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METHODOLOGY INVESTIGATION

FINAL REPORT

IMPROVEMENT OF SHOCK AND VIBRATION TESTING SCHEDULES

FOR

TRANSPORT OF LOOSE, RESTRAINED AND SECURED CARGO

BY

EMIL L. EHLERS

HARRY T. CLINE OF HARRY T. CLINE AND ASSOCIATES

SEPTEMBER 1981

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27 May 80 - 30 Apr 81

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The development of laboratory shock and vibration has been on-going for a number of years with no firm knowledge as to the number of miles that ammunition and general equipment is transported as secured-cargo and as restrained or loose cargo. This investigation was developed to study and document the number of miles that cargo is transported as secured, restrained and/or loose cargo as a basis for future work in developing more realistic laboratory vibration and loosely stowed cargo test schedules. This investigation was conducted by Harry T. Cline and Associates from 27 May 1980 through 30 April 1981.		

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20. The contractor conducted extensive literature reviews, interviews with personnel, and visits to other installations. The findings show that ammunition and general equipment are transported a total of 4500 miles and that the restraint systems vary from securely fastened in three planes to loosely blocked in just two horizontal planes.
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## SECTION 1. SUMMARY

### 1.1 BACKGROUND

Laboratory simulation of the transport environment for all types of military equipment has been conducted by the US Army Test and Evaluation Command (TECOM) for a number of years as an expeditious means of determining if a given piece of equipment will survive the real world environment. The laboratory test schedules, both vibration and loosely-stowed cargo, given in MIL-STD-810C and various TECOM test documents were developed in the early 1960s based on shock and vibration data measured on vehicles tested under controlled conditions of loading and fixed-course configurations. Recent investigations have revealed that existing laboratory simulation tests are not descriptive of the "real world" cargo transport environment and thus have posed a serious question as to the validity of the entire laboratory-simulated testing approach--including the amount of time materiel is subjected to both vibration and loose cargo testing as well as the type and amount of restraint imposed on cargo during laboratory testing.

A plan of action dealing with the total problem was developed by the US Army Aberdeen Proving Ground (APG) and was presented to and subsequently approved by TECOM's Shock and Vibration Technical Committee at their March 1978 meeting. This plan detailed an orderly progression through a series of methodology investigations in order to totally define, measure, and ultimately recreate in the laboratory the "real world" environment as it relates to ground vehicles containing both cargo and installed-equipment.

The first investigation of this plan was to determine and document the actual field procedures and techniques used by the US Army to secure/restrain ammunition and general-equipment (e.g., generators and air conditioners) cargo in the various ground transport vehicles. The investigation was purposely limited to these two types of cargo because they are the predominant types subjected to laboratory testing. To expedite completion of this investigation, it was accomplished by a contract effort; the contract was awarded in October 1978 to Harry T. Cline and Associates, Churchville, MD under contract DAAK 11-79-0007. The contractor's final report was received by APG in May 1979 and the final APG report (APG-MT-5319) was approved and published in November, 1979.

The second investigation of this plan was to determine and document the distances that ammunition and general equipment may be transported as loose, restrained and secured cargo. The investigation was again purposely limited to these two types of

cargo for the reason previously stated. To expedite completion of this investigation, it was again accomplished by a contract effort; the contract was awarded in May 1980 to Harry T. Cline and Associates, Churchville, MD under contract DAADO5-80-Q-5285. The contractor's final report was received by APG in January 1981.

## 1.2 OBJECTIVE

The objective was to determine the distances that ammunition and items of general equipment may be transported in air, ground and rail vehicles, both commercial and military, as secured, restrained and loose cargo.

## 1.3 SUMMARY OF PROCEDURES

To conduct this investigation, the contractor made an in-depth review of the available technical publications, reports, and photographs dealing with the subject; he also visited various US Army Schools and installations to research the available information. The various sources of information are in the contractor's report.

## 1.4 SUMMARY OF RESULTS

a. Movement within CONUS. Movement of materiel within CONUS is accomplished by either motor freight or rail. Figure 1 of the contractor's report indicates that the distance from the point of manufacture to the depot is no further than 3218 km (2000 mi). It also indicates that the depot is no more than 3218 km (2000 mi) from the point of embarkation and that a maximum of 6436 km (4000 mi) of transport within CONUS is entirely realistic. Table I of the contractor's report lists the most widely used transportation systems within CONUS as well as the method(s) of cargo restraint used with each system. The 6436 km (4000 mi) that materiel could be transported commercially could be via all highway, all rail, or infinite variations of the two modes.

b. Intercontinent transportation. Movement of materiel to other continents is accomplished by either ocean-going vessels or air. From a supply tonnage viewpoint, the greatest percentage by far is moved by ocean-going vessels. To a lesser degree, materiel is moved by air--but this is more on a priority basis. Figure 1 of the contractor's report indicates that the distance materiel can be moved from the point of embarkation to the foreign continent can vary between 6436 and 16,090 km (4000 and 10,000 mi).

Ocean-going vessels transport cargo either as break-bulk cargo, wherein the cargo is tightly blocked in all three planes, or as containerized cargo, wherein the cargo in the container is blocked (tightly to very loosely) in two planes and the container itself is secured in three planes. Since the vibration of ocean-going vessels is extremely low (less than  $1/2$  g in the vertical plane), the cargo essentially can be considered secured regardless of whether it is break-bulk or containerized.

Cargo transported by air will probably be transported by jet-powered aircraft for long distances and by propeller-driven aircraft for short distances. In each case, the cargo is palletized and secured to the flight deck. Also, the vibration levels of both types of aircraft are negligible. The only possible significant inputs to the cargo that could occur would result from total plane motions caused by maneuvers, turbulence, rough landings, or rough taxi strips; however, these motions are infrequent, random or transient in nature, and usually of short duration.

c. Foreign continent transportation. Movement of materiel within foreign continents will be primarily by usable railroads and secondarily by military ground vehicles. Figure 1 of the contractor's report indicates that the distance from the port of debarkation to the using unit may vary from 563 km (350 mi) (European theater) to 805 km (500 mi) (other theaters). The preferred modes of transportation and methods of cargo restraint for foreign theaters are contained in Table II of the contractor's report. The transportation area where the cargo would be restrained the least would be from the corps storage area to the unit, a distance ranging from 80 to 240 km (50 to 150 mi) (fig. 1 and 2 of the contractor's report). Within this area, the materiel can pass through several forward supply and transfer points. It is within this area that the materiel is transported by military trucks, two-wheeled trailers which are towed behind these trucks, and M548 tracked cargo carriers. With rare exception, all cargo moved in this area is placed in the vehicle bed with no restraint.

## 1.5 ANALYSIS

The contractor's report indicates that the maximum distance that cargo is transported by rail or ground vehicles is 7241 km (4500 mi). Of this, 6436 km (4000 mi) would be in CONUS and the remaining 805 km (500 mi) would be in the theater of operations.

Since the contractor's report contains sufficient information to establish these as maximum distances, the wording of paragraph 5.2 of the contractor's report should have stated that the 7241 km (4500 mi) is a maximum rather than an average distance.

It is possible that the cargo could be transported the entire CONUS distance of 6436 km (4000 mi) by highway or rail, or it could be transported this distance by combinations of the two modes. Within CONUS, ammunition and general equipment is only transported as secured-cargo (secured in three planes) when shipped on flat bed trucks, flat rack containers, or flat bed rail cars--all three of these modes being used less frequently than the other modes, as pointed out in table 1 of the contractor's report. When transported by the other modes, ammunition is only rigidly blocked in the two horizontal planes and general equipment is not blocked to any specified standards and may have as much as 51 mm (2 in.) clearance on all sides (loosely-stowed).

The contractor's report points out that movement of materiel overseas may be expected to cover a distance of 6463 to 16,000 km (4000 to 10,000 mi) by either ocean-going vessels or aircraft. Since the vibration environment associated with these two modes of transportation is considerably less severe than that of ground vehicles, the distances associated with these transport environments need not be included in the laboratory tests.

In foreign continents, ammunition and general equipment could be transported by ground vehicles (automotive or rail) a distance of 805 km (500 mi). The movement for the first 563 km (350 mi) would be the same as for CONUS transport, the only exception being that some of the secondary roads in foreign theaters may not be in as good repair as those in CONUS. For the remaining 241 km (150 mi), both ammunition and general equipment would be transported as loosely-stowed cargo over unimproved roads or cross-country.

The contractor discusses in the report the dynamics of the transport environment (para 4.0) which includes the dynamics of (1) the cargo; (2) commercial versus military vehicles; and (3) the cargo bed. In paragraph 4.2 of that report, the contractor points out that military automotive vehicles differ from commercial vehicles primarily in ways that do not affect their dynamic response.

Current laboratory test schedules in MIL-STD-810C and various TECOM test documents simulate 9012 km (5600 mi) of secured-cargo transport over various vehicles (excluding tracked vehicles) plus 241 km (150 mi) of loosely-stowed cargo transport. This is in contrast to the findings of this investigation which indicates a maximum of 7241 km (4500 mi), which includes loosely-stowed, rigidly blocked, and secured cargo transport. The rigidly-blocked environment has not been previously identified or studied; consequently, data on this environment and its effects are not yet available. In addition, the severity of the road/terrain conditions

incorporated in the current test schedules may differ considerably from the conditions reflected in the transport environment described in this investigation. Consequently, although paragraphs 5.5 and 5.6 of the contractor's report indicate that certain immediate changes to the current test schedules should be implemented, proper and validated changes to these schedules can only be accomplished after additional investigations are conducted.

## 1.6 CONCLUSIONS

It is concluded that:

- a. The objectives of the investigation were met.
- b. The maximum number of miles that army materiel will be moved by road and/or rail transport systems is 7241 km (4500 mi).
- c. The cargo may be transported the entire distance as secured, as restrained or as loosely-stowed cargo; however, it probably will be transported under some combination of those three conditions as follows:
  - (1) Ammunition transported from the manufacturer to the corps storage area (a total of 6999 km (4350 mi) of ground transport) will, in most instances, be rigidly blocked in the two horizontal planes. There are a few isolated modes of transport (i.e., flat bed trucks, flat rack containers, or flat rail cars) that could be used so that the ammunition could be transported the entire distance as secured cargo. The ammunition can be moved this entire distance by highway, by rail, or by a combination of both.
  - (2) General equipment cargo transported from the manufacturer to the corps storage area (again 6999 km) will generally be loosely stowed for either highway or rail transport. Again, there are the same few isolated modes of transport as described in paragraph (1) above, that could be used so that these items could be transported as secured cargo.
  - (3) Ammunition and general equipment is transported the remaining 241 km (150 mi) (from the corps storage area to the using unit) as loosely stowed cargo in military trucks, 2-wheeled trailers or the M584 tracked cargo carrier. This terrain will generally be unimproved roads or cross-country.

## 1.7 RECOMMENDATIONS

It is recommended that:

a. Both the secured-cargo and the loosely-stowed cargo laboratory tests be retained in their present form in current TECOM test operating procedures until updated laboratory test schedules are developed. This agency nonconcurs with the test schedules proposed in paragraphs 5.5, 5.6 and the first sentence of paragraph 6.0 of the contractor's report due to the lack of supporting data.

b. Updated laboratory test schedules be developed to simulate the secured-cargo, rigidly blocked, and loosely-stowed cargo environments in accordance with the TECOM Shock and Vibration Committee's adopted plan of action. These schedules should reflect the findings of reference 1 of the contractor's report (Section 2 of this report) plus the conclusions of this report. These schedules must include the development and verification of laboratory procedures to simulate the restraint mechanisms used in the field for secured, rigidly blocked, and/or loose cargo.

## SECTION 2. DETAILS OF INVESTIGATION

**CONTRACTOR'S REPORT:** A study of Cargo Configuration and Restraint in Military Ground Vehicles by Harry T. Cline and Associates.

**Special Study of  
Improvement of Shock and Vibration  
Testing Schedules for Transport  
of Loose, Restrained and Secured  
Cargo**

**By**

**Harry T. Cline**

**January 1981**

**This study was prepared for Materiel Testing  
Directorate, Aberdeen Proving Ground, Md. under  
Contract DAAD80-M-8668.**



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## 1. BACKGROUND

Items of Army materiel, both ammunition and items of general equipment, may be transported many thousands of miles between the point of manufacture and the point of ultimate use. It may be moved by a wide variety of transport modes. In any mode, the materiel will be exposed to potentially damaging forces of varying magnitudes and durations depending on the movement of the deck of the transporting vehicle. These forces may be as transient as the shock resulting from a single drop onto a rigid surface. They may be repetitive shocks caused by a series of "chuckholes" in a road surface occurring at a random rate depending on spacing and road speed. Forces may also be in the form of continuous excitation over some period of time. This last form represents vibration from continuous irregularities in the road surface profile. How the force environments of the cargo decks of the transporting vehicles affect the materiel being transported depends, to a large extent, on how the materiel is restrained to the cargo deck. The base of materiel, securely restrained to the deck, moves with the deck. The base of materiel, loosely placed on the deck, is free to move relative to the deck. If a vertical force of 1g or more is applied at the deck, the cargo will bounce vertically and impact with the deck causing a shock excitation of both the cargo and the deck. Lateral forces which exceed the coefficient of friction existing between the cargo and the deck will cause the cargo to slide. Sliding cargo will impact other cargo or wall of the cargo deck also producing a shock input to the cargo and the deck. Vector forces of combined vertical and longitudinal excitation may cause impact with both the deck and other cargo. It may even cause some package configurations to rotate and impact on a surface other than the base.

In a previous study (Reference 1), the procedures and techniques used by the U.S. Army to load, secure or restrain materiel during logistical transport were determined. This study concluded that existing laboratory simulation tests were not descriptive of the field environment determined during the study. They were not descriptive with respect to the amount of time materiel was subjected to both vibration and bounce tests, nor with respect to the use of sinusoidal vibration tests. Additional work was recommended to provide a basis for adjusting the test times to better reflect the need for more bounce simulation and less vibration simulation.

## 2. OBJECTIVE

This study was conducted to identify the number of miles ammunition and other items of materiel may be transported in air, ground and rail vehicles, both Commercial and Military, in the following configurations:

Securely tied to the bed of the transport vehicle.

Restrained in the two horizontal planes in the bed of the transport vehicle.

Stowed loosely in the transport vehicle with little or no restraint.

The objective is further expanded to provide a rationale for adjusting the amount of time materiel is vibrated and bounced under existing test schedules to better reflect the ratio of transportation as restrained or a secured cargo as recommended in Reference 1.

### 3.0 Transportation of Materiel

Distances shown on Figure 1 (extracted from Reference 1) represent the movement of ammunition from manufacturer to user. These distances apply equally to all other items of materiel since the same supply channels are used for both explosive and inert supplies. These distances were developed by the U.S. Army Logistics Center in 1975 (Reference 2). They are based on logistical support to a European theater of operation. Sea and air route distances and distances from ports of debarkation to corps storage areas may need to be extended for operations in other theaters. Generally speaking, the distances from ports of debarkation to corps storage areas (previously called rear ammunition supply points) should not increase by a factor greater than 50 percent. Data shown on Figure 1 were verified as still being a proper description during a visit to the center at Ft. Lee, Va. on 24 Sept. 1980. Based on these data, it is estimated that materiel will be transported in the three general areas of CONUS (Continental United States), inter-continent and foreign continent.

#### 3.1 CONUS

Ammunition and other items of materiel are normally shipped from the point of manufacture to a supply depot. At some later point in time, they may be shipped to either a using service within CONUS or shipped to a port of embarkation. It is not possible to specify the number of overland or air miles these items will be shipped. It is only possible to estimate a high average number of miles the materiel may be transported overland. The width of the continent by road from west coast ports to east coast ports is, on the average, 2900 miles. The greatest distance, diagonally from Seattle, Washington, to Miami, Florida is about 3260 miles (Reference 3). Distances shown on Figure 1 suggest that the point of manufacture is no further from the depot than 2000 miles. It also suggests that the depot should be no more than 2000 miles from the port of embarkation. A maximum 4000 mile shipping distance within CONUS seems entirely reasonable.



Mass movements of materiel within CONUS are accomplished by common carrier; either by motor freight or by rail. The most widely used transportation systems are listed on Table 1, together with the normal method of cargo restraint used with each system. It is not possible to classify loading configurations or techniques as being developed specifically for either highway or rail transport. In fact, there is a certain commonality in the techniques used in loading all transport vehicles listed in Table 1 except for the flatbed vehicles identified as c,f,i and l. In addition, the intermodal concept of operating semi-trailer vans and containers over highways and transporting them on railcars within CONUS precludes specific classification of loading configurations and techniques. Intermodal concepts apply also to overseas shipments by sea and air which will be discussed later.

The most frequently used vehicles for transporting materiel (those classed as 1 and 2 on Table 1) employ cargo pallet blocking in two planes to some degree. Ammunition pallets are blocked tightly because of regulations and outloading drawings published by DARCOM Ammunition Center. Examples of tightly blocked cargo are shown on Figures 9,10 and 11 of Reference 1. Pallets of general equipment and other inert items of materiel are not blocked to specified standards and may have as much as two inches of clearance on all sides of the pallet. Rigidly blocked pallets can move from the cargo deck and impact in a vertical direction only. Loosely blocked pallets can impact the walls of the transporting vehicle and other pallets as well as the deck.

Within CONUS, materiel could be transported commercially over the entire 4000 miles by highway; it could be transported the entire distance by rail or it could be transported in infinite variations in percentage of distances by combinations of the two modes. In either mode, there is a definite probability that ammunition will be more tightly blocked in two planes than other materiel.

### 3.2 Intercontinental Transportation

Logistical movement of materiel overseas is accomplished by two modes. From a supply tonnage viewpoint, the greatest percentage by far is moved by ocean going vessels. To a lesser degree, materiel is moved by air but this is more on a priority basis.

Ocean going general-cargo type vessels fall into three general classifications; break-bulk type, Container Ships and the Roll On/Roll Off (RO/RO) or Lighter Aboard Ship (LASH) type vessels which accommodate automotive trucks or semi-trailers and preloaded barges. Break-bulk vessels handle the majority of military cargo at this point in time and will probably continue to do so in the event of emergencies in the foreseeable future. Containerization is second to break-bulk shipment in terms of tonnage and its preference has

CONUS




Transporting  
Vehicle

Common Carrier	Use Preference
a. Truck, Van	3
b. Truck, Open Top Bed	3
c. Truck, Flat Bed	4
d. Semi-trailer, Van	1
e. Semi-trailer, Open Top	2
f. Semi-trailer, Flat Bed	4
g. 20 ft. Container (Mil Van)	1
h. 40 ft. Container	1
i. 40 ft. Container, Flatrack	5
j. Rail Car, Box	1
k. Rail Car, Open Top (Gondola)	3
l. Rail Car, (Flat or Depressed Center)	4

Method of Cargo Restraint

Ammunition	General Equipment
7 to 8	7 to 10
7 to 8	7 to 10
6	6
7 to 8	7 to 10
7 to 8	7 to 10
6	6
7 to 8	7 to 9
7 to 8	7 to 9
6	6
7	7-8
7 to 8	7 to 9
6	6

Use Preference

- 1= Most Frequent  
2=   
3=   
4=   
5= Least Frequent

Method of Cargo Restraint

- 6= Securely Tied Down or Tommed  
7= Blocked Tightly in Two Horizontal Planes  
8= Blocked Loosely in Two Horizontal Planes \*  
9= Blocked Very Loosely Horizontally \*\*  
10= Loosely Stowed

\* 0.5 inch clearance on all sides.  
\*\* As much as 2 inch clearance on all sides.

Table I. Transportation Modes and Methods of Restraint within CONUS.

grown faster than its capacity. Vessels of the RO/RO and LASH configurations are more rare but from an operational and stowage viewpoint can almost be classified as container ships since they accommodate preloaded unitized cargo.

With respect to cargo restraint, procedures for loading and stowing military ammunition and explosives aboard break-bulk merchant ships is described in TM55-607 (Reference 4). Stowing and blocking procedures require tight blocking in the two horizontal planes similar to the blocking specified for highway and rail transport by DARCOM Ammunition Center. For sea transport of break-bulk cargo, additional blocking (called tomming) is provided in the vertical plane by shoring from the top of the cargo to the underside of the deck above. This rigid blocking of cargo is required not so much for the protection of the cargo as for protection of the vessel. Shifting of the cargo in heavy seas has been known to create forces of sufficient magnitude to buckle plates and shift the vessels' center of gravity. Because of this, the same techniques of blocking tightly in all three planes are applied to inert items of materiel.

Ocean going vessels carrying containers and trailers are relieved of the cost and time required to block cargo. Containers are placed in prepared guide rails within the holds of the ship and can be locked to other containers in the stack using the coupling clamps provided for coupling intermodal containers. The same clamps couple containers to each other when containers are carried as above deck cargo. Containers restrain the cargo within their walls and major shifting of cargo in heavy seas is prevented.

Long range air movement of materiel is normally accomplished by such military aircraft as the C130, C141 and C5A. On the commercial side, a wide range of aircraft make up the Civil Reserve Air Fleet (CRAF). This fleet is composed of the Boeing 707, 727 and 747; Douglas DC-8 and DC-10 and the Lockheed 1011. There is little difference in the basic methods by which military and civil aircraft accommodate cargo. In both cases, the cargo is placed on light weight pallets which are moved on rollers attached to the aircraft deck. The military aircraft use the 453L air cargo system which revolves around the 108" X 88" pallet. Most military aircraft are aft loading but some are fore and aft loading as well as side loading. Civil aircraft are mostly of the side loading type while a few have forward loading capability. Some civil aircraft will accommodate the 463L pallet while others accommodate only a commercial pallet (Reference 5). The major difference between these pallets is size. The method of loading (fore, aft or side) has no measurable affect on the dynamics input to the cargo during flight. Neither does the relatively small difference in pallet size. All cargo is restrained to withstand at least 8g



Foreign Continent Transport Vehicles	Military Carriers	Use Preference		Method of Cargo Restraint	
		Long Distance	Close Support	Ammunition	General Equipme.
m. Truck Open Top Bed*		1	1	8	8 to 10
n. Truck Dump Body		not used	5	9-10	not used
o. Truck Flat Bed		3	3	6	6
p. Semi-trailer, Van		3	not used	8	8 to 9
q. Semi-trailer, Open Top		1	not used	8	8 to 9
r. Semi-trailer, Flat		2	not used	6	6
g. 20 ft. Container (Mil Van)		1	not used	7 to 9	7 to 9
h. 40 ft. Container		1	not used	7 to 9	7 to 9
i. 40 ft. Container, Flatrack		5	not used	6	6
j-v. Rail Car, Box **		1	not used	7	7 to 8
k-w. Rail Car, Open Top		1	not used	7 to 8	7 to 8
l-x. Rail Car, Flat		3	not used	6	6
y. Tracklaying Vehicle M548		5	3	10	10
z. Two Wheeled Trailer		5	2	9 to 10	9 to 10

\* Includes 4x4 Goers, and 4x4, 6x6 and 8x8 Cargo Trucks.  
 \*\* May be either Commercially or Military owned equipment.

Use Preference		Method of Cargo Restraint	
1 = Most Frequent	↓	6 = Securely Tied Down or Tommed.	
2 =	↓	7 = Blocked Tightly in Two Horizontal Planes	*
3 =	↓	8 = Blocked Loosely in Two Horizontal Planes	*
4 =	↓	9 = Blocked Very Loosely Horizontally	**
5 = Least Frequent	↓	10 = Loosely Stowed	

\* 0.5 inch clearance on all sides.  
 \*\* As much as 2 inch clearance on all sides.

Table II. Transportation Modes and Methods of Restraint within Foreign Theaters of Operation.



force in the forward longitudinal plane for crash safety purposes. Chains, steel cable and nylon webb straps or nets are used to restrain air cargo. Cargo must be classified as being securely restrained despite the fact that nylon has a tendency to stretch and provide for relative movement between the deck and the cargo. A review of transport aircraft design criteria, speeds and flight regimen shows no difference in the flight environment between military and civil transport craft.

For intercontinental transport cargo may be expected to travel at least 4000 miles and as much as 10,000 miles. All of this travel by sea or air will be classed as secured cargo.

### 3.3 Foreign Continent Transportation

Most break-bulk cargo arriving by sea on foreign continents will probably be moved inland by such usable railroads as are available. This will be the primary transport mode. Motor transport would be the secondary mode for long distance inland movement. Total distances over which cargo will be transported in European theaters is 350 miles according to Figure 1. If operations were in other theaters, the total supply distance should not be greater than about 500 miles. Preferred modes of transportation and methods of cargo restraint for foreign theaters are shown on Table II. Longer distance movements should be similar to long distance movement within CONUS with the respect to the type of equipment used. It is doubtful that the condition of railroad beds and trackage in the foreign theater will be worse than CONUS. The same may not be true of highways. While many possible theaters of operation have highways similar to the CONUS Interstate System, their secondary roads may not withstand heavy cargo movement without constant maintenance. The degree of restraint for break-bulk type cargo can be expected to be less restrictive than that used within CONUS. Since the containerized materiel moves as an entity from the point of origin to Corps Storage area, the degree to which blocking restrains the contents should not change unless the container is damaged en route.

Probably the transportation which is considered to cause the most severe dynamic input to cargo is that distance between the Corps Storage area and the user. Regardless of the theater, this distance could range from 50 miles to 150 miles. Within this distance, the materiel can pass through forward supply points and forward transfer points. It is between these forward points and the user that the materiel is transported almost entirely by military trucks of the 4 x 4, 6 x 6 and 8 x 8 running gear arrangement. It may also be hauled in two-wheeled trailers which are towed behind them. With rare exception, all cargo moved in this forward area is placed in the truck beds with almost no restraint. Separate loading projectiles and charges transported in the M548 tracklaying vehicle almost always have no degree of restraint. A current appraisal of

XXX CORPS  
 XX DIVISION  
 X BRIGADE

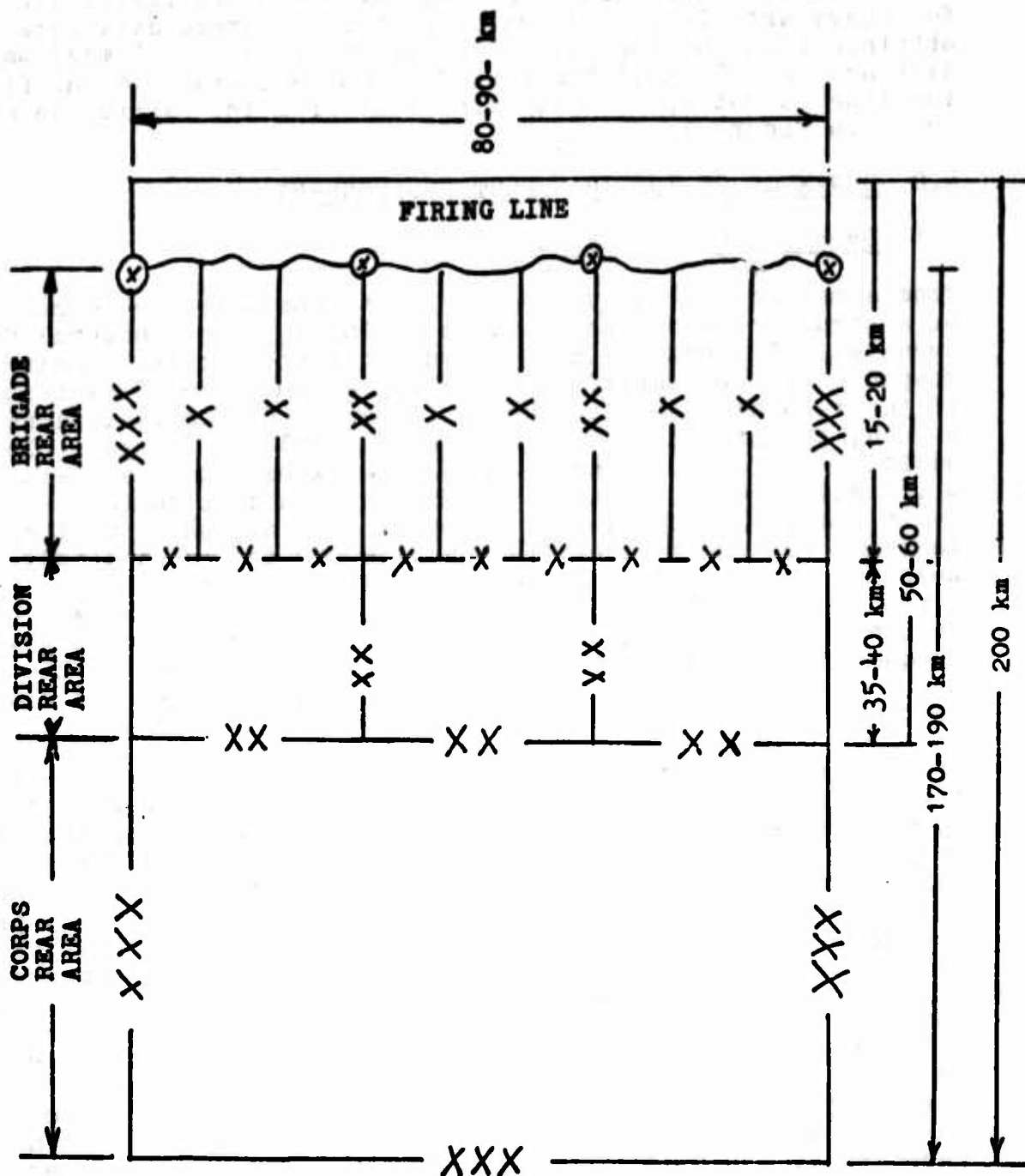


Figure 2. Supply Distance for Field Artillery in Foreign Theaters of Operation. (Data Obtained from U.S. Army Logistics Center, September 1980).

the distance between Corps Storage area and the firing line for heavy artillery is shown on Figure 2. These data were obtained from the Logistics Center, Ft. Lee, Va. A maximum distance of 200 Km (125 miles) from Corps Storage to the firing line is not appreciably different from the earlier data shown in Figure 1.

#### 4.0 DYNAMICS OF THE TRANSPORT ENVIRONMENT

##### 4.1 Dynamics of the Cargo

From a mechanical viewpoint, cargo is considered to be made up of a structure and substructures having different natural frequencies. If these natural frequencies are excited, their response will be amplified depending on the type of excitation. If the response is great enough in magnitude and lasts long enough, the structure may break as a result of fatigue. In addition to fatigue, the cargo may be exposed to transient forces which may scratch, abrade or deform the basic structure. To avoid damaging the items of materiel that are shipped, they are packaged to some degree. The package may be designed only to keep the contents from being deformed; or if it is highly fragile, to keep it from being broken. Other packaging may be designed to contain elastomer isolators which prevent high-frequency components of shock excitation from reaching the contents of the package. In any event, these packages are usually combined with others of like size into pallet loads.

If the package or pallet is securely tied to the cargo deck of the transporting vehicle, it moves with the cargo deck. In this case, the exterior of the package is not damaged from impact and only the natural frequencies of the packaging and its contents may be excited in a manner commensurate with the type of input. For example; if the input is continuous and its frequency precisely matches a natural frequency of the cargo, resonant response at that natural frequency could result. The term resonance is subject to many different interpretations but is used here in one specific context. In defining resonance, American Standards Association documentation (Reference 6) states that resonance exists in a system in forced vibration until some change in the forcing frequency, however slight, causes a decrease in the response of the system. Resonance then, is that finite condition of maximum response at the natural frequency. It is a condition where the phase angle relationship between the input and response must be a constant  $90^\circ$  with the response lagging the input. If the input force is continuous but the frequency varies randomly with a varying phase relationship, resonant response cannot occur. Amplified response will occur at the natural frequency but not of a magnitude approaching that of resonance.

Response of secured cargo to shock input will also cause the materiel to respond at its natural frequencies with some degree of amplification. The degree of amplification depends on the duration of the shock excitation and the natural frequencies being excited. Maximum response will occur when shock duration equals half the period of the natural frequency. Like random vibration, shock cannot cause resonance. Shock excites the natural frequency which oscillate at a decreasing amplitude, depending on the degree of damping, until equilibrium occurs. These oscillations may create stress reversals within the materiel which contribute to and result in fatigue. If the rate of shock excitation is frequent enough to again excite the response before it damps to equilibrium, the response would appear continuous and be interpreted as vibrating response. Shock excitation, like random vibration input, can contribute to a series of stress reversals of sufficient magnitude to cause metal fatigue but neither form of excitation can cause resonant response.

Response of lightly blocked or loosely stowed (unsecured) cargo to shock input should be similar to that described above with respect to the interior of the package. The major difference is that the shock input is not the same. A shock input greater than 1g causes the unit package in whatever shape, weight or configuration to leave the cargo deck by some distance. The magnitude of shock generated at the time of impact depends on at least two factors. It depends on the total relative impact velocity between the materiel and the cargo deck or side walls. The duration of the shock depends on the total deflection or "give" between the two impact surfaces. The magnitude and duration of a given shock is difficult to predict. The two surfaces may be moving in the same or opposite directions at the instant of impact. Impact may occur on flat, edge or corner surfaces which would definitely affect the degree of deflection or give at the point of impact. Ground effects (an air-cushion effect) between a smooth cargo deck and a low-density large-area package surface can lessen the effect of impact. Loosely stowed cargo total response to shock excitation is judged to be more severe than the response of secured cargo to shock excitation of equal magnitude.

#### 4.2 Dynamics of Commercial Vehicles vs Military Vehicles

Military automotive vehicles differ from commercial vehicles primarily in ways that do not affect their dynamic response. The major difference is usually found to be that military vehicles are intended to operate on and off paved roads while commercial trucks are intended to operate primarily on paved roads. Engines of military vehicles, for example, are waterproofed to operate under water (with the aid of snorkles) and permit deep water stream fording. Such features are not necessary on commercial trucks. The major difference in running gear is manifested by the fact that military trucks have power to all wheels while only the rear axle or rear bogie of most commercial trucks is powered. All wheel drive

does not necessarily permit vehicles to travel over rougher surfaces than partial wheel drive vehicles. Rather, it permits vehicle operation on low-traction, off-road surfaces or the negotiation of slopes in the 50 to 60 percent grade range. Drivers rarely use all wheel drive on surfaces where wheel slippage is not present. In those rare cases where it is used on dry, paved, high-traction roads, it is used only for very short distances of travel at very slow speeds. Differences in rolling distances per revolution of each tire results from uneven wear and differences in tire inflation pressure. This causes friction to build up in the power train that can only be relieved through wheel slippage. The friction is highly undesirable for it increases power train wear, tire wear and fuel consumption.

With respect to dynamics, the transfer function (response/input) of an equally loaded axle on either a military or commercial vehicle should be about the same. The nominal natural frequency of each is about 1 to 3 Hz depending on the amount of axle load. When a vehicle is operated over a continuous rough road (such as the APG Belgian block course) the shape of the vibration spectrum is more a function of road speed, number of axles and wheel base. The number of axles on military trucks range from two to four while commercial trucks have mostly two or three axles. Wheelbase varies for a given axle configuration in military vehicles. Both the M151  $\frac{1}{2}$  ton truck (Jeep) and the M548, 8 ton truck (Goer) are classified as 4 x 4 vehicles but have vastly different wheel base dimensions. As a result, the spectral envelope of the two vehicles having the same running gear classification may be significantly different. Variations in the vibration spectrum may be as great for the broad range of military vehicle running gear configurations as for combined military, commercial vehicle configurations. The same rationale can be applied to the tractor semi-trailer combination. There should be no measurable differences between commercial and military models when operated over a given road profile and comparable vehicle speeds.

A difference in construction exists between the cargo decks of commercial vehicles and military vehicles in only some models. The vast majority of commercial vehicles (i.e. vans, semi-trailers and containers) have hard-wood cargo decks faced with metal skid strips. This same type of construction is found in some models of military vehicles; mostly in the full trailer, semi-trailer and Mil Vans. Other military transport vehicles such as the 4 x 4, 6 x 6 and 8 x 8 cargo trucks and cart type trailers have steel cargo beds. They consist of relatively light gage steel plate (less than  $\frac{3}{16}$  inch thick) welded to a chassis fabricated of structural and automotive shaped steel channel members. Differences in construction materials used in fabricating cargo decks should have little or no affect on the dynamic behavior of cargo

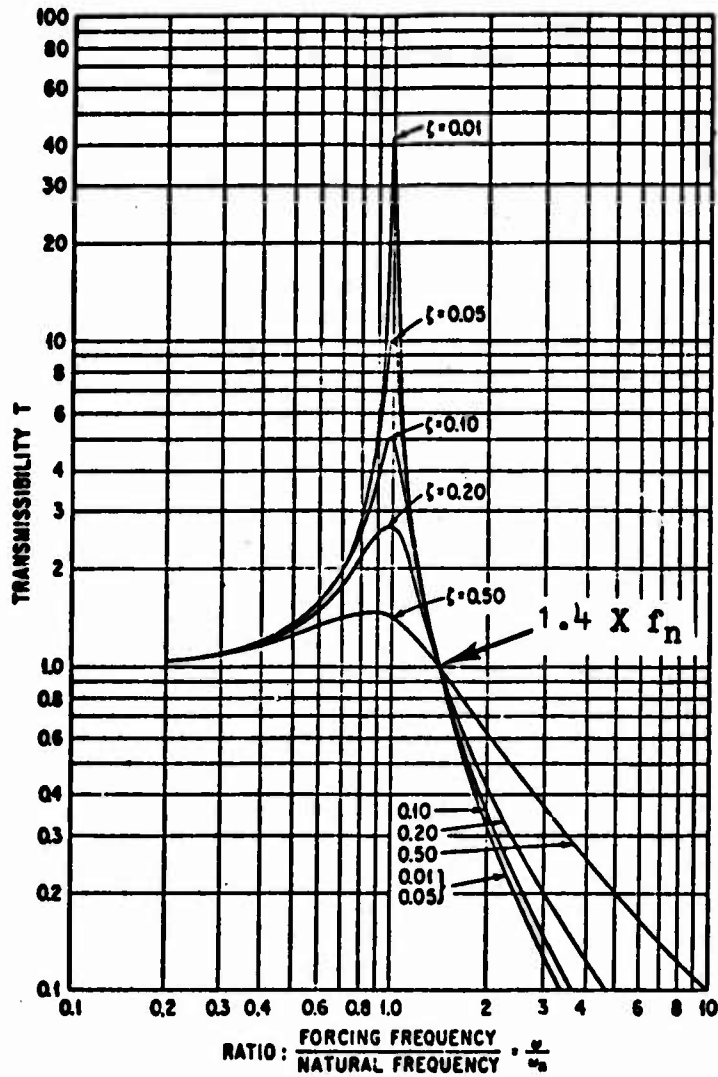


FIG. 3 Transmissability of a viscous-damped system. Force transmissibility and motion transmissability are identical. The fraction of critical damping is denoted by  $\zeta$



secured so as to move with the deck. The difference could influence the dynamic of loosely stowed cargo which leaves the deck and then impacts it with some force. Effects of cargo deck material will be discussed in section 4.4.

#### 4.3 Dynamics of Cargo Beds

Running gear suspension systems of both highway and rail transport vehicles have similar dynamics. They are designed to have damped natural frequencies in the 1 to 3 Hz range. The basic formula for calculating the natural frequency of any spring mass system is  $\frac{1}{2\pi} \sqrt{\frac{k}{m}}$  where:

k = Spring rate (weight deflection)  
m = Mass

Assuming k to be constant, a low mass would produce the higher natural frequency while a larger mass would cause oscillation at the lower natural frequency. A simple spring mass system will normally attenuate the transmission of forces occurring at repetition rates greater than  $1.4 \times f_n$  (see Figure 3). The suspension of a heavily loaded cargo bed has the lower natural frequency and consequently the softer ride. A very low natural frequency provides the best ride environment for all cargo whether it be human or inanimate but it is particularly good for the human body. Rigid body natural frequency of a person is in the range 4 to 6 Hz. It is important to attenuate input forces generated by the road in the 4 to 6 Hz range. It is not easy to design natural frequencies lower than 1 Hz into the vehicle suspension system because of the large spring deflection needed. A road excitation of  $\frac{1}{2}g$  at 1 Hz requires clearance between the axle and frame for 10 inches double amplitude movement of the axle. If the suspension system is too soft, impact or bottoming may occur between the axle and the frame resulting in shock which may cause damage, particularly to the vehicle frame. The natural frequency of rail car suspensions is more in the range of 2 to 3 Hz. A major difference between rail and highway vehicles is that highway vehicle suspensions are heavily damped and rail vehicles suspensions are not.

Dominant frequencies measured on the cargo deck are usually the rigid body motion of the deck. These are almost always suspension frequencies and harmonics of the suspension frequency. The harmonics are often identifiable with the number of axles on the vehicle which are inducing similar input to the deck at different instances in time. Sometimes, when operating over surfaces having uniformly spaced irregularities, the frequencies may be related to speed/wavelength. In most cases, all wheeled vehicle vibration spectrums are limited to less than 50 Hz.

These vibrational frequency relationships were established in Reference 7, and there have been no changes in vehicle design which would alter these relationships.

In many tests where vehicle bed dynamics were measured in the field, some response has been observed in the frequency range above 25 Hz. These measurements were usually observed in the output signal of accelerometers mounted on unloaded areas of the cargo bed. The source of these higher frequencies has been identified with impact of the cargo bed with the truck frame at the front of the bed. It has also been identified with the rattling of removable side rails on the cargo bed or the rattling of the tail gate or its chains. Some of the frequencies might not be sensed had the accelerometer been mounted under a heavily loaded portion of the cargo deck. Much of the data used in developing vibration schedules for simulating the transportation environment has been based on the unidirectional acceleration measured at the worst case location on the vehicle deck. Frequently, this worst case location is at the extreme rear of the deck. This location usually describes not only the vertical or bounce mode of the cargo bed but also its pitch mode.

Regardless of the type of automotive vehicles used, it cannot generate a rigid body sinusoidal motion greater than 1g. This statement is based on the fact that 1g or more applied at the wheel will cause the vehicle to leave the ground but since the wheel is not attached to the ground, the restoring force is limited to 1g. The dynamic response of a cargo bed is best described as a non-linear system. This description is reinforced when the vehicle is equipped with helper springs that come into action when the vehicle is fully loaded and encounters a relatively high forcing input. In addition to the non-linear behavior of the vehicle, it has been found that a wheeled automotive vehicle cannot generate resonant response in an object transported in the cargo bed. Inability of wheeled vehicles to generate resonant response is described in Reference 8. It shows that wheeled vehicle vibratory response to overland movement is, for the most part, random and always has a constantly changing phase relationship.

Rail car decks, like automotive vehicles, tend to oscillate vertically at the natural frequency of the springs in the trucks. The rail car truck springs lack the degree of damping found in automotive vehicle suspensions. The rail bed is comparatively smooth as compared with shocks created on highways. It does not cause pitching motions of the rail car that must be quickly damped for safe control of the vehicle. The most severe repetitive forces measured on rail cars are usually in the horizontal plane. They are measured at the extreme ends of a car and result from a yawing motion. A review of literature dealing with the vertical and lateral vibration forces at the deck of a rail car are almost always less than  $\frac{1}{2}$ g at very low frequencies. Damaging forces exerted on rail cargo result from shocks occurring when long trains



of cars are started or when coasting cars are stopped by impact with other cars in a rail classification yard.

Jet powered aircraft make up the primary military and civil reserve air fleets used for long distance movement of materiel. Propeller driven aircraft are used as a secondary air transport mode, but for shorter hauls. From an internally generated vibration viewpoint, the empty cargo deck of a propeller driven aircraft may respond at engine speed related frequencies. The decks of most jet aircraft, on the other hand, are extremely quiet. Rarely is a ripple seen on the surface of a glass of liquid placed on the deck. Vibration levels in propeller driven aircraft are only a small fraction of  $1g$  as shown on References 9, 10 and 11. The mass of the aluminum aircraft deck is small in comparison with the weight of pallets of cargo placed on it. Loaded pallets usually tend to change the structure of the deck and alter its dynamics by eliminating the low-level, high-frequencies. The origin of most of the rigid body motions of an aircraft cargo deck is external to the aircraft. These motions come from ground operations over rough taxi strips or runways and hard landings. They also come from maneuvers, thermal and other turbulent conditions. All of these rigid body motions are random or transient in nature and their occurrence is usually of short term duration. Cargo is secured to the deck for only two reasons; for crash safety and to prevent damage to the air frame should turbulence produce more than  $1g$  in the upward direction. Cargo is not restrained for protection of the cargo. The aircraft environment is generally mild and any forces greater than  $1g$  are transient and of short duration.

Rigid body motions in pitch, roll and yaw modes of ocean going vessels occur in rough seas at very low frequencies. The frequency is usually several seconds per cycle. In the pitch mode, it is possible that hull reentry into a wave can generate a shock pulse. It is also possible that the ship's propeller can generate a short term hull vibration when the stern leaves the water and then reenters. This input frequency would be at  $10Hz$  at best and, because of propeller shaft speed changes, the phase angle relationship of the input would be constantly changing. In addition to the heavy seas environment, low-level vibration has been measured on empty cargo decks. Frequency of these vibrations are related to the propulsion machinery. Limited data are available on the vibration level of ships decks. However, those data, as described in Reference 12, show the level to be less than  $\frac{1}{2}g$ . Data were acquired on statistical accelerometers mounted in two 40 ft. containers of separate loading projectiles enroute from Port Chicago, California to Cam Ranh Bay, Viet Nam (Reference 10). The accelerometers, which were capable of measuring as low as  $\frac{1}{2}g$ , showed no response during the entire voyage.

#### 4.4 DISCUSSION

The U.S. Army Test and Evaluation Command is confronted with a

complex problem. It must insure that army materiel will withstand the transport environment, yet the test used to demonstrate this must be reasonable. It must not be overly severe and require redesign that results in a needless increase in cost, weight and size in order to pass the test. The question always arises, "what is a reasonable or an acceptable test"? This question cannot be resolved at this point in time on a scientific basis. The current test schedules were based on subjective decisions. If these decisions were wrong, and it is apparent that they were, corrections must also be made on subjective decisions. There is some evidence to support the assumption that the current 84 minute sinusoidal test is not reasonable. A test shipment of 226, 40 ft. containers was made from Dayline, La. to Pleiku, Viet Nam in 1970 (Reference 13). This cargo consisted of boxed 2.75 inch rockets and pallets of 155mm separate loading projectiles. The shipment was made over 2000 miles of CONUS highway and 144 miles of rather poorly maintained road in Viet Nam. Sea lane distance is not known but is approximated to be between 8,000 and 9,000 miles. The cargo arrived totally intact. Two containers sustained major damage prior to shipboard loading in California, but this was handling damage to the containers and caused no damage to the contents. There is no reason to suspect that the pallets would have been damaged if the highway distance was doubled.

Current 84 minute laboratory tests of the palletized separate loading projectiles show extensive damage to the pallets in the two planes that they are vibrated. Unless the pallet is modified, it will disintegrate part way through the test in the vertical plane. Modifications required consist of one of two courses of action. Either the skids under the pallet must be removed or additional blocking must be placed under the base to eliminate pallet bending modes in the 5 to 200 Hz frequency band (see Figure 4). When vibrated in one of the horizontal planes, the pallet will not withstand the environment and the rounds must be vibrated out of the pallet. Boxes of 2.75 inch rockets and various caliber fixed and semi-fixed cartridges withstand the 84 minutes of vibration in each of two planes but they also withstood the overseas shipping environment. The fact that the pallets of separate loading projectiles will withstand the shipping environments but not the laboratory test strongly supports the statement that the laboratory test is not realistic.

In sections 3.1 and 3.3 it was rationalized that the maximum number of miles cargo can be expected to move by automotive vehicle is 4,500 miles. Most of this distance, at least 4,000 miles, should be over CONUS highways. The method of restraint for ammunition would range from secured to tightly blocked in two planes. The method for restraining packaged items of general equipment would range from loosely blocked to little or no restraint. It is expected that the final 500 miles of this distance would be in a theater of operation. Here, because of the inability to maintain

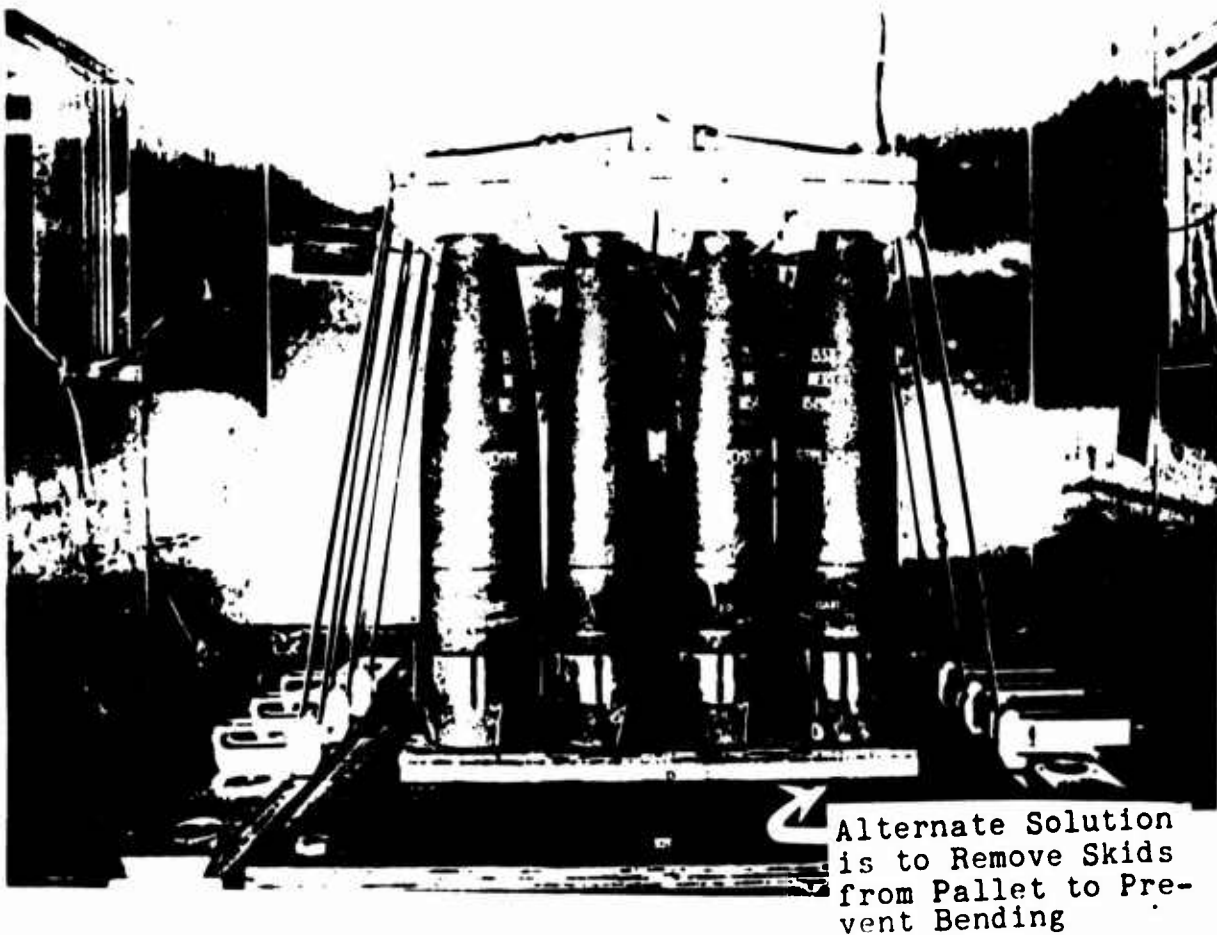
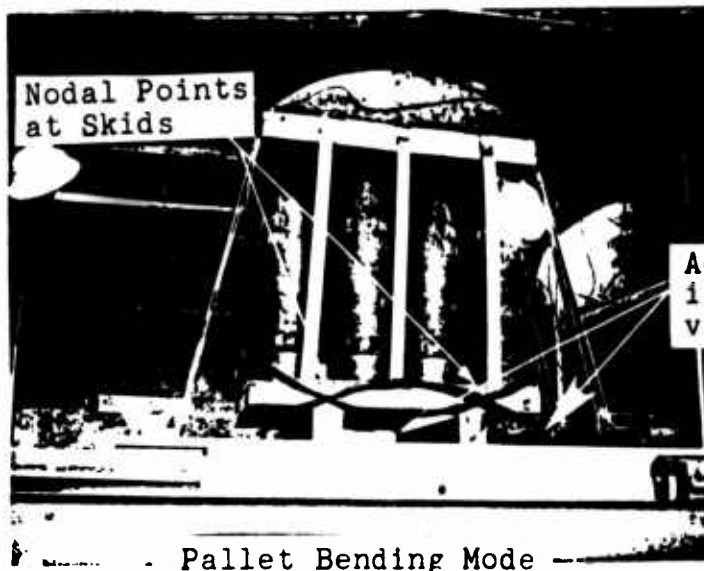


Fig. 4. Pallet Bending During Vibration in the Vertical Plane

them in times of emergency, road surfaces should be rougher and the degree of cargo restraint would probably be less than during CONUS movement.

Current laboratory vibration test procedures require 84 minutes of test time in each of two planes for ammunition, and in each of three planes for items of general equipment. These schedules are based on the hypothesis that 15 minutes of vibration in each plane at the specified g level represents the force damage potential to the cargo of 1,000 miles of overland transport. The hypothesis assumes that the worst vibration environment measured on the vehicle bed, measured on the worst course and at the worst speed, exists for the entire 1000 miles distance. This assumption builds severity into the test. Even though a road may be rough for 1000 miles, a vehicle driver would probably not tolerate such an uncomfortable environment for more than a minute or two at a time. If 15 minutes of vibration equals 1000 miles travel, then 84 minutes represents 5,600 miles of worst case travel. This grossly oversimulates the damage potential of 4500 miles of total projected travel of which only a few hundred miles may be comparable in roughness to the Belgain block course on which the basic data were obtained.

The original development of the engineering test standard which evolved into the current TOP 1-2-601 (Reference 14) and Mil-Std 810C (Reference 15) vibration schedules (Reference 14 and 15) have been researched. In Reference 12, it was concluded that 15 minutes of vibration in each of three planes at the appropriate g level, would be adequate to insure that the test specimen would withstand the automotive environment encountered in worldwide shipment. This conclusion was based on the fact that the sinusoidal sweep would excite each natural frequency in the specimen within the test spectrum to that unique response condition defined as resonance. It was known at that time the automotive environment could not induce resonance, and that the 15 minute test in reality simulated the damage potential of several thousand miles of actual shipment. At that point in time, the Air Force specified in Mil-Std 810 a vibration test of three hours duration in each plane that would encompass the environment of worldwide shipment by air. In 1963, TECOM combined the 15 minute automotive schedule with the three hour aircraft schedule for a total test time of 195 minutes in each plane. But, because of the cylindrical shape of most items of ammunition, it was not possible to identify two specific axes in the minor dimension. Also, the rounds were free to rotate in their shipping boxes or pallets. As a result ammunition testing was limited to only two planes of vibration; one through the axis of major dimension and one through the axis of minor dimension. Vibration of items of materiel having three well defined planes were vibrated through three planes. Because the TECOM method of equating vibration simulation for ground vehicles was superior to other methods of that period, the TECOM data were incorporated into Mil-Std 810A and 810B by the interservice vibration committee. By the

time the "B" version of the standard was published in 1967, the aircraft test duration was reduced to 1 hour of aircraft plus the 15 minutes of ground transportation, and this was designated "Transportation by Common Carrier". In the 1970's the Air Force personnel concluded that the air transport environment for cargo was insignificant as compared with the ground vehicle. They recommended that the flight simulation portion of the test be deleted and that only the ground vehicle vibration tests need be conducted. This recommendation could and should have been interpreted as requiring only 15 minutes of sinusoidal vibration over the spectrum 5 to 200 Hz. The recommendation was not accepted by a majority of the committee members. They subjectively reasoned that reducing the test time to only 15 minutes might incur criticism from some observers that the test was inadequate. Consequently, it was decided to add the aircraft time to the ground vehicle time for 75 minutes. But in eliminating the aircraft phase of the test, the spectrum was reduced from an upper frequency of 500 Hz to 200 Hz. By doing so, it was not possible to sweep the spectrum in 7.5 minutes at .88 octaves per minute. The new sweep rate was 6 minutes from 5 to 200 Hz. It was agreed in committee action, that an 84 minute test consisting of 14 sinusoidal sweeps would constitute an acceptable test time. This change is reflected in the "C" version of Mil-Std 810 published in 1975, which is the current test at the time of this writing.

The earlier assessment in this discussion that the 15 minute sinusoidal vibration will simulate the force environment of worldwide travel as military motor freight appears valid. This is particularly true since it does not conflict with conclusions drawn during the development of the original automotive vibration schedule 17 years ago. Recommending the 15 minute test with .88 octave/minute sweep rate presents a timing problem for a spectrum with an upper limit of 200 Hz. This can be solved in one of two ways: Changing the total test time or altering the sweep rate. Suggested variations are as follows:

1. Maintain the sweep rate at .88 octaves per minute and extend test time to 18 minutes. This will constitute three, six minute sweeps.
2. Conduct test for 15 minutes at two sweeps of 7.5 minutes each. This reduces the sweep rate to about .7 octaves per minute. The slower rate will allow extremely high q (or amplification factor) resonances to fully develop.
3. Conduct the test for 15 minutes at three sweeps of 5 minutes each. This increases the sweep rate to 1.05 octaves per minute. The faster sweep rate may restrict resonant development of high q natural frequencies.

Any of the three options outlined above should be acceptable.

A transport system recognizes only the mass acting in its cargo deck. It does not alter or adjust the dynamic environment to suit



the fragility factor or the potential hazard associated with the cargo it carries. In terms of severity, the 15 minute sinusoidal test recommended for general cargo could apply equally well to items of ammunition. However, ammunition is vibrated as part of a safety test of the ammunition. Only a total of a few hundred rounds are tested, but there is a need to assure a high degree of confidence that the round is safe to handle, transport and fire. Since it is not possible to test and fire a sufficient number of rounds to develop the desired statistical confidence, the few rounds that are tested are subjected to higher than normal levels of test severity. Testers may desire to increase ammunition vibration time by a factor of two or more depending on their appraisal of the need for increased severity. The severity of the test for any item of cargo should be adjusted at the option of the tester provided the rationale is justified in terms of the test objective.

The derivation of a test schedule within TECOM encompassing the environment for loosely restrained or totally unrestrained cargo was done in 1966 (Reference 16). This time schedule was based on a comparison of the dimensional change in pine blocks transported loosely in the back of an M35 truck over the Belgain block test course and when they were bounced on a package tester. It was found that eleven minutes exposure to the environment of a package tester operating at 284 revolutions per minute resulted in the same average change of block dimension as was found after 50 miles of vehicle transport over the Belgain block test course. A package tester bed having 1 inch double amplitude displacement operating at 284 r.p.m. generates a vertical force of 1.14g. At that time, it was concluded that the simulation of about 150 miles of operation (30 minutes of test time) would constitute the environment for items issued to individual soldiers and carried loosely in the cargo bed of vehicles. As previously stated, the vehicle bed is not cognizant of what is being transported. Consequently, the test time was applied to all items of general equipment. For tests of loosely stowed items of ammunition, the severity of the test was subjectively increased in the late 1960's. The increase was in force, not time. The package tester is operated at 300 r.p.m. for ammunition instead of 284 r.p.m. for general equipment. A speed of 300 r.p.m. develops a vertical force of 1.3g.

Objections to the hypothesis used in developing the loose cargo test have been voiced within the testing community in the past. The reason is that the wood blocks used as the specimen represented only one frangibility factor, and was believed by some to have been a poor choice. Regardless of the wisdom of the choice, the data provided some basis for determining the input g level and duration of the loose cargo test.

The 30 minute test is still considered by most as being descriptive of 150 miles of the worst case transport on very rough roads in

foreign theaters of operation. While it is doubtful that this degree of road roughness would be encountered in CONUS, it is possible that occasional transient inputs of greater than 1g could be encountered. To protect against the possibility that cargo could be shipped the entire 4,500 miles as loosely restrained cargo, it seems necessary that the duration of the package tester test be extended. How much it should be extended is a subjective reasoning decision. It seems reasonable to expect that an additional 30 minutes of the bounce table test might simulate the impact damage potential of 4000 miles of CONUS interstate highway travel. A total of one hour bounce testing on a package tester should indicate that materiel can be transported worldwide as loosely blocked or unsecured cargo. One hour of testing at 284 r.p.m. produces 16,992 shock inputs while the same amount of testing at 300 r.p.m. produces 18,000 shock inputs.

Assuming half the time represents extreme rough roads and the other half represents interstate highways. Then 9000 shocks for 150 miles of operation equals 60 shocks per mile or one shock per 88 feet traveled. The remaining 9000 shocks for 4000 miles highway travel equals 2.25 shocks per mile or one shock per 2350 feet traveled.

Since all materiel can be transported overland either as secured cargo or as loosely stowed cargo, it should be subjected to both modes. Until new vibration test schedules covering the random vibration environment are developed, the best approach is to alter the sinusoidal vibration test schedule time as follows:

General equipment should be vibrated for 15 to 18 minutes per axis (depending on selected sweep rate) in each of three axes.

Ammunition should be vibrated for 30 minutes per axis in each of two axes.

To simulate loosely blocked or stowed materiel:

General equipment should be bounced for a total of 1 hour at 284 r.p.m. bounce table speed.

Ammunition should be bounced for a total of 1 hour at 300 r.p.m. bounce table speed.

This estimate is a proposed loose cargo bounce test for simulating the world wide transportation environment based on the number of impacts (time) and force input only. It does not consider variables which test personnel must resolve, such as; the number of sides the package should be tested on; or, the ratio of time that an item of materiel should be bounced in a packaged and unpackaged configuration. These variables should be considered during the

preparation of the test plan for the specific test item. In the absence of specific guidance, the decisions must be made by the test operating personnel. When this is done, the report should state the reasoning behind the decision and equate the seriousness of any damage found under test conditions with the probability that the same condition could occur in the field.

## 5.0 CONCLUSIONS

5.1 It is not possible to identify the number of miles ammunition and other items of materiel may be transported in air, ground, or rail vehicles as secured, restrained in two planes, or loosely stowed cargo.

5.2 On an average, cargo of Army materiel should not be moved more than 4,500 miles by highway transport systems.

5.3 The cargo may travel the entire distance as secured cargo or as loosely blocked cargo. It is more likely that the shipment will consist of some combination of the two methods of restraint.

5.4 Highway transportation creates a more severe force environment than rail, sea or air transport except for the few shocks rail cars experience in classification yards.

5.5 For items of general equipment, the following tests should adequately demonstrate structural integrity of the test specimen to withstand worldwide transport by all modes:

- a. Sinusoidal vibration for 15 to 18 minutes duration swept over the spectrum 5 to 200 Hz in each of three planes.
- b. One hour of bounce testing on a package tester operating at 284 r.p.m.
- c. The appropriate drop tests using the general guidelines described in Mil-Std 810C.

5.6 The following tests should adequately demonstrate the ability of ammunition to withstand worldwide transport modes and be safe to handle and fire:

- a. Sinusoidal vibration for 30 minutes swept over the spectrum 5 to 200 Hz in each of two planes.
- b. One hour of bounce testing on a package tester operating at 300 r.p.m.
- c. Sequential 7 ft. packaged drop.
- d. Sequential 5 ft. unpackaged drop.
- e. 40 ft. drop test. (specimen need only be safe to dispose of as a result of the drop).



## **6.0 RECOMMENDATIONS**

**It is recommended that:**

**As an interim measure, time durations of sinusoidal vibration tests and bounce tests for general equipment and ammunition be adjusted to conform with conclusions 5.5 and 5.6 respectively at the earliest opportunity.**

**Future methodology studies regarding transportation vibration should be directed toward development of random schedules. These schedules should reflect the effect of test specimen weight on the required frequency spectrum. The required spectrum should be determined from results of proposed TECOM Project 7-CO-RD9-AP1-001 which is intended to establish the equivalent mass of cargo beds vibrating at various frequencies.**

**The validity of the bounce test schedule developed in 1966 should be reaffirmed or altered in accordance with the results of the current loose cargo studies being conducted by White Sands Missile Range under TECOM Project 7-CO-PB0-AP1-006**

## REFERENCES

1. Cline, H.T. "A Study of Cargo Configuration and Restraint in Military Vehicles". Prepared Under Contract for Materiel Testing Directorate, Aberdeen Proving Ground, Maryland, May 1979.
2. Letter dated 13 February 1975. Subject: "Transportation Vibration of Ammunition". U.S. Army Logistics Center, Ft. Lee, Va.
3. Rand McNally Road Atlas of the United States, Canada and Mexico. 52nd Annual Edition.
4. TM55-607 "Loading and Stowage of Military Ammunition and Explosives Aboard Breakbulk Merchant Ships". Sept. 1976.
5. AFSC DH1-11 "Air Transportability Design Handbook". Wright-Patterson Air Force Base, Ohio 45433. Dated 25 Sept. 1976.
6. American Standards Association Terminology, S1.1-1960 American Standards Association, May 25, 1960.
7. Cline, H.T. "Road Shock and Vibration Environment for a Series of Wheeled and Track-laying Vehicles". Report DPS 999, Aberdeen Proving Ground, Md., June 1963.
8. Cline, H.T., Coen, R., Lowry, D. "Vibration Associated with Ground Vehicles". Report No. APG-MT-3787, February 1971.
9. Thomas, C.E. "Flight Vibration Survey of C-130A Aircraft". Report No. ASD-TDR 62-267, Wright-Patterson Air Force Base, Ohio, March 1962.
10. Bolds, P.G. "Flight Vibration Survey of C-133 Aircraft". Report No. ASD-TDR 62-383, Wright-Patterson Air Force Base, Ohio, April 1962.
11. Thomas, C.E. "Flight Vibration Survey of C-123 Aircraft". Report No. ASD-TDR 62-235, Wright-Patterson Air Force Base, Ohio, February 1962.
12. Tolen, J.A. "The Development of an Engineering Test Standard Covering the Transportation Environment for Materiel". Aberdeen Proving Ground, Md., Report No. DPS-1190, Dec. 1963.
13. Grier, John H. "D.O.D. Ammunition Test Shipment in Sea Land Containers". U.S. Army Transportation Engineering Agency. Report No. 70-7, April 1970.

14. Test Operations Procedure 1-2-601. Test and Evaluation Command, Aberdeen Proving Ground, Md.
15. Mil-Std 810C. "Environmental Test Methods". 10 March 1975.
16. Tolen, J.A., Lefever, G.F. "Test Procedure for Laboratory Simulation of Rough Handling". Aberdeen Proving Ground, Md. Report DPS 1937, March 1966.

SECTION 3. APPENDICES

APPENDIX A - METHODOLOGY INVESTIGATION  
PROPOSAL AND DIRECTIVE



DEPARTMENT OF THE ARMY  
HEADQUARTERS, U. S. ARMY TEST AND EVALUATION COMMAND  
ABERDEEN PROVING GROUND, MARYLAND 21005

S: 15 Nov 79

DRSTE-AD-M

1 NOV 1979

SUBJECT: Directive, Improvement of Shock and Vibration Testing -  
Test Schedules for Transport of Loose Restrained and  
Secured Cargo, TRMS No. 7-CO-RDO-API-008

Commander  
US Army Aberdeen Proving Ground  
ATTN: STEAP-MT-S  
Aberdeen Proving Ground, MD 21005

1. Reference is made to TECOM Regulation 70-12, dated 1 June 1973.
2. This letter and attached STE Forms 1188 and 1189 (Incl 1) constitute a directive for the subject investigation under the TECOM Methodology Improvement Program 1T665702D625.
3. The MIP at Inclosure 2 and the attached guidance at Inclosure 3 are the bases for headquarters approval of the subject investigation.
4. Special Instructions:
  - a. All reporting will be in consonance with paragraph 9 of the reference. The final report, when applicable, will be submitted to this headquarters, ATTN: DRSTE-AD-M, in consonance with Test Event 52, STE Form 1189.
  - b. Recommendations of new TOPs or revisions to existing TOPs will be included as part of the recommendation section of the final report. Final decision on the scope of the TOP effort will be made by this headquarters as part of the report approval process.
  - c. The utilization of the funds provided to support the final investigation is governed by the rules of incremental funding.
  - d. The addressee will determine whether any classified information is involved and will assure that proper security measures are taken when appropriate.

DRSTE-AD-M

5 NOV 1979


SUBJECT: Directive, Improvement of Shock and Vibration Testing -  
Test Schedules for Transport of Loose Restrained and  
Secured Cargo, TRMS No. 7-CO-RDO-API-008

e. Upon receipt of this directive, test milestone schedules will be immediately reviewed in light of known other workload and projected available resources, in accordance with provisions of paragraph 2-4 to TECOM Regulation 70-8. If rescheduling is necessary, this headquarters, ATTN: DRSTE-TO-O, will be notified by 1st Indorsement not later than 15 November 1979. If schedules can be met, a P8 entry will be made directly into TRMS master file by that date.

f. The Methodology Improvement Division point-of-contact is Mr. Richard Hayes, ATTN: DRSTE-AD-M, AUTOVON 283-2170/2375.

FOR THE COMMANDER:

3 Incl  
as

*for*   
SIDNEY WISE  
Chief

Methodology Improvement Division  
Analysis Directorate

Nov 79

METHODOLOGY INVESTIGATION PROPOSAL - FY80

1. TITLE. Improvement of Shock and Vibration Testing - Testing Schedules for Transport of Loose Restrained and Secured Cargo

2. INSTALLATION. Materiel Testing Directorate  
Aberdeen Proving Ground  
Aberdeen Proving Ground, MD 21005

3. PRINCIPAL INVESTIGATOR. Mr. E. L. Ehlers  
Measurements and Analysis Division  
STEAP-MT-G  
Autovon 283-3410

4. STATEMENT OF THE PROBLEM. Requirements documents state that Army materiel must not be degraded by the shock and vibration environment associated with all normal modes of transportation. To verify this by loading equipment on the various vehicles and transporting it for the appropriate number of miles over test courses would be prohibitive in cost, so laboratory simulation, in which time is condensed, is used. Presently, cargo tested in the laboratory is secured to the vibration exciter and subjected to a sinusoidal laboratory vibration environment. It has been determined by previous methodology investigations that the field vibration environment is random for secured cargo in wheeled transport vehicles and that not all cargo is transported in the secured mode. Random vibration schedules derived from field vibration data are therefore required in order to provide the best laboratory simulation. In order to provide realistic schedules, the mileage figures associated with secured cargo and restrained cargo transportation must be determined.

5. BACKGROUND.

a. An investigation was started into vibration under the title "Updating and Developing Laboratory Test Schedules" TRMS 7-CO-PB5-API-077. The findings of this investigation are contained in the report APG-MT-4821 dated June 1976. This preliminary work showed the field environment for wheeled cargo vehicles to be predominately random and track-layers was a combination of random and sinusoidal and developed a method for converting real-time field vibration data to random laboratory test schedules. It also raised the question as to whether cargo was always secured to the cargo bed or whether it was transported in a loose (restrained) configuration.

b. A second investigation entitled "Cargo Configuration and Restraint in Military Ground Vehicles" was conducted under TRMS 7-CO-RD8-API-002 to determine the loading configuration of military ground vehicles to include the percentage of cargo bed utilized and the methods used in securing/restraining the cargo. This investigation was conducted under contract DAAK11-79-C-0007

## **Improvement of Shock and Vibration Testing - Testing Schedules for Transport of Loose Restrained and Secured Cargo - Cont'd**

with Harry T. Cline and Associates. The results of this investigation included the finding that not all cargo was transported as secured cargo but was instead often transported in the restrained or even loose form when loaded on military vehicles. It was not within the scope of that investigation to determine the actual mileage relationships of cargo being transported as secured, restrained or loose.

6. GOAL. The investigation will determine the number of miles that ammunition and general equipment is transported as secured cargo and as restrained or loose cargo. It will result in changes to TOP 1-2-601.

### **7. DESCRIPTION.**

a. The existing data generated during the methodology investigation entitled "Cargo Configuration and Restraint in Military Ground Vehicles" will be utilized in determining the number of miles that ammunition and general equipment types of cargo can be expected to be transported as either secured, restrained or loosely stowed cargo. The existing data will be supplemented as required with information from various Army transportation agencies and from using units.

b. The existing data will be reviewed and analyzed (and supplemented as determined necessary) to identify the number of miles that the subject cargo is transported in military ground vehicles in the following configurations:

- (1) Securely tied to the bed of the cargo vehicle.
- (2) Restrained in the two horizontal planes in the bed of the cargo vehicle.
- (3) Stowed loosely (little or no restraint) in the cargo vehicle.

It is proposed that this review, analysis and supplementation be performed by a contractor.

#### **c. Milestones are:**

Start Project	December 80
Review, Analyze (and Supplement data if required)	January 80 - April 80
Prepare Report	May 80
Complete Project	July 80

## Improvement of Shock and Vibration Testing - Testing Schedules for Transport of Loose Restrained and Secured Cargo - Cont'd

d. The investigation will result in the improvement of laboratory vibration test schedules and will be reflected in changes to TOP 1-2-601.

### 8. PROGRESS. New Investigation.

### 9. JUSTIFICATION.

a. Present capability, limitations, improvement and impact of test if not approved. The present laboratory testing techniques for simulating transport of ammunition and general equipment consist of two tests, one a loosely stowed cargo test and the other a secured cargo sinusoidal vibration test. Newly developed technology indicates that the vibration environment is primarily random for military wheeled vehicles and that the cargo is transported more in the restrained/loosely stowed configuration than as secured cargo. The rationale behind the development of the loosely stowed cargo test schedule has long been a manner of controversy as has the correlation of field and laboratory vibration data. The development of these schedules will provide more realistic laboratory test procedures and schedules. To provide these realistic schedules, it is imperative that the amount of miles the cargo is transported as secured, restrained, or loose be established. If this investigation is not performed, APG, other TECOM agencies as well as private contractors will continue to use improper laboratory schedules. Also if this investigation is not performed in this proposed timeframe, the overall program for the improvement of laboratory shock and vibration test schedules (which is a multiyear program approved by TECOM's Shock and Vibration Technical Committee) will be delayed as this mileage information is vital to determining test durations in the laboratory.

b. Dollar Savings. Savings will result from the reduction of retests that are required due to failures from improper schedules. This savings is spread over the elimination of several damaged test items as well as the time saved by eliminating costly over/under design and the time required for redesign and retest. Additional savings can be realized from the design and fabrication of less intricate and complex test fixtures than are presently required to meet existing schedules.

c. Workload. Over the past four years APG has conducted an average of 40 laboratory vibration/rough handling tests per year. The future workload is anticipated to be equally as high. Examples of items anticipated for testing are:

	<u>FY</u>	<u>81</u>	<u>82</u>	<u>83</u>
Ctg, 75 mm (HIMAG)		DT II	DT II	DT II
Ctg, 105 mm, HEAT-T, XM801		DT III		
Ctg, 105 mm		DT II	DT II	DT II
Ctg, 120 mm, APFSDS-T, XM829		DT II	DT II	DT II



**Improvement of Shock and Vibration Testing - Testing Schedules for Transport of Loose Restrained and Secured Cargo - Cont'd**

- d. Recommended TRMS Priority: N/A
- e. Association With Requirements Documents: N/A
- f. Other. N/A

**10. RESOURCES.**

**a. Financial.**

**(1) Funding Breakdown.**

	<u>Dollars in Thousands</u>	
	<u>FY80</u>	
	<u>In-house</u>	<u>Out-of-house</u>
Personnel Compensation	3.0	
Travel		
Contractural Support		7.0
Consultants and Other Services		
Materials and Supplies		
Equipment		
Subtotals	<u>3.0</u>	<u>7.0</u>
FY Totals		
	<hr/>	
	10.0	

**(2) Explanation of Cost Categories.**

(a) Personnel Compensation - This represents compensation chargeable to the investigation for utilizing civilian personnel in the contract preparation, monitoring, and preparation and review of APG's final report based on the contractor's report.

(b) Contractural Support - The total investigation is planned to be carried out under contract as stated in para 7b. This will amount to an estimated \$7000 to be obligated in FY80. The contract will be written upon approval of this proposal.

b. Anticipated Delays. None

Improvement of Shock and Vibration Testing - Testing Schedules for Transport of Loose Restrained and Secured Cargo - Cont'd

c. Obligation Plan

	FQ	1	2	3	4	TOTAL
Obligation Rate (Thousands)		1.0	4.0	4.0	1.0	10.0

d. In-House Personnel

	Number	FY80		Study Hours Required
		Required	Available	
Engr Tech, GS-0802	1	100	100	
Mech Engr, GS-0830	1	20	20	
Editing and Typing	1	56	56	
Methodology Spec.	1	24	24	
		<u>200</u>	<u>200</u>	<u>120</u>

11. INVESTIGATION SCHEDULE.

	FY80											
	O	N	D	J	F	M	A	M	J	J	A	S
In-House				-	-							
Contract				A	-	-	-	-	-	-	R	

Symbols: --- Active investigation work  
 ... Contract monitoring  
 A Award of Contract  
 R Final report due at HQ, TECOM

12. ASSOCIATION WITH TOP PROGRAM. TOP 1-2-601 will be revised as a result of this investigation.

JOHN A. FEROLI  
 Chief, Methodology and Test Management Division  
 Materiel Testing Directorate

### SUMMARY SHEET

ORGANIZATION: Aberdeen Proving Ground

INVESTIGATION: Improvement of Shock and Vibration Testing - Test  
Schedules for Transport of Loose Restrained and  
Secured Cargo

TRMS NO.: 7-CO-RDO-AP1-008

TOTAL COST FY 80: \$10.0K

APPROVED COST FY 80: \$10.0K

UNFUNDED FY 80: 0

#### HISTORY:

- COMMENT:
- a. This directive will be reviewed and processed in accordance with paragraph 2-4, TECR 70-8.
  - b. The subject methodology investigation shall be established initially on a success basis.
  - c. An interim letter report is required by 15 May 80, and the report will include the results of the technical progress, status of funds, and reprogramming recommendations. Appendix D of TECR 70-12 covers Methodology Investigation Final Report formats. The format for the letter report is flexible, but it should cover the topics listed in Sections 1 and 2 of Figure D-2 in TECR 70-12.
  - d. This investigation will not be terminated unless the work is completed or it is canceled by HQ, TECOM. If funds are expended or withdrawn, the critical events will be rescheduled or the investigation will be suspended.

# APPENDIX B - DISTRIBUTION LIST

TECOM Project No. 7-CO-RDO-AP1-008

<u>Addressee</u>	<u>Final Report</u>
Commander US Army Test and Evaluation Command ATTN: DRSTE-AD-M Aberdeen Proving Ground, MD 21005	3
Commander US Army Yuma Proving Ground ATTN: STEYP-TD Yuma, AZ 85364	1
Commander US Army White Sands Missile Range ATTN: STEWS-TE-P New Mexico 88002	1
Commander US Naval Weapons Center ATTN: Code 4530 China Lake, CA 93555	1
Commander US Army Jefferson Proving Ground ATTN: STEJP-TD Madison, IN 47250	1
Commander US Army Electronic Proving Ground ATTN: STEEP-MT-I Fort Huachuca, AZ 85613	1
Commander US Army Tank-Automotive Command ATTN: DRDTA-U (Mr. Burg) Warren, MI 48090	1
Director MTMC Transportation Engineering Agency ATTN: MTT-TRC (Mr. F. R. Fisher) P.O. Box 6276 Newport News, VA 23606	1
Director US Army Ballistic Research Laboratory ATTN: DRDAR-TSB-S Aberdeen Proving Ground, MD 21005	2

<u>Addressee</u>	<u>Final Report</u>
Commander	
US Army Aberdeen Proving Ground	
ATTN: STEAP-MT-M	11
STEAP-MT-G	8
STEAP-MT-X	1
STEAP-MT-O	1
Aberdeen Proving Ground, MD 21005	
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