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DESIGN OF CUSHIONING SYSTEMS FOR AIRDROP

by

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Foreword

The analytical and experimental methods presented in this report have resulted from the compilation and organization of data and techniques that have been developed over a number of years by various organizations interested in the protection of supplies and equipment against the airdrop impact environment.

The preponderance of work in this area has been conducted under U.S. Army Project No. 7X87-03-004, entitled "Aerial Delivery Equipment". Almost all the basic paper honeycomb data was developed by the Structural Mechanics Research Laboratories of the University of Texas, Austin, Texas under various contracts with the Quartermaster Research and Engineering Command, now designated the U.S. Army Natick Laboratories. The significant contributions of Professors J. Neil Thompson and E.A. Ripperger, Director and Associate Director, respectively, of the Structural Mechanics Research Laboratory to the impact energy dissipater state-of-the-art are acknowledged. The techniques of application were developed in complementary fashion by both the University of Texas and the Natick Laboratories.

The information in this report was originally presented as a paper, with the same title, at the 30th Symposium on Shock, Vibration, and Associated Environments held in Detroit, Michigan on October 10-12, 1961. The paper was subsequently published in the proceedings of the symposium.

This report was recently reviewed and the material updated.

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Table of Contents

	Page
List of Figures	v
Abstract	vi
I Introduction	1
II Analysis	1
III Energy Dissipater Configurations for Rigid Bodies	4
IV Energy Dissipater Configurations for Flexible Bodies	5
V Energy Dissipater Configurations for Multiple Flexible Bodies	8
VI Instrumentation	10
VII Rebound Energy	11
VIII Practical Considerations	13
IX Summary	15
References	17

List of Figures

Figure		Page
1	Typical Paper Honeycomb - Expanded and Crushed	18
2	Stress vs. Strain for 80/0/ 1/2 Paper Honeycomb	19
3	Rebound Energy of 80/0/ 1/2 Paper Honeycomb	20
4	C-Rations Rigged for Airdrop Using Paper Honeycomb as Energy Dissipater	21
5	55-Gallon Drums Rigged for Airdrop Using Paper honeycomb as the Energy Dissipater	22
6	Typical Energy Dissipater Configuration for Standard Army Vehicles	23
7	View, with Vehicle Removed, of Typical Energy Dissipater Configuration	24
8	Resilience vs. Maximum Strain for 80/0/ 1/2 Paper Honeycomb	25
9	Typical Variation in Crushing of 80/0/ 1/ 2 Paper Honeycomb with Design Deceleration G's	26

Abstract

Complementary analytical and empirical techniques for the design of energy dissipater configurations for airdropped items are presented. The techniques are applicable to the use of single-shot, sheet-type energy dissipater materials which have an essentially rectangular stress-strain curve for the greatest part of their deformation, such as paper honeycomb, metal honeycombs, and certain foamed plastics.

The analytical portion discusses the design of configurations for three orders of item complexity as follows:

a. A single rigid body.
b. A single flexible body.
c. Multiple flexible body.

The difference between an item assumed to be a single flexible body and an item assumed to be composed of multiple flexible bodies lies in the degree of coupling between the masses.

Use of the analytical methods requires some information which as yet can only be obtained experimentally. The test methods that can be used to obtain this information are described in enough detail so that, together with the analytical methods, the reader will be able to design his own energy dissipater configurations.

The rebound properties of the energy dissipater are considered and the limitations that these properties impose upon the design of the configuration are discussed.

A number of practical considerations such as the aspect ratio of the energy dissipater stack, the use of load spreaders, and the use of build-up stacks which are necessary for the successful use of the energy dissipater in the field are presented.

DESIGN OF CUSHIONING SYSTEMS FOR AIRDROP

I. Introduction: The techniques described in this report apply to the use of single-shot, sheet-type energy dissipater materials for the control of accelerations during an airdrop impact. An airdrop impact is different from most transportation impacts in that the item being dropped is impacted on a selected surface and the energy absorbed is from three to ten times greater than that in a typical transportation shock. This increased energy usually results in a requirement for a greater deflection of the energy absorber than is normally considered for transportation packaging.

The energy dissipater materials that fall within the scope of this report are assumed to have mechanical properties similar to those exhibited by the paper honeycomb (Figure 1) now in use by the U. S. Army. Specifically these mechanical properties are:

a. An essentially rectangular stress-strain curve over a wide range of strain.

b. Low rebound energy.

c. Mechanical properties which are constant over a wide range of environments.

Figure 2 shows typical stress-strain curves for standard U. S. Army paper honeycomb for two maximum strains.[1] It is apparent that the curve with a maximum strain of approximately 70 percent does have an essentially rectangular stress-strain curve while the curve with a maximum strain of approximately 85 percent departs from being essentially rectangular and rises rapidly in the region of 75 to 85 percent strain. This phenomenon which occurs as the paper packs together at the conclusion of its crushing is called "bottoming". Energy dissipater configurations are usually designed so that the honeycomb is strained from 60 to 70 percent. The amount of rebound energy stored in the paper is indicated by the area under the unloading curve as shown in Figure 3* and is equal to about 8 percent of the energy absorbed for strains up to 70 percent. Above 70 percent strain, the percentage of rebound energy rises rapidly.

II. Analysis: The standard analytical technique for the use of energy dissipaters within the scope of this report is based on the assumptions that the body being accelerated is rigid and that there are only two forces to consider; one, the weight of the body and two, a constant force exerted by the paper honeycomb. With these assumptions, the use of Newton's second law results in the following equation:

*See reference 1

$$A = \frac{W(G+1)}{S_a} \qquad (1)$$

where A = Area of paper honeycomb - sq. ft.

W = Weight of item - lbs.

G = a/g
where a = acceleration of item - ft/sec^2
g = acceleration of gravity - ft/sec^2

S_a = Average crushing stress of energy dissipater lbs/sq. ft.

Obviously, this equation is used to determine the area of energy dissipater necessary to decelerate a given item a given amount. Further, this equation shows that the dissipater area is the factor that is most significant in controlling the deceleration of an item. As long as the dissipater crushes, but does not bottom; impact velocity, drop hieght, or dissipater thickness have no effect on the deceleration of the item. Normally, impact terrain has little effect on the deceleration of the item and, usually, this effect can be neglected. There then remains the need to determine what thickness of energy dissipater of area A is required to insure that the item is decelerated to zero vertical velocity without bottoming the energy dissipater.

The deceleration distance of the item can be obtained by equating the work done by the energy dissipater to the change in kinetic and potential energy during crushing. This yields the following equations:

$$S_a As = 1/2 \frac{W}{g} V^2 + Ws$$

Substituting from Eq (1) and solving for s:

$$s = \frac{V^2}{2gG} \qquad (2)$$

where s = Deceleration distance - ft.

V = Impact velocity - ft. per sec.

The thickness of energy dissipater required to provide this distance without bottoming is calculated from the following equation:

$$t = \frac{s}{E} \qquad (3)$$

where t = dissipater thickness - ft.

E = Maximum strain - expressed as a fraction

Combining equations (2) and (3) results in the following equation:

$$t = \frac{V^2}{2gGE} \qquad (4)$$

The area equation, (1), and the thickness equation, (4), form the basis for the design of energy dissipater configurations.

These equations are most easily applied in the design of energy dissipater configurations for items which can be considered homogeneous and are uniformly supported by the energy dissipater. Such Army items as rations, ammunition, and liquids in drums, rigged in the usual manner for airdrop (see Figures 4 & 5), fall within this category and the configurations as designed are quite successful.

The main difficulty in the application of these equations arises in determining the value of G that an item can withstand. In the airdrop field, the symbol G when it is used to describe the inherent strength of an item has been identified by a variety of names such as shock rating, fragility factor, or damage susceptibility factor. All of these terms imply that the ability of an item to withstand an impact can be described by a single number. As will be shown later, this concept oversimplifies the problem but it does present a convenient tool for considering airdrop impacts.

The U. S. Army's main use for energy dissipaters in airdrop is for the protection of large, complex, built-up structural items such as trucks, howitzers and tank-like vehicles. The energy dissipater configurations for such structures are characterized by a number of small stacks of energy dissipater positioned at various locations beneath the item and between the item and a platform. An energy dissipater configuration for a typical U. S. Army vehicle is shown in Figure 6. (See Reference 2) A sketch of the same configuration with the vehicle removed is shown in Figure 7. (See Reference 2) Configurations of this type make it unrealistic to specify a single value of G which describes vehicle strength. In the case of the homogeneous item that is uniformly supported, deceleration at too high a value of G would most likely result in a simple compressive failure of the item.

However, for vehicles, the energy dissipater stacks can be positioned at an infinite combination of locations beneath the item. Since each configuration will introduce the applied forces in a different manner, structural failures of various types can occur at many locations. Thus the item can have a number of different values for the factor, G, describing its inherent strength depending on the dissipater configuration. Presently, there are no suitable analytical techniques for determining a value of G even for the rather simple items such as rations, ammunition, and liquids. Since G is shown here to be a rather nebulous number, or numbers, a purely analytical application of the area and thickness equations is not possible. At this point, testing techniques must be used to supplement the analysis in order to arrive at a useable energy dissipater configuration.

In the past, consideration has been given to a variety of testing machines that could be used to determine some significant parameters of the items or to subject the items to a duplication of the impact environment. Because of the inadequacies of the analytical work conducted to date, measurement of item parameters such as static strength, natural frequencies, etc., is not useful since these values cannot be correlated to any impact damage criterion. Thus, it appears that duplication of the impact environment is now probably the best way to determine a value of G. It has been found that in light of the range of item weights and impact velocities of interest to the Army, the cheapest, most reliable, and most imitative method of duplicating an airdrop impact without actually airdropping the item is to free-fall the item from a height calculated to produce the desired impact velocity and to use paper honeycomb in its energy dissipater configuration to produce the applied forces on the item.

III. Energy Dissipater Configurations for Rigid Bodies

For items that can be consiered rigid bodies, the energy dissipater configuration can be obtained through either of the following procedures depending upon whether the item is rigged one unit high such as the 55-gallon drums in Figure 5 or stacked in layers such as the boxes of rations shown in Figure 4:

a. For single-layer items:

(1) Choose a low value of G

(2) Calculate the required area and thickness of paper honeycomb based on chosen value of G.

(3) If the calculated area is much smaller than the base area of the item, a suitable load spreader should be used to preclude bending of the item. In airdrop practice, if an item is undamaged when subjected to the accelerations produced by having the area of the honeycomb equal or just slightly larger than the item's base area, no further increase in honeycomb area and thus G level is tested as long as the thickness of honeycomb required at that G level is not unreasonable. For instance, in Figure 5, the area of honeycomb shown is not necessarily producing the maximum deceleration that the drums can withstand. However, at the G level that the honeycomb is producing, the thickness of honeycomb required is quite reasonable and forms a stable energy dissipater configuration. A further increase in honeycomb area would serve only to reduce the required thickness of dissipater at the expense of a larger, heavier load spreader to insure crushing of the entire area and would result in a less efficient utilization of the aircraft floor space.

(4) Rig the item and drop from the necessary height to produce desired impact velocity.

(5) If the item is undamaged, choose a higher value of G and repeat the testing procedure until damage occurs.

(6) If damage occurs after a number of drop tests, it would be well to test again at the damaging G level with a new item to negate any effects due to the repeated impacts.

b. In multi-layered items, the testing procedure is modified to duplicate the forces acting on the item in the bottom layer which is the most severely loaded item. This can be accomplished by simply placing ballast on the test item equal to the weight supported by the item and conducting the remainder of the test as described for the single-layer items.

IV. Energy Dissipater Configurations for Flexible Bodies

For items that are considered to be single flexible bodies, that is, bodies that are not continuously supported by the energy dissipater and thus are allowed to bend, the determination of the energy dissipater configuration becomes somewhat complicated. The practical objective in determining dissipater configurations is to arrive at the minimum number of dissipater stacks necessary to decelerate the item with no bending failure and preferably with a minimum of elastic bending. With this in mind the following procedure is used:

(1) Choose an arbitrary low value of G (between 7 and 10 G's is reasonable for typical Army Vehicles and equipment).

(2) Based on this value of G and the total weight of the item, calculate the total area of paper honeycomb required.

(3) Arbitrarily select a number of locations on the item where the individual small dissipater stacks are to be positioned. (Intuition and experience show that the locations should be near or at large dense components of the item such as near or at the engine, transmission, or differential housing of a vehicle. Also stacks can be placed beneath the main structural members of the item.

(4) From a knowledge of the weight distribution of the item, calculate the weight supported by each energy dissipater stack.

Often the exact weight distribution is not known and is not available. In this case estimates of the weights of the major components of the item and the assumption that all other weight is uniformly distributed will suffice for the first trial.

(5) Calculate the area required for each stack that will produce the same acceleration at each point (most logically the original value of G chosen).

The reason for calculating the total area initially when it isn't used in the calculations is to provide the designer with a feel for the amount of energy dissipater that will have to be distributed among a number of stacks. This feel will allow the designer to better estimate the number of stacks he can use without having intolerably large or small stack areas.

(6) Calculate the energy dissipater thickness required.

(7) Rig the item and subject it to the impact.

(8) Inspect the item and the energy dissipater after impact. This inspection can provide much information. Bottoming of a stack indicates that the weight supported by the stack at this point was underestimated and the resulting acceleration which was quite low required a longer crushing stroke. Incomplete crushing of a stack indicates that the weight supported by the stack was overestimated and the resulting acceleration was quite high or the impact energy was absorbed wholly or partially by the structure of the item. Care must be taken at this point to understand that the height of the stacks is only an indication of the maximum strain to which the energy dissipater was subjected. As can be seen in Figure 2, paper honeycomb which is dynamically strained to 70 percent returns to approximately 50 percent strain after impact. Permanent

deformation of the item indicates that the accelerations at the various stacks were different enough so that the relative motion between portions of the item was great enough to exceed the elastic limit of the structure or if the acceleration of the item was uniform, that the deformation of the structure due to the inertia loads was too great. In the first case, appropriate changes in the stack areas to insure an approximately uniform acceleration at each stack are necessary. In the second case, either the overall G level must be reduced or additional stacks inserted at appropriate locations to insure elastic deformations only.

In the initial determination of the locations of the dissipater stacks, a helpful aid in precluding bending failure of the main structural members of an item is to conduct a static load analysis of the item structure based on the dynamic forces exerted on it during the impact. The applied loads will be the weights of the item's major components and the distributed weights each times (G + 1). The reactions will be the average forces exerted by the energy dissipater stacks while crushing. The bending moments and the bending stresses throughout the item structure are then calculated. Although the numerical values of the moments and stresses so calculated will not be too meaningful, the occurrence of a relatively large bending stress at one point will indicate that the point will probably be the first location of a failure in the structural members. To carry the analysis one step further, if the first solution does indicate a point or points on the structure where the bending stresses are relatively high, the locations of the reaction forces (the energy dissipater stacks) should be changed until the bending stress peaks and valleys have been smoothened out as much as practical.

This method is useful because it has been found through extensive drop testing of Army equipment that structural failure often seems to occur because of an excessive aperiodic displacement of the structure, thus somewhat analagous to a static loading structural failure. Of course, because most of these tests were close duplications of standard operational conditions, many parameters which could influence the type of structural failure were held approximately constant. For instance, since paper honeycomb type energy dissipaters were always used, the shape of the input acceleration pulse did not change markedly during the tests; most of the instrumented tests were conducted at impact velocities between 20 and 30 feet per second; and the duration of the impact pulse was usually between 20 and 100 milliseconds. Thus, all of the Army's experience has been in a regime as partially defined above and may not be indicative of results of impacts outside of this regime.

(9) If item is undamaged, choose progressively higher values of G and repeat the tests, shifting, changing, or adding energy dissipater stacks as necessary until a suitable

configuration is established. If the item is damaged, modify the stacks as necessary and repeat at the same G level until successful.

V. Energy Dissipater Configurations for Multiple Flexible Bodies

An item is considered to be composed of multiple flexible bodies when it consists of identifiable parts that are connected, but are able to move with respect to each other an amount that is much greater than the amount that these parts deform in themselves during impact. Therefore, in essence, the determination of whether an item is a single flexible body or is composed of multiple flexible bodies depends on the amount of coupling between the parts of an item. An item consisting of tightly coupled parts is considered to be a single flexible body; an item consisting of loosely coupled parts is considered to be composed of multiple flexible bodies. Thus a vehicle with its wheel-axle combinations, which in themselves are flexible, that are loosely coupled through the suspension system to a flexible frame is considered to be composed of multiple flexible bodies.

In this case, the procedure for the design of the energy dissipater configuration is essentially the same as for the single flexible body case. An additional consideration, however, is that each of the flexible bodies can have a different inherent strength and thus each could be accelerated at a different G level. This permits some alternate methods of designing energy dissipater configurations which, in certain cases, can simplify the configurations.

If, for some reason, it is desired to decelerate all of the bodies at the same G level, the method described for a single flexible body is used for each body. Calculation of the weight supported by each stack must take into account the load transfer through the coupling devices which, in the scope of this paper, usually are springs and dampers. Then, if the calculation or estimate of the weight distribution was accurate, each of the flexible bodies would be decelerated at approximately the same G level and there would be very little relative motion between the flexible bodies.

Alternate designs are based on the non-uniform acceleration of the flexible bodies. Two possibilities arise here. Either the relative motion of the various bodies under different accelerations is small and thus the coupling devices (springs) are not bottomed, i.e., the bodies remain loosely coupled; or the relative motion is large and the springs bottom. Either possibility can be predicted and controlled by choice of the proper dissipater areas and thus the accelerations of each body. Dissipater designs which are based on non-uniform accelerations of the bodies usually require less thickness of energy dissipater than those based on uniform accelerations. This occurs because in the case of the uniformly accelerated bodies, each body must be accelerated at the amount that can be sustained by the weakest body. In the case of non-uniform accelerations, each body is accelerated according to its own inherent strength. Therefore, an item composed of multiple flexible bodies decelerated non-uniformly can be decelerated at a higher average or overall G level than when it is decelerated uniformly. Of course, the higher average G level case requires less dissipater thickness.

Specific steps for the design of energy dissipater configurations for an item composed of multiple flexible bodies which are not uniformly accelerated are as follows:

a. Choose an arbitrary low value of G for each flexible body (in many cases a low value of G for one body may be a very high value of G for another).

b. Based on the chosen values of G and the total weight of each body, calculate the total area of honeycomb required for each body.

c. Arbitrarily select a number of locations on each body where the individual dissipater stacks are to be positioned. (In some cases, one or many of the bodies could be uniformly supported by the energy dissipater stacks.)

d. Calculate the weight supported by each energy dissipater stack.

e. Calculate the area of dissipater required for each stack.

f. Calculate the energy dissipater thickness required. This step can become quite complicated because of the different design accelerations of the bodies and the changing acceleration of each body as the load on the body exerted by the coupling devices varies. In this case, it is often simpler to consider the absorption of the kinetic and potential energy of the item by the paper honeycomb. Basically, the solution would consist of equating the energy absorbed by the paper honeycomb under each of the bodies (which is simply the honeycomb crushing force times the deceleration stroke) to the total energy change of the item. For any given item, some analysis, ingenuity, and knowledge of the characteristics of the coupling devices is required to determine the relative motion of the bodies and the proportion of the total energy that honeycomb under each body absorbs.

g. Inspect the item and the energy dissipater after impact using the criteria described for single flexible bodies.

h. If the item is damaged, modify the stacks as necessary, and repeat the tests at the same G level until successful. If the item is undamaged, choose progressively higher values of G and repeat the tests, modifying the stacks as necessary until a suitable configuration is established.

VI. Instrumentation: In describing the detailed steps to be taken to determine an energy dissipater configuration, it will be noted that the term "inspect the item after impact" was used consistently and no mention was made of any data measurement. It has been found during numerous drop tests of Army vehicles that, except for special cases the use of extensive instrumentation is not too helpful. An example of a special case is where a small item or a small component of a large item has had extensive shock testing in the laboratory, the maximum shock accelerations that can be applied to it are well known, and it is desired to insure that these accelerations are not exceeded during impact. (The question then arises whether the dynamic forces were applied to the item in the laboratory in the same manner as they are applied in the cushioned drop test.) Another case is where the data is required to substantiate or help construct impact damage theory. Consider the following points:

a. The mechanical properties of the energy dissipater are well defined. As long as the honeycomb crushes, the dynamic input forces to the item are known by calculation. Accelerometers placed on the dissipater stacks would merely substantiate the values of the mechanical properties of the dissipater.

b. An accelerometer mounted at a location on the structure of an item will certainly read the acceleration of the structure at that point. However, to the structural designer, the fact that point A on the structure was subject to "X" g's is meaningless. He will not know whether the structure is overstrength or understrength. He does not know what mass is associated with that acceleration so he will not even be able to calculate a force. The designer will want to know, however, if the structure failed or not.

c. The use of strain gages seems desirable. However, the likelihood of a strain gage rosette being located at a point of maximum stress is very small. A prodigious quantity of gages could be mounted so that even though a gage was not located at a maximum stress point, the stress at the critical point could be extrapolated from plots of the readings at other points. There is still the problem of what stress the structure can withstand under the dynamic conditions encountered. The designer still cannot determine whether his structure is overstrength or understrength unless he knows whether the structure failed or not.

d. The measurement of vibrational frequencies has not provided any useable data either. Although much work has been carried out in the past years to determine theories that predict vibrational damage from shock pulses, the results of impact tests of many Army vehicles and equipment conducted at a number of test facilities have indicated no failure of any component due to vibration. All failures were discovered either through visual inspection of the item after impact or through deficiencies in the operation of the item after impact. As stated previously, most failures appeared to be caused by excessive aperiodic deflection of the damaged item. The other failures were caused by mutual collision of adjacent bodies none of which were necessarily deflecting excessively.

Information that is quite useful is that obtained from high-speed motion pictures in the range of 1,000 to 4,000 frames per second. The relative motion between parts of the item during the impact may be observed and correlated with the conclusions obtained from the observation of the crushed dissipater stacks after impact. Sometimes, the nature of the failure of a component can be ascertained. Also, the maximum dynamic strain of each energy dissipater stack can be measured and compared with calculated values or with other stacks.

Until theories are developed that will allow the designer to determine from the data presented him (other than that the structure failed) whether the structure is overstrength, understrength, or satisfactory, the designer has no basis for determining whether or not he should redesign the structure. Also without adequate theories the data gathered from a successful test conducted at "X" g's cannot be used to determine if a test conducted at "X plus delta" g's will cause structural failure.

It is well known that there are a number of researchers studying this problem, and it appears to be only a matter of time before the sought after theories will be available.

VII. Rebound Energy

An important property of an energy dissipater is its plasticity, that is, its lack of resiliency. The resiliency of a practical energy dissipater must be low enough to preclude damage to an item occurring from secondary impacts of the protected surface and to prevent overturning which would result in impacts of unprotected surfaces. Quantitatively, resilience is defined as the ratio in percent of the rebound energy to the absorbed energy. Figure 8 shows the resilience of standard Army paper honeycomb plotted versus maximum strain.[1] For maximum strains from 40 to 70 percent, the resilience is constant at 8 percent. Above 70 percent maximum strain, the resilience rises rapidly and is double at approximately 85 percent maximum strain. Since most paper honeycomb configurations are designed to be strained to 70 percent or less, it will be assumed for the remainder of this discussion that resilience is a constant. A constant resilience implies that the amount of rebound energy provided by the paper honeycomb is determined by the amount of energy that the item has at impact. Thus, if a given item protected by an energy dissipater impacts at a certain velocity, the rebound energy due to the energy dissipater will be a fixed amount regardless of the thickness or distribution of the energy dissipater. The effect of the rebound energy can be determined by equating the rebound energy to the change in potential energy of the item as it bounces upward. Thus:

$$.08\ (1/2\ mV^2 + Ws) = Wh$$

where h = height of rebound - ft.

$$h = \frac{.08V^2}{2g}\ (1 + 1/G)$$

This equation shows that rebound height is primarily a function of impact velocity and is independent of item weight.

In the range of G's that are encountered in typical airdrop operations, the calculated height of rebound due to the energy dissipater does not present much of a problem at impact velocities of 20 to 30 feet per second. However, at impact velocities of 80 feet per second and up, which are encountered in special cases of airdrop operations, the calculated rebound heights are quite large, on the order of 10 feet, and would certainly present problems. Fortunately, some unpublished data from University of Texas tests show that the actual rebound height is never as high as calculated and that as the impact velocity increases, the ratio of actual rebound height to calculated rebound height decreases. In the range of impact velocities from 20 to 30 feet per second, the actual and calculated rebound heights were not too different. However, at 80 feet per second, the actual height of rebound was as low as half of the calculated heights. The difference in heights can probably be attributed to the random use of the rebound energy such as rotating the item or imparting some horizontal motion to the item.

A second source of rebound energy is the item itself. It's quite obvious that while the energy dissipater is crushing, all parts of the structure being decelerated are deforming also. If the energy dissipater configuration has been designed satisfactorily, none of the parts will yield or fail. Thus all of the structural deformations will be elastic deformations, and therefore, an efficient source of rebound energy. No analytical methods are available to quantitatively determine the amount of energy absorbed elastically by the item and returned as rebound energy. A limited amount of data obtained from tests conducted at the University of Texas show that as the energy dissipater G level increases the item absorbs more and more of the impact energy and the energy dissipater less and less.[3] A point is eventually reached where the force required to crush the very large area of energy dissipater is so great that the item deforms sufficiently, either elastically or plastically, to absorb all of the impact energy without crushing the paper honeycomb. Since the derivation of the thickness equation (equation 4) is based on the assumption that the item being decelerated absorbs none of the impact energy, it can be seen that solution of this equation yields the maximum required thickness of energy dissipater. In practice, absorption of some of the impact energy through means other than the energy dissipater such as item flexibility, impact surface flexibility, etc., will cause less than the maximum required thickness of energy dissipater to be necessary. Figure 9 shows a typical decrease in the amount of actual crushing of an energy dissipater configuration compared to the calculated amount as the design G's are increased.

VIII. Practical Considerations

The preceding discussions of the design of energy dissipater configurations have stressed heavily the need for drop tests closely duplicating airdrop impacts. In preparing for and conducting these drop tests, there are a number of practical considerations that should be taken into account for maximum effectiveness of the configuration. Some of these considerations derived through first-hand experience in conducting drop tests and which may be no more than rules of thumb will be described.

An important consideration while initially determining the area and thickness of the energy dissipater stacks is the aspect ratio of the stacks. The aspect ratio of an energy dissipater stack is defined as the ratio of the thickness of the stack to the length of the shortest side. This ratio is an indication of the stability of the stack, that is, the ability of the stack to resist toppling when transverse motions are imparted to the stack or to resist column failure under compressive loads. No experimental data on the effect of aspect ratio on stack stability is available; however, experience has shown that little difficulty is encountered when the aspect ratio is not much higher than a value of one. Of course, some variance from this value will be necessary in special situations. In many instances, dodges must be used to circumvent the equation mathematics which sometimes dictate the use of high aspect ratio stacks. The most effective dodge is to use a paper honeycomb of lower average crushing stress which would allow a larger area (thus longer sides) of the dissipater without increasing the force level. At present, the Army is using only one type of paper honeycomb for obvious reasons of logistics and thus this method is not available to it. Another dodge, is, if possible, to combine adjacent stacks to form one stack of a larger area. Other methods which are limited in number only by the ingenuity of the designer consist of changing the planform of the stack. The objective is to increase the length of the sides of the stack while retaining the same total area. This can be accomplished by using more complex shapes for the stacks such as hollow squares and rectangles, or gluing a number of small spaced unstable stacks to load spreaders top and bottom to form a stable sandwich construction.

Another consideration to be taken into account is the use of build-up stacks. In the situation where the required thickness has been determined either analytically or experimentally and it is found that this thickness is less than the distance between the particular portion of the structure that it is to support and the platform, built-up stacks are used to fill the void. Their use can be seen in Figure 7. When build-up stacks are used, they are usually of larger area than the stacks to be crushed and are of stable proportions. Thus their use helps reduce the problem of too high an aspect ratio.

The final consideration to be discussed is the use of load spreaders. Often, that part of a structure that is in contact with an energy dissipater stack has a smaller area than the area of the stack. This presents the problem that although the stack area has been carefully chosen to provide a given force level, the structure will crush only a portion of the dissipater area and the desired force and acceleration will not be achieved. The solution to this problem has been to insert a load spreader with an area equal to the stack area between the structure and the stack. The load spreaders are generally made of sheets of plywood of sufficient thickness to preclude failure in bending upon impact. Presently the thickness is determined by trial and error during the conduct of the impact tests to determine dissipater area and thickness. It is possible to analytically determine the required thickness of the load spreader by the use of standard static stress analysis methods. The solution would require the analysis of a flat plate uniformly supported on its bottom surface with its top surface loaded according to the nature of the contact surface of the structure. This static analysis of the dynamic loading will probably be conservative and will result in a load spreader thickness greater than physically necessary. It does, however, provide a good beginning for a small number of trial and error tests to determine the minimum load spreader thickness.

In special cases, load spreaders can be built up using beams and sheets to match complex contours of the structures. Even in these cases, wooden load spreaders are preferred for a number of reasons. One, wooden load spreaders used in this one time application are expandable; two, they are easily fabricated even into complex shapes; three, they are easily glued to the paper honeycomb to form a good secure stack; and four, they locally deform easily and preclude stress concentrations due to irregularities of the structure.

IX Summary

In summary, there are two basic analytical tools for the design of energy dissipater configurations for airdrop. These tools are the equations for the calculation of the required area and maximum thickness of the energy dissipater. The area equation is used to calculate the area required to produce a given G level. The thickness equation is used to calculate the maximum required thickness necessary for the energy dissipater to decelerate the item to zero velocity without the dissipater bottoming. The actual thickness crushed is usually less than calculated because some of the impact energy destined to be absorbed by the paper honeycomb is absorbed elsewhere. The application of the equations in practical problems is hindered by the lack of analytical techniques to determine the inherent strength of an item and therefore a means for choosing a value of G for insertion in the equations. Drop testing, wherein the impact velocity and energy dissipater configuration are duplicated, must be used in conjunction with the equations to achieve successful configurations. The actual procedure for the drop testing is varied depending on the complexity of the structure of the item. Instructions are included in the text for the drop testing of an item that may be considered to be:

a. a single rigid body
b. a single flexible body
c. multiple flexible bodies

The use of instrumentation in these tests is limited for the data obtained is not too helpful. There are no analyses for the data to be compared with nor are there any analytical methods which would use the data to predict results under different test conditions. The tests are primarily a succession of go-no go tests until either a suitable energy dissipater configuration has been achieved or the item fails.

A consideration of the rebound energy that is available during the impact from a number of sources other than the paper honeycomb indicates that the actual thickness of honeycomb crushed is always less than calculated from the thickness euqation and, therefore, allows a reduction in the necessary thickness of energy dissipater. The greater the G's exerted by the energy dissipater, the more energy is absorbed by the item, and the less the thickness of energy dissipater crushed.

Finally there are a number of practical considerations that must be used in performing the drop tests.

The aspect ratio of the dissipater stacks should not be much greater than a value of one for stack stability; build-up stacks are used to increase the stability of the stacks while filling the voids between item and platform; and load spreaders, usually fabricated from plywood, are used to insure that the entire area of the energy dissipater stacks is crushed.

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2. Covingtor, Clarke, and Richard Shield, Fragility Studies, Part II, Cargo Truck, M37, 3/4-Ton, Structural Mechanics Research Laboratory, The University of Texas, Austin, April 12, 1960.

3. Shield, Richard, and Clarke Covington, Fragility Studies, Part V, Water Tank Trailer, XM107E2, 1 1/2-Ton, Structural Mechanics Research Laboratory, The University of Texas, Austin, September 1960.

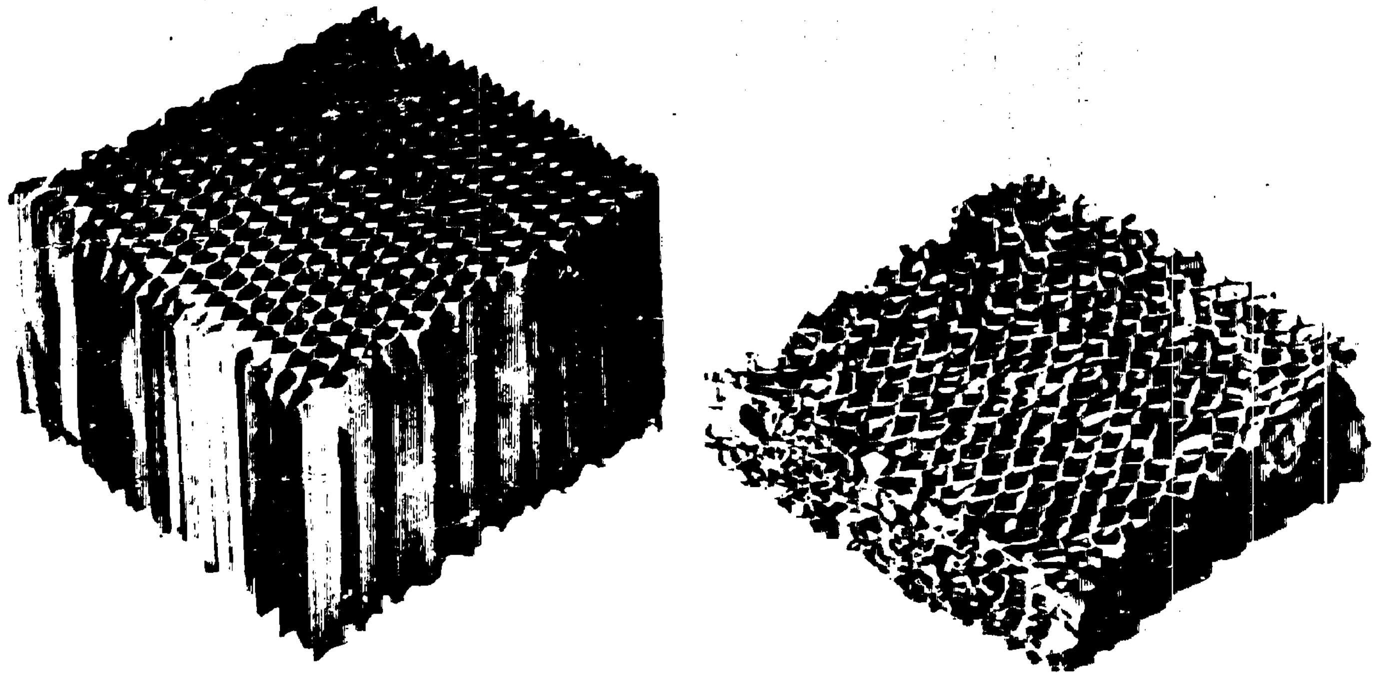

FIG 1. TYPICAL PAPER HONEYCOMB-EXPANDED AND CRUSHED

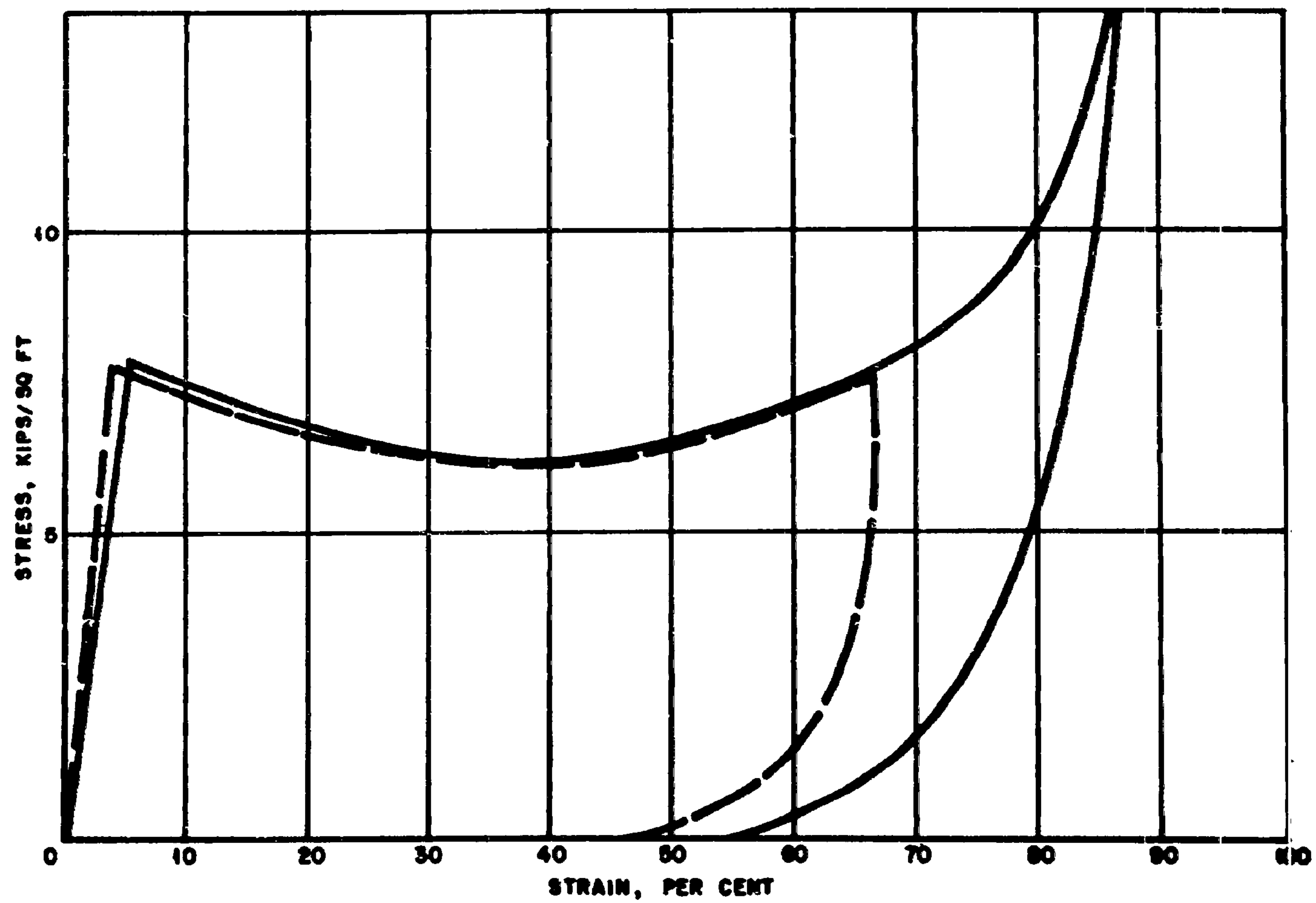

FIG 2. STRESS VS STRAIN FOR 80/0/½ PAPER HONEYCOMB

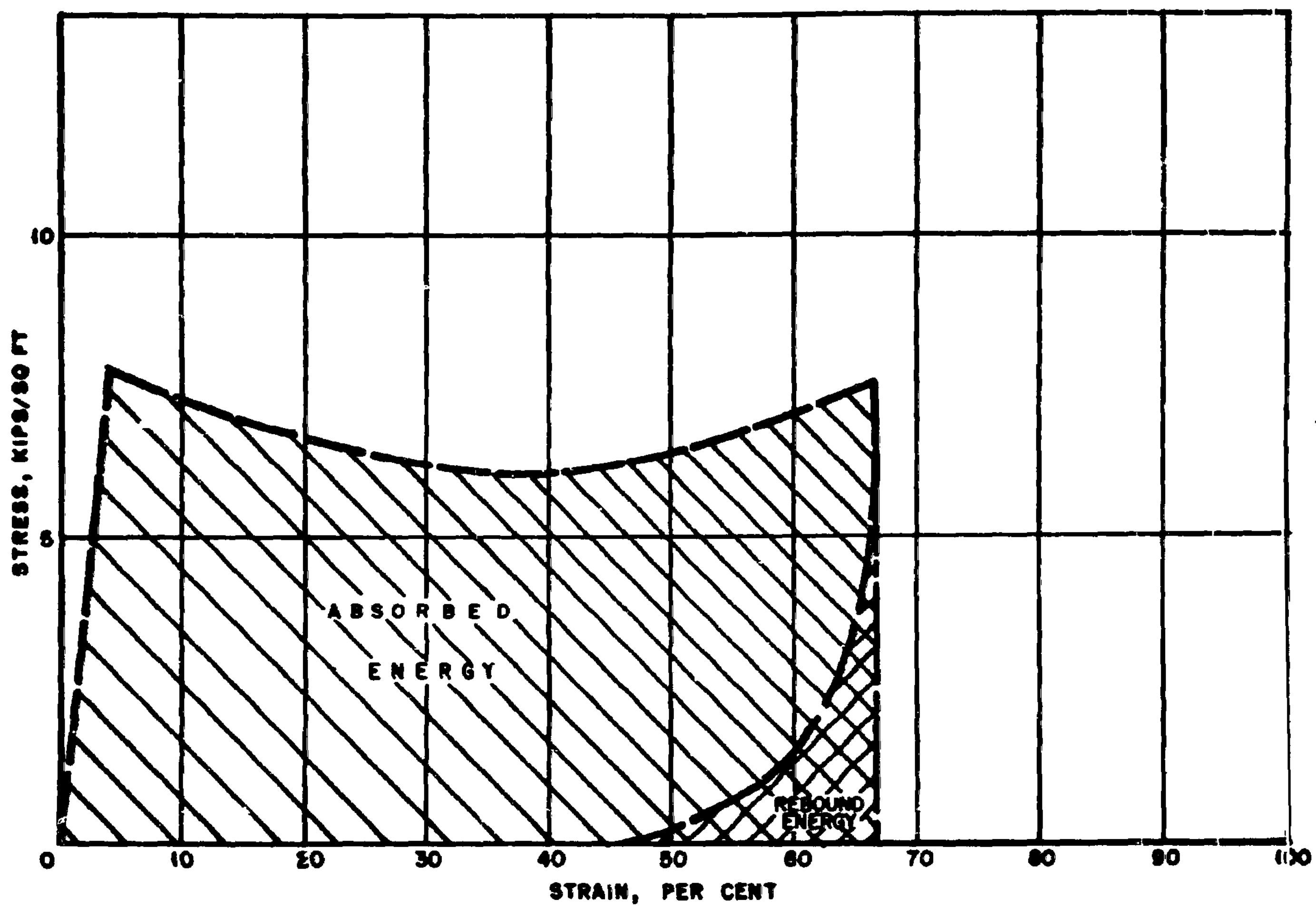

FIG 3. REBOUND ENERGY OF 80/0/½ PAPER HONEYCOMB

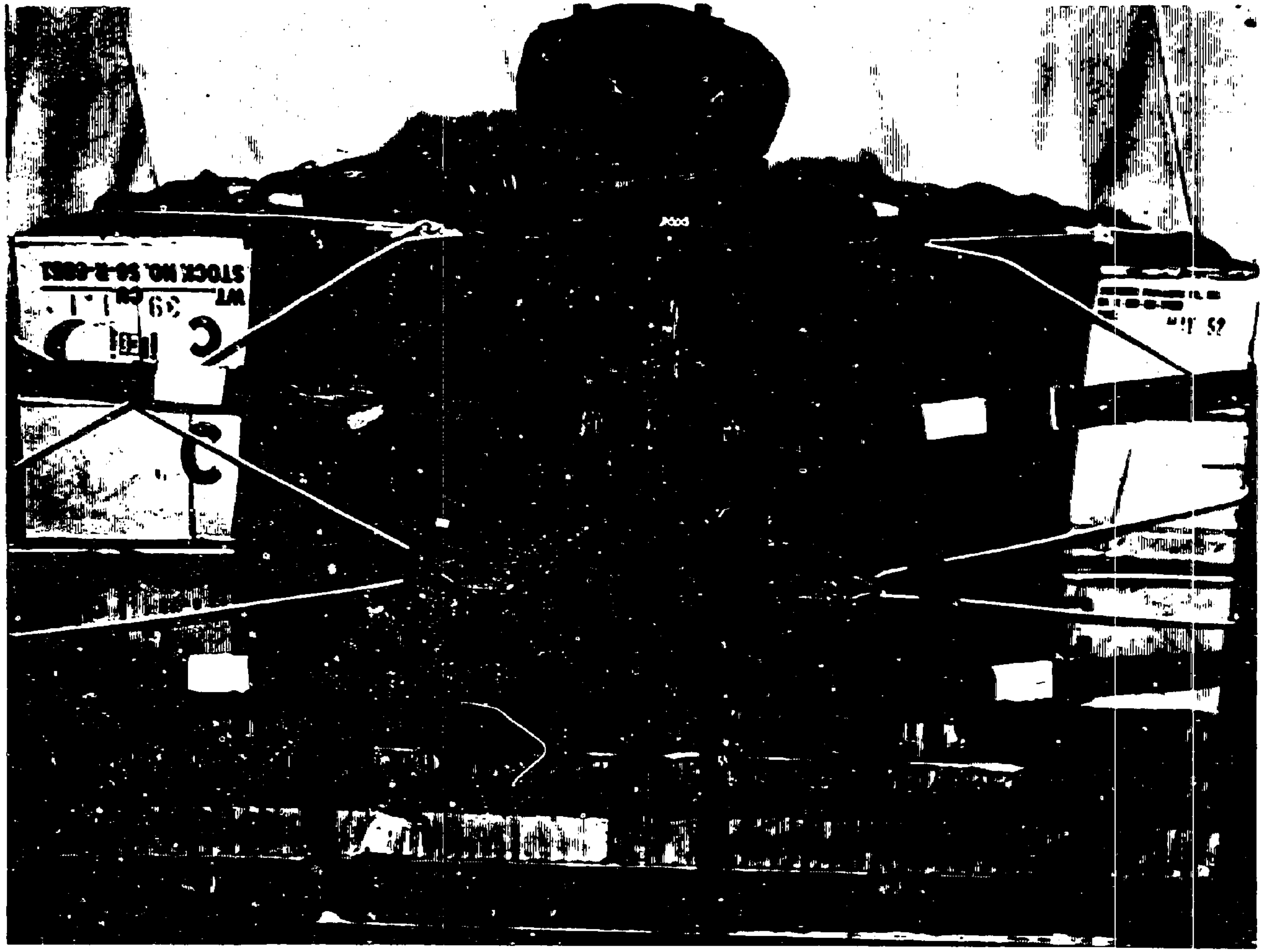

FIG. 4. C-RATIONS RIGGED FOR AIRDROP USING PAPER HONEYCOMB AS ENERGY DISSIPATER

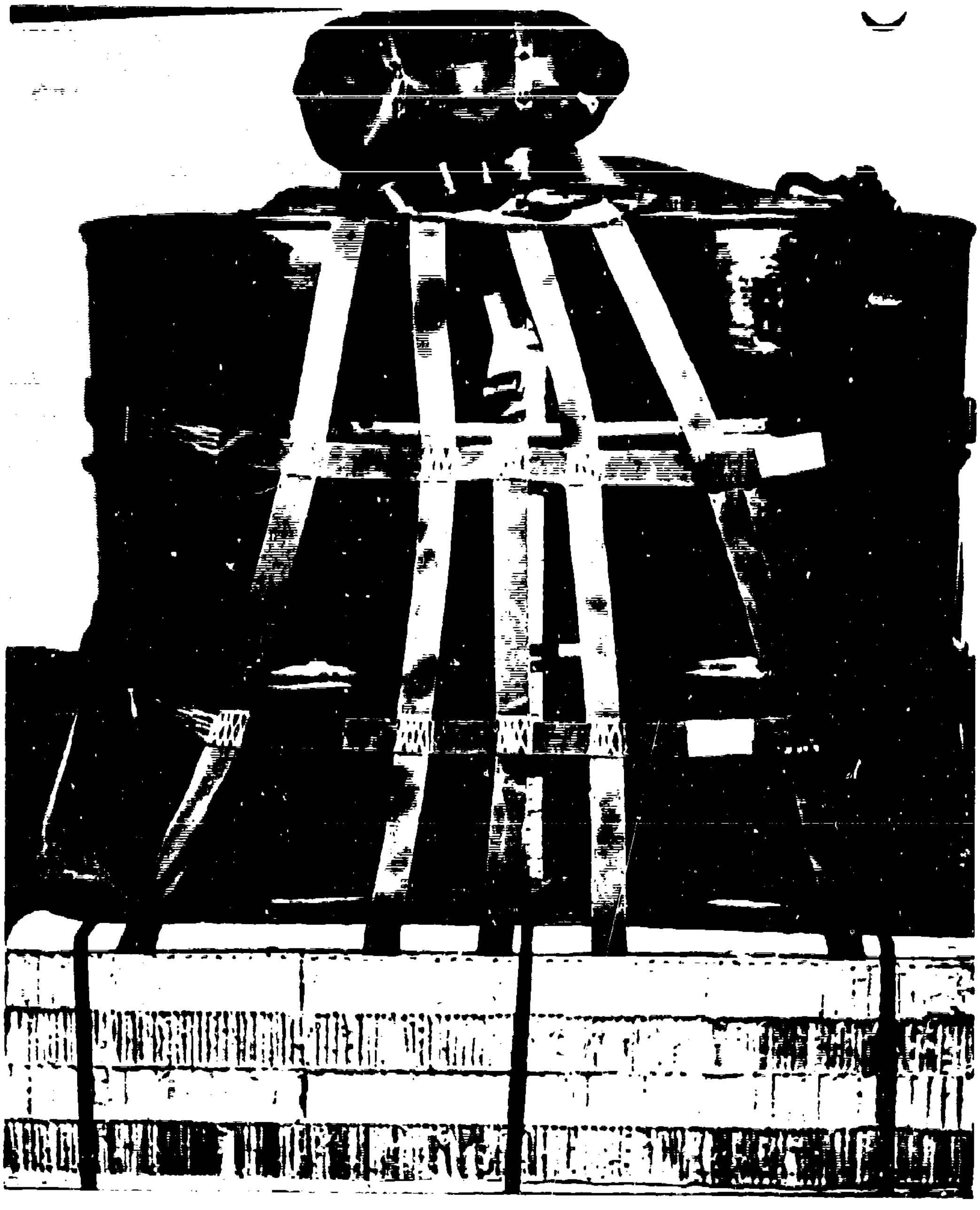

FIG. 5 55-GALLON DRUMS RIGGED FOR AIRDROP USING PAPER HONEYCOMB AS ENERGY DISSIPATER

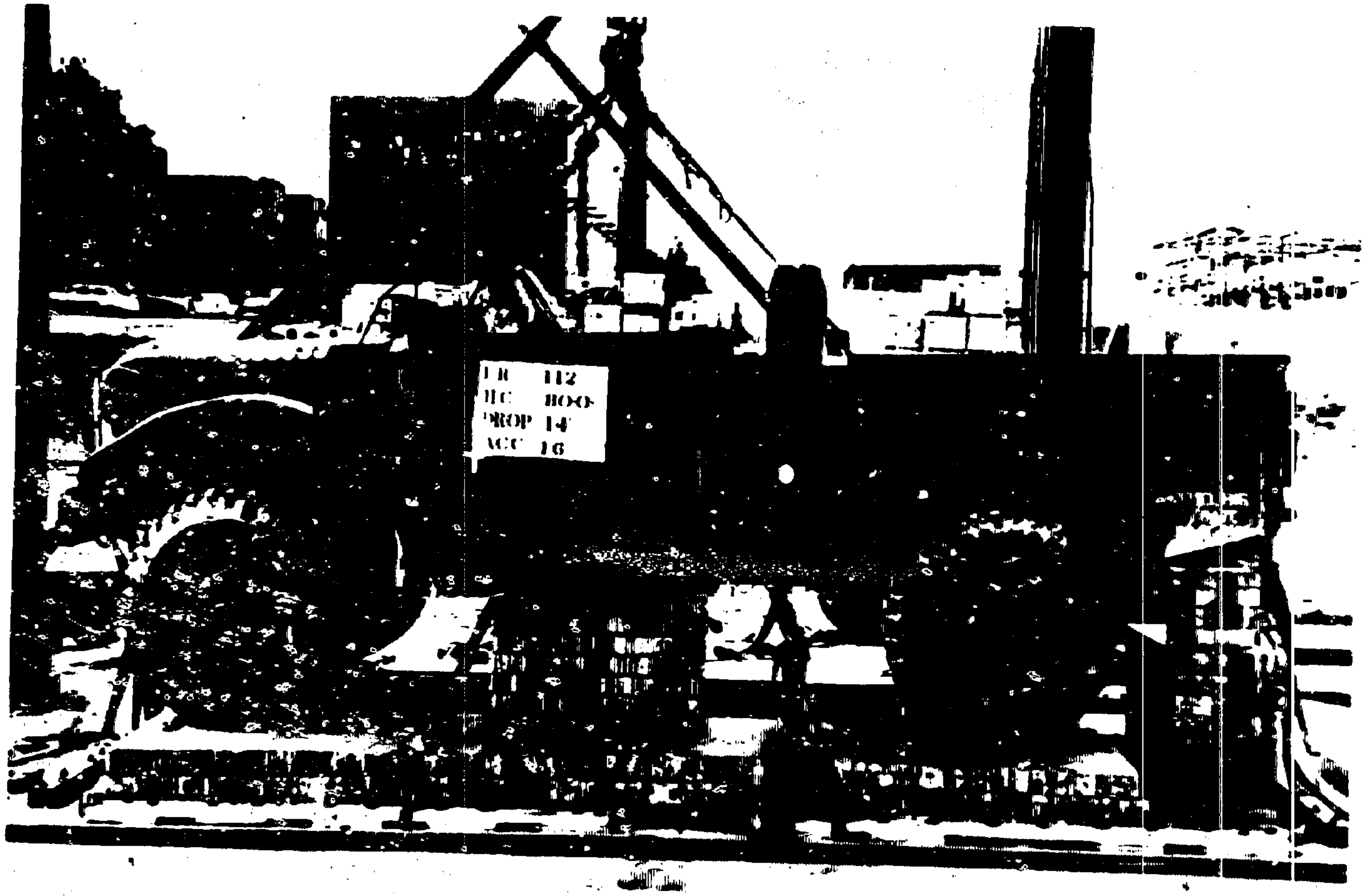

FIG 6. TYPICAL ENERGY DISSIPATER CONFIGURATION FOR STANDARD ARMY VEHICLE

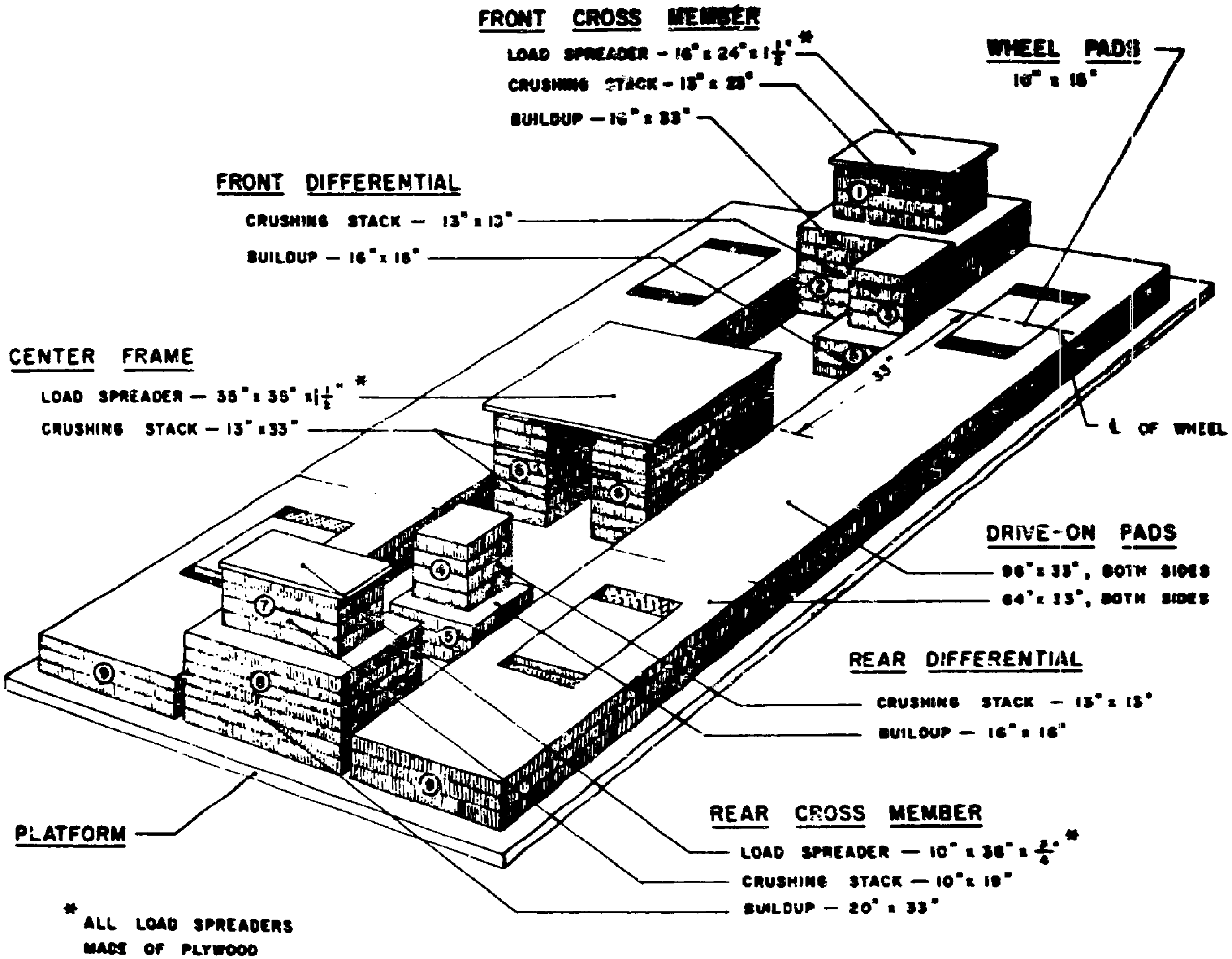

FIG 7. VIEW, WITH VEHICLE REMOVED, OF TYPICAL ENERGY DISSIPATER CONFIGURATION

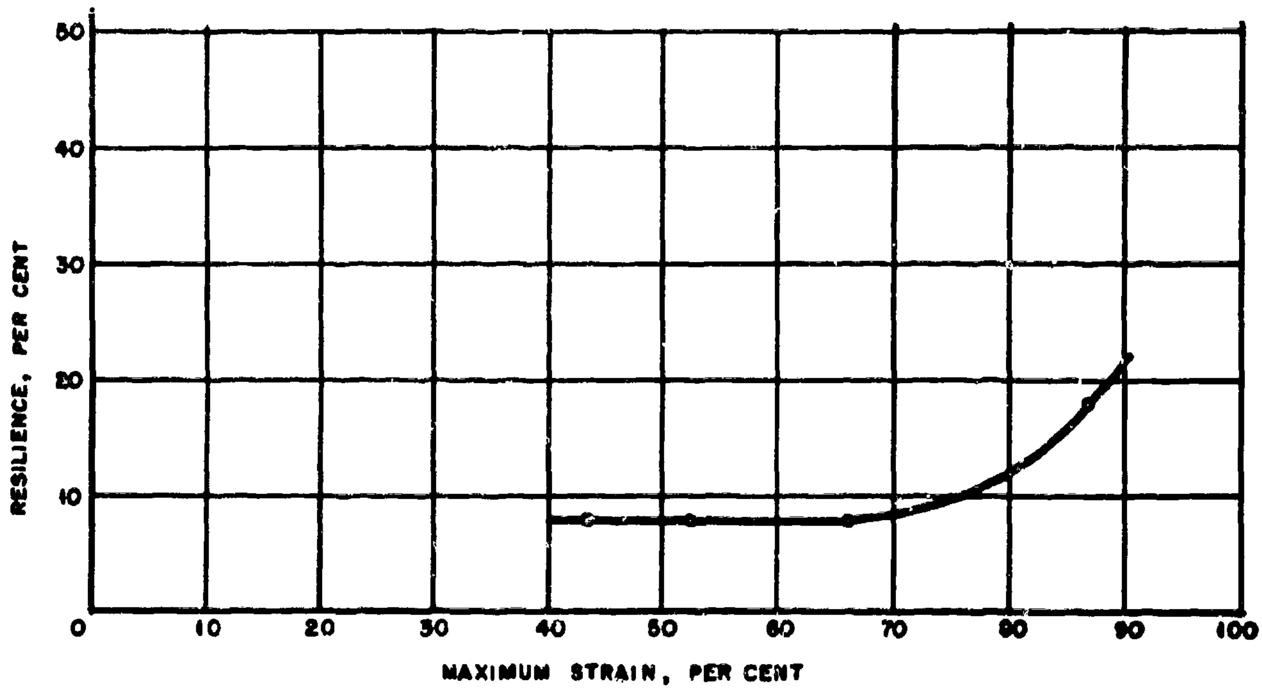

FIG 8. RESILIENCE VS MAXIMUM STRAIN FOR 80/0/½ PAPER HONEYCOMB

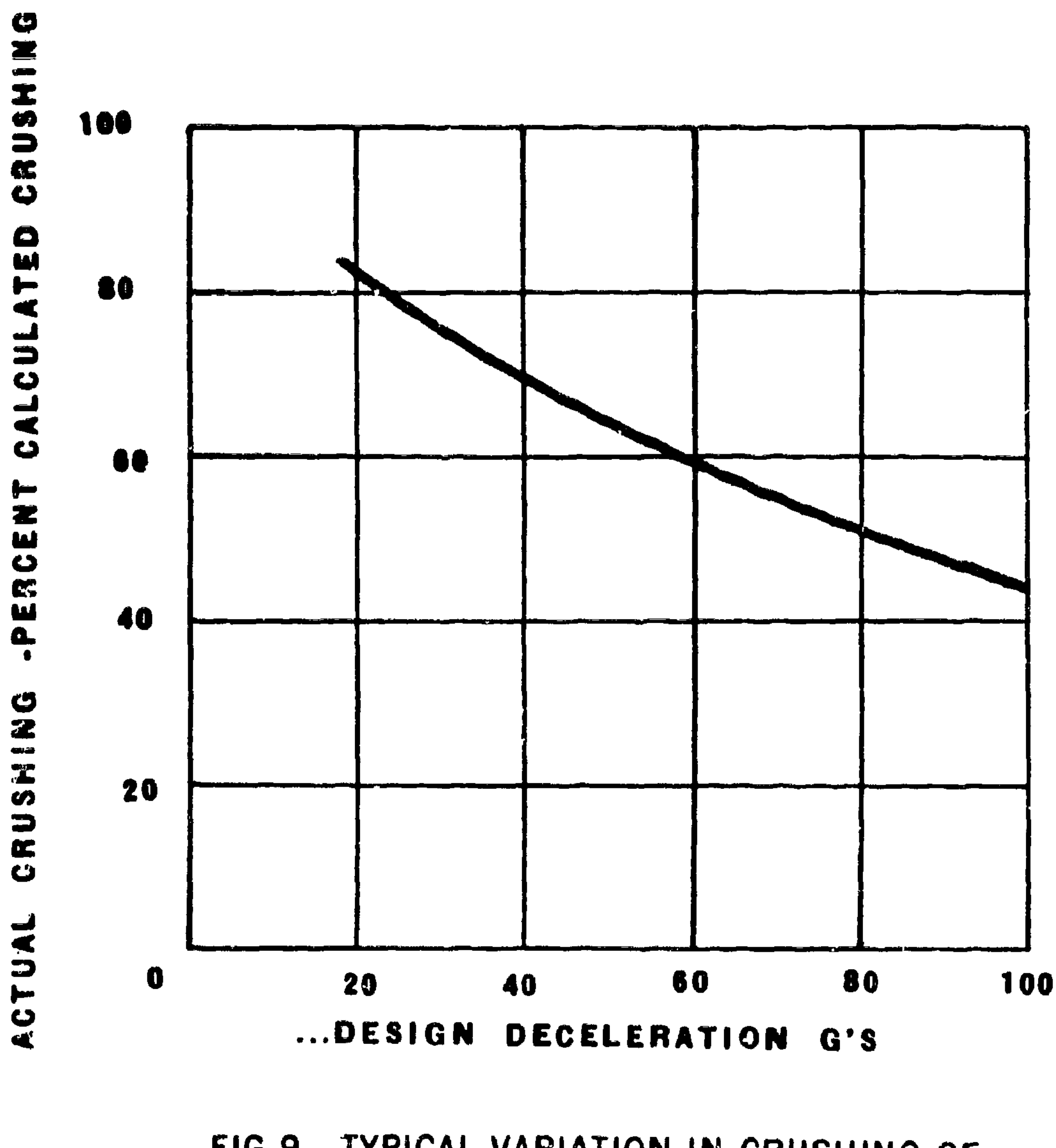

FIG 9. TYPICAL VARIATION IN CRUSHING OF 80/0/½ PAPER HONEYCOMB WITH DESIGN DECELERATION G's

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13. ABSTRACT Complementary analytical and empirical techniques for the design of energy dissipater configurations for airdropped items are presented. The techniques are applicable to the use of single-shot, sheet-type energy dissipater materials which have an essentially rectangular stress-strain curve for the greatest part of their deformation, such as paper honeycomb, metal honeycombs, and certain foamed plastics.

The analytical portion discusses the design of configurations for three orders of item complexity as follows:

a. A single rigid body
b. A single flexible body
c. Multiple flexible body

The difference between an item assumed to be a single flexible body and an item assumed to be composed of multiple flexible bodies lies in the degree of coupling between the masses.

(continued)

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Use of the analytical methods requires some information which as yet can only be obtained experimentally. The test methods that can be used to obtain this information are described in enough detail so that, together with the analytical methods, the reader will be able to design his own energy dissipater configurations.

The rebound properties of the energy dissipater are considered and the limitations that these properties impose upon the design of the configuration are discussed.

A number of practical considerations such as the aspect ratio of the energy dissipater stack, the use of load spreaders, and the use of build-up stacks which are necessary for the successful use of the energy dissipater in the field are presented.