pounds, the vibratory accelerations shall be reduced by +/− 1 g for each 20-pound increment of weight over 80 pounds. However, the vibratory acceleration shall in no case be less than 50 percent of the specified curve level.

Note 2: Test items of equipment normally provided with vibration isolators first shall be tested with the isolators in place. (Part 1) The isolators then shall be removed, and the test item rigidly mounted and subjected to the test level indicated. (Part 2). Isolators shall be replaced and the test item subjected to the test level indicated. (Part 3).

B. Curve selection chart for category (c) equipment

Equipment location by vehicle section	Appromimate thrust to weight ratio or thrust in pounds	Vibration test curves	
		Sinusoidal	Random
All except booster	ALL	P or Q	AE, AF, or AG
By individual booster stage	250,000 lbs. or less	Q or R	AH, AJ, or AK
	250,000 lbs to 500,000 lbs	R or S	AK, AL, or AK
	Over 500,000 lbs	T or U	AM, AN, or AP

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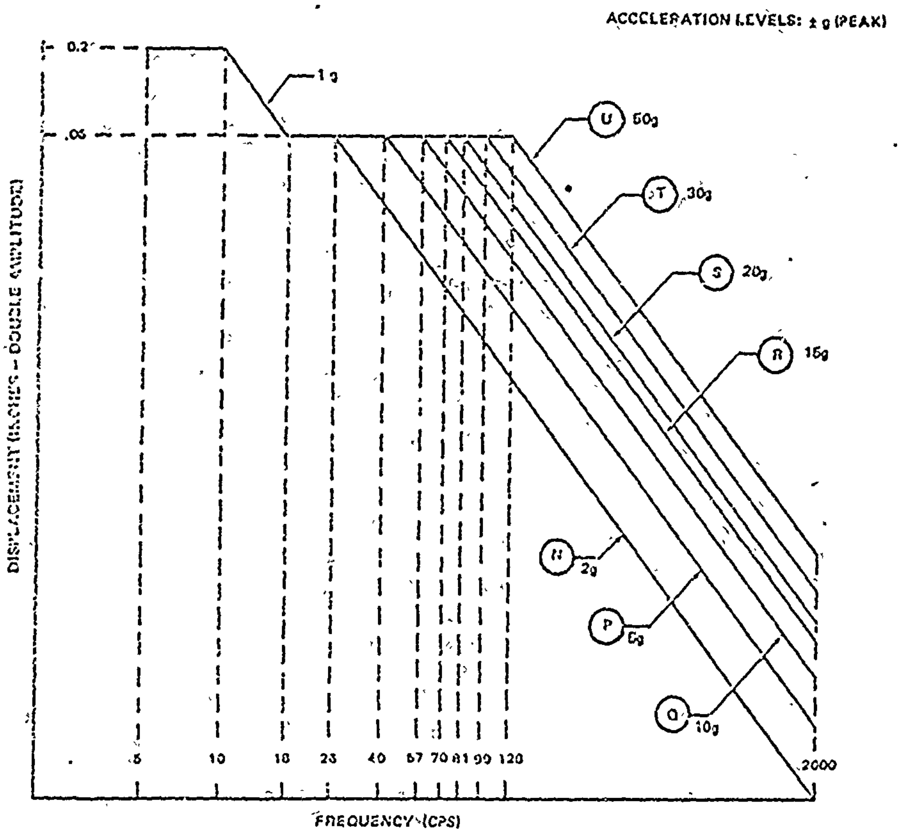
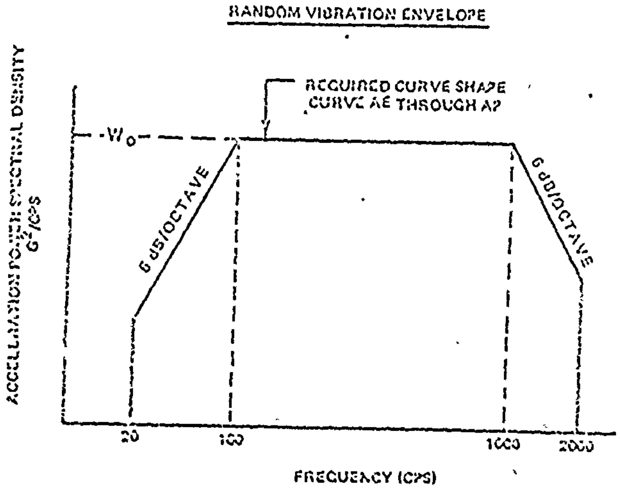
SINUSOIDAL VIBRATION CURVES



RANDOM VIBRATION CURVES



RANDOM VIBRATION TEST LEVELS

TEST CURVE	ACCELERATION POWER SPECTRAL DENSITY W_0 (G^2/CPS)	COMPOSITE G–RMS MINIMUM
AE	0.02	5.4
AF	0.04	7.6
AG	0.06	9.3
AH	0.10	12.0
AJ	0.20	16.9
AK	0.30	20.7
AL	0.40	23.9
AM	0.60	29.3
AN	1.00	37.9
AP	1.50	46.4

NOTE: COMPOSITE G–rms $= \left[\int_{f_1}^{f_2} W(f)df\right]^{1/2}$

WHERE f_1 AND f_2 ARE THE LOWER AND UPPER TEST FREQUENCY LIMITS, RESPECTIVELY. W(f) IS THE ACCELERATION POWER SPECTRAL DENSITY IN G²/CPS UNITS.

FIGURE 514.1–5. Vibration test curves for equipment installed in ground launched missiles – equipment category (c)

TABLE 514.1-VI

A. Test procedure and time schedule chart for equipment installed in ground vehicles – equipment category (f)

Equipment conditions	Procedure number	Procedure part number	Applicable tests (see 4 for test procedures)				Test time schedule (per axis)			Curve
			Resonance search (4.5.1.1)	Resonance dwell (4.5.1.2)	Sinusoidal cycling (4.5.1.3)	Bounce vehicular (4.14.2)	Dwell time at each resonance (4.5.1.2)	Sinusoidal cycling time (4.5.1.3)	Sweep time 5-500-5 cps	
							Schedule A			
Vehicle and mileage unknown	VIII		X	X	X		30 min	3 hrs less dwell time	15 min (note 1)	V,W,or Y.
							Schedule B			
Vehicle known	VIII		X	X	X		Dwell 1/6 of cycling time at each resonance (30 min max.)	20 min/1000 vehicle miles or as determined from vehicle mileage chart	15 min (Note 1)	V,W,or Y
To be used only when specified	IX	1	X			X	See 4.14.1			
		2				X	See 4.14.2			
	XIII					See 4.18.2				

Note 1: Sweep time shall be 18 minutes if test frequencies go to 2 cps.

B. Curve selection chart for category (f) equipment

Selection criteria	Curve
Wheeled vehicles except two-wheeled trailers	V
Tracked vehicles	W
Two-wheeled trailers	Y

C. Vehicle mileage selection chart

Group	Classification	Total Mileage
Trailers, semitrailers, and dollies:		
A	Trailers, semitrailers and dollies	6,000
B	Trailer bodies and equipment	3,000
C	Electronic and missile systems trailers and semitrailers	4,000
Wheeled vehicles:		
D	Tactical trucks (See Note)	25,000
E	Truck bodies, equipment (See Note)	11,400
F	Light weight, low mileage trucks	
	1 – Sprung type	4,000
	2 – Unsprung types	5,000
G	High flotation vehicles	4,000
H	Amphibious	8,400
I	Fire trucks	5,000
J	Commercial trucks, buses, passenger cars	35,000
Tracked Vehicles:		
K	Tanks and self-propelled (SP) weapons	5,000
L	Armored personnel carriers (APC), cargo carriers, missile support vehicles, wreckers, recovery vehicles and cargo tractors (with towed load)	6,000
M	Engineer combat vehicle (ECF) and engineer assault vehicle, etc	5,000
N	Engineer crawler tractors – military type	6,000
O	Amphibious vehicle (LVT type)	5,000
P	Turret-mounted accessories such as integrally mounted flamethrowers and search lights	700

Note:

Unless otherwise specified, when equipment mounted in group D or E vehicles is not part of the basic vehicle structures, the total test mileage for group B or C vehicles, as applicable, shall be used to determine the test time of the time schedule B.

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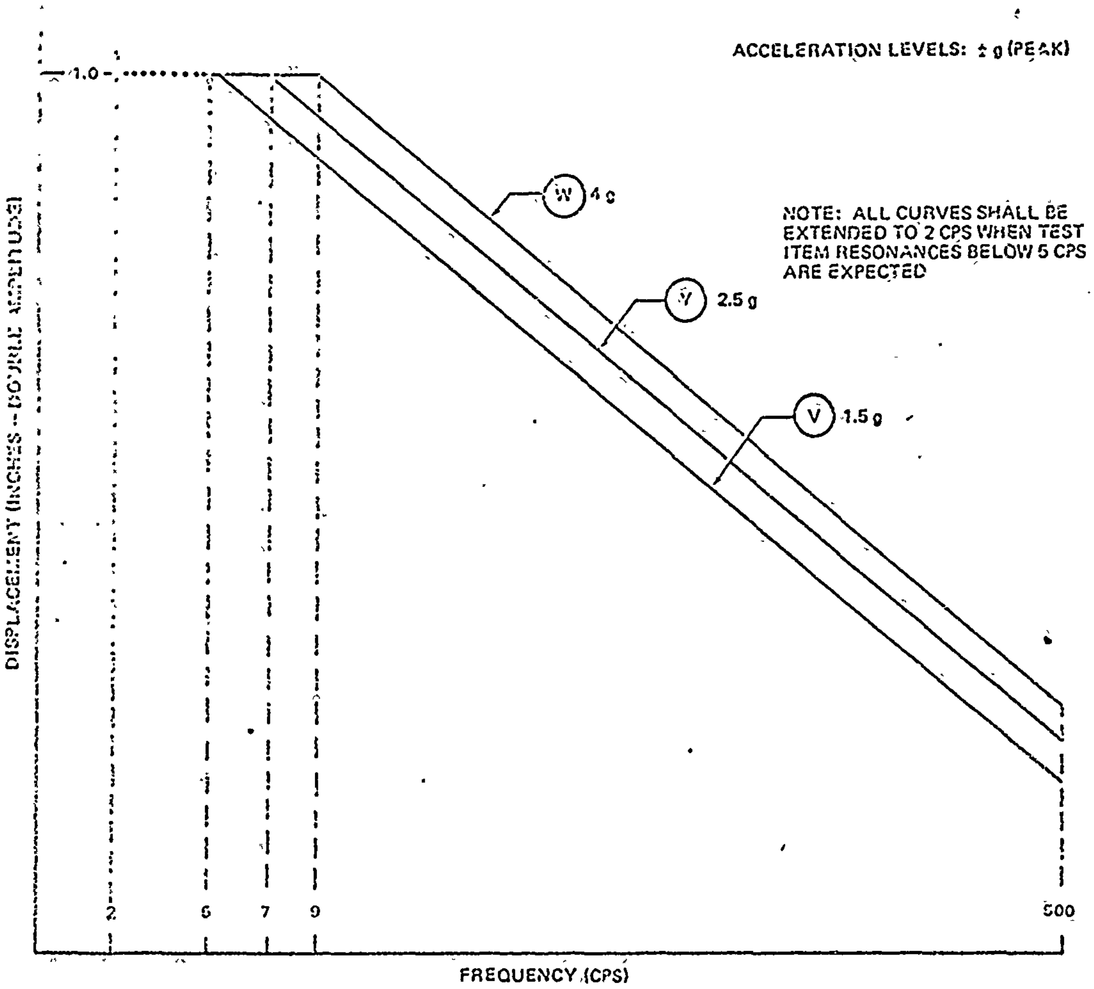

FIGURE 514.1–6. Vibration test curves for equipment installed in ground vehicles – equipment category (f)

TABLE 514.1-VII

A. Test procedure and time schedule chart for equipment transported by common carrier, land or air – equipment category (g)

Equipment conditions	Procedure number	Procedure part number	Applicable tests (see 4 for test procedures)				Time schedule (per axis)						Curve
			Resonance search (4.5.1.1)	Resonance dwell (4.5.1.2)	Sinusoidal cycling (4.5.1.3)	Bounce loose cargo (4.16.2)	Dwell time at each resonance (4.5.1.2)		Sinusoidal cycling time (4.5.1.3)		Sweep time 5-500-5 cps (note 3)		(notes 1 and 2)
							Land	Air	Land	Air	Land	Air	
Tied down (notes 4, 6 and 7)	X		X	X	X		2.5 min (note 5)	10 min (note 5)	15 min (note 5)	1 hr. (note 5)	15 min	15 min (note 2)	AV, AW, AX, AY, AA or AQ
Loose cargo (Note 7)	XI	1	X					See 4.16.1					
		2				X		See 4.16.2					

Note 1: For sinusoidal vibration resonance tests and cycling tests of items transported in airplanes and helicopters and weighing more than 100 pounds, the vibratory accelerations shall be reduced by +/-1 g for each 25-pound increment of weight over 100 pounds. Derating shall apply only to the highest test level of curve AY. However, the vibratory acceleration shall in no case be less than 1.5g.

Note 2: For equipment transported in aircraft and weighing more than 100 pounds, the upper frequency limit of curve AY of figure 514.1-7 may be reduced according to the cut-off frequency vs. weight requirement of figure 514.1-9. When a transit case or crate is provided for the item, the case or crate shall be included in the test set-up for acceleration and frequency derating.

Note 3: Sweep time may be as long as 18 minutes if test frequencies go to 2 cps.

Note 4: When testing vibration isolated items, the resonant dwell time shall be broken into 5-minute test periods with 2-minute shut down intervals.

Note 5: Total test time per axis (resonant dwells plus cycling) is 15 minutes per 1000 miles for land transportation or one hour for aircraft transportation. For equipment shipped by both land and air, both tests shall be performed. (The load vehicle cycling time of 15 minutes per 1000 miles per axis is reduced 2.5 minutes per 1000 miles for resonance in that axis, and the aircraft cycling time of 1 hour per axis is reduced 10 minutes for each resonance in that axis. Land transportation times are per 1000 vehicle miles, which may be determined from table 514.1-VIC).

Note 6: Land and air curves for Procedure X shall be cycled separately in accordance with the applicable time schedules. The dwell time for each resonance of non-isolated items shall be determined from the total test time of the applicable curves. For example, if the resonance occurs where the applicable land vehicle curve represents a higher G level, the item shall be tested at each resonance (maximum of four) to the G level of the applicable land vehicle curve with a test time for each resonance equal to 1/6 of the total test time per axis for the land vehicle. Conversely, if the aircraft curve is equal to, or higher than, the land vehicle curve, the item shall be tested for each resonance (maximum of four) to the G level of the aircraft curve with a test time for each resonance equal to 1/6 of the cycling time per axis for aircraft.

Note 7: When a transit case or crate is provided for the test item, the case or crate shall be included in the test setup.

B. Curve selection chart for category (g) equipment

Selection criteria		Curve
Equipment shipped by tracked vehicles		AV
Equipment shipped by truck, semitrailer, or railroad		AW
Equipment shipped by two wheeled trailers		AX
Equipment shipped by aircraft		AY
Mounted items with vibration isolators (Note 1)	Cycling	AA
	Resonance dwell	AQ

Note 1: For vibration isolated items, curves AA and AQ are to be used in the lower frequency range (below 13 and 20 cps, respectively) and a curve appropriate to the mode of transportation (AV, AW, AX, or AY) for higher frequencies.

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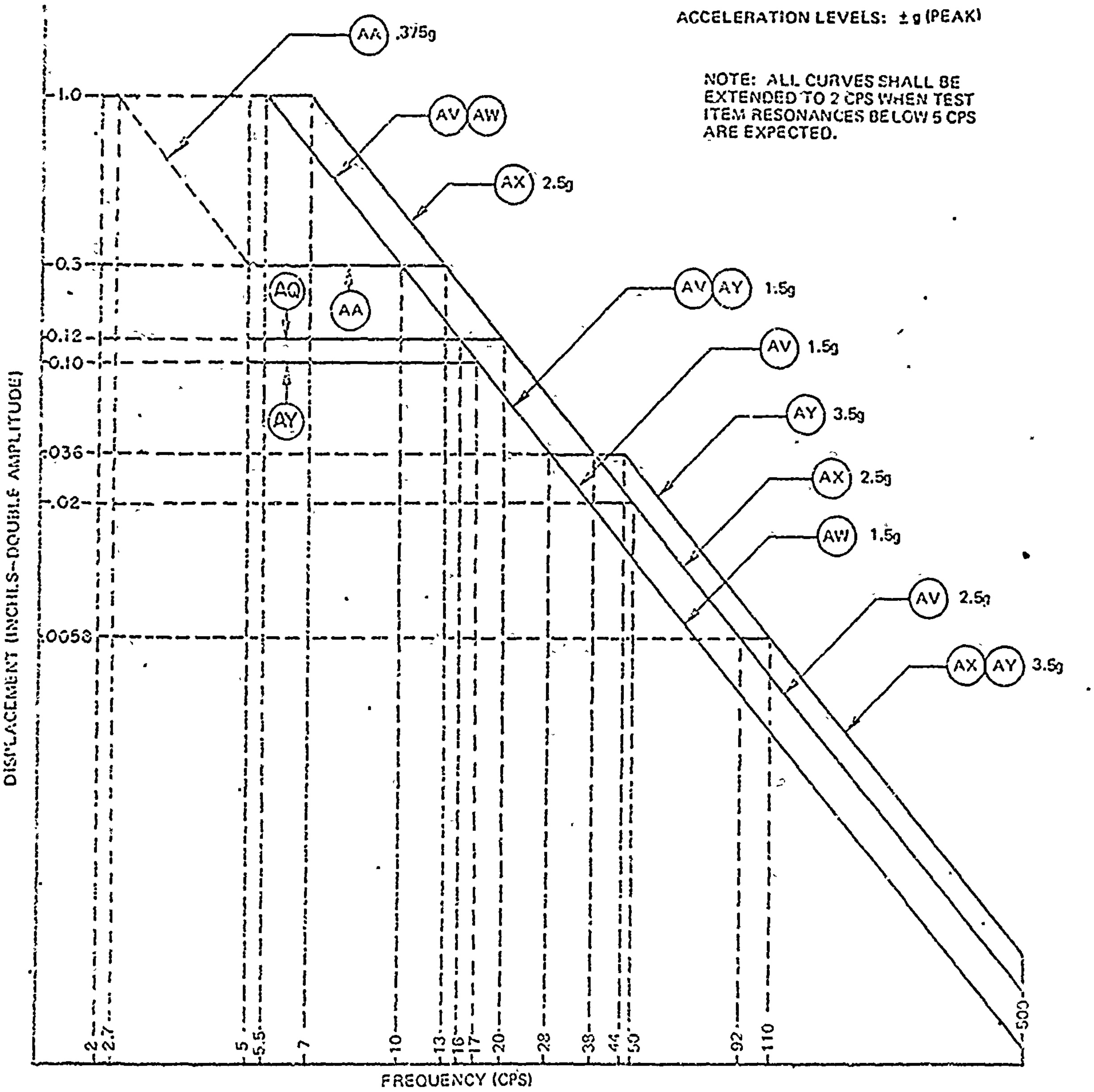

FIGURE 514.1-7. Vibration test curves for equipment transported by common carrier, land or air — equipment category (g)

TABLE 514.1-IX
Linear cycling rates

Total frequency range	Frequency band (cps)	Sweep time in minutes (min-max-min)	Linear cycling rate (cps/min)
2-500 cps or 5-500 cps as applicable	2 to 5	3	2
	5 to 22.5	6	5.8
	22.5 to 110	5	35
	110 to 500	4	195
5-2000 cps	5 to 22.5	6	5.8
	22.5 to 110	5	35
	110 to 500	4	195
	500 to 900	3	267
	900 to 2,000	2	1,100

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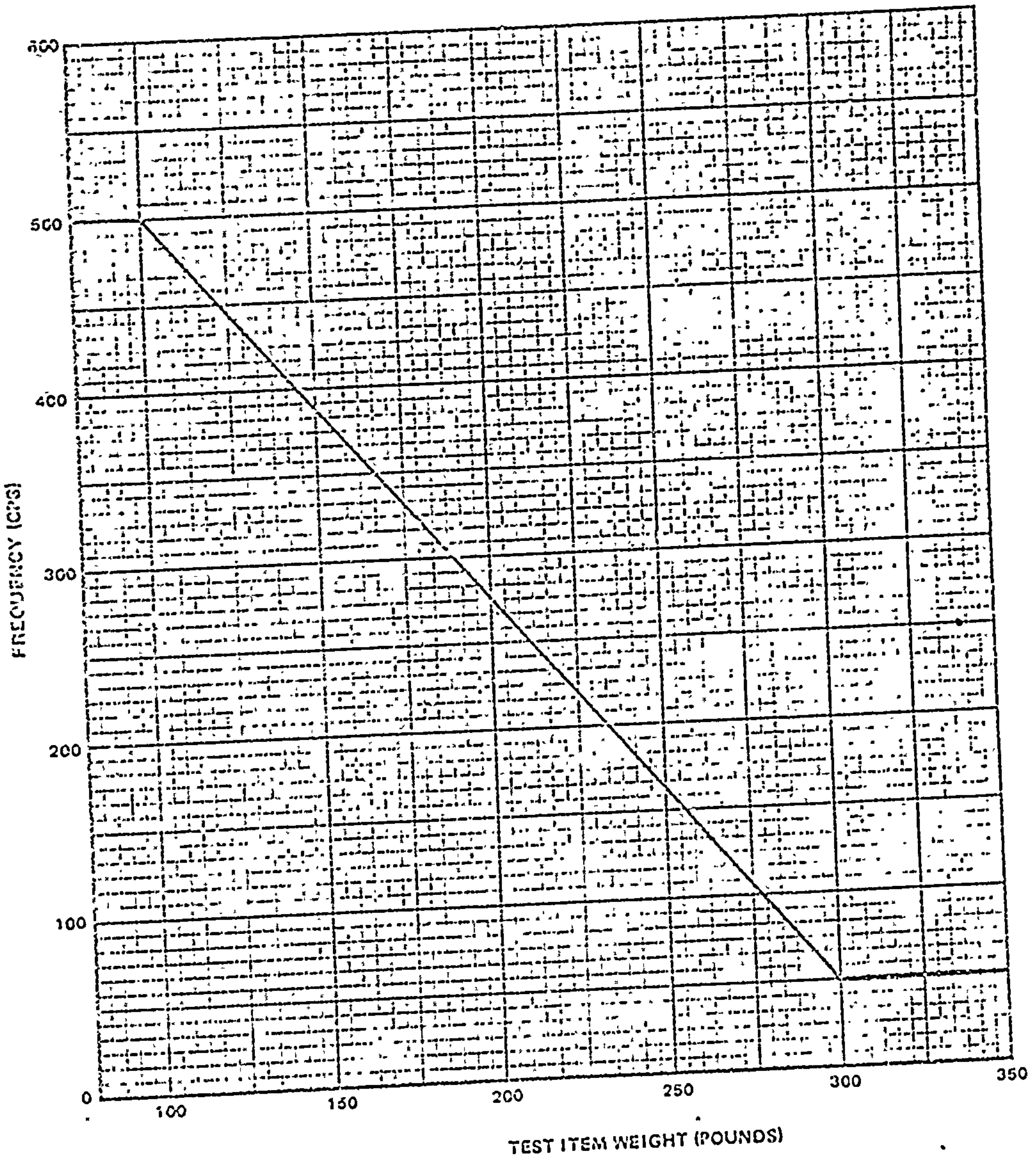

FIGURE 514.1–9. Cut-off frequency vs weight; equipment shipped by aricraft

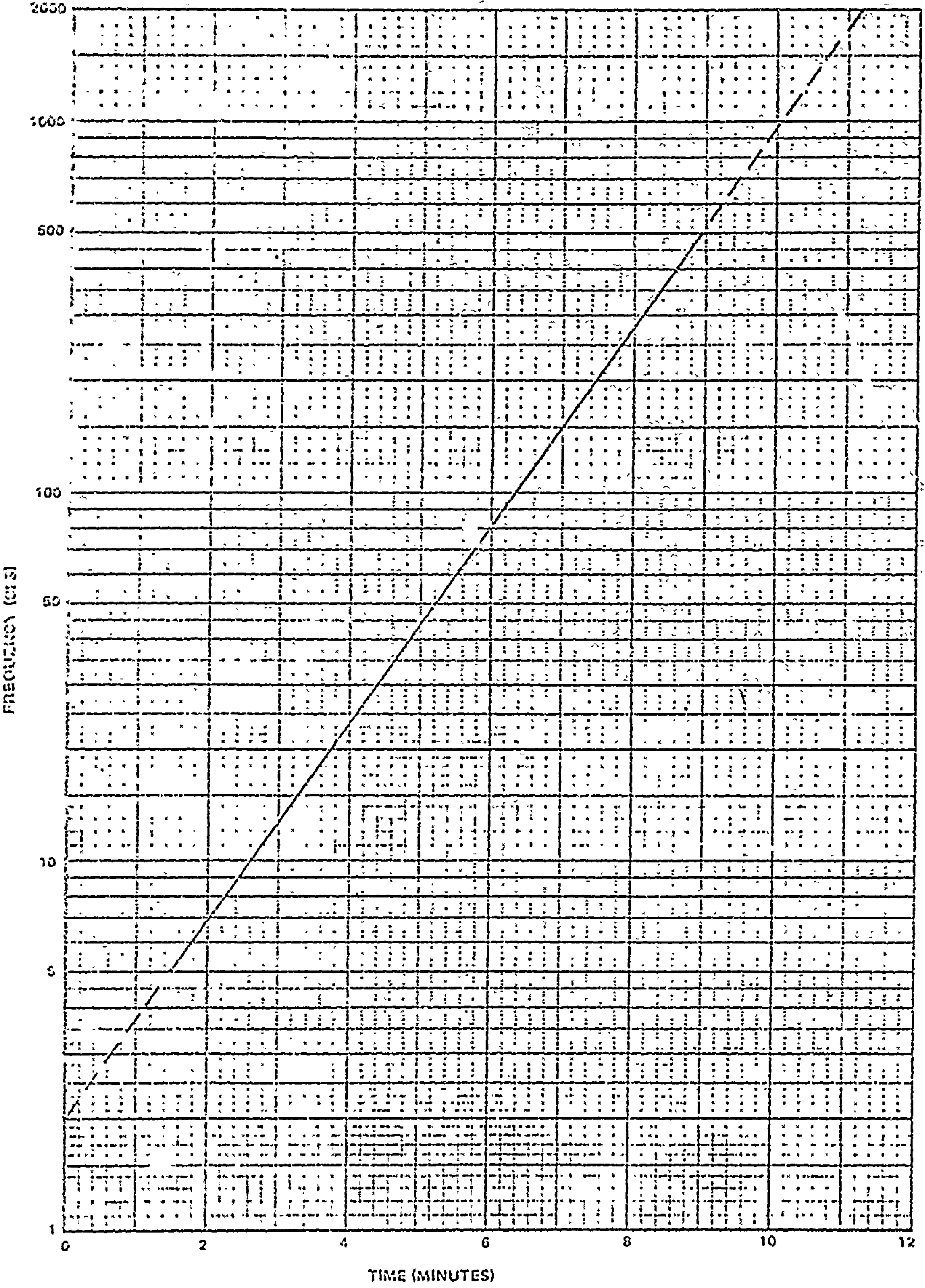

FIGURE 514.1–10. Logarithmic sweep

The Source for pages C-46 through C-73 is:
<u>Military Standard Environmental Test Methods.</u>
MIL-STD-810B, 15 June, 1967.

METHOD 513

ACCELERATION

1. Purpose. The acceleration test is to determine structural soundness and satisfactory performance of equipment in an environment of steady state acceleration other than gravity. Procedure I is the structural test and Procedure II is the operational test.

2. Apparatus. Either of two facilities may be utilized for acceleration tests: a centrifuge, or a track and rocket sled facility. A centrifuge of adequate size is recommended for all structural and most operational tests because of the convenience and ease of control. However, the performance of space oriented equipments, such as gyros, space control platforms, etc., are difficult to test on a centrifuge, even when a counter-rotating fixture is employed. A rocket sled run is advantageous where strictly linear acceleration is required.

3. Procedures. The test item shall be subjected to both the structural and the operational test, unless otherwise specified by the equipment specification.

3.1 Mounting of test item. Normally the location of the test item on the centrifuge, with reference to the G level established for the test, shall be determined from a measurement taken from the center of the centrifuge to the geometric center of the test item. Should any point of the test item nearest the center of the centrifuge experience less than 90 percent of the specified G level, the test item shall be moved outward on the radius of the centrifuge or the speed of rotation shall be increased until not less than 90 percent of the specified G level is obtained. Caution: If the furthest end of the test item experiences more than 110 percent of the desired G level at the geometric center (while the nearest end experiences 90 percent or under) then the test item may be tested using a lower speed and a larger radius centrifuge arm.

3.2 Procedure I structural test. The test item shall be installed on the acceleration apparatus in accordance with section 3, paragraph 3.2.2, by its normal mounting means. The test item shall be nonoperating during the test. The G level to be applied to the test item is contingent on two factors: the forward acceleration level (A) of the vehicle, and the orientation of the test item within the vehicle.

3.2.1 *G level of vehicle known, orientation of test item known.* When the forward acceleration level (A) of the vehicle is known and the orientation of the test item in the vehicle is known, the test level shall be determined as follows:

DIRECTION OF MOTION (See figure 513-1.)

Fore 1.5 x A = G test level
Aft 0.5 x A = G test level
Up 0.75 x A = G test level
Down 2.25 x A = G test level
Lateral 1.0 x A = G test level

Where: A = The highest possible forward acceleration assumed, calculated, or measured.

3.2.2 *G level of vehicle known, orientation of test item unknown.* When the G level of the vehicle is known, and the orientation of the test item is unknown, the test level should be determined as follows:

2.25 X A = G test level

3.2.3 *G level of vehicle unknown, orientation of test item known.* When the forward acceleration level (A) of the vehicle is not known, and orientation of the test item in the vehicle is known, the test level shall be within the ranges shown in table 513-I for the applicable vehicle category.

TABLE 513-I. *G levels for structural test*

Vehicle category		Direction				
		Fore	Aft	Up	Down	Lateral
Aircraft and helicopters		9.0	3.0	4.5	13.5	6.0
Manned aerospace vehicles		9.0 to 18.0	3.0 to 6.0	4.5 to 9.0	13.5 to 27.0	6.0 to 12.0
Air launched missiles		13.5 to 45.0	4.5 to 15.0	7.0 to 23.0	20.0 to 23.0	4.5 to 30.0
Ground launched missiles	Liquid boosters	9.0 to 18.0	3.0 to 6.0	—	—	6.0 to 12.0
	Solid boosters	9.0 to 45.0	3.0 to 15.0	—	—	6.0 to 30.0

3.2.4 *G level of vehicle unknown, orientation of test item unknown.* When both the forward acceleration level (A) of the vehicle and the orientation of the test item in the vehicle are unknown, the test level sl d be within the highest range shown in table 513-I for the applicable vehicle category.

3.2.5 *Performance of test.* The G level determined for the test shall be applied along at least three mutually perpendicular axes in two opposite directions along each axis. The test time duration in each direction shall be at least one minute following centrifuge stabilization. A test time of 1 minute is usually sufficient to determine structural soundness, however, the test time may be increased. At the conclusion of the test the test item shall be operated and the results compared with the data obtained in accordance with section 3, paragraph 3.2.1. The test item shall then be inspected as specified in section 3, paragraph 3.2.4.

3.3 Procedure II operational test. The test item shall be installed on the acceleration apparatus in accordance with section 3, paragraph 3.2.2, by its normal mounting means. The test item shall be operating during the test. The G level to be applied to the test item is contingent on two factors; the forward acceleration level (A) of the vehicle, and the orientation of the test item within the vehicle.

3.3.1 *G level of vehicle known, orientation of test item known.* When the forward acceleration level (A) of the vehicle is known and the orientation of the test item in the vehicle is known, the test level shall be determined as follows:

DIRECTION OF MOTION

Fore	1.1 x A = G test level
Aft	0.33 x A = G test level
Up	0.5 x A = G test level
Down	1.5 x A = G test level
Lateral	0.66 x A = G test level

Where A = The highest possible forward acceleration assumed, calculated or measured.

3.3.2 *G level of vehicle known, orientation of test item unknown.* When the G level of the vehicle is known and the orientation of the test item in the vehicle is unknown, the test level shall be determined as follows:

$$1.5 \times A = G \text{ test level}$$

3.3.3 *G level of vehicle unknown, orientation of test item known.* When the forward acceleration level (A) of the vehicle is not known, and the orientation of the test item in the vehicle is known, the test level shall be within the ranges shown on table 513-II for the applicable vehicle category.

TABLE 513-II. *G levels for operational test*

Vehicle category		Direction				
		Fore	Aft	Up	Down	Lateral
Aircraft and helicopters		6.0	2.0	3.0	9.0	4.0
Manned aerospace vehicles		6.0 to 12.0	2.0 to 4.0	3.0 to 6.0	9.0 to 18.0	4.0 to 8.0
Air launched missiles		9.0 to 30.0	3.0 to 10.0	4.5 to 15.0	13.5 to 45.0	6.0 to 20.0
Ground launched missiles	Liquid boosters	6.0 to 12.0	2.0 to 4.0	—	—	4.0 to 8.0
	Solid boosters	6.0 to 30.0	2.0 to 10.0	—	—	4.0 to 20.0

3.3.4 *G level of vehicle unknown, orientation of test item unknown.* When both the forward acceleration level (A) of the vehicle and the orientation of the test item in the vehicle are unknown, the test level shall be within the ranges in the "fore" direction shown in table 513-II for the applicable vehicle category.

3.3.5 *Performance of test.* The G level determined for the test shall be applied along at least three mutually perpendicular axes in two opposite directions along each axis. The test time duration in each direction shall be at least 1 minute following centrifuge stabilization. A test time of 1 minute is usually sufficient to determine proper operation; however, the test time may be increased. The test item shall be operated before, during, and at the conclusion of each test, and the results compared with the data obtained in accordance with section 3, paragraph 3.2.1. The test item shall then be inspected as specified in section 3, paragraph 3.2.4.

4. Summary. The following details shall be specified in the equipment specification:

(a) Procedure number if both procedures are not required (see 3).

(b) Pretest data required (section 3, paragraph 3.2.1).

(c) Test level and test time (see 3.2 and 3.3).

(d) Length of time required for operation and measurements.

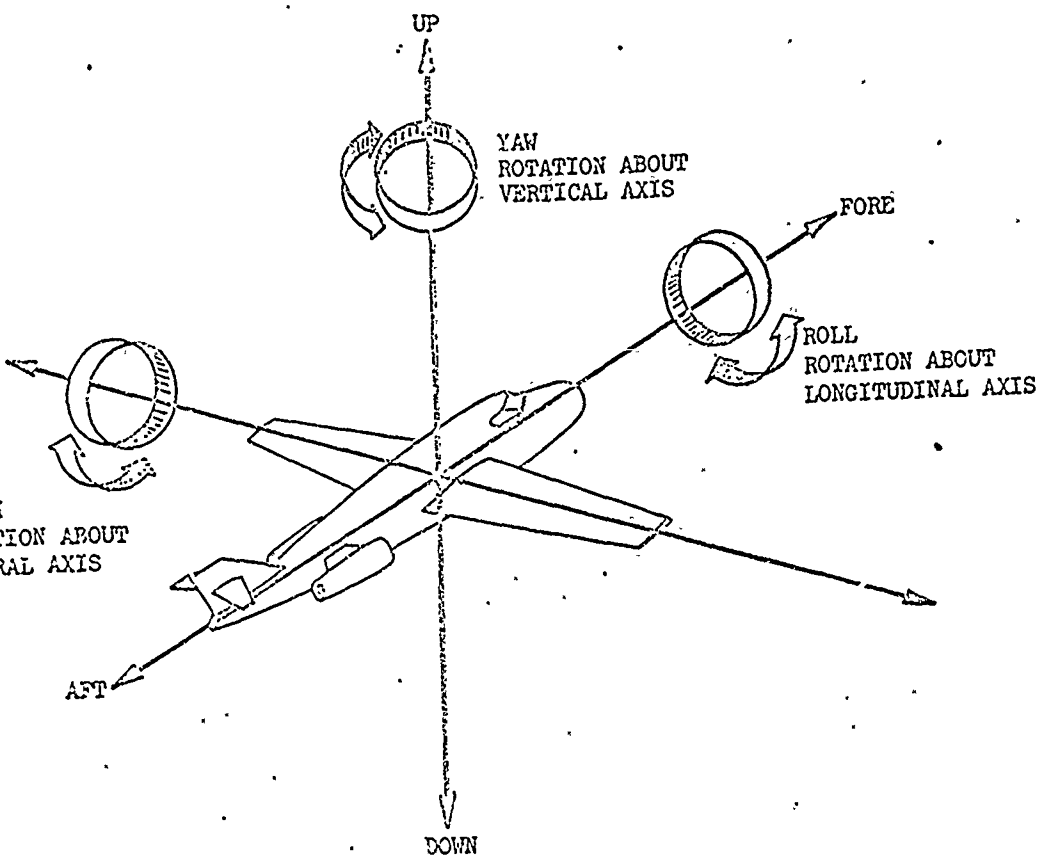

FIGURE 513-1. *Motion orientation*

METHOD 514

VIBRATON

1. Purpose. The vibration test is conducted to determine if the equipment is constructed to withstand expected dynamic vibrational stresses and the performance degradations or malfunctions will not be produced by the simulated service vibration environment. The tests specified herein are established for equipment to be used in a variety of military applications. The vibration test selection chart, table 514–1, provides a convenient means of selecting test procedures for these various military applications. The table is divided into two major sections. The section, captioned "Equipment category", refers to the equipment to be tested. The second section, captioned "Procedure Number", specifies the tests to be imposed on the equipment.

2. Apparatus. Vibration equipment.

3. General.

3.1 Equipment category. For purposes of this test method, equipment is categorized according to the vehicle in which it will be installed or according to other conditions as follows:

CATEGORY

(a) Aircraft (including helicopters)

(b) Aircraft (excluding helicopters)

(c) Helicopters

(d) Air launched vehicle

(e) Ground launched vehicle

(f) Ground vehicles

(g) Shipment by common carrier, land, or air

(h) Ground equipment (excluding category (f).)

(i) Shipboard equipment or when a ship is the common carrier

3.2 Selection of test procedures. One of the following test procedures shall be selected from table 514–I and specified in the equipment specification:

3.2.1 Aircraft/helicopter, air launched vehicle, or ground launched vehicle equipment mounted without vibration isolators; procedure I (parts 1, 2, and 3), II, or V, respectively.

3.2.2 Aircraft/helicopter, air launched vehicle or ground launched vehicle equipment mounted with vibration isolators; procedure I, III or VI, respectively.

3.2.3 Aircraft/helicopter, air launched vehicle or ground launched vehicle equipment normally using vibration isolators, but tested without vibration isolators; procedure I (part 4), IV or VII, respectively.

3.2.4 Equipment mounted in ground vehicles; procedure I (parts 1, 2, and 3), VIII or IX. Procedure I is a general procedure to be used when the vehicle (in which the equipment is to be mounted) or its mileage schedule is not known. Procedure VIII is to be used for more realistic testing when the vehicle is known. Procedure IX is used in addition to procedures I and VIII when the equipment might not always be installed but may be carried in a vehicle.

3.2.5 Equipment shipped by common carrier (land or air), either tied down or loose cargo; procedure X or XI, respectively.

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3.2.6 Ground equipment, excluding ground vehicles; procedures X or XI. Procedure X is generally used for tied down ground equipment and procedure XI is used in addition to procedure X when ground equipment might be subject to rough handling.

3.2.7 Shipboard and amphibious equipment, or when a ship is the common carrier, procedure XII.

3.3 Number of tests. All tests listed beside the applicable procedure number in table 514-I shall be performed. For example, referring to table 514-I for testing equipment in category (d) when procedure III is selected, there are four parts with four different test levels indicated by the test curves. The tests indicated by (x) in all four parts shall be performed to evaluate equipment installed in an air launched vehicle for both the captive and flight phase.

3.4 Selection of test curves. Test curves by equipment category are given in figures 514-1 through 514-6. In some instances, several curves are shown for one equipment category. A curve shall be selected and specified in the equipment specification after making a detailed analysis of the expected vibration environment within the particular vehicle involved. A primary consideration is the equipment location with respect to predominant vibration sources such as high intensity noise of jet and rocket exhausts, aerodynamic excitation including atmospheric wind and turbulence, and unbalance of rotating parts. Additional factors to be considered shall include attenuation or amplification and filtering by structural members. Suggested vibration test curves for missiles according to missile thrust to weight ratios and equipment locations are provided in table 514-III.

3.5 Test identification. The equipment specification shall identify which tests are imposed on the equipment by specifying a selected procedure and curve. Table 514-I is arranged to accommodate this identification. For example, when the specification calls for the following:

Example No. 1

Procedure I
Curve D (parts 1, 2, and 3)
Curve A (part 4)

Referring to table 514-I, the above identification specifies a resonance search (part 1), a resonance dwell (part 2), and a sinusoidal vibration cycling (part 3) and parts 1, 2, and 3 repeated with vibration isolators removed for part 4. Test to the level of curve D from figure 514-1 within the time schedule I of table 514-II for parts 2 and 3. Part 4 is performed to the test level of curve A from figure 514-1 within the time schedule II of table 514-II.

Example No. 2

Procedure II
Curves C, P, AF

Referring to table 514-I and since all tests shown for any one procedure in a category must be performed, the above identification specifies for part 1, a resonance search, a resonance dwell, and a sinusoidal vibration cycling. Test to the level of curve C from figure 514-1 within the time schedule V of table 514-II. These tests are followed by part 2, a sinusoidal cycling test to the level of curve P from figure 514-3, within the time schedule II of table 514-II, followed by part 3, a random test to the level of curve AF from figure 514-4 within the time schedule II of table 514-II.

4. Test procedures. Test procedures consist of all the tests to the right of the test procedure number indicated by an "x" in the applicable colume of table 514-I with the duration of the test designated by a Roman

numeral referring to table 514–II. The vibration environment specified by the curve shall be applied to each of the three mutually perpendicular axes of the test item. The entire sequence of tests may be accomplished for any one axis before changing to the next axis. Unless otherwise specified, for one axis before changing to the next axis. Unless otherwise specified, for resonance and sinusoidal vibration cycling tests of items weighing more than 50 pounds, the vibratory accelerations shall be reduced by ±1 g for each 10 pound increment of weight over 50 pounds. However, the vibratory acceleration shall in no case be less than 50 percent of the specified curve level. When a test item performance test is required during a vibration test and the duration of the performance test is greater than the duration of the vibration test, the performance test shall be abbreviated accordingly.

4.1 Procedure I.

4.1.1. *Part 1, resonance search.* The test item shall be installed in accordance with section 3, paragraph 3.2.2, and attached by its normal mounting means directly to the vibration exciter table, or by means of a rigid fixture capable of transmitting the vibration conditions specified herein. Whenever possible, the test load shall be distributed uniformly on the vibration exciter table in order to minimize effects of unbalanced loads.

Resonant modes of the equipment shall be determined by varying the frequency of applied vibration slowly through the specified range at reduced input amplitudes. Individual resonance searches shall be conducted with vibration applied along each of the three mutually perpendicular axis of the equipment.

4.1.2 *Part 2, resonance dwell.* Unless otherwise specified, the test item shall be operating during the test so that functional effects caused by internal resonances may be observed. The test item shall be vibrated along each axis at the most severe resonant frequencies according to the time schedule I of table 514–II and according to the applicable double amplitudes or accelerations of the specified curve from figure 514–1, 514–2, or 514–5. If more than four significant resonances have been found for any one axis, the four most severe resonances shall be chosen for the test. If a change in the resonant frequency occurs during the test, immediately the frequency shall be adjusted to maintain the resonance condition. At the conclusion of the test, the test item shall be operated and the results compared with the data obtained in accordance with section 3, paragraph 3.2.1. The test item shall then be inspected in accordance with section 3, paragraph 3.2.4.

4.1.3 *Part 3, vibration cycling.* Unless otherwise specified, the test item shall be operating throughout the vibration cycling test. The frequency of applied vibration shall be cycled at a logarithmic rate between the frequency limits and at the vibratory acceleration levels of the specified curve from figure 514–1, 514–2, or 514–5. Logarithmic cycling rates shall be in accordance with figure 514–8 and the time schedule I of table 514–II. A linear cycling rate may be substituted for logarithmic cycling when performed in accordance with 5.2. During, and at the conclusion of the test, the operation of the test item shall be compared with the data obtained in accordance with section 3, paragraph 3.2.1, and shall meet the requirements of the equipment specification. The test item shall then be inspected in accordance with section 3, paragraph 3.2.4.

4.1.4 *Part 4, vibration isolated equipment with isolators removed.* The test item shall be mounted directly to the vibration table with external vibration isolators removed but including any other required holding devices. The test item shall then be tested in accordance with parts 1, 2, and 3. except that the test level shall be the lower g level specified and the time schedule II of table 514–II.

4.2 Procedure II.

4.2.1 *Part 1.* Proceed the same as in procedure I, parts 1, 2, and 3, except that the test level shall be in accordance with curve C, D, H or J from figure 514-1 and time schedule V of table 514-II.

4.2.2 *Part 2.* Proceed the same as in procedure I, part 3, except that the test level shall be in accordance with curve P, Q, R, and S from figure 514-3 and time schedule II of table 514-II.

4.2.3 *Part 3, random.* Random vibration (controlled and analyzed according to 5.3) shall be applied according to one specified curve of AF through AK from figure 514-4 and time schedule II of table 514-II. Unless otherwise specified, during, and at the conclusion of the test, the operation of the test item shall be compared with the data obtained in accordance with section 3, paragraph 3.2.1, and shall meet the requirements of the equipment specification. The test item shall then be inspected in accordance with section 3, paragraph 3.2.4.

4.3 Procedure III.

4.3.1 *Part 1.* Test items of equipment normally provided with vibration isolators shall be first tested with the isolators in place the same as in procedure I, parts 1, 2, and 3, except that the test level shall be in accordance with curve C, D, H, or J from figure 514-1 and time schedule V of table 514-II.

4.3.2 *Part 2.* The isolators shall then be removed, the test item rigidly mounted and the resonance and sinusoidal vibration cycling tests repeated as in procedure I, parts 1, 2, and 3, except that the test level shall be in accordance with curve A, B, or K from figure 514-1 and time schedule II of table 514-II.

4.3.3 *Part 3.* The vibration isolators shall be replaced and the test continued using procedure I, part 3, except that the test level shall be in accordance with curve P, Q, R, or S from figure 514-3 and time schedule II of table 514-II.

4.3.4 *Part 4, random.* Again with isolators in place, random vibration, (controlled and analyzed according to 5.3) shall be applied to the test item according to one specified curve of AF through AK from figure 514-4 and time schedule II or table 514-II. Unless otherwise specified, during, and at the conclusion of the test, the operation of the test item shall be compared with the data obtained in accordance with section 3, paragraph 3.2.1, and shall meet the requirements of the equipment specification. The test item shall then be inspected in accordance with section 3, paragraph 3.2.4.

4.4 Procedure IV.

4.4.1 *Part 1.* Proceed the same as in procedures I, parts 1, 2, and 3, except that the test level shall be in accordance with curve A, B, or K from figure 514-1 and time schedule V of table 514-II.

4.4.2 *Part 2.* Proceed the same as in procedure I, part 3, except that the test level shall be in accordance with curve N from figure 514-3 and time schedule II of table 514-II.

4.4.3 *Part 3, random.* Random vibration (controlled and analyzed according to 5.3) shall be applied according to curve AE from figure 514-4 and time schedule II of table 514-II. Unless otherwise specified, during, and at the conclusion of the test, the operation of the test item shall be compared with the data obtained in accordance with section 3, paragraph 3.2.1, and shall meet the requirements of the equipment specificaton. The test item shall then be inspected in accordance with section 3, paragraph 3.2.4.

4.5 Procedure V.

4.5.1 *Part 1.* Proceed the same as in procedure I, part 3, except that the test level shall be in accordance with one curve of P through U from figure 514-3 and time schedule II of table 514-II.

4.5.2 *Part 2, random.* Random vibration (controlled and analyzed according to 5.3) shall be applied according to one specified curve of AE through AP from figure 514-4 and time schedule II of table 514-II. Unless otherwise specified, during, and at the conclusion of the test, the operation of the test item shall be compared with the data obtained in accordance with section 3, paragraph 3.2.1, and shall meet the requirements of the equipment specification. The test item shall then be inspected in accordance with section 3, paragraph 3.2.4.

4.6 Procedure VI.

4.6.1 *Part 1.* Equipment normally provided with vibration isolators shall be first tested with the isolators in place. Proceed the same as in procedure I, part 3, except that the test level shall be in accordance with one curve of P through U from figure 514-3 and time schedule II of table 514-II.

4.6.2 *Part 2.* The isolators shall then be removed; the equipment rigidly mounted, and tested again in accordance with procedure I, part 3, except the test level shall be in accordance with curve N from figure 514-3 and time schedule II of table 514-II.

4.6.3 *Part 3, random.* The vibration isolators shall be replaced and random vibration (controlled and analyzed according to 5.3) shall be applied according to one specified curve of AE through AP from figure 514-4 and time schedule II of table 514-II. Unless otherwise specified, during, and at the conclusion of the test, the operation of the test item shall be compared with the data obtained in accordance with section 3, paragraph 3.2.1, and shall meet the requirements of the equipment specification. The test item shall then be inspected in accordance with section 3, paragraph 3.2.4.

4.7 Procedure VII.

4.7.1 *Part 1.* Proceed the same as in procedure I, part 3, except that the test level shall be in accordance with curve N from figure 514-3 and time schedule II of table 514-II.

4.7.2 *Part 2, random.* Random vibration (controlled and analyzed according to 5.3) shall be applied according to one specified curve AE from figure 514-4 and time schedule II of table 514-II. Unless otherwise specified, during, and at the conclusion of the test, the operation of the test item shall be compared with the data obtained in accordance with section 3, paragraph 3.2.1, and shall meet the requirements of the equipment specification. The test item shall then be inspected in accordance with section 3, paragraph 3.2.4.

4.8 Procedure VIII. Proceed the same as in procedure I, parts 1, 2, 3, using curve V, W, or Y from figure 514-5 and time schedule III of table 514-II.

4.9 Procedure IX.

4.9.1 *Part 1, vibration (resonance search).*

4.9.1.1 *Test conditions.* The test item shall be secured to a vibration table that can be controlled within 10 percent of the specified amplitude. Mounting method shall be such that the vibration within the test item can be observed and measured. To facilitate this observation and measurement, sub-assemblies may be tested separately, provided they are secured to the table in a manner similar to that used to mount them in the test item.

4.9.1.2 *Performance of test.* The shockmounts (if any) of the test item shall be blocked. The test item shall be vibrated successively in three mutually perpendicular directions over a frequency range of 10 to 55 cycles per second. The total excursion of the applied vibration shall not be less than 0.030 inch. In each of the three directions, the frequency shall be changed in steps of 1 cycle per second and maintained for at least 10 seconds. Vibration amplitudes shall be measured by optical or any other means, provided that the vibration of the test item is not affected by the measurement.

4.9.1.3 *Failure criteria.* The equipment shall have no resonance in the frequency range of 10 to 55 cycles per second that exceed twice the amplitude of the applied vibration. This applies for equipment designed to operate with or without shock mounts.

4.9.2 *Part 2; bounce, vehicular.*

4.9.2.1 *Apparatus.* A package tester of suitable capacity for testing military equipment as made by L.A.B. Corporation, Skaneateles, New York, or equal.

4.9.2.2 *Test conditions.*

(a) Cover the test bed of the package tester with a panel of 1/2-inch plywood, with the grain parallel to the drive chain. Secure the plywood with sixpenny nails, with top of heads flush with, or slightly below, the surface. Space nails at 6-inch intervals around all four edges. If the distance between either pair of fences is greater than 24 inches, the plywood shall also be nailed at 3-inch intervals in a 6-inch square at the center of the test area.

(b) Using suitable wooden fences, constrain the vehicular, or simulated, adapter plate to a horizontal motion of not more than 2 inches in any lateral direction. Fences shall be a distance from the test item more than sufficient to insure that the test item will not rebound from fence to fence. Additional barriers may be used to safeguard personnel.

4.9.2.3 *Performance of test.*

Step 1—Secure the test item to the vehicular, or simulated, adapter plate in accordance with section 3, paragraph 3.2.2, and place on the package tester within the constraints outlined in 4.9.2.2 (b). If the test item weighs over 200 pounds, a simulated adapter plate shall be used.

Step 2—Attach an accelerometer as close as possible to the point of test item attachment, to record the shock transmitted to the test item.

Step 3—Adjust the package tester, shafts in phase and table operating in a vertical linear motion, to a speed such that the average value of the random acceleration peaks shall be 7.5 ± 2.5 g's. Measure this input with an accurate measuring or recording system incorporating a 100 cycles per second low pass filter. Due to the random nature of the input, pulses greater than 10 g's can be expected to occur, however, if they are infrequent, they need not be used in calculating the average. In no case shall the speed of the package tester exceed 285 revolutions per minute. Conduct the test for a total of 3 hours. At the end of each 3/4-hour period, rotate the adapter plate and test item 90 degrees, each time in the same direction.

Step 4—At the end of the 3-hour period, operate the test item and compare the results with the data outlined in accordance with section 3, paragraph 3.2.1. Then inspect the test item as specified in section 3, paragraph 3.2.4.

4.10 Procedure X. Proceed the same as in procedure I, parts 1, 2, and 3, except that the test level shall be in accordance with curve AB, or curves AA and AQ from figure 514-6 and time schedule IV of table 514-II.

4.11 Procedure XI.

4.11.1 *Part 1.* Proceed the same as in part 1 of procedure IX.

4.11.2 *Part 2. Bounce, loose cargo.*

4.11.2.1 *Purpose.* To determine that the equipment, as prepared for field use, shall be capable of withstanding the vibrations normally induced during transportation as loose cargo. Equipment in this class is normally transported in a shipping case, transit case, or combination case.

4.11.2.2 *Apparatus.* A package tester of suitable capacity for testing military equipment as made by L.A.B. Corporation, Skaneateles, New York, or equal.

4.11.2.3 *Test conditions.* The test bed of the package tester shall be covered with a panel of ½-inch plywood, with the grain parallel to the drive chain. The plywood shall be secured with sixpenny nails, with top of heads flush with or slightly below the surface. Nails shall be spaced at 6-inch intervals around all four edges. If the distance between either pair of fences is greater than 24 inches, the plywood shall also be nailed at 3-inch intervals in a 6-inch square at the center of the test area. Using suitable wooden fences, constrain the test item to a horizontal motion of not more than 2 inches in a direction parallel to the axes of the shafts of the package tester, and in a direction perpendicular to the axes of the shafts, a distance more than sufficient to insure the test item will not rebound from fence to fence.

4.11.2.4 *Performance of test.* The test item, as secured in its shipping case, transit case, or combination case, or as otherwise prepared for field transportation, shall be placed on the package tester within the constraints outlined above. The package tester shall be operated in the synchronous mode with the shafts in phase. (In this mode any point on the bed of the tester will move in a circular path in a vertical plane perpendicular to the axes of the shafts.) The tester shall be operated at a speed of 284 rpm ±2 rpm for a total of 3 hours. At the end of each ½-hour period, turn the test item to rest on a different face, so that at the end of the 3-hour period the test item will have rested on each of its six faces (top, bottom, sides and ends). At the end of the 3-hour period, the test item shall be operated and the results compared with the data obtained in accordance with section 3, paragraph 3.2.1. The test item shall then be inspected as specified in section 3, paragraph 3.2.4. The package tester shall be operated in the vertical linear mode (straight up and down in the vertical plane) instead of in the synchronous mode when one of the following conditions occurs:

(a) Bouncing of the test item is very severe and presents a hazard to personnel.

(b) Forward and rear oscillations cannot be reduced. When operated in the vertical linear mode, wooden fences shall be placed on all four sides of the test item to constrain its motion to not more than 2 inches in either direction.

4.12 Procedure XII. For shipboard and amphibious equipment or when a ship is the common carrier, the vibration test shall be in accordance with Type I of MIL-STD-167.

5. Test details and techniques.

5.1 Combined sinusoidal cycling and random vibration test. The sinusoidal cycling random vibration test may be combined when the test apparatus permits. The sinusoidal vibration test curve acceleration level (specified in peak g) shall be converted to rms G. The acceleration level to be used for the combined test shall then be determined by squaring both test curve acceleration levels, adding them, and then taking the square root of the sum. The combined test level may then be achieved by obtaining the lower of the two separate levels first, then advancing the gain control for the other separate level until the overall combined test level is achieved. All other test parameters shall be the same as the separate test instructions.

5.2 Substitution of linear cycling for logarithmic cycling. When linear cycling rate is used, the total frequency range shall be divided into logarithmic frequency bands of equal cycling time intervals. The linear cycling rate for each band is then determined by dividing each bandwidth in cps by the time in minutes for each band. The logarithmic frequency bands may be readily determined from figure 514-8. The frequency bands and linear cycling rates shown in table 514-IV shall be used for the 2 to 500 cps and 5 to 2,000 cps frequency ranges. For test frequency ranges of 100 cps or less, no correction of the linear cycling rate is required.

5.3 Control and analysis of random vibration. The instantaneous random vibration acceleration peaks may be limited to 3 times the rms acceleration level. Resonant modes of the moving mass (vibration exciter moving element, fixture and either the test item or substitute equivalent mass) shall be equalized or compensated for within the frequency range of the test curve. The applied vibration spectrum shall normally be within the tolerances of +40, —30 percent between the frequencies of 50 and 1,000 cps, and within +100, —50 percent between 1,000 and 2,000 cps. For a power spectral density analysis of the test spectrum, these tolerances may be expressed at ±1.5 db and ±3 db, respectively. Tolerance levels in terms of db are defined as:

$$db = 10 \log \frac{(G_1)^2/cps}{(G_0)^2/cps} \text{ or}$$

$$db = 20 \log \frac{G_1}{G_0} .$$

Where $(G_1)^2/cps$ = acceleration power spectral density, and

G_1 = G rms (measured over the analyzer effective bandwidth).

The term G_0 defines the specified level.

A wave analyzer shall be used to assure the specified equalization tolerances. The following wave analyzer characteristics shall be required for each test:

(a) Filter bandwidths = B = 25 cps max. below 1000 cps and 1/3 octave max. above 1000 cps

(b) Sweep rate = R = $B^2/32$ cps/sec. max.

(c) Integrator time constant = 1 second minimum

5.4 Sinusoidal vibration input control. The vibratory acceleration levels or double amplitudes of the specified test curve shall be maintained at the test item mounting points. When the input vibration is measured at more than one control point, the minimum input vibration shall normally be that of the specified curve. For massive test items, fixtures, large force exciters or multiple vibration exciters, it is recommended that the input control level be an average of at least three or more inputs. Unless otherwise specified, the transverse motion at the input monitoring point(s) shall be limited to 100 [illegible] input location is within the [illegible] full limitation of [illegible] 50 pounds or less, can usually [illegible]. For larger equipment such cross [illegible] may not be possible.

[illegible] accelerometer(s) shall be rigidly [illegible] located on or near the [illegible] points of the test item.

[illegible] temperature-vibration test [illegible] be conducted under room ambient conditions unless the equipment specification [illegible] a high or low temperature vibration [illegible] in which case the temperature extremes and time duration shall be as specified in the equipment specification.

6. Summary. The following details shall be specified in the equipment specification:

(a) Procedure number (see 3.2).

(b) [illegible] required (section 3, paragraph 3.2.1).

(c) Curve selection (see 3.4).

(d) Nonoperation of equipment during test, if desired.

(e) Limitation of transverse motion if other than 100 percent (see 5.4).

(f) Temperature extremes and test time duration (see 5.6).

TABLE 514-I. Vibration test selection chart

Equipment category (Par. 3.1)	Test procedures										[illegible]
	Procedure number (Par. 3.2)	Curve (Par. 3.4) (Note 1)	Fig. 514-	Parts	Test type						
					Resonance search	Resonance dwell	Sinusoidal cycling	Random	Bounce, vehicular	Bounce, loose cargo	
(a) Aircraft including helicopters	I	Z	1	Parts 1, 2, and 3	X	X	X				I
		B	1	Part 4	X	X	X				II
(b) Aircraft except helicopters	I	C, D, E, F, G, H, J, or L	1 or 2	Parts 1, 2, and 3	X	X	X				I
		A, B or K	1 or 2	Part 4	X	X	X				II
(c) Helicopters	I	M	1	Parts 1, 2, and 3	X	X	X				I
		B	1	Part 4	X	X	X				II
(d) Air launched vehicles	II	C, D, H or J	1 or 2	Captive phase Part 1	X	X	X				V
		P, Q, R or S	3	Flight phase Part 2			X				II
		one of AF thru AK	4	Part 3				X			II
	III	C, D, H or J	1 or 2	Captive phase (Note 2) Part 1	X	X	X				V
		A, B or K	1 or 2	Part 2	X	X	X				II
		P, Q, R or S	3	Flight phase Part 3			X				II
		one of AF thru AK	4	Part 4				X			II
	IV	A, B or K	1 or 2	Captive phase Part 1	X	X	X				V
		N	3	Flight phase Part 2			X				II
		AE	4	Part 3				X			II

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TABLE 514-I. *Vibration test selection chart* (continued)

Equipment category (Par. 3.1)	Test procedures										Time schedule table 514-II
	Procedure number (Par. 3.2)	Curve (Par. 3.4) (Note 1)	Fig. 514-	Parts	Test type						
					Resonance search	Resonance dwell	Sinusoidal cycling	Random	Bounce, vehicular	Bounce, loose cargo	
(e) Ground launched vehicles	V	one of P thru U	3	Part 1			X				II
		one of AE thru AP	4	Part 2				X			II
	VI	one of P thru U	3	Part 1			X				II
		N	3	Part 2 (Note 2)			X				II
		one of AE thru AP	4	Part 3				X			II
	VII	N	3	Part 1			X				II
		AE	4	Part 2				X			II
(f) Ground vehicles	I	V, W or Y	5	Parts 1, 2, and 3 (Note 3)	X	X	X				I
	VIII	V, W or Y	5	(Note 3)	X	X	X				III
	IX			Parts 1 and 2	X				X		
(g) Shipment by com. carrier	X	AB or (AA & AQ)	6	(Note 3)	X	X	X				IV
	XI			Parts 1 and 2	X					X	
(h) Ground equipment excluding cat. (f)	X	AB or (AA & AQ)	6	(Note 3)	X	X	X				IV
	XI			Parts 1 and 2	X					X	
(i) Shipboard	XII										

TABLE 514-I. *Vibration test selection chart* (continued)

Note 1 Unless otherwise specified in the equipment specification, for resonance and sinusoidal vibration cycling tests of items weighing more than 50 pounds, the vibratory accelerations shall be reduced by ±1 g for each 10 pound increment of weight over 50 pounds. However, the vibratory acceleration shall in no case be less than 50 percent of the specified curve level.

Note 2 Test items of equipment normally provided with vibration isolators shall first be tested with the isolators in place. The isolators shall then be removed, the test item rigidly mounted, and subjected at the lower g level indicated.

Note 3 When a transit case or crate is provided for the item, the case or crate shall be included in the test setup. For equipment weighing more than 100 pounds, the upper frequency limit of figure 514-5 or 514-6 shall be reduced according to the cut-off frequency vs. weight requirement of figure 514-7.

TABLE 514-II. *Time table*

Time schedule	Resonance dwell		Cycling time per axis	Random time per axis	Sweep time	
	Number of resonances	Time at resonance per axis			5-500-5 cps	5-2000-5 cps
I	0	—	3 hr.		15 min.	20 min.
	1	½ hr.	2½ hr.		(Note 1)	
	2	1 hr.	2 hr.			
	3	1½ hr.	1½ hr.			
	4	2 hr.	1 hr.			
	Dwell 30 min. at each resonance					
II	0	—	30 min.	30 min.	15 min.	20 min.
	1	10 min.				
	2	20 min.				
	3	30 min.				
	4	40 min.				
	Dwell 10 min. at each resonance					
III	0	—	20 min/1000 miles as determined from vehicle mileage chart or equipment specification — see table 514-V		15 min.	
	1	Dwell 1/8 of cycling time at each resonance (30 min. max.)			(Note 1)	
	2					
	3					
	4					
IV	0	—	45 min.		15 min.	
	1	½ hr.	(Note 1)			
	2	1 hr.			(Note 1)	
	3	1½ hr.				

TABLE 514-II. *Time table* (continued)

Time schedule	Resonance dwell		Cycling time per axis	Random time per axis	Sweep time	
	Number of resonances	Time at resonance per axis			5-500-5 cps	5-2000-5 cps
IV (Cont.)	4	2 hr.				
	Dwell 30 min. at each resonance (see Note 2)					
V	0	—	2 hr.		15 min.	20 min.
	1	½ hr.	1½ hr.			
	2	1 hr.	1 hr.			
	3	1½ hr.	½ hr.			
	4	2 hr.	0			
	Dwell 30 min. at each resonance					

Note 1: Sweep time can be as long as 18 minutes if test frequencies go lower than 5 cps (see figures 514-5 and 514-6).

Note 2: When testing to curve AQ of figure 514-6, the 30 minute dwell time shall be broken into six 5-minute vibrations with five 2-minute shut down intervals.

TABLE 514-III. *Suggested vibration test curves (launched vehicles)*

Vehicle type	Vibration test curves		Approx. thrust to weight ratio or thrust in pounds	Equipment location by vehicle section
	Sinusoidal Fig. 514-3	Random Fig. 514-4		
Air launched (flight phase)	S	AK	20/1 or greater	Booster
	R	AJ	5/1 thru 20/1	
	Q	AH	5/1 or less	
	Q	AG	15/1 or greater	All except booster
	P	AF	Less than 15/1	

TABLE 514-III. *Suggested vibration test curves (launched vehicles)* (Continued)

Vehicle type	Vibration test curves		Approx. thrust to weight ratio or thrust in pounds	Equipment location by vehicle section
	Sinusoidal Fig. 514-3	Random Fig. 514-4		
Ground launched	P or Q	AE, AF or AG	ALL —	All except booster
	Q or R	AH, AJ or AK	250,000 lb. or less	By individual booster stage
	R or S	AK, AL or AM	250,000 lb. - 500,000 lb.	
	T or U	AM, AN or AP	Over 500,000 lb.	

TABLE 514-IV. *Linear cycling rates*

Total frequency range	Frequency bands	Sweep time in minutes	Linear cycling rate (cps/min)
2-500 cps	2 to 5	1.5	2
	5 to 22.5	2.5	7
	22.5 to 100	2.5	31
	100 to 500	2.5	160
5-2000 cps	5 to 22.5	2.5	7
	22.5 to 100	2.5	31
	100 to 500	2.5	160
	500 to 2000	2.5	600

TABLE 514-V. *Mileage schedule*

Group	*Classification*	*Total mileage*
Trailers, semitrailers, and dollies:		
A	Trailers, semitrailers and dollies	6,000
B	Trailer bodies and equipment	3,000
C	Electronic and missile systems trailers and semitrailers	4,000
Wheeled vehicles:		
D	Tactical trucks	25,000
E	Truck bodies, equipment	11,400
F	Light weight, low mileage trucks	
	1 — Sprung type	4,000
	2 — Unsprung types	5,000
G	High flotation vehicle	4,000

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H	Amphibious	8,400
I	Fire trucks	5,000
J	Commercial trucks, buses, passenger cars	35,000
Tracked vehicles:		
K	Tanks and self-propelled (SP) weapons	5,000
L	Armored personnel carriers (APC), cargo carriers, missile support vehicles, wreckers, recovery vehicles and cargo tractors (with towed load)	6,000
M	Engineer combat vehicle (ECF) and engineer assault vehicle, etc.	5,000
N	Engineer crawler tractors — military type	6,000
O	Amphibious vehicles (LVT type)	5,000
P	Turret-mounted accessories such as integrally mounted flamethrowers and searchlights	700
Q	Bulldozers	200
R	Fording kits	50

NOTES FOR FIGURES 514-1 AND 514-2

Aircraft equipment location

Curve	
A	Equipment installed on vibration isolated panels and racks when the panel or rack is not available for test and when specified in Table 514-I for aircraft application.
B	Equipment installed on vibartion isolated panels and racks when the panel or rack is not available for test and when specified in Table 514-I for helicopter application.
C	Equipment in forward half of fuselage or equipment in wing areas of aircraft with engines at rear of fuselage.
D	Equipment in rear half of fuselage or equipment in wing areas of aircraft with wing mounted engines or other locations not specifically mentioned for other curves.
E	Equipment located in the engine compartment or pylon.
F	Equipment mounted directly on aircraft engine.
G through L	Same as A and C through F where higher frequencies are anticipated.
M	Equipment designed for helicopter application.
Z	Equipment designed for both helicopter and airplane application.

Air launched vehicle (captive phase)

A, B	Same as for aircraft.
C	Equipment in vehicle attached to wing of aircraft with engine in rear of fuselage.
D	Equipment in vehicle carried in aircraft fuselage or attached to wing in aircraft with wing mounted engines.
H through K	Same as A, C, and D where higher frequencies are anticipated.

C 65

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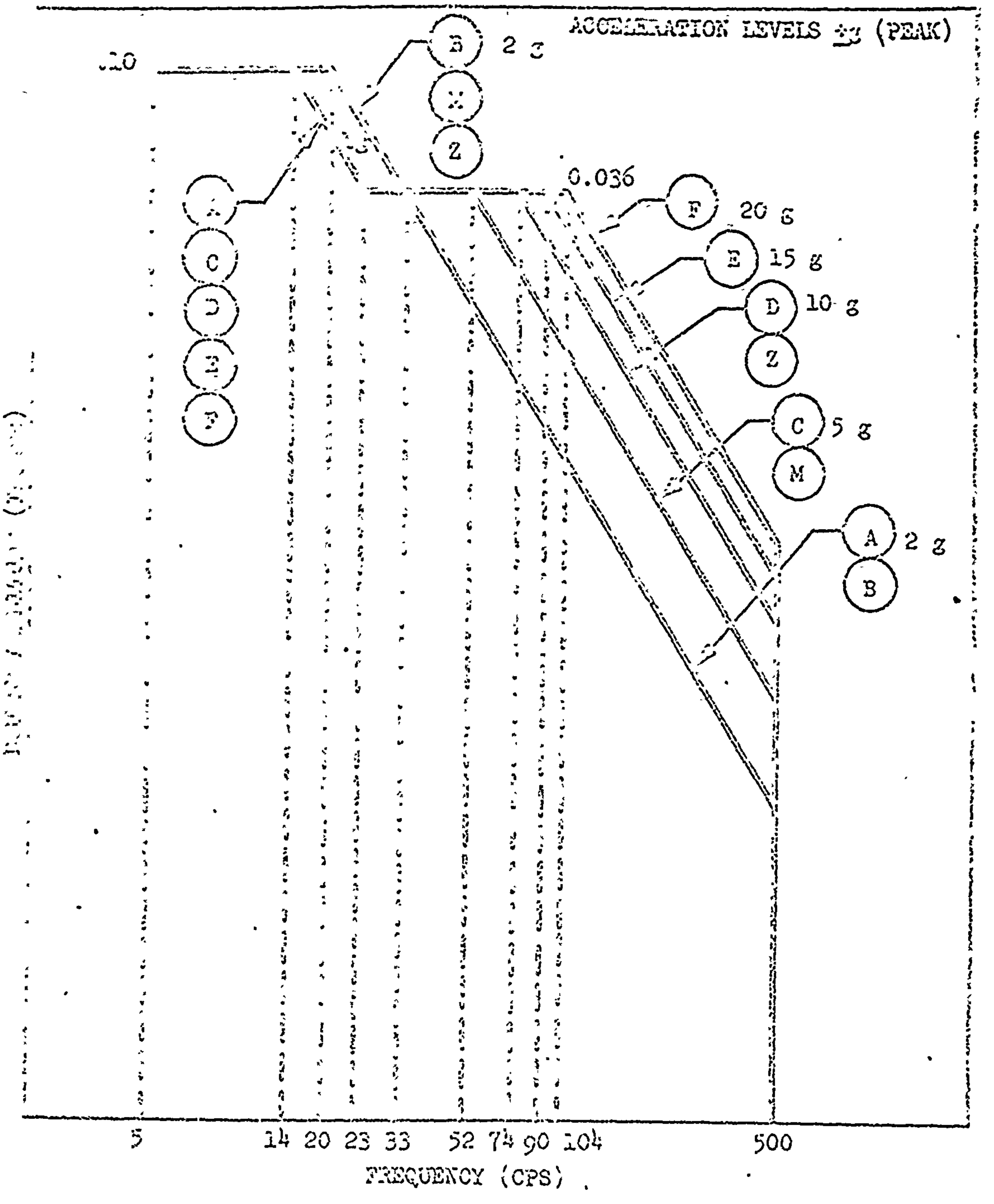


FIGURE 514-1. Vibration test curves (sinusoidal) aircraft and helicopter, and air launched vehicles (cruise phase) equipment with maximum frequency of 500 cps.

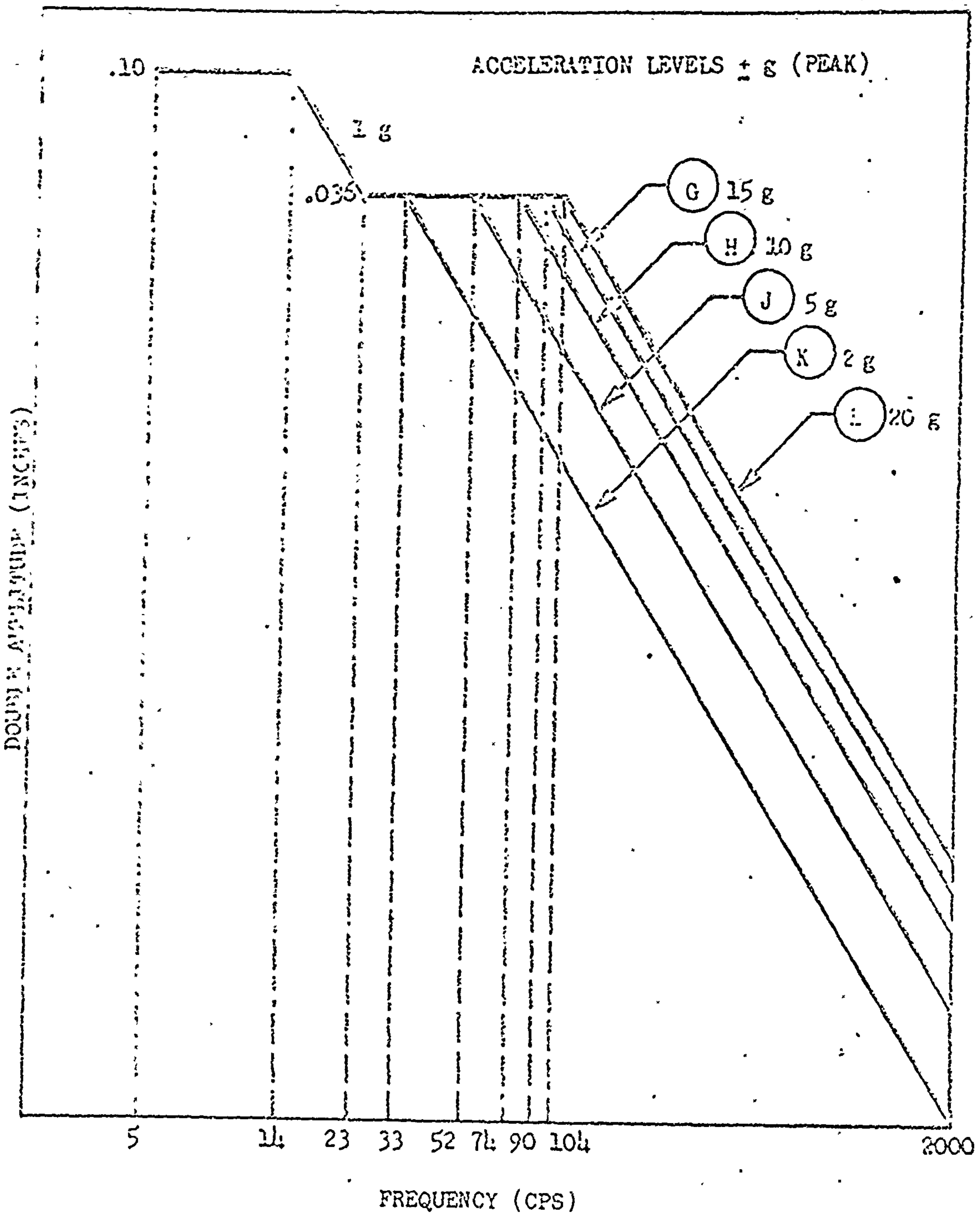


FIGURE 514-2. *Vibration test curves (sinusoidal) aircraft and air launched vehicle (captive phase) equipment with maximum frequency of 2,000 cps.*

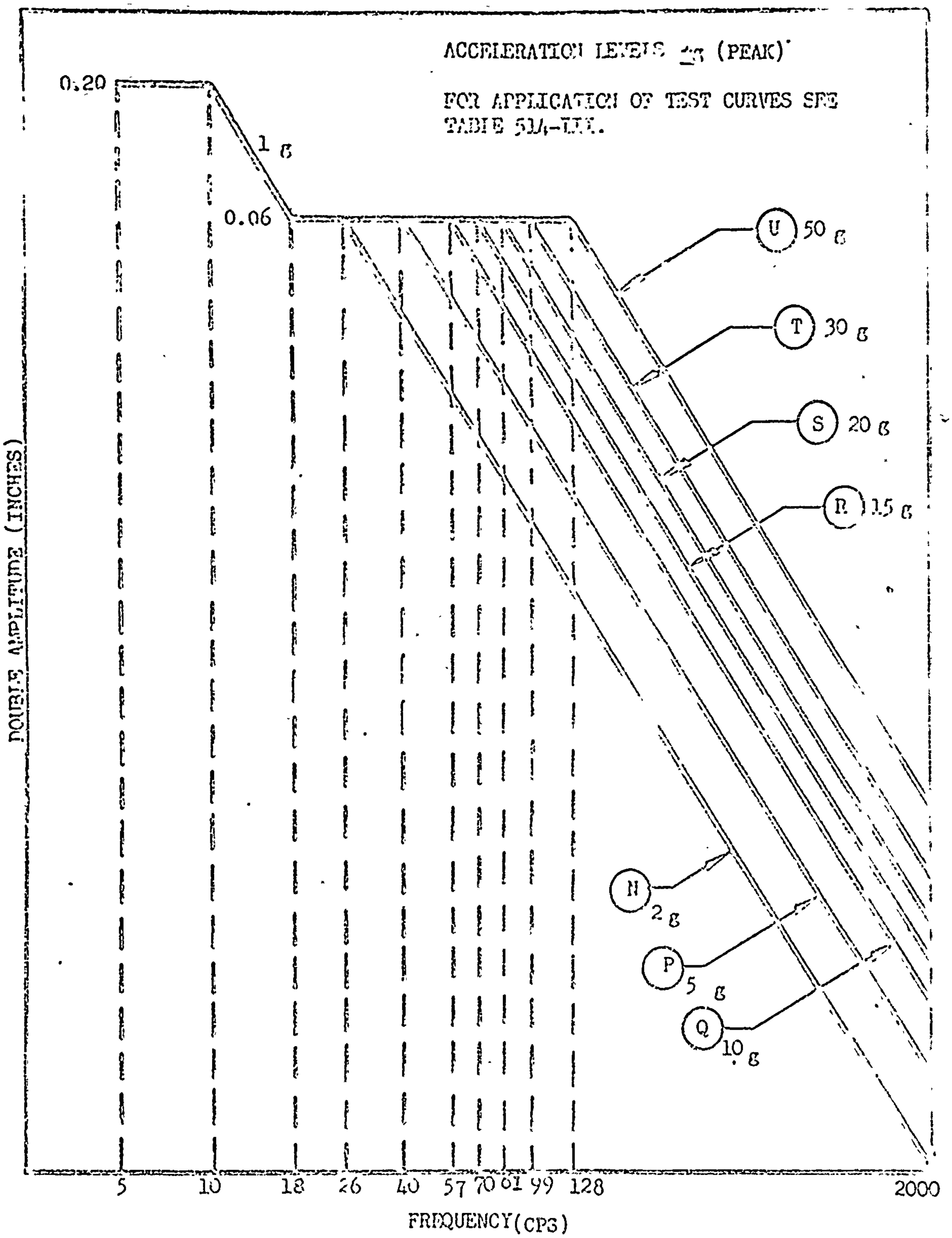
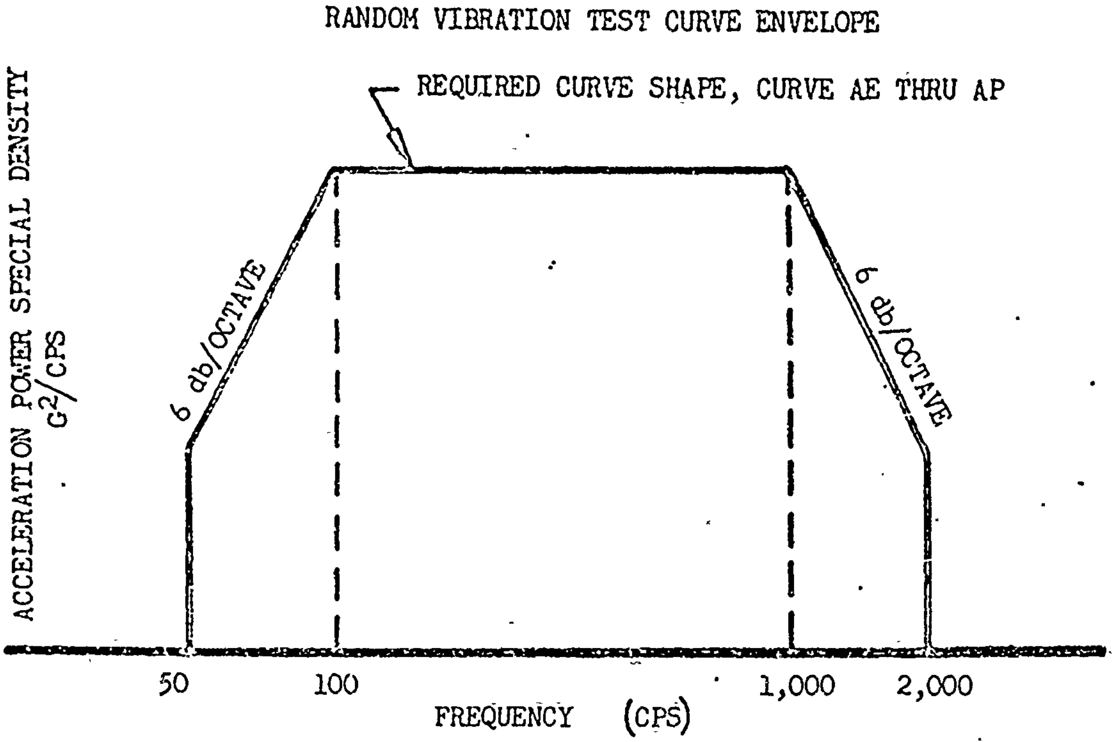


FIGURE 514-3. *Vibration test curves (sinusoidal), air launched vehicle (flight phase) and ground launched vehicle (flight phase) equipment.*



TEST CURVE	ACCELERATION POWER SPECTRAL DENSITY	OVERALL RMS G MINIMUM
AE	0.02	5.3
AF	0.04	7.4
AG	0.06	9.3
AH	0.1	11.9
AJ	0.2	16.9
AK	0.3	20.7
AL	0.4	23.9
AM	0.6	29.3
AN	1.0	37.8
AP	1.5	46.3

NOTE: $\text{OVERALL RMS G} = \left(\int_{f_1}^{f_2} W(f)df \right)^{\frac{1}{2}}$ Where f_1 & f_2 ARE THE LOWER AND UPPER TEST FREQUENCY LIMITS RESPECTFULLY; & $W(f)$ = ACCELERATION POWER SPECTRAL DENSITY, IN G^2/CPS UNITS.

FIGURE 514-4. *Vibration test curves (random), air launched vehicles (flight phase) and ground launched vehicles (flight phase) equipment.*

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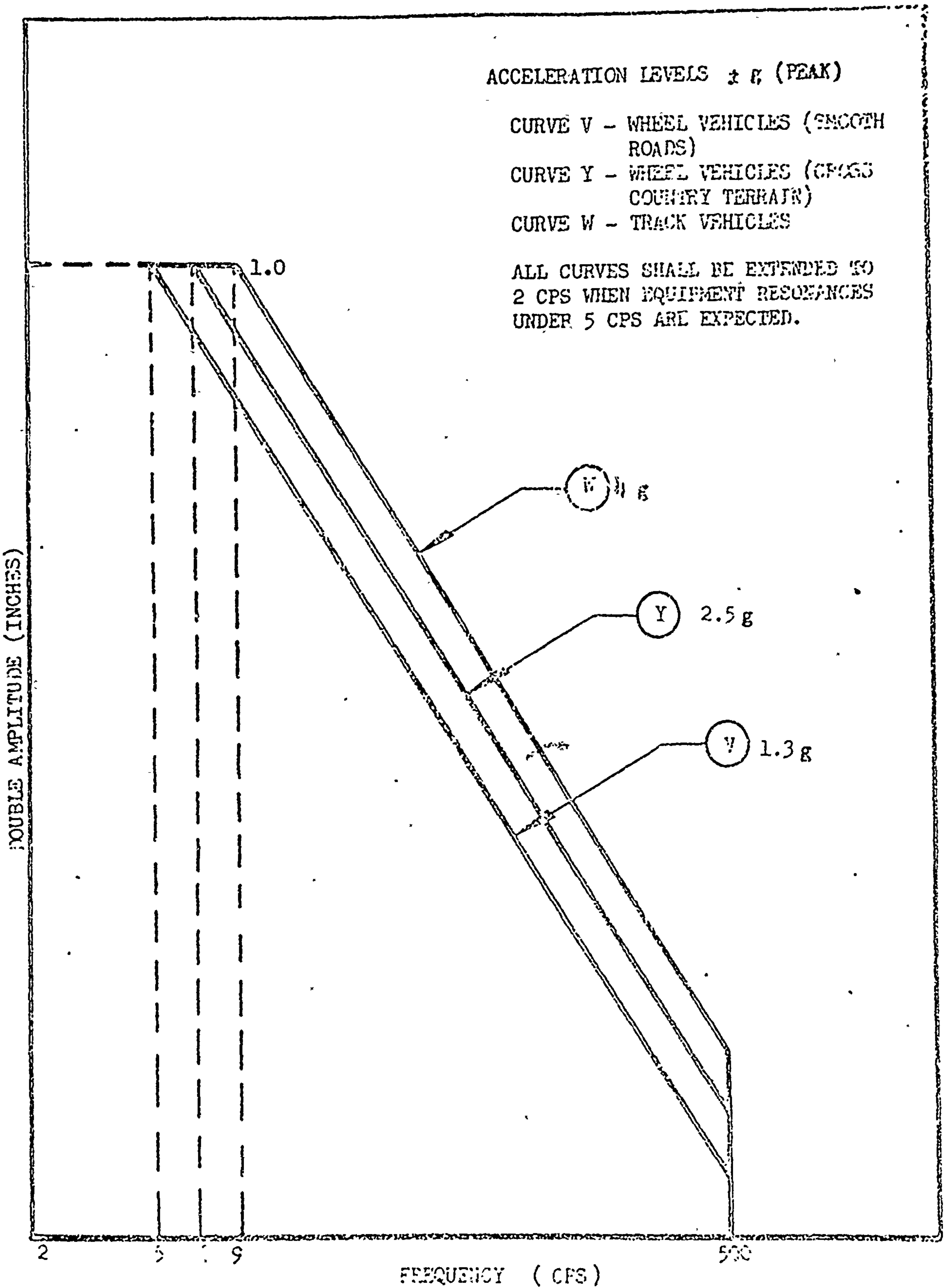

FIGURE 514-3. *Vibration test curves (sinusoidal) equipment installed in ground vehicles.*

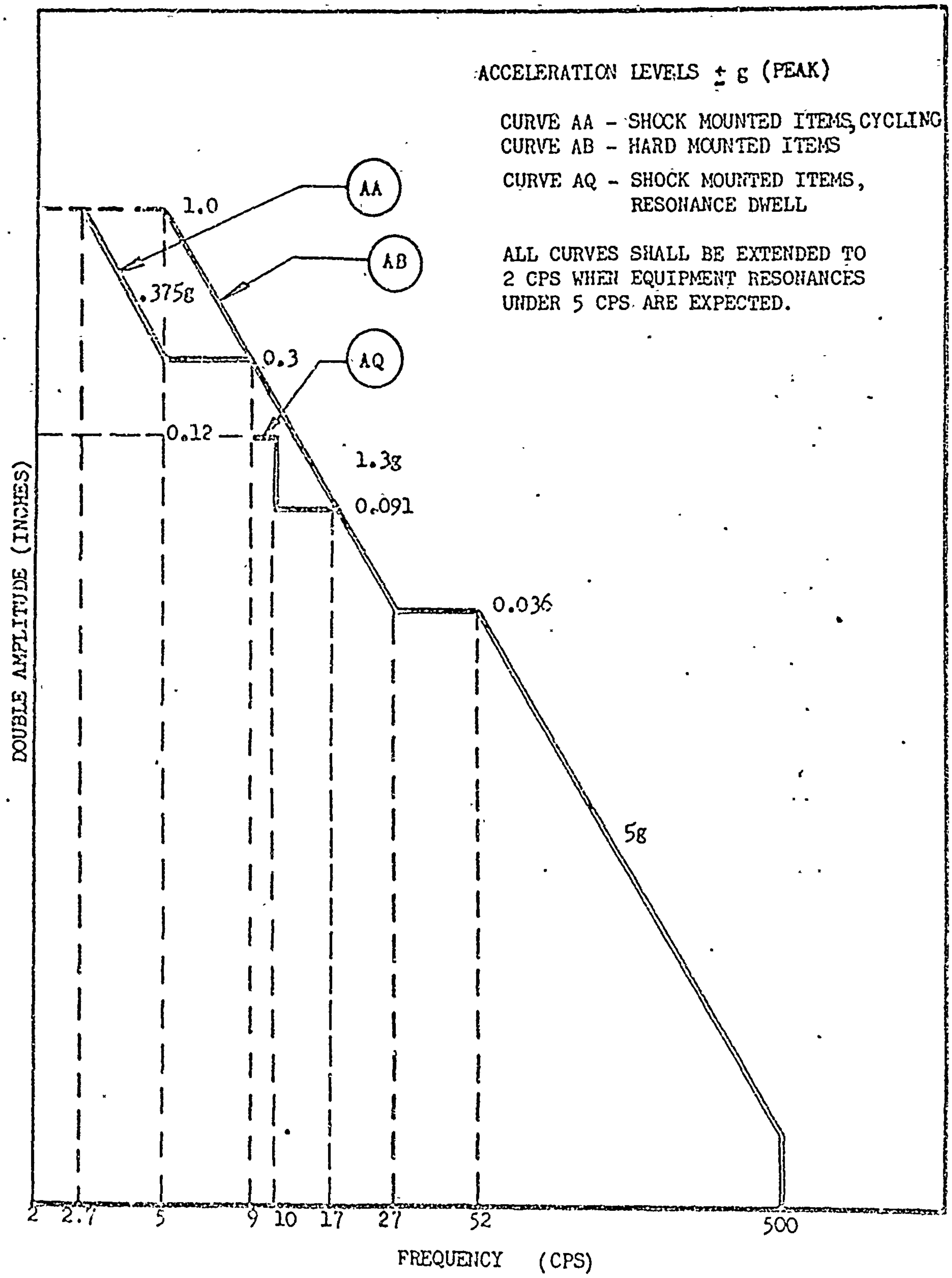

FIGURE 514-6. *Vibration test curves (sinusoidal) ground equipment and equipment transported by common carrier (land or air) tied down.*

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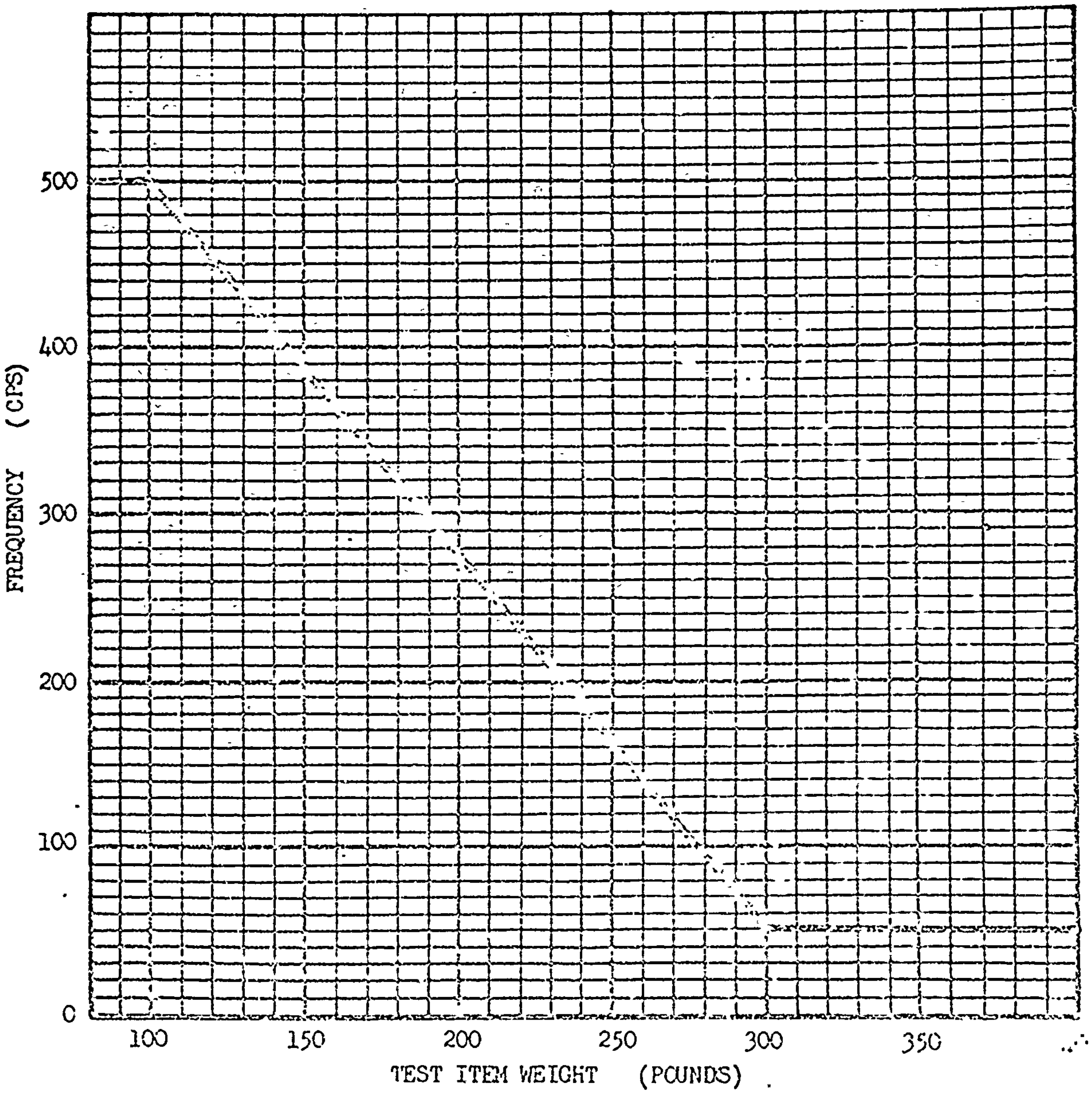

FIGURE 514-7. *Cut-off frequency vs. weight. Equipment shipped by common carrier, ground equipment and equipment installed in ground vehicles.*

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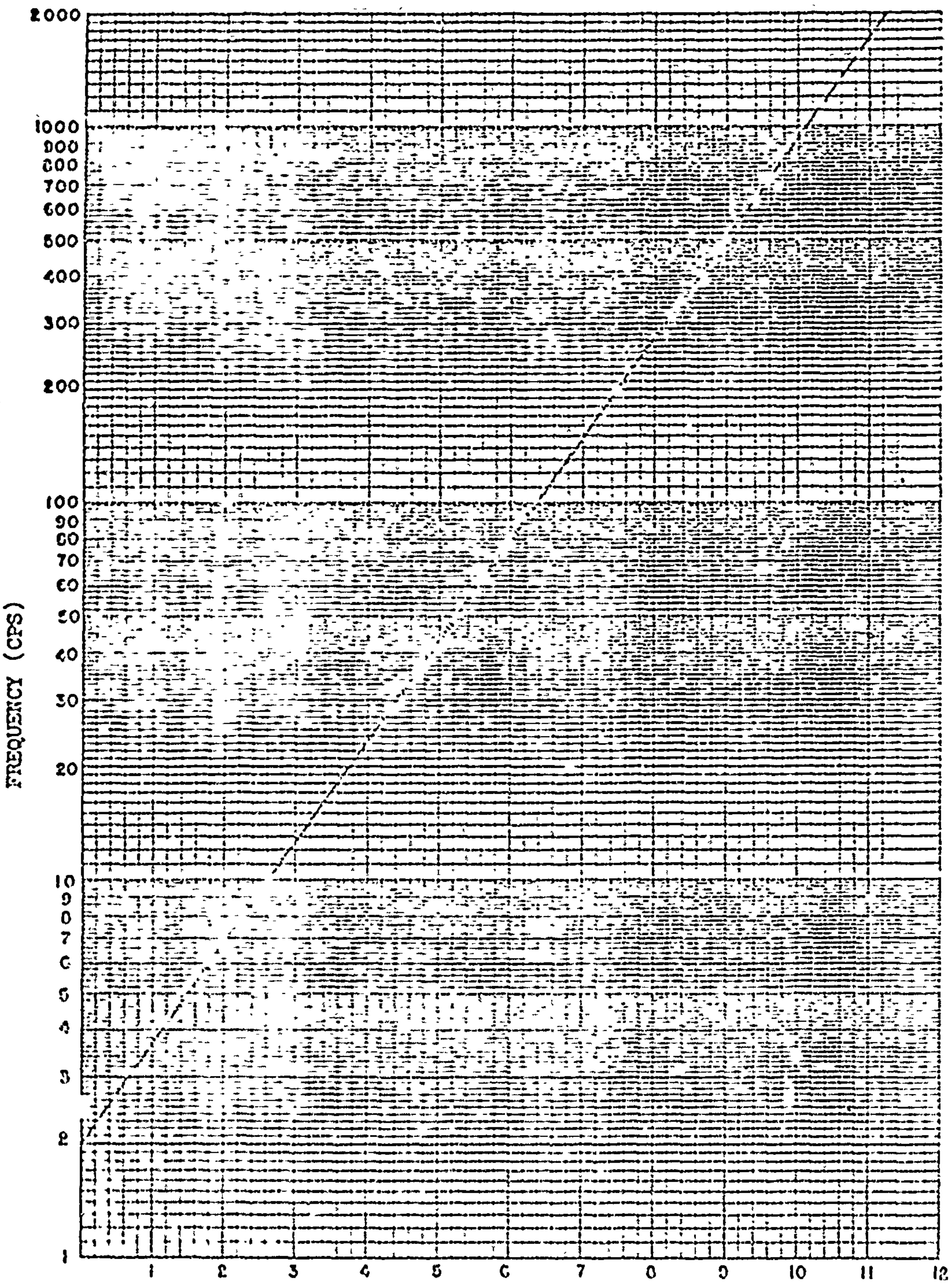

FIGURE 514-8. *Logarithmic cycling rates: For cycling tes's of less than 500 cps maximum frequency, the frequency range shall be cycled logarithmically from 5 cps to maximum in 7.5 minutes for the total cycling time specified.*

The Source for pages C-74 through C-81 is:
Military Standard Environmental Test Methods.
MIL-STD-810B, 15 June, 1967.

METHOD 516

SHOCK

1. Purpose. The shock test is conducted to determine that structural integrity and performance of equipment are satisfactory with respect to the mechanical shock environment expected in handling, transportation, and service use.

2. Apparatus.

2.1 Shock machine. The shock machine utilized for procedures I, III, and IV shall be capable of producing the specified input shock pulse shown in figure 516-1 or 516-2. The shock machine may be free fall, resilient rebound, nonresilient, hydraulic, compressed gas, or other.

2.1.1 *Shock machine calibration.* The actual test item, a rejected item, or a rigid dummy mass shall be used to calibrate the shock machine for conformance with the specified wave shape. When a rigid dummy mass is used, it shall have the same center of gravity and the same mass as that of the test item and shall be installed in a manner similar to that of the test item. (When a rigid dummy mass or rejected item is used for calibration, the waveform during the actual test may be somewhat different from that observed during calibration.) The calibrating load shall then be removed and the shock test performed on the actual test item. Provided all conditions remain the same, other than the substitution of the test item for the calibrating load, the test shall be considered to meet the requirements of the specified waveform. (It is recommended that the actual test waveform be recorded for later use in a failure analysis if the test item fails.)

2.2 Instrumentation. The instrumentation used to measure the input shock pulse, in order to meet the tolerance requirements of the test procedure, shall have the characteristics specified in the following paragraphs.

2.2.1 *Frequency response.* The frequency response of the complete measuring system, from the accelerometer through the readout instrument, shall be as specified by figure 516-3. Particular care shall be exercised in the selection of each individual instrument of the shock measuring instrumentation system in order to assure compatibility with the prescribed frequency response tolerance.

2.2.2 *Accelerometer, piezoelectric.* When a piezoelectric accelerometer is employed as the shock sensor, the fundamental resonant frequency of the accelerometer shall be greater than 14,000 cps (resonant frequencies of 30 kc or higher are recommended). For suitable low frequency response the accelerometer and load (cathode follower, amplifier, or other load) shall have the following characteristics:

$$RC > 0.2$$

Where R = Load resistance (ohms)
C = Accelerometer, capacitance plus shunt capacitance of cable and load (farads)

2.2.3 *Accelerometer, strain gage.* A strain gage accelerometer may be used, provided the undamped natural frequency is equal to or greater than 1,500 cps with damping approximately 0.61 to 0.70 of critical.

2.2.4 *Accelerometer calibration.* The accelerometer shall be calibrated against a standard transducer or by optical means.

2.2.5 *Accelerometer mounting.* The monitoring accelerometer shall be rigidly attached to the test item support fixture at or near the attachment point(s) of the test item.

3. Procedures.

3.1 Shock pulse. The shock pulses shall be as shown in figure 516-1 or 516-2 (whichever is specified in the equipment specification). All points of the acceleration wave form obtained shall lie within the area enclosed by the tolerance limit lines. In general, it is recommended that the saw tooth shock pulse be used, since its broad frequency spectrum tends to excite all resonant frequencies.

3.2 Mounting of test item. The test item shall be rigidly attached to the shock machine table for procedures I, III, and IV, in accordance with section 3, paragraph 3.2.2. Wherever possible, the test load shall be distributed uniformly on the test platform in order to minimize the effects of unbalanced loads.

3.3 Procedure I. Basic design test. This procedure shall be used for shock testing equipment assemblies (mechanical, electrical, hydraulic, electronic, etc.) of medium size, including items which mount on vibration isolators and equipment racks. Three shocks in each direction shall be applied along the three mutually perpendicular axes of the test item (total of 18 shocks). If the test item is normally mounted on vibration isolators, the isolators shall be functional during the test. The shock pulse shape shall be in accordance with either figure 516-1 or 516-2, of amplitude a or b and time duration c or d, as specified in the equipment specification. The test item shall be operating during the test if required by the equipment specification. At the conclusion of the test, the test item shall be operated and the results compared with the data obtained in accordance with section 3, paragraph 3.2.1. The test item shall then be inspected as specified in section 3, paragraph 3.2.4.

3.4 Procedure II. Transit drop test.

3.4.1 *Purpose.* The equipment, in its transit or combination case as prepared for field use, shall be capable of withstanding the shocks normally induced by loading and unloading of equipment.

3.4.2 *Test conditions.* The test item shall be in its transit or combination case. For equipment 1,000 pounds or less, the floor or barrier receiving the impact shall be of solid wood, 2-inch thick fir backed by concrete or a rigid steel frame. For equipment over 1,000 pounds, the floor or barrier shall be concrete or its equivalent.

3.4.3 *Performance of test.* Subject the test item to the number and heights of drop as required in table 516-I. Upon completion of the test, the test item shall be operated and the results compared with the data obtained in accordance with section 3, paragraph 3.2.1. The test item shall then be inspected as specified in section 3, paragraph 3.2.4.

TABLE 516-I. *Transit drop test (procedure II)*

Weight of test item, including case	Largest dimension (inches)	Notes	Height of drop (in.)	No. of drops
Under 100 pounds man-packed and man-portable	Under 36	A	48	Drop on each face, edge, and corner. Total of 26 drops.
	36 and over	A	30	
100 to 200 pounds, inclusive	Under 36	A	30	Drop on each corner. Total of 8 drops.
	36 and over	A	24	
Over 200 to 1,000 pounds, inclusive	Under 36	A	24	
	36 to 60	B	36	
	Over 60	B	24	

TABLE 516-I. *Transit drop test (procedure II)* (Continued)

Weight of test item, including case	Largest dimension (inches)	Notes	Height of drop (in.)	No. of drops
Over 1,000 pounds	No limit	C	18	4 edgewise drops. 2 corner drops.

Note A. Drops shall be made from a quick-release hook; or pendulum tester as made by the L.A.B. Corporation, Skaneateles, New York, or equal. The test item shall be oriented for the corner drops so that the sides are at an angle of 45 degrees.

Note B. With the longest dimension parallel to the floor, the transit or combination case, with the test item within, shall be supported at the corner of one end by a block 5 inches in height, and at the other corner of the same end by a block 12 inches in height. The opposite end of the case shall then be raised to the specified height at the lowest unsupported corner and allowed to fall freely.

Note C. With the normal transit position and the largest dimension in that position parallel to the floor, the transit or combination case, with the test item within, shall be subjected to the edgewise and cornerwise drop test as follows:

1. *Edgewise drop test.* One edge of the base of the test item shall be supported on a sill 5 to 6 inches in height. The opposite edge shall be raised to the specified height and allowed to fall freely. The test shall be applied once to each edge of the base of the test item (total of four drops).
2. *Cornerwise drop test.* One corner of the base of the test item shall be supported on a block approximately 5 inches in height. A block nominally 12 inches in height shall be placed under the other corner of the same end. The opposite end of the test item shall be raised to the specified height at the lowest unsupported corner and allowed to fall freely. This test shall be applied once to each of two diagonally opposite corners of the base (total of two drops). When the proportions of width and height of the test item are such as to cause instability in the cornerwise drop test, edgewise drops shall be substituted. In such instances two more edgewise drops on each end shall be conducted (total of four drops).

3.5 Procedure III. Crash safety test. This test is conducted to determine the structural integrity of equipment mounting means. The test item or dummy load shall be attached by its normal points of attachment. The test item or dummy load shall be subjected to two shocks in each direction along the three mutually perpendicular axes of the equipment (total of 12 shocks). The shock pulse shape shall be in accordance with either figure 516-1 or 516-2, of amplitude a or b and time duration c or d, as specified in equipment specification. There shall be no failure of the mounting attachment and the test item or dummy load shall remain in place and not create a hazard. However, bending and distortion shall be permitted.

3.6 Procedure IV. High intensity test. This procedure shall be used where high acceleration, short time duration shock excitation results from handling, stage ignition, separation, re-entry, and high velocity aerodynamic buffeting experienced by missiles and high performance weapon systems. This test shall be utilized for testing such items as small, high density electronic equipments and other items of small size mounted without shock and vibration isolators. Two shocks shall be applied to the test item in each direction along each of the three mutually perpendicular axes (total of 12 shocks). The shock pulse shape shall be in accordance with either figure 516-1 or 516-2, of amplitude a or b and time duration c or d, as specified in equipment specification. The test item shall be operating during the test if required by the equipment specification. At the conclusion of the test, the test item shall be operated and the results compared with the data obtained in accordance with section 3, paragraph 3.2.1. The test item shall then be inspected as specified in section 3, paragraph 3.2.4.

3.7 Procedure V. Bench handling test. This test is conducted to determine the ability of equipment to withstand the shock encountered during servicing. The chassis and front panel assembly shall be removed from its enclosure, as for servicing, and placed in a suitable position for servicing on a horizontal, solid wooden bench top at least 1-3/4 inches thick. The test shall be performed, as follows, in a manner simulating shocks liable to occur during servicing:

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Step 1—Using one edge as a pivot, lift the opposite edge of the chassis until one of the following conditions occurs (whichever occurs first):

(a) The chassis forms an angle of 45 degrees with the horizontal bench top.

(b) The lifted edge of the chassis has been raised 4 inches above the horizontal bench top.

(c) The lifted edge of the chassis is just below the point of perfect balance.

Let the chassis drop back freely to the horizontal bench top. Repeat, using other practical edges of the same horizontal face as pivot points, for a total of four drops.

Step 2—Repeat step 1, with the test item resting on other faces until it has been dropped for a total of four times on each face on which the test item could be placed practicably during servicing. The test item shall not be operating during the test. At the conclusion of the test, the test item shall be operated and the results compared with the data obtained in accordance with section 3, paragraph 3.2.1. The test item shall then be inspected as specified in section 3, paragraph 3.2.4.

3.8 Procedure VI. Rail impact test. This test is performed to determine the effect that impact, due to shipping and other types of transportation, will have on equipment. If an item can be shipped in two orientations, it shall be impacted once in each direction of each orientation at speeds of 8, 9, and 10 miles per hour (total of 12 impacts). If an item can be shipped only in one orientation, it shall be impacted twice in each direction of each orientation at speeds of 8, 9, and 10 miles per hour (total of 12 impacts).

3.8.1 *Apparatus.* The following equipment will be necessary to perform this test:

(a) Three ordinary railroad cars, only one of which is a flat car, with standard draft gear couplings.

(b) A prime mover for moving the cars.

(c) A calibrated means to determine the speed at time of impact within ±5 percent.

(d) Accelerometers and associated circuitry to measure the impact shock, if required by the equipment specification.

3.8.2 *Performance of test.*

(a) Two cars will act as buffer cars and be located on a level section of track. The air brakes shall be set in the emergency application position on both cars. The total buffer load excluding car weights shall be 140,000 pounds minimum.

(b) The test item shall be mounted on the end of the test car (flat) in direct contact with the floor and adequately blocked and secured to prevent any longitudinal, vertical, or lateral movement. Metal banding, or wire, of sufficient size or strength shall be used to provide additional tiedown strength. Positions of the equipment with respect to the test car and whether or not packaging is necessary shall be specified in the equipment specification.

(c) Impact the test car (flat) into the two loaded cars.

(d) Impacts shall be made in progres-

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sive steps with impacts at 8, 9, and 10 miles per hour. The speed just prior to impact shall be measured by electronic or electrical means having an accuracy of ±5 percent.

3.9 Related shock tests.

3.9.1 *Missile impact.* A test for simulating missile impact, hard landings, etc., may be performed by employing a rocket sled test facility with a suitable impact barrier.

3.9.2 *Hardsites.* Equipment located in or at missile hardsites usually demands special tests, however, for some zones special adaptations of conventional shock machines can be used. For the critical zones, shock tubes, explosion chambers, hydraulic actuators, etc., can be used.

3.9.3 *High impact.* Unless otherwise specified, ballistic shock tests and high impact tests shall be conducted in accordance with MIL-S-901.

3.9.4 *Shipboard equipment.* Shock tests for shipboard equipment shall be conducted in accordance with MIL-S-901.

3.10 Combined temperature-shock test. Tests shall be conducted under room ambient conditions unless the equipment specification requires a high or low temperature shock test in which case the temperature extremes shall be as specified in the equipment specification.

4. Summary.

The following details shall be specified in the equipment specification:

(a) Pretest data required (section 3, paragraph 3.2.1).

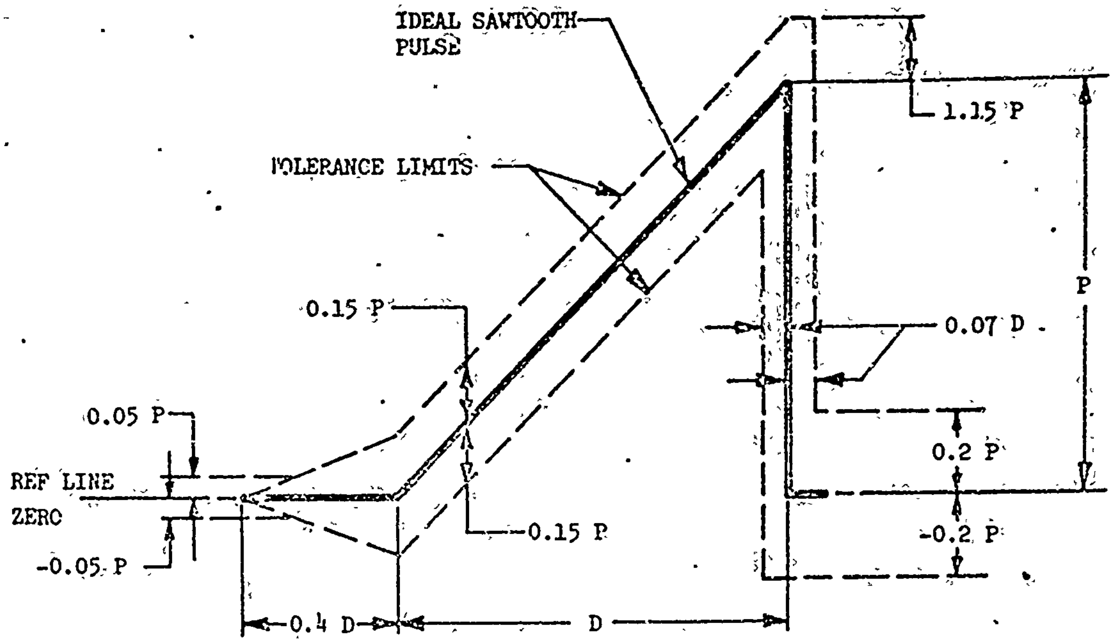
(b) Procedure number.

(c) Shock pulse selection, specify shape, peak value, and duration.

(d) Temperature extremes (see 3.10).

(e) Filter(s) used shall be identified.

(f) Whether operation during the test is required, and if and how the operation is to be monitored.

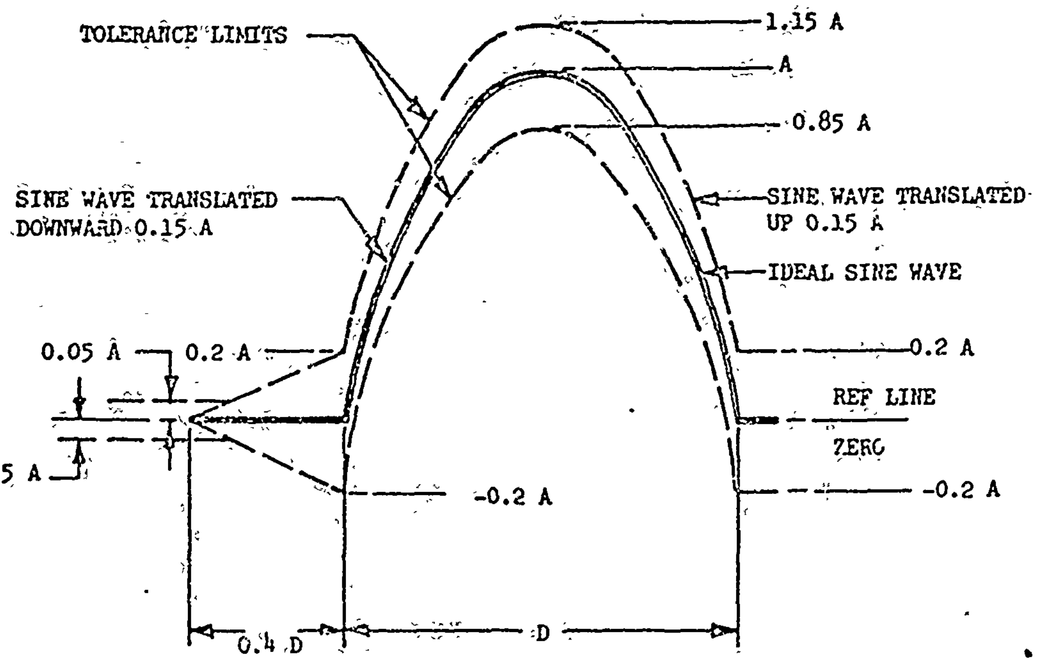


PROCEDURE	TEST	PEAK VALUE (P) g's		NOMINAL DURATION (D) ms	
		FLIGHT VEHICLE EQUIPMENT (a)	GROUND EQUIPMENT (b)	FLIGHT VEHICLE EQUIPMENT (c)	GROUND EQUIPMENT (d)
I	BASIC DESIGN	20	40	11	18
III	CRASH SAFETY	40	75	11	11
IV	HIGH INTENSITY	100	100	6	11

NOTE: SHOCK PARAMETERS (a) AND (c): RECOMMENDED FOR EQUIPMENT NOT SHOCK MOUNTED AND WEIGHING LESS THAN 300 POUNDS.

THE OSCILLOGRAM SHALL INCLUDE A TIME ABOUT 3D LONG WITH A PULSE LOCATED APPROXIMATELY IN THE CENTER. THE PEAK ACCELERATION MAGNITUDE OF THE SAWTOOTH PULSE IS P AND ITS DURATION IS D. ANY MEASURED ACCELERATION PULSE WHICH CAN BE CONTAINED BETWEEN THE BROKEN LINE BOUNDARIES IS ACCEPTABLE. THE MEASURED VELOCITY CHANGE (WHICH MAY BE OBTAINED BY INTEGRATION OF THE ACCELERATION PULSE) SHALL BE WITHIN THE LIMITS OF V_i ±0.1 V_i, WHERE V_i IS THE VELOCITY CHANGE ASSOCIATED WITH THE IDEAL PULSE WHICH EQUALS 0.5 DP. THE INTEGRATION TO DETERMINE VELOCITY CHANGE SHALL EXTEND FROM 0.4D BEFORE THE PULSE TO 0.1D BEYOND THE PULSE.

FIGURE 516-1. *Terminal-peak sawtooth shock pulse configuration and its tolerance limits.*



PROCEDURE	TEST	PEAK VALUE (A) g's		NOMINAL DURATION (D) ms	
		FLIGHT VEHICLE EQUIPMENT (a)	GROUND EQUIPMENT (b)	FLIGHT VEHICLE EQUIPMENT (c)	GROUND EQUIPMENT (d)
I	BASIC DESIGN	15	40	11	18
III	CRASH SAFETY	30	75	11	11
IV	HIGH INTENSITY	100	100	6	6

NOTE: SHOCK PARAMETERS (a) AND (c): RECOMMENDED FOR EQUIPMENT SHOCK MOUNTED OR WEIGHING 300 POUNDS OR MORE.

THE OSCILLOGRAM SHALL INCLUDE A TIME ABOUT 3D LONG WITH A PULSE LOCATED APPROXIMATELY IN THE CENTER. THE ACCELERATION AMPLITUDE OF THE IDEAL HALF SINE PULSE IS A AND ITS DURATION IS D. ANY MEASURED ACCELERATION PULSE WHICH CAN BE CONTAINED BETWEEN THE BROKEN LINE BOUNDARIES IS ACCEPTABLE. THE MEASURED VELOCITY CHANGE (WHICH MAY BE OBTAINED BY INTEGRATION OF THE ACCELERATION PULSE) SHALL BE WITHIN THE LIMITS $V_i \pm 0.1\ V_i$ WHERE V_i IS THE VELOCITY-CHANGE ASSOCIATED WITH THE IDEAL PULSE WHICH EQUALS $2\ AD/\pi$. THE INTEGRATION TO DETERMINE VELOCITY CHANGE SHALL EXTEND FROM 0.1D BEFORE THE PULSE TO 0.1D BEYOND THE PULSE.

FIGURE 516-2. *Half sine shock pulse configuration and its tolerance limits.*

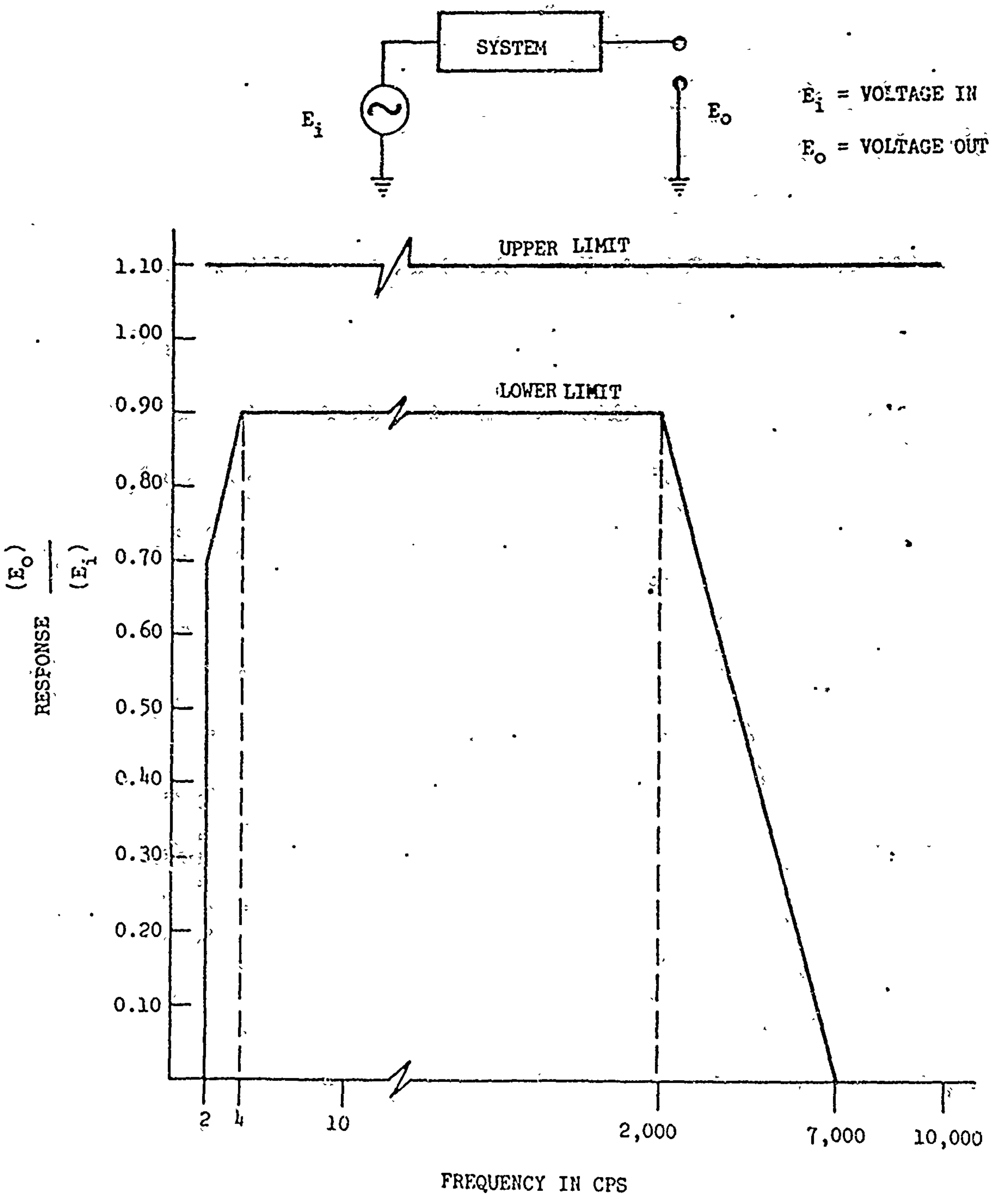


FIGURE 516-3. *System frequency response.*

Appendix D

University Consultants, Inc.

LASHING SYSTEMS

FOR

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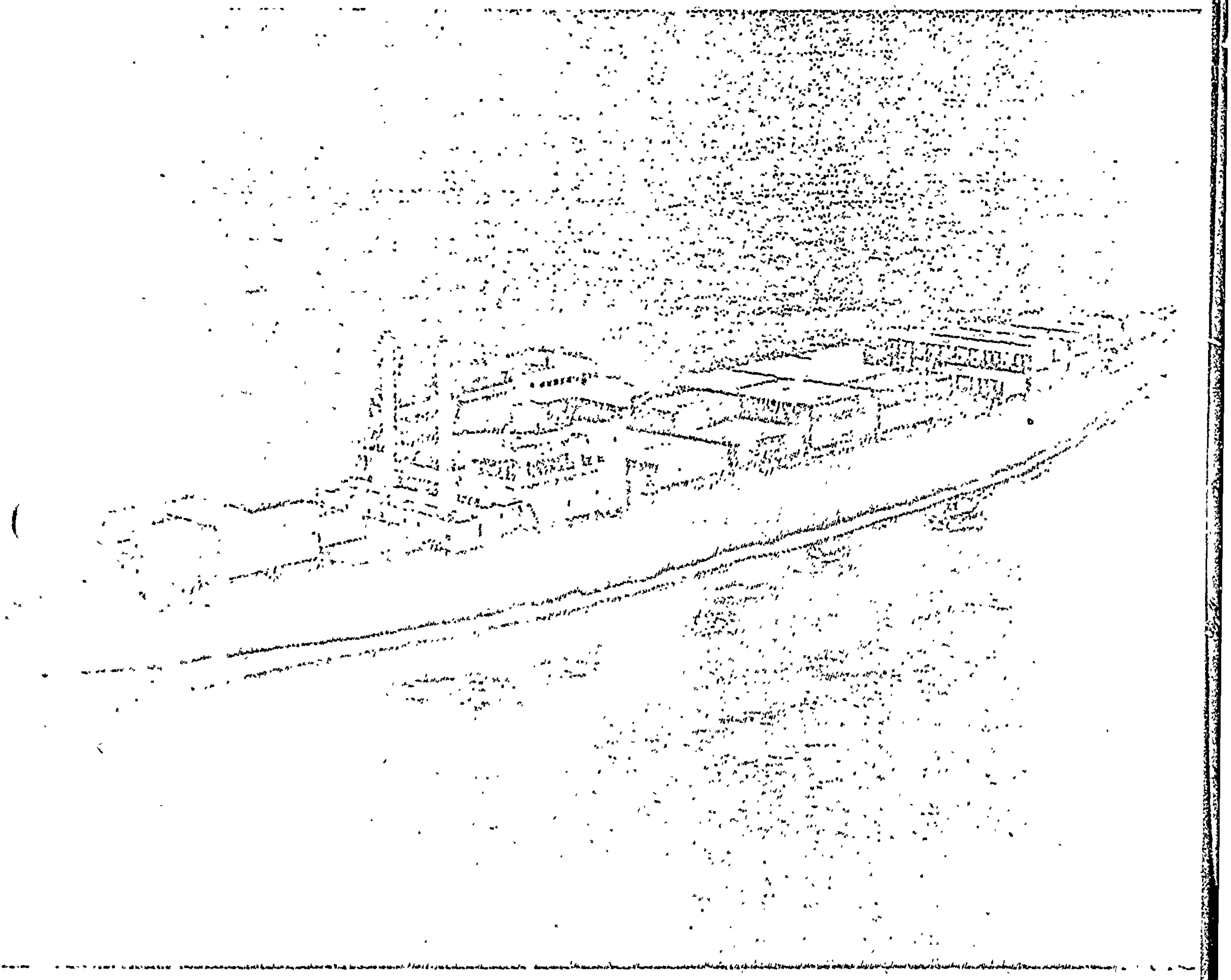
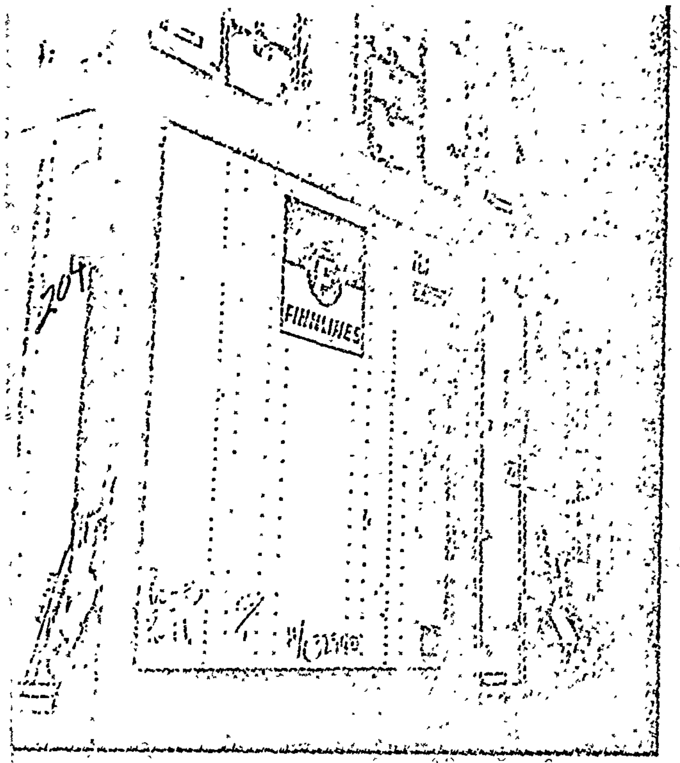
CONTAINERS • RO/RO • VEHICLES & HEAVY LIFTS



U.S. LINES "AMERICAN LEGION" completely equipped with Peck & Hale container lashings & fittings

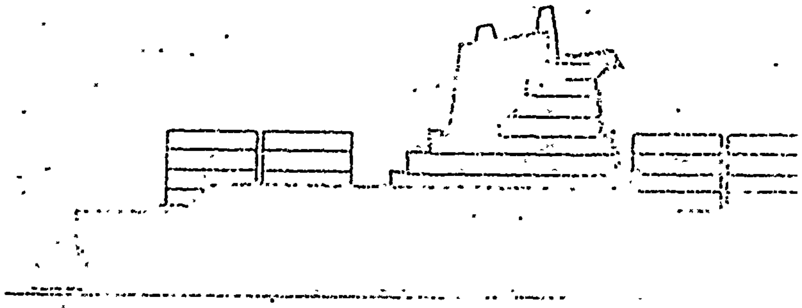
PECK & HALE INC.

WEST SAYVILLE, LONG ISLAND, NEW YORK 11796
TEL. 516 LT 9-2510, 212 FL 7-4031 TWX 510-228-7796



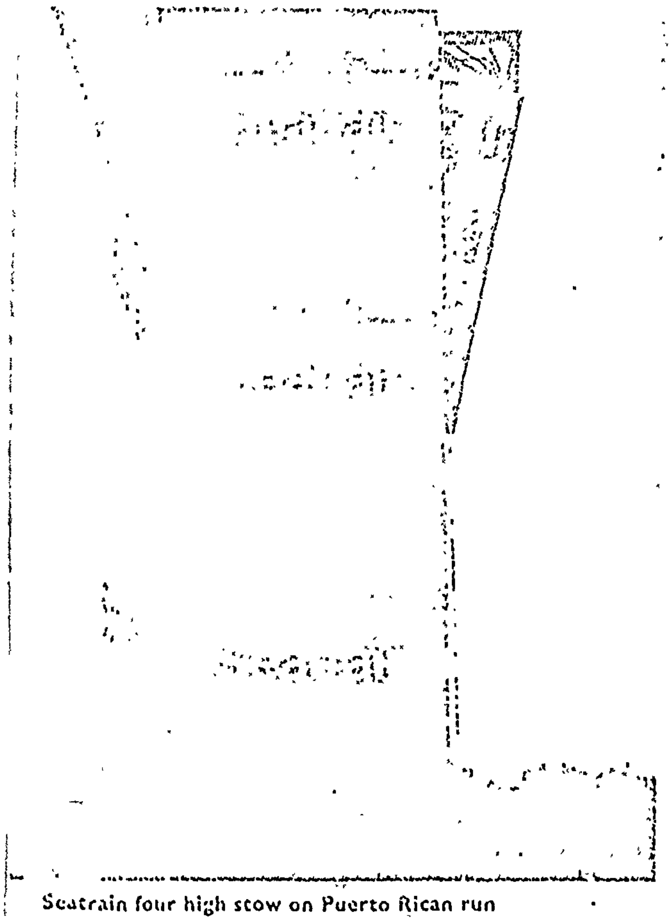
Finnlines two high stow with vertical lashings

ENGINEERED SECURING



Views of cargo stowage showing P & H Adjust-a-matic Lashing Cables, which have been widely adopted because:

1. Fast and easy operation
2. Little or no maintenance
3. Repeated uses
4. Will not ease off or open in heavy sea conditions



Seatrain four high stow on Puerto Rican run

CARGO SYSTEMS

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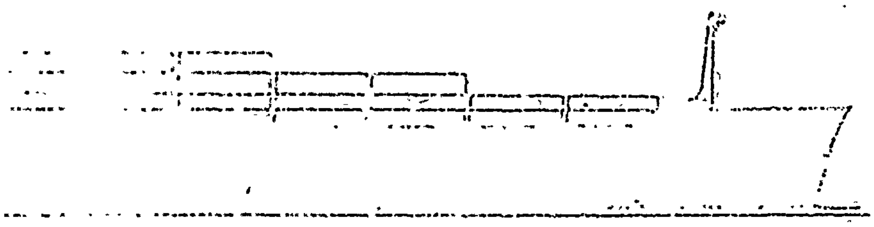


FOR

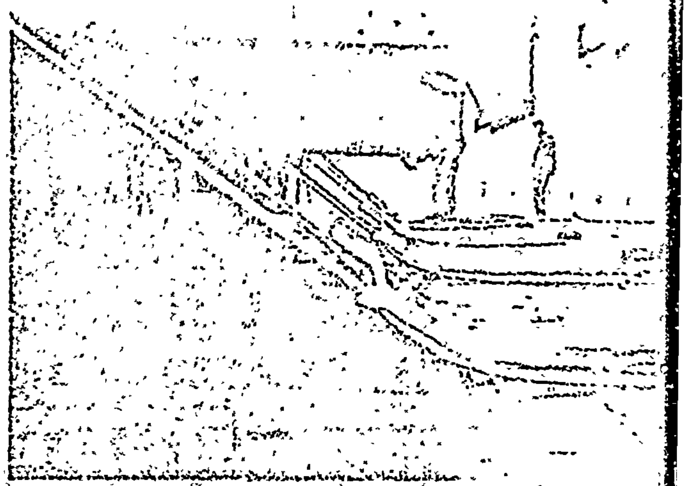
CONTAINERS

ROLL-ON ROLL-OFF

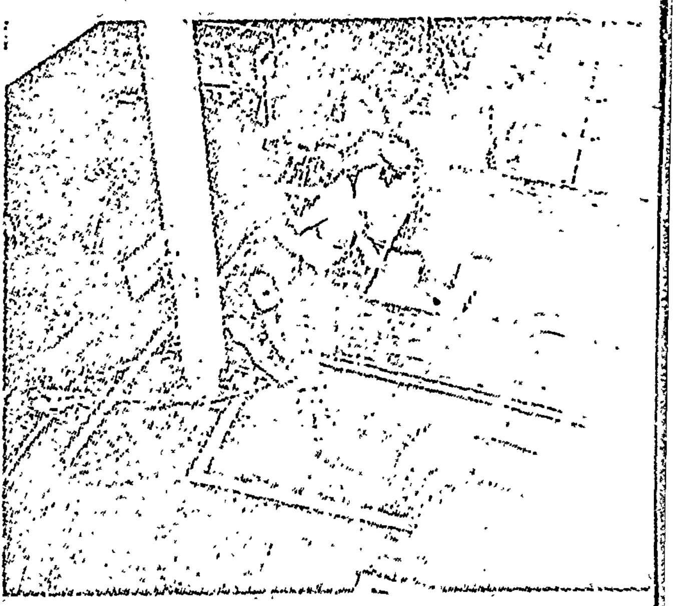
VEHICLES

AND

HEAVY LIFTS



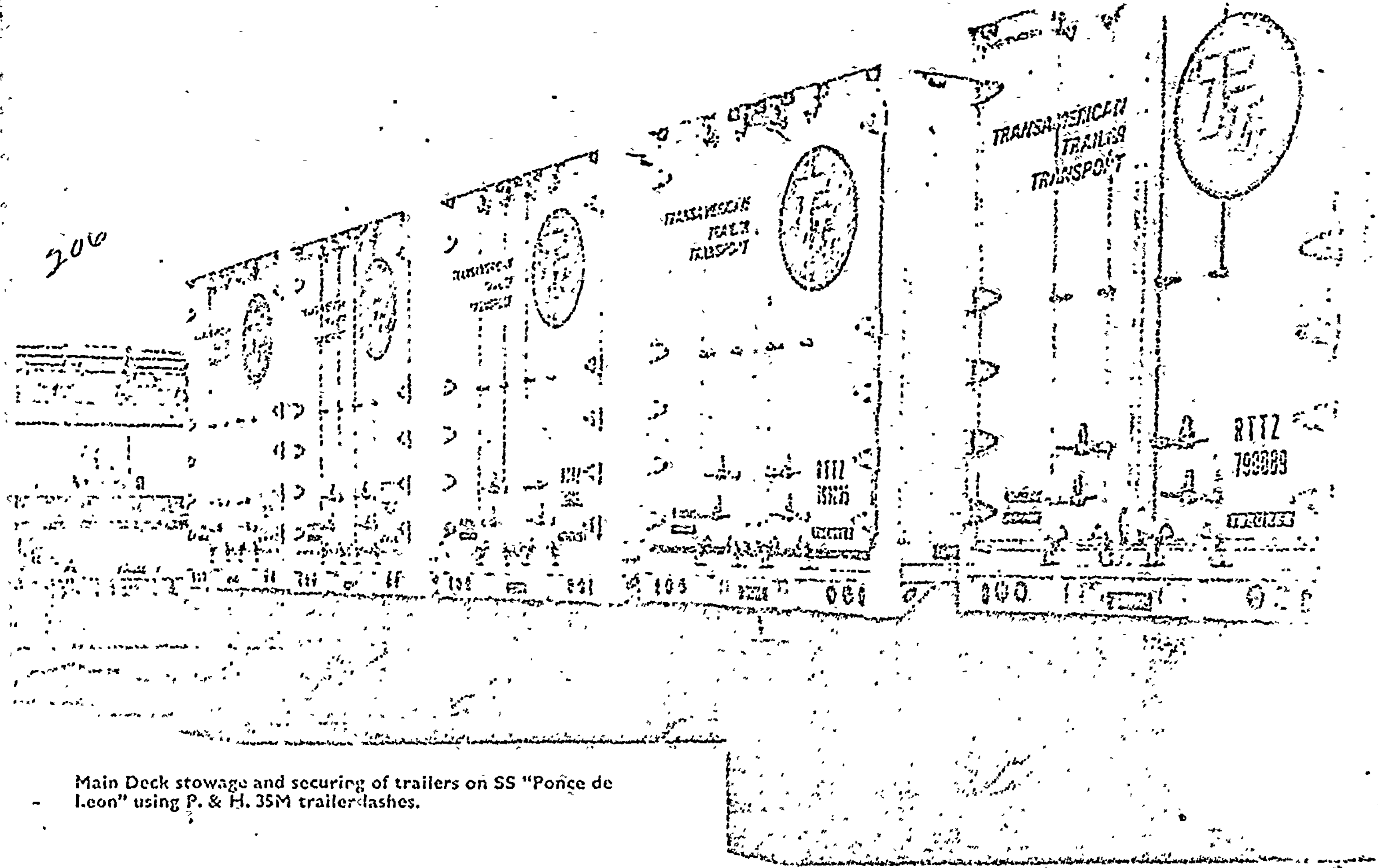
S.S. Ponce de Leon, a new ro/ro vessel uses P & H 35M Adjust-matic Cables with recoil-less handle on tensioner



U.S. Lines—Mixed stow of heavy-lift vehicles are lashed with inter changeable P & H lashes and are anchored to P & H F105/ "D" Rings

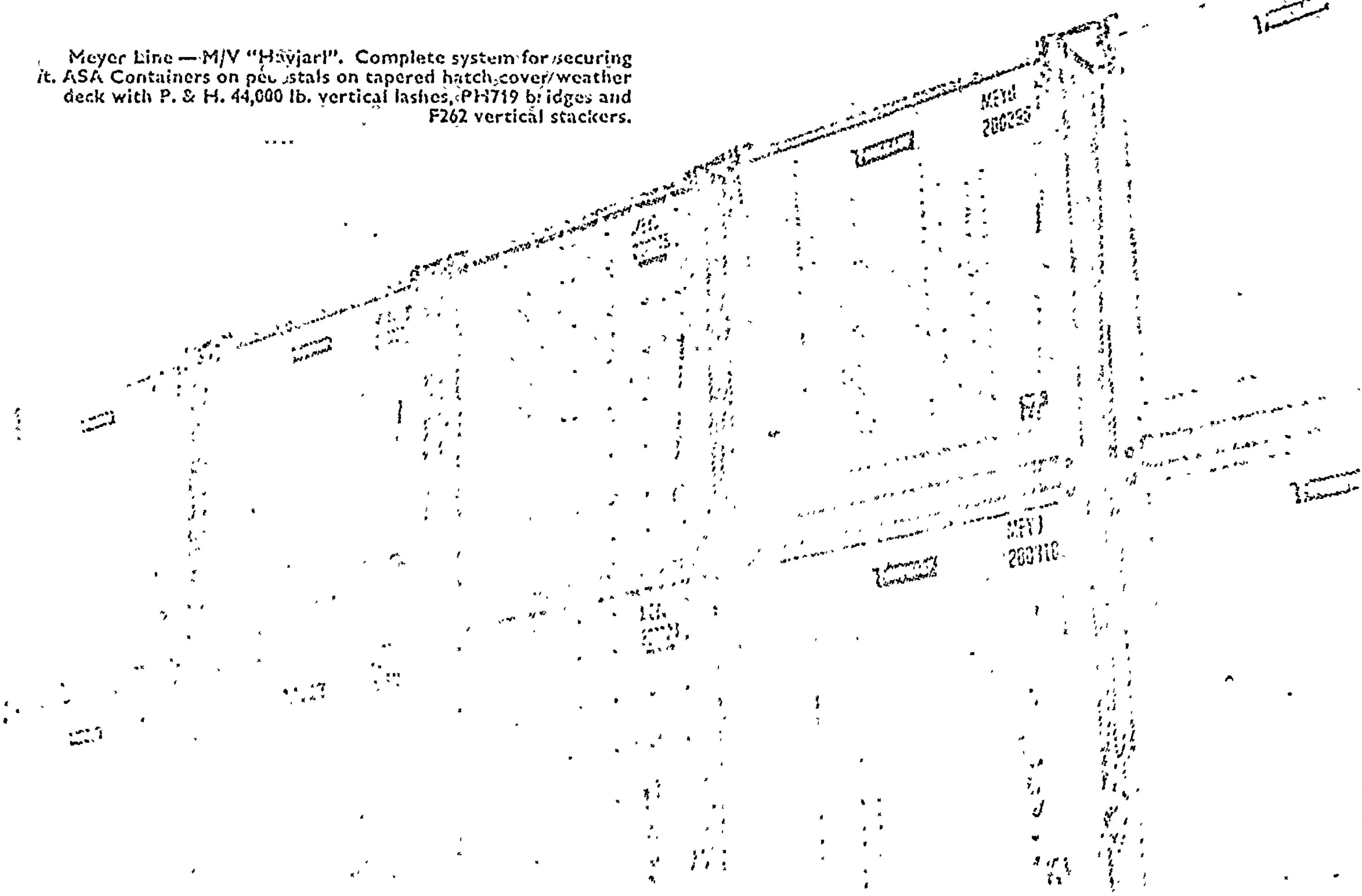
Transamerican Trailer Transport—P & H 7M car lashes with specially designed hook to engage clover leaf deck fittings are shown

200



Main Deck stowage and securing of trailers on SS "Ponce de Leon" using P. & H. 35M trailer lashes.

Meyer Line — M/V "Høyjarl". Complete system for securing it. ASA Containers on pedestals on tapered hatch cover/weather deck with P. & H. 44,000 lb. vertical lashes, PH719 bridges and F262 vertical stackers.



PECK & HALE INC.

West Sayville,
Long Island,
New York 11796

Established in 1947, Peck & Hale is a pioneer manufacturer of basic and specialized cargo securing and load control systems for the Transport Industry. All Peck & Hale products and systems have been designed and perfected to meet the requirements of modern cargo handling at lower cost.

The basic systems described herein are adapted to each user's requirements by an experienced engineering and installation staff. This staff is available to research and solve the customer's related cargo securing problems.

All installations are initially supervised to insure satisfactory operation.

The range of basic equipment manufactured by Peck & Hale includes:

- **Adjust-a-matic Cables and Lashing Gear for tieing down or lashing cargo, both break-bulk and containerized.**
- **Roll-flex Net Shoring Systems — wire rope nets for securing break-bulk cargo.**
- **D-rings, deck pads and sockets, etc.**
- **Container securing fittings — bridges, stackers, couplers.**

Peck & Hale systems were developed by experience from the earliest days of Containerization. The Company now possesses the widest experience of Container securing. P. & H. equipment and systems are used by many of the leading Shipping Lines in North America and Europe.

P. & H. systems are also used extensively for safe, reliable securing of Roll-on/Roll-off vehicles.

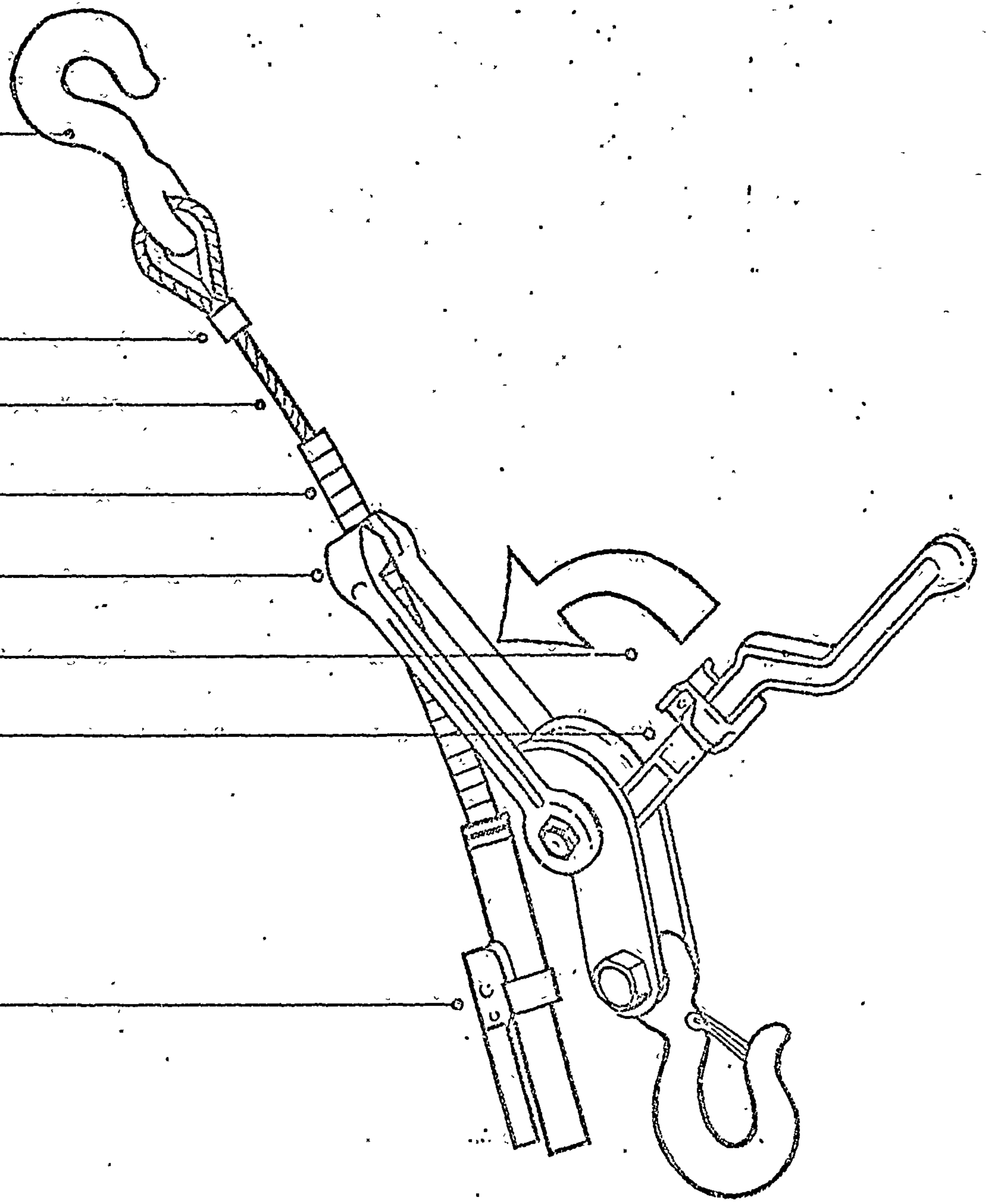
Some of the Owners who entrust the safety of their cargo to the reliability of P. & H. gear are listed below:

American Export Isbrandtsen Lines
American Mail Lines
Belgian Lines
Bristol City Line
British Ykon Navigation Co.
Canadian National Railway
Central Gulf Lines
Container Marine Lines
Farrell Lines
Finnlines
Grace Lines
Grancolombiana
Hapag Lloyd
Italian Line
Lykes Lines
Matson Lines
Meyer Lines
Moller (Maersk) Lines
Moore-McCormack Lines
Motorships, Inc.
Pacific Far East Lines
Peruvian State Lines
Prudential Lines
Sea-Land
Seatrain Lines
South Atlantic & Caribbean Lines
States Line
States Marine Lines
Transamerican Trailer Transport
United States Lines
U.S. Military Sea Transport Service
United States Navy

Adjust-a-matic Cable

(patented)

72



- End fittings to suit customer's requirements.
- Swaged fittings used on all models equal to rated cable strength.
- Finest aircraft quality wire rope — galvanized — stainless, or special types. (Quality certified.)
- Small sliding bead spacers for rapid length adjustment and maximum tension.
- Tensioner jaw receives bead spacers without damage to cable.
- Tension is automatically applied to lash as lever pin is moved "past-center" by closing handle.

Past-center action plus safety latch makes a positive lock that cannot lose off or open under load conditions.

- Optional High-Tension feature allows in-transit retensioning without opening basic tensioner lock.

LASH ACCESSORIES

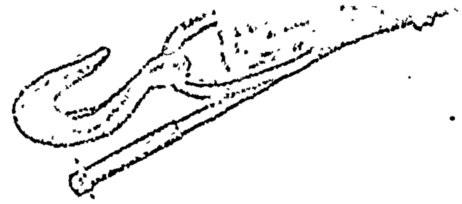
Bridles — Short wire rope or chain lengths are available for wrapping around irregular attachment points, especially on vehicles.

Pendants — Simple wire rope assemblies are available for extending lash lengths. Useful for multiple heights of Container stacks.

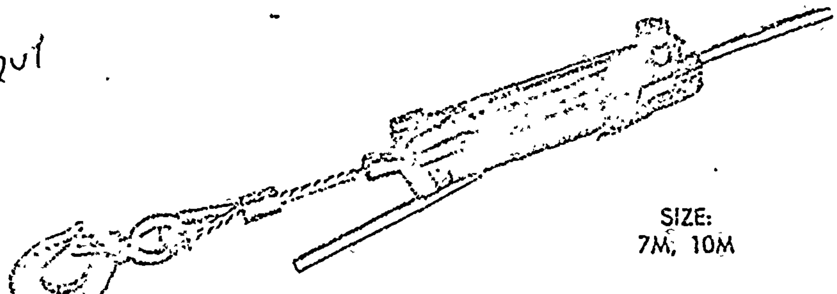
High Tension Feature — Accessory is available for ADJUST-A-MATIC CABLE beaded end for fine adjustment or "in-transit" tensioning.

Multi-Length — A series of swaged stops which can be fabricated in ADJUST-A-MATIC CABLES. Useful for multiple height Container stacks.

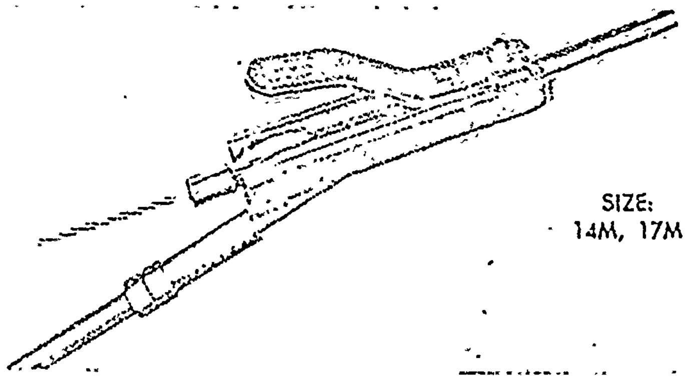
201



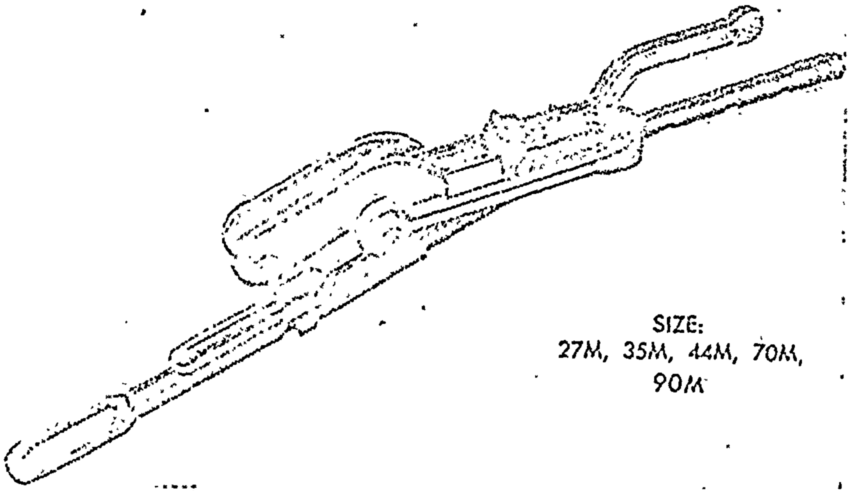
SIZE:
2M, 4M, 7M



SIZE:
7M, 10M



SIZE:
14M, 17M



SIZE:
27M, 35M, 44M, 70M, 90M

Adjust-a-matic Cable

Data

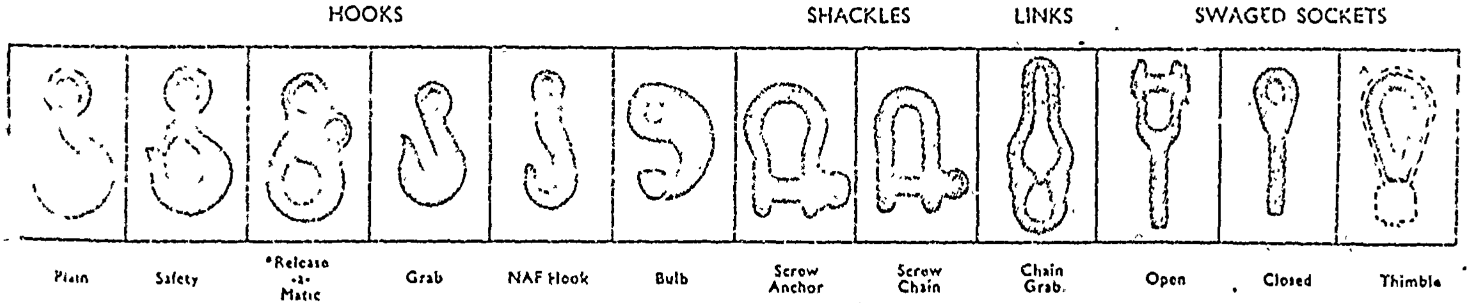
Size No.	Break Strength	Cable Dia.	Tension	General Uses
2M 4M 7M	2,000 lb. 4,000 lb. 7,000 lb.	1/8" 3/16" 1/4"	500 lb. 500 lb. 500 lb.	Light tie-down for Air Cargo, Trucking, Guying, etc.
7M 10M	7,000 lb. 10,000 lb.	1/4" 5/16"	1,000 lb. 1,000 lb.	Standard Model for Car and Light Truck lashing
14M 17M	14,000 lb. 17,000 lb.	3/8" 13/32"	1,500 lb. 1,500 lb.	Marine lashing for Medium Trucks and Containers
27M 35M 44M	27,000 lb. 35,000 lb. 44,000 lb.	1/2" 19/32" 5/8"	1,700 lb. 1,700 lb. 1,700 lb.	Heavy marine lashing for Trucks, Tanks, Trailers, Vans, Containers
70M 90M	70,000 lb. 90,000 lb.	7/8" 1"	2,000 lb. 2,000 lb.	Extra heavy duty marine lashing for Containers, and Heavy Lifts

Weight — Average weight of operational units complete is less than 1 pound per 1,000 lb. of break strength.

Finish — All parts normally are protected by galvanizing or cadmium-iridite plating. Stainless steel, aluminium, and bronze parts are available for special applications.

Proof loading — For complete reliability and quality control, each Adjust-a-matic Cable is individually proof-loaded to 50% of rated strength.

STANDARD END FITTINGS

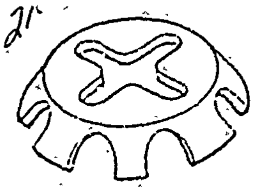


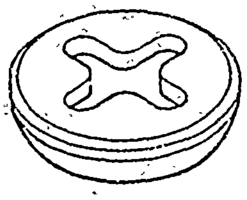
*Patented

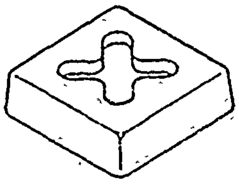
DECK SECURING FITTINGS

Vehicle Lashing Sockets

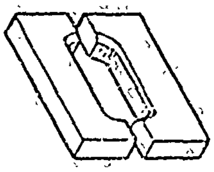
"Cloverleaf" fittings take four lashes
(Max. size lashing in brackets)

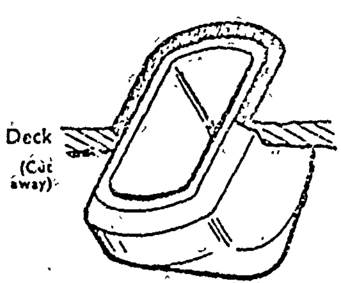

Raised
F265-1 (17M)
F266-1 (70M)


Flush
PH509-1 (17M)
PH438-1 (70M)


Raised
F149-1 (35M)

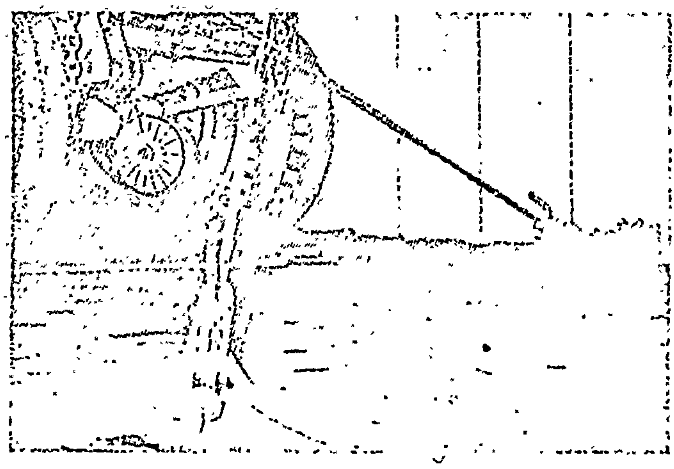
Container Deck Fittings


Drain Vent
F288-1
Raised Fitting



F272-1
Flush Fitting

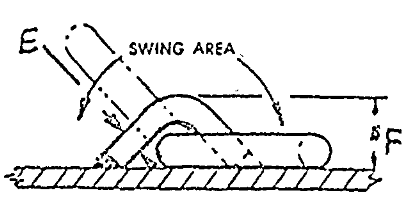

Above P. & H. Container deck fittings
F288 Deck Sockets; F275 Key Stackers
F186A "D" Rings on doubler plates

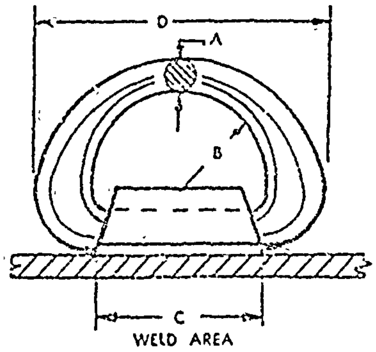

Above Flush "Cloverleaf" — PH438-1
in use with Bulb Hook lash end.

"D"-Rings — Drop Forged

FOLDING FEATURE & LOW PROJECTION FOR GREATER SAFETY

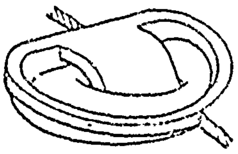
1. "D" Ring assumes angle of lead in all uses, eliminating bending and stress features.
2. When not in use, ring lies flat and presents a rounded surface for minimum deck obstruction and personnel hazard.
3. The weldless ring is drop-forged and heat treated for maximum strength and safety.



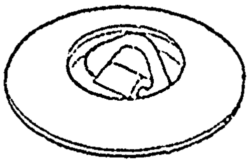


D-Ring	Elastic* Limit lb.	Minimum Break Strength lb.	A	B	C	D	E	F
F187	15,000	19,000	$\frac{1}{2}$	$1\frac{3}{4}$	2	$4\frac{13}{16}$	$\frac{1}{4}$	$\frac{13}{16}$
F186A	70,000	90,000	$\frac{13}{16}$	$2\frac{1}{2}$	4	$8\frac{3}{4}$	$\frac{1}{2}$	$1\frac{7}{16}$
F327	90,000	110,000	1	$2\frac{1}{2}$	4	$9\frac{1}{4}$	$\frac{5}{8}$	$1\frac{13}{16}$
F198	100,000	140,000	1	$2\frac{3}{4}$	$5\frac{1}{4}$	$10\frac{3}{8}$	$\frac{5}{8}$	2

**All test data complied on a 45° angle pull*


Recessed fittings are available for flush installation.

Dishheads are available for tapering to deck



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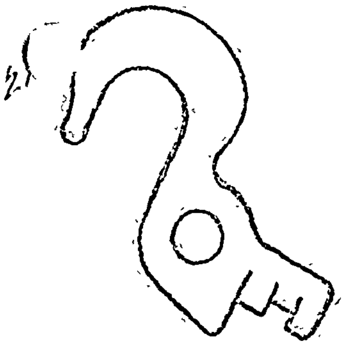
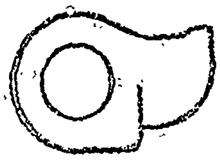
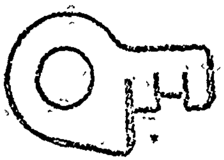
FOR U.S.A.S.I. — MH5.1 CONTAINERS



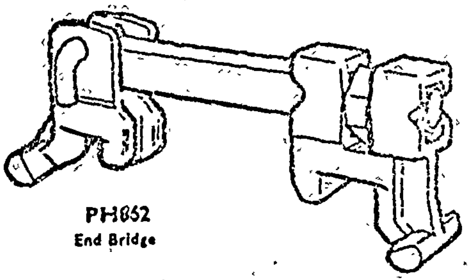
* H1441 DUAL HOOK
Top hook with bottom plug



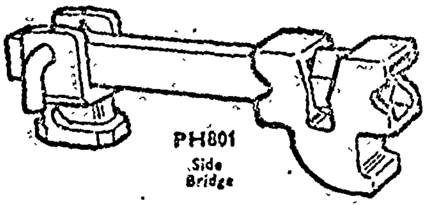
H111B-1 TOP CORNER
End Plug



H141-1 BOTTOM
CORNER PLUG/HOOK

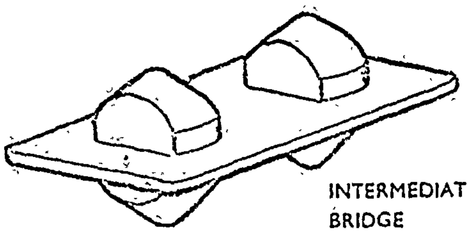


PH852
End Bridge



PH801
Side
Bridge

*Pat. Pending



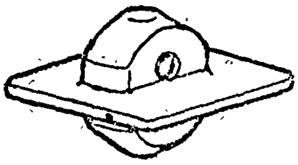
F368
Two Corner

INTERMEDIATE STACKER BRIDGE
For two and four corner installation.
(Made to order)

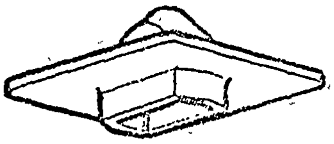
F267-2

WELDABLE CONE
Weld to deck or in special design parts.

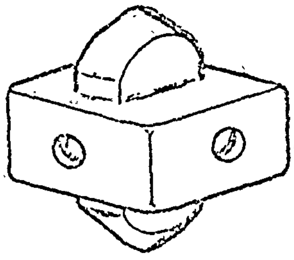
STACKER KEYS
Drop-in
Type



F262
Double

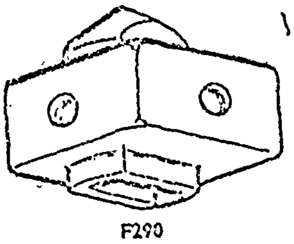


F292
Single



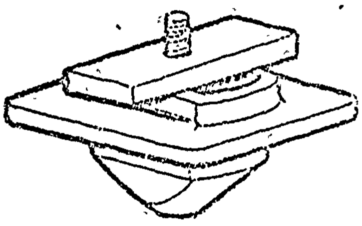
F275
Double

FLANGE
STACKERS
Provide 3½"
clearance
between Containers to clear
king pins and
flanges.



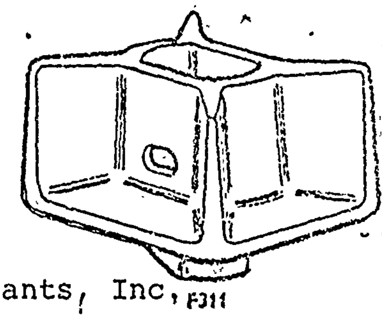
F290
Single

STACKER KEY
Screw Lock Type
Place in bottom of Container.
No personnel required on stacks.

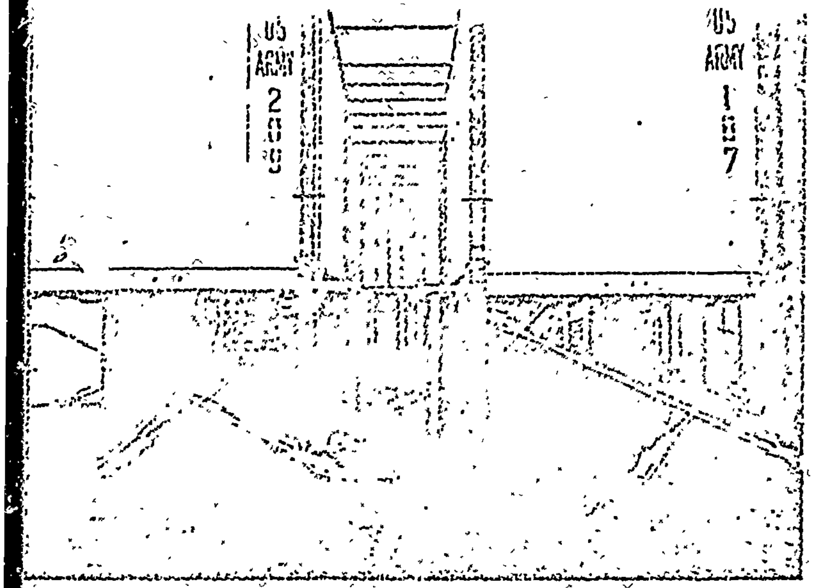


F362

PEDESTAL
For leveling mixed height container stacks.



F311



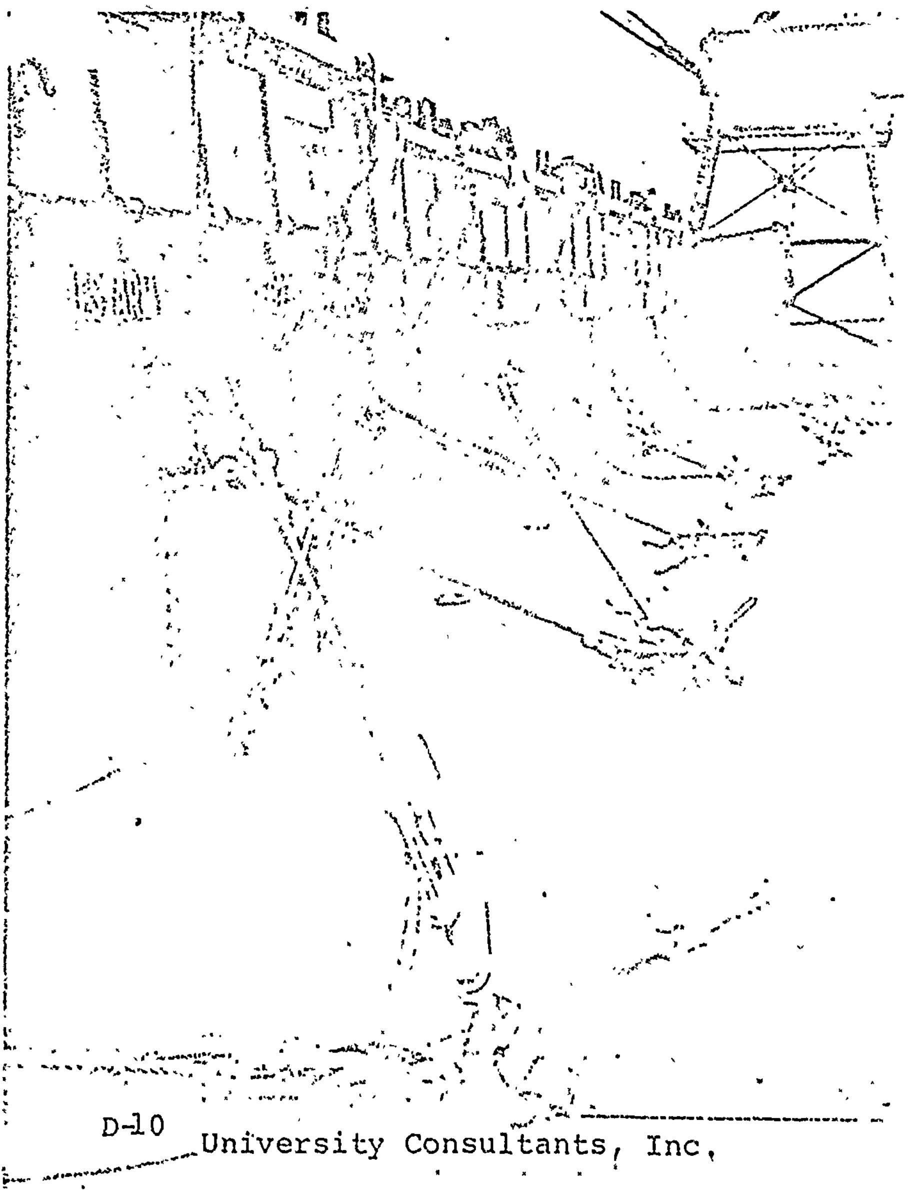
P & H

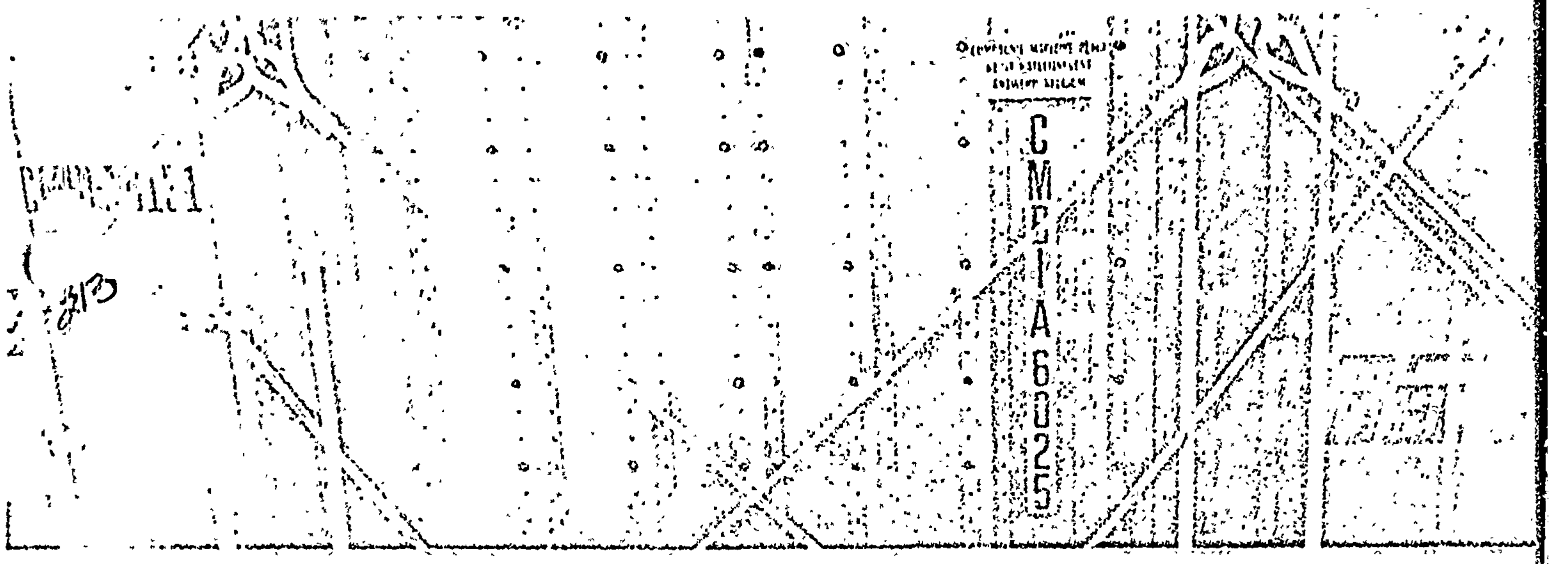
Typical RO/RO Lashing Arrangement

GTS. "Admiral Callaghan"

Above: 'tween-decks stowage of vehicles using P. & H. lashings Type 35M.

Right: Main-deck stowage using P. & H. lashings Type 35M and P. & H. "D"-rings Type F186A.



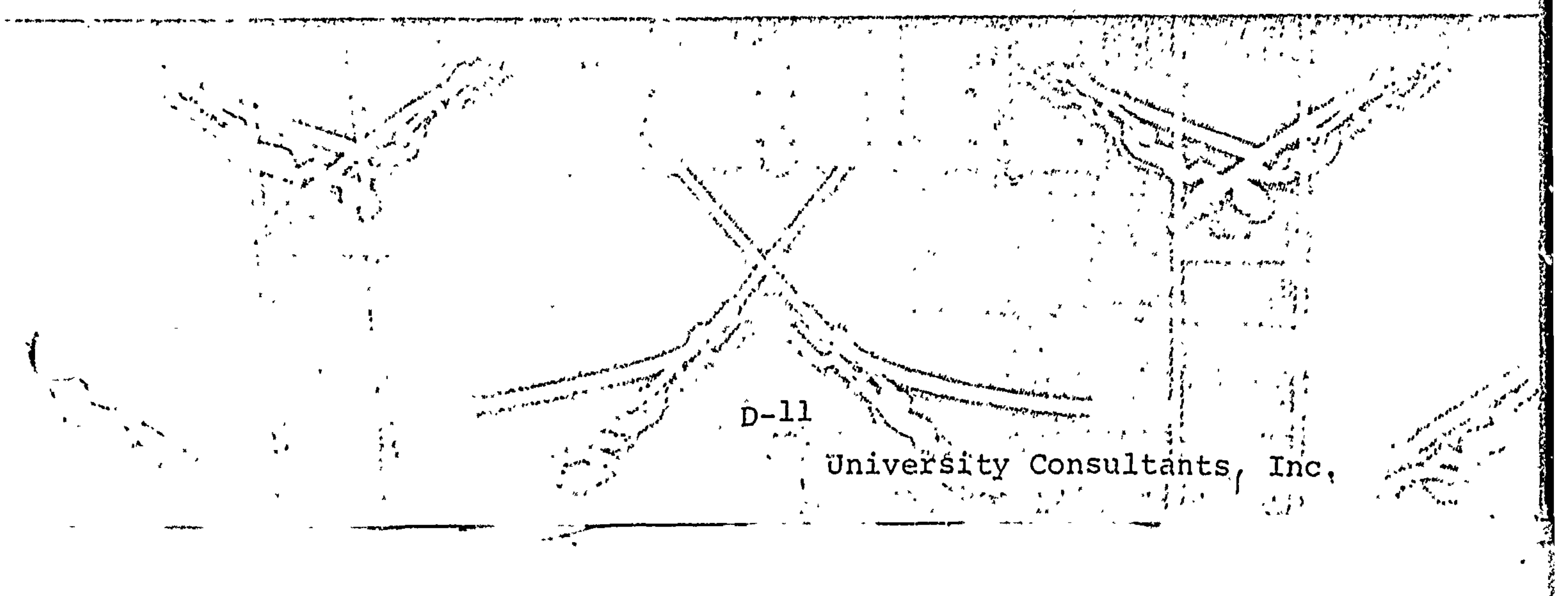


Typical Container Lash Arrangement

(Belgian Line)

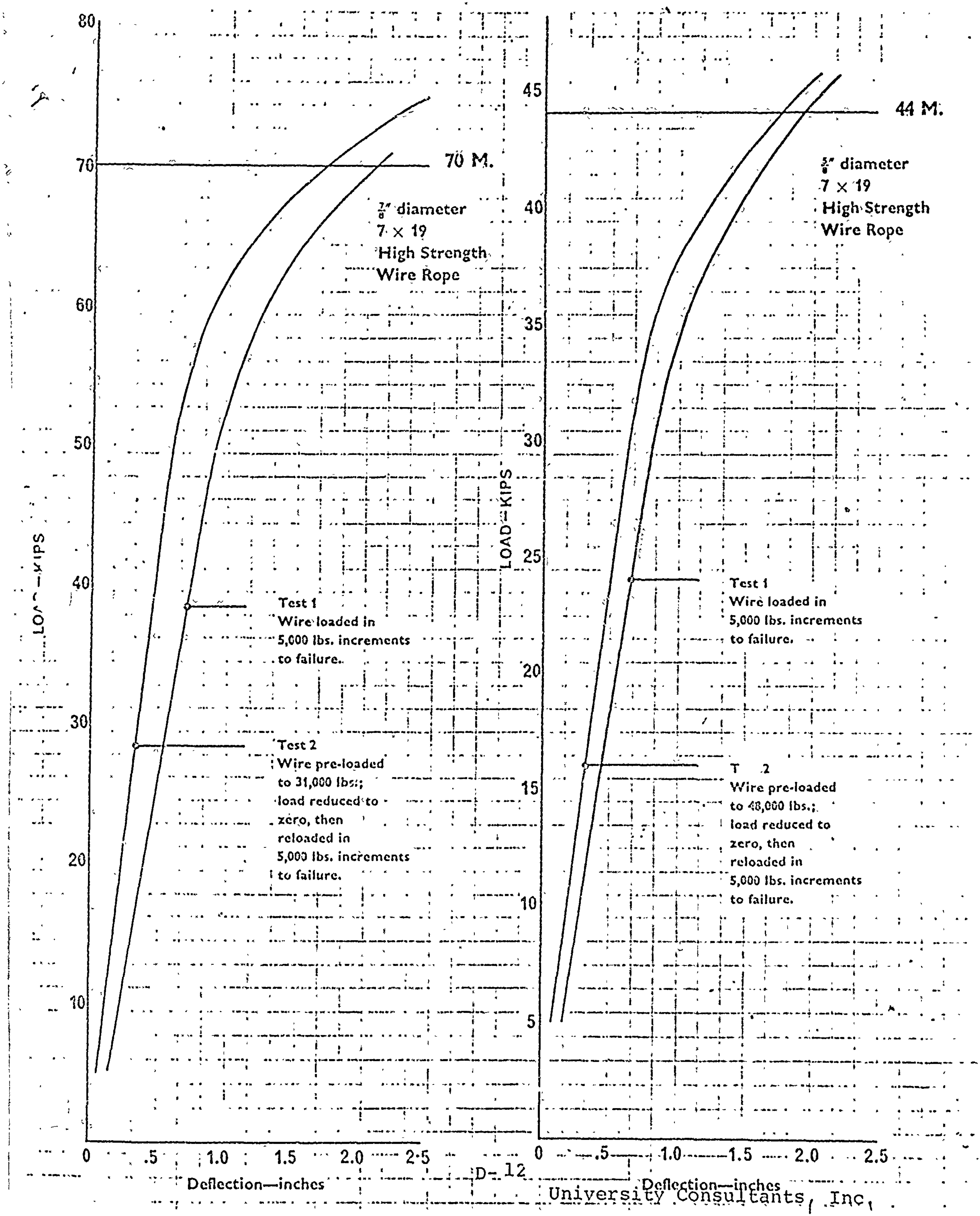
Three-high Container Securing System.
Top and Intermediate Bridge Stackers with vertical and diagonal lashes create a block container stow distributing racking forces evenly throughout Containers at uneven weights.

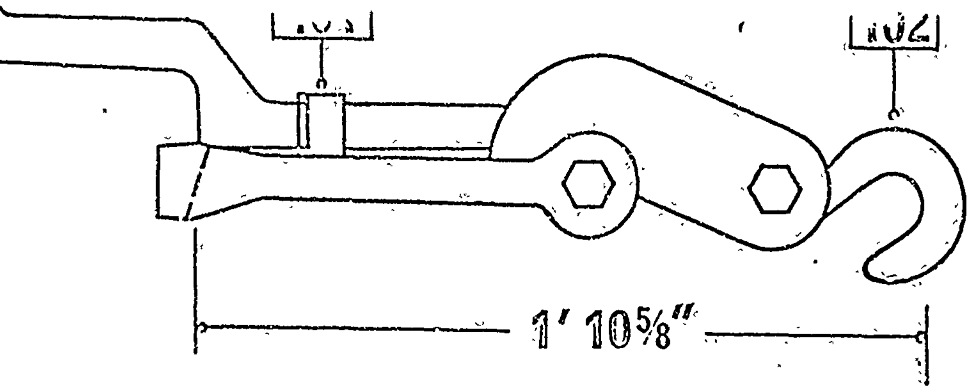
Equipment:
Vertical lashes P. & H. 70,000 lb. MBS.
Diagonal lashes P. & H. 44,000 lb. MBS.
F275 Stackers
F186A "D" Rings

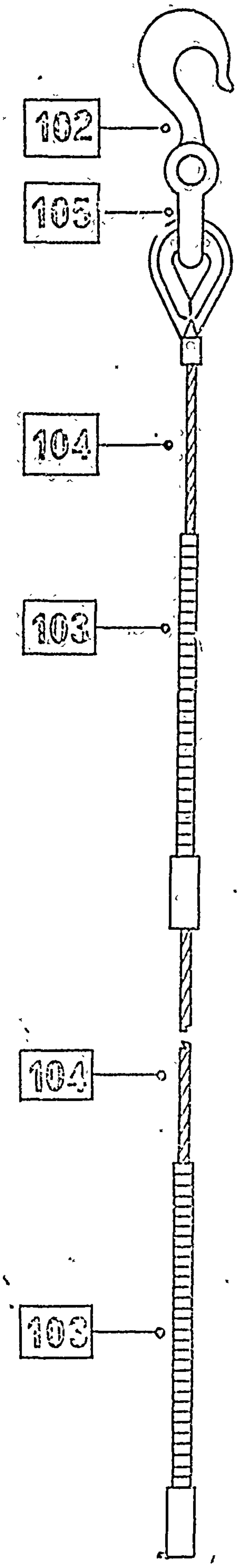


Typical Wire Rope Elongation Analysis

Deflection vs. Load







70M/864 A & B Adj. Cable Container Lashing for Belgian Lines

Notes:

1. Proof test to 35,000 lb., MBS 70,000 lb.
2. 70M/864A Vertical Container Lashing for 2 and 3 high on hatch SQ.
3. 70M/864B Vertical Container Lashing for 2 and 3 high on outboard corners of hatch # 5.
4. Useable lengths,
   70M/864A — 18' 8" to 15' 11" and 27' 5" to 24' 1".
   70M/864B — 25' 3" to 22' 10" and 34' 0" to 31' 1".
5. Wire rope is galvanized, all other parts have equal or superior corrosion resistance.
6. Test per DWG # PH691. Item No. 105, shackle movement at full strength not to exceed $\pm\frac{1}{16}$.

List of Major Components

Item No.	*Description*
105	S.C. Shackle, 8½T.
104	⅜ Galv. W.R., 70,000 min. brk. str.
103	Adjustment Washer # PH722-2.
102	Hook, C-M # HA290.
101	Tensioner, recoil-less, forged.

PECK & HALE, INC., West Sayville, L.I., New York

Tolerance (except as noted) DEC. ± FRAC. ± ANG. ±

Mat'l.:	Drn.:	Date:
	Appd.:	Scale: None
	Sheet 1 of 1	
H.T. Fin.	1411 Dwg. No.	C Rev.

P & H

Systems Design Capability

The design of lashings for deck-stowage of containers cannot be determined by any empirical formula. Quite apart from the type of lashing gear and associated hardware, the lashing system will depend upon many other factors which influence an adequate securing plan and container stow:—

The strength and construction of the Containers,
the G.M. of the vessel,
ship's speed,
roll characteristics,
the nature of the container loadings,
height of stack,

will all serve to affect the design of the lashing system.

Theoretical studies have been made of the characteristics required for an adequate securing system for various stowage configurations. These have been based upon the known and estimated factors which are involved and the results have been the subject of computerized analysis

Typical arrangements for 3-high and 4-high on-deck stowage are shown on page 13, 14 and 15.

Such researches produce results which yield several advantages:

1. optimum and uniform strength of all items of equipment in the system
2. maximum cost effectiveness for system hardware
3. maximum security of on-deck containers
4. minimum damage to containers in ocean environment
5. optimum degree of simplicity of equipment and system
6. optimum ease of application of lashing system.

Similar studies can be carried out for other stowage arrangements and securing plans.

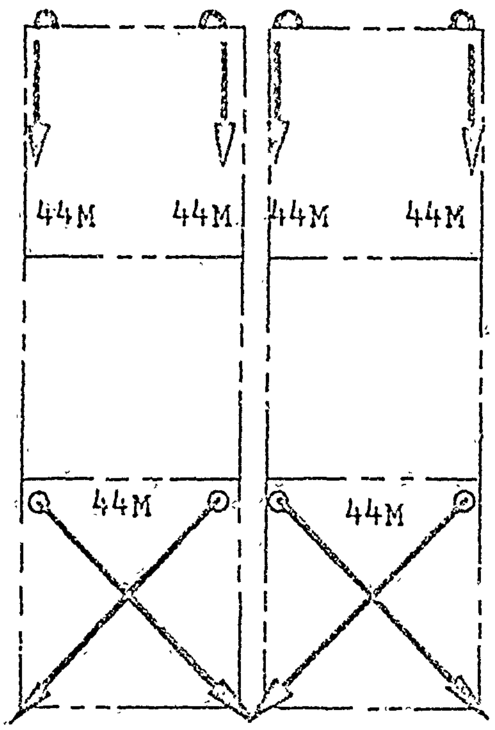
No such study is adequate without the most vital element of lashing design — EXPERIENCE.

Peck & Hale has had MORE lashing system experience than any other manufacturer — by far.

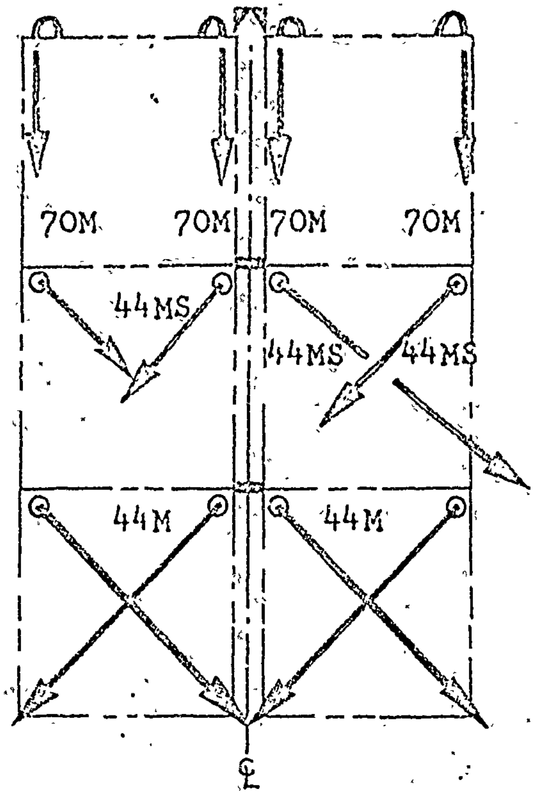
P & H know-how and experience is freely available to ship-constructors, owners and others concerned with this important aspect of modern shipping.

Ask for further information.

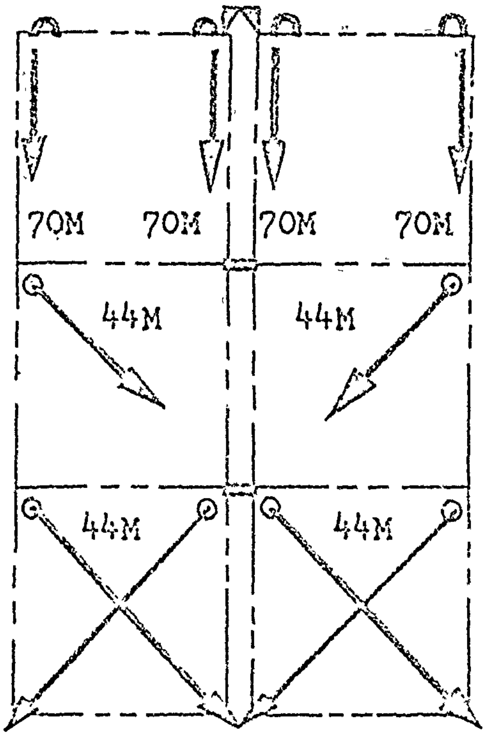
USL



BELGIAN LINES



MORMAC



Main deck container securing systems in use on North Atlantic

PECK & HALE, INC., West Sayville, L.I., New York

Tolerance (except as noted) DEC. ±	FRAC. ±	ANG. ±
Mat'l.:	Drn.:	Date:
	Appd.:	Scale: None
H.T.	Sheet 1 of 1	
FIN.	1632 Dwg. No.	Rev.

∩ — Top Hook

○ — Plug Hook

↙ — Lash

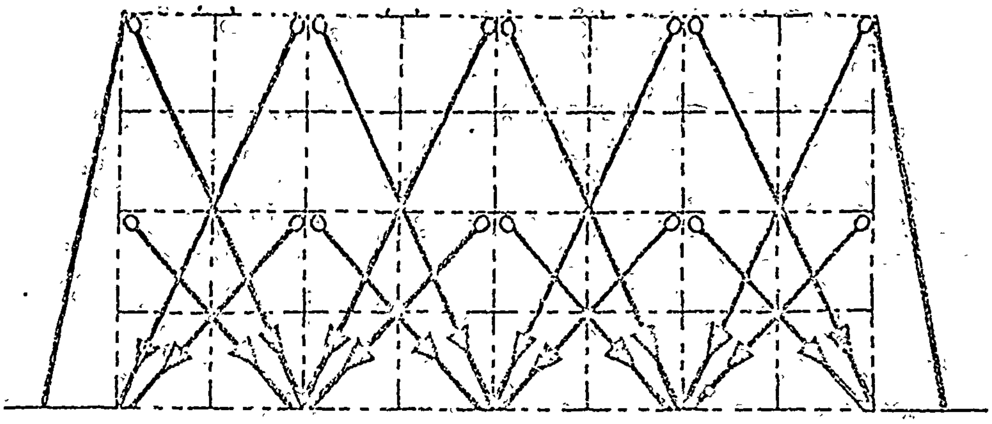
⋀ — Top Bridge

▬ — Intermediate Bridge

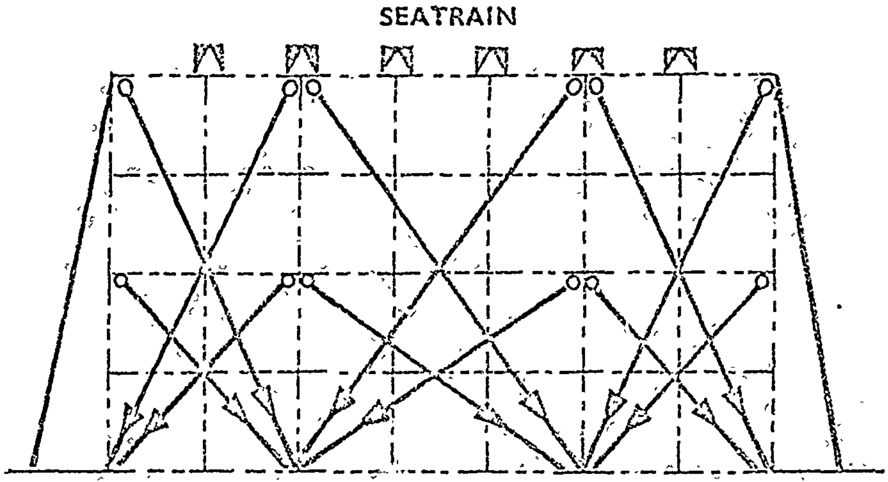
70M — 70,000 M.B.S. Container Lash (7/8)

44MS — 44,000 M.B.S. Container Lash (7/8) (non-stretch design)

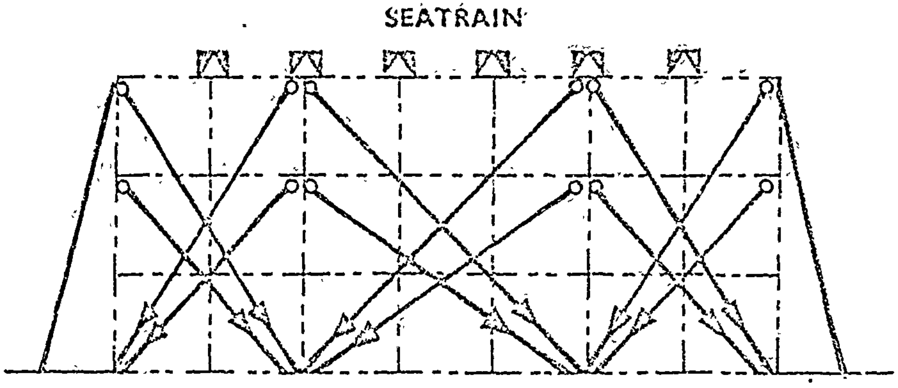
44M — 44,000 M.B.S. Container Lash (5/8)



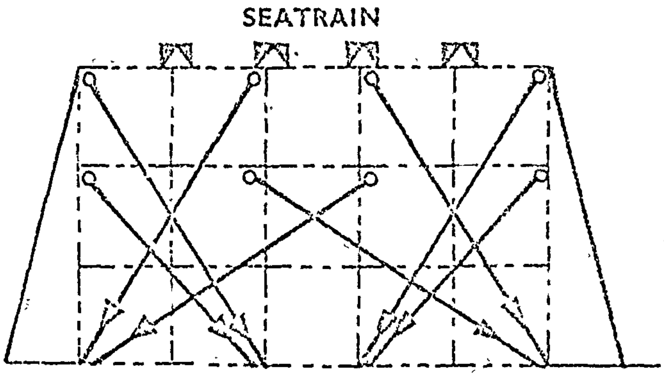
TYPICAL 4 HIGH
STOW 8 ACROSS



TYPICAL 4 HIGH
STOW 7 ACROSS



TYPICAL 3 HIGH
STOW 7 ACROSS



TYPICAL
3 HIGH
STOW
5 ACROSS

LASH SPECS.: ½" wire rope, 60,000 lb. M.B.S.

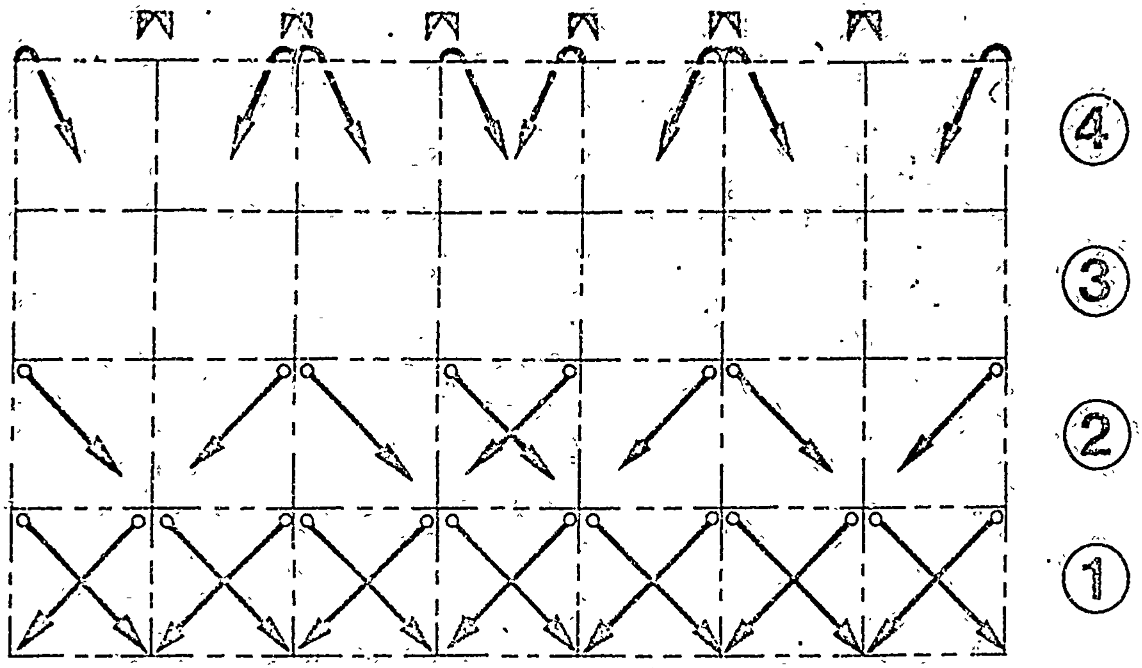
Proposed main deck securing system for North Atlantic as determined by computer analysis

PECK & HALE, INC., West Sayville, L.I., New York

Tolerance (except as noted) DEC. ± FRAC. ± ANG. ±

Mat'l.:
DRN.: — Date: —
Appd.: — Scale: —
Sheet 1 of 1
H.T.:
FIN.:
1667
Dwg. No.
Rev.

PROPOSED SYSTEM FOR NORTH ATLANTIC (HAPAG LLOYD)



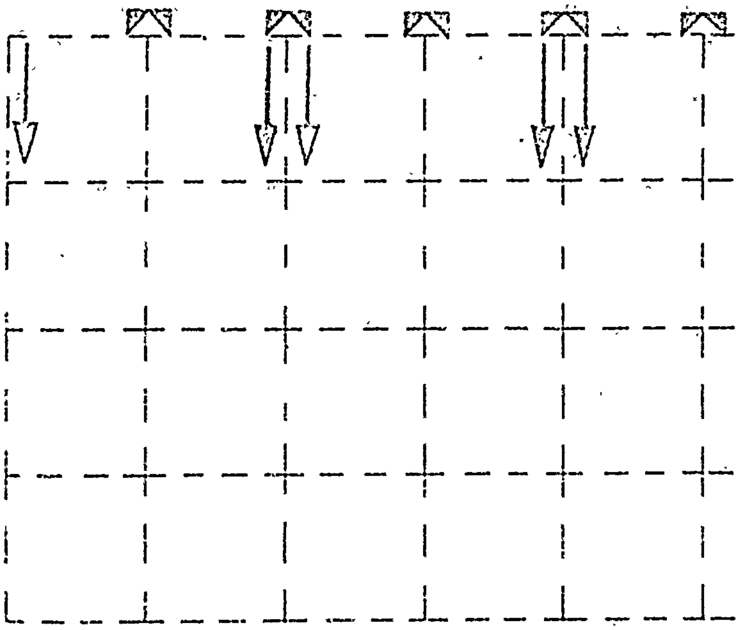
Row 1 — ⅝ wire, 44M lash — cross lash every Container as shown.

Row 2 — ⅝ wire, 44M lash — cross lash every other Container as shown.

Row 3 — No lash.

Row 4 — ⅞ wire, 70M lash — cross lash every other Container as shown.

MATSON—4 HIGH STOW—PACIFIC



⅞ wire, 70M lash—every other stack bridge each stack at top.

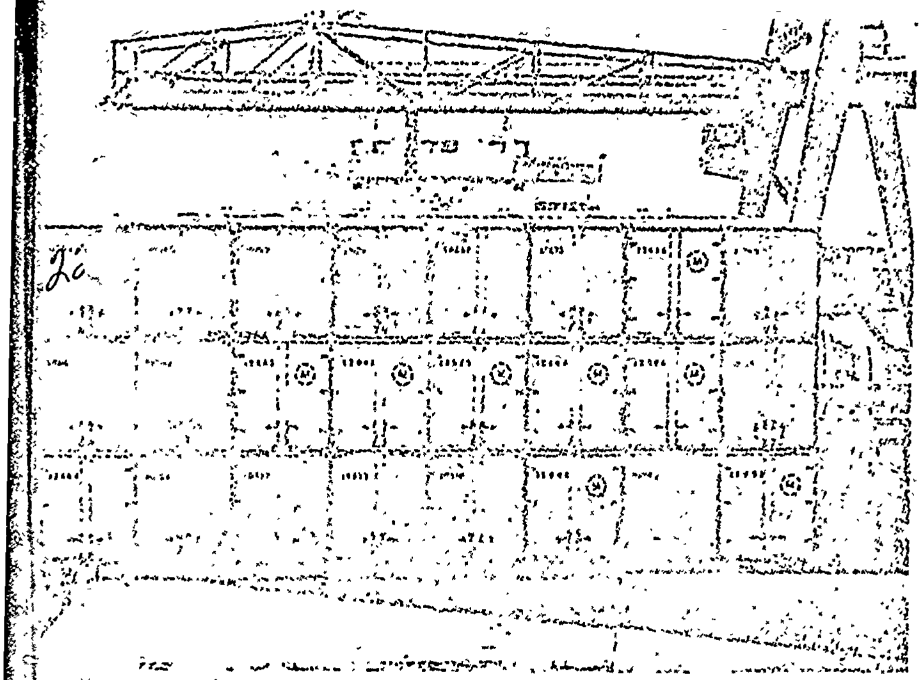
Examples of main deck container securing Atlantic & Pacific

PECK & HALE, INC., West Sayville, L.I., New York

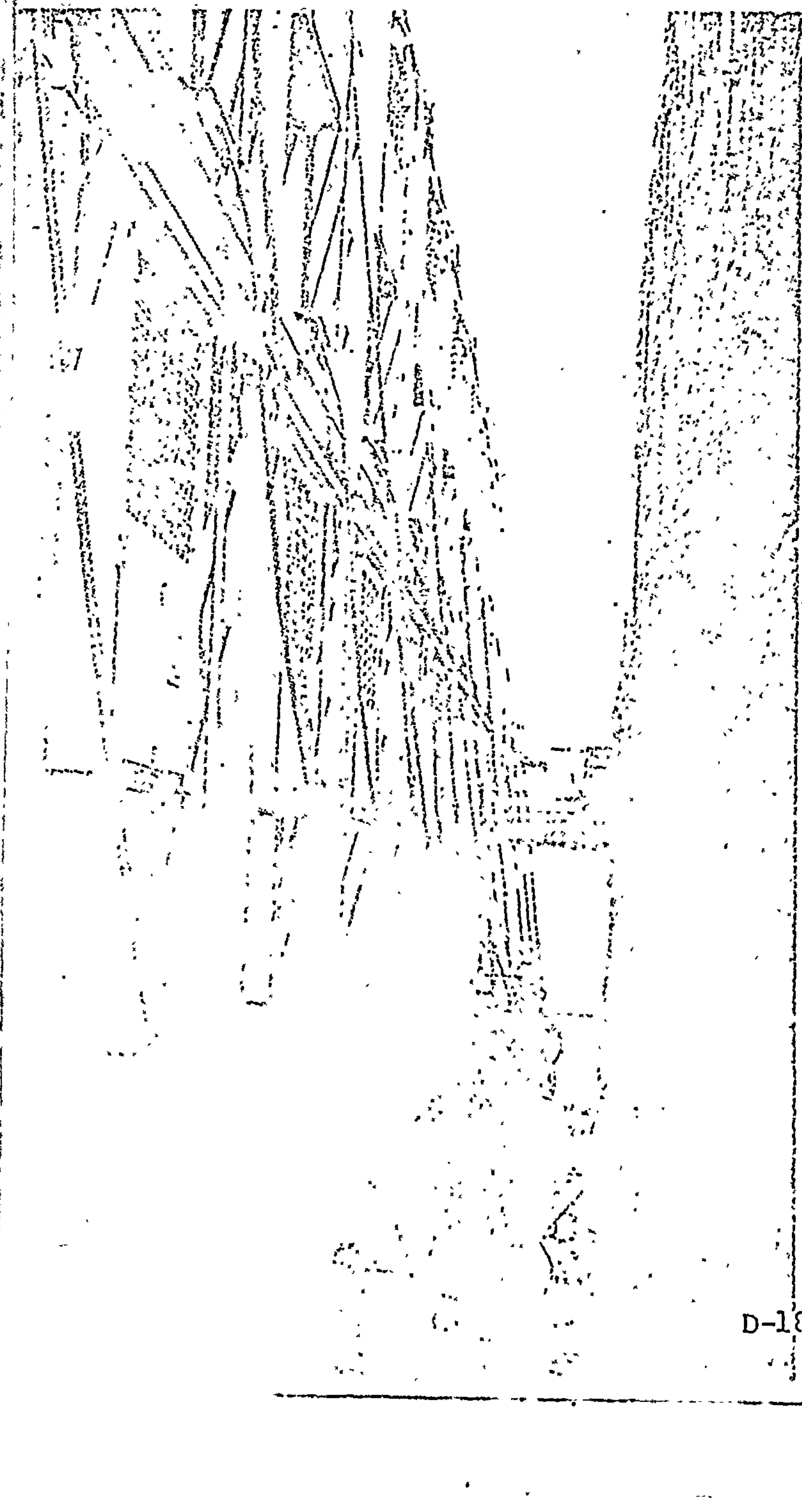
Tolerance (except as noted)	DEC. ±	FRAC. ± ANG. ±
Mat'l.:	Drn.: —	Date: —
	Appd.: —	Scale: —
	Sheet 1 of 1	
H.T.	1663 Dwg. No.	Rev.
FIN.:		

⩚	Top Bridge	⌒	Top Hook
○	Plug Hook	↙	Lash

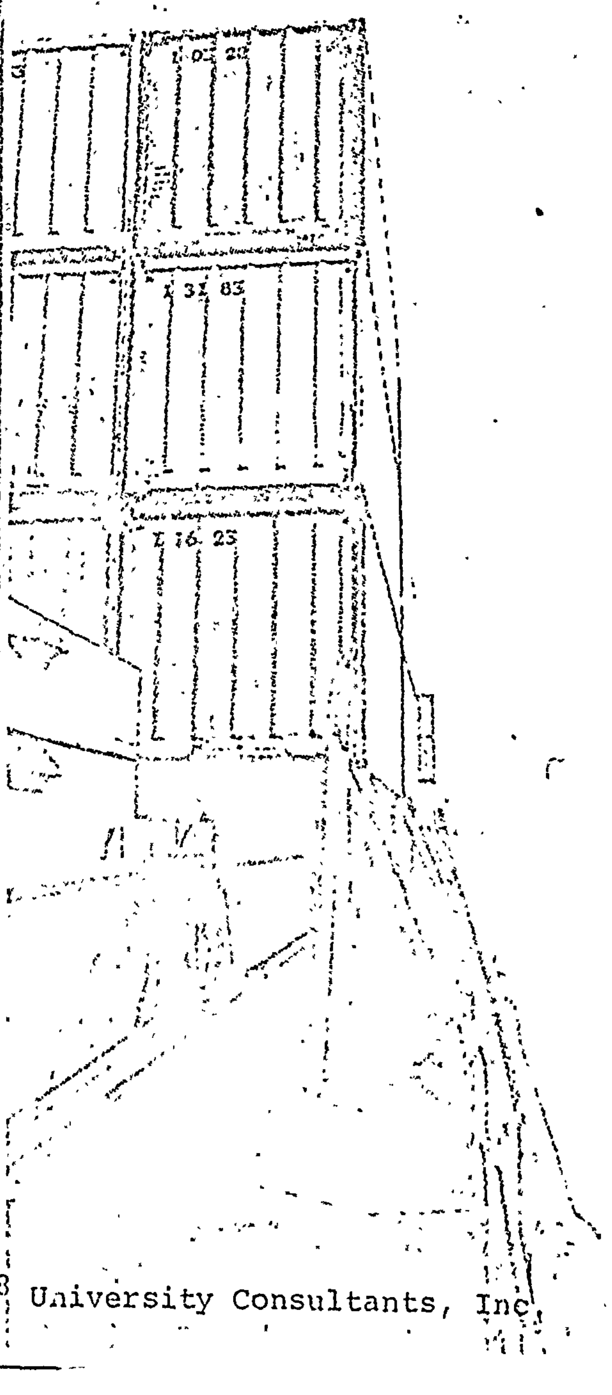
University Consultants, Inc.



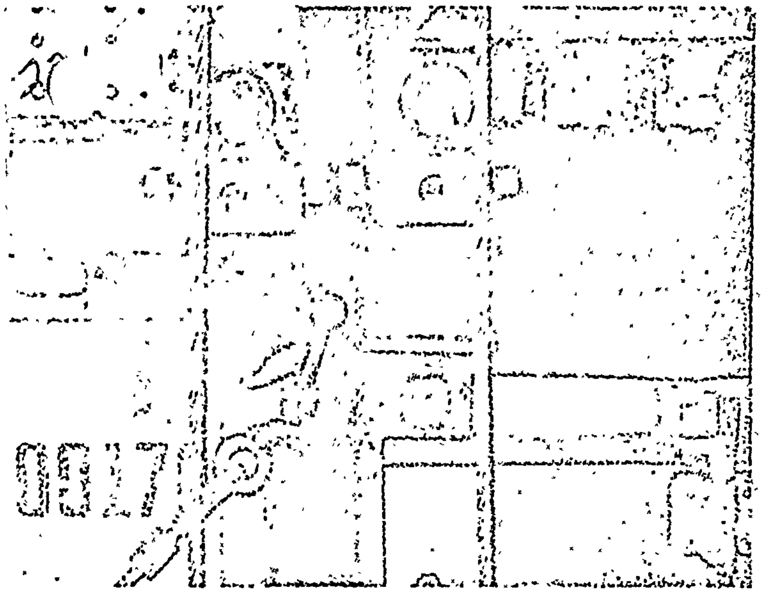
left 3-high stack Matson Line (C4 Conversion)



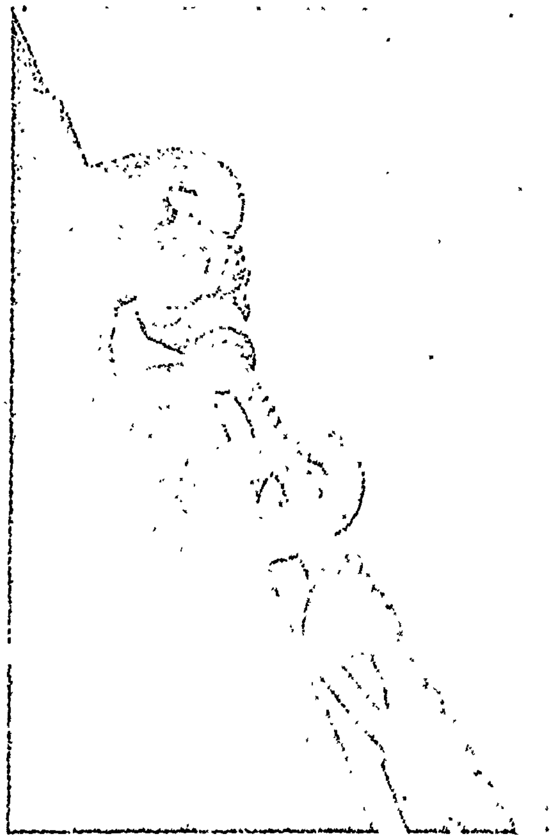
below left U.S.L. New Lancer Class Athwartship Stow on Hatch Covers.



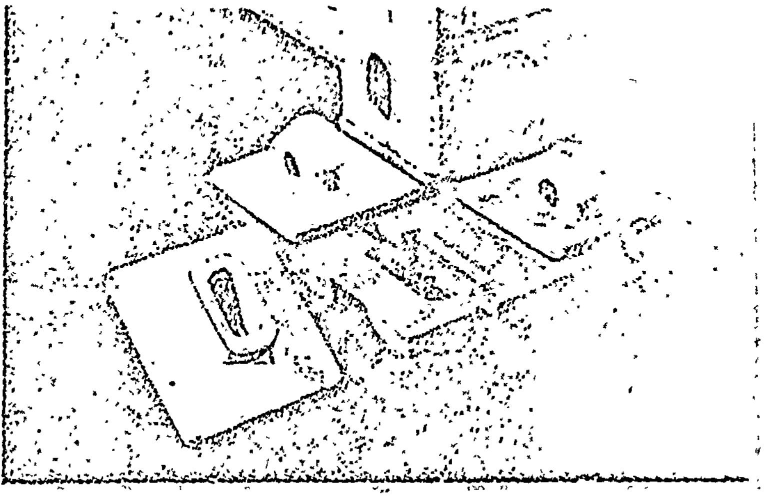
below right Looking aft a three high container stowage on Matson's new S/S Hawaiian Monarch. Nesting cones and recessed coaming sockets for lashing shown in foreground.



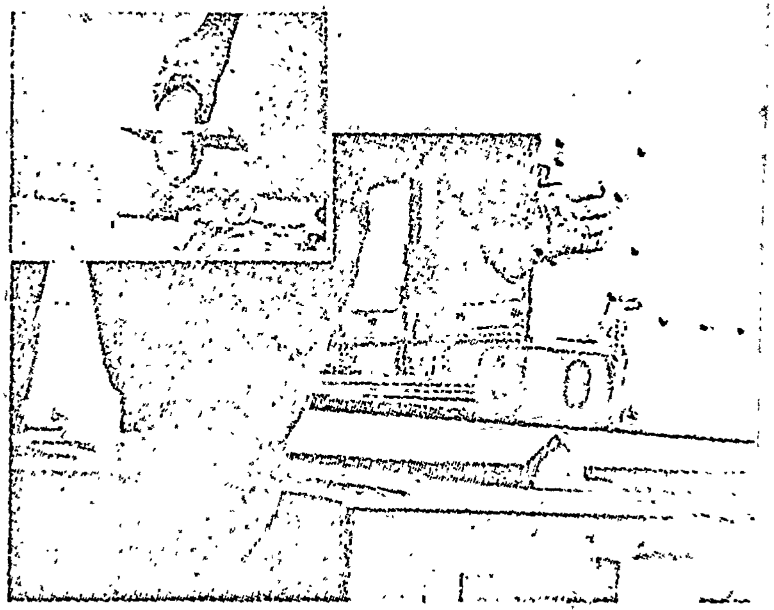
Detail of intermediate stud stacker along with F311 twist lock pedestal for leveling off 8' and 8' 6" containers.



P & H No H111B end hole plug hook which can be used on either a vertical or diagonal lash.

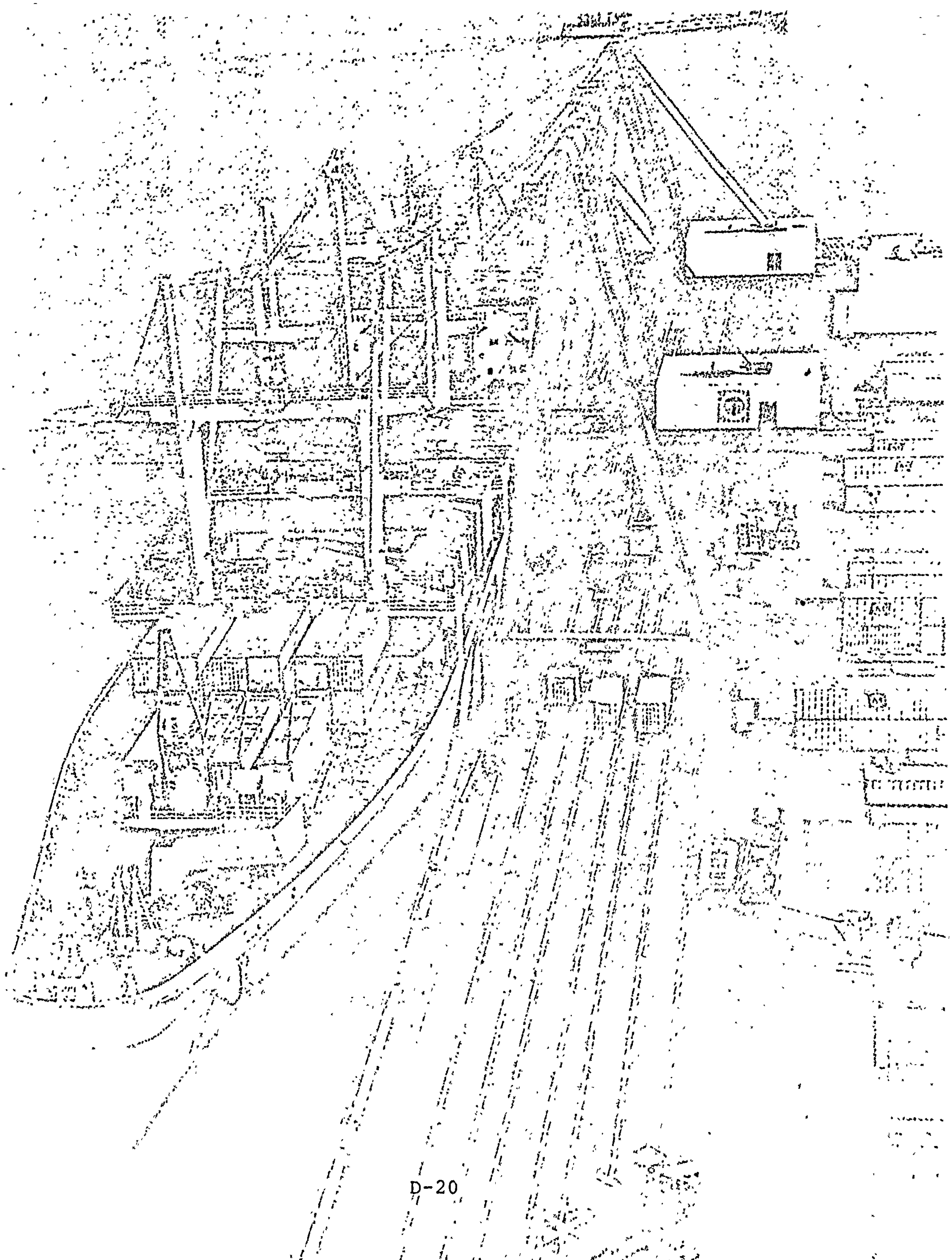


S/S Mormacsea showing close-up of P & H F288 raised socket and F292 stacking adapter. This same Adapter is used at the deck level and between 1 & 2 high container stows.



Detail of ASA Vertical Stacker and/or Adapter showing insertion in top corner casting of container. Shown below is use of same Stacker in bottom corner casting and pontoon socket for positioning and stowage of container.

PH801 Bridge Fitting in container corners ready for tensioning



New S.S. Mormacsea RO/RO and Container Vessel which is completely equipped with P & H Vehical lashing gear in the trailer deck and container securing gear for one, two and three high container stow on deck

Printed in England by Fyson & Co., Ltd., Bath.

The source for pages D-21 through D-32 is: Cargo Loading, USAF Series, C-141A Aircraft, AF 33(657)-8835, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967

2-69A. PERSONNEL WARNING SIGNS. (AF66-205 AND UP, AND AIRCRAFT MODIFIED BY T.O. 1C-141A-1120) (See figure 2-20A.) Aircraft AF66-205 and up, and aircraft modified by T.O. 1C-141A-1120 have provisions for installing personnel warning signs in three locations: at approximate buttock line 40 left and right at fuselage station 958, and at fuselage station 1292 near the center of the overhead. Each sign has three legends readable from either side: NO SMOKING, FASTEN SEAT BELTS, and DON OXYGEN MASKS. The legends may be controlled independently of each other by using the three PERSONNEL WARNING SIGNS switches on the pilot's overhead control panel. Provisions for the installation of these signs consist of electrical receptacles and mounting provisions for the signs themselves. Each electrical receptacle is covered by a dust cap when the signs are not installed. When the signs are installed, the dust cap is removed from the electrical receptacle and installed on a nearby stowage receptacle. The provisions at fuselage station 958 includes a strap assembly near each electrical receptacle to tie the electrical cables up and out of the way when the signs are installed.

2-69B. Although there are provisions for three personnel warning signs, only two signs are used at the same time, and only two signs are included in alternate mission kit No. 4 (3D10004-105). Normally, when the aircraft is in an all passenger configuration, only one sign is used, and this sign is installed at fuselage station 1292. When the aircraft is in a litter configuration, both signs are installed at fuselage station 958. The signs themselves attach to their mounting provisions by means of 3/4-turn fasteners.

2-70. CARGO TIEDOWN FITTINGS.

CAUTION

Keep all tiedownfitting receptacles free of water, solvents, dirt, and other foreign material. Water freezing in floor receptacles during flight when tiedown fittings are installed can cause damage to the receptacle or prevent later removal of the fitting. Frozen fittings must not be forced from the receptacles. Apply heat first to melt the ice and then remove the fitting in the normal manner.

2-71. RECEPTACLES. (See figure 2-21.) Receptacles for the installation of quick-disconnect tiedown fittings are spaced evenly in rows which run the length and width of the cargo compartment floor and ramp. Three types of receptacles are used: one for connecting individual 10,000-pound fittings, one for connecting individual 25,000-pound fittings, and a continuous-track type for connecting troop seat fittings and 10,000-pound fittings. The restraint rail restraint fittings utilize the same receptacles as the 25,000-pound fittings.

2-72. The individual receptacles for 10,000-pound tiedown fittings are spaced evenly in three rows which run the length and width of the cargo compartment floor. The receptacles are installed on 20-inch centers in the rows. All 10,000-pound receptacles accept the same quick-disconnect tiedown fittings.

2-73. Four rows of seat tracks are also located across the floor, and when used in combination with the individual tiedown fittings, provide a 20-inch square grid of 10,000-pound receptacles over the entire cargo compartment floor. Since troop seats are never installed on the ramp, seat tracks do not run into this area, and individual 10,000-pound receptacles are installed on a 20-inch square grid pattern. (See figure 2-29.)

CAUTION

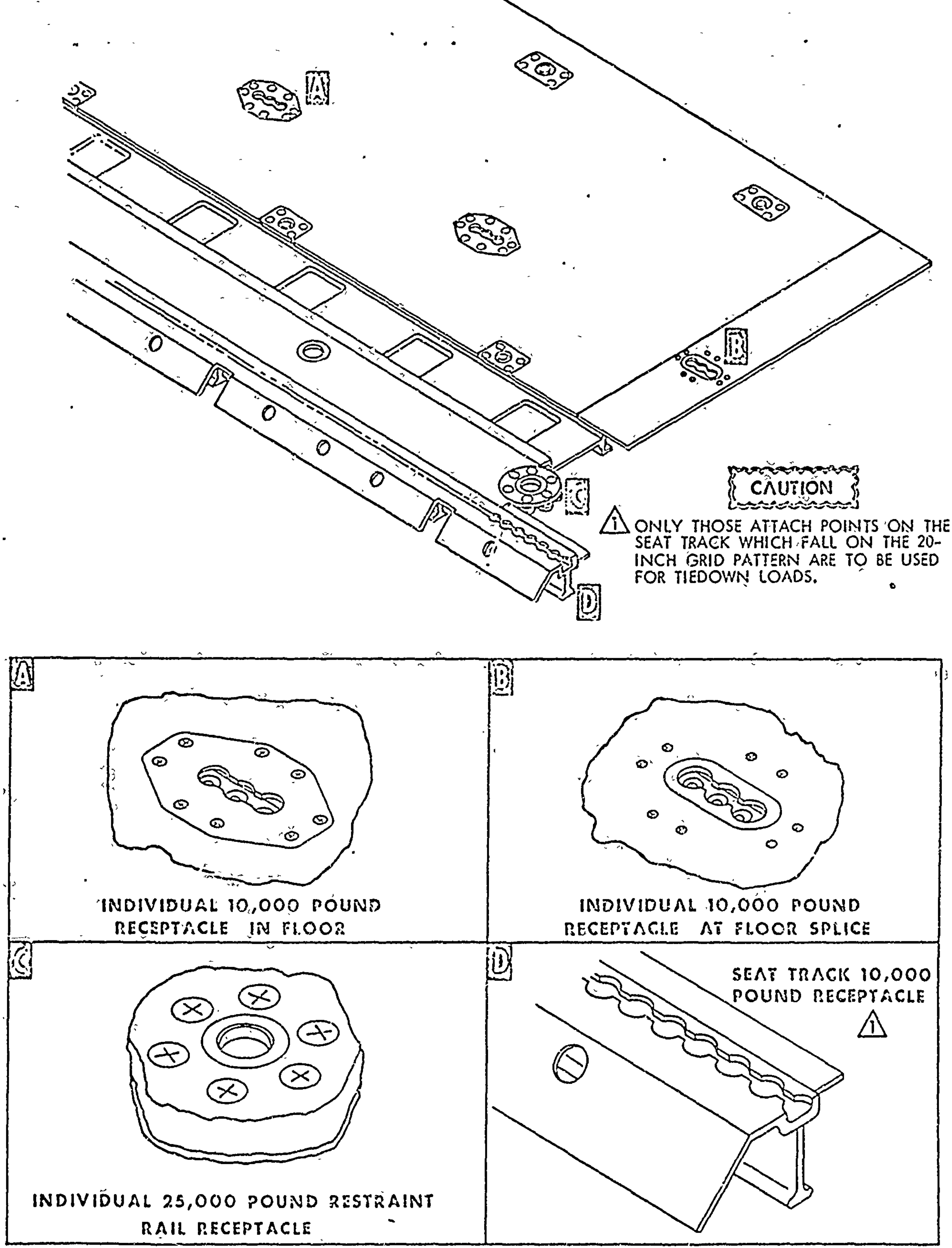
On aircraft AF66-159, 66-161 and up and aircraft modified by T.O. 1C-141A-1186, the aft row of tiedown receptacles on the ramp will accept only 25,000-pound floor fittings. These fittings are for use with the pressure door auxiliary latches. If necessary to use these fittings for restraint of cargo, use 25,000-pound floor fittings but limit the restraint capability to a maximum of 10,000 pounds.

2-74. One row of receptacles for 25,000-pound tiedown fittings is on each side of the cargo compartment and ramp at butt line 56. These receptacles are used for either restraint rail tiedown fittings or 25,000-pound tiedown fittings.

2-75. 10,000-POUND TIEDOWN FITTINGS. (See figure 2-22.) A quantity of interchangeable quick-disconnect fittings for insertion in the 10,000-pound tiedown receptacles and in the seat track tiedown attach points are stowed in the cargo compartment. A spring-loaded pull ring on the fitting must be turned a quarter turn to insert the fitting in the receptacle. After insertion, the ring is turned another quarter turn and the fitting locks securely to the floor. In this position, the heavy tiedown ring will swivel to facilitate connection to the load. The ring is compatible for

From: Cargo Loading, USAF Series, C-141A Aircraft, AF33(657)-8835, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967.

2-1



CAUTION

⚠1 ONLY THOSE ATTACH POINTS ON THE SEAT TRACK WHICH FALL ON THE 20-INCH GRID PATTERN ARE TO BE USED FOR TIEDOWN LOADS.

A: INDIVIDUAL 10,000 POUND RECEPTACLE IN FLOOR

B: INDIVIDUAL 10,000 POUND RECEPTACLE AT FLOOR SPLICE

C: INDIVIDUAL 25,000 POUND RESTRAINT RAIL RECEPTACLE

D: SEAT TRACK 10,000 POUND RECEPTACLE ⚠1

Figure 2-21. Cargo Tiedown Fitting Receptacles

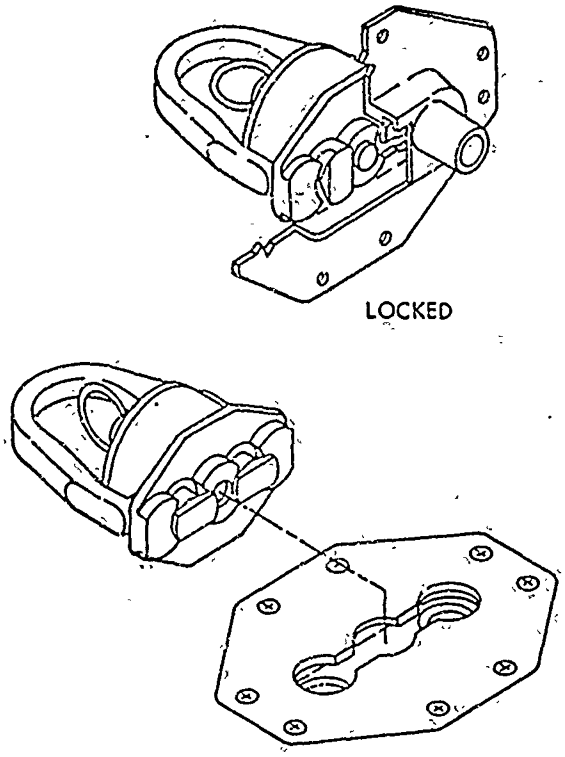


Figure 2-22. 10,000-Pound Tiedown Fitting (6,667-Pound Design Limit Load)

utilization with the hook on the Type MB-1 device. When the fitting is no longer needed, the pull-ring is lifted and turned to release the fitting from the floor. The design limit load for the 10,000-pound fitting is 6,667 pounds.

CAUTION

Use only MB-1 tiedown devices with 10,000-pounds tiedown fittings. Use only one tiedown device per fitting. Swivel the fitting to align the ring of the fitting with the direction of force prior to application of the force.

2-76. The 10,000-pound fittings are stowed on a rack on the right sidewall of the cargo compartment between fuselage stations 469 and 498. (See figure 2-23.)

Note

10,000 and 25,000 pounds are the rated ultimate strength values of the cargo tiedown fittings. The values of 10,000/25,000 pounds should be used only for tiedown for cargo. Use of these fittings for other than cargo tiedown applications, such as snatch block tiedowns, should be based on the design limit load value of the fittings.

2-77. 25,000-POUND TIEDOWN FITTINGS. (See figure 2-24.) A quantity of interchangeable quick-disconnect fittings for insertion in the 25,000-pound tiedown receptacles are stowed in the cargo compartment. A spring-loaded pull ring on the fitting must be pulled up to insert the fitting in the receptacle. After insertion, the spring is released and the fitting locks securely to the floor. In this position, the heavy tiedown ring will swivel to facilitate connection to the load. The ring is compatible for utilization with the hook on one Type MB-2 device. When the fitting is no longer needed, the pull-ring is lifted up to release the fitting from the floor. The design limit load for the 25,000-pound fitting is 16,667 pounds.

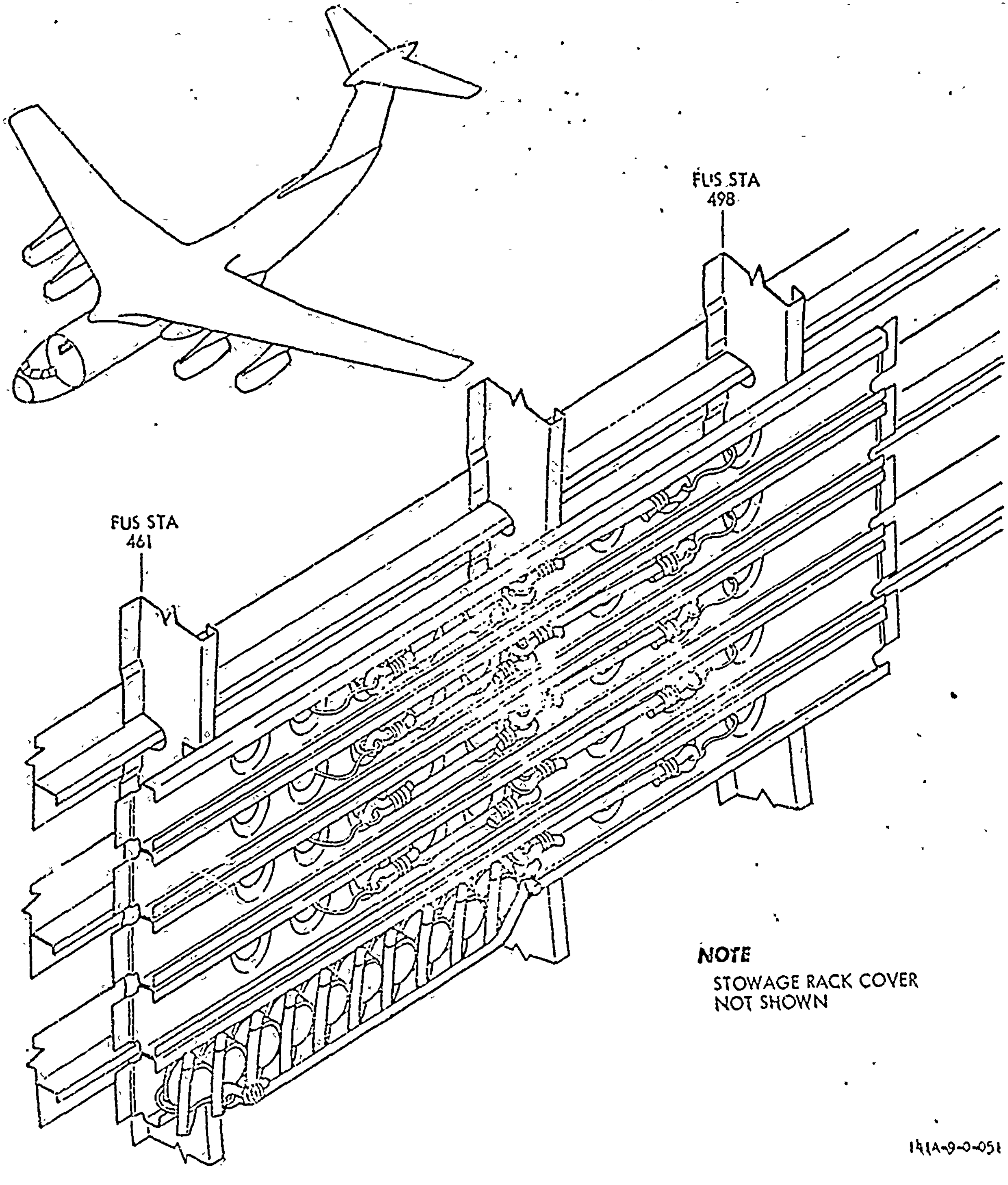
CAUTION

Use only MB-1 or MB-2 tiedown devices with 25,000-pounds tiedown fittings. When using the MB-1 tiedown device with the 25,000-pounds tiedown fittings, do not exceed the rated capacity of the MB-1 device.

2-78. Stowage for the 25,000-pound tiedown fittings is provided in the forward tiedown chain stowage locker on the right side of the cargo compartment between fuselage stations 558 and 578. This locker is divided by a partition; one half is used for fitting

From: Cargo Loading, USAF Series, C-141A Aircraft, AF 33(657)-8835, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967.

From: Cargo Loading, USAF Series, C-141A Aircraft, AF 33(657)-8855, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967.



NOTE

STOWAGE RACK COVER NOT SHOWN

Figure 2-23. 10,000-Pound Tiedown Fitting Stowage

From: Cargo Loading, USAF Series, C-141A Aircraft, AF 33(657)-8835, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967.

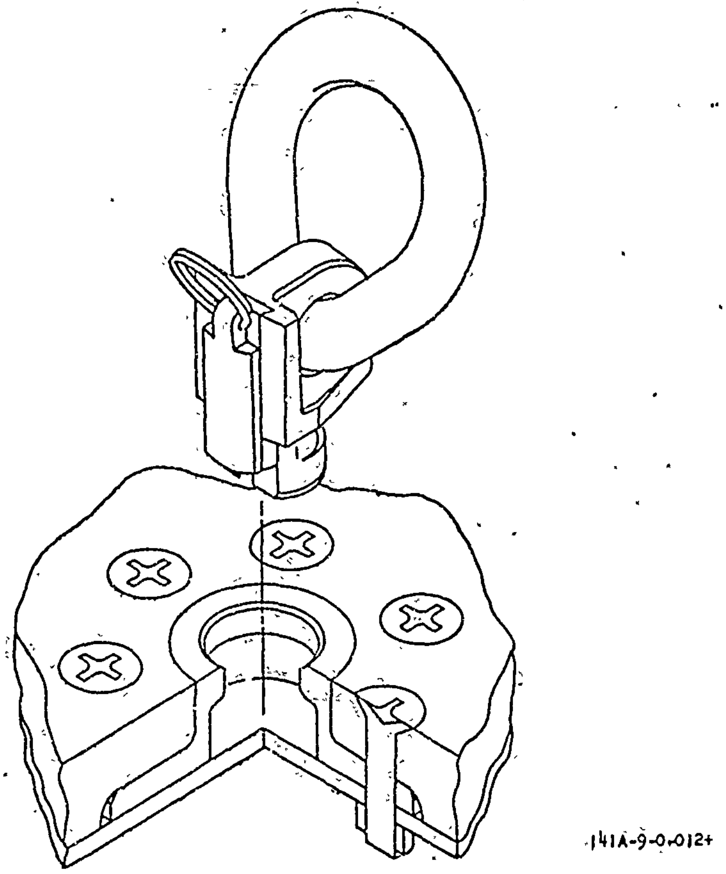


Figure 2-24. 25,000-Pound Tiedown Fitting

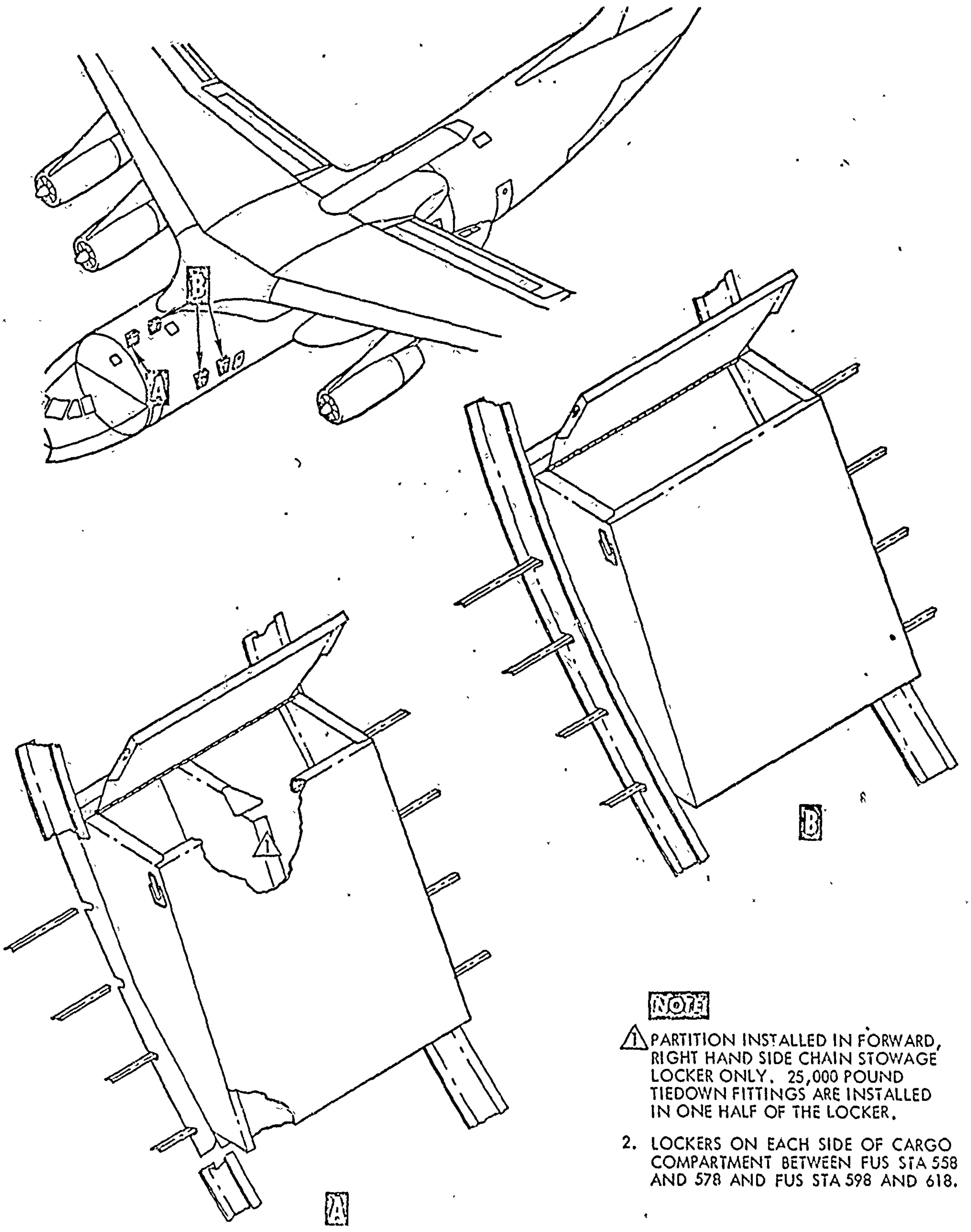
stowage and the other half for chain stowage. (See figure 2-25.)

2-79. RESTRAINT RAIL TIEDOWN FITTINGS (SINGLE). (See figure 2-26.) A quantity of interchangeable quick-disconnect fittings for securing the restraint rails and the restraint rail end bumpers to the cargo floor are stowed in the cargo compartment. A ring which is mounted on the shank of the fitting is moved up to unlock the fitting or down to lock the fitting. The single restraint rail tiedown fitting does not provide any rings or hooks which can be used for attaching tiedown chains.

2-80. When not in use, the restraint rail tiedown fittings are stowed in receptacles in the vertical face of the rail on which the fitting is to be used. (See figure 2-27.)

2-81. RESTRAINT RAIL TIEDOWN FITTINGS (COMBINATION). (See figure 2-28.) A quantity of interchangeable quick-disconnect fittings for securing the restraint rail concurrently with a separate load are stowed in the cargo compartment. The portion of this fitting used to secure a restraint rail is identical to the single restraint rail fitting except that a short length of chain is attached to it. On the other end of the chain is a ring of the same type used with the 25,000-pound fittings. This ring will accept the hook from one Type MB-2 tiedown device and provide a 25,000-pound tiedown attachment point for cargo. The overall length of the fitting is 12 inches, which provides clearance of the ring over the restraint rail. The combination fittings are used only when carrying a mixed load of pallets and vehicles to provide tiedown of vehicles where all other receptacles are covered by the pallets or the restraint rails. Use the fittings only at specifically designated points.

2-82. CARGO COMPARTMENT FLOOR TIEDOWN RECEPTACLE IDENTIFICATION. (See figure 2-29.) A grid system is used to identify the 10,000-pound seat track and tiedown receptacles. There are a total of 7 rows of tiedown fitting receptacles across the cargo compartment floor and 42 rows of receptacles from the front of the compartment to the front end of the ramp. The rows across the width are designated "A" through "G" beginning at the left side. The rows down the length are designated "1" through "42," beginning at the front. The grid system thus formed identifies each fitting by letter and number. The correct letter and number combination is permanently etched into the floor adjacent to each of the fittings. In addition, on aircraft AF63-8077 modified by ECP LH-C141-100-225K, on aircraft AF61-2775 through 61-2778, 63-8075, 63-8076, and 63-8078 through 63-8087 modified by T.O. 1C-141A-672, and on aircraft AF61-2779 and 63-8088 and up, a yellow disc is cemented in the center hole of each tiedown location in the continuous seat track to further identify the proper 20-inch tiedown grid. The 25,000-pound tiedown receptacles are unmarked.



NOTE

1. PARTITION INSTALLED IN FORWARD, RIGHT HAND SIDE CHAIN STOWAGE LOCKER ONLY. 25,000 POUND TIEDOWN FITTINGS ARE INSTALLED IN ONE HALF OF THE LOCKER.
2. LOCKERS ON EACH SIDE OF CARGO COMPARTMENT BETWEEN FUS STA 558 AND 578 AND FUS STA 598 AND 618.

141A-9-0-059

Figure 2-25. Tiedown Chain and 25,000-Pound Fitting Stowage

From: Cargo Loading, USAF Series, C-141A Aircraft, AF 33 (657)-8835, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967.

Figure 2-26. Restraint Rail Tiedown Fitting (Single)

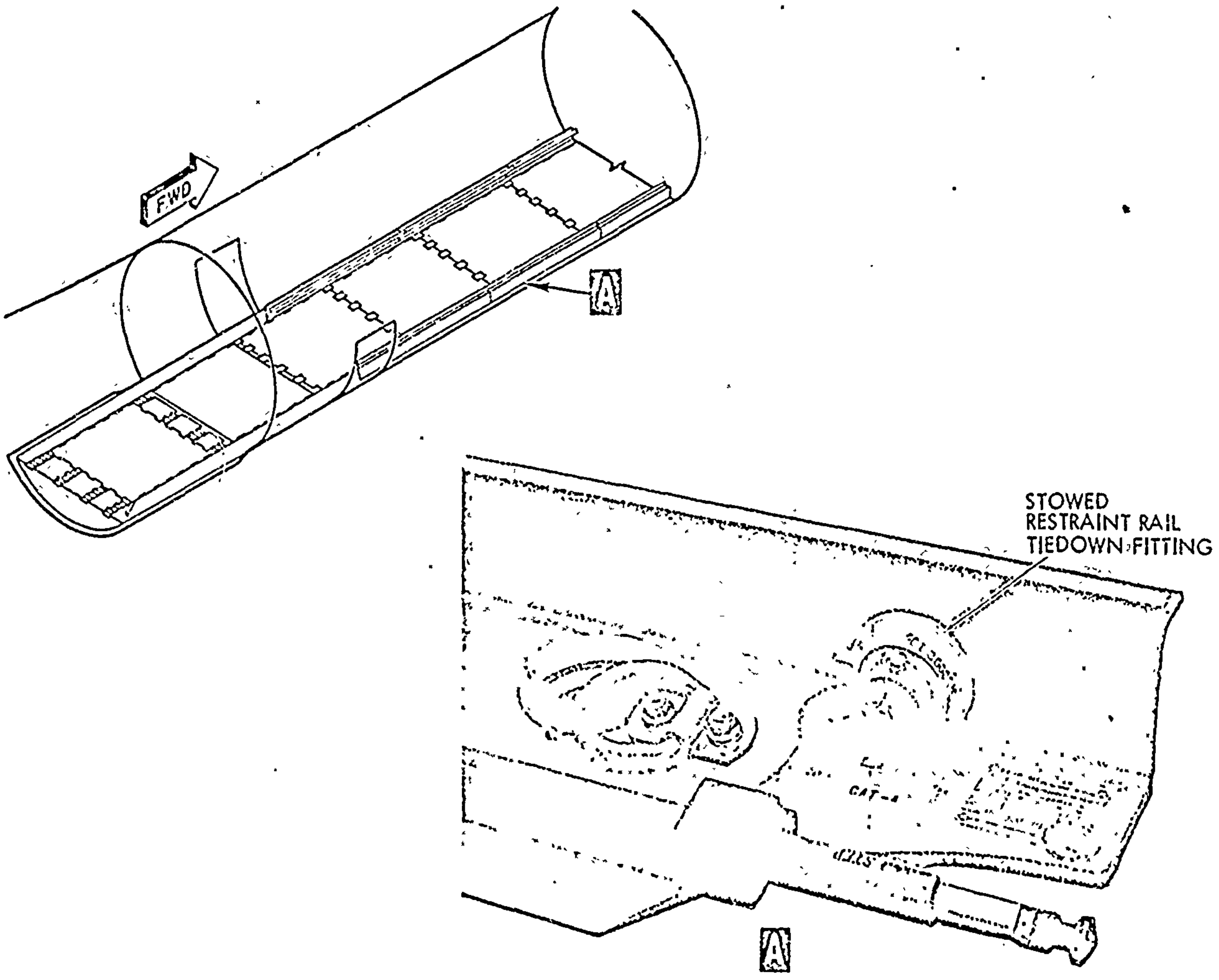
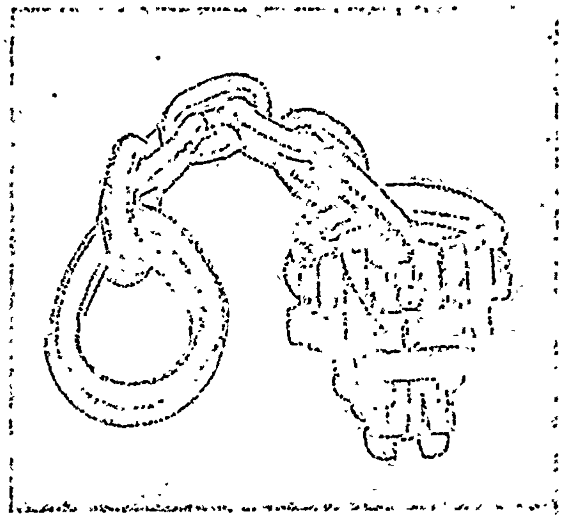


Figure 2-27. Restraint Rail Tiedown Fitting Stowage

From: Cargo Loading, USAF Series, C-141A Aircraft, AF 33(657)-8835, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967.



141A-9-0-136

Figure 2-28. Restraint Rail Tiedown Fitting (Combination)

2-83. CARGO RAMP TIEDOWN RECEPTACLE IDENTIFICATION. (See figure 2-29.) A grid system of etched numbers and letters is used on the ramp floor to identify each of the 10,000-pound tiedown receptacles. The rows are numbered "1" through "6" from front to rear and "A" through "G" from left to right.

2-84. TIEDOWN DEVICES. Two types of tiedown devices are used to secure cargo: MB-1 and MB-2.

2-85. MB-1 TIEDOWN DEVICE. (See figure 2-30.) The MB-1 tiedown device is rated at 10,000 pounds. It consists of an adjustable hook, tensioning grip, chain lock, quick-release lever, and 9-foot chain.

2-86. MB-2 TIEDOWN DEVICE. (See figure 2-31.) The MB-2 tiedown device is rated at 25,000 pounds. It consists of an adjustable hook, tensioning grip, chain lock, quick-release lever, and 9-foot chain.

2-87. MB-1 AND MB-2 TIEDOWN DEVICE STOWAGE. (See figure 2-32.) Hangers for stowing the adjustable hooks of MB-1 and MB-2 tiedown devices are provided in sidewall lockers on the right side of the cargo compartment between fuselage stations 918 and 1058, and on the left side of the cargo compartment between fuselage stations 998 and 1058. An elastic snubber cord with an end hook, which will attach to the tiedown device and hold it secure, is provided in the locker. The chains for the tiedown devices are stowed separately. The adjustable hooks for the MB-1 and MB-2 tiedown devices are stowed (see figure 2-32) as follows:

Note

> Before attempting to install the hooks make sure the hanger is equipped with 2 washers. This number of washers will ensure proper installation.

a. Slide the top end of the adjustable hook on the hanger bolt.

b. On the MB-2 tiedown adjustable hook, attach the elastic snubber cord to the lower (hook) end of the device.

c. On the MB-1 tiedown adjustable hook pull back the elastic restraint cord sufficiently to allow the lower (hook) end of the device to swing outboard of the cord.

2-88. Two boxes for stowing chains removed from MB-1 and MB-2 tiedown devices are located on each side of the cargo compartment between fuselage stations 558 and 578, and 598 and 618, forward of the wing. The forward box on the right side also holds 25,000-pound tiedown fittings.

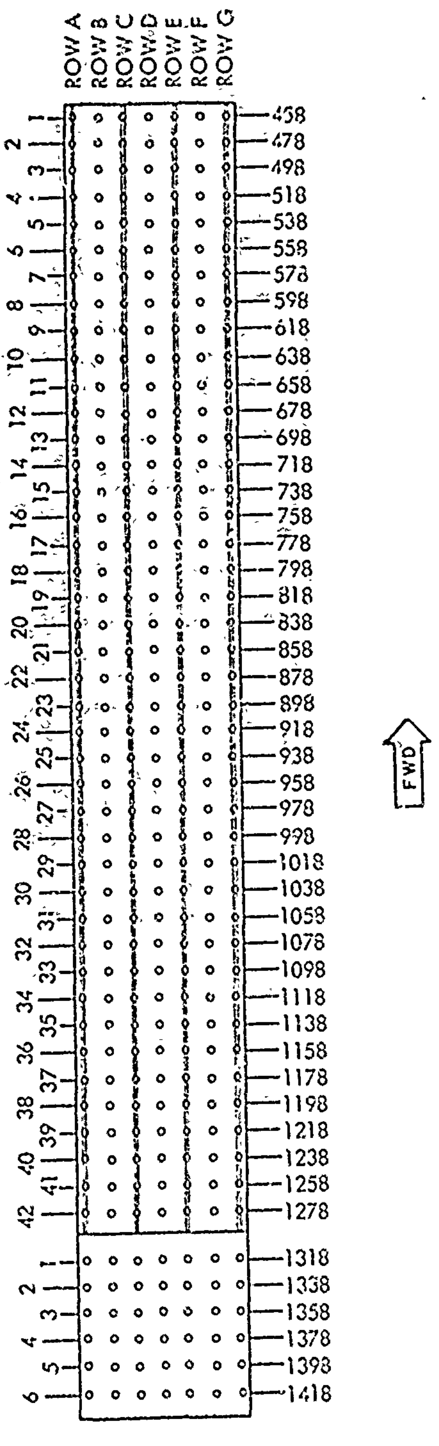
2-89. ROLLER CONVEYORS.
(See figure 2-33.)

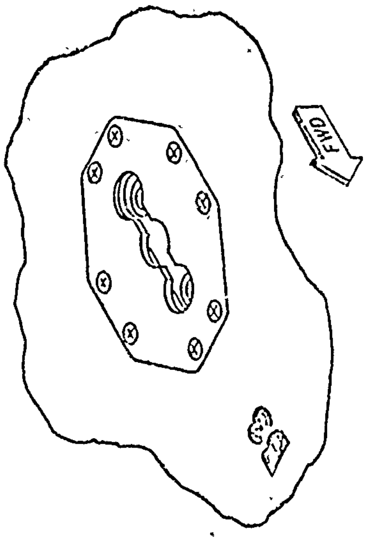
CAUTION

> Keep all roller conveyor drip pans free of water, solvents, dirt, and other foreign material. Water freezing in the drip pans during flight can cause damage to the rollers or prevent later removal of the conveyors. Frozen conveyors must not be forced from the floor. Apply heat first to melt the ice and then remove the conveyors in the normal manner.

2-90. Four channels for the insertion of removable roller conveyor sections are permanently recessed into the cargo compartment and ramp floors. The support channels are located symmetrically across the floor at left and right butt lines 15 and 51. The conveyor sections fit into the channels with the rollers above the surrounding floor level when placed for palletized cargo loading or for airdrops, but may be turned over in the channels and locked into place

From: Cargo Loading, USAF Series, C-141A Aircraft, AF 33(657)-8835, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967.





TYPICAL TIE DOWN MARKING
(FITTING 3 IN ROW B)

—o— 10,000-POUND SEAT TRACK RECEPTACLE △2

o 10,000-POUND INDIVIDUAL RECEPTACLE

NOTE

1. THE 25,000-POUND TIEDOWN RECEPTACLES ARE NOT IDENTIFIED ON THE AIRCRAFT.

△2 A YELLOW DISC IS CEMENTED IN THE CENTER HOLE OF EACH RECEPTACLE IN THE SEAT TRACK WHICH LIES ON THE 20-INCH GRID PATTERN ON AIRCRAFT AF63-8077 MODIFIED BY ECP LH-C141-100-225K, ON AIRCRAFT AF61-2775 THROUGH 61-2778, 63-8075, 63-8076, AND 63-2078 THROUGH 63-8087 MODIFIED BY T.O. 1C-141A-672, AND ON AIRCRAFT AF61-2779 AND 63-8088 AND UP.

141A-9-784-142

Figure 2-29. Tiedown Receptacle Identification

From: Cargo Loading, USAF Series, C-141A Aircraft, AF 33(657)-8835, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967.

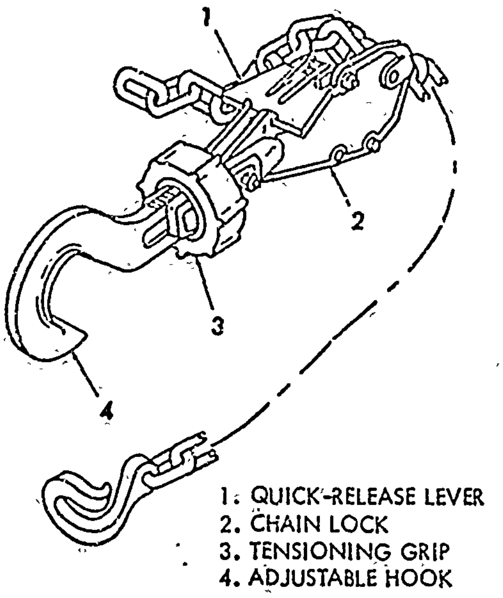


Figure 2-30. Type MB-1 Tiedown Device

with their smooth bottom surfaces flush with the surrounding floor for vehicle or troop loading. Regardless of the way they are turned, the conveyor sections always remain with the aircraft and are available for immediate use.

2-91. CONVEYOR SECTIONS. Each conveyor section consists of a U-shaped channel which is flat on the bottom and contains rollers in the open side. A strip of soundproofing seal is installed down the length of each side of the channel to reduce noise coming from beneath the cargo floor. The channels are 4-1/2 inches wide and vary in length from approximately 7 feet long for the forward and center cargo compartment sections to 7-1/2 feet for the aft cargo compartment and 10-1/2 feet for the ramp sections. All of the sections are interchangeable with other sections laterally, but only certain of the sections are interchangeable longitudinally due to their varying lengths. The most forward and the most aft lateral rows of conveyors in the cargo compartment are limited to and must remain in their lateral row locations.

2-92. Each conveyor section contains individual bearing-mounted aluminum rollers on approximate 10-inch centers. The rollers are 1-7/8 inches in diameter and 3-1/2 inches long. When the conveyor is turned upright, the rollers project 1-1/2 inches above the floor level. When the conveyor sections are inverted, the rollers project down into cutouts in the conveyor tracks.

2-93. CONVEYOR LOCKS. A manually operated quick-release lock is permanently installed in the conveyor track between each two conveyor sections. A tapered lip on the forward section of the lock holds the aft end of the conveyor section forward of the lock, and a spring-loaded plunger with finger hole on the aft end of the lock holds the forward end of the conveyor section aft of the lock.

2-94. RESTRAINT RAILS.

2-95. Retractable restraint rails are provided on both sides of the cargo compartment and ramp floor to aid in loading, tying down, and unloading palletized cargo and airdrop platforms. When fixed in position, the rails provide a continuous narrow channel down both sides of the compartment, for the entire length of the cargo compartment and ramp. These channels guide platform and pallets in and out of the aircraft, hold them down against the rollers; and with restraint mechanisms provided, prevent forward and aft movement. During airdrops, restraint mechanisms on the right rail may be set to apply a variable amount of aft restraint to the platforms.

2-96. The rails for each side of the aircraft are built in ten sections to facilitate handling. All sections forward of the troop door openings are attached to the side of the cargo floor by hinge straps and can be folded up under the side walkways when not in use. The remaining sections are stowed as loose equipment when not in use.

2-97. Two stowage racks (figure 2-34) which hold two restraint rails each are located on the left and on the right sides of the cargo compartment in the ramp area between fuselage stations 1292 and 1398. For stowage, the rails are placed so that the holes normally used for inserting tiedown fittings align with holes on the stowage racks. The tiedown fittings used with the rails are then fitted through the two holes to hold the rails secure. The aft removable restraint

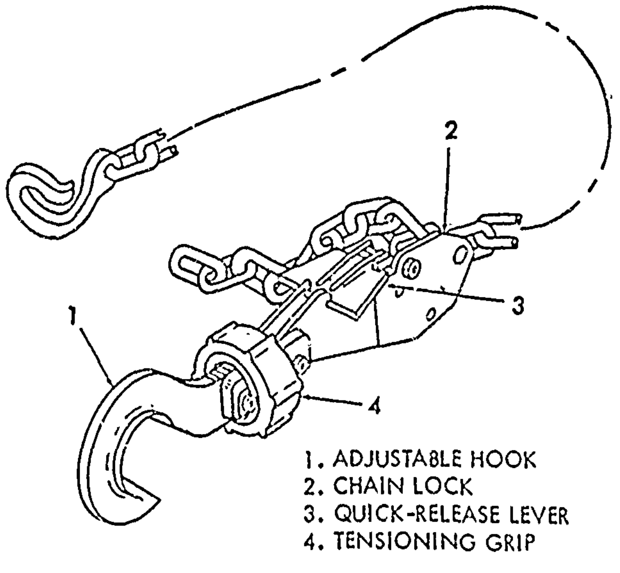


Figure 2-31. Type MB-2 Tiedown Device

From: Cargo Loading, USAF Series, C-141A Aircraft, AF 33(657)-8835, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967.

From: Camp Loading, USAF Series, C-141A Aircraft, AF 33(657)-8835, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967.

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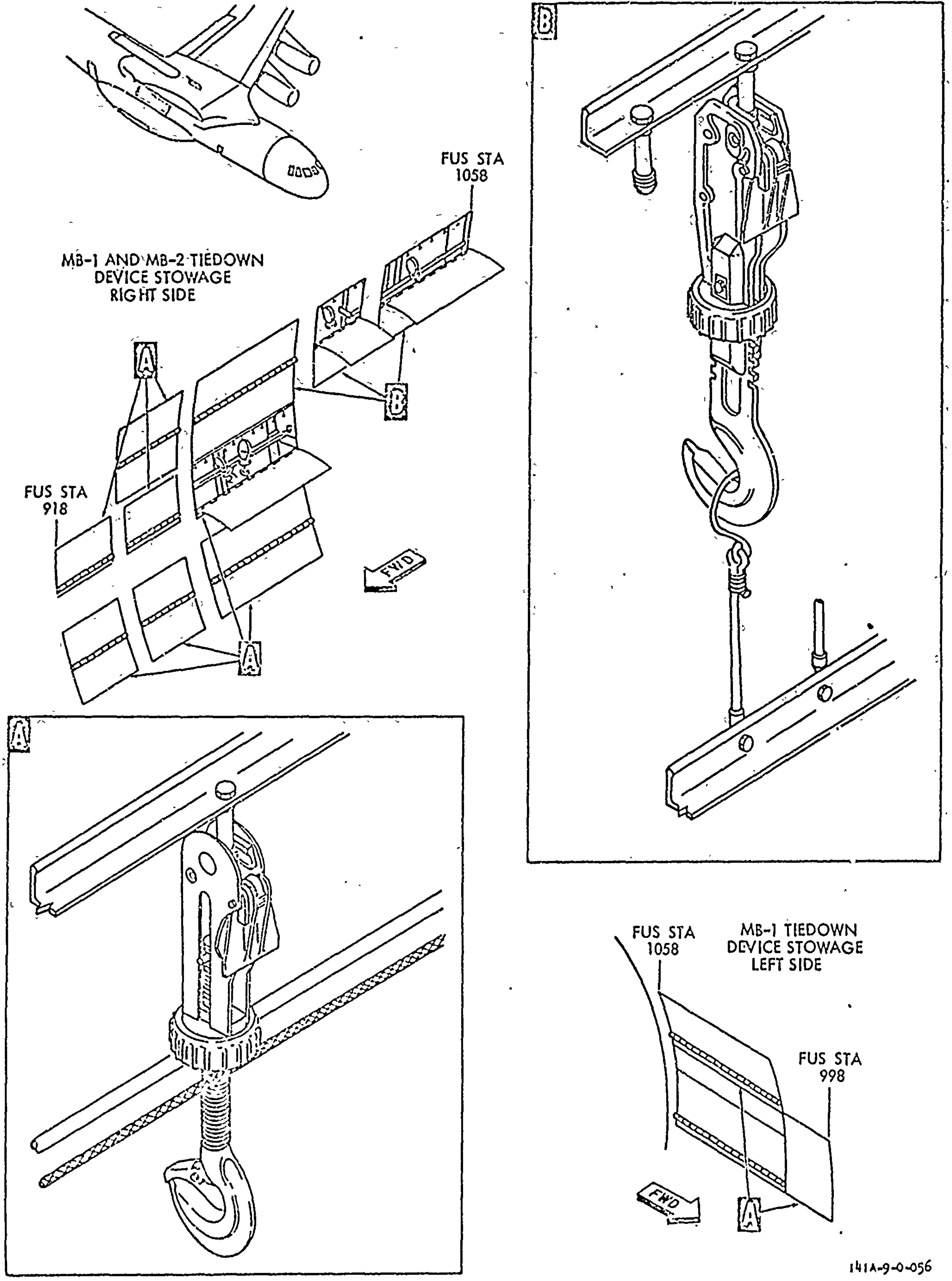


Figure 2-32. MB-1 and MB-2 Tiedown Device Stowage

From: Cargo Loading, USAF Series, C-141A Aircraft, AF 33(657)-8835, AF 33(657)-14885, T.O. 1C-141A-9, April 6, 1967.

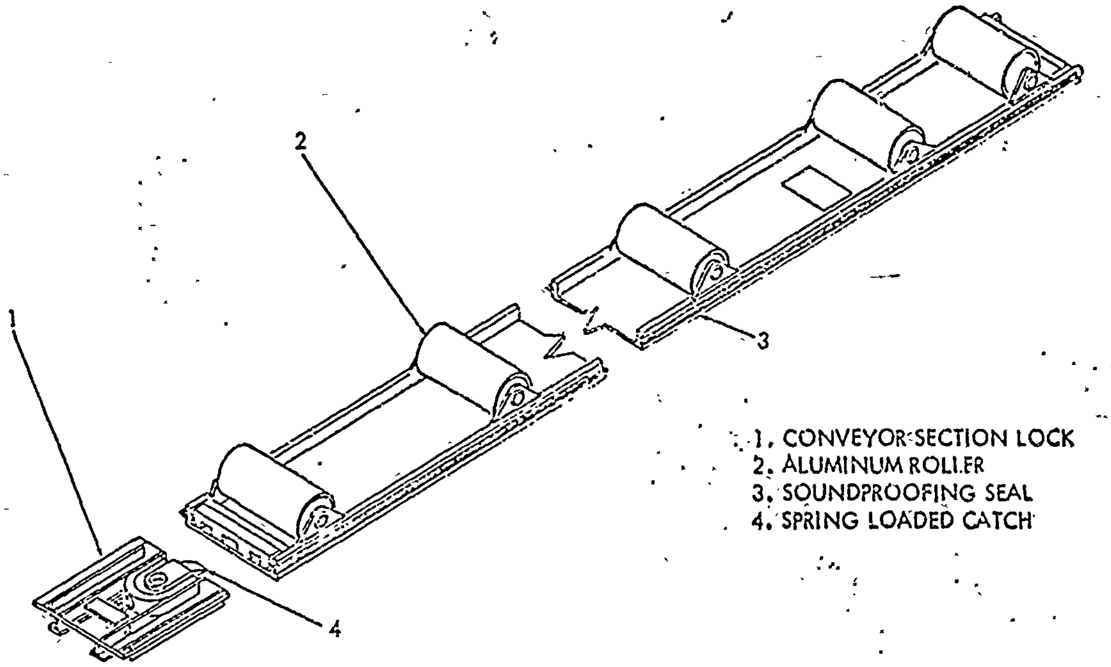


Figure 2-33. Roller Conveyors

141A-9-0-019+R

rail in the cargo compartment and the aft restraint rail on the ramp are stowed in the forward stowage rack. The forward removable cargo floor and forward ramp restraint rails are stowed in the aft stowage rack.

2-97A. On aircraft AF66-192 and up, canvas straps are provided at each stowage location to secure the stowed rails tightly to the structure. This eliminates the noise sometimes caused by the rails vibrating against the stowage racks.

2-98. RESTRAINT RAIL END BUMPERS. (See figure 2-35.) Two restraint rail end bumpers, each containing a block of steel-faced rubber, are provided for attachment at the forward end of the two forward restraint rails at fuselage station 487 to prevent overtravel of pallets or platforms. One restraint rail end bumper is attached to the forward end of the left rail and one is attached to the forward end of the right rail. Each end bumper contains two mounting holes which permit one attachment to the restraint rail and one attachment to a cargo floor 25,000-pound receptacle. The standard restraint rail tiedown fitting is used to attach the bumper to the floor.

2-99. When not in use the two restraint rail end bumpers are stowed together in brackets (figure 2-36) on the right side of the cargo compartment near the forward end. Each bumper attaches to its stowage brackets by the tiedown fitting used to attach the bumper to the cargo floor when it is in use.

2-100. LOADING AIDS.

2-101. The following loading equipment is furnished for use in loading the C-141 aircraft.

2-102. CARGO WINCH PROVISIONS (AIRCRAFT AF61-2775 THROUGH 64-623 NOT MODIFIED BY T.O. 1C-141A-545). (See figure 2-37.) A compartment for permanently stowing and operating a cargo winch is recessed at the forward end of the cargo compartment floor, beneath the flight station. The removable winch attaches to the floor of the winch compartment, or to any two 10,000-pound receptacles in the cargo compartment, by two fittings at its forward end. An electrical connector adjacent to the compartment supplies 400-cycle, 3-phase, 200-volt electric power from the No. 3 main AC bus for operation. A remote control on an extension cable permits the operator freedom of movement while operating the winch.

Note

Cargo winches for use in these compartments are not available.

2-103. A removable cable guide roller is installed on the aft edge of the winch platform to keep the winch cable close to the compartment floor. This permits the cable to be run under forward pallets or platforms to drag in more cargo from the rear. It also prevents the winch cable from damaging the ceiling of the winch compartment. Removable fabric covers completely enclose the winch compartment when the winch is not in use.

2-104. CARGO WINCH PROVISIONS (AIRCRAFT AF61-2775 THROUGH 64-623 MODIFIED BY T.O. 1C-141A-545 AND AIRCRAFT AF64-624 AND UP). (See figure 2-38.) A recessed compartment for permanently stowing a cargo winch is located at the forward end of the cargo compartment floor, beneath the flight station. The winch has a retractable wheel at each corner and may be rolled out of the compartment and attached to standard cargo compartment floor tiedown fittings if desired. Normally the winch is operated without removing it from the compartment, and snatch blocks are used to provide side pulls if necessary.

The Source for pages D-33 through D-37 is: Preparation of Freight For Air Shipment, December, 1969 DSAM 4145.7, TM38-236, NAVAIR 15-01-3, AFP 71-8, MCO P4030.30A, Section 1-19.

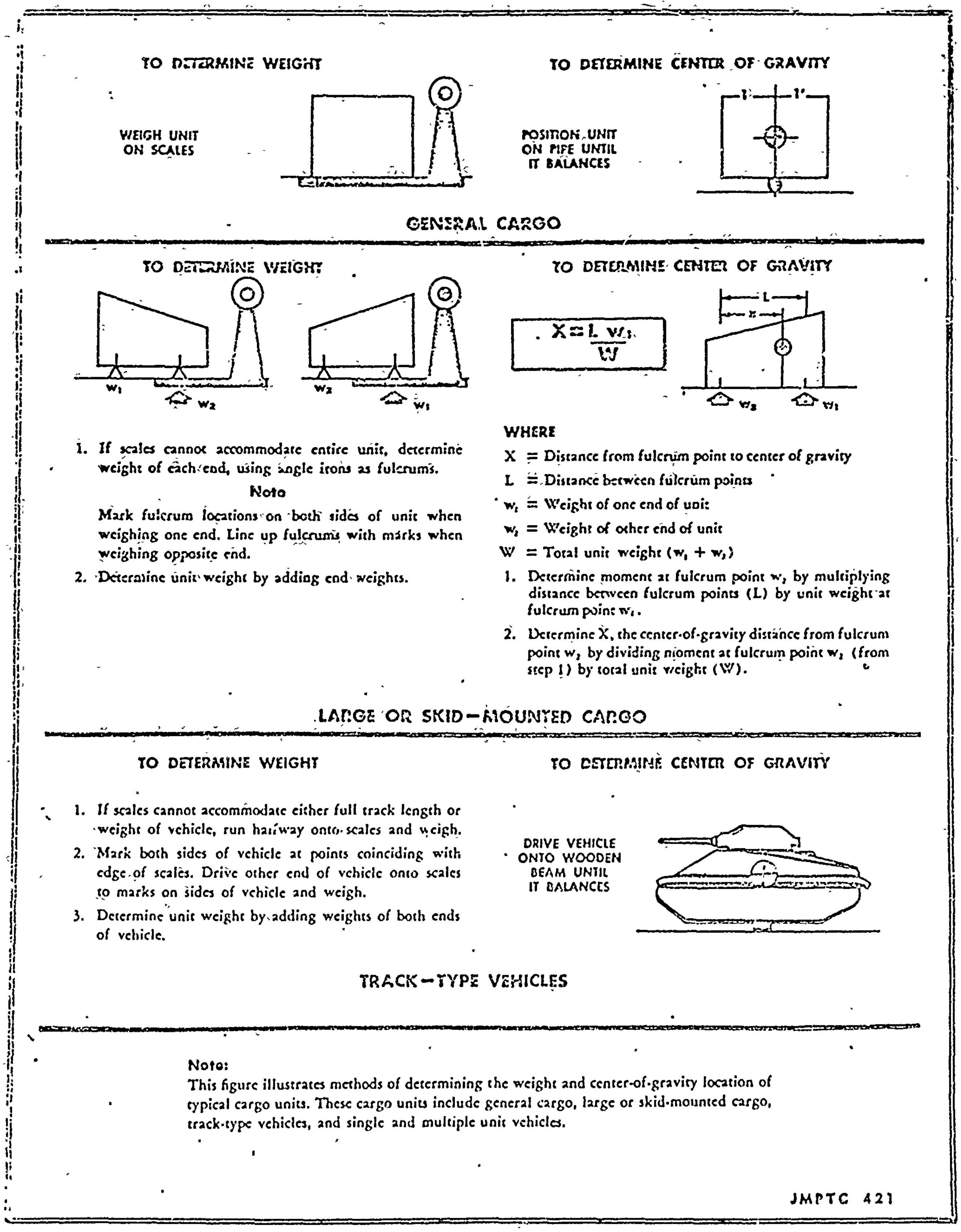
1-19. Cargo Tiedown Devices

Cargo tiedown devices are used to secure cargo in the aircraft and to prevent it from shifting during flight. The most commonly used tiedown devices are the D-1, C-2, MB-1, MB-2, A-1A, and MC-1. Cargo tiedown nets are also used to secure and restrain cargo.

a. D-1 Tiedown Device. The D-1 tiedown device is rated at 25,000 pounds and used to restrain heavy cargo. This device consists of a turnbuckle and jaw arrangement attached to a chain. The turnbuckle is attached to the chain by inserting the chain by means of the offset hook to the cargo and attaching the jaws of the turnbuckle to a 25,000-pound tiedown fitting in the floor of the aircraft. The chain is then tightened by turning the tensioning collar in the center of the turnbuckle (fig. 1-13).

b. C-2 Tiedown Device. The C-2 tiedown device is rated at 10,000 pounds. It is similar to the D-1 device except for size and weight limitations. This device is constructed and installed in the same manner as the D-1 device. It is attached to the 10,000-pound tiedown rings in the cargo floor (fig. 1-13).

c. MB-1 and MB-2 Tiedown Devices. The MB-1 and MB-2 devices serve the same purpose as the D-1 and C-2 devices, but are different in design. Instead of jaws which are attached to the tiedown ring, the MB-1 and MB-2 devices have a heavy hook which is engaged with the ring. The MB-1 and MB-2 devices are used with the same type of hooked chain as the D-1 and C-2 cargo tiedown devices, but the MB-1 and MB-2 devices have a quick-release feature which makes it possible to detach the device from the chain instantly, regardless of the tension on the chain. The MB-1 and MB-2 devices have knurled ring (tensioning collar) which is turned to tighten the tiedown chain. The MB-1 device is rated at



TO DETERMINE WEIGHT

WEIGH UNIT ON SCALES

TO DETERMINE CENTER OF GRAVITY

POSITION UNIT ON PIPE UNTIL IT BALANCES

GENERAL CARGO

TO DETERMINE WEIGHT

1. If scales cannot accommodate entire unit, determine weight of each end, using angle irons as fulcrums.

Note

Mark fulcrum locations on both sides of unit when weighing one end. Line up fulcrums with marks when weighing opposite end.

2. Determine unit weight by adding end weights.

TO DETERMINE CENTER OF GRAVITY

$$X = \frac{L\,w_1}{W}$$

WHERE

X = Distance from fulcrum point to center of gravity

L = Distance between fulcrum points

w_1 = Weight of one end of unit

w_2 = Weight of other end of unit

W = Total unit weight ($w_1 + w_2$)

1. Determine moment at fulcrum point w_2 by multiplying distance between fulcrum points (L) by unit weight at fulcrum point w_1.
2. Determine X, the center-of-gravity distance from fulcrum point w_2 by dividing moment at fulcrum point w_2 (from step 1) by total unit weight (W).

LARGE OR SKID-MOUNTED CARGO

TO DETERMINE WEIGHT

1. If scales cannot accommodate either full track length or weight of vehicle, run halfway onto scales and weigh.
2. Mark both sides of vehicle at points coinciding with edge of scales. Drive other end of vehicle onto scales to marks on sides of vehicle and weigh.
3. Determine unit weight by adding weights of both ends of vehicle.

TO DETERMINE CENTER OF GRAVITY

DRIVE VEHICLE ONTO WOODEN BEAM UNTIL IT BALANCES

TRACK-TYPE VEHICLES

Note:

This figure illustrates methods of determining the weight and center-of-gravity location of typical cargo units. These cargo units include general cargo, large or skid-mounted cargo, track-type vehicles, and single and multiple unit vehicles.

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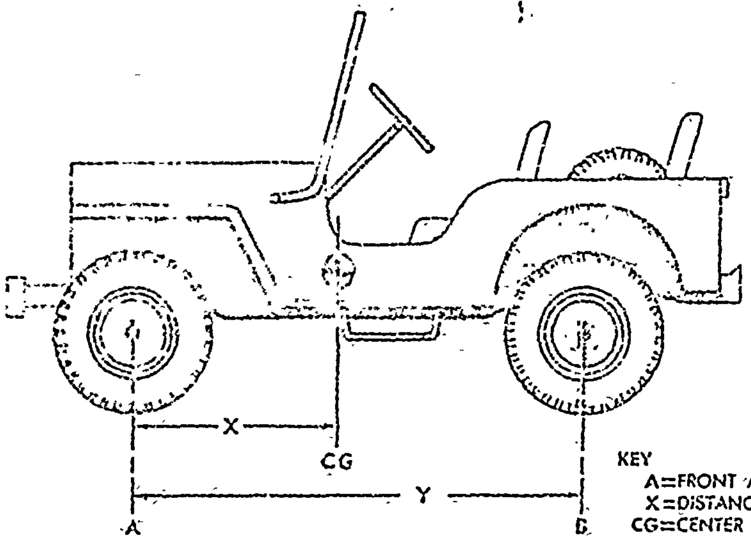
Figure 1-11. Determining unit weight and center of gravity.

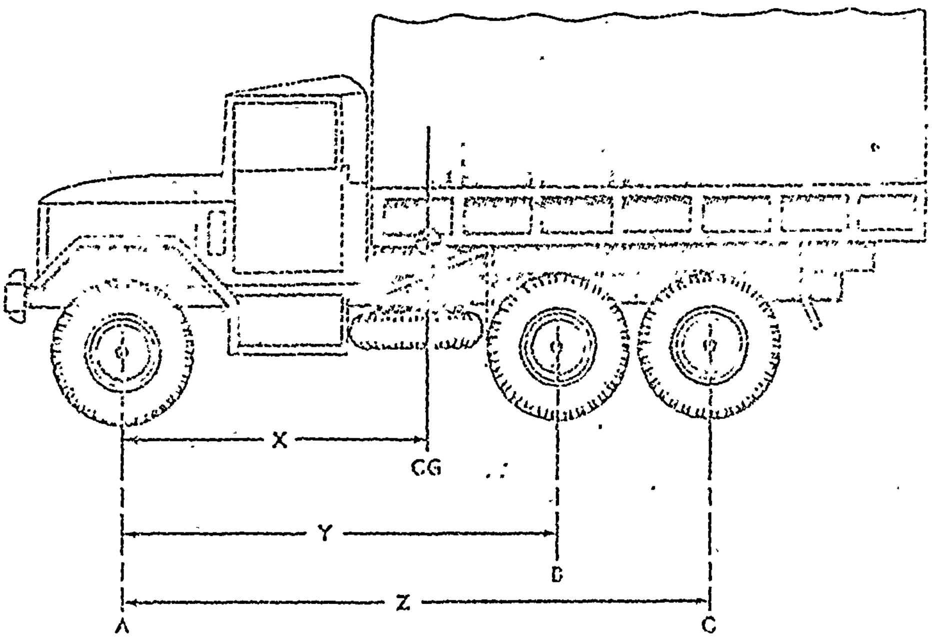
From: Preparation of Freight For Air Shipment, December 1969,
DSAM 4145.7, TM38-236, NAVAIR 15-01-3, AFP 71-8, MCO P4030.30A, Section 1-1



FORMULA--X=$\frac{B \times Y}{A + B}$

KEY
A=FRONT AXLE WEIGHT
X=DISTANCE FROM FRONT AXLE TO CENTER OF GRAVITY
CG=CENTER OF GRAVITY
Y=DISTANCE FROM FRONT AXLE TO REAR AXLE
B=REAR AXLE WEIGHT

TWO AXLED VEHICLE



KEY
A=FRONT AXLE WEIGHT
X=DISTANCE FROM FRONT AXLE TO CENTER OF GRAVITY
Y=DISTANCE FROM FRONT AXLE TO FRONT TANDEM AXLE
CG=CENTER OF GRAVITY
Z=DISTANCE FROM FRONT AXLE TO REAR TANDEM AXLE
B=FRONT TANDEM AXLE WEIGHT
C=REAR TANDEM AXLE WEIGHT

FORMULA--X=$\frac{(B \times Y) + (C \times Z)}{A + B + C}$

THREE AXLED VEHICLE

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Figure 1-12. Determining vehicle weight and center of gravity.

From: Preparation of Freight For Air Shipment, December 1969, DSAM 4145.7, TM38-236, NAVAIR 15-01-3, AFP 71-8, MCO P4030.30A, Section 1-19

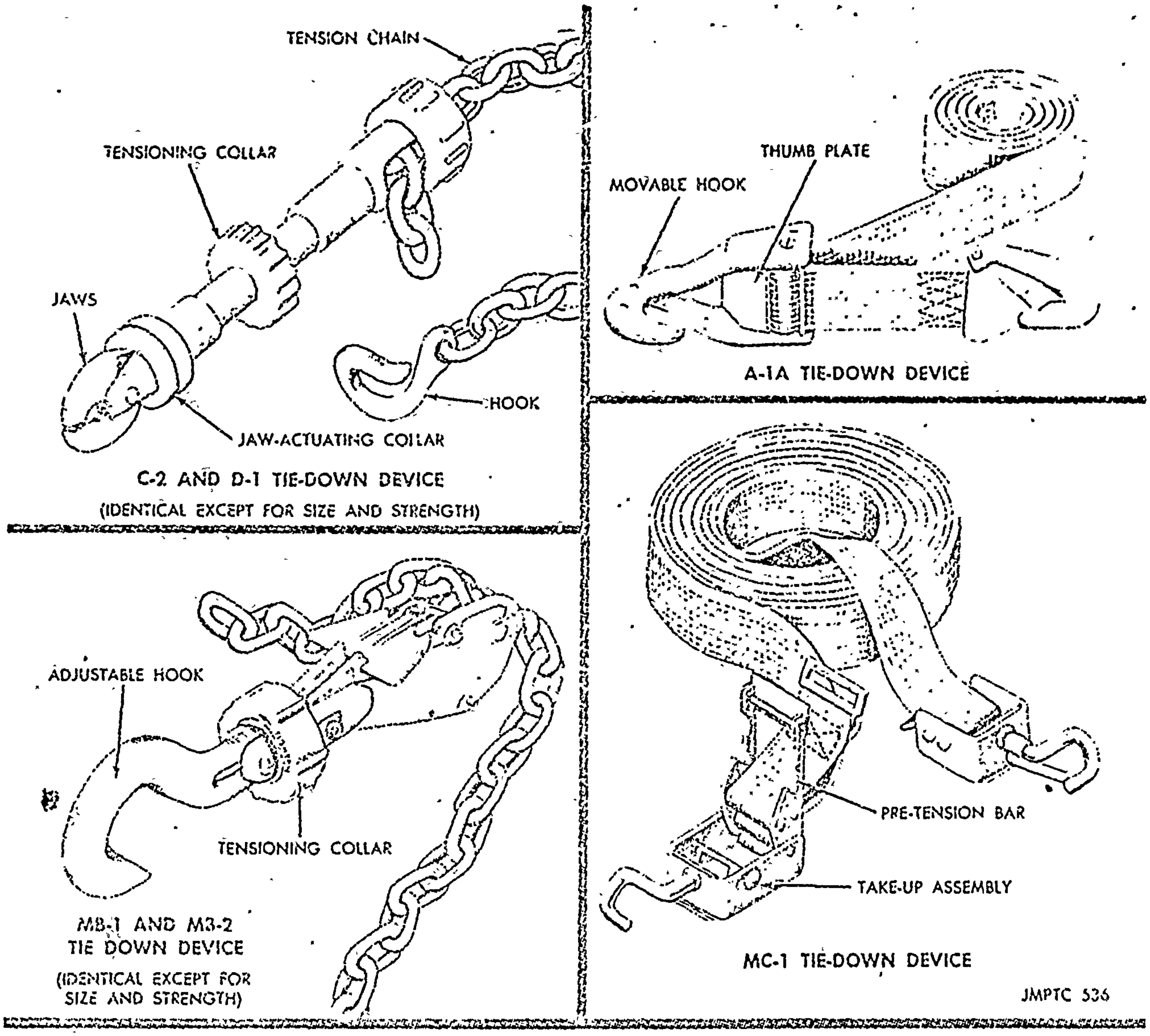

Figure 1-13. Cargo tiedown devices.

10,000 pounds and the MB-2 device at 25,000 pounds (fig. 1-13).

d. MC-1 Tiedown Device. The MC-1 tiedown device is rated at 5,000 pounds. This device consists of a web strap and two metal hooks. One hook is stationary and one is movable. The MC-1 tiedown device is installed by hooking the stationary hook on the end of the strap to one of the tiedown fittings. The other end is passed over the cargo and the movable hook is hooked to another tiedown fitting. The strap is tightened by pulling the free end through the pretension bar which automatically locks in place. The MC-1 tiedown device is removed by pressing the takeup assembly (fig. 1-13).

e. A-1A Tiedown Device. The A-1A tiedown device is similar to the MC-1 device, but is lighter. It is rated at 1,250 pounds. The A-1A device has a stationary hook and a movable hook. It is tightened by pulling the free end through the thumb plate which automatically locks in place (fig. 1-13).

f. Cargo Nets. Cargo nets are used to secure general cargo in the aircraft. The use of cargo nets minimizes the individual tiedown device requirements (fig. 1-14).

g. Cargo Tiedown Fittings. There are two types of cargo tiedown fittings that are permanently installed on cargo aircraft. The first is an AN fitting or light cargo tiedown fitting. The AN fittings are bolted to the aircraft floor as permanent installations. The second type of tiedown fit-

From: ~~Preparation of Freight For Air Shipment~~, December 1969, DSAM 4145.7, TM38-236, NAVAIR 15-01-3, AFP 71-8, MCO P4030.30A, Section 1-19.

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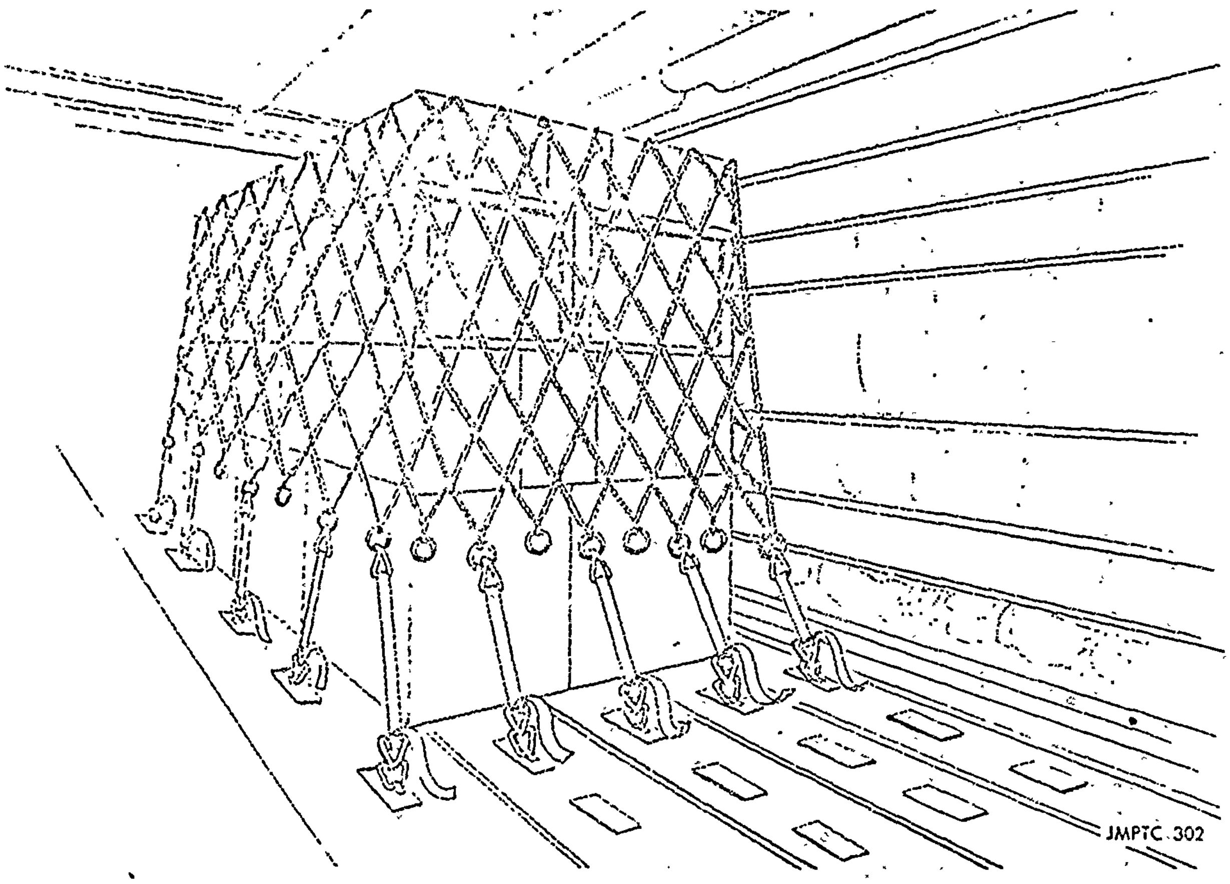

Figure 1-14. Application of net tiedown.

tings is a heavy cargo tiedown. These fittings are fastened directly to the floor structure and are used to tie down vehicles and heavy cargo items. The tiedown rings are designed to withstand different loads. Examples of tiedown fittings on a C-130 aircraft are—

(1) *The 10,000-pound tiedown rings.* These are D-ring type fittings located 20 inches on center in the cargo floor.

(2) *The 25,000-pound tiedown rings.* These are D-ring type fittings of which 8 or more may be installed in the cargo floor.

(3) *The 5,000-pound tiedown rings.* These fittings are installed on the ramp and sidewalls of the cargo compartment.

h. Restraint Criteria. Cargo in the aircraft is subjected to forces resulting from rough air, accelerations, rough landings, crash landings, extreme attitudes, and decelerations. Cargo has a tendency to move forward when the aircraft is suddenly slowed. Other forces tend to move the cargo aft, to either side (laterally), or up from the cargo floor (vertically). The amount of restraint needed to keep cargo from moving in a specific direction is called restraint criteria. Restraint criteria, including minimum restraint forces, palletized load restraint, and techniques of applying restraining devices are found in the applicable technical order covering each aircraft. An example is: TO IC-141A-9, *Cargo Loading,* which is applicable for the C-141 aircraft.

From: Preparation of Freight For Air Shipment, December 1969, DSAM 4145.7, TM38-236, NAVAIR 15-01-3, AFI 71-8, MCO P4030.30A, Section 1-19.

The Source of pages D-38 through D-46 is: Advanced Shipboard Chain Tensioner System. Bulletin 5045A, Aeroquip, Van Wert, Ohio, June 1970.

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DESCRIPTION

Considering the requirements for a shipboard vehicle tiedown against the background of existing equipment and possible approaches, Aeroquip designers evolved a family of three similar chain tensioner devices that operate with a simplified deck track. This approach is an outgrowth of experience with cargo tiedown systems currently used in cargo aircraft. It avoids or minimizes the shortcomings of the existing shipboard systems, but takes full advantage of successful experience accumulated with current Mil-spec and FSN devices.

Deck Track

The deck track is welded to the deck in all spaces where vehicles or cargo might be located. Track can also be installed or shifted as desired while the ship is in service without creating structural problems. Length of track and spacing between tracks is very flexible, depending on vehicle or cargo types anticipated. Whatever the requirement, the broad flexibility in track layout provides a very high density pattern of deck attachment points. The track has the following design features:

1. Low Silhouette - The track rises only 1 1/8 inch from the deck, across a symmetrical width of 8 inches. This low silhouette does not interfere with normal operation of vehicles, and works to prevent sudden transitional loading of the deck by a vehicle traversing at an angle. The track is also entirely compatible with normal forklift truck operations. See Aeroquip Test Report 63944.

2. Attachment Points - These are simply 1 3/4 inch holes spaced on 4 inch centers along the length of the track. Such high density of attachment points always assures a wide selection of tiedown points and angles.

3. Scupper Drain Holes - These are 1 1/2 inch radius holes on 4 inch centers spaced alternately on each side of the track.

4. Strength - In tension or shear, the track is designed to offer restraint exceeding 35,000 pounds per attachment at any angle of pull, including the vertical. In compression, the strength will exceed 100,000 pounds per lineal foot.

Track design and strength preclude high unit loading of the track or the deck under compression loads.

Installation of Deck Track

Since the cargo and vehicle loading plan for a ship can vary so widely, depending on the mission, it may be unwise to tailor the track plan to any particular vehicle or vehicle mix. The recommended installation plan for track would call for a simple fore and aft layout in all areas where vehicles or cargo must be secured. In all cases, the deck track provides extra strength in the deck itself, in addition to its other functions. The track can also be cut to fit, as required. In all cases, welding of track to the deck is done according to normal shipyard practice. In no case is it necessary to cut or penetrate the deck itself.

Chain Lashing Assemblies

The chain lashing assemblies consist of three primary components:

Chain Tensioner
Chain, Grab Hook Assembly
Deck Fitting

These assemblies are available in three sizes:

7,000 lb MUSR (weight: 13.7 lbs)
15,000 lb MUSR (weight: 18.0 lbs)
35,000 lb MUSR (weight: 36.7 lbs)

Note: MUSR = Minimum Ultimate Strength Rating

1. Chain Tensioner

The chain tensioner contains a chain link locking jaw, a quick release mechanism, a pre-tension load cell, and a tension indicator. This unit operates as follows:

a. The chain link locking jaw traps and holds a chain link during installation of a chain lashing and drops it during release.

b. The energy absorbing pre-tension and tension load cells permit the secured cargo to "live" with the action of the

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ship in the seaway. This "soft" restraint eliminates overloading and the possible failure of any single tiedown, yet limits travel safely, and securely restrains the load.

c. The tension indicator permits the degree of tension to be easily determined by visual inspection, significantly decreasing the time necessary for routine inspection of secured vehicles and simplifying training of personnel in cargo restraint technique.

d. The tension rod terminates in a clevis configuration facilitating the rapid change of attachment fittings.

e. The release method permits remote release if desired.

2. Chain, Grab Hook Assembly

Each size of chain will mate only with the equivalent strength chain tensioner and have a grab hook sized to the chain installed on the one end. A standard length of chain is 108", but could be longer or shorter, as desired. The "bent" shape of the grab hook permits even load distribution.

3. Attachment Fittings

These end fittings will be supplied as follows:

a. A 35,000 lb quick fit, deck track attachment fitting is used in the pierced holes of the deck track. This fitting, with a cargo tiedown ring incorporated, can be supplied for special use with other types of tiedowns.

The 35,000 lb fitting is omnidirectional and cannot accidentally be partially attached, or misattached to the deck track. It is sufficiently strong to permit use with all three sizes of lashing assemblies, thus eliminating any possibility of mismatching. It also utilizes a positive lock to prevent inadvertent release under shock conditions.

b. A safety snap hook with a spring-loaded safety latch can be provided for use with the five bar dimple fittings installed in the hangar and helicopter flight decks. These

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hooks may also be used with standard tiedown rings or pad eyes when required.

c. A "bulb hook" which mates with deck sockets designed in accordance with BuShips Drawing S2700-F-1213717 can be supplied for use in cargo and vehicle spaces fitted with these sockets.

For exact lengths and other facts about the chain lashing assembly and deck track system, see the data sheet.

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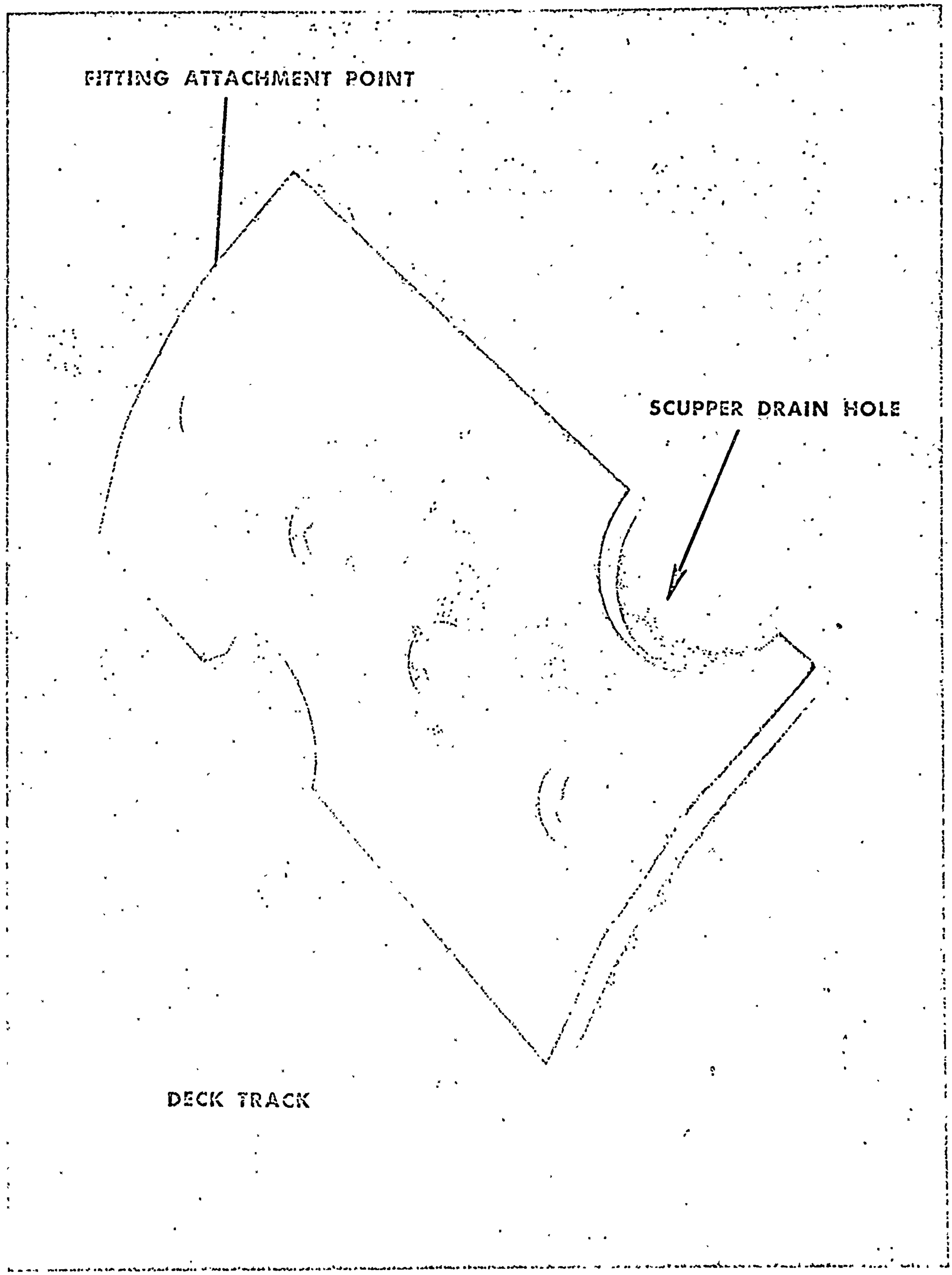
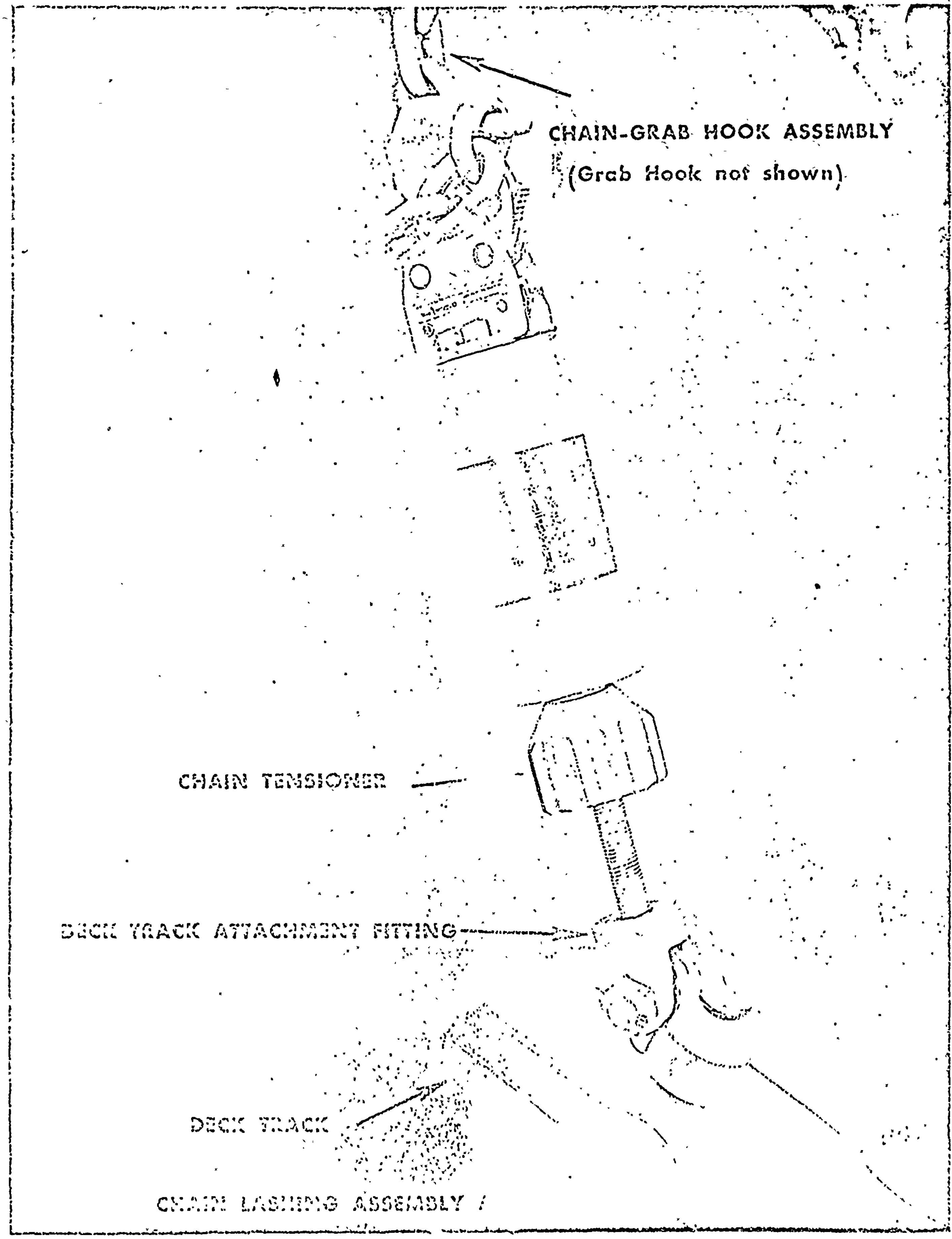
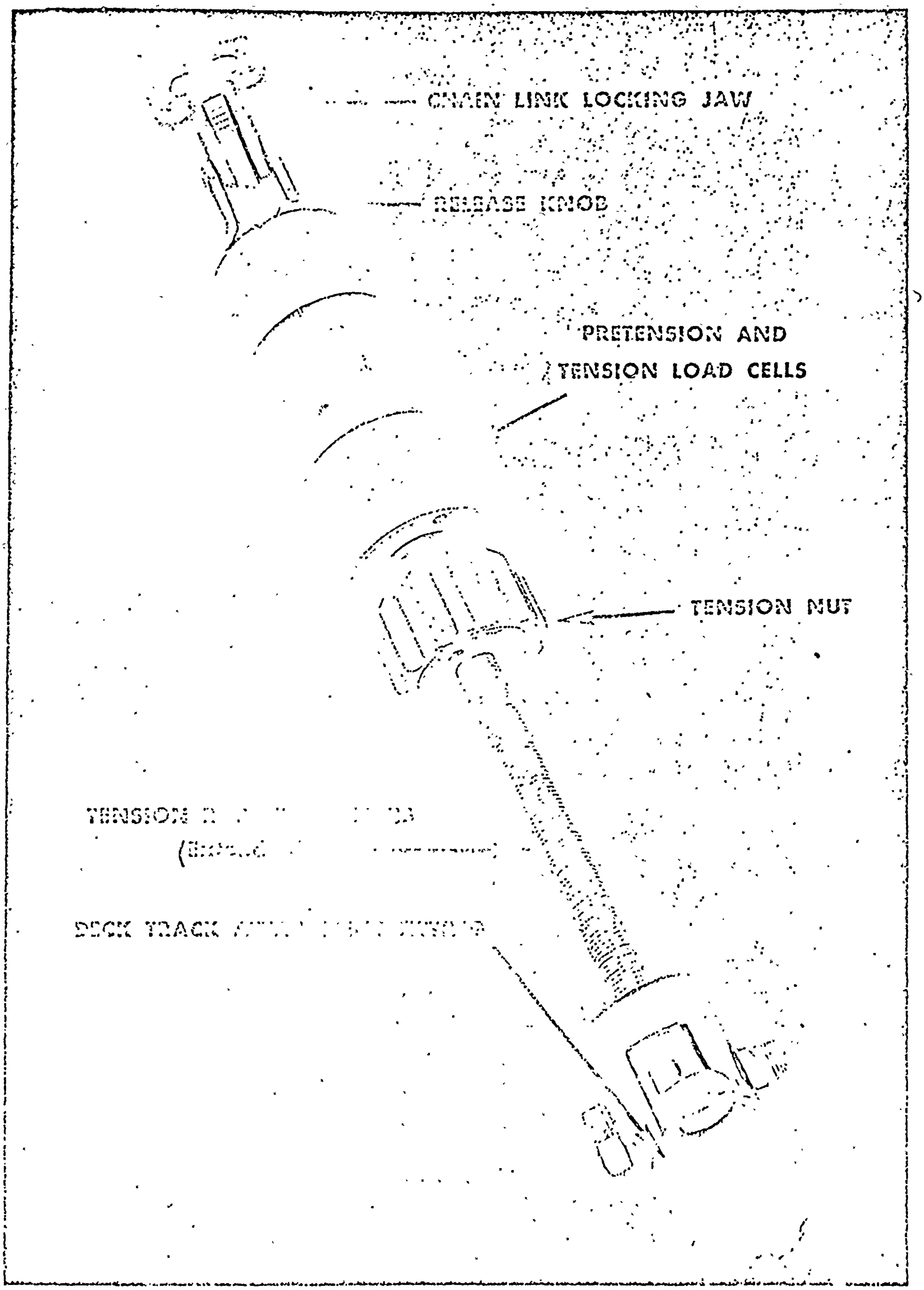
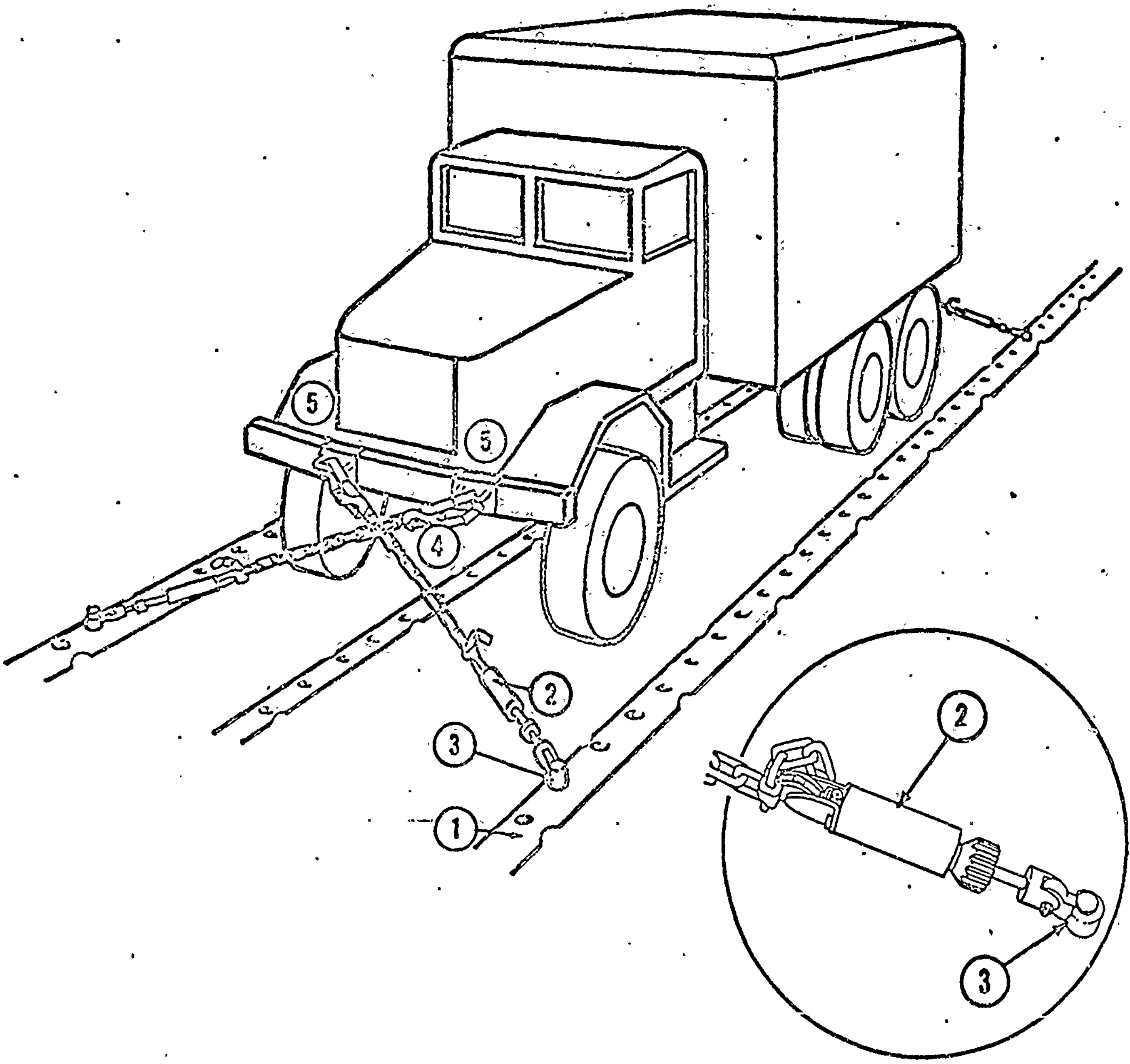



CHAIN-GRAB HOOK ASSEMBLY
(Grab Hook not shown)
CHAIN TENSIONER
DECK TRACK ATTACHMENT FITTING
DECK TRACK
CHAIN LASHING ASSEMBLY /



CHAIN TENSIONER AND DECK TRACK ATTACHMENT FITTING

Heavy Vehicle Tie-Down



1. Deck Track
2. Chain Tensioner
3. Deck Track Attachment Fitting
4. Chain/Grab Hook Assembly
5. Vehicle Attachment Points

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Description

A. CHAIN LASHING ASSEMBLIES

1. Maximum Length
2. Minimum Length
3. Adjustable Length
4. Weight

B. CHAIN TENSIONER

1. Maximum Length (Tension rod extended, no spring load)
2. Minimum Length (Tension rod retracted)
3. Adjustable Length
4. Maximum Width
5. Pretension Load Cell
    a. Maximum Tension
    b. Force Required
    c. Travel at Maximum Tension
6. Tension Load Cell
    a. Travel at Maximum Tension
    b. Spring Load at Maximum Travel
    c. Energy Absorbed (Average spring rate times distance)
7. Minimum Tension Released by 50 lbs Force on Release Latch
8. Weight
9. Clevis Throat Width and Clevis Pin Diameter

C. CHAIN, GRAB HOOK ASSEMBLY

1. Chain Size
2. Chain Weight
3. Chain Length

D. DECK TRACK ATTACHMENT FITTING

1. Weight

E. DECK TRACK

1. Weight/Lineal Foot
2. Compressive Strength/Lineal Foot
3. Minimum Strength of Attachment Points
4. Attachment Points/Lineal Foot
5. Scupper Drain Holes/Lineal Foot

Y AND DECK TRACK ASSEMBLY

Characteristics

7,000 lb MUSR	15,000 lb MUSR	35,000 lb MUSR
124.0 in	128.0 in	131.0 in
17.0 in	20.0 in	25.0 in
107.0 in	108.0 in	106.0 in
13.7 lb	18.0 lb	36.7 lb
17.5 in	21.9 in	25.8 in
13.0 in	15.2 in	17.8 in
4.5 in	6.7 in	8.0 in
2.7 in	2.8 in	3.5 in
300.0 lbs	300.0 lb	350.0 lb
35.0 in-lb	16.1 in-lb	23.0 in-lb
.15 in	0.7 in	.8 in
.85 in	.8 in	.7 in
2,100.0 lb	4,600.0 lb	10,500.0 lb
1,000 in-lb	1,860 in-lb	3,670 in-lb
5,000 lb	5,000 lb	5,000 lb
7.0 lb	9.6 lb	15.0 lb
.87 in/.750 in.	.87 in/.750 in	.87 in/.750 in
.218 in	.281 in	0.468 in
5.0 lb	7.0 lb	20.0 lb
108.0 in	108.0 in	108.0 in
35,000 MUSR	35,000 MUSR	35,000 MUSR
1.86 lb	1.86 lb	1.86 lb
10.35 lb	10.35 lb	10.35 lb
100,000 lb	100,000 lb	100,000 lb
35,000 lb	35,000 lb	35,000 lb
3.0	3.0	3.0
3.0	3.0	3.0

Figure 11

The Source for pages D-47 through D-54 is:
Military Specification Air Transportability Requirements, General Specification for.
MIL-A-8421C(USAF) 14 August, 1969.

MIL-A-8421C(USAF)
14 August 1969
SUPERSEDING
MIL-A-8421B(USAF)
5 May 1960

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MILITARY SPECIFICATION

AIR TRANSPORTABILITY REQUIREMENTS, GENERAL SPECIFICATION FOR

1. SCOPE

*1.1 Scope. This specification covers general design and performance requirements for air transportability of military equipment. The complete air transportability requirements for an item of equipment not specified herein shall be specified in the individual equipment specification (see 6.3).

*1.2 Applicability. The requirements and tests contained in this specification apply to the air transportability aspects of all items of military equipment. They represent the minimum acceptable transportability features. When it is known that the equipment will require transportability features that are more severe than the transportability features stated herein, the transportability features may be more stringent in the individual equipment specification.

2. APPLICABLE DOCUMENTS

*2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

SPECIFICATIONS

Military

MIL-M-8090	Mobility, Towed Aerospace Ground Equipment, General Requirements for
MIL-T-25959	Tie Downs, Cargo, Aircraft
MIL-T-27260	Tie Down, Cargo, Aircraft CGU-1/B

STANDARD

Military

MIL-STD-143	Specifications and Standards, Order of Precedence for the Selection of

*(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

FSC 1510

3. REQUIREMENTS

3.1 Selection of specifications and standards. Specifications and standards for necessary commodities and services not specified herein shall be selected in accordance with MIL-STD-143.

3.2 Size and configuration of equipment items. Equipment items shall be of such size and configuration that they can be loaded into an aircraft as a unit. When specified in the governing specification, partial disassembly and packaging will be permitted.

3.2.1 To facilitate handling, the equipment shall be as compact and lightweight as practical; however, ease of maintenance and serviceability shall not be impaired in meeting this requirement.

3.2.2 It shall be possible to load the equipment into the aircraft and readily position the equipment without damage to the aircraft structure using a minimum amount of handling equipment.

3.2.3 It shall be possible to secure the equipment against all loads encountered during flight, taxiing, and ground handling of aircraft without damage to the aircraft or equipment.

3.3 Design. Design features of equipment shall meet the following general requirements:

*3.3.1 Aircraft floor loading. Individual wheel or axle loads and general floor loading, as determined from the plan view of the equipment, shall conform to the fuselage zone and compartment limitations for the aircraft concerned (see 6.3).

*3.3.2 Wheeled equipment. In addition to the requirements herein, wheeled equipment shall meet the requirements of MIL-M-8090.

*3.3.3 Flight and taxiing loads. The equipment shall withstand, without loss of serviceability, an acceleration of 3g for a minimum of 3 seconds applied independently along each of the longitudinal and vertical axes in each direction, and 1-1/2g for a minimum of 3 seconds applied independently along the lateral axis in each direction.

3.3.4 Emergency landing loads. Equipment shall be designed to withstand the following loads encountered in crash landings without any of the major components of items being transported breaking loose. The item need not be serviceable after being subjected to such accelerations.

*a. A minimum of 8g in either direction applied independently along each horizontal axis for a minimum of 3 seconds. When the equipment is of such size or configuration that it can be loaded into cargo aircraft with only a particular axis parallel to the longitudinal axis of the aircraft (i.e., a truck that can be driven forward or backed into the aircraft), the 9g requirement need be met in both directions along this particular axis (i.e., long axis of the truck). When the loading direction is fixed or specified for an item (i.e., a truck that can only be driven forward into the aircraft), the 9g requirement need be met only the forward direction and a 2g requirement shall be applicable in the rearward direction.

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*b. A minimum of 4-1/2g vertically downward for a minimum of 3 seconds in such a direction that equipment carried in a cargo compartment imposes a load on its wheels or supports in a downward direction.

3.3.5 Attachments

*3.3.5.1 Attachment devices. Equipment shall be provided with attachment points that will accommodate both ends of the tiedown devices specified in 3.3.5.1.1 and shall be marked in accordance with 3.4. These attachment points shall be suitable for use in conjunction with the attachment points on the aircraft floor which, in general, have a capacity of 10,000 pounds and are placed on 20-inch centers. The attachment points shall permit the application of adequate restraint to the equipment when subjected to the accelerations specified in 3.3.3 and 3.3.4 during flight, taxiing, and emergency landing.

*3.3.5.1.1 If the configuration of the equipment permits the use of the following tiedown devices of the appropriate rated capacity and provides adequate strength in a particular tiedown location without the use of standard attachment fittings, provisions for the attachment fittings specified in 3.3.5.1 in such locations may be deleted:

Item Nomenclature	Specification	Rated Capacity
Tie Down, Cargo, Aircraft CGU-1/B	MIL-T-27260	5,000 pounds
Tie Downs, Cargo, Aircraft	MIL-T-25959	10,000 pounds (MB-1) 25,000 pounds (MB-2).

3.3.5.2 Location of attachments. The location of provisions for attachment fittings shall be determined after considering the following:

a. Tiedown grid patterns for the particular aircraft in which the equipment is to be transported, including the number and location of higher capacity tiedown points

b. The accessibility of attachment points on the aircraft in view of requirements for personnel escape clearances and flight aisleway clearances

c. Position of attachment points around the horizontal periphery of the equipment

d. Position of attachment points with reference to the vertical center of gravity of the equipment

Angle of tiedown with horizontal plane

29 Accessibility of attachment points on both equipment being transported and aircraft in which equipment is transported

g. Typical loading diagram of the equipment to be transported in each aircraft providing air transport capability.

3.3.5.3 Number of attachments. The number of locations for attachment fittings shall be not less than four.

3.4 Marking

3.4.1 Equipment. Equipment shall be marked to provide the information necessary to facilitate loading in the aircraft. Unless otherwise specified, the marking shall be stenciled in an appropriate location on the exterior of the equipment. Marking shall include at least the following:

3.4.1.1 Tiedown fittings. Tiedown attachments or fittings shall be identified and the allowable load shall be indicated.

3.4.1.2 Shipping weight and center of gravity location. The shipping weight of the equipment in an air transportable condition shall be marked in a conspicuous location. The center of gravity along each axis influencing the method of loading and tiedown shall be marked on the item.

3.4.1.3 Hoisting fittings. Hoisting fittings shall be identified and the required hoisting capacity marked. The locations where forklifts may be applied shall be identified.

*3.4.2 Other markings. Other markings shall be provided to cover the following, where applicable:

a. Instructions for retraction of wheels or casters to provide greater bearing surface or clearance

b. Installation of special struts or braces to meet flight loads

c. Orientation in aircraft when critical

d. Instructions for special servicing or other preparation for air shipment

e. Other precautions to be observed during loading, flight, or unloading.

4. QUALITY ASSURANCE PROVISIONS

*4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

*4.2 Air transportability tests. Air transportability tests shall be performed on developmental test items, preproduction test items, qualification test items, or sample items as provided for in the individual equipment specification.

4.2.1 Examination of product. The item of equipment, drawings, or other data defining the item shall be examined to determine conformance to the requirements of this specification. Deviations from these requirements not permitted by the individual equipment specification shall be cause for rejection.

4.2.2 Ramp test. For mobile equipment, the ramp test specified in MIL-M-8090 shall be performed.

4.2.3 Acceleration load tests. The following tests shall be performed to determine compliance with the acceleration load requirements specified herein:

*4.2.3.1 Flight and taxiing loads. The equipment shall be restrained in a manner as for loading in an aircraft. The item shall be accelerated so as to produce the accelerations specified in 3.3.3, as measured by an accelerometer. Following these tests, the equipment shall be examined, operated, and subjected to the performance tests specified in the individual equipment specification. Evidence of permanent deformation of structural members or failure to operate and meet the performance requirements of the individual equipment specification shall be cause for rejection.

4.2.3.2 Emergency landing loads. Upon successful completion of the tests in 4.2.1, 4.2.2, and 4.2.3.1, the equipment shall be subjected to the accelerations listed below in the order specified. Following these tests, the equipment shall be examined. Breaking loose of the equipment from the tiedowns, or separation of a component from the main body of the equipment shall be cause for rejection. The item need not be serviceable after being subjected to these accelerations.

*a. 9g as specified in 3.3.4a

b. 4-1/2g as specified in 3.3.4b.

4.2.2.2 If application of the load to equipment along the vertical axis imposes great complications on test equipment, the vertical acceleration may be applied statically.

4.2.2.3 Alternate load tests. In lieu of the above tests, an analytical proof may be substituted to show that the equipment and all its components will conform to the requirements and tests specified herein. The analytical proof shall be subject to verification by actual test on any component.

4.2.4 Loading demonstration. The equipment shall be loaded into an aircraft typical of those in which it could normally be carried and in the manner specified by the loading handbook for the aircraft. Difficulties encountered in this loading operation shall be recorded with particular reference to interference with aircraft structure, damage to cargo floor, or unusual positioning operation required. This record shall be submitted to the procuring activity. The equipment shall then be tied down in accordance with the restraint criteria specified in the loading handbook of the aircraft. Further details on the arrangement of tiedown attachments to the aircraft floor shall be included in the test instructions.

4.2.4.1 Any difficulty in achieving a satisfactory tiedown shall be noted. Following the tiedown demonstration, the equipment item shall be unloaded and any difficulties encountered during the operation shall be noted. When an aircraft cannot be readily secured in the case of contractor-conducted tests, demonstrations of satisfactory loading, tiedown, and unloading characteristics may be made by means of scale models or comprehensive scale drawings showing each stage of operation.

5. PREPARATION FOR DELIVERY

5.1 This section is not applicable to this specification.

6. NOTES

6.1 Intended use. This specification is intended to establish uniform requirements and tests for air transportability characteristics to be incorporated in the design of military equipment.

6.2 General application. Prior to use of this specification, the required operating conditions of the particular item of equipment should be reviewed to determine the applicable air transportability criteria. The tests of this specification may be modified or supplemented to meet the individual air transportability requirements of the equipment; for instance, bomb bay transportability, modification of aircraft, or special handling methods that must be applied.

6.3 Additional data to be included in the individual equipment specification. The following information should be included in the individual equipment specification to further define the degree and type of air transportability required:

a. Individual aircraft type(s) or general class, such as large cargo aircraft in which equipment will be transportable

b. Special loading conditions, such as transporting in bomb bay or carrying external to the aircraft structure

c. Amount and kind of disassembly permissible to achieve loading in a particular aircraft; eg, removal of wheel assembly to load a van type semitrailer in the Type C-119 aircraft

d. Special provisions, such as auxiliary wheels or full swiveling casters necessary to meet a particular loading configuration or positioning requirement

e. Loading and unloading time allowable to achieve a particular aircraft turn-around time. Also, time required for equipment to be operational after air landing, in the case of assault or staging operations

f. Detailed structural limitations of the attachment provisions on the item being transported for equipment designed to transport other items

g. Overall weight and size limitation imposed by aircraft. Also, weight and size limitations imposed by air cargo ground handling equipment should be considered. Limitations of internal aircraft cargo handling provisions should also be considered if these are to be used.

6.4 The margins of this specification are marked with an asterisk to indicate where changes (additions, modifications, corrections, deletions) from the previous issue were made. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations and relationship to the last previous issue.

Custodian:
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SPECIFICATION ANALYSIS SHEET	Form Approved Budget Bureau No. 22-R255

INSTRUCTIONS: This sheet is to be filled out by personnel, either Government or contractor, involved in the use of the specification in procurement of products for ultimate use by the Department of Defense. This sheet is provided for obtaining information on the use of this specification which will insure that suitable products can be procured with a minimum amount of delay and at the least cost. Comments and the return of this form will be appreciated. Fold on lines on reverse side, staple in corner, and send to preparing activity. Comments and suggestions submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or serve to amend contractual requirements.

SPECIFICATION

ORGANIZATION

CITY AND STATE

CONTRACT NUMBER

MATERIAL PROCURED UNDER A

☐ DIRECT GOVERNMENT CONTRACT ☐ SUBCONTRACT

1. HAS ANY PART OF THE SPECIFICATION CREATED PROBLEMS OR REQUIRED INTERPRETATION IN PROCUREMENT USE?
   A. GIVE PARAGRAPH NUMBER AND WORDING.
   B. RECOMMENDATIONS FOR CORRECTING THE DEFICIENCIES

2. COMMENTS ON ANY SPECIFICATION REQUIREMENT CONSIDERED TOO RIGID

3. IS THE SPECIFICATION RESTRICTIVE?

   ☐ YES ☐ NO *(If "yes", in what way?)*

4. REMARKS *(Attach any pertinent data which may be of use in improving this specification. If there are additional papers, attach to form and place both in an envelope addressed to preparing activity)*

SUBMITTED BY *(Printed or typed name and activity - Optional)*

DATE

DD FORM 1426 1 JAN 66

REPLACES EDITION OF 1 OCT 64 WHICH MAY BE USED.

AFLC–WPAFB–OCT 67 2M

Appendix E

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Appendix F

Persons Interviewed in the Study

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Persons Interviewed:

1. Peck and Hale, Inc., West Sayville, New York.
   --Robert Schultz,
   Vice President - Engineering

   --George Peck,
   Vice President and Sales Manager

   --Joseph Morris,
   Assistant Vice President &
   Assistant Sales Manager

2. Maritime Transportation Research Board, National Academy of Sciences -- National Research Council -- National Academy of Engineering, Washington, D.C.

   --S. L. Walton, Jr.,
   Project Director

3. American Association of Railroads, Washington, D.C.

   --L. P. Myers,
   Mechanical Division

4. NAVSUP

   --Herbert Lapidas,
   Head, Packaging Branch

5. U.S. Marine Corps

   --Major J. F. McDonough,
   Marine Corps Development and Education Command,
   Quantico, Virginia

   --Lt. Col. E.A. Silverthorne,
   Amphibious Ships Plans,
   Office of Operations

   --Major C. H. Shelton,
   Amphibious Ships Plans,
   Office of Operations

6. U. S. Army, Technical Engineering Agency, Military Traffic Management and Terminal Service

   --Robert A. Meldrum,
   Fort Eustis, Virginia

   --F. Faus,
   Fort Eustis, Virginia

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Persons Interviewed (Cont.):

7. U. S. Army General Equipment Test Agency

--Capt. J. Ferraro
Fort Lee, Virginia

--A. Evans,
Fort Lee, Virginia

8. Joint Military Packaging and Training Center, Aberdeen Proving Grounds, Aberdeen, Maryland

--S. R. Jankowski,
Chief, Department of Instruction

--T. Marchard,
Department of Instruction

9. Naval Amphibious Base, Little Creek, Norfolk, Virginia

--Commander M. Betts
Amphibious Warfare Board

--Major Wilson
Training Officer

10. Naval Research Laboratory

--E. Schell
Shock and Vibration Branch
Washington, D.C.

END