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SYSTEMS FOR RAPID PREPARATION OF AIRDROP LOADS

W. L. Black, et al

AAI Corporation

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TECHNICAL REPORT

72-79-AD

SYSTEMS FOR RAPID PREPARATION OF AIRDROP LOADS

by

W. L. Black

and

A. L. Farinacci

AAI Corporation

Baltimore, Maryland

Contract No. DAAG 17-70-C-0174

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July 1972

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Airdrop Engineering Laboratory

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13. ABSTRACT

A study was conducted to develop new concepts and procedures for the airdrop of supplies and equipment which would significantly reduce the time and labor required to prepare airdrop loads for airdrop and retrieve them after the drop. A goal of equal importance is the reduction of airdrop malfunctions caused by improper rigging. Study of current rigging designs and procedures identified the tasks that were the most time consuming and the operations that contributed the higher rates of malfunctions. Thirty-two (32) concepts for equipment and procedures were developed which were judged to have sufficient merit to warrant consideration in the search for a system solution. Some concepts address particular aspects of the problem and diminish in value when evaluated from a system viewpoint. Five system concepts were formulated and analyzed in detail. An appraisal is made of their feasibility and an evaluation is performed by a scheme that produces figures of merit whereby the concepts may be compared with each other and with the current system.

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AIRDROP ENGINEERING LABORATORY
US ARMY NATICK LABORATORIES
NATICK, MASSACHUSETTS

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FOREWORD

This program was conducted by the AAI Corporation, Cockeysville, Maryland for the Airdrop Engineering Laboratory, U. S. Army Natick Laboratories, Natick, Massachusetts under Contract DAAG17-70-C-0174. The program was concerned with the development of new ideas and concepts for equipment and procedures which would significantly improve the efficiency of preparing airdrop loads for airdrop and retrieving and conditioning the equipment for use following the airdrop. The study concentrated primarily on the development of concepts to achieve the goals, appraisal of their feasibility and a comparative evaluation of their merit. Several concepts were evolved that are recommended for further consideration.

The program was performed under the direction of James F. Falcone of Natick Laboratories. The project was managed at the AAI Corporation by W. L. Black under the supervision of R. G. Strickland, Department Manager. The principal investigators were B. W. Jezek, and A. L. Farinacci.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

LIST OF TABLES

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I. INTRODUCTION

This report is a summary of the work performed on Contract DAAG17-70-C-0174, a study of systems for the rapid preparation and derigging of airdrop loads. The major goal of the program was to find ways to improve equipment and procedures for accomplishing the airdrop of supplies and equipment so that the time required to prepare airdrop loads and retrieve them after the drop can be significantly reduced. The effort concentrated primarily on the generation of new concepts that, after a period of development, would result in the fulfillment of this goal. Solutions providing major benefits and requiring possibly eight to ten years to develop and introduce into practice were sought rather than minor changes that might improve current rigging methods.

The study began with a review of current airdrop loads preparation practices. This review was helpful in several ways but particularly so in two areas. One, it produced some factual information on the parts of the rigging task that consume the majority of the rigging effort, and two, data was accumulated on the extent that rigging mistakes contribute to the malfunction of an airdrop. The information and understanding acquired in this review aided considerably in the formulation of new concepts.

Thirty-two (32) concepts were conceived during the program which were judged to have sufficient merit to warrant consideration and inclusion in this report. As the study progressed, certain ideas began to emerge that appeared to have greater merit than others. This led to the formulation of a few system concepts that could provide the rapid rigging capability that is being sought. Five of the more promising concepts are analyzed in detail in the analysis section and a figure of merit that provides a comparative index of the value for each concept has been developed.

II. SYSTEM REQUIREMENTS

A. Specific Contracts Requirements

The purpose of this contract was to formulate methods for airdropping heavy platform type loads which would provide significant reductions in the time and cost required to prepare loads for airdrop and for retrieval after drops. The aim of the study was to develop concepts which would replace the current heavy drop system and be operational in 8 to 10 years. During the course of the program, agreement was reached with the contracting agency that effort would be concentrated on generation of concepts. The original system and contract requirements served as strong guidelines when evaluating the feasibility of the various concepts and are presented in the following section.

1. Certain aspects of the performance shall be upgraded, such as increasing the tolerable horizontal wind velocity from 15 knots to 30 knots, permitting drops from aircraft flying at speeds of 150 to 300 knots, and permitting operation at terrain altitudes from zero to 10,000 feet and higher.

2. Three aircraft, the C-130, C-141 and C-5A shall be investigated to determine the differing characteristics of each that will significantly affect the results of the studies and analyses performed on the system.

3. Single cargo airdrop, intermittent cargo airdrop from a single aircraft and multiple consecutive cargo airdrop from mass formations (30 aircraft) shall be considered.

4. Preparation of a single item for airdrop as well as assembly line rigging of large quantities of equipment shall be considered.

5. Systems necessary to prepare loads for airdrop will be compatible with the present materials handling equipment unless new systems include material handling equipment as part of the system.

6. Rigging systems must be usable for the preparation of all present airdrop platform loads.

7. Systems shall have a quick retrieval capability following the airdrop.

8. Disposal methods for clearing the drop zone of residual materials used in rigging the airloads shall receive careful consideration.

B. Rigging System Design Requirements

The concepts formulated and investigated in this study must incorporate the following design requirements.

1. In-Flight Requirements

a. Load factors on the cargo and system components must be kept below the following values until initiation of the airdrop sequence:

(1)	Forward	4.0 g
(2)	Aft	1.5 g
(3)	Lateral	1.5 g
(4)	Up	2.0 g
(5)	Down	4.5 g

b. Hardware components used for preparing airdrop loads must be designed to comply with the following factor of safety requirements.

(1) Suspension System

Limit Load = 1.5 x suspended weight
Yield Strength = 1.5 x limit load
Ultimate Strength = 1.65 x limit load

(2) Extraction System

Limit Load = 1.5 x gross rigged weight
Yield Strength = 1.5 x limit load
Ultimate Strength:

For loads < 25,000 lb = 1.65 x limit load
For loads > 25,000 lb = 1.75 x limit load

c. The tiedown provisions must be limited to the following values:

Limit Loads (for each tiedown)

For airdrop weight < 5000 lbs. = 5000 lb.
For airdrop weight 5000 - 15,000 lbs. = 10,000 lb.
For airdrop weight > 15,000 lbs. = 20,000 lbs.

Yield Strength $\geq$ limit load

Ultimate Strength = 1.5 x limit load

2. Cargo Requirements

a. Extraction forces applied to the cargo shall not exceed 1.5 times the extracted weight of the cargo.

b. The system(s) shall be usable for unit cargo weights from 2000 to 35,000 pounds on airdrop platforms for the airdrop of all Army material which is now airdroppable. Consideration must be given to the potential application of systems for use with the C-5A aircraft and with increased load weights of 50,000 pounds.

C. Airdrop System Environment

The new rapid load preparation system(s) must perform in the environment described as follows:

1. At aircraft altitudes of 1100 feet above the terrain for loads up to 25,000 pounds and 1500 feet for loads over 25,000 pounds. Also, systems must be compatible for use with special loads airdroppable at all altitudes from zero to 15,000 feet.

2. At aircraft speeds from 110 to 150 knots with consideration of extending the capability to aircraft speeds in the 150-300 knot range.

3. With horizontal impact velocities in ground winds from zero to at least 30 knots.

4. In operations employing single aircraft or mass formations of up to thirty (30) aircraft airdropping single and multiple cargo units.

5. With the fewest possible restrictions on the drop zone characteristics such as size, unobstructed area, flatness, and texture of terrain.

6. With ground impact conditions which results in loading of equipment equivalent to the current system employing nominal cargo vertical impact velocities of 25 feet per second and using paper honeycomb as an energy dissipator.

7. At terrain altitudes between zero and 10,000 feet or higher.

8. At air temperatures between $-65^{\circ}F$ and $125^{\circ}F$ under adverse weather conditions.

9. In operations which employ paratroopers jumping after cargo exit from the same aircraft.

III. DISCUSSION OF PROBLEM AREAS

To achieve maximum mobility the Army has developed a capability of transporting personnel, materiel and equipment by air and airdropping them into the desired combat zone. Not only is initial assault accomplished by airdrop but often supply of the troops is sustained in this manner. This program is concerned with finding ways to improve the efficiency and effectiveness of airdropping these extensive quantities of supplies and equipment. In particular, it is concerned with the tasks of preparing materials and equipment for airdrop delivery, and recovery and conditioning the materiels for use once they have been airdropped at the combat zone.

The capability for accomplishing this type of airdrop delivery is a fairly recent creation, and for this reason, there has been a tendency to improvise solutions for individual problems as they were encountered and procedures have evolved that appear to have been given very little consideration from an overall or systems viewpoint. Some very competent engineering has been invested in some of the individual solutions but from an overall operational standpoint, the effect is far from optimal. To the layman, the appearance of a rigged airdrop load is a total nightmare, and to a considerable extent this is true, because rigging procedures are complex, difficult to learn, and require large amounts of labor and expertise. Because of this complexity and the large amounts of labor involved, human factors have a highly significant effect on the reliability of the system. In particular, reducing the number of components and operations that must be performed will increase overall reliability.

Some problems of current systems are listed and discussed briefly as follows:

1. Range of airdrop items - size, shape, weight, etc.
2. Energy dissipator
3. Tiedown lashings
4. Component weight and bulk
5. Level of skill
6. Retrieval

The range in the types of materiel and equipment that must be airdropped has grown to considerable proportions and apparently as new items came into the airdrop inventory, provisions for handling them were developed on an individual basis. As a result, a considerable range exists in the size, configuration, weight, etc., of the rigged loads that must be prepared for airdrop. To reduce this complex problem somewhat, some work has been done on containerization of materiels as evidenced by the A-7A, A-21 and A-22 cargo bags. However, this approach has not been pursued vigorously, and containerization of loads appears to be a concept that should receive attention in the search for rapid rigging solutions.

Energy dissipation or cushioning of the loads at impact to protect them from physical damage is a major problem. The Army has developed, and extensively uses, crushable paper honeycomb for this purpose. This material, although it has remarkable properties, is the source of significant complexity and labor. The problems associated with paper honeycomb are poor quality control causing large tolerances on the crushing stress, the bulk size causes logistics problems, the adaptability to all field type environments is poor, and the time and complexities involved in rigging and retrieval operations are significant.

An energy dissipator capable of replacing honeycomb must exhibit the following properties:

a. Light-weight
b. As close as possible to a rectangular stress-strain curve, i.e.. the load remains constant but strain continues over a fairly large range. This results in the dissipation of large amounts of energy.
c. Low rebound energy
d. Low cost

The problem of finding a suitable energy dissipator is complicated also by the fact that the loads vary considerably in their structural properties. Rigid loads are not too difficult to accommodate but semi-rigid or flexible loads present a more difficult proposition and multiple flexibile loads are a bona fide headache. Representative of the latter type are the vehicles that must be airdropped. An additional complication is the fact that the damage threshhold, commonly expressed in G's, for various items is quite often not available and must be derived in some manner. The Army resorts to actual drop testing in most instances to derive these data. If a different energy absorption method could be devised where labor is reduced or eliminated through design ingenuity, a giant step toward solution of system problems would be made.

Lashing or securing the loads to airdrop platforms is a complex operation. This must be done in order to restrain the load to the platform during the ground and air-transportation phases as well as during actual airdrop. A series of tiedown straps have been developed for this purpose and their application, in some instances, is quite complicated. Some way to avoid or simplify this operation - again through ingenuity of design - is needed. The present rigging system uses straps, load binders, clevises and tape in the load tiedown rigging activity. This event consumes appreciable time and is an area of high human error. Modification of this activity can result in improved systems performance and reduce rigging time and cost.

The bulk and weight of materials required to airdrop useable goods and equipment are important. These materials take up otherwise useable space and are just as costly to transport as the useable goods themselves; therefore, in the conception and analysis of new concepts, this facet of the problem must receive consideration.

As previously mentioned, current methods of preparing airdrop loads require large amounts of labor. Moreover, since rigging is a highly complex specialized task, it requires skills that can only be acquired through considerable training. This is costly, and also a source of trouble, because the level of training provided usually is just barely adequate. An objective will be that, through design, labor requirements and skills will be reduced to a minimum.

Limited attention has been given to the retrieval problem because it is assumed that a good retrieval capability will often come from a good preparation capability.

Performance Improvements

The primary requirement of this program is to determine a system which will significantly reduce the time and cost for the preparation and retrieval of airdrop loads. Also desired is the improvement of certain aspects of the present airdrop system performance. These improvements are: (1) to increase the tolerable horizontal wind velocity at ground impact from 15 to 30 knots; (2) to permit dropping from an aircraft flying at 150-300 knots; (3) to permit operation at any terrain altitude from zero to 10,000 feet or higher; and (4) to permit the airdrop of special loads at all altitudes up to 15,000 feet.

Each of these items presents additional problems for consideration in designing a system for rapid load preparation and retrieval. Increasing the wind velocity operating limit results in higher cargo horizontal velocities and overturning moments at ground impact. Low altitude airdrops would minimize this effect; however, normal airdrops, in which near steady-state descent is achieved, would be most adversely affected. Not only would the impact be more severe but the descending parachute-cargo system would tend to drift further distances under the 30-knot wind. For example, if steady state were achieved after 700 feet of descent from a release altitude of 1100 feet, the horizontal drift of the cargo would be 812 feet due only to the 30-knot wind. The acceptability of this drift and high horizontal velocity are questionable, and consequently any new concepts should consider means for solution of the problems of landing in high wind situations. The wind drift could cause accuracy problems in areas where the drop zone size is limited, but appears secondary for this particular study.

The application of airdrop systems to high altitude drop zones from 10,000 feet and up causes operational problems. The reduction in air density, 26% for 10,000 feet, causes higher cargo impact velocities which necessitates the addition of decelerators. For the present airdrop system, an additional parachute would be required; however, new parachutes or other systems could be designed with high altitude operation being included as a possible design constraint.

IV. TECHNICAL INVESTIGATIONS

A. Study Methodology

1. General Method of Study

The general goals of this study program were to formulate new concepts of systems which will permit faster and more economical preparation and retrieval of airdrop platform loads, and to provide sufficient evidence to substantiate the feasibility of proposed concepts. The study approach employed is based on techniques of systems analysis. However, rather than a "pure" systems analysis approach, the methods were modified, and increased emphasis was placed on concept generation and system feasibility with less effort devoted to system factors such as task analyses, costs, reliability, human factors, maintainability, etc. This approach was adopted because the resources allotted to the contract did not permit a full system analysis and the identification of feasible concepts is a necessary initial step in the development process. The de-emphasized factors become important after feasible concepts have been established and decisions are being considered on which concept to develop and whether or not the investment of resources is justified.

The methodology used in developing these rapid preparation airdrop system concepts can be divided into the following activities:

- Identify system objectives
- Describe objectives in terms of system functions and constraints
- Develop implementation concepts
- Analyze concepts to measure conformance with system objectives

Much of the work in developing the various concepts was done in "brain storming" type sessions. Contributions of each member of the analysis group served to further the ideas until a relatively complete concept had been formulated. If the concept was deemed to have potential, additional analysis was undertaken. Design engineers produced sketches and layouts so that geometric considerations could be presented more clearly while members of the analytical group evaluated the underlying theory. By the next session the results were ready for further evaluation. If the preliminary analysis revealed increased potential, the study was continued in more detail, if not, the study was stopped or redirected. Often, solutions of problems associated with one system led to ideas for a completely different concept. In addition, the above study technique allowed each member of the group to contribute his special talent while receiving feedback from others that prompted original thinking.

2. Background Studies

The approach to the generation of new concepts was prefaced by a thorough look at current load preparation practices to ascertain both its desirable and undesirable features. This included visits to Fort Lee and Fort Bragg to observe airdrop loads being prepared and discussions of the subject with the experienced and knowledgeable personnel at these bases. Considerable quantities of data on current airdrop experience was acquired and analyzed to determine which operations in the preparation procedure were the most time consuming. Also, a series of malfunction reports were studied to determine the cause of airdrop failures, the aim being that through conceptual design, the failure rate can be materially reduced. The results of this review of current practices is outlined below.

a. Malfunction Analysis

In conducting a malfunctional analysis it may be said that the reliability of the system is being assessed. The subject has been researched and defined under the reliability nomenclature and a short discussion of reliability factors is included to provide an insight as to the attributes looked for in conducting the malfunction analysis. Reliability, per se, although an extremely important factor in the achievement of a successful airdrop system, has not been used in evaluating the different concepts at the conclusion of this report. There is a twofold reason for this. First, in the conceptual phase, complexity is believed to be a more meaningful criterion because the simpler the design the better the opportunities are to make the system function reliably, and second, reliability is greatly dependent upon detail design for it is possible to make the most complex systems reliable with proper attention to its design. In conceptual work, design details are lacking but the complexity of the concept can be evaluated fairly readily, and for these reasons, this criterion has been used in the evaluation scheme rather than reliability.

(1) Reliability Factors

Airdrop system reliability (R_s) in general can be described as a function of two values: mechanical reliability (R_m), and human reliability (R_H). R_m is defined as the probability that no equipment malfunctions with the power to degrade mission success will occur during any phase of an airdrop operation, and R_H is similarly defined as the probability that no degradation of mission success will be caused by human error. If it is assumed that these measures are independent, the following equation holds:

$$R_s = R_m \times R_H$$

For the purposes of this study, this is a suitable working definition of R_S. However, it should be poinced out that these two variables are not always completely independent, as an inappropriate manual operation, such as overstressing a mechanical component, can precipitate an equipment failure.

When the concept of the independence of R_m and R_H is adopted it is assumed that R_m does not begin to affect system reliability until extraction of the load from the aircraft is initiated. At this point, the operator is no longer an integral part of the system, and R_H is not considered a contributor to system reliability until retrieval operations are initiated. While the operator has no control, mission success will be the result of each component performing its proper function at the prescribed time and the values for reliability of the individual elements must be obtained from test data or by analysis. Mechanical reliability in a well designed system is ordinarily very good. Therefore, the goal is to achieve an equally high value of human reliability and, to a very considerable extent, this is a function of the system configuration. For this reason, most of this discussion deals with the human element in the airdrop rigging system and the bulk of the effort will be directed towards the cargo preparation, loading, and retrieval phases.

Human Reliability

As systems have become progressively more complex the problem of Human Reliability (R_H) investigation and quantification has become increasingly important. Many techniques for prediction of R_H have been proposed, but at this time, most of these methods are unwieldy, their cost effectiveness characteristics appear to be unfavorable, and no particular technique is either universally applicable or widely accepted. Consequently, it is necessary to formulate an approach which is tailored to the system under consideration and to justify that approach with respect to the particular system.

Any critical human error (an operator action which contributes to the degradation of system performance) can be classified as either an error of omission or an error of commission. An error of omission is defined as the failure of an operator to perform a specified or require task, while an error of commission can be further broken down to one of the following three categories:

- The incorrect performance of a specified or required task;
- The performance of a task out of the specified or proper sequence:

- o The performance of a task that is not specified or required under the system operational procedures.

Of course, the occurrence of a human error fitting into the above classification scheme need not degrade the human reliability value for a system, since to adversely affect R_H, the error must have some effect on system performance. For example, consider the installation of a tie-down bolt, the specified torque for which is 150 ft-lbs. If the operator torques the bolt to 160 ft-lbs, he has commmitted an error. However, if his action in no way affects system performance, he has not reduced the probability of system success, and his error is considered noncritical.

Another aspect of human error that must be considered is the attribute of reversibility. An error is said to be reversible if it can be detected and negated before system performance is adversely affected. It may be possible for the operator to detect the error himself, particularly if the error consequence interferes with subsequent system operational events, or the error may be detected in the course of test or inspection routines.

Since the reversibility of an error is primarily a function of the design of associated equipment, the system design group should consider the possibilities of introducing mechanical task interferents which operate to prevent task completion when an error has been commited. This approach is generally more rewarding in terms of increased R_H than inspections, because the nature of the inspection process is such that it is susceptible to variations in personnel factors. That is, an inspector can commit a critical error in failing to detect a rigging or assembly error that could affect R_H. Nevertheless, the inspection process is considered an important contributor to error reversibility, and extensive inspections are desirable for new systems.

(2) Functional Analysis

A Functional Activity is defined as a series of manual operations required during assembly, rigging and retrieval of airdrop systems from platform preparation through removal of the payload and rigging components from the drop zone. The Functional Activities that comprise the standard airdrop system can be grouped into five main categories:

Preparation of Components

Rigging of the Load

Aircraft Operations

Dropping of the Load

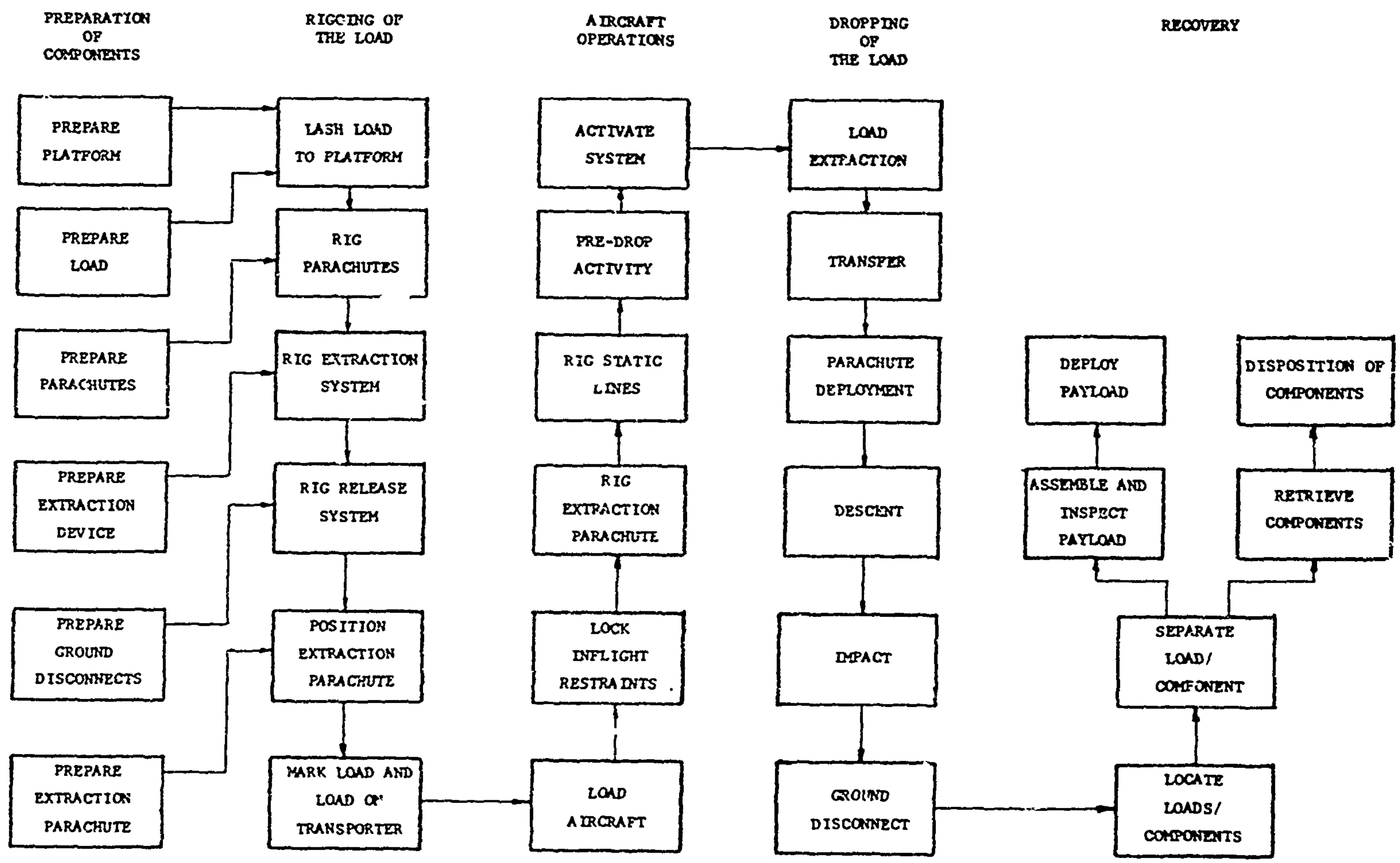
Equipment Recovery

The Functional Activities contained in each of these categories and their sequence of occurrence (where applicable) were defined for the airdrop of the 3/4 ton, 4 x 4 Emergency Repair Shop Truck. (Reference 1) This load is typical of a family of vehicles that are airdroppable and serves as a good example of a functional activity breakdown. The chart shown in Figure 1 illustrates the breakdown.

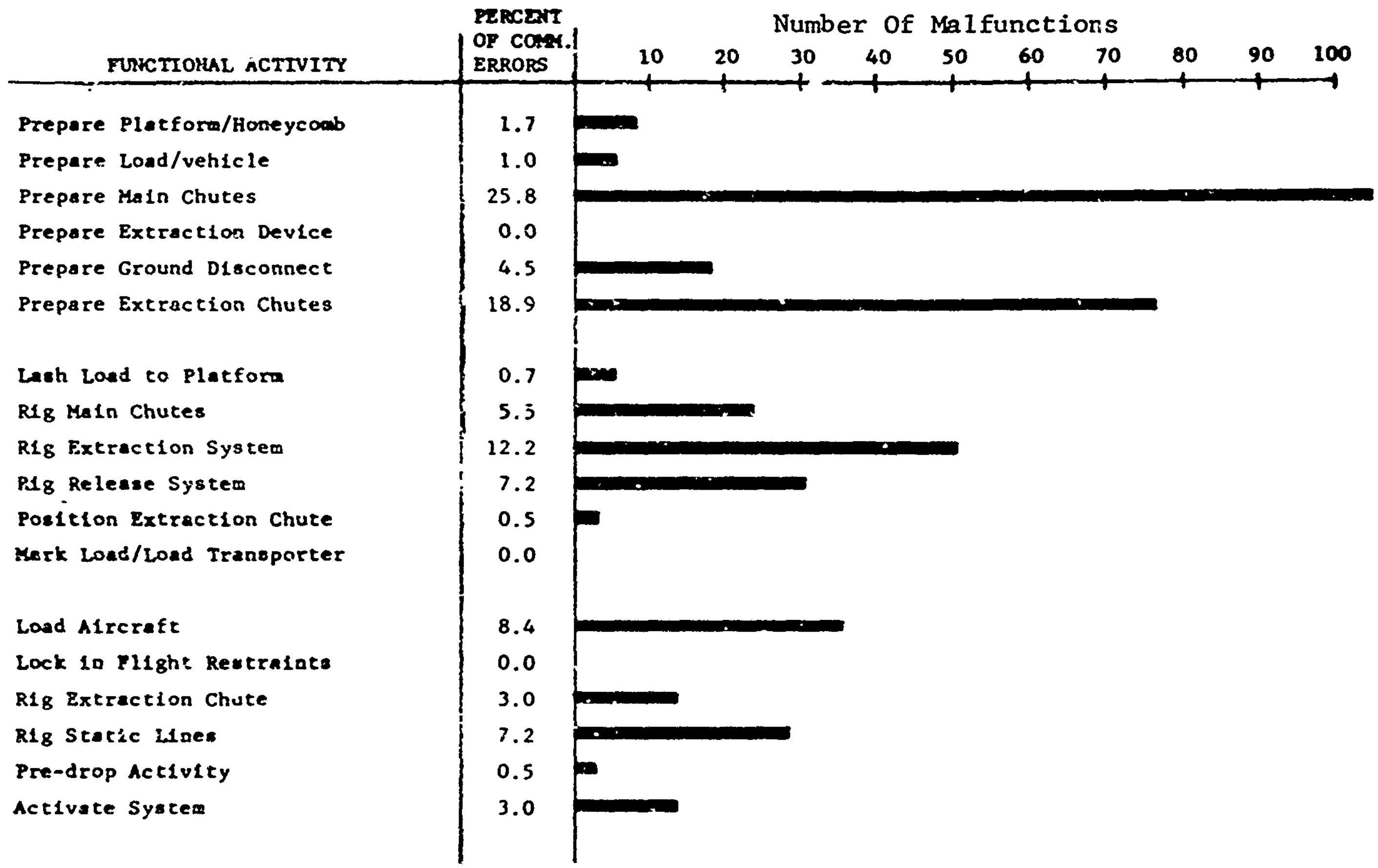
The events of the first category, Component Preparation, are not sequentially related. However, the other four events are to be performed in a prescribed sequence. It is inherent in the assembly and rigging of an airdrop system that each major component must be prepared prior to mating with other system components or assemblies. The sequence in which the components are prepared (Component Preparation) is not defined, i.e., the preparation of one prime component is not a prerequisite for the preparation of another. In fact, it is highly probable that the components will be pre-prepared and treated as "shelf items" in assembling the delivery unit.

To qualitatively identify the primary sources of human error by functional activity, failure reports abstracted from the "Quarterly Airdrop Review and Malfunction Analysis" (April 1967 through January 1968) were reviewed (reference 1), and those failures attributed to "Improper Procedures" were further classified by error source. If the source of the error could not be stated with certainty, it was assigned to the most probable functional category. It should also be pointed out that some of the malfunctions listed as equipment failures could have been prevented by adequate equipment inspection. These failures were treated as human errors and were included in the distribution of probable human errors in Figure 2.

Examination of the probable human error distribution indicated that the major human errors occurred in preparing the main or recovery and extraction parachutes. Since parachute packing is not a portion of this study, the applicability of each of the functional activities to this rigging study was determined. The functional activities were rated in the order of most errors committed to least in Table 1 and the percent of errors committed also was computed with the preparation of the main and extraction parachutes activities eliminated. The function activities were studied and their applicability to the present contract determined. As can be seen, many of the high-error activities are not within the scope of this program which indicates the desirability for investigation into these functions.



FUNCTIONAL ACTIVITY FLOW CHART
Figure 1



DISBRIBUTION OF PROBABLE HUMAN ERRORS BY FUNCTIONAL ACTIVITY: ABSTRACTED FROM "QUARTERLY AIRDROP REVIEW AND MALFUNCTION ANALYSIS" APRIL 1967 - JANUARY 1968

Figure 2

TABLE 1 . HUMAN ERRORS BY FUNCTIONAL ACTIVITY

Functional Activity	Percent of Committed Errors: Total	Percent of Committed Errors: Without Packing Chutes	Applicable For Study
Prepare Main Chutes	25.7		No
Prepare Extraction Chutes	18.9		No
Rig Extraction System	12.2	22.0	Yes
Load Aircraft	8.4	15.2	No
Rig Release System	7.2	13.0	Yes
Rig Static Line	7.2	13.0	Yes
Rig Main Parachutes	5.5	9.9	Yes
Prepare Ground Disconnect	4.5	8.1	Yes
Rig Extraction Chute	3.0	5.4	Yes
Activate System	3.0	5.4	No
Prepare Platform/Honeycomb	1.7	3.1	Yes
Prepare Load/Vehicle	1.0	1.8	Yes
Lash Load to Platform	0.7	1.3	Yes
Pre-Drop Activity	0.5	.9	No
Position Extraction Chute	0.5	.9	Yes
Lock In-Flight Restraint	0		
Mark Load/Load Transporter	0		
Prepare Extraction Device	0		
TOTAL	100.0	100.0	

b. Opinion Sampling

The opinions of individuals experienced in airdrop operations were solicited during the visitations at the Army bases. The question was asked "what system changes do you feel would be most helpful in reducing the time required to prepare a load for airdrop?" A few suggestions were made pertaining to components in the current system and in most instances engineering effort is already in process to improve or correct these items. Several individuals that had given the matter some serious thought expressed the need for a drive-on, drive-off capability for vehicular loads. Simplification of the restraint harness with netting or some other substitute was sometimes suggested. Rigging on load bearing platforms, in the few instances where this is practiced, received favorable comment.

Very few specific suggestions resulted from these inquiries, but the almost universal desire to have a drive-on, drive-off capability for vehicular loads influenced the thought in the search for new rapid rigging concepts.

3. Time Considerations

Using the functional activity flow chart as a guide the required man-hours and skill levels by functional activity were determined in a detailed task analysis of the present airdrop rigging system for the 3/4 ton emergency repair shop truck (reference 1). This load item was selected as a typical platform cargo item with sufficient complexity indicative of vehicle-type cargoes. Only the preparation of components, rigging of the load, and the aircraft operations were evaluated in the task analysis, since dropping of the load activity is not a rigging activity and insufficient data exists for the recovery activity. The results of the task analyses are summarized in Table 2.

The total man-hours required to rig the 3/4 ton emergency repair shop truck are 18.96, and 12.08 man-hours of this total are required to prepare the main and extraction parachutes. Since this rigging study is not considering packing the parachutes as an area of investigation, the man-hours to rig this load are 6.88. The term "load rigging" as used here includes some aircraft operations. To determine the most time consuming events, the percent of time required for each event was computed with the time to pack the main and extraction parachutes deleted. These numerical values are listed in Table 3 with the most time consuming event listed first.

TABLE 2 . MAN-HOUR REQUIREMENT FOR THE PRESENT AIRDROP SYSTEM FOR THE 3/4 TON EMERGENCY REPAIR SHOP TRUCK

Functional Activity	Man-Hours	Percent	Percent * W/O Chutes
Prepare Components			
1. Prepare Platform	.57	3.0	8.3
2. Prepare Truck	2.36	12.4	34.4
3. Prepare Main Parchutes	11.80	62.2	-
4. Prepare Extraction Device	.03	0.2	0.5
5. Prepare Ground Disconnects	.37	1.9	5.3
6. Prepare Extraction Parachute	.28	1.5	-
Rig Load			
1. Lash Load to Platform	.93	4.9	13.6
2. Rig Main Parachutes	.57	3.0	8.2
3. Rig Extraction System	.19	1.0	2.8
4. Rig Release System	.28	1.5	4.1
5. Position Extraction Parachute	.01	0.04	0.1
6. Mark Load and Load on Transporter	.28	1.5	4.0
Aircraft Operations			
1. Load Aircraft	.60	3.2	8.7
2. Lock Inflight Restraints	.23	1.2	3.3
3. Rig Extraction Parachute	.18	1.0	2.7
4. Rig Static Lines	.13	0.7	2.0
5. Pre-Drop Activity	.13	0.7	1.8
6. Activate System	.02	0.1	0.2
TOTALS	18.96	100.0	100.0

* The "Prepare Main Parachutes" and "Prepare Extraction Parachute" functional activities have been eliminated from consideration.

TABLE 3 . SUMMARY OF MAN-HOUR REQUIREMENT TO RIG EMERGENCY REPAIR SHOP TRUCK (WITHOUT CHUTE PACKING)

Functional Activity	Percent Of Total Man-Hours	Actual Man-Hours	Applicable To Study
Prepare Truck	34.4	2.36	Yes
Lash Load to Platform	13.6	.93	Yes
Load Aircraft	8.7	.60	No
Prepare Platform	8.3	.57	Yes
Rig Main Parachutes	8.2	.57	Yes
Prepare Ground Disconnect	5.3	.37	Yes
Rig Release System	4.1	.28	Yes
Mark Load and Load Transporter	4.0	.28	Yes
Lock In-Flight Restraints	3.3	.23	No
Rig Extraction System	2.8	.19	Yes
Rig Extraction Parachute	2.7	.18	Yes
Rig Static Lines	2.0	.13	Yes
Pre-Drop Activity	1.8	.13	No
Prepare Extraction Device	0.5	.03	Yes
Activate System	0.2	.02	No
Position Extraction Parachute	0.1	.01	Yes

The most time consuming event is the preparation of the vehicle which includes the securing of numerous truck equipment and components and installing of supports, straps and slings to prevent damage to the vehicle on impact. This event consumes one-third of the rigging time (excluding parachute preparation). Concepts seeking ways to improve this operation have been pursued in the concept development section. One method of reducing the time for this event is to develop a soft landing system which would reduce the forces imposed at landing and eliminate the need to secure various vehicle components.

The applicability of each functional activity or event to this rapid rigging system has been designated by a "yes or no" in Table 3.

The major rigging functions of concern from a time consumption standpoint are:

a. Preparing the Vehicle

b. Lashing the Load to the Platform

c. Preparing the Platform

d. Rigging the Main Parachutes

and concept investigations have been concentrated on these events.

B. Concept Discussions

1. General

During the course of the program, the greater portion of the effort was spent on generating as many different concepts as possible with the expectation that the numerous ideas would lead to the merging of two or more into a workable system. It is to be understood that some of the concepts have more merit than others. However, it is with the possibility of merging and extending certain ideas that all concepts are presented even though the present state of the art may make some of them appear impractical or impossible. Many of the concepts have shown potential in reducing the rigging time and increasing reliability by reducing the number and difficulty of the tasks that must be performed by rigging personnel. However, this simplification has sometimes introduced new problems and been achieved with an increase of cost and weight.

Certain of the concepts presented have much more potential for final development than others. Selected concepts will be analyzed and evaluated in the Concept Evaluation Section. Much of the quantitative information needed to evaluate the feasible concepts will necessarily be estimates based upon past experience with similar systems and any other available source of information. Nonetheless, the analysis will aid in formulating the next steps that should be taken to arrive at the optimum system.

2. Areas For Investigation

In the present airdrop system the philosophy of using universal components and one basic system has been extended to allow airdropping numerous and varied equipment and supplies in the U. S. Army inventory. This philosophy provides excellent flexibility to the present airdrop system, since cargo items not detailed in a specific rigging manual can be rigged by following proper rigging procedures, applicable to any airdrop item, through the application of the particular rigger's talents. Skilled riggers are capable of achieving outstanding success in terms of time-to-rig, reliability, and minimal malfunctions per airdrop item; provided rapid rigging on an assembly-line basis is not required. Herein lies a deficiency of the present airdrop system. Under combat or simulated combat conditions, assembly-line rigging is required to rig the equipment and supplies in the time frame allowed. The use of unskilled personnel, lacking the proper training to efficiently and reliably rig cargo items for airdrop, results in malfunctions which in many instances are catastrophic. Discussions with rigging instructors at Ft. Lee indicated many problems associated with training military personnel in the field to rig airdrop items. Recent airdrop maneuvers in Italy revealed the extent of the malfunctions which result when assembly-line rigging is used and unqualified personnel employed as riggers. In this operation numerous items were damaged and some were lost due to improper rigging.

The need to minimize the human element involved in rigging is quite clear. The benefit gained by eliminating or simplifying the personal attention required to rig specific airdrop items - especially vehicle-type and heavy weight cargoes - is sufficient to warrant the development of new airdrop loads preparation methods.

An analyses of the man-hours required to perform specific tasks for the present airdrop system revealed that the most time-consuming items which can be effectively treated in this study are:

a. Preparing the vehicles, weapons or equipment
b. Lashing the load to the platform
c. Preparing the platform and energy dissipator
d. Rigging the parachutes on the load.

Vehicle preparation is the most time consuming event and consists primarily of securing numerous parts of the vehicle with supports, straps, slings, etc., to prevent damage to the vehicle on impact. Quite often components must be removed and stored elsewhere on the vehicle to prevent damage. Lashing the load to the platform consists of stowing ancillary equipment, positioning the load on the platform and installing the lashings. The platform preparation includes inspecting the platform, positioning the platform to start rigging, and preparing and positioning the paper honeycomb on the platform. The parachute rigging time increases as the number of parachutes used increases. The rigging items common to any number of parachutes are: attaching and stowing the riser extensions, installing the parachute stowage platform, placing the parachures on the stowage platform, installing the deployment line, installing the restraint strap attaching the safety line to the extraction system, installing the release strap, and safetying the release knife.

A considerable variety of concepts were considered during the study each of them designed to improve conditions in one or more of the major time consuming areas. The concepts considered included increased use of containers, alternate energy dissipation devices which would replace the current paper honeycomb materials, the use of load bearing platforms, alternate means of restraining the load to the platform, and different ways of rigging the parachutes to the airdrop assembly. It was believed that a drive-on, drive-off capability for wheeled and tracked vehicles would constitute a marked improvement and a considerable number of the concepts focused on providing this feature. A corollary effect of this drive-on, drive-off feature is a reduction of the vehicle preparation time which is a major goal of any new system since this task currently consumes a major share of the rigging time. Some concepts to eliminate force transfer were considered because this simplifies the rigging preparations somewhat, and in addition, promises other benefits especially where low altitude airdrops are desirable. The problem of landing safely in high wind conditions was also considered and some concepts specifically address this problem. Various concepts embodying these goals are described in the section that follows.

The presentation is divided into several subsections depending upon the primary area of consideration. The major areas of investigation have been Soft Landing, Restraint, and High Wind Conditions. The contents as they are presented are not always complete systems. However, it should be possible to combine them in such a way as to synthesize complete systems. For instance, it may be desired to use one of the restraint systems with standard impact attenuation or eliminate the honeycomb energy dissipator and use standard lashing procedures with an alternate energy dissipating concept. The number of combinations is extensive and for this reason, the concepts for each area of investigation have been presented individually.

C. Concept Descriptions

1. Soft Landing System

The term "soft landing" is defined in this context to mean that the decelerations at ground impact are limited to the design values expected under ordinary vehicle operational conditions. If this can be accomplished, shoring-up "soft spots" of the vehicle plus some of the vehicle preparations will not be necessary. The reasoning here is that whenever the landing decelerations are such as to require auxiliary support of the soft spots of the vehicle, special handling equipment to lift and place the vehicle in place will be necessary and procedures must remain pretty much as they are at present, leaving little opportunity for simplification of the airdrop loads preparation process. In contrast, if the objective of a "soft landing" concept can be achieved, the vehicle would be rolled or driven into position on the pallet, it would be secured with appropriate rigging against fore and aft and lateral movement, and the parachutes would be attached to the pallet. This would complete the preparation process and promises a significant simplification of the airdrop loads preparation procedures. Likewise, derigging of the load would be simplified for unfastening the restraints that secure the vehicle to the pallet is all that is necessary to permit rolling or driving the vehicle from the pallet.

To achieve a "soft landing" it is necessary to make the energy absorbers operate over a longer distance and at a reduced force as compared to the current practice using honeycomb energy absorption material. Theoretically, honeycomb materials could aslo be used to achieve a "soft landing" by using taller stacks with reduced plan areas, but practically its use in this manner is not feasible because the rigged height of the load would exceed the limitations of the aircraft. This problem can be avoided in concepts employing mechanical energy absorbers so that the rigged height is no greater than, and in some instances is less than, the height of current loads.

Some tests would be necessary to determine the deceleration level that would qualify as a "soft landing" but an arbitrary value of 5 g's was chosen for these preliminary studies. Intuitively, this figure seems to be in the correct range and subsequent studies are not expected to alter this value any great amount. The descent velocity for the 87 loads most frequently airdropped and which range in weight from 2500 to 22,500 pounds, is nominally 25 fps. Using this velocity and a constant 5 g deceleration for all loads, the kinetic energy at impact is:

$$KE = 1/2\ mv^2$$
$$= 1/2\ \frac{W}{g}\ (25.0)^2$$
$$= 312\ W/g\ \text{ft-lb.}$$

If the energy dissipator generates a constant force of 5 g's, the stroke (S) required to dissipate 312 W/g ft-lb of energy is

$$S = KE/F$$
$$= \frac{\frac{312W}{g}}{5W}$$
$$= \frac{312}{(5)(32.2)} = 1.94\ \text{ft.}$$
$$= 23.3$$

In the designs subsequently described, a stroke of 24 inches has been used because it is realized that all impact velocities are not identical and sometimes the attitude of the assembly at impact will cause the energy dissipating system to behave differently from the ideal action. When this happens, the full value of the deceleration force will not be realized at the instant of initial ground contact. A dynamic analysis of the motion of the assembly at ground impact can be made to predict the required stroke more precisely, but for these preliminary studies, an arbitrary stroke of 24 inches has been chosen.

a. Mechanical Soft Landing Systems

(1) Folding Cup Energy Dissipator

One of the mechanical energy dissipation concepts is a telescoping tube where the force required to move one tube inside the other is controlled at a constant value by the action of a folding cup. The energy absorbers would be fastened along the edge of a load bearing platform so that the required decelerating force could be evenly distributed.

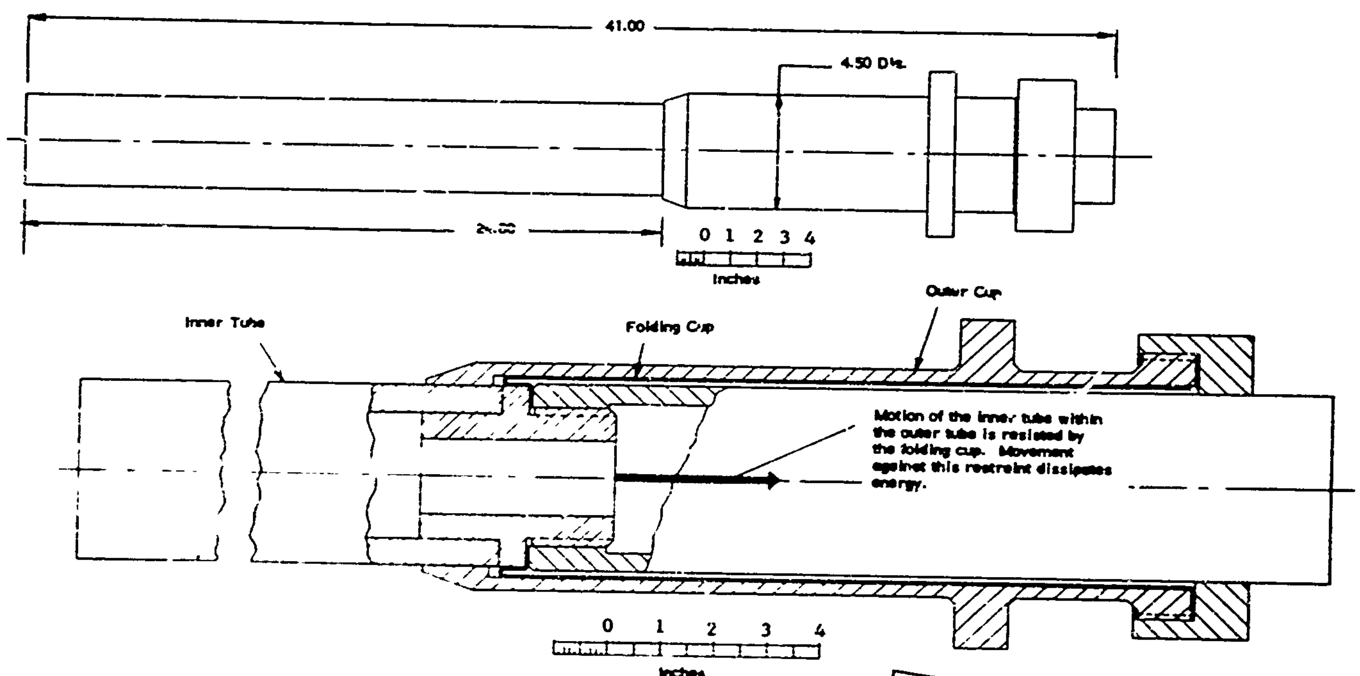
Figure 3 is a drawing of the energy absorber unit. It consists of a 4.50 inch upper tube arranged to guide the sliding motion of a 3.60 inch inner tube. Sliding motion is restrained by a folding cup so any relative motion between the two tubes is accompanied by a rolling or folding action in the cup. The cup is made of mild steel .050 inches thick which, for the configuration shown, will require a force (F) of about 7,500 pounds to induce the folding action. The total stroke (S) available is 24 inches (2 feet) so that the energy (E) required to stroke the inside tube through the total range is:

$$E = S \times F$$

$$= 2 \times 7{,}500$$

$$= 15{,}000 \text{ ft-lbs.}$$

The design theory of energy absorbers of this type has become well established and their performance can be predicted with a good degree of certainty. An interesting application of such a design has been sponsored by the Department of Transportation for use as crash barriers where the possibility of a head-on collision exists, as for instance, at the dividing point of a highway. The barrier rail is supported by two energy absorbers of the type proposed here except that the stroke is 55 inches instead of the 24 inches proposed for this design. These energy absorbers are reusable for the cup will fold both ways and a resetting tool can be provided that would reset each energy absorber. The number of times the unit can be reset is limited, however, because the cup tends to work harden after a number of cycles and must be replaced. The allowable number of cycles depends upon the design configuration and the materials and would be determined by experimentation, but somewhere between 5 and 10 cycles might be expected.

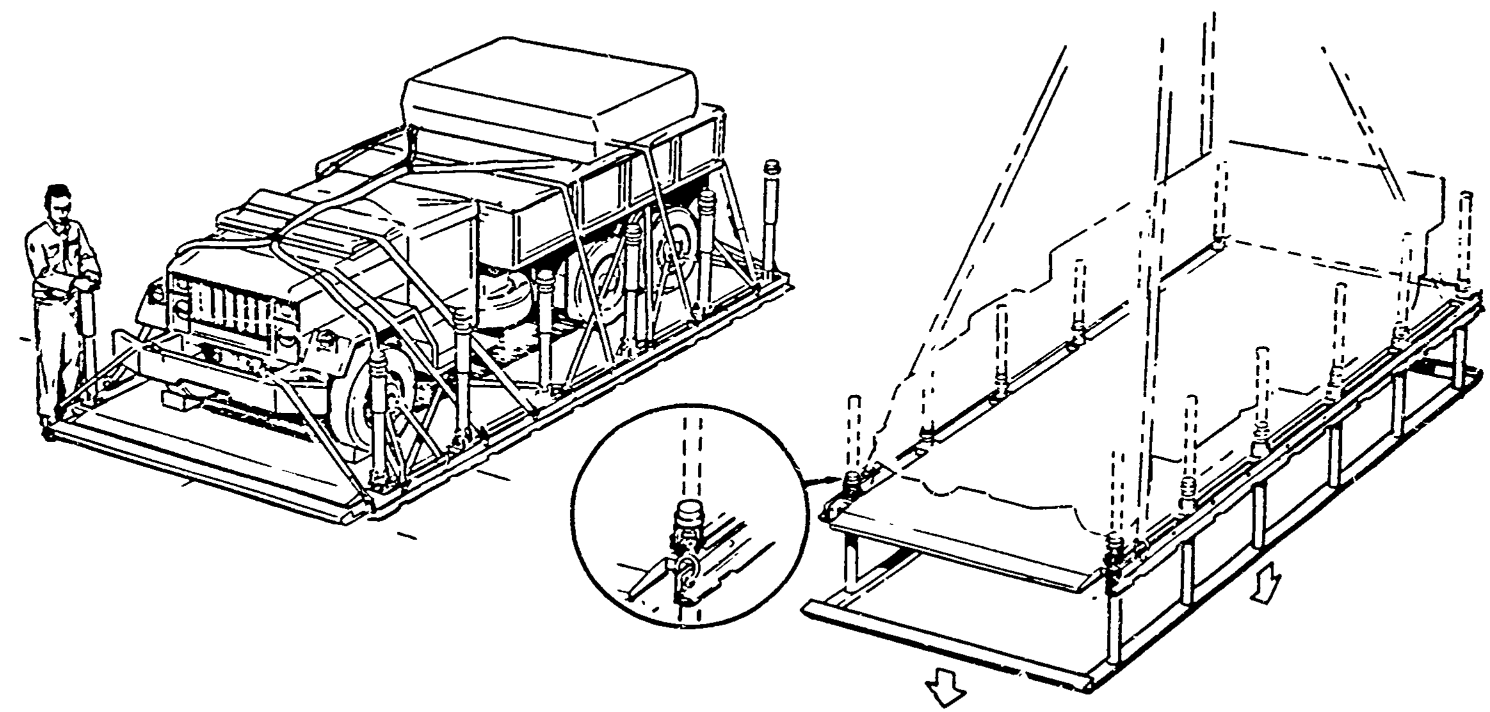


FOLDING CUP ENERGY DISSIPATOR

FIGURE 3

These energy absorbers applied to a 24 foot pallet on which an M-34, 2-1/2 ton truck has been rigged is illustrated in Figure 4. The left-hand view shows the pallet rigged for the airdrop. The right-hand view shows the assembly suspended on the parachutes with the energy absorbers extended and latched in place ready for landing. A quick-connect arrangement would be provided for attaching the energy absorbers to the extendable frame so they can be removed from the assembly for resetting and provide unencumbered access to the pallet during the rigging of the load. The vehicle would be rolled or driven onto the pallet and the harness attached to restrain the vehicle against fore and aft and lateral movement. The energy absorbers would then be installed and the parachutes attached and placed on the load. This would constitute the rigging task except for preparation of the vehicle, but here too, the task would be simplified because the "soft landing" would eliminate the need for several special precautions such as securing the battery box, removing the muffler and tail pipe, installing the engine straps, etc. A load bearing pallet or platform would be required which is capable of surviving, without damage, the 5g loads expected at landing. Twelve energy dissipator assemblies would be required to dissipate the energy in a 20,000 pound airdrop load. If a twenty-four foot pallet is used, the dissipators would be located at four foot intervals on either side of the pallet. The number of units and spacing must be adjusted to suit the load which is a negative feature of the concept. The parachutes would be attached directly to the platform. Figure 4 illustrates various features of the concept.

An extendable frame is shown to which the energy absorbers are secured. A design for this frame is the only part of the concept that is difficult to project at this time. It is believed that a frame of fairly substantial design that would act as a skid to prevent the ends of the energy absorbers from digging into the ground would suffice. The edges of this skid would be rounded to enhance its ability to skim over the ground. The horizontal component of motion of the assembly at touchdown will produce side loads in the energy absorbers of appreciable magnitude, particularly in high winds and soft ground situations. Connecting all of the energy absorbers with a frame will distribute these side loads to a number of units so that the design for this condition remains reasonable. Some experimental work probably would be required to settle the configuration of this part of the design, expecially since weight is a consideration. Filling the center of this frame with a panel can be envisioned and the advantages it would provide in stiffness and protection during skids can be readily appreciated. However, this would add weight which is to be avoided if a frame-type construction would suffice. The extendable frame would be latched to the pallet for ground operations and handling in the airplane. When the main parachutes are deployed, these latches would be released and the frame with the energy absorbers attached would extend due to the gravity force. At the extended position, the energy absorbers automatically lock so that at ground impact any movement of the inner tube relative to the outer tube is resisted by the folding cup.



FOLDING CUP SOFT LANDING CONCEPT

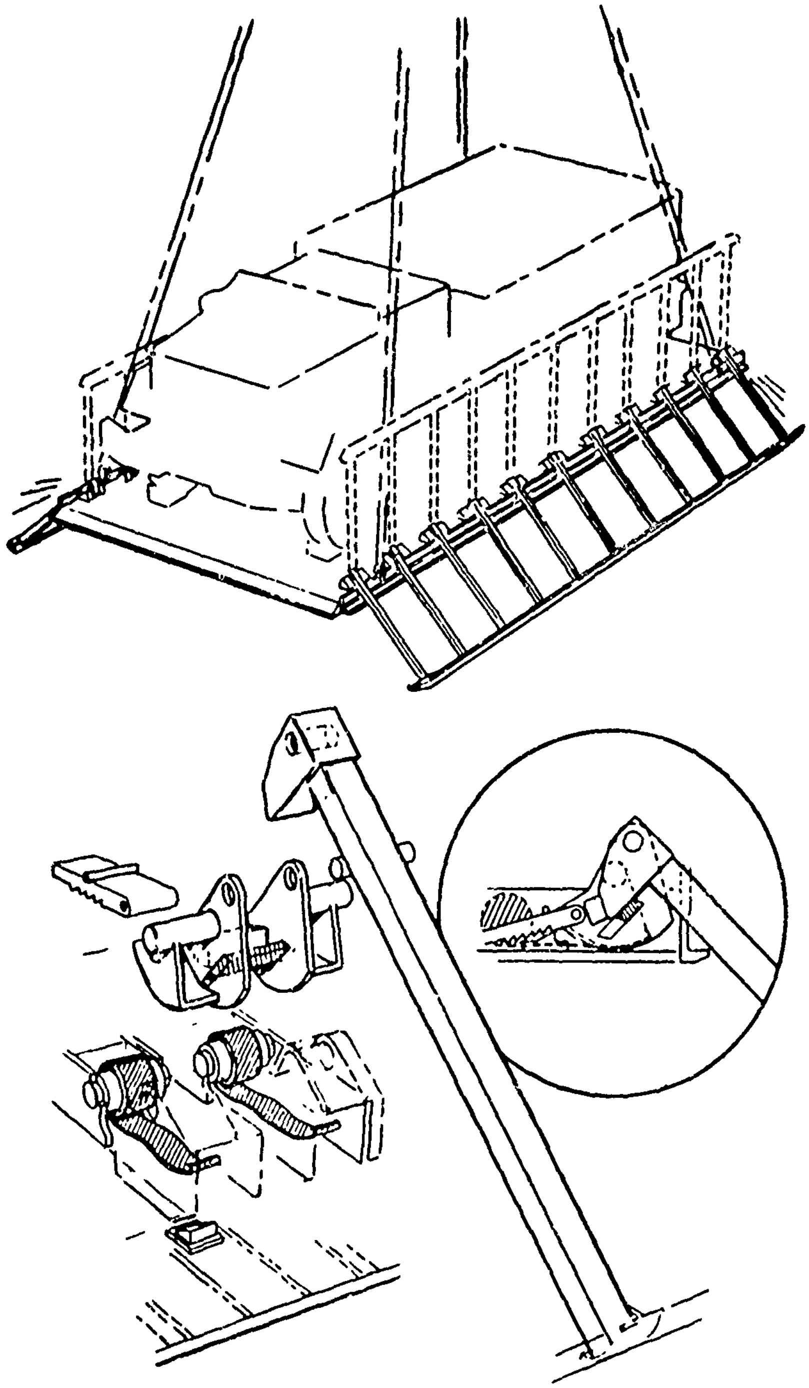
FIGURE 4

This concept possesses many of the attributes looked for in a rapid r ing concept and if it were converted to a practical operating syst , it would provide a simpler and much more rapid method of preparing and retrieving the airloads. The different components of this ystem are all based upon proven principles and are entirely feasible. If the overall system can be made to operate as conceived, then a feasible system with rapid airdrop loads preparation properties can be realized. However, there is a price that must be paid for all this convenience, and there are a few operational characteristics that need further study. The price that must be paid is the weight of the airdrop equipment. For instance, a load bearing platform is proposed which must necessarily be heavier than the pallets used in current practice. Also, the energy absorbers are heavier than the honeycomb materials currently used for this purpose. A preliminary but conservative estimate of the increase in the rigged weight of the M-34 2-1/2 ton truck is 7% or 1260 pounds.

From a functional viewpoint the possibility of problems in three areas is recognized and the system needs to be analyzed more completely to determine if indeed problems exist, and if they do, the severity of the problems. First, the "soft landing" decelerations were estimated from elementary calculations and ideal conditions. Dynamic analyses along with some mock-up simulated drops should be performed with the airload at different attitudes and various horizontal velocities in order to determine the performance of the assembly during impact. A second concern would be the increased tendency for the load to overturn because the c.g. is at a greater height when initial contact with the ground occurs. This increase in the height to the c.g. is not as much as it might appear in the illustrations because the rigged height in the "soft landing" concept is less than in the current system. The reason for this is that the c.g. of the truck is elevated 8 to 12 inches above its natural location when it is positioned on the honeycomb. In the "soft landing' scheme, the c.g. is at its natural location but the pallet is thicker than the current units. When all allownaces are accounted for, the overall increase in the distance from the ground to the c.g. of the load at initial ground contact would be 10 to 13 inches. A third problem is matching the energy dissipator to the load. The force level of the folding cup dissipator is not adjustable so the number of dissipator assemblies employed must be varied to suit the load. This is similar to current procedures where the honeycomb pattern is varied to suit the load, a procedure that should be avoided if possible.

(2) Spring Motor Energy Dissipator

A concept based upon the use of a negator spring motor is illustrated in Figure 5. The theory and the configuration of the equipment is identical to the previous concept except that the folding cup energy absorbers are replaced with the negator spring motor devices.



SPRING MOTOR SOFT LANDING CONCEPT

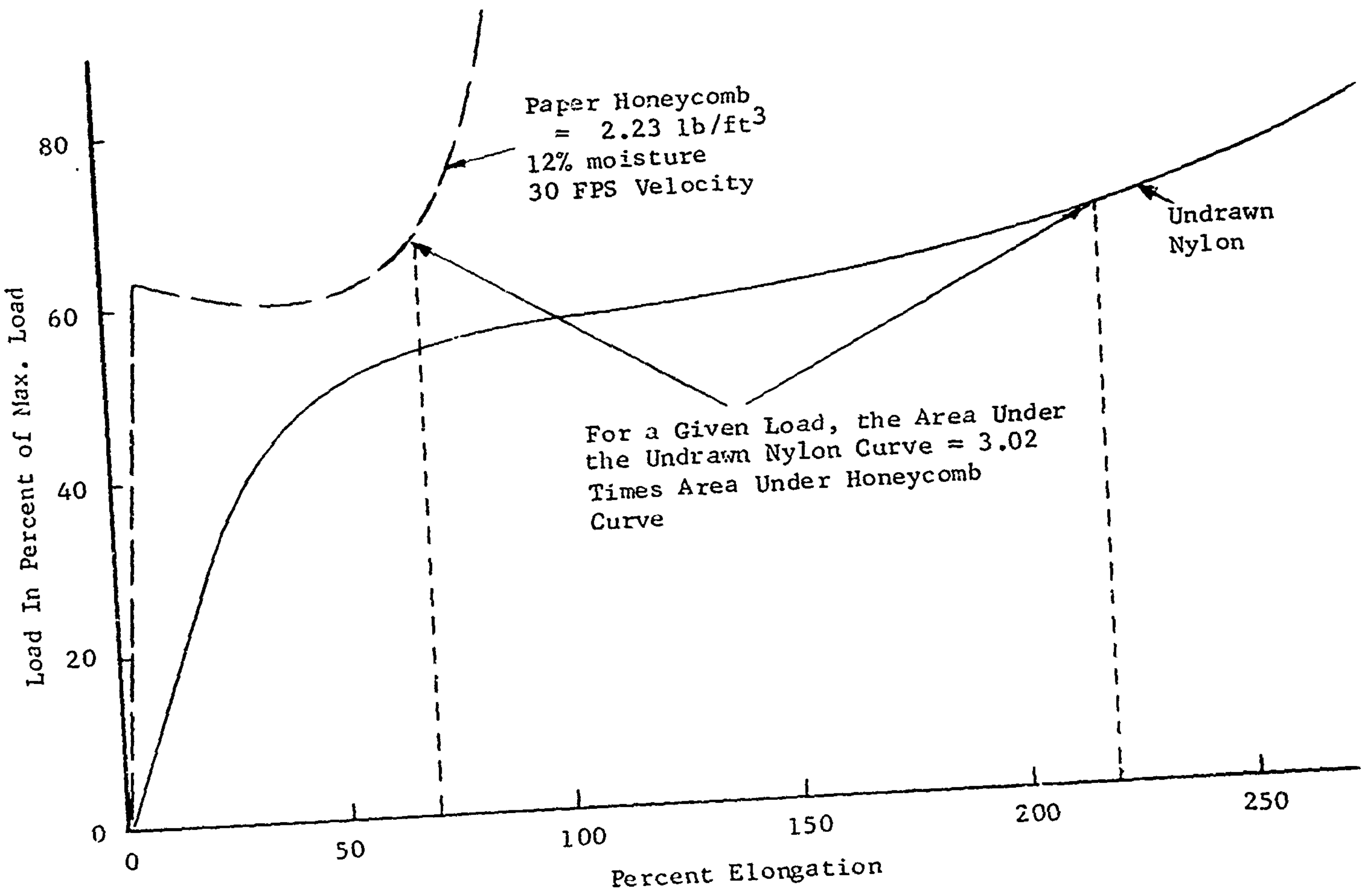
FIGURE 5

Designs based on available standard components indicate that more spring motors will be needed than folding cups to dissipate equal amounts of energy. Indications are that roughly twice as many spring motors as folding cups would be needed to accomplish identical tasks so 20 to 24 spring motors would be needed to soft land a 20,000 pound airdrop load. The motors are located along the edge of the pallet and operate individual arms or struts. These arms would be positioned and latched in an upright position during the rigging and handling phases. When the main parachutes deploy during the airdrop, the latch(s) are released which permits these arms to rotate to the extended position. The extended position is an attitude of about 45 degrees from the horizontal. The arms are joined together with a structural element resembling the runner on a sled as in the folding cup design. This will inhibit the tendency for digging into the ground. As the load settles toward the ground following initial contact, the arms fold up, but this motion is resisted by the spring motors and the kinetic energy in the airdrop assembly is arrested by the work performed by the spring motors. The arresting force in this concept theoretically is non-linear due to the changing attitude of the arms with respect to the pallet. However, it is close enough to being constant to comprise a feasible scheme.

The same arguments pro and con can be made for this scheme as for the folding cup approach. In comparison to the folding cup approach it is heavier and a bit more complex. However, it would not be as likely to overturn because the configuration of the spreading arms give it a considerably wider base in contact with the ground, although satisfactory performance under high horizontal velocity conditions must still be confirmed.

(3) Direct Undrawn Nylon Suspension

Undrawn nylon ropes were used on the EXIARP airdrop program as a force attenuator to reduce the peak loadings on the riser extension and suspension slings. Sufficient energy was absorbed during elongation of the undrawn nylon lines to decrease the line tension forces to acceptable levels. During previous investigations of undrawn nylon, numerous static tensile tests were conducted to obtain stress-strain type data. This data is plotted as force-versus-percent elongation in Figure 6, and compared to similar data for paper honeycomb in the same figure. Assuming that undrawn nylon strands are operational to 225% elongation, the energy absorption capability of undrawn nylon is three times greater than paper honeycomb. Actual airdrop tests conducted at NAF El Centro, California have confirmed the static tensile test results, and proven that undrawn nylon is operational beyond 225% elongation. The desirable characteristics of undrawn nylon as an energy absorber indicate that this material could replace paper honeycomb, provided a feasible concept could be developed which utilized these capabilities.



FORCE VS ELONGATION FOR UNDRAWN NYLON LINE AND PAPER HONEYCOMB

FIGURE 6

Several concepts were investigated in an attempt to apply undrawn nylon to a rapid rigging system. In one of the concepts studied, undrawn nylon lines were attached from a rigid structure, mounted on each side of the platform, to the axles of the cargo vehicle as shown in Figure 7. (For study purposes a wheeled vehicle was considered, since this cargo item is the most difficult to work with in designing a feasible system.)

The vehicle is elevated above the platform to allow sufficient distance for the undrawn nylon lines to elongate and absorb energy. The forces developed by the undrawn nylon lines during elongation must be carried by the structure along each side of the vehicle. This requires the platform to be reinforced to withstand the reaction forces at the support of the structure. Some of the advantages of this system are:

(1) Paper honeycomb is eliminated.

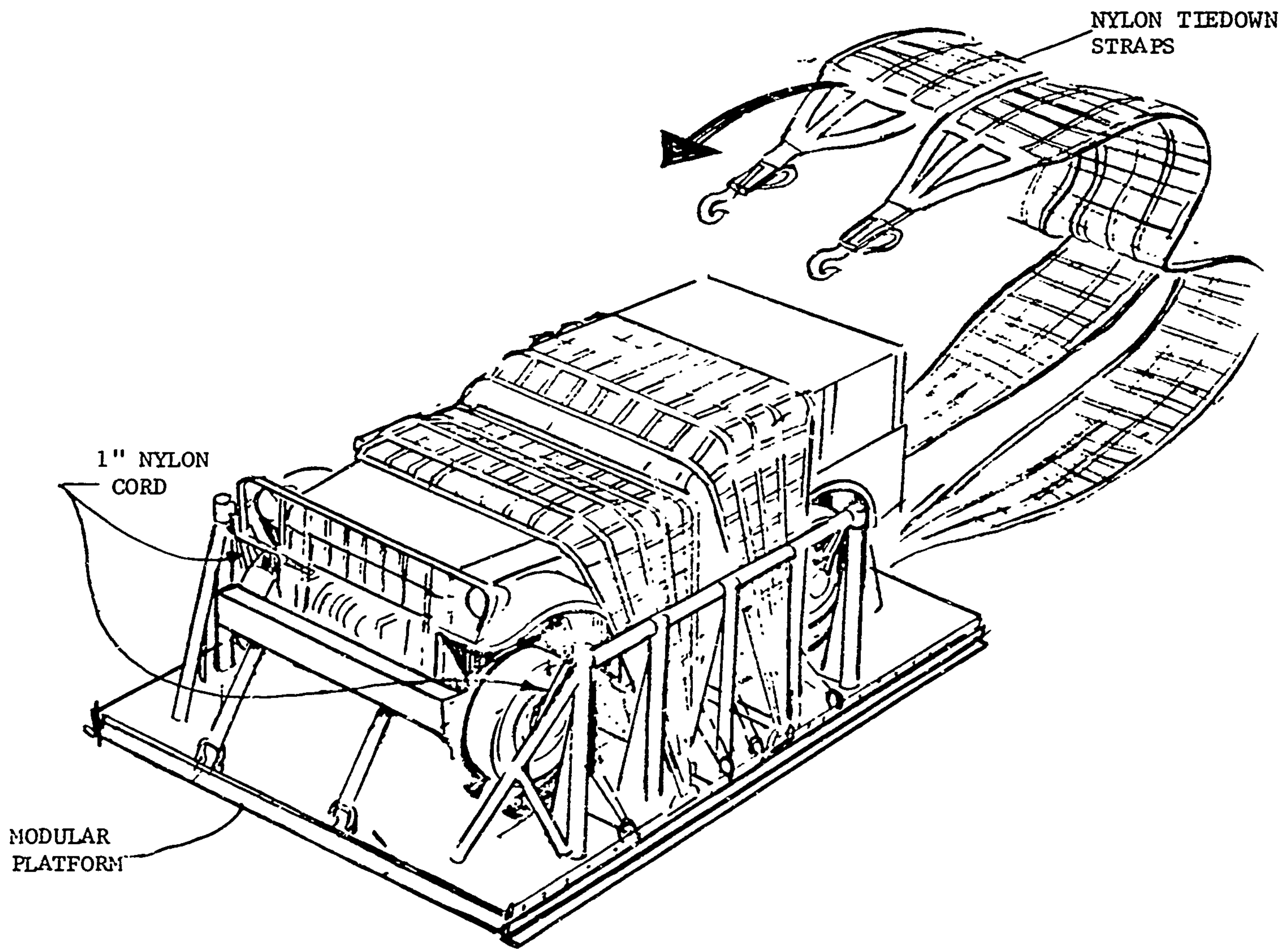
(2) The rigging time is reduced by using netting type tiedowns. Also, the time required to prepare and position the paper honeycomb is eliminated.

Some of the disadvantages are:

(1) The elongation required to obtain the desired energy absorption is 225%, resulting in the cargo being elevated several inches above the platform. This could cause the cargo to overturn on impact.

(2) The undrawn nylon is not reuseable. This could become a major cost consideration, especially in training operations.

(3) The force required to initially elongate the undrawn nylon lines is low, resulting in the possibility of elongation of the lines during flight maneuvers.



UNDRAWN NYLON; DIRECT SUSPENSION

FIGURE 7

(4) All the impact load is transmitted through the vehicle suspension system.

(5) Undrawn nylon has a tendency to become unstable after extended storage. Some material has deteriorated to such an extent that it falls apart upon handling after a few years storage.

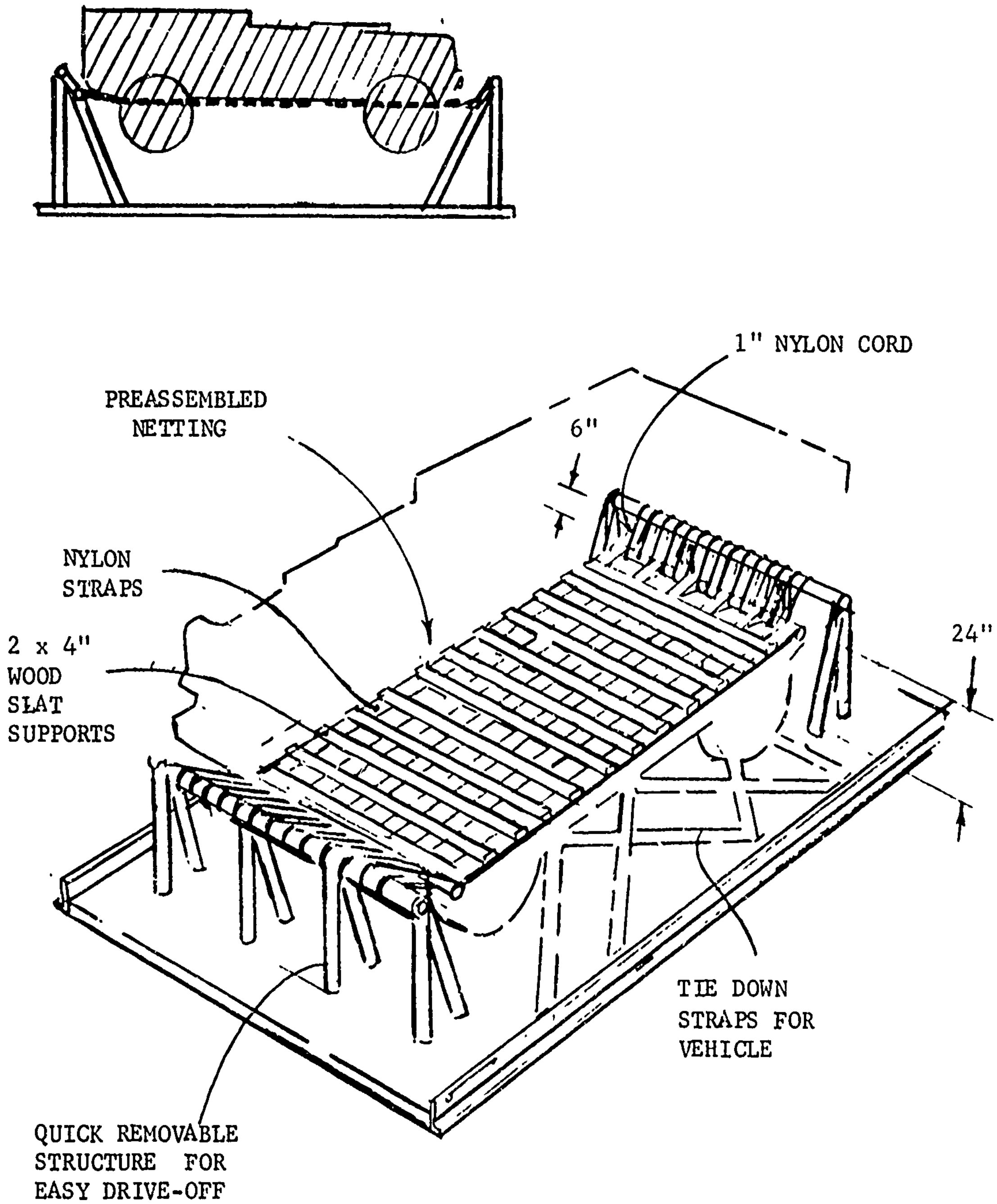
The energy absorption capability of the undrawn nylon was analyzed for a 50,000 pound cargo to determine the size, quantity and length of lines needed. Calculations show that 178 lines, 6 inches long and 1 inch in diameter, would absorb all of the impact energy after 225% elongation. This would require the cargo to be elevated 2.25 feet above the platform. The feasibility of attaching this many one-inch lines to four or six suspension points is unrealistic. Even though the properties of undrawn nylon are desirable and useful, the direct suspension concept does not appear to be a feasible means of utilizing these properties.

(4) Indirect Undrawn Nylon Suspension

In an attempt to resolve the problems involved with the direct suspension undrawn nylon concept, several indirect suspension designs were investigated. Transverse and longitudinal indirect suspension systems are shown in Figures 8 and 9. Each concept eliminates attaching numerous lines to a single connection point. This is accomplished by using a load spreading device consisting of webbing and wooden members which support the cargo. The undrawn nylon lines are attached to the webbing and a support structure. In these designs the impact load is uniformly transmitted from the cargo to the energy absorption system.

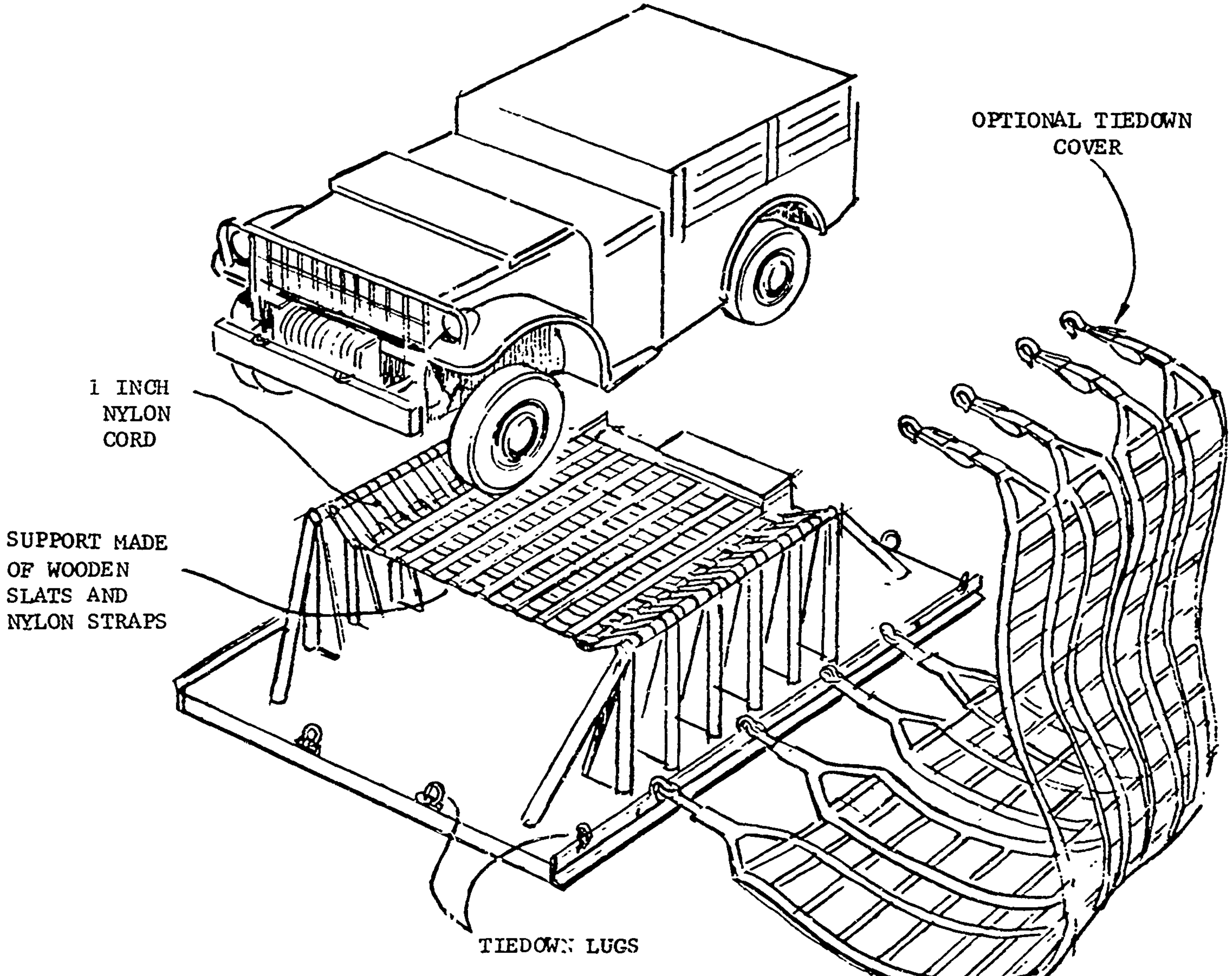
A means of removing the structural supports for the energy dissipation system must be provided to achieve a drive-off capability. To minimize the tiedown rigging, a tiedown cover as depicted in Figure 9 could be used.

Preliminary analysis indicates that wood could be used as the material for the structural supports, but these members would be of considerable size. The design does appear feasible though not practical. In conclusion, the cost and complexities of the concept are of sufficient extent to eliminate this concept from serious consideration.



UNDRAWN NYLON - LONGITUDINAL SUSPENSION

FIGURE 8



UNDRAWN NYLON - TRANSFERSE SUSPENSION

FIGURE 9

(5) Collapsible Leg Concept

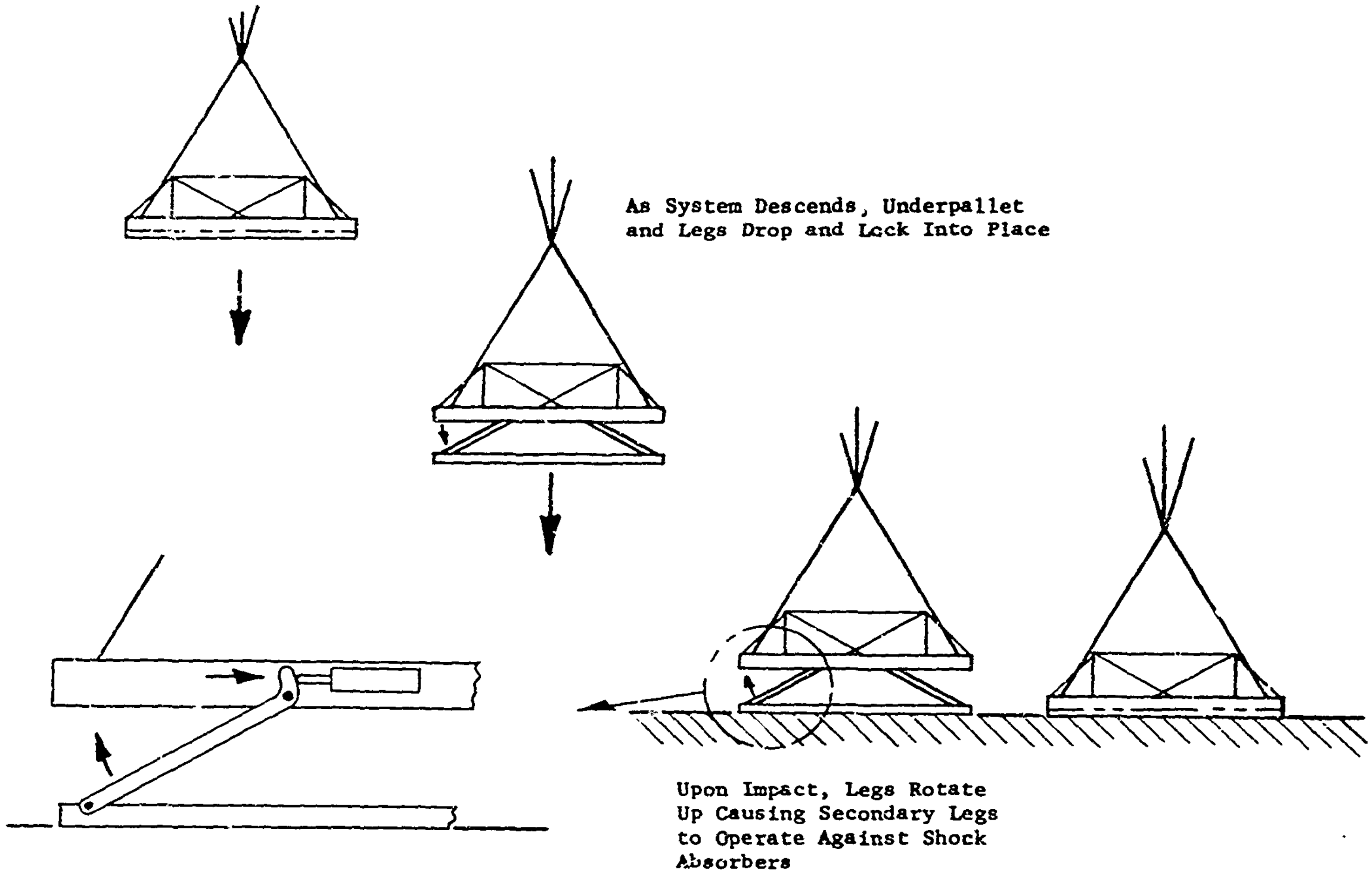
Another method proposed for soft landing is the collapsible leg concept illustrated in Figure 10. Hydraulic shock absorbers are mounted horizontally in a load bearing pallet and connected through a bell-crank mechanism to legs extending from the bottom of the pallet. During flight and the extraction phase, the legs are stored inside the pallet. As the cargo descends, the legs rotate out from the pallet and lock in place. When the legs impact the ground they are rotated back into the pallet while pushing on the horizontally mounted shock absorbers. The large ratio of the leg lengths (approximately 9:1) allows the use of extremely high force short stroke shock absorbers. Preliminary calculations for a 20,000 pound load indicates that eight 2 inch diameter, 2 inch stroke shock absorbers rated at 47,000 in-lb each would be sufficient to achieve a "soft landing". Shock absorbers of this size and rating are commercially available as off-the-shelf items.

There are several possible variations of the basic concept depending upon how the legs fold out. The technique shown in Figure 10 allows the legs to drop into position and lock in place. The legs can be tied together by independent skids or by a complete "underpallet". A second technique would be to rotate the legs outward from the pallet as shown in Figure 11. The second method could not be used with a complete underpallet but must employ skids. The outward rotation creates a wider impact configuration but the load must be oriented into the wind so that the horizontal velocity at impact is parallel to the skids.

The collapsible leg concept allows soft landing with the use of hydraulic shock absorbers without the column-failure problems associated with long strokes and high length/diameter ratios. In addition, the use of adjustable or, better yet, self metering shock absorbers would allow closer regulation of the deceleration force for various weight loads. On the other hand, the collapsible leg concept faces the same high c.g. disadvantages as the folding cup and spring motor concepts, i.e., tip-over in high horizontal velocity wind conditions.

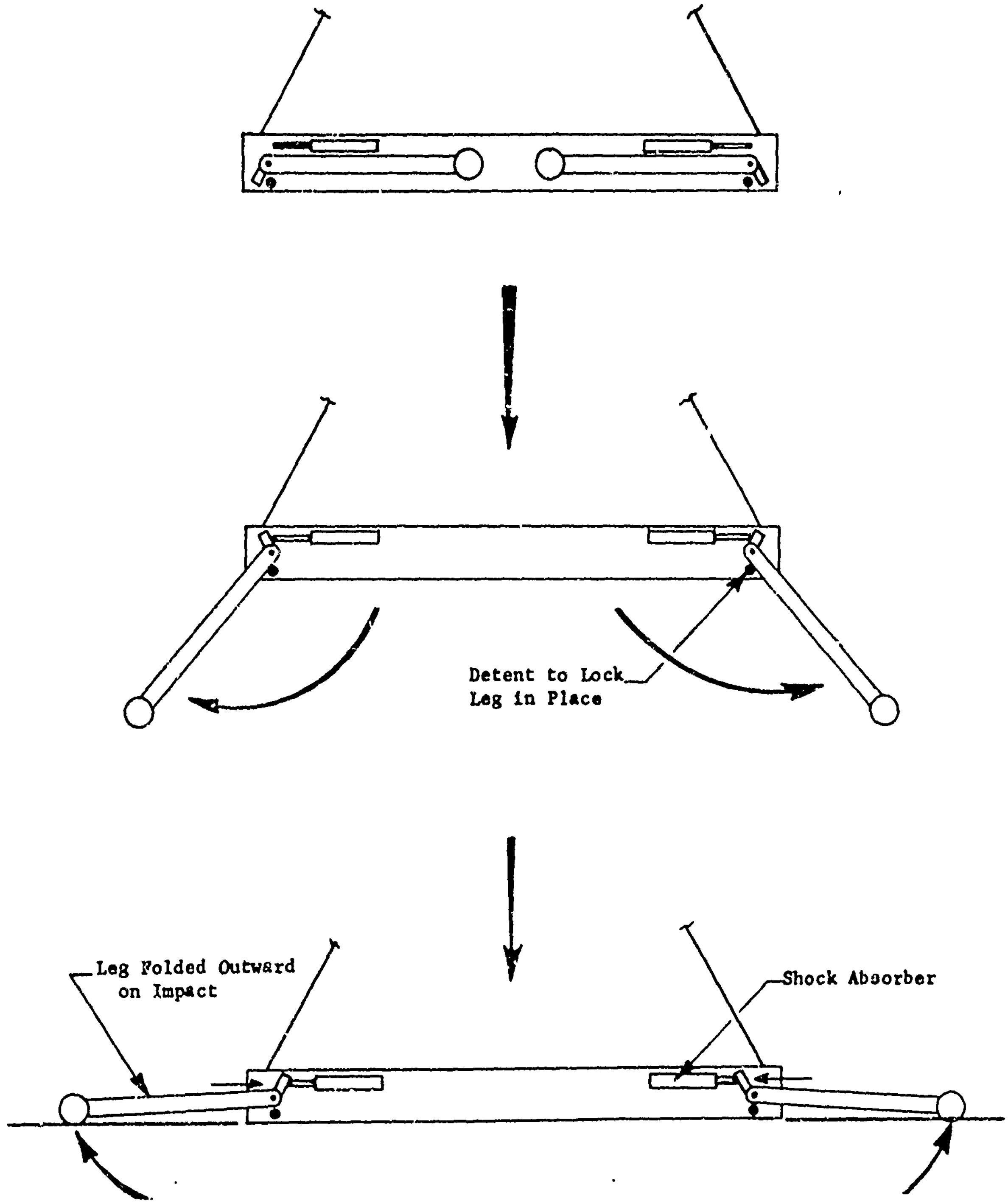
(6) Steel Ribbon Concept

This soft landing system illustrated in Figure 12 is similar to the collapsible leg concept in that shock absorbers are mounted horizontally under a load bearing pallet. The stock absorbers are connected to two sliding side rails through a roller and flexible steel ribbon. Upon impact, the side rails are driven upward pulling on the shock absorbers. Preliminary calculations show that for a 20,000 lb. load, 12 shock absorbers rated at 155,000 in-lb each, are needed, and to transmit these shock obsorber forces to the side rails, steel ribbons .015 inches thick and 3.0 inches wide would be required.

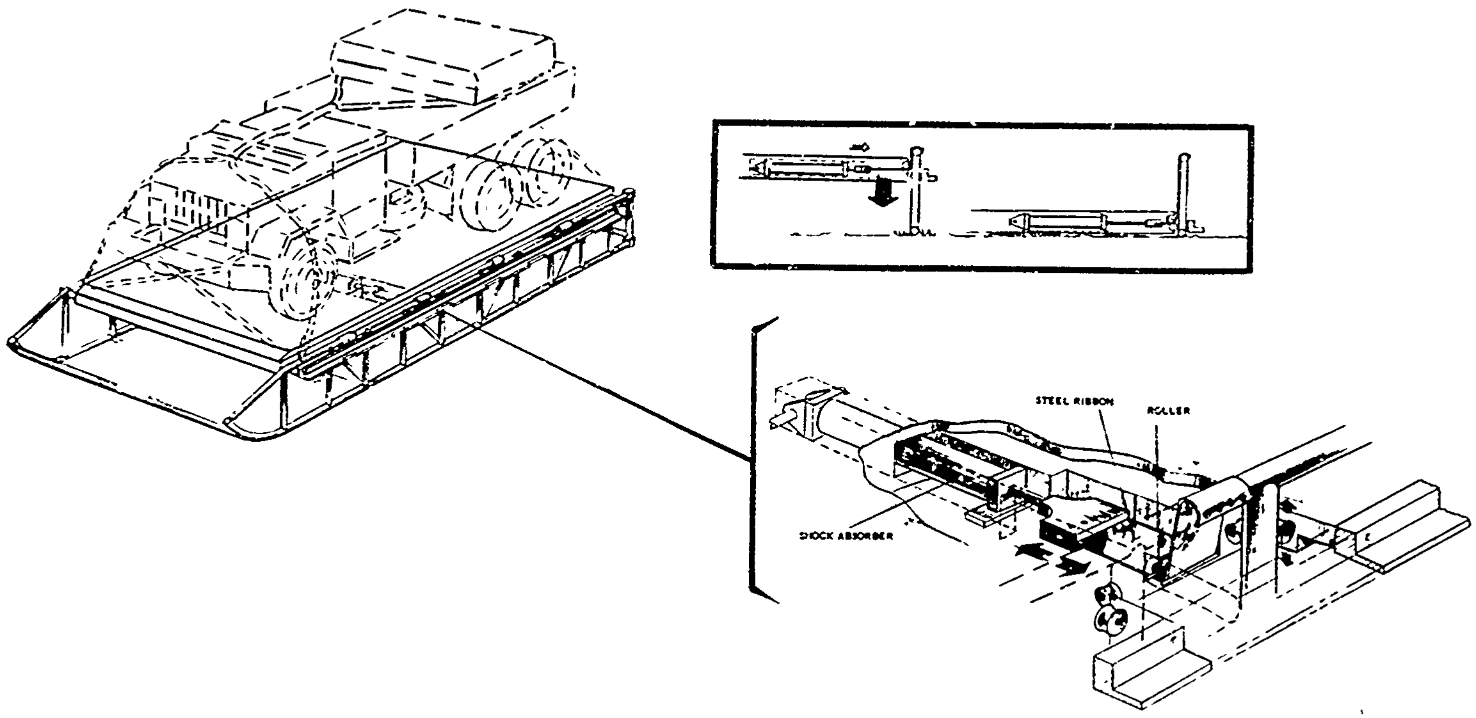


COLLAPSIBLE LEG ENERGY DISSIPATOR

FIGURE 10



COLLAPSIBLE LEG CONCEPT
WIDE STANCE CONFIGURATION
FIGURE 11



STEEL RIBBON SOFT LANDING CONCEPT

FIGURE 12

While in the aircraft, the side rails are stored in a retracted position next to the cargo. After extraction, return springs in the shock absorbers pull the side rails down into position. A skid surface is mounted on the front of the pallet so that, with proper orientation, sliding of the platform will be facilitated under high wind conditions. The aft end of the pallet consists of two cross members that help to support the side rails. These cross members swing open to allow drive-on;drive-off capability.

Because the action on the shock absorbers is one of pulling rather than pushing, the "steel ribbon" concept allows the use of long stroke shock absorbers without the column bending problems associated with long compression strokes. The ribbons serve as a compact means of effecting a 90° change in the direction of the deceleration forces. The length of the pallet could be controlled by adding or subtracting sections and adjustable shock absorbers would allow the same components to be used for all weights of cargo. However, the high c.g. configuration again presents the tip-over problem as well as the necessity of proper nose-first orientation. For these reasons the feasibility of the system is doubtful.

B. Rocket Powered Soft Landing Systems

1. Skirt Jet Principle

The use of rockets in a soft landing system has great appeal because of the possibility of storing a large source of energy in a relatively small volume. One concept considered is the Jet Curtain Retardation System shown in Figure 13. The system consists of a series of several rocket nozzles mounted around the perimeter of the load. When the cargo approaches the ground the rockets fire, decelerating the load through retro-rocket action as well as creating and maintaining a plenum chamber within the curtain. This added bonus of the air cushion increases the effectiveness of the rockets and supplies a ground effect action similar to a hover-craft.

Development and testing of such a system was undertaken by Northrop Corporation in 1965. A test vehicle weighing 1100 lb. and 42 inches in diameter was decelerated from velocities of 13-20 fps to around 3 fps with 3.3 lb. of propellant. The existence of the hover effect generated by the rocket curtain was substantiated and measured during test drops from heights of 4.5 to 7 feet.

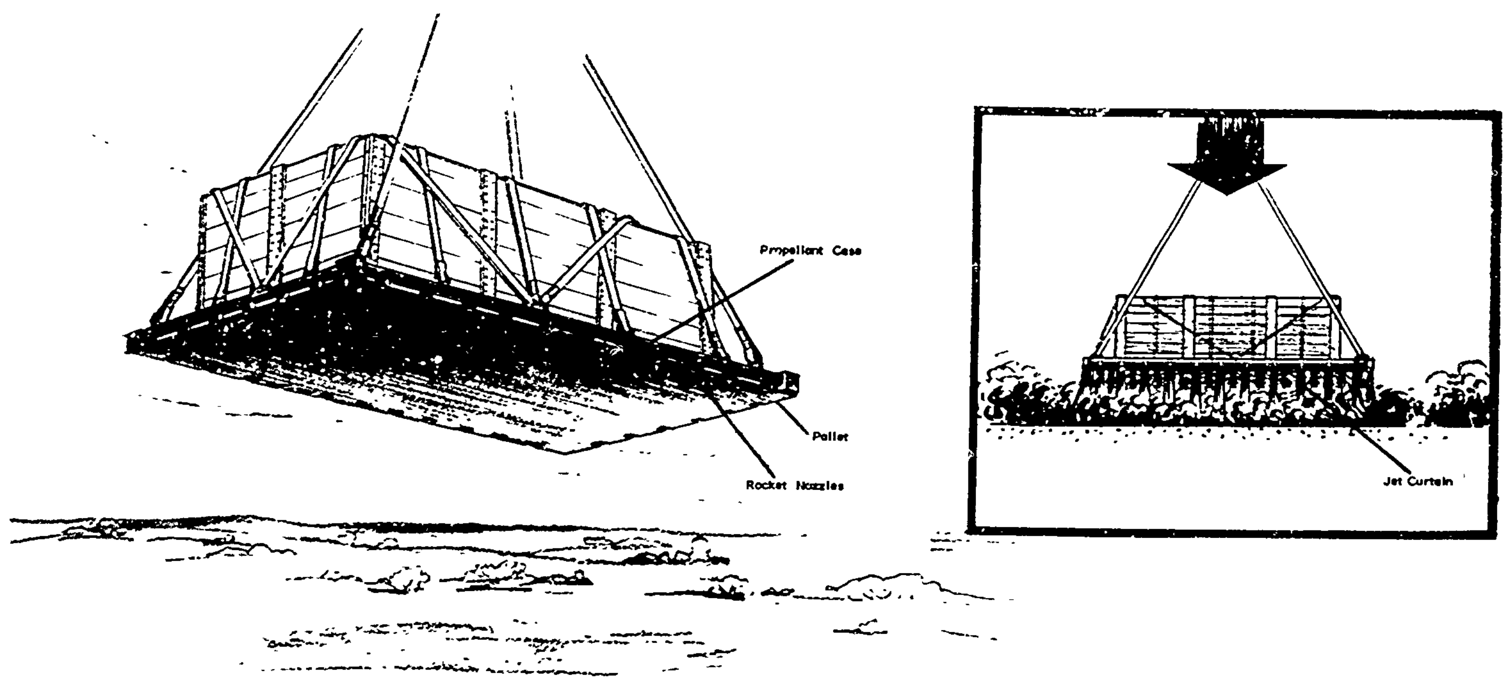
The test data on this style equipment is limited, but an estimate of airdrop requirements can be obtained based upon weight and energy scaling. The test model had a nominal burn time of .050 seconds for its 3.3 lb. propellant charge. In one test, the rockets were initiated when the test vehicle had a velocity of 17 fps at a height of 20 inches. Burnout occurred at a height of 14 inches and a velocity of 6 fps. The deceleration experienced during this test was

$$a = \frac{v_F^2 - v_o^2}{2S} = \frac{(6)^2 - (17)^2}{2(.5)}$$

$$= 252 \text{ ft/sec}^2 = 7.82 \text{ g's}$$

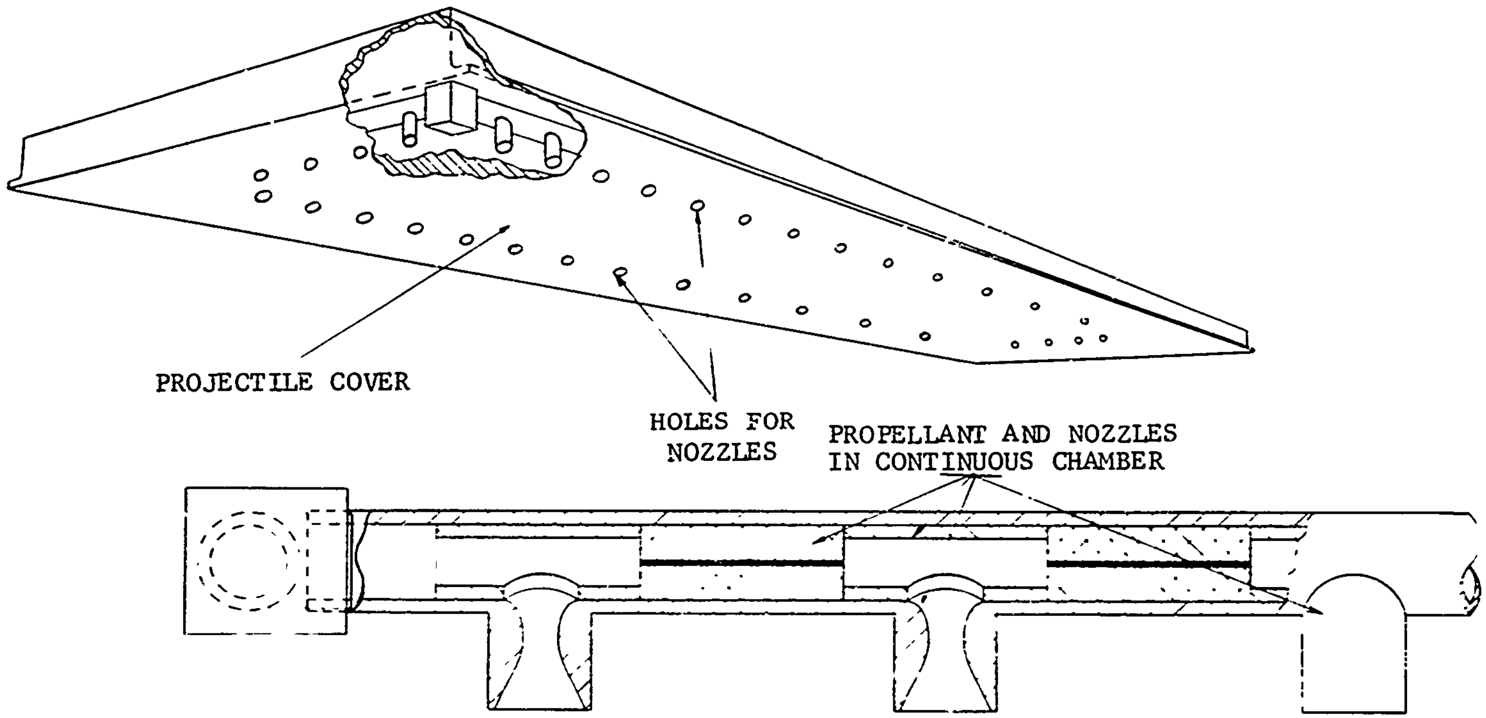
This is close to the goal of 5 g's that the equipment is expected to withstand and only a small adjustment would be necessary to meet this goal.

For large scale systems, Northrup has suggested individual rocket segments weighing five pounds each and containing 2.5 pounds of propellant. These segments would be combined into a long chamber running the length or width of the platform and having several nozzles as shown in Figure 14. Each segment would produce a total impulse of 630 pound-seconds. If the system is designed for a constant 5 g deceleration, a burn time of .155 seconds is required to decelerate the



SKIRT-JET RETARDATION CONCEPT

FIGURE 13



ROCKET UNIT FOR SKIRT-JET CONCEPT

FIGURE 14

load from a velocity of 25 fps to zero. If the propellant grain is designed to produce 630 pound-seconds of impulse in .155 seconds, the rocket thrust would be 4060 pounds. The forces required to decelerate various weight loads from 25 fps at a constant deceleration of 5 g's along with the estimated number of rocket units required are shown in Table 4.

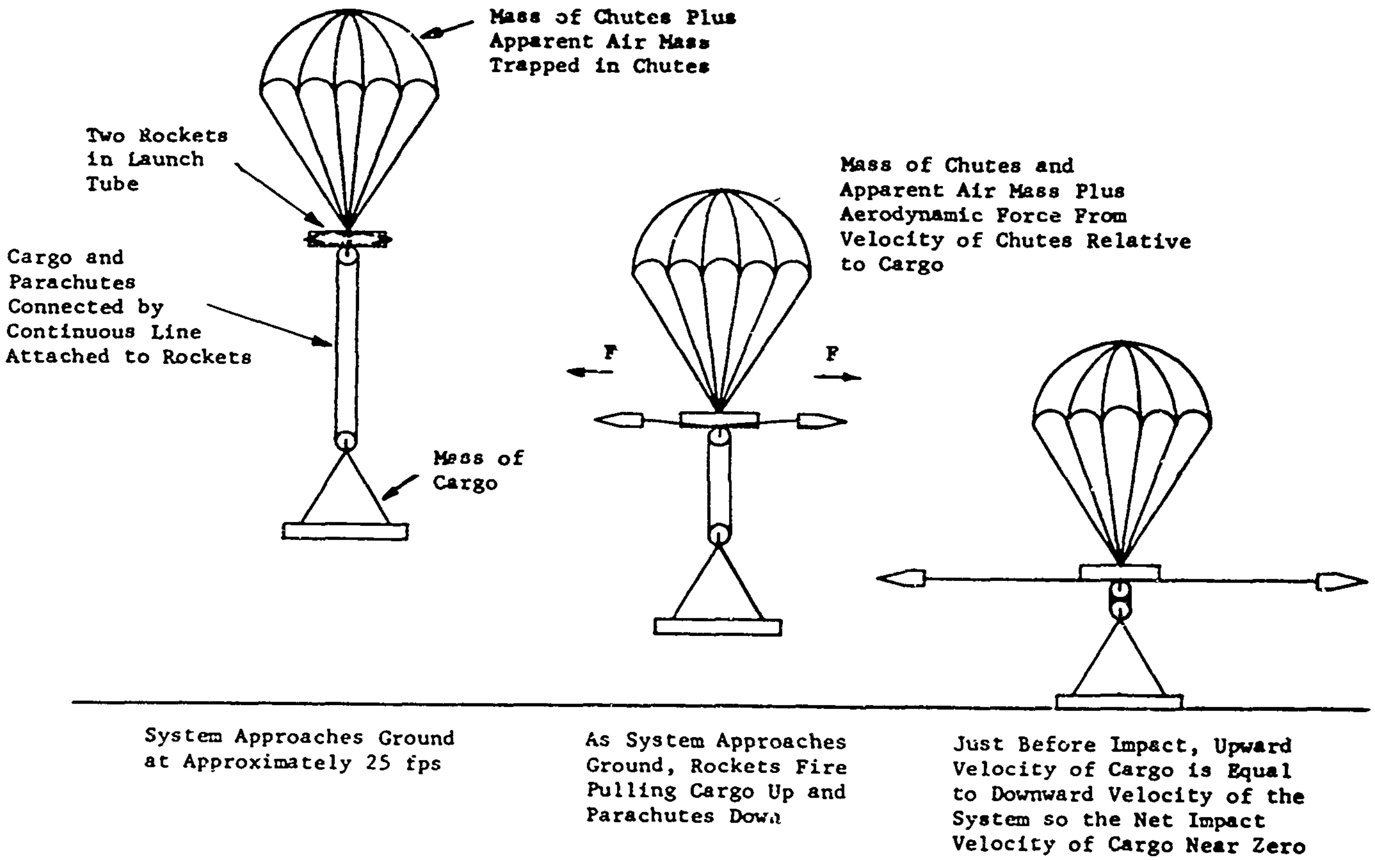
TABLE 4. ROCKETS NEEDED TO SOFT LAND VARIOUS LOADS

Total Payload (lb)	Average Decelerating Force (lb)	No. Of Rocket Units At 4060# Thrust	Total Rocket Weight (lb)
5,000	25,000	7	35
10,000	50,000	13	65
15,000	75,000	19	95
20,000	100,000	25	125

This is a preliminary estimate of rocket requirements and the result is quite favorable. The concept would require a load bearing platform and a drive-on, drive-off capability can be envisioned. If this is combined with a simplified restraint system, the overall arrangement is quite favorable as a rapid rigging concept. It would necessitate the use of an accurate ground sensor to initiate the rockets at about 2.0 feet above the ground. The short distance to the ground, however, might make a mechanical sensor feasible which would be very accurate and should be inexpensive.

2. Sky-Hook Principle

Another rocket technique is the Sky Hook Decelerator. The principle is illustrated in Figure 15. The cargo and parachutes are connected through a pulley system to which two rockets are attached. When the system approaches the ground, the rockets fire, pulling the parachutes down and the cargo up. Just before impact, the upward velocity of the cargo is equal to the downward velocity of the system so that the cargo touchdown velocity is zero.



SKY-HOOK CONCEPT

FIGURE 15

As a single example, consider a 20,000 pound cargo falling at 25 fps and retarded by six G-11A parachutes. Assume that each chute is a 60 foot diameter hemisphere and that, because of the compressibility of air, the effective mass of the air in each chute is 1/3 the total mass confined. Thus, for six chutes, the total effective mass is 278 slugs and the mass of the cargo is 625 slugs. Taking into account the added force generated by the parachutes because of the increased velocity after the rockets fire, the equations of motion for the two bodies are

$$M_{p_o} \ddot{x}_p + \frac{C_D \rho A (\dot{x}_p)^2}{2} = 2F \quad \text{(parachute)}$$

$$M_c \ddot{x}_c = 2F \quad \text{(load)}$$

where: M_{p_o} = initial effective mass of parachutes and air

C_D = drag coefficient of chutes

A = total projected area of chutes

ρ = density of air

$\ddot{x}_p$ = acceleration of chutes

t = time

M_c = mass of cargo

$\ddot{x}_c$ = acceleration of cargo

F = thrust of rockets

$\dot{x}_p$ = velocity of parachute

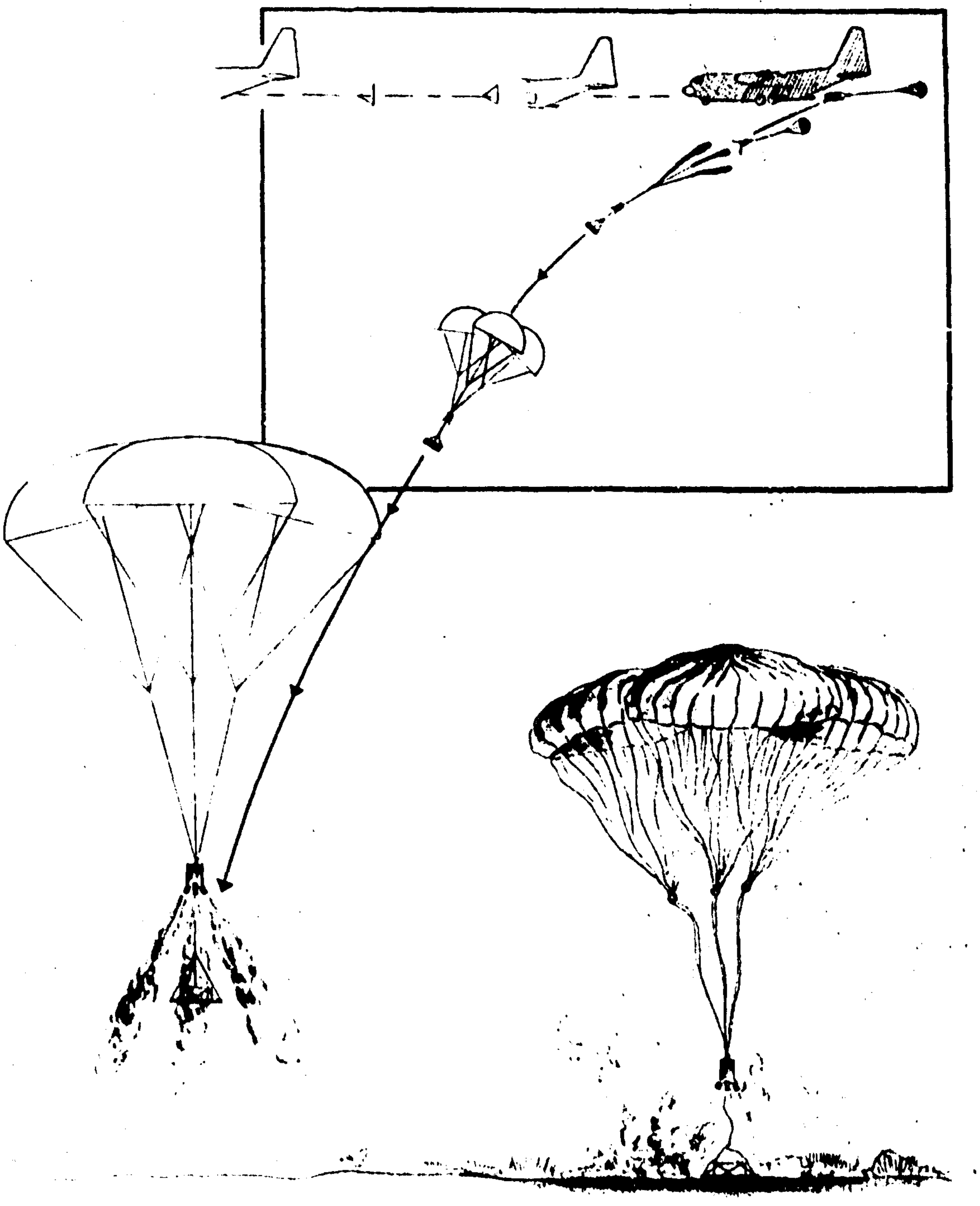
Solution of these differential equations shows that two rockets with a thrust of 15,500 pounds each burning for 1.40 seconds will reduce the velocity of the 20,000 pound cargo from 25 fps to zero in a distance of 17.5 feet. The parachute in the meantime, will increase in velocity to about 31 fps and travel a distance of about 42 feet. The distance between the parachute and the load will decrease about 24.5 feet in the 1.40 seconds which is quite reasonable. The rockets would acquire a maximum outward velocity of about 42 fps which could be arrested by the cables so they would stay attached to the load and a possible safety hazard would be avoided.

This concept would employ a load bearing platform, a drive-on, drive-off vehicle capability, and a simplified restraint system to provide a good solution to the rapid rigging problem. It, like the jet curtain, would require the use of an accurate ground sensor to initiate the rockets at a distance of about 17.5 feet above the ground. The deceleration forces generated by the rockets in this example are very small, about 0.5 g's. If the rocket thrust were increased the cargo deceleration would increase and actuation of the process could begin close enough to the ground to make a mechanical sensor feasible. This system is quite simple in concept and early experiments of the principle could be made using current airdrop equipment.

3. Parachute Retrorocket Airdrop System

A soft landing concept based upon the use of retrorockets is illustrated in Figure 16. This concept is based upon the idea of the PRADS system (Parachute Retrorocket Airdrop System) which may be developed in the near future. The idea is to fire a set of rockets as the airdrop nears its landing location. These rockets will generate a thrust force that can be used to rapdily diminish the descent velocity just before touchdown. Theoretically the descent velocity can be reduced almost to zero just before touchdown so that a soft landing will result. The degree of control required to assure a soft landing may prove to be difficult, but this situation should be monitored as the system progresses through development to determine if precise control of the touchdown velocity is feasible. If a positive answer is obtained, the benefits derived from simplification of the rigging procedures could overshadow the primary reason for current system development.

The concept involves the same approach as the previous two rocket assisted designs. In this instance, however, initiation of the rockets occurs at a greater height because smaller parachutes are used and descent velocities are higher at time of rocket firing (this is a characteristic of the PRADS system). A sensor will be developed which will work at the proper height. Accuracy requirements for this height sensor may be more rigid for soft landing than conventional PRADS and this aspect of the problem must be studied as information on the PRADS system becomes available.



PARACHUTE RETROROCKET AIRDROP SYSTEM

FIGURE 16

c. Miscellaneous Soft Landing Systems

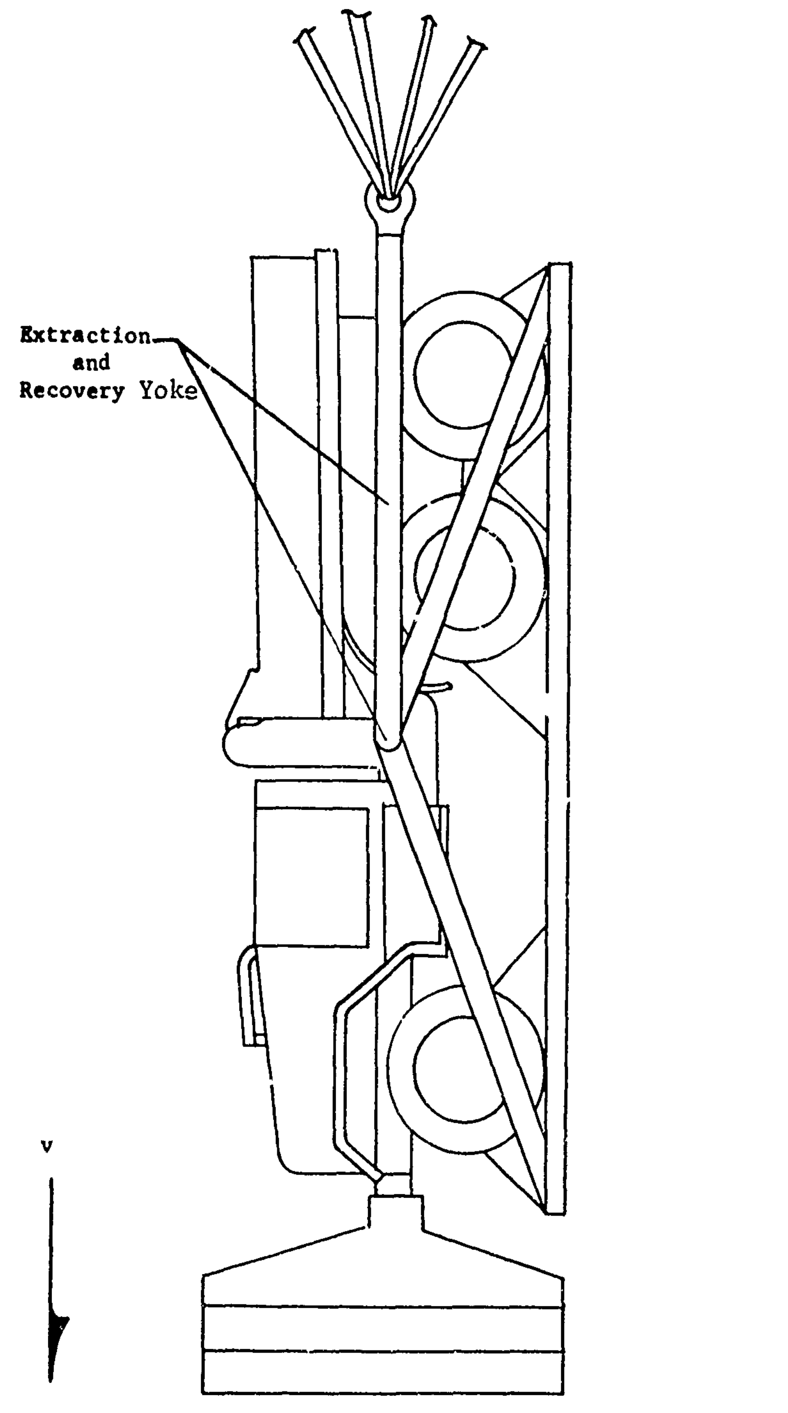
(1) No-Force Transfer System

A No-Force Transfer Concept was investigated based upon the premise that elimination of the force transfer event would simplify the extraction system and airdrop sequence thus improving overall performance. In essence the system eliminates force transfer by positioning the energy dissipator at the end of the cargo as shown in Figure 17. It was realized that vehicular loads are not intended to absorb impact in this direction but it was felt that if a "soft landing" could be achieved, the cargo would sustain the landing deceleration forces.

As a first estimate, an energy dissipator system based on paper honeycomb was studied. Several types of honey comb were examined with energy absorbing characteristics from 1460 to 5960 ft-lb/ft^3 at average stresses of 2100 to 8500 lb/ft^2 respectively. Based on a strain of 70 percent, the height of honeycomb for any of the honeycomb materials and any cargo weight is about 2.75 ft. The critical parameter is the stress area. This condition simplifies the design of the decelerator because it will be possible to use standardized units of honeycomb.

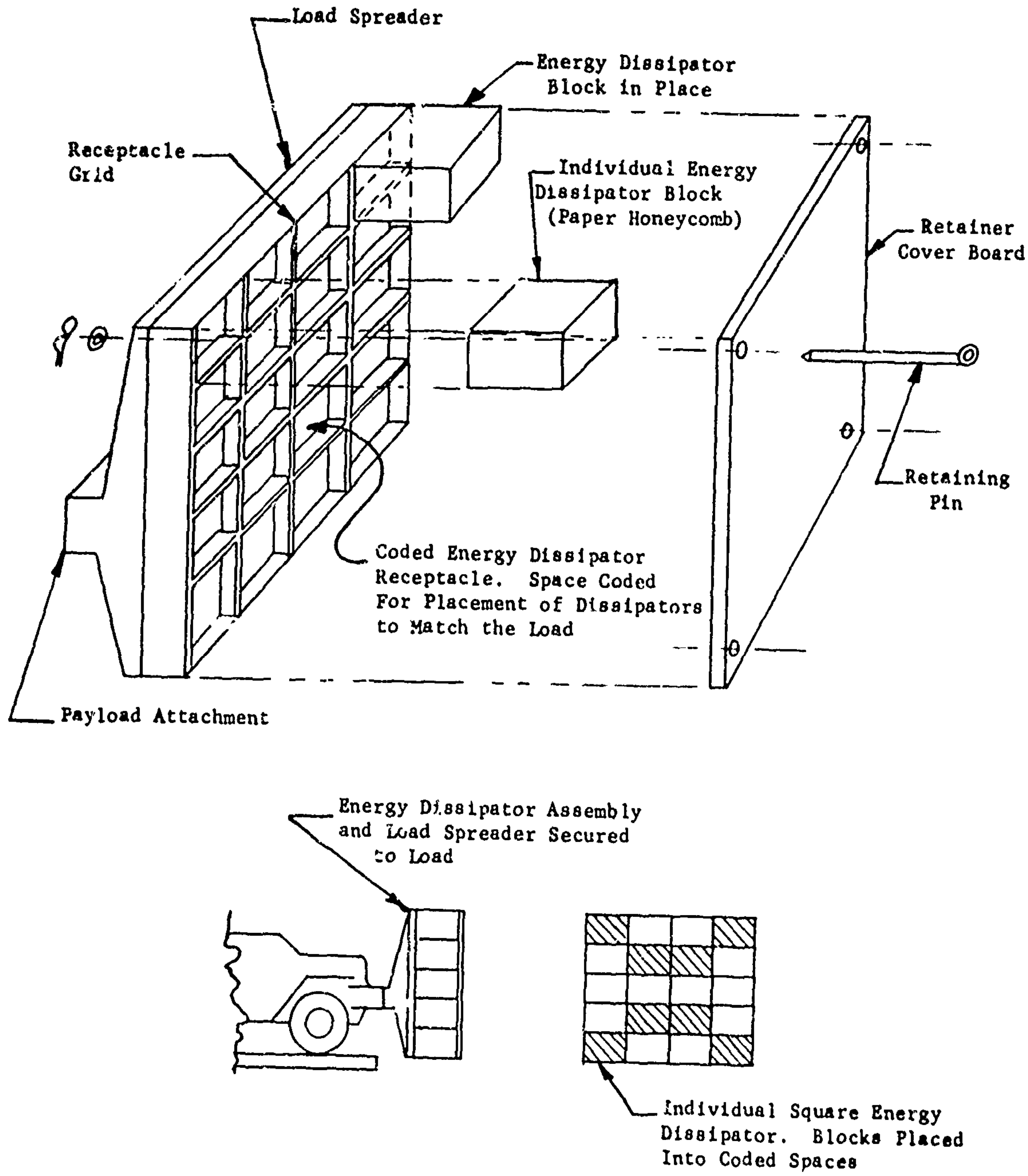
One concept for such a system is illustrated in Figure 18. A load spreader which is attached to the cargo is divided into grid sections of one square foot each so that the standard honeycomb units can be set in place. The weight of the cargo does not have an effect on the total required stroke since the deceleration of 5 g's is held constant. For a given honeycomb material and assuming an average crushing force, the only factor that changes for different cargoes is the stress area. For instance, considering a honeycomb material rated at 2470 ft-lb/ft^3 at an average stress of 3500 lb/ft^2, a 5000 lb cargo requires a stress area of 7.1 ft^2, a 10,000 lb cargo will require 14.3 ft^2, etc. Thus, by adjusting the number of honeycomb units, the desired stress area can be obtained for any cargo. The same load spreader could be used for all cargoes and the number of honeycomb units and their locations could be color or number coded in the spreader grid itself to simplify rigging.

A principal concern with the concept is protecting the cargo as it tips over from its nose or tail down landing orientation. Several possible methods are illustrated in Figures 19,20 & 21. Figure 19 shows how roll bars can be used to prevent the cargo from directly impacting the ground. Figure 20 presents a modification of the simple roll bar in that a cover of some light but strong corrugated



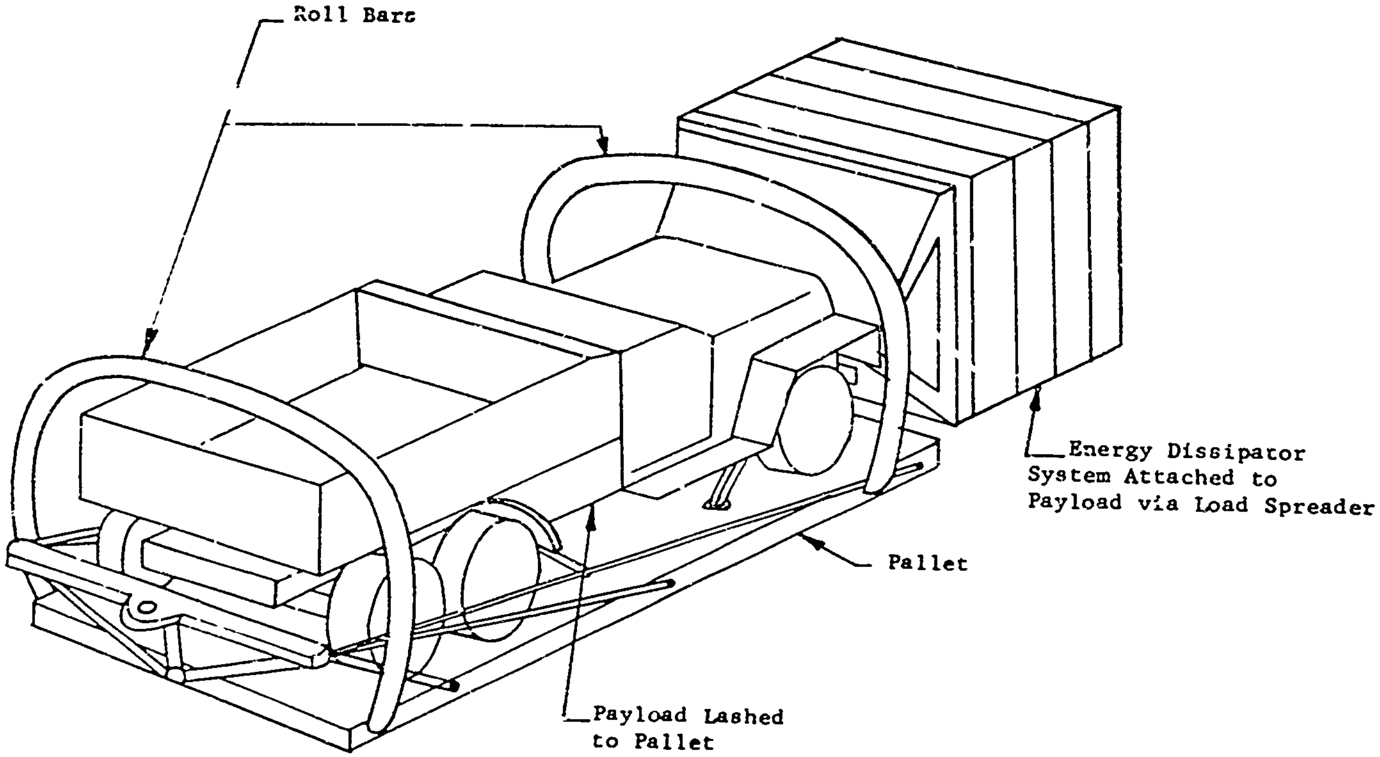
NO FORCE TRANSFER CONCEPT

FIGURE 17



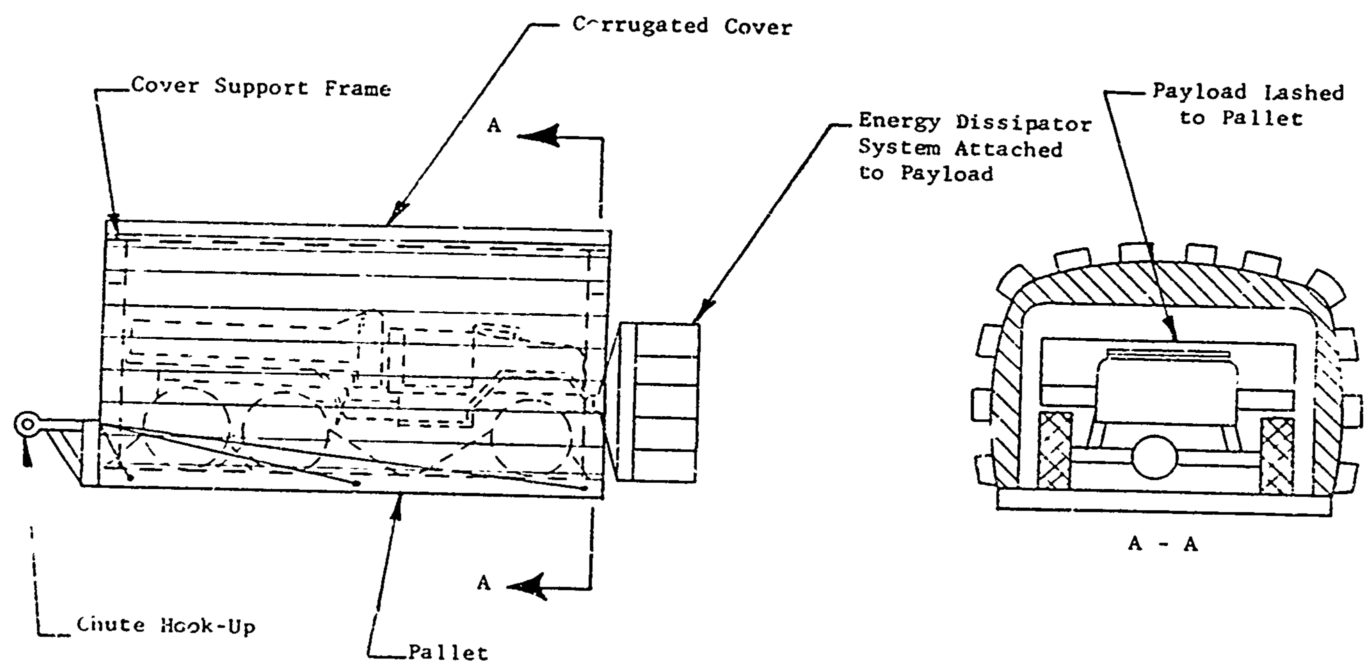
ADJUSTABLE ENERGY DISSIPATOR

FIGURE 18



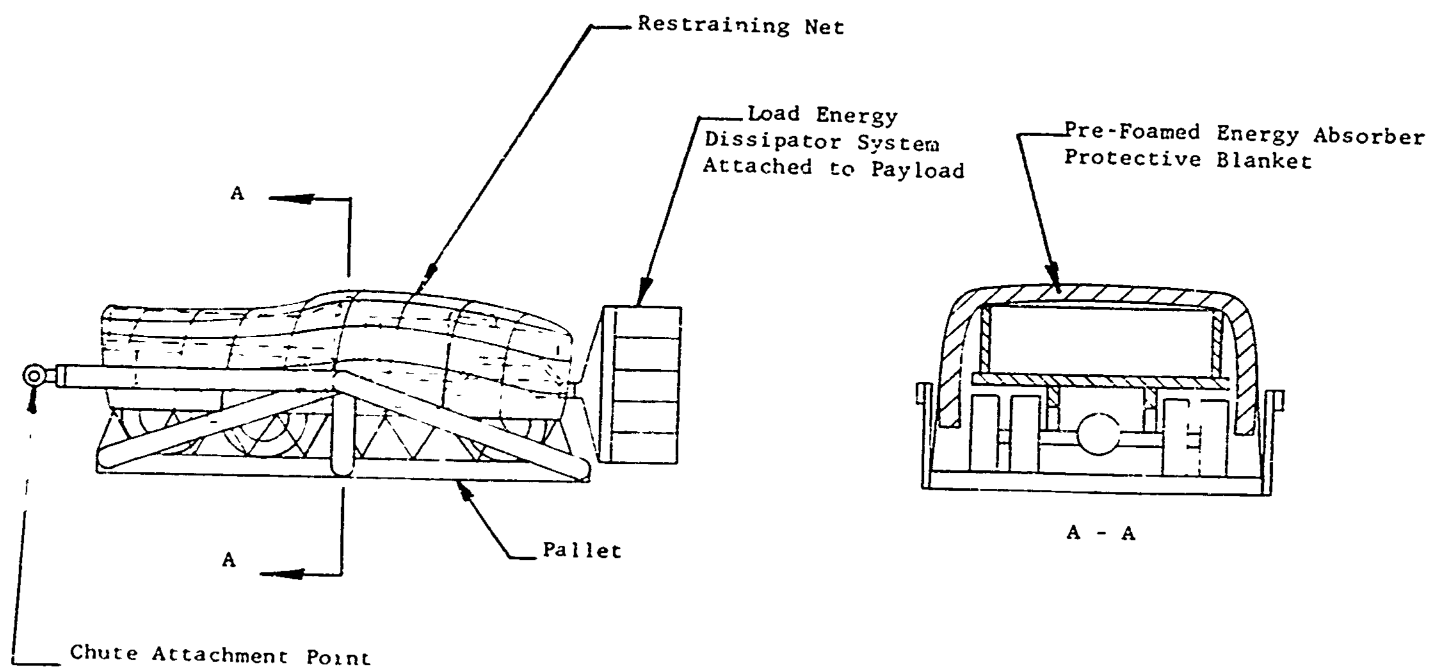
ROLL BAR PROTECTOR

FIGURE 19



ROLL-OVE : PROTECTIVE COVER AND RIGHTING AID

FIGURE 20



PROTECTIVE FOAM BLANKET

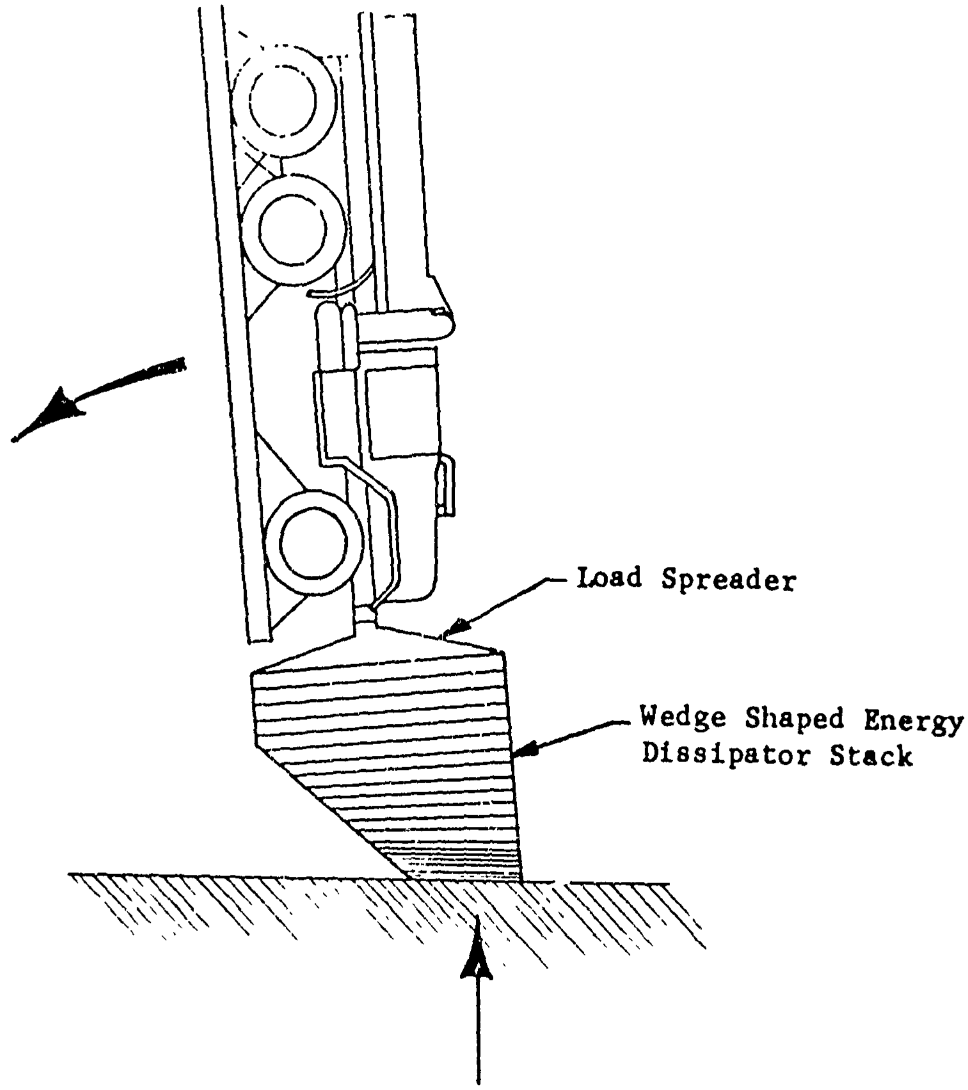
FIGURE 21

material such as aluminum or glass filled plastic is mounted over the roll bars. The covering would present a larger surface area in contact with the ground and prevent the roll bars from sinking into soft soil or sand. Both systems have a sufficient radius to aid in rolling the cargo to the proper drive-off orientation. A third possibility is shown in Figure 21 and consists of a blanket of energy absorbing foam placed over the cargo and held in place by a net. The net could be drawn down tight and used to supply a great deal of the required vertical restraint.

All of the above systems are designed for a random toppling of the cargo. If the payload can always be made to topple in the direction of the wheels, the suspension system of the vehicle can be used to absorb some of the energy. Figures 22 and 23 illustrate two possible techniques for tipping the payload in the desired direction. The use of a wedge shaped dissipator is shown in Figure 22 . The angle is greatly exaggerated in the drawing but shows how a wedge shaped cover used on the standard load spreader discussed earlier could be used to bias the tipping direction. The system shown in Figure 23 is similar to the wedge system,only the tipping moment is supplied by a rigid section in one side of the dissipator. The stiff member is designed so that it prevents continued crushing of one side of the dissipator after nearly all of the kinetic energy is absorbed. As the unsupported side continues to deflect, the cargo topples in the direction of the crushing motion.

From the standpoint of energy absorbtion it is most desirable to have the cargo topple onto the wheels. Considering a 20 foot long 20,000 pound load (2-1/2 ton truck), the kinetic energy of the toppling cargo is about 130,000 foot-lbs. Considering a combined spring rate for tires and suspension system of 3660 lb/in for each wheel and an allowable deflection of 8 inches, the energy absorbed is 77,700 ft-lb. If the additional 52,300 ft-lb could be absorbed through about 6 inches of honeycomb, the average decelerating force could be reduced to around 5.5 g's.

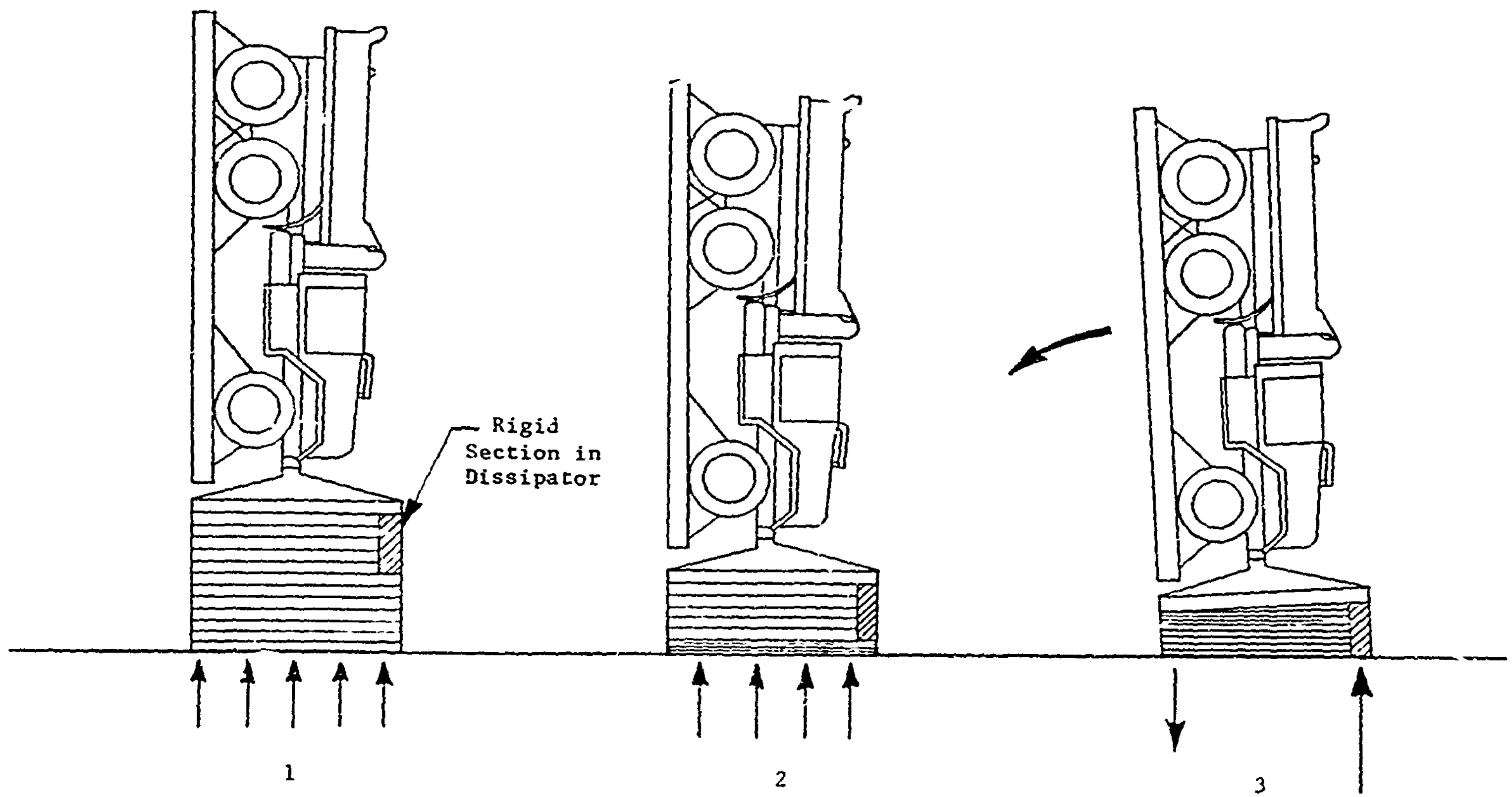
In addition to the toppling problem and the added weight and number of components to solve it, the no force transfer concept possesses some other drawbacks. Higher opening shocks of longer time duration will probably result, and the use of larger parachutes such as the 135 foot flat circular parachute being developed could result in excessive extraction and/or suspension forces. Also the addition of an energy dissipator to the forward end of the cargo would reduce the quantity of load items which could be placed in the aircraft cargo compartment not to mention the unanswered question of whether a vehicle can withstand the end-first decelerations.



WEDGE SHAPED ENERGY DISSIPATOR TO

TIP PAYLOAD DURING CRUSHING

FIGURE 22



RIGID SECTION TIPPING AID

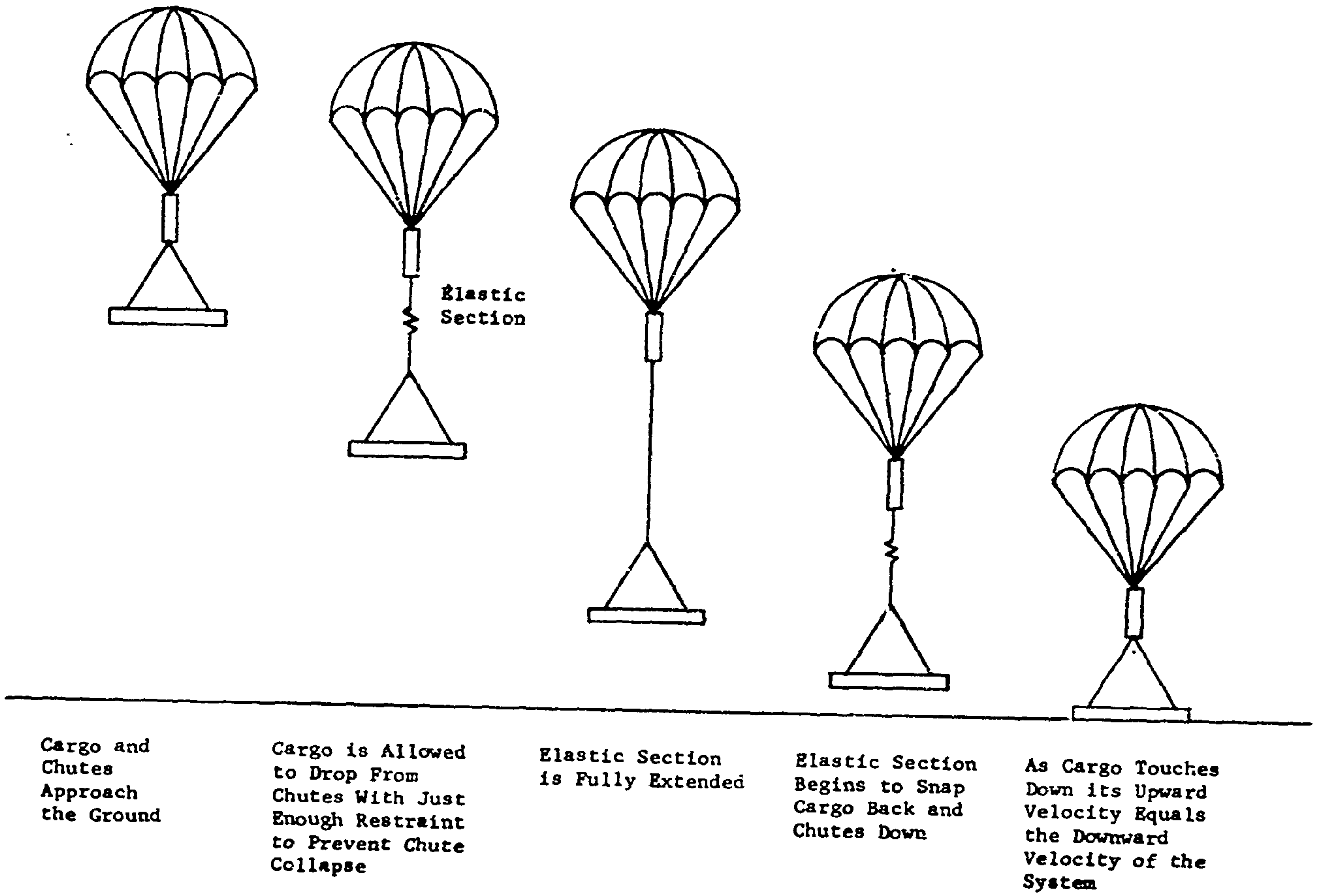
FIGURE 23

These problems cast doubt on the feasibility of the concept, at least for moderate to heavy vehicular loads. However, the system appears to be very well suited to containerized supply loads and perhaps some light vehicles and for this reason it should not be completely disregarded.

(2) Yo-Yo Concept

A novel idea that was considered is the "Yo-Yo" concept shown in Figure 24 which is somewhat similar to the Sky-Hook Concept. An elastic section (extension springs, etc.) is mounted between the parachute and the cargo such that under normal descent conditions the section has considerable slack. At the proper instant the cargo is allowed to separate from the parachutes and fall with only enough resistance to keep the chutes inflated. The falling cargo stretches the elastic section until the separation velocity reaches zero. At this point the elastic section pulls the chutes and cargo together and the cargo touches down as its closing velocity relative to the parachutes, equals the downward velocity of the parachutes. Touchdown is thus, accomplished at a zero decent velocity, relative to the ground.

Preliminary calculations for a 20,000 pound load show that for the system to function and give an upward cargo velocity of 25 fps relative to the parachutes, the elastic section must have a spring constant of 3100 lb/ft and be deflected 10 feet by the time the cargo free falls 31 feet. Although the system is theoretically possible, several problems must be overcome before it could become operational. Finding an elastic system that could supply the necessary spring force and deflection characteristics and still be light and compact could be a problem. In addition, the system would need a sensitive and accurate ground sensing device because timing is critical for proper operation. Also, the spring assembly would require tuning or matching to each load which could be a troublesome operational feature. Its advantage is conceptual simplicity and for this reason it merits consideration.



YO-YO CONCEPT

FIGURE 24

2. Restraint Concepts

Another major area of investigation was the techniques used to restrain the cargo during ground handling, flight, drop and impact. At present, the cargo is lashed to the pallet with cotton or nylon straps which entails both considerable time and skill. Any method that could reduce the weight, size, complexity or number of restraint devices needed for rigging airdrop loads would be of significance. Included in the following section are a number of restraint techniques that were given consideration during the study.

a. Containers

The use of a container to house an airdrop cargo would provide several improvements over the present rigging system. the rigging of the extraction, and suspension parachute systems would be simplified resulting in cost and time savings and improved reliability. However, the need for internal restraint between the container and the cargo to prevent relative motion becomes a critical problem.

To determine the present state of the art for container development an investigative study was conducted. Numerous reports and publications such as "Container News" were reviewed to determine the adaptability of containers to airdrop. Containers are used for shipping and handling supplies in an efficient manner. For supply type loads the present airdrop rigging system has utilized this containerization principle. However, the adaptability of vehicles to containerization would require extensive research. Conclusions about containerization for airdrop were somewhat negative but because of the many possible advantages, the following concepts are presented with the hope that they may spark continued investigation in this area.

(1) Viscous Fluid Container

In this concept the cargo is placed inside a container filled with a very viscous fluid which dampens response to container motions. In effect the cargo is contained in its own artificial "womb". The concept is technically feasible on a small scale and some delicate instrumentation is protected in this manner. However, the weight of fluid required to package large vehicles would be exorbitant not to mention sealing problems. Unless a major advance in the state-of-the-art produces an extremely light, highly viscous fluid, the concept appears to be totally unfeasible.

(2) Airbags Encapsulated in a Container

This concept is illustrated in the artist's sketch of Figure 25 . Small air bags are positioned between the cargo and the walls of the container housing the cargo and air bags. The purpose of the air bags is to provide the necessary in-flight restraint and to prevent cargo damage on impact. The use of the container to enclose the cargo would provide attachment points for the extraction and suspension lines.

Some of the advantages of using this technique are:

1. The tiedown lashings and all the hardware associated with the tiedowns are eliminated.

2. The use of a container allows easy connection for the suspension and extraction lines.

3. A readily available location for the parachutes is provided by the container's flat surface.

Some of the disadvantages are:

1. The system cost can be greater due to the high cost of the air bags and container.

2. The container and air bag weight will be heavier than the present rigging components.

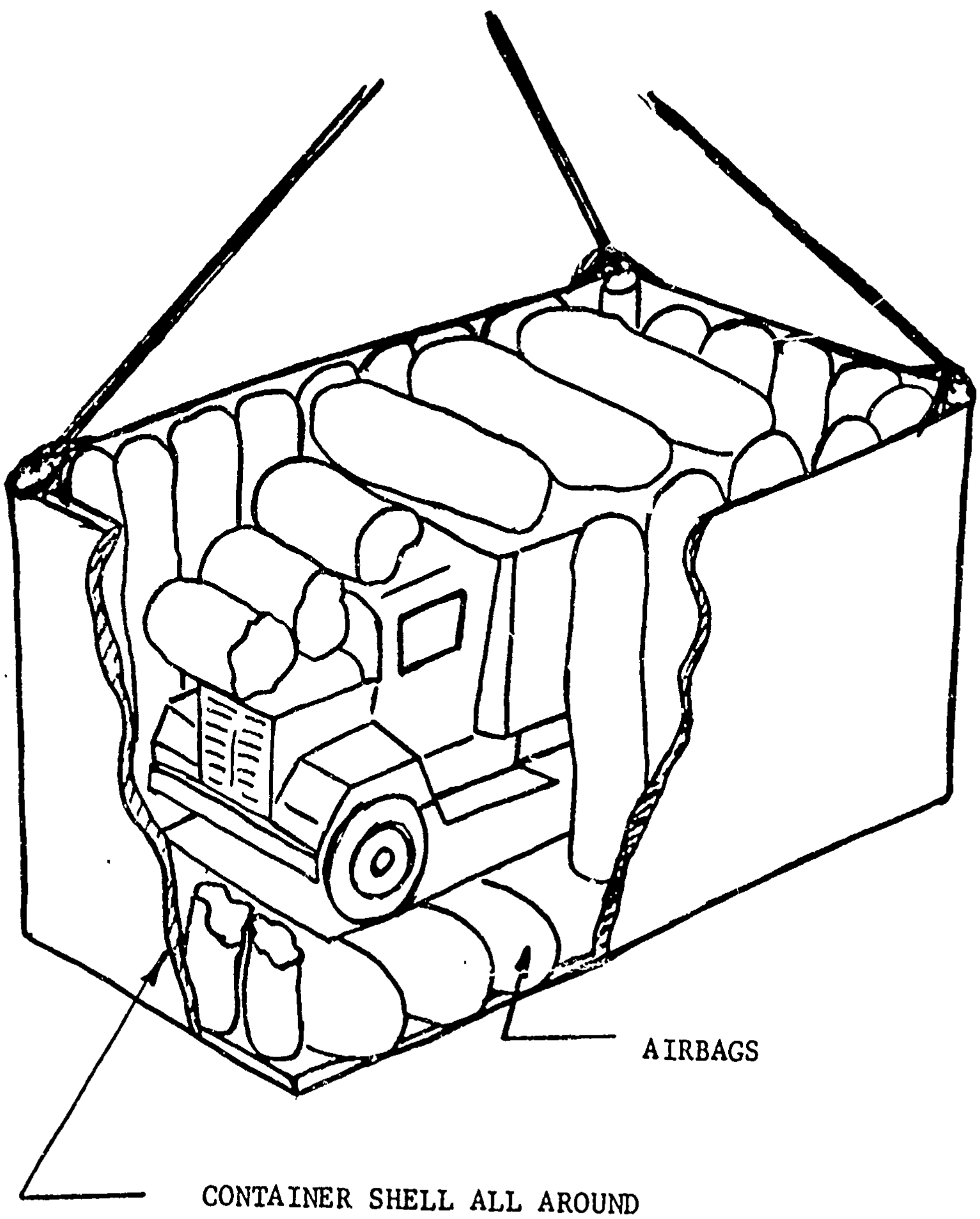
3. A large container structure is required to withstand the loadings imposed.

4. The retrieval characteristics of the system are poor. A large residue will result and the air bags must be removed from the underside of the vehicle to allow removal of vehicles from the container.

5. Inflation of the air bags requires additional new equipment to be included in the airdrop inventory

6. Some sort of energy dissipator may still be needed because the air bags would have a tendency to cause rebound.

7. Altitude differential causes pressure changes in bags resulting in varying restraint.



CONTAINER-AIRBAG CONCEPT

FIGURE 25

The weight and cost of this approach would be rather high. Also excessive rebound action is likely upon impact, which could result in a damaged cargo. The idea is not considered feasible.

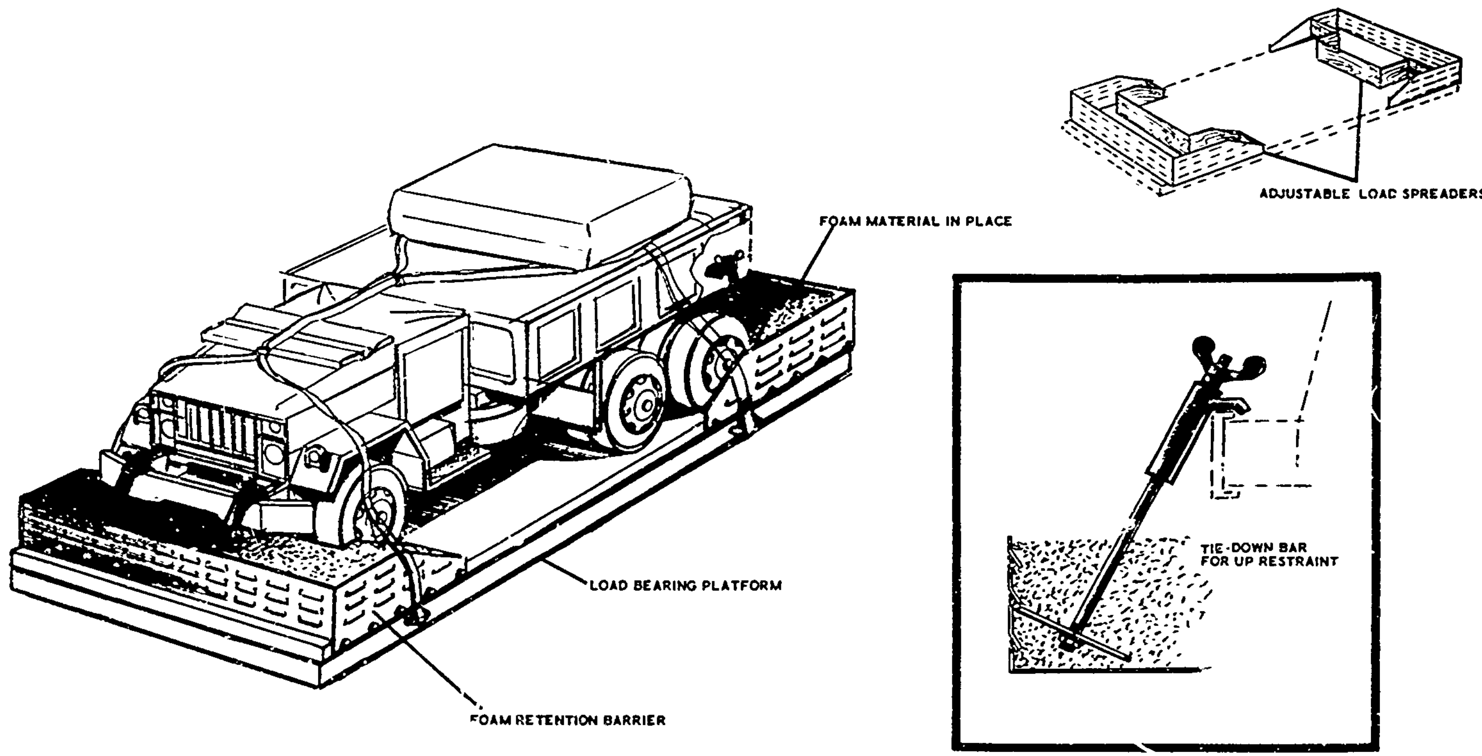
(3) Foam-in-Place Restraint

Another concept was the use of foam-in-place restraint for the cargo. One such system is illustrated in Figure 26. Two containers are formed at either end of the vehicle. An adjustable load spreader is positioned for the specific vehicle under consideration, tie-down bars are set in place and dense rigid foam material pumped into the cavities. The volume of foam required for most cargoes will be on the order of 30-60 cubic feet. Assuming that the foam density is on the order of 5 lb/ft^3, the weight of foam needed will be about 300 pounds and there are portable machines available that can mix and pump foam at rates up to 100 pounds per minute. It appears that this system could provide a rapid means of rigging using equipment that is currently in use in industry. After the foam has set up, the tie-down bars can be tightened down. The foam is held in place by teeth along the walls of the containers and, if necessary, a lip at the top of the container. The tiedown bars are held in place by plates. The foam supplies fore and aft restraint while the tie-down bars prevent the cargo from moving away from the pallet. If the upward restraint force must be 4 g's and six tie-down bars are used, the force on each for a 20,000 pound load is 13,300 pounds. If the plate area is 225 in^2, the compressive stress in the foam is 59 psi. Commercial foams of around 2.4 lb/ft^3 density are available with compressive strengths of 60 psi. If compressive strength can be increased by perhaps increasing the density, smaller or fewer tie-downs can be used.

Some of the problems associated with the system are:

1. Increased weight
2. Increased machinery required for rigging.
3. Retrieval characteristics are poor because of a large derigging time and the problem of disposing of the residue.

All in all it does not appear that the above system would have much advantage over the current rigging system. The plastic will require some cure time and various climatic conditions may



FOAM-IN-PLACE RESTRAINT

FIGURE 26

have effects on the density and strength of the foam. For these reasons the feasibility of the concept is questionable.

(4) Vacuum Packing

Several methods of applying vacuum packing techniques were considered:

1. Restraining the cargo to the pallet

2. Supporting weak items such as windshield, muffler, tail pipes, etc.

3. Rigidizing loose cargo such as boxes of food, ammunition, etc.

Cargo restraint would be achieved by completely enclosing the cargo and pallet in a plastic coated fabric bag and drawing a vacuum. If all the slack could be taken up, the vertical restraint would be equal to the sum of the pressure differential acting over the cargo and pallet area plus the strength of the bag material acting through its total cross-section.

Considering a 20,000 pound cargo on a 8' x 20' pallet, if a 5 psi pressure differential is drawn on the bag, the force acting to restrain the cargo to the pallet is 115,000 pound or about 5.75g's. A vehicle may be able to withstand this constant force but it must be remembered that these conditions exist at ground level. If an unpressurized aircraft went as high as 10,000 feet, the atmospheric pressure would drop to about 70% of what it was at ground level. If this happened, the 5 psi differential would drop to about .40 psi for a restraining force of only 9200 pounds or .46g. If the pressure differential were increased so that a 4g restraint could be achieved at 10,000 feet altitude, the pressure differential at ground level would have to be about 9.6 psi. This would create a force on the cargo of 222,000 pound which may be high enough to cause some damage to the vehicle particularly at weak sections such as windows or radiator. A pressurized cargo compartment would partially releave some of this problem. However, when the cargo door was opened in preparation for extraction, the problem would still be present. This would be especially acute if the terrain altitude of the drop zone was much higher than the rigging altitude. For example, the restraint characteristics would vary if the load were rigged at sea level and dropped at a location 5000 ft high in the mountains.

Even if pressure forces were no problem the cargo would still require additional fore, aft and lateral restraint. For all practical purposes the bending strength of the bag material is zero so that the horizontal restraint comes only from the friction of the tires against the pallet if a soft landing system is used or the friction and shear strength of paper honeycomb if conventional energy dissipation is used. If the coefficient of friction of rubber tires on a smooth surface is .17 and an equivalent force for a 4g vertical restraint at 10,000 feet is used, the horizontal restraint is 13,500 pounds which is not enough to meet the 1.5g lateral and aft requirements. No information could be found as to the shear strength of paper honeycomb but it is felt that it would not be sufficient to meet the minimum requirements.

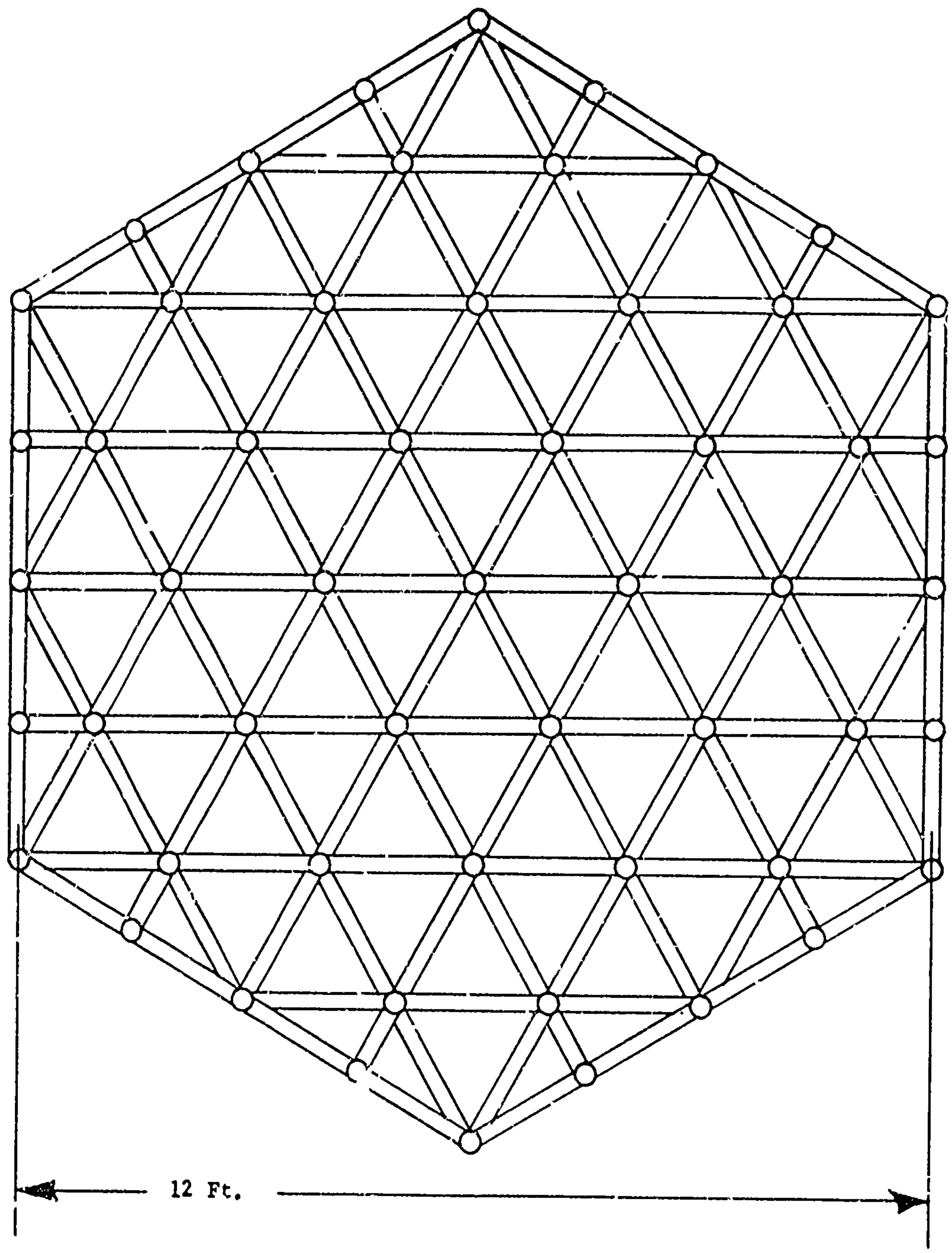
Similar problems are encountered when attempting to use vacuum packing to support engine, transmission, exhaust pipes, etc. Pressure differentials that are sufficient for support at higher altitudes may be large enough to actually damage underbody members at ground level. Using vacuum packing to "rigidize" loose cargo does seem feasible. Such cargo would be packed in boxes, crates and drums that could be stacked in a tight enough configuration that higher pressures would present no problem.

At the present time it appears that the use of vacuum packing for cargo-pallet restraint or support is not feasible. Vacuum packing loose cargo to make it one "solid" body for easier handling does seem possible. However, there is one primary area of caution with any vacuum system. Unless a self-sealing bag is used, great care must be exercised in handling the cargo for a small pin hole could result in loss of vacuum and, as a result, loss of all restraint.

(5) Universal Net

The use of a universal restraint net, Figure 27 was considered because of the simplicity in rigging and de-rigging it would afford. The net would be constructed of woven nylon webbing connected through metal rings. The webbing would be strong enough to supply restraint for the loads. The net would be hexagonally shaped and measure 12 feet across the flats. Proper sizing would allow the net to be used on all loads by folding if necessary on small loads and combining several nets on large ones. Restraint would be supplied by tiedown devices similar to the standard B-1A or C-2 or the "universal tiedown device" discussed in a later section of this report.

Nets are currently used to secure loose cargo to pallets or the aircraft floor. The weakness with the current nets is that each type of net is designed to be used with a particular cargo pallet. The proposed net would be similar to the HCU-11/C tiedown net but a metal ring is used at each web connection. The added flexibility would allow its use on various cargo shapes because the additional rings would supply many points for the attachment of tiedown devices. This



UNIVERSAL RESTRAINT NET

FIGURE 27

would be particularly valuable when securing vehicles and other irregular shapes. Larger loads may require more than one net but this presents no problem because the design of the nets would allow them to be tied together easily.

Because of their simplicity, nets should be given greater consideration at least for the lighter weight class loads.

b. Miscellaneous Restraint Concepts

(1) Elastic Bands

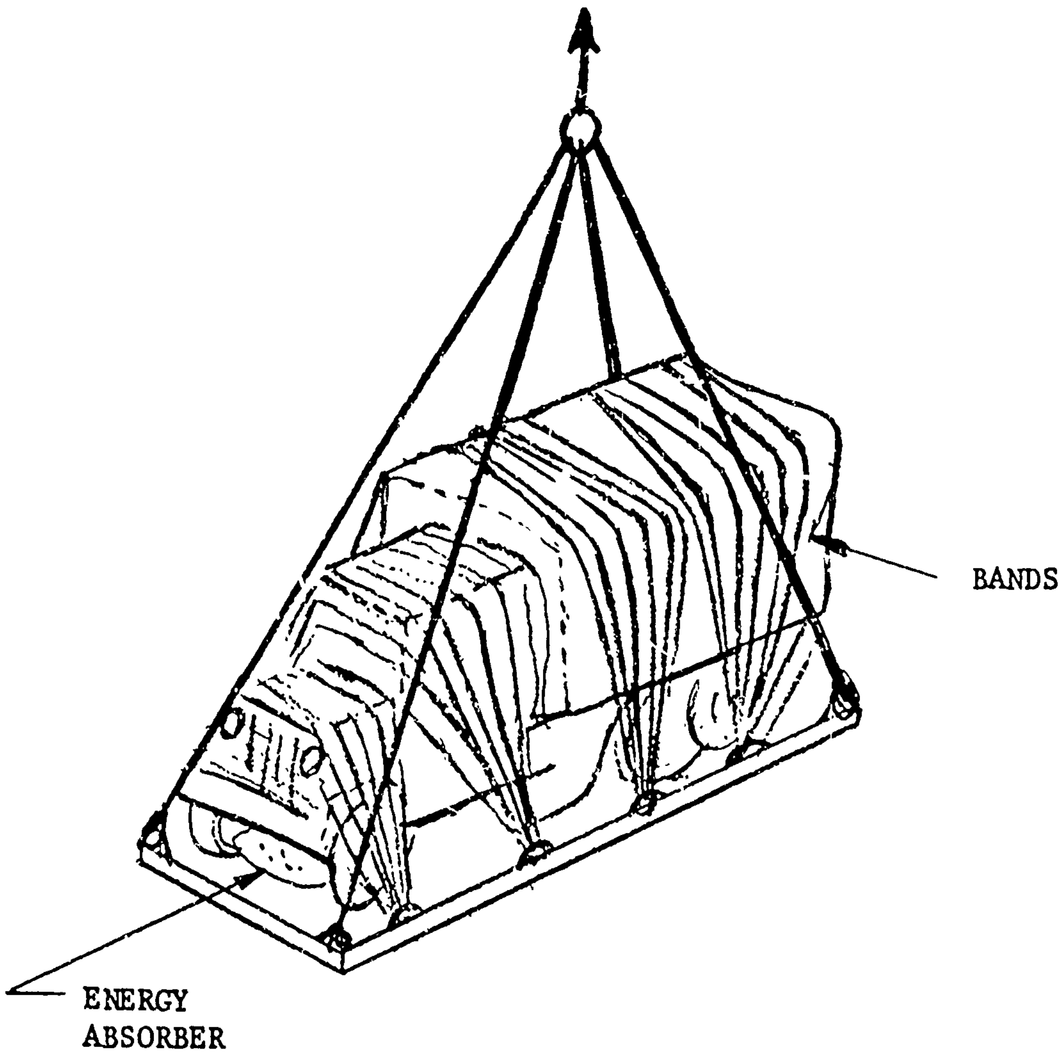
The possibility of using elastic bands as a restraint device rather than cotton or nylon straps was considered and is shown in Figure 28 . The purpose of using elastic bands is to simplify the tiedown system by eliminating the numerous components presently used and reducing the time required to attach the tiedown elements from the platform to the cargo. Several advantages can be realized through the use of this method. By preparing the elastic bands in units of predetermined lengths, the rigging time is reduced and simplified. Hence, system reliability should be increased, especially if untrained personnel is used for the bulk of the rigging operation. Because of the higher tension in the bands, the number of tiedown points could be reduced, and a marking system could be used to identify where the bands should be attached, simplifying the rigging and reducing the rigging time.

Some of the disadvantages of using elastic tension restraint must also be considered. Care must be taken in rigging the elastic bands to prevent bowing the modular platform especially since the modular platform can be easily bowed using the existing tiedown equipment. A much stronger and heavier platform would be needed. In addition the straps themselves may be subject to deterioration and easy prey to an accidental sharp edge that might cause untimely breakage.

This concept appears to have some measure of feasibility and it may be profitable to investigate the idea. It is possible that it would work with some type loads and not others. The idea is simple and could be examine at very reasonable cost.

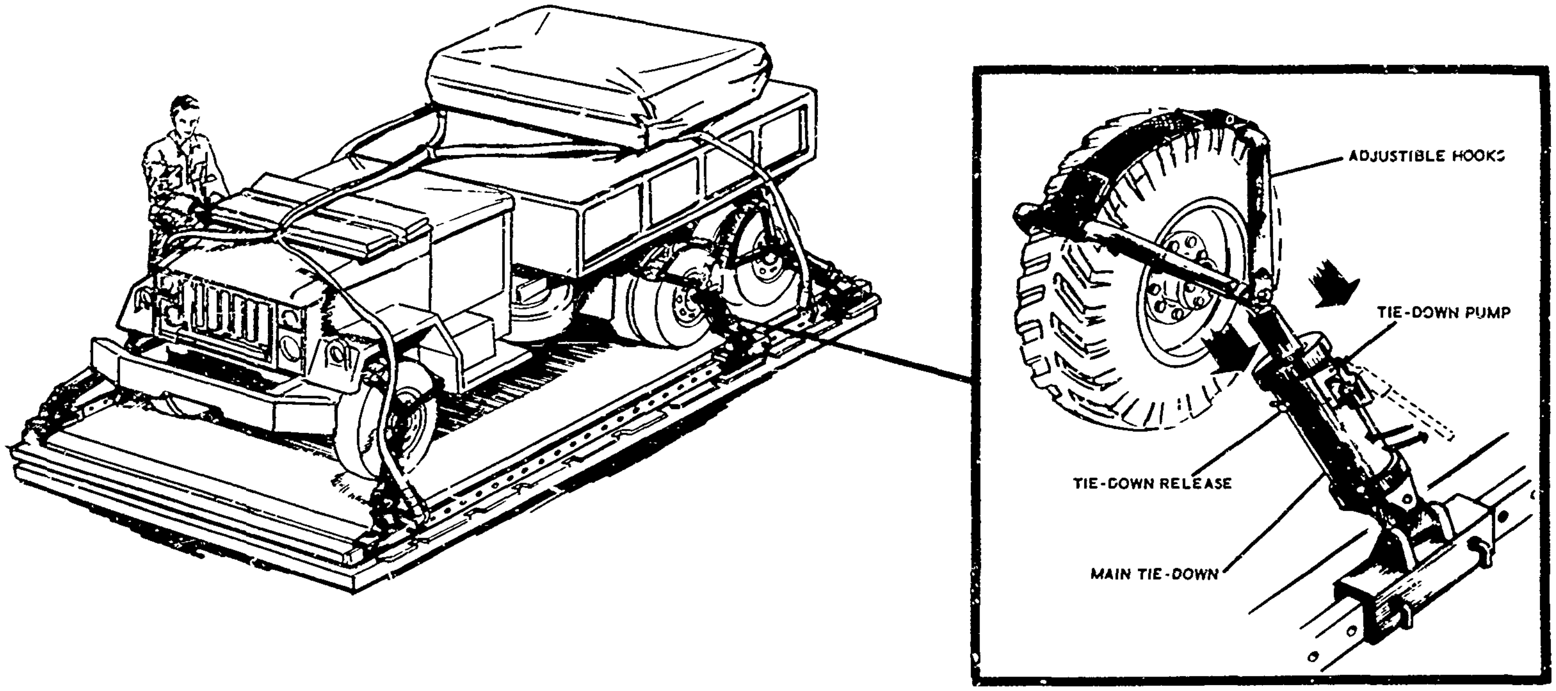
(2) Universal Restraint Device

Another restraint device that was considered is illustrated in Figure 29 and consists of an adjustable "double-hook" section that will fit over the tire of any vehicle. It is necessary that the hooks extend far enough over the tire so that the restraint



ELASTIC BAND RESTRAINT

FIGURE 28



UNIVERSAL RESTRAINT DEVICE

FIGURE 29

device will not be thrown off when the tires deflect upon impact. The hook is connected to the draw-down section which in turn attaches to the pallet. A hook that attaches to the tires of a vehicle has been illustrated, but it is obvious that attachment to other portions of the vehicle could be arranged as well. The restraint force is supplied by either a mechanical or hydraulic jack.

The restraint device would be fixed directly to the pallet at the proper angle with respect to the given wheel at one of the attachment points that are evenly placed along the edge of the pallet. The restraint devices will be light enough (20-30 lb) for one man to position it, bolt it to the pallet and jack it down in about two minutes. The devices could be coded in such a way as to insure that all the devices are tightened equally and to the proper amount for the given cargo. Angular mounting of the devices affords fore and [illegible] as well as vertical restraint.

The universal restraint device is an excellent method by which a light, easy-to-handle item may be used by minimum trained personnel to rig almost any load and for this reason it should be given further consideration. Investigation may prove that such a device might be feasible with the standard honeycomb impact systems as well as the suggested "soft landing" systems.

3. High Wind Condition Concepts

As long as there is little or no ground wind, the horizontal velocity of the cargo presents no problem. However, as the wind velocity increases the horizontal component of the descent velocity increases also and the danger of cargo tip-over and damage becomes a major consideration. The problem is particularly acute with some of the soft landing concepts discussed because the center of gravity is raised to obtain more deceleration travel and the length to width ratio of the platform is conducive to overturning if the horizontal velocity vector is perpendicular to the long side.

There are a number of approaches that have been considered as solutions to this problem. One of them has already been mentioned in disucssing the soft landing systems. It is the idea of spreading the rails in an outrigger fashion to resist overturning of the load. Other schemes have been considered as possible solutions. The following is a discussion of these concepts.

a. Gliding Descent System

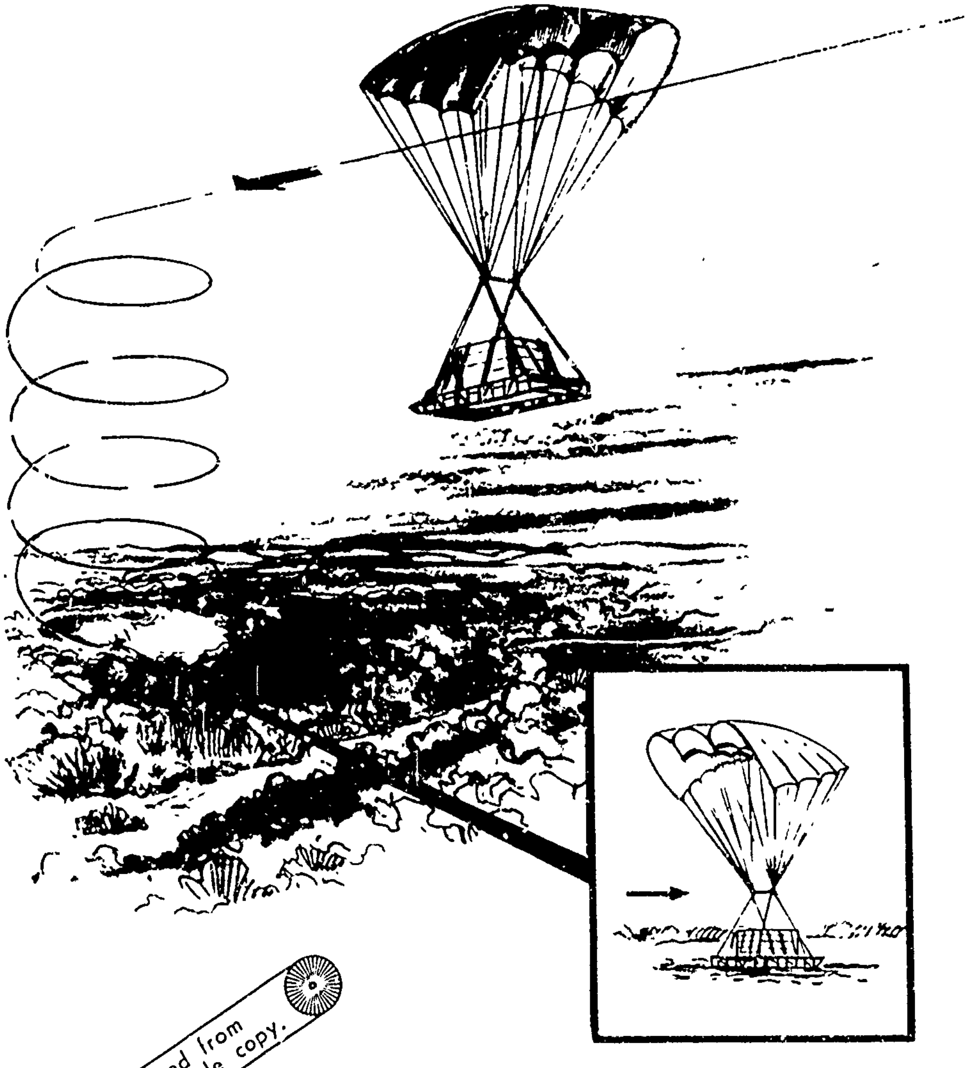
One technique for landing an airdrop in high wind conditions that has received attention for several years is the use of parawings or parafoils as illustrated in Figure 30. These systems have usually been considered because the use of a radio controlled guidence system allows the cargo to be steered to the target. This not only permits high landing accuracy but also provides a means for orienting the flight path into the wind so that the load glides to touchdown in an attitude favorable to a safe landing.

For a given wing loading, the total aerodynamic velocity of the parafoil system remains relatively constant with respect to angle of attack. However, the horizontal and vertical components that make up the total velocity vector are dependent on angle of attack and it is this characteristic that allows the "flare" landing maneuver. For example, for a parafoil wing loading of 2 lb/ft^2, the total aerodynamic velocity remains at a nearly constant 45-50 ft/sec. At a 10^o angle of attack the horizontal velocity is 40 ft/sec and the vertical velocity is about 10 ft/sec. If the angle of attack is increased to 80^o, the horizontal velocity drops to 10 ft/sec and the vertical velocity increases to about 42 ft/sec.

Consider a glider design where the horizontal component of the relative wind velocity is 50 feet per second. The system must be designed to land in a no wind as well as a high wind condition, so it must have the capability of gliding to a safe landing at a hoirzontal ground speed of at least 50 fps. If the guidance system includes the capability of orientation into the wind at touchdown, then landing in high winds is easily accomplished for the ground speed in a 30 knot wind, for example, would be very nearly zero. If no control can be established for the gliding system, then its value as a solution for landing in high winds is greatly diminished. For example, if the landing is made in a 30 knot tail wind, the horizontal ground speed will be about 100 fps which probably is impractical. The value of gliding systems, therefore, appears to depend upon the ability to obtain guidance so that at least a partial orientation into the wind at touchdown can be assured. This technique appears to have sufficient merit to attract continued interest and study.

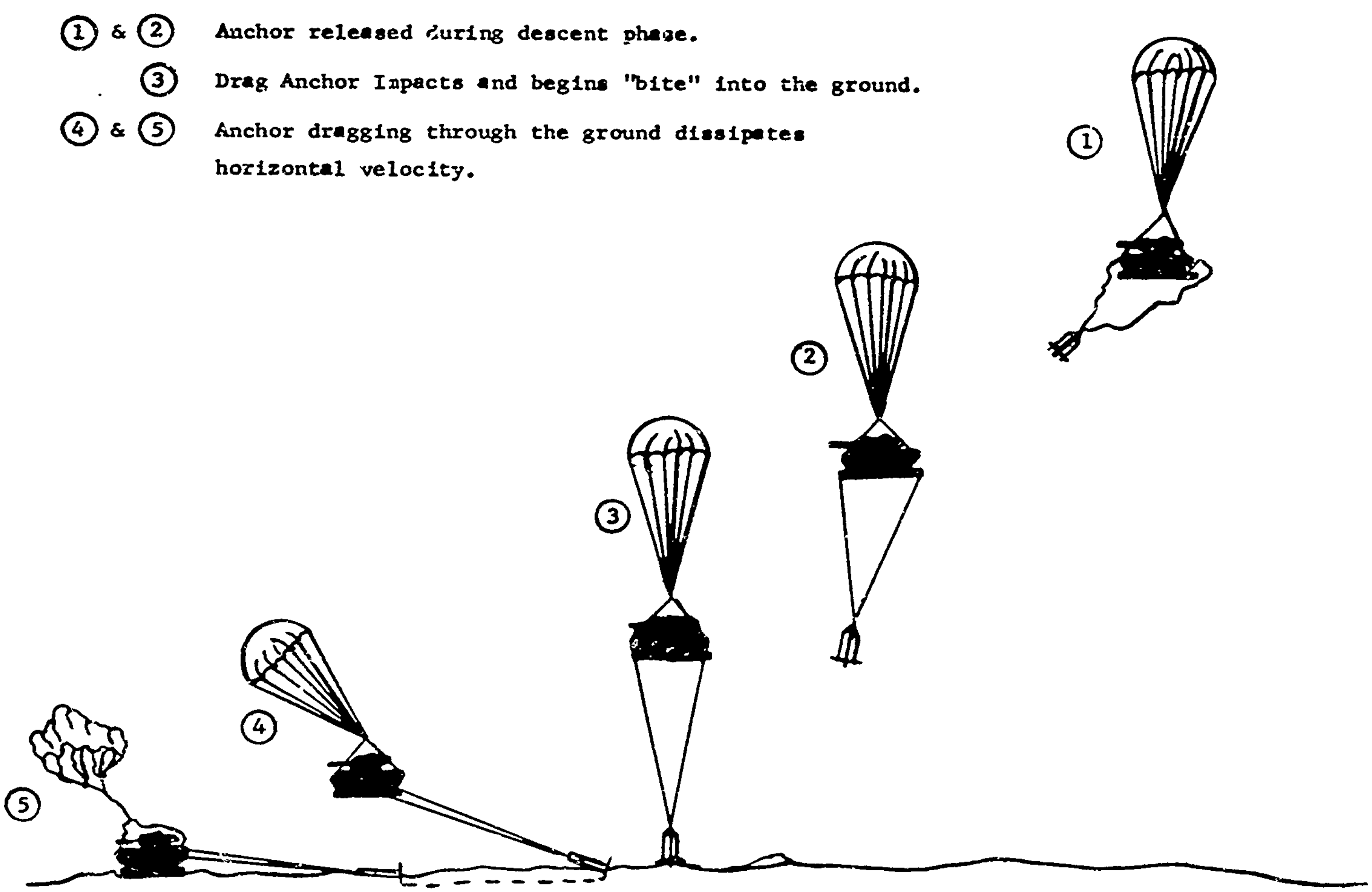
b. Ground Anchor Concept

In a previous study, reference 2, an investigation was conducted of Ground Wind Effects of Heavy Cargo Airdrops. One of the techniques suggested for decreasing the horizontal velocity of a drifting airdrop load was dragging a ground anchor attached to the payload by a long line as shown in Figure 31. Several problems are encountered with the technique. In order to stop a 20,000 lb. load drifting at 50 ft/sec without subjecting it to more than a 4g deceleration, an average force of 40,000 lbs for 20 ft. is needed. The holding power of commercial anchors is dependent to a large extend upon the type and consistency of soil in which they are employed. In addition, it is doubtful



GLIDING DESCENT SYSTEM

FIGURE 30



DRAG ANCHOR HORIZONTAL VELOCITY DISSIPATOR

FIGURE 31

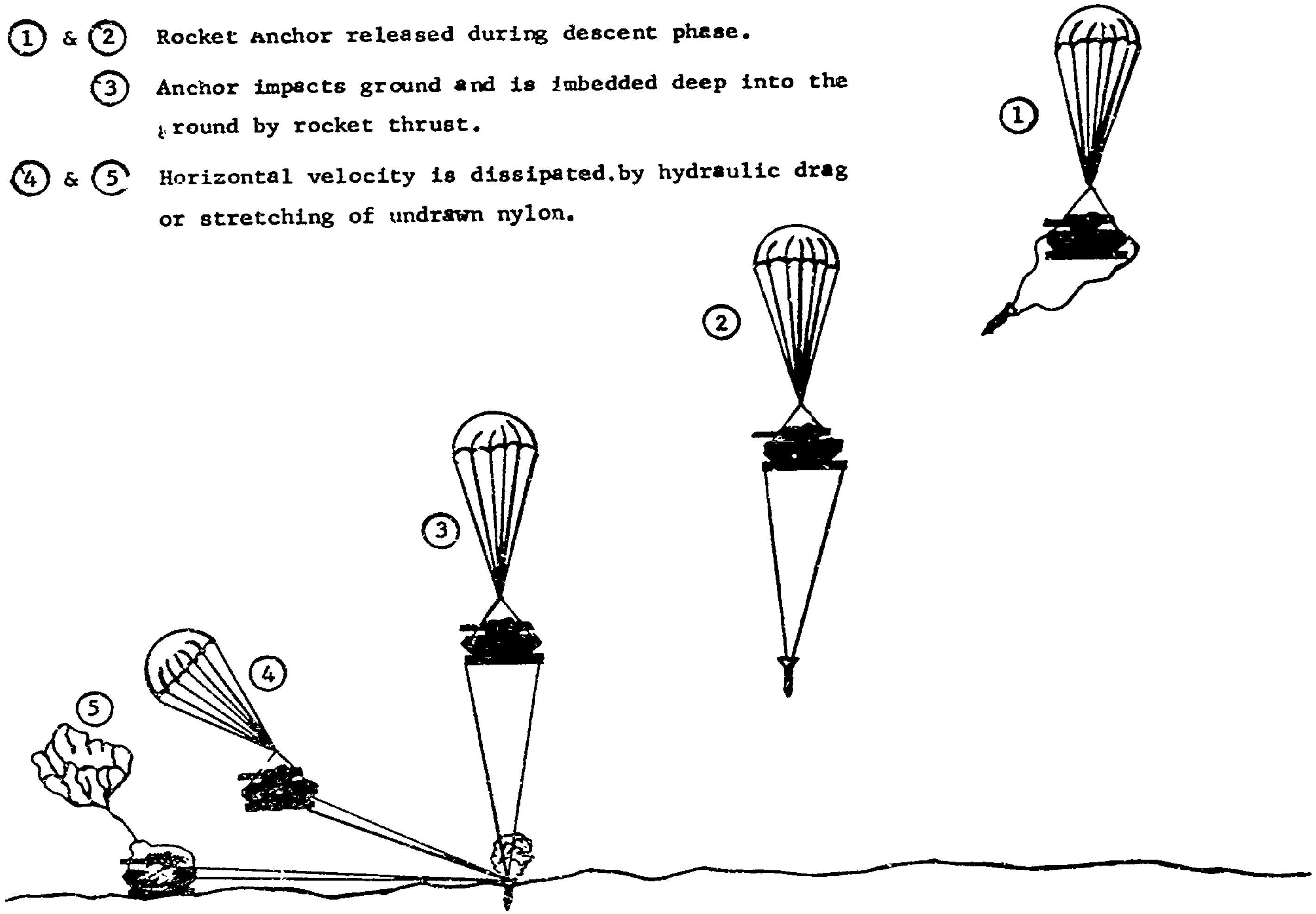
whether the soil condition would be consistent enough to insure a constant drag force. Anchor weight and size are also problems. In another study made for the U. S. Army Research and Development Command at Fort Belvoir, Virginia, reference 3, it was found that the lightest and most effective commercially available drag anchor was the "Paravane". The purpose of the study was to find light mooring systems for surface vessels under muddy bottom conditions. A paravane sufficient to develop 40,000 lb. of force would weigh about 500 lb. and would have to be buried about 20 feet deep. Emplacement of such a device is simply not compatible with the surface terrain in the airdrop environment.

A possible solution may be to use a permanent rocket emplaced anchor as illustrated in Figure 32. In this approach, dragging would not be necessary and the energy absorption could be obtained by a hydraulic drag device similar to a fishing reel or the stretch of undrawn nylon anchor lines. The disadvantages of undrawn nylon were discussed earlier in the report and the length, diameter and weight of line needed to withstand the required deceleration forces would present a storage problem.

For the most part, the ground anchor concept appears to be impractical, at least for moderate to heavy loads. Lighter loads in the 5000 lb. weight range could be managed with about a 10,000 lb. decelerating force. This magnitude force would require about a 4-5 ft. anchor burial which is not at all unreasonable, and the concept might be feasible for this class of airloads.

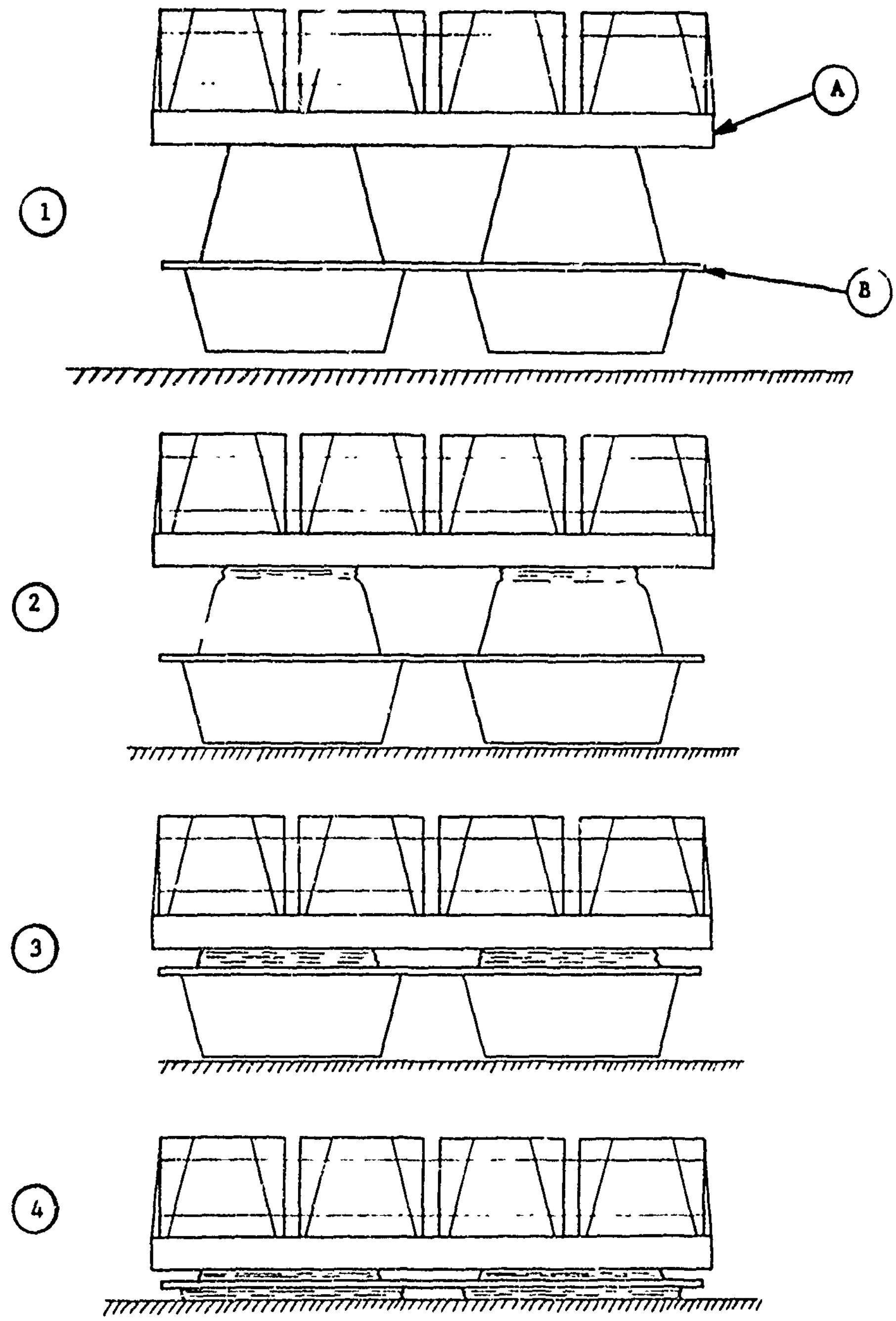
c. Bertin Air Bag (Atterroglisseur)

An airdrop system using air bags as the primary impact attenuation device has been developed by a French company (Bertin) and has been successfully tested on a limited scale. The operation of the system is shown schematically in Figure 33 . The concept consists of a platform "A" to which the cargo is secured and flexible bags or balloons fixed underneath. The outer ends of the balloons are attached to a light tray "B" and a set of flexible aprons are secured under the tray. The assembly with the balloons and aprons deflated, as shown in condition (4) are placed on a platform that engages the rail systems of the aircraft. Upon extraction, the balloons and aprons descend under their own weight as shown in condition (1) . The ballons and aprons have been so designed that on impact the balloons are compressed before the aprons, forcing their air into the apron cavities. This action arrests the vertical energy and the assembly reaches condition (3) . During the time that the balloons are collapsing, the air in the aprons



ROCKET GROUND ANCHOR HORIZONTAL VELOCITY DISSIPATOR

FIGURE 32



BERTIN AIR BAG DECELLERATION SYSTEM

FIGURE 33

provides a ground-effect which permits the assembly to glide across the ground. Gradually the air escapes from the aprons and the apparatus passes from ground-effect gliding to solid gliding, eventually coming to rest as shown in condition (4).

Tests have been run by dropping cargo loads from cranes and from aircraft. Two size platforms have been tried:

(1) 6 ft x 12 ft with 1200 - 5000 lb loads

(2) 9 ft x 18 ft with 6000 - 16000 lb loads

The weight of the airbags and aprons used on the first size platform is 100 lb and on the second size platform is 450 lb. The weights of the platforms themselves are not given. The results of the tests as presented by Bertin are shown in Table 5.

The main advantages of the system are the possibility of dropping in horizontal wind conditions up to 50 fps and the possibility of allowing descent velocities over 50 fps insuring higher accuracy and less probability of detection. The ground effects aspect of this concept gives it considerable merit especially if impact decelerations can be controlled sufficiently to affect a soft landing. It is conceivable that a simple adjustment of the orifice opening between the balloon and apron sections is all that would be required to adjust the system for various load weights.

The overall desirability of the system on the basis of the limited test data appears good. The indicated impact decelerations are still on the order of 15 g's which is approximately that of the current paper honeycomb system. In addition, the cargoes shown in Bertin's published data are all mass type supply loads and none of the information indicates that vehicular drops have been tried. Unless the deceleration loading can be reduced to about 5 g's to affect a soft landing, it does not offer very much in the search for a rapid rigging method. Its most appealing feature is the ability to land in high winds due to the ground effects feature.

TABLE 5. SUMMARY OF TESTS OF BERTIN AIR BAG SYSTEM (ATTERROGLISSEUR)

Tests Performed	Load Weight	Descent Speed	Horizontal Speed	Type Of Ground	Max. Measured Deceleration
Under Mobile Crane	1,200 to 5,000 lbs.	17 feet to 23 feet/s	0 to 33 feet/s	Concrete or grass	15 g
From Airplane (Transall C 160)	3,000 lbs.	20 feet to 43 feet/s	0 to 50 feet/s	grass	15 g
From Airplane (Transall C 160)	16,000 lbs.	26 feet/s	25 feet/s	grass	Not Given

4. Miscellaneous Standard Impact Systems

a. Modular Units

A modular unit consisting of a platform, energy dissipator and tiedown lashings which is pre-assembled for rapid installation is illustrated in Figure 34.

These modules would be designed to be compatible with the dual-rail cargo handling system, and are inserted under the various loads to provide the proper support, restraint and energy absorption. Each module would have the tiedown lashings permanently attached for easy fit to the cargo. This system uses existing airdrop hardware to make up the components for each module. The basic unit would consist of a four-foot pallet with the paper honeycomb positioned in the appropriate locations. Paper honeycomb stacks on the modules would be designed for worst case conditions with possibly three groups of modules employed based on cargo weight. Tiedown lashings will be designed such that minimum adjustment is required. This can be accomplished by using fixed size tiedown straps similar to the present tiedown components with the addition of quick disconnect attachments at the load connection and permenent attachments at the rail connection of the platform. Basically, this concept is an adaption of the present rigging system with the addition of the modular concept and improved connecting and disconnecting devices.

Advantages

1. Reduces the time required to lash the load to the platform and prepare the platform.

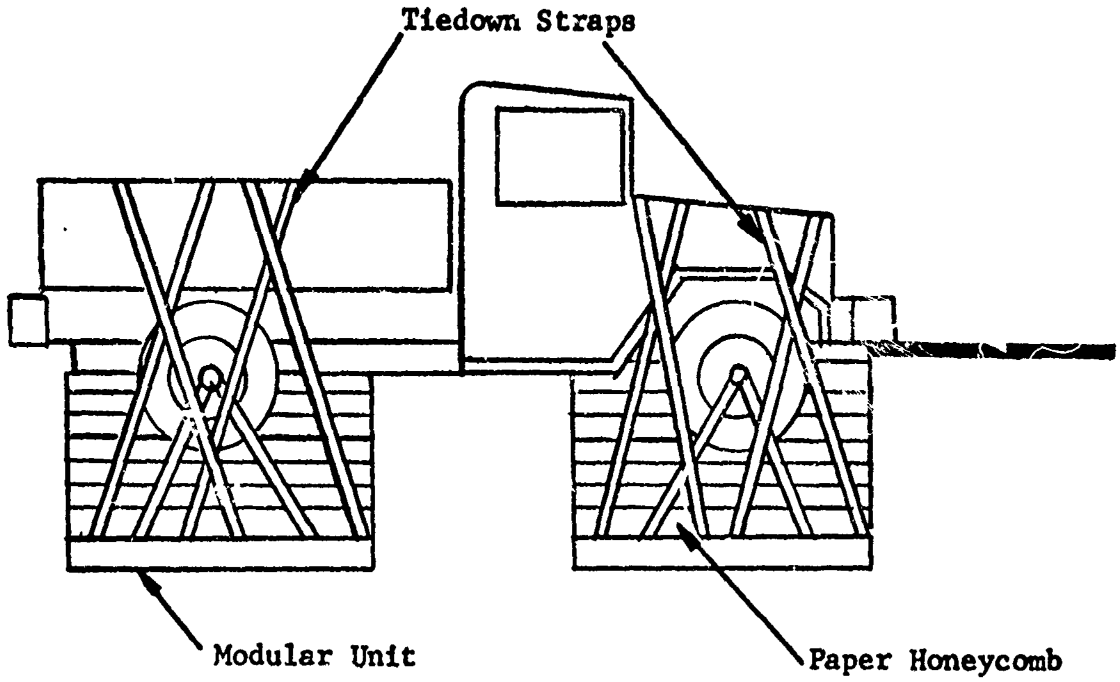
2. Increases the reliability by minimizing the human effort involved in lashing the load and preparing the platform.

3. Minimizes the hardware required for an airdrop rigging system.

Disadvantages

1. The retrieval problems are comparable to the present system, high residue and poor drive-off capability due to load elevation caused by paper honeycomb.

2. The short length of the module pallet causes L/D problems. During extraction cocking of the pallet produces high frictional forces, thus increasing the cargo release force.



MODULAR PLATFORM UNITS

FIGURE 34

3. Pre-assembly of the modules causes storage and transportation limitations due to the size of each module.

4. The area of the paper honeycomb may be increased causing higher impact loads. Also, the use of the same size paper honeycomb stack for different cargoes will cause the impact loadings to vary for each cargo.

The major disadvantage of this concept is the possibility of developing excessive restraint forces during extraction caused by cocking of the short units. This may endanger the safety of the aircraft. Solution of this problem without elimination of the module principle could result in a feasible design. One approach would be to tie the modules together to produce a load with a higher length/width ratio. However the overall concept does not appear desirable because the savings over the present rigging system would, at best, be minimal.

b. Airbag Surrounding Cargo

In this concept an airbag surrounds the cargo on five sides with the top open. Locations are provided at the top of the air bag for attachment of the suspension slings. Figure 35 is an artist sketch illustrating a vehicle encapsulated by the air bag. The air bag would be stowed within the platform until extraction occurs, and inflated during the descent phases of the airdrop. The addition of blow-out valves to the air bag will be needed to dissipate the impact energy and prevent excessive rebound and overturning of the cargo. Surrounding the cargo with the air bag minimizes the chances of undesirable impact angles which could affect the energy absorption capabilities of the air bag.

Some advantages of the above technique are:

1. The concept is extremely simple, requiring very little personal attention.

2. The tiedown equipment is minimized.

3. Paper honeycomb is eliminated.

4. The concept allows for a drive-on, drive-off capability for vehicles, greatly enhancing the retrieval mode of operation.

For this concept to work, a method must be devised for supplying in-flight restraint to the vehicle. The bag will not be inflated in-flight, and hence, does not supply any restraint. If this problem is resolved then the following disadvantages must also be overcome:

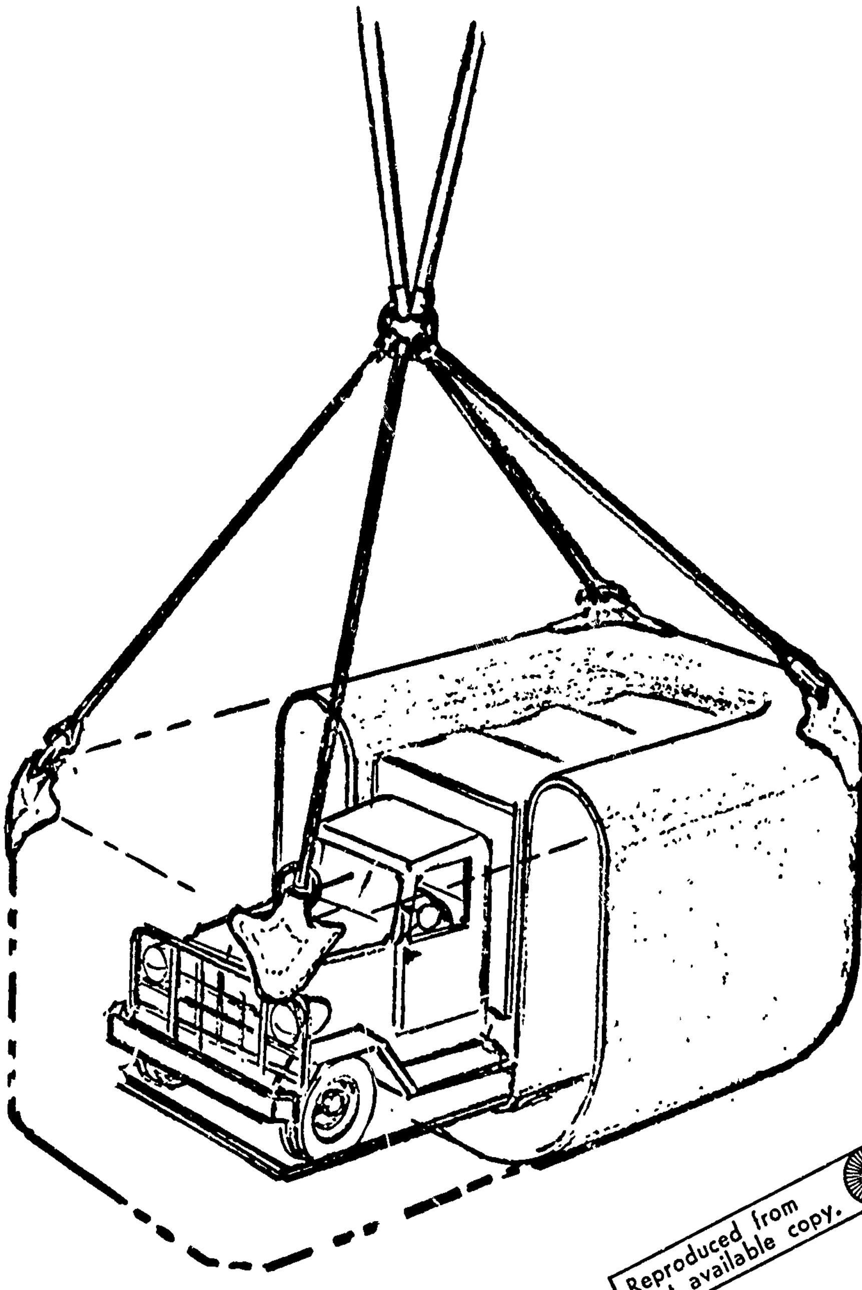
1. The bag must have sufficient strength to carry the suspension loads.

2. The means for supplying extraction are complex.

3. Numerous size air bags will be necessary to make the system work acceptably.

4. The suspension system of the vehicle must withstand the load which is necessary to deflect the air bag during transmission of the impact force to the air bag.

5. A means must be supplied to stow the air bag in the platform prior to extraction of the cargo from the aircraft. Since the air bag must be mounted under the platform, additional transport and extraction problems are created.



AIR BAG SURROUNDING CARGO

FIGURE 35

The problems associated with this concept are so numerous that its feasibility appears almost non-existant.

c. Shock Strut Energy Dissipator

An energy absorption system was developed by the All American Engineering Company which utilizes the energy at impact to push a steel tube through a steel mandrel into which a stainless steel ball has been inserted to create an interference fit with the tube. This shock strut was inserted between the vehicle suspension system and the frame, and at impact the deflection of the vehicle suspension caused the shock strut to deform and absorb energy.

Feasibility of this concept was investigated in a series of airdrop tests and the results are summarized in reference 4. The tests revealed that the vehicle structure could not withstand the loadings without numerous modifications to the suspension system and running gear. These modifications are not acceptable, since the cost of redesigning the vehicles presently airdropped would be excessive. Consequently, this concept is unacceptable as a rapid rigging system.

d. Platform Energy Dissipator

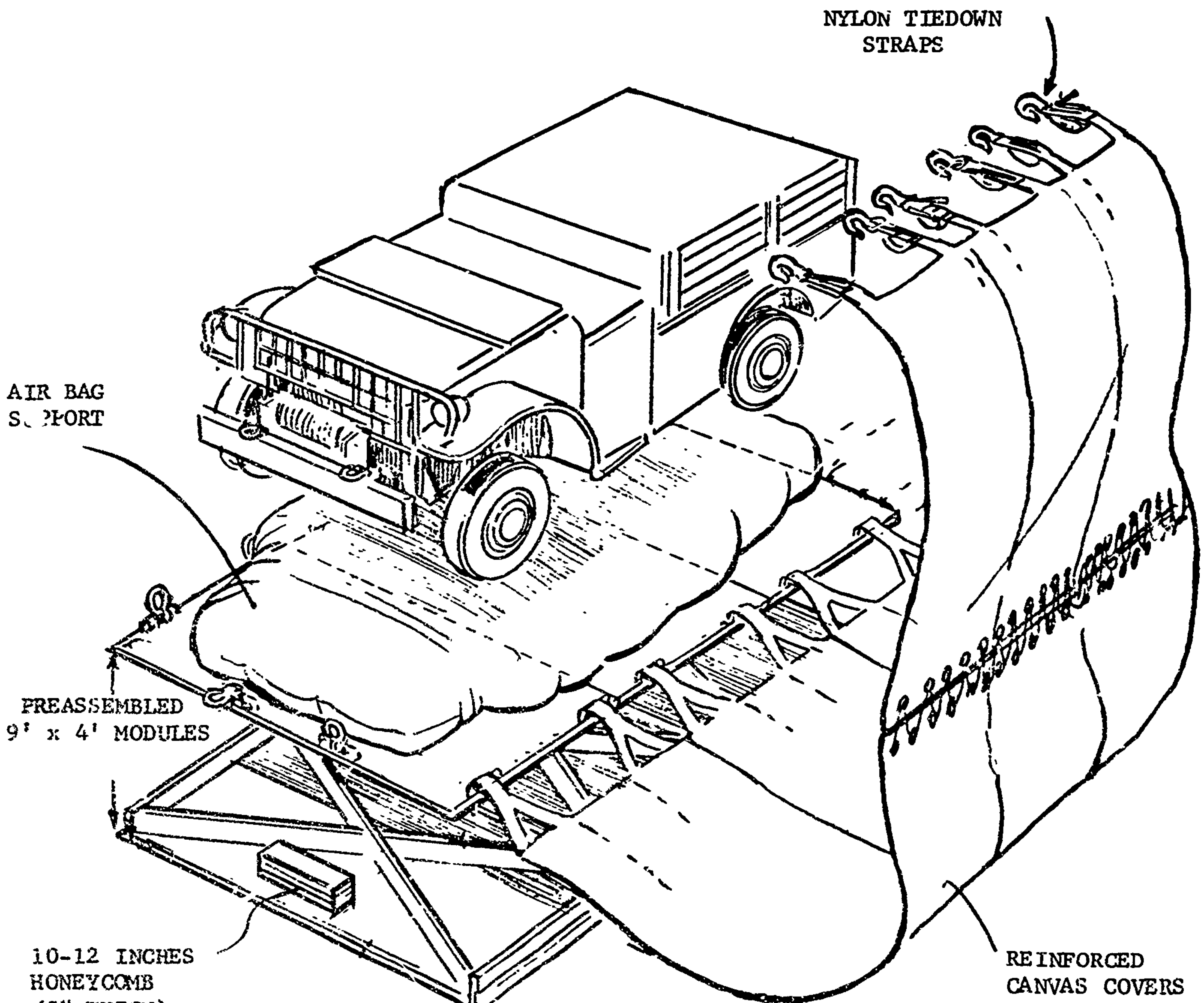
This concept employs a structural platform with the energy dissipator contained between the top and bottom cover plates of the platform. Using a platform with an integral energy dissipator material has numerous advantages which are helpful in achieving a rapid rigging system. Preparing the platform is one of the more time consuming events in the present rigging system, therefore, use of a platform construction that eliminates or reduces the paper honeycomb preparation event will result in a significant time savings. The concept is illustrated in Figure 36.

The problem of transmitting the impact force from the cargo to the platform must also be resolved. The concept illustrated in Figure 36 uses an air bag to transmit the impact loading. This concept and the method of transmitting the impact force to the platform with the air bag is described as follows:

1. The energy dissipator platform is assembled and the cargo placed on the platform. Vehicles can be driven on by use of a ramp.

2. The uninflated air bag is placed under the cargo.

3. The tiedown lashings are preloaded to the impact force expected. This is determined from the design impact load required to crush the energy dissipator material.



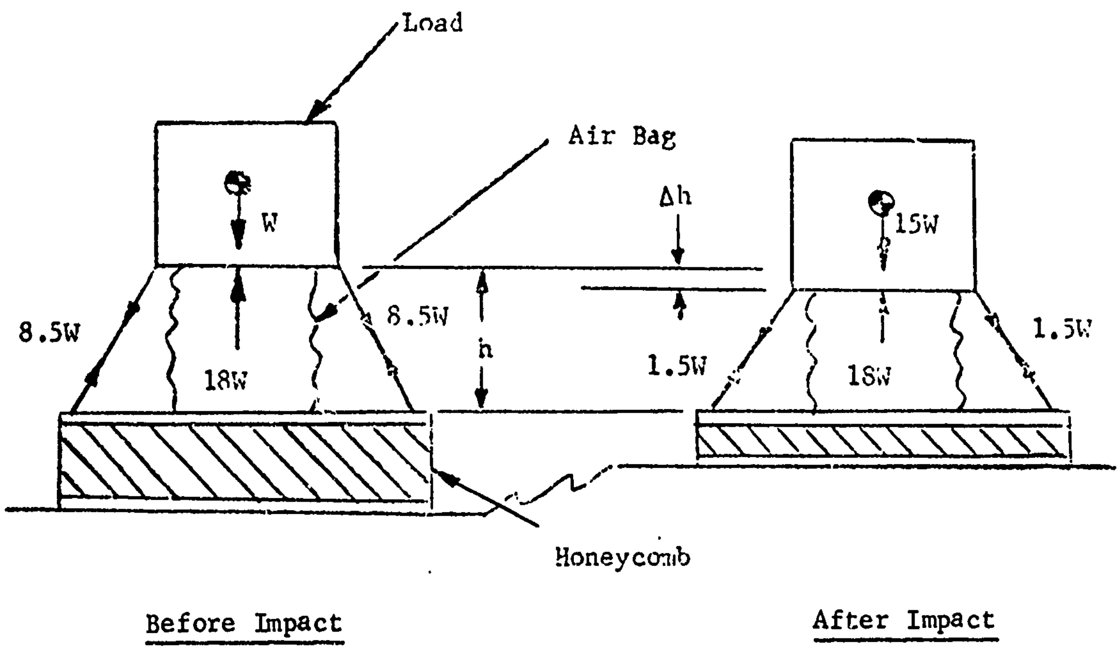
SUB-PALLET ENERGY ABSORPTION, CANVAS RESTRAINT

FIGURE 36

4. The air bag is inflated to a pressure equivalent to the expected impact loading.

5. At impact the inertia load causes the air bag to deflect and the tiedown lashings to unload, thus transmitting the impact load to the platform and the energy dissipation system.

The forces in each of the system components before and after impact are illustrated in the following schematic where the air bag has been inflated to exert a pre-impact force on the cargo of 18 g's with the peak deceleration loading being limited to 15 g's by the paper honeycomb.



Two components are critical in this proposed concept to achieve the desired performance. These components are the tiedown lashings and the energy dissipation material. Paper honeycomb exhibits all of the required characteristics for a good energy dissipator and is proposed for use in this concept. The tiedown lashings must have low elongation properties or the required deflection of the air bag to unload the tiedows will be excessive. This low elongation feature is important to the concept for it is the means by which oscillations of the system are controlled within acceptable limits. It may be necessary to look for alternate materials for the webbing currently in use since these have an elongation or 15 to 20 percent.

Summarizing the advantages and disadvantages of this concept:

Advantages:

1. The time to prepare and position the paper honeycomb is reduced.

2. An integral platform-energy dissipation unit is used which improves the system reliability, since these units can be prepared by untrained personnel in a prerigging assembly operation.

3. The use of low-elongation tiedown canvas-type covers will reduce the rigging time.

4. Vehicle-type cargos can be driven on and off the platform by using a ramp.

5. The retrieval time is reduced since the air bag can be rapidly deflated and the tiedown system can be rapidly disconnected.

Disadvantages:

1. A stressed or structural-type platform is required which will be more costly than the present platform.

2. More paper honeycomb will be used to achieve a universal platform module, hence, a small increase in material costs.

3. The tiedown material must have low elongation properties eliminating the use of present webbing material.

4. Total system cost will increase due to the cost of the air bag, the stressed platform and the additional paper honeycomb.

5. The payload-to-rigged weight will be less than the present system for the lighter weight cargos.

This concept is considered to be feasible although the problems to be solved are considerable. The most questionnable feature is considered to be the airbag that supports the vehicle. It is not known if the underside of a vehicle can be loaded in this manner. Also the problem of airbag leakage is an item of concern.

5. Special Rigging Considerations

There are several operations in the current aircrop system which are time consuming and result in a significant portion of the malfunctions. The items include:

- o Rigging the main parachutes
- o Tiedown lashings
- o Rigging the extraction system

Except for the concepts which eliminate the force transfer function, very little attention has been devoted to rigging the extraction system. There is equipment under development at Natick Labs which should simplify the rigging of some of the systems and improve their functional reliability. This is a fertile area for improvement because rigging of the extraction systems has the third largest malfunction rate, 12.2 percent.

Rigging the parachute to the cargo is a major time consuming rigging activity and also an activity resulting in a high malfunction rate, 8.9 percent. Many time consuming and detailed rigging events cause this activity to be a rather laborious task. The complexity, time-to-rig, and malfunction rate increase as the number of recovery parachutes increases. When numerous parachutes are rigged on the cargo, the detailed rigging is concealed by the parachutes, preventing careful inspection of the parachute rigging. Consequently, the malfunction rate increases. The use of load bearing platforms should help this problem some because the parachutes will be connected to the platforms rather than the load. This brings the attachment points out where the view is better for inspection and attachments will always be made at the same location and in the same manner. This uniformity should tend to increase the quality of the operation and reduce the rigging time.

The present airdrop system uses a series of tiedown straps of varying lengths to facilitate the tiedown lashing operation in rigging the cargo. The present system requires numerous components, including the tiedown straps, load binders, tape, and clevises. Another problem associated with the present rigging system is that no positive control exists for tensioning the tiedown lashings. Under these conditions the modular platform can be bowed which leads to additional time consuming problems at installation in the airplane. The use of the load bearing platform and a revised restraint system such as the universal restraint devices proposed herein should contribute significantly to the solution of the tiedown or lashing problems.

V. CONCEPT EVALUATIONS

A. Discussion of Evaluation Technique

1. General

In order to establish some means of comparing the systems objectively, an evaluation method was generated based upon techniques that have been used successfully in similar programs. The method consists of first determining the parameters or factors that indicate the usefulness of an airdrop loads preparation system, then devising a technique for generating a numerical coefficient (λ) that shows how each concept rates regarding the various parameters. These coefficients (λ's) are then weighted for relative importance then summed to provide a figure of merit for each concept. These figures of merit and the scores used to generate them, serve as aids in comparing the different concepts and reaching engineering decisions regarding them.

One of the problems with evaluating systems in this manner is that for ultimate accuracy, each system should be analyzed for each airdrop load. However, there are about 87 variations of loads listed in the airdrop inventory. In order to reduce the task to a realistic level, the various loads were broken down into several weight categories depending on net payload and average accompanying load. This permits development of a score for each weight class within each parameter so that an "adjusted parameter value" can be calculated for use in determining the system scores. The fraction of the total number of cargos included in each weight category is a basis for weighting the scores within each parameter. The percentages for each cargo weight class are shown in Table 6.

TABLE 6 - CLASSIFICATION OF AIRDROP CARGOES BY WEIGHT AND THE RELATIVE RATE OF THEIR OCCURENCE

Weight Class Net Cargo (lb)	Percentage of Total Loads (%)
Under 5000	55.0
5,000 - 10,000	12.7
10,000 - 15,000	15.0
15,000 - 20,000	15.0
Over 20,000	2.3

Adjusting each parameter score according to cargo weight is beneficial because it prevents a system that may be particularly effecient for an uncommon weight class from overshadowing a system that functions well for common loads, but not for uncommon ones. For instance, 55% of the current airdrop loads are under 5,000 pounds and only 2.3 percent are over 20,000 lbs. Thus, a particular system that is extremely efficient for loads under 5000 pounds but does not function for loads over 20,000 pounds should not be eliminated from consideration on this basis alone. Instead, the most common drops could be handled with the particular system while the standard procedure or another new method could be applied to other loads.

2. Parameters

Nine specific parameters were used to evaluate and compare the various candidate systems. They are discussed separately in the following section along with the technique for generating their numerical coefficients (λ's). The nine parameters are the following:

- Rig-Derig Time
- Complexity
- Development Cost
- Development Time
- Capability
- Potential (risk)
- Component Cost
- Maintenance
- Weight

a. Rig-Derig Time

Since the purpose of this program was to develop concepts for the rapid preparation of airloads, the most important consideration in any evaluation method is time. Included in this parameter is the man-hour requirements to prepare the vehicle or load for airdrop, preparation time for the platform including cutting and positioning the honeycomb if this material is used, rigging the load to the platform, and those aircraft operations necessary to prepare for extraction. The time required to derig the load and prepare the equipment for use after the airdrop is also included. The time consumed in disposal of residual materials, if any, must also be considered. Any system that employs parachutes to land the load will require the same effort to prepare and pack the descent and extraction parachutes so this time was not considered in the basic analysis. This assumption is not entirely valid, however, in the cases of the PRADS and Gliding descent systems, so a second analysis was performed with the parachutes included. The basic analysis actually shows the improvements in airloads rigging procedures. The second analysis indicates overall system preparation values where changes have been introduced that are not wholly of a rigging nature. If overall airloads preparation time can be reduced by these changes then they are of particular interest, therefore, a dual analysis has been performed.

The primary airloads preparation task was viewed as preparing the loads and platform for airdrop and securing the loads to the platform plus the time required to retrieve the loads after the drop and prepare the equipment for operation. Concepts that would reduce the man-hours to accomplish these operations were sought and a scheme was employed that gave those concepts that reduced the labor required to prepare the airload a higher coefficient. The method of scoring is illustrated in Figure 37.

b. Complexity

As the term implies, this is a measure of the physical complexity of the rigging operations and the equipment used to accomplish the rigging. Factors considered to be indicators of the complexity of a system were the following: the number of components comprising the rigging system, the number of men required to rig the equipment, the extent of the vehicle or loads preparation task, the number of attachments and adjustments required, the difficulty of the inspection task, the training required to produce qualified riggers, and the extent to which auxiliary equipment such as cranes or hoists are required to accomplish the rigging. The negative of this term, simplicity, is the indicator of a good rigging system and a method was devised of scoring so that a complex system accumulated a low coefficient for this parameter. The method of scoring is illustrated in Figure 38.

c. Development Costs

New concepts must be reduced to practice to make them useful and in many instances the cost of the development effort required to convert them to operational systems is significant. A method was devised to rate the different concepts on the basis of their expected development cost.

It was considered that the wholly undeveloped concepts must go through four stages in reaching operational status. These four stages are:

If man-hours to prepare load, platforms, lash load to platform and de-rig is		λ
Greater Than	But Less Than	
20		0
19	20	.05
18	19	.10
17	18	.15
16	17	.20
15	16	.25
14	15	.30
13	14	.35
12	13	.40
11	12	.45
10	11	.50
9	10	.55
8	9	.60
7	8	.65
6	7	.70
5	6	.75
4	5	.80
3	4	.85
2	3	.90
1	2	.95
	1	1.00

RIGGING TIME PARAMETER COEFFICIENT

Figure 37

For Each Cargo The Following Are True	Yes	No
1. Number of rigging components $\leq$ 500		
2. Number of rigging components $\leq$ 300		
3. Number of rigging components $\leq$ 100		
4. Number of components that must be handled by two or more men $\leq$ 10		
5. Number handled by two or more men $\leq$ 5		
6. Necessary rigging adjustments are coded such that they can be made by untrained personnel.		
7. Systems allows drive-on capability.		
8. System requires no new handling equipment.		
9. Vehicle requires no extensive preparation.		
10. Adjustments allow simple visual inspection by minimum trained personnel.		
11. Number of required restraint adjustments $\leq$ 50.		
12. Number of required restraint adjustments $\leq$ 25.		
13. Number of required restraint adjustments $\leq$ 10.		
14. System presents no danger from explosive or pyrotechnic components.		
15. Adjustments do not require above average strength or judgement.		

$$\text{Parameter Score } \lambda = \frac{\text{Number "Yes"}}{15}$$

COMPLEXITY PARAMETER COEFFICIENT

Figure 38

- Feasibility Study
- Exploratory Development
- Advanced Development
- Engineering Development

Some concepts have progressed through one or more of these stages. PRADS, for example, is ready for advanced development. In the feasibility phase the concept would be investigated by a combination of analysis and design effort to first determine the soundness of the concept. If it is determined that the concept is sound, then preliminary designs would be established and a program generated for the development of the system. The analysis would include an in depth appraisal of the merits of the system as a rapid airdrop loads preparation solution and a detailed estimate of the time and cost required to develop the system.

Exploratory development would provide for the design and field testing of conceptual ideas. In this phase it is likely that more than one approach to some features of the design would be included. This part of the process further evaluates the feasibility and value of the concept and narrows the choice of alternatives so that the features of the final system are fairly well defined.

Advanced development would continue the design and field testing activities, this time concentrating on improvements to the system. It is possible that investigation of some alternatives may also be evaluated. This phase of the program would produce a definition of the final system configuration.

Engineering design would produce final production designs, drawings, and specification so that procurement could be accomplished and the system introduced as an operational method for the preparation of airdrop loads. This phase would include further field testing in the early stages to provide information for the refinement of the production designs.

A scheme for generating the coefficient that evaluates the concepts relative to this parameter is shown in Figure 39.

d. Development Time

As the name implies this parameter is concerned with the time required to develop the concept and introduce the system

For each system the following are true (all must be checked):	Yes	No
FEASIBILITY STUDY COST:		
1) less than or = .5 million dollars		
2) less than or = .3 million dollars		
3) less than or = .1 million dollars		
4) less than or = .05 million dollars		
EXPLORATORY DEVELOPMENT COST:		
5) less than or = 1 million dollars		
6) less than or = .75 million dollars		
7) less than or = .50 million dollars		
8) less than or = .25 million dollars		
ADVANCED DEVELOPMENT COST:		
9) less than or = 1 million dollars		
10) less than or = .75 million dollars		
11) less than or = .50 million dollars		
12) less than or = .25 million dollars		
ENGINEERING DEVELOPMENT COST:		
13) less than or = 1 million dollars		
13) less than or = .75 million dollars		
14) less than or = .50 million dollars		
15) less than or = .25 million dollars		
Development Cost Coefficient $\lambda = \frac{\text{Number "yes"}}{16}$		

DEVELOPMENT COST PARAMETER COEFFICIENT

FIGURE 39

into operational practice. The development task has been separated into the four steps outlined in the preceeding discussion of development cost and a method devised for scoring the different concepts by the time expected to be spent in each step. The concept requiring the least amount of development time receives the best score. The scheme for developing the development time coefficient is illustrated in Figure 40.

e. Capability

This parameter attempts to evaluate the different concepts on the extent to which they provide the features considered desireable in a rapid rigging system. The extended performance goals such as being able to operate safely in high winds, and at altitudes up to 10,000 feet are included here. A long list of desireable features has been compiled and an assessment is made of the probability of the concept satisfying each goal. This information is used to generate a coefficient for this parameter. The procedure is illustrated in Figure 41.

f. Potential (risk)

This parameter attempts to evaluate the likelihood that the concept can be developed into an operational system that satisfies the goals for a rapid airdrop loads preparation system. A list of factors has been generated that describes these risks. One set of factors purports an evaluation of the current status of development, the rationale being that the further advanced the development of the concept, the greater the potential or the lower the risks. The other set lists potential problem areas which if not resolved satisfactorily could prevent the successful development of the concept. A scheme for generating a coefficient for this parameter is shown in Figure 42.

g. Component Cost

The cost of acquiring a system after development has been completed and the system enters production was considered important and the various concepts are evaluated for this parameter. The parachutes have been included in these acquisition costs. Costs are available on the components that comprise the current system but the costs for the other concepts must be estimated. A method for generating a cost coefficient is illustrated in Figure 43.

h. Maintenance

Maintenance is the effort required to maintain an airdrop system in operational condition. To evaluate this parameter a list of qualitative and quantitative features has been composed that determine the difficulty of maintaining a system. These items describe

For each system the following are true (all must be checked):	Yes	No
FEASIBILITY STUDY:		
1) less than or = 2 years		
2) less than or = 1.5 years		
3) less than or = 1 year		
4) less than or = .5 year		
EXPLORATORY DEVELOPMENT:		
5) less than or = 3 years		
6) less than or = 2.5 years		
7) less than or = 2 years		
8) less than or = 1.5 years		
9) less than or = 1 year		
ADVANCED DEVELOPMENT:		
10) less than or = 3 years		
11) less than or = 2.5 years		
12) less than or = 2 years		
13) less than or = 1.5 years		
14) less than or = 1 year		
ENGINEERING DEVELOPMENT:		
15) less than or = 3 years		
16) less than or = 2.5 years		
17) less than or = 2 years		
18) less than or = 1.5 years		
19) less than or = 1 year		
Development Time Coefficient - $\lambda = \frac{\text{number "yes"}}{19}$		

DEVELOPMENT TIME PARAMETER COEFFICIENT

FIGURE 40

For a load rigged with the candidate system, the following are true:	Probability of Success 76-100% (4)	51-75% (3)	25-50% (2)	0-25% (1)
1) Increases capability in wind conditions from 15-30 knots.				
2) Aircraft velocity at extraction is increased in range from 130-150 knots to 130-300 knots.				
3) Operational at terrain altitudes of over 10,000.				
4) Usable in the C-130, C-141, and C-5A aircraft.				
5) Capable of single item or mass formation (30 aircraft) drop.				
6) Capable of single item or assembly line rigging.				
7) Compatible with present materials handling equip.				
8) Extraction forces less than 1.5 times extracted weight.				
9) No restrictions to drop zone.				
10) Performs at aircraft altitudes of 1100 ft. for loads less than 25,000 lb. and 1500 ft. for loads over 25,000 lb.				
11) Compatible with delivery from altitudes lower than 500 ft.				
12) Compatible with delivery from altitudes over 1500 ft.				
13) Usable at temperatures from -65 to +165°F.				
14) Paratroops can jump from same plane after cargo.				
15) Single system usable for total weight range with no adjustments.				
16) Required adjustments can be made by hand with standard tools.				
17) Required adjustments are coded so that little or no training is necessary.				
18) Identical components can be used for all loads.				
19) System is totally reusable.				
20) Cost of disposable components less than 50% of total system component cost.				
21) Cost of disposable components less than 25%.				
22) Weight of reusable items less than 50% of total rigging weight.				
23) Weight of reusable items less than 25%.				
24) Derigging time less than rigging time.				
25) Derigging time less than half of rigging time				
Capability score λ = [No. in (4)x4]+[No. in (3)x3]+[No. in (2)x2]+[No. in (1)x1] / 100				

CAPABILITY PARAMETER COEFFICIENT CHART

FIGURE 41

For any system the following are true:	Yes	No
1) Concept has proven feasibility through model test or advance analysis.		
2) Concept has undergone exploratory development.		
3) Concept has undergone advanced development.		
4) Concept is operational on limited scale.		
5) Concept is totally operational.		
6) No mechanical components are beyond current state of the art.		
7) No required materials are beyond the current state of the art.		
8) No required electronic components are beyond the current state of the art.		
9) No required acoustical components are beyond the current state of the art.		
10) No required ordnance components are beyond the current state of the art.		

Parameter Score $\lambda = \frac{\text{Number "yes"}}{10}$

POTENTIAL (RISK) COEFFICIENT

FIGURE 42

If the total dollar cost of components per load is: Greater Than	But Less Than	λ =
10,000		0
9,500	10,000	.05
9,000	9,500	.10
8,500	9,000	.15
8,000	8,500	.20
7,500	8,000	.25
7,000	7,500	.30
6,500	7,000	.35
6,000	6,500	.40
5,500	6,000	.45
5,000	5,500	.50
4,500	5,000	.55
4,000	4,500	.60
3,500	4,000	.65
3,000	3,500	.70
2,500	3,000	.75
2,000	2,500	.80
1,500	2,000	.85
1,000	1,500	.90
500	1,000	.95
	500	1.00

COMPONENT COST PARAMETER COEFFICIENT

Figure 43

such features as the size and number of components that must be maintained and stored, and the type of material or component involved. A system for generating the parameter coefficient is shown in Figure 44.

i. Weight

As a rule an airdrop load cubes out before it weighs out meaning that the aircraft is physically filled before the weight limits are exceeded. The importance of this parameter is diminished because of this situation. However, there are many good reasons for limiting the weight of the airdrop system as much as possible. The results of good weight control show up as greater ease of handling, lower fuel costs, lower acquisition costs, and greater ease of rigging to mention a few. The scheme for evaluating this parameter is the following expression.

$$\lambda_{weight} = 1 - \frac{\text{Total Rigged Weight - Cargo Weight}}{\text{Cargo Weight}}$$

The numerator of the fraction is the weight of the rigging components. In the event that the fraction becomes greater than 1.0 the coefficient is set equal to zero.

3. Final Scoring Method

In order to be meaningful, the coefficients generated for the nine individual parameters must be used to produce a figure of merit for each concept. The technique used to generate this final score or figure of merit was the following:

$$S = \Sigma_i (W_i)(\lambda_i) \qquad i = 1, 2, 3, \ldots, 8$$

where:

S = Total system score

W_i = A weighting factor for the i^{th} parameter

ℓ_i = The adjusted parameter value

and:

$$\ell_i = \Sigma (U_j) (\lambda_{ij}) \qquad j = 1, 2, \ldots, 5 \quad i = 1, 2, \ldots, 8$$

For the candidate system the following are true:	Yes	No
1) Regular service interval is greater than one year.		
2) Components unaffected by adverse storage condition.		
3) There are ≤ 200 components per load.		
4) There are ≤ 100 components per load.		
5) Total storage space for total system is less than 400 ft^3.		
6) Required storage space is less than 250 ft^3.		
7) Required storage space is less than 100 ft^3.		
8) System requires less than 50 man hours maintenance per year.		
9) System requires less than 10 man hours maintenance per year.		
10) Inspections can be made visually.		
11) System requires no textile maintenance.		
12) System requires no mechanical maintenance.		
13) System requires no electronic maintenance.		
14) System requires no hydraulic maintenance.		
15) System requires no acoustical maintenance.		
16) System requires no ordnance-pyrotechnic maintenance.		
Maintenance score $\lambda = \frac{\text{Number "yes"}}{16}$		

MAINTENANCE PARAMETER COEFFICIENT CHART

FIGURE 44

where:

U_j = Weight factor for the J^{th} load weight class

λ_{iJ} = Score for the i^{th} parameter in the J^{th} weight class

Note that this methcd involves the use of two weighting factors namely; W_i and U_j. The weighting factor, W_i, is a number assigned to each of the eight parameters that rates its relative importance. These numbers add to 1.0. These weighting factors were arbitrarily assigned by a committee composed of contractor and Natick personnel. The factor, U_J was derived by determining the percent of the total number of airdropable loads that occur in each weight class. (See Table 6). The rationale for this was that the more frequently a particular airdrop load is dropped the more urgent is the requirement that it be prepared in a rapid manner. This method of generating a total score for each concept is illustrated in Figure 45.

B. Summary of Most Feasible Concepts

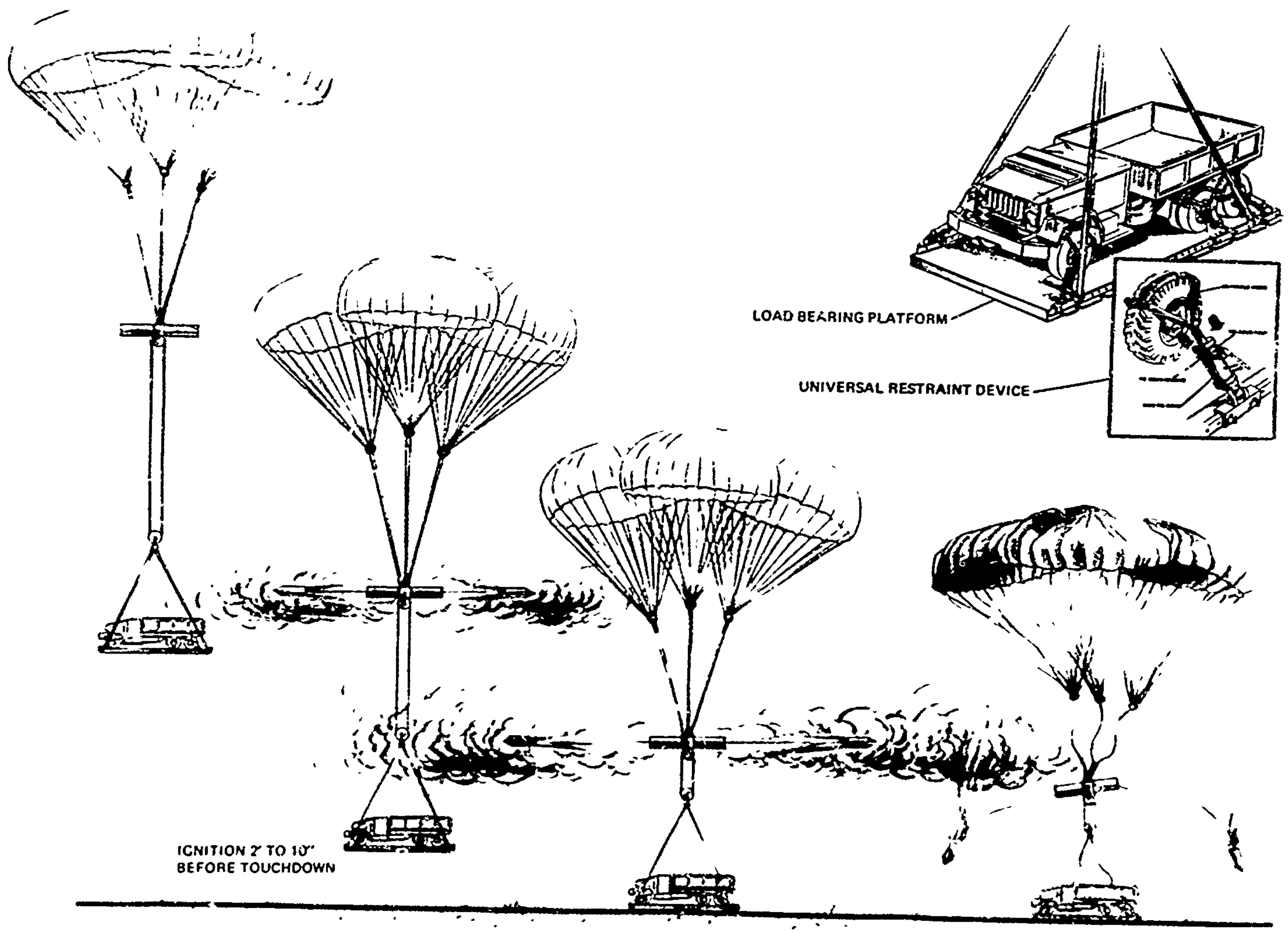
From the individual concepts presented in Section IV those that were considered to be most feasible were combined to produce system concepts that possessed the attributes favorable to the rapid preparation of the loads for airdrop. The concepts were selected by a committee composed of contractor and Natick Laboratory personnel. Five new system concepts were generated and analyzed, along with the current airdrop system, using the methods described in the preceeding section. This analysis provides a means for comparing the different concepts with each other and with the current airdrop system. Details of these five concepts are illustrated in Figures 46 through 50.

A number of conclusions have been reached as a result of this study, as to the features needed in an airdrop system that will have a rapid preparation and retrieval capability. First, it was concluded that a drive-on, drive-off capability was highly desireable for vehicular type loads. To achieve this goal, the concept of the soft-landing was generated, and closely allied to this was the idea of the load bearing platform, for in some of the concepts it was necessary to use this type of platform to incorporate the soft landing decelerators. A third area where changes were sought was the restraint system. Current airdrop designs employ a rather complex system of straps to secure the airloads to the platform and a considerable amount of skill is required to install them properly. The soft-landing concept reduces the restraint problem appreciably by making it possible to secure the vehicles by attachment to the carriage section alone. This lead to

Load Class Weight Factor U_j → Parameter	Load Class: Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.	Adjusted Parameter Value $\ell_i = \Sigma(U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	.550	.127	.150	.150	.023			
Rig-Derig Time	λ_{11}				λ_{15}	-	.30	-
Complexity						-	.20	-
Development Cost						-	.10	-
Development Time						-	.10	-
Capability						-	.08	-
Potential (Risk)						-	.07	-
Component Cost						-	.06	-
Maintenance						-	.05	-
Weight	λ_{91}				λ_{95}	-	.04	-
							$S = \Sigma_i (W_i)(\ell_i)$ →	-

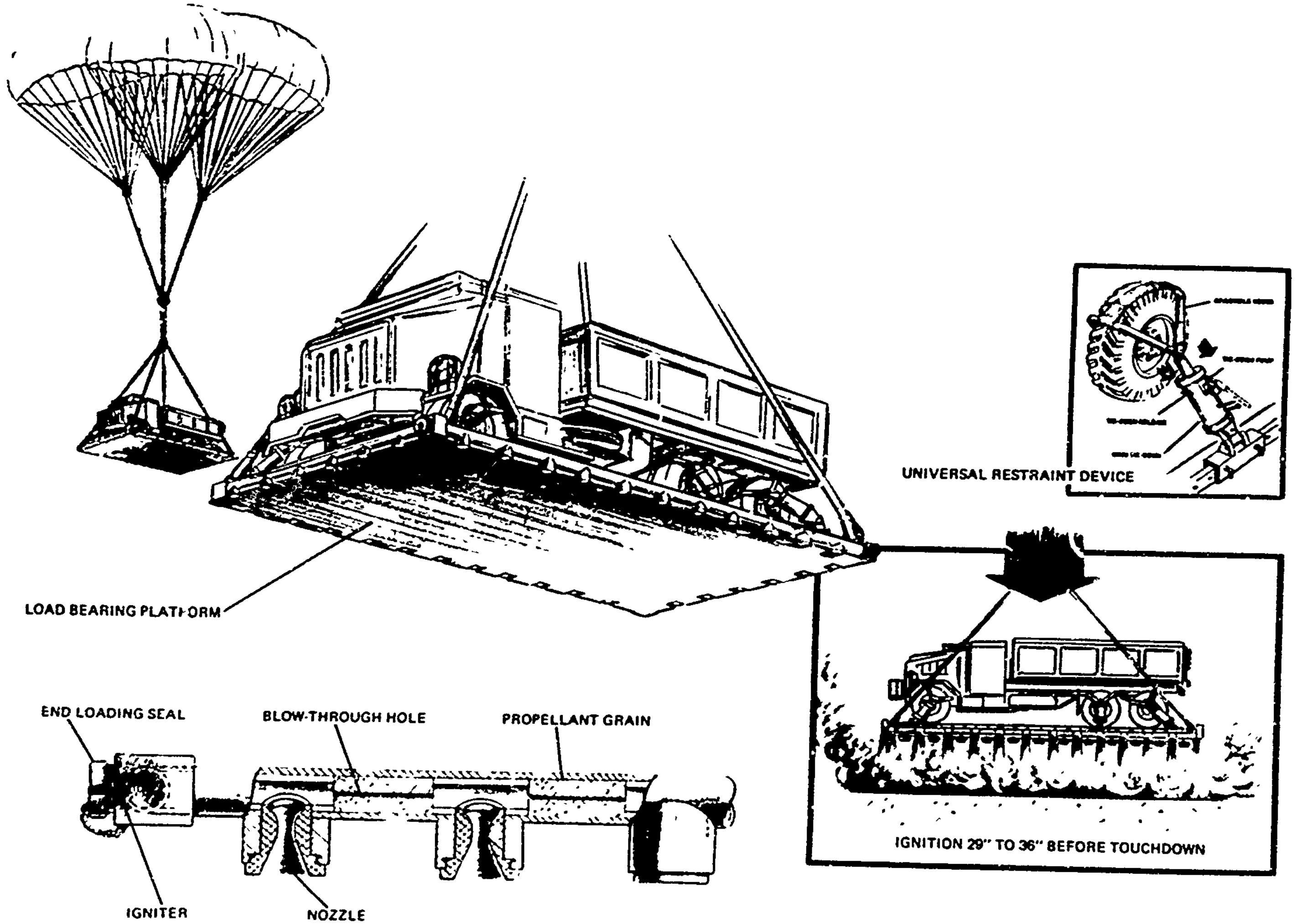
ILLUSTRATION - TOTAL SCORING METHOD

Figure 45



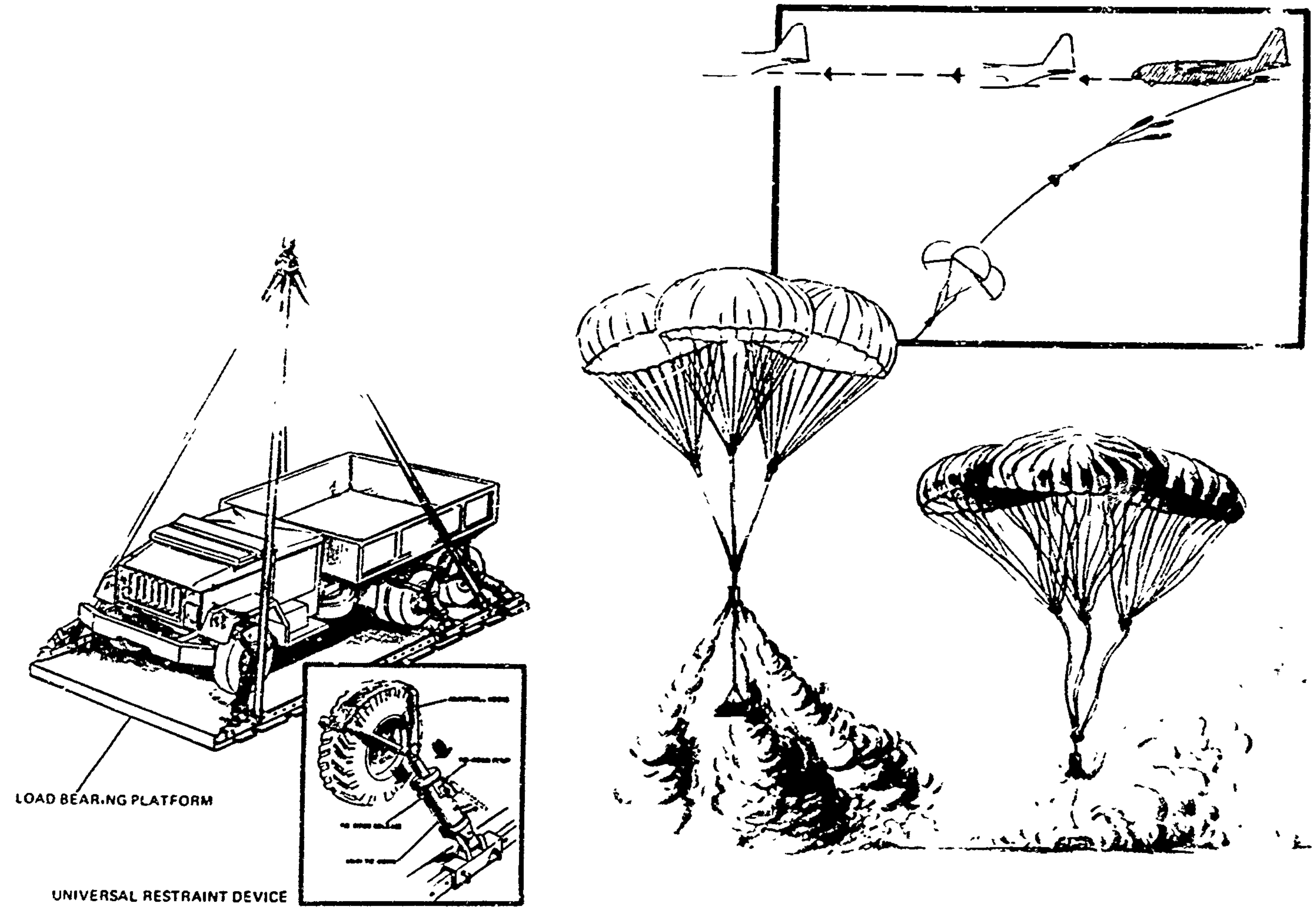
SKY HOOK CONCEPT

FIGURE 46



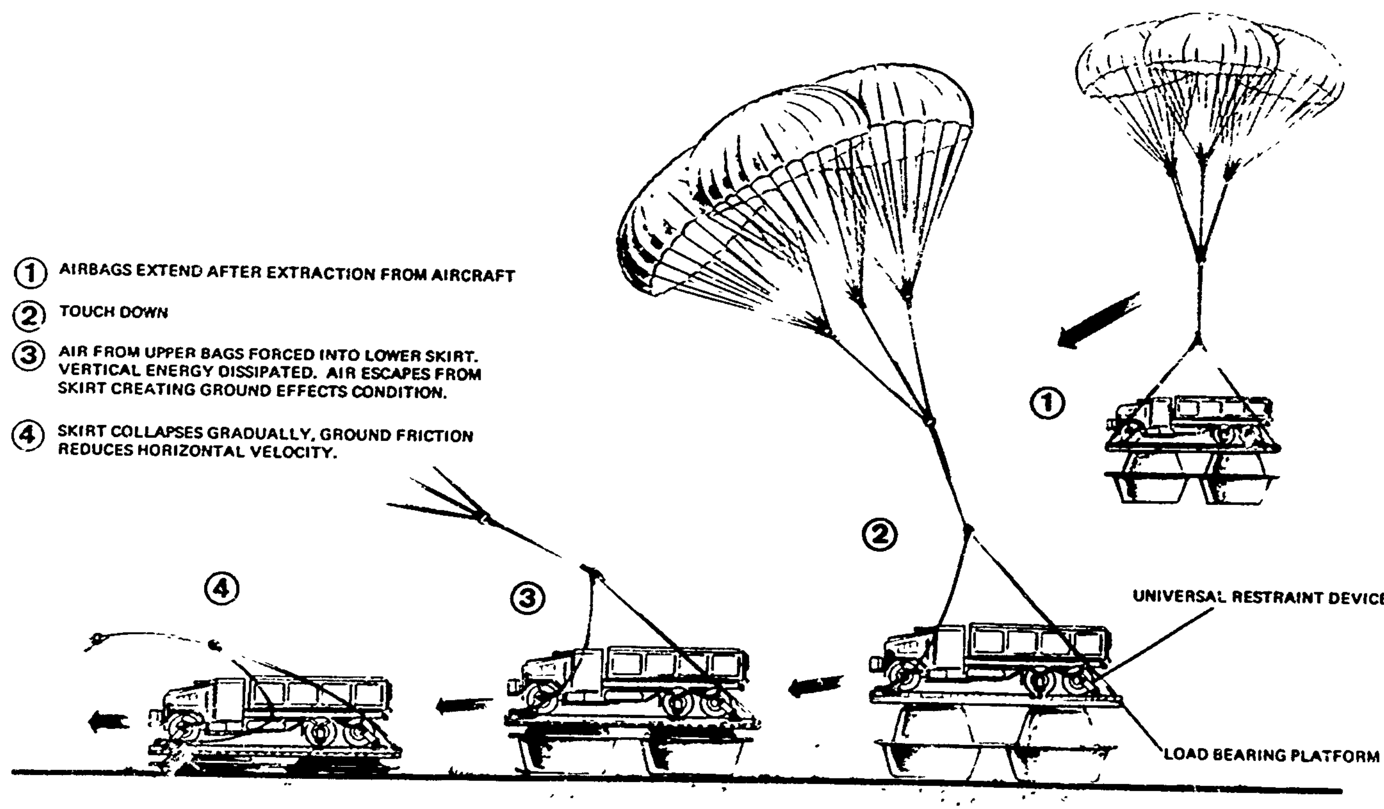
SKIRT JET

FIGURE 47



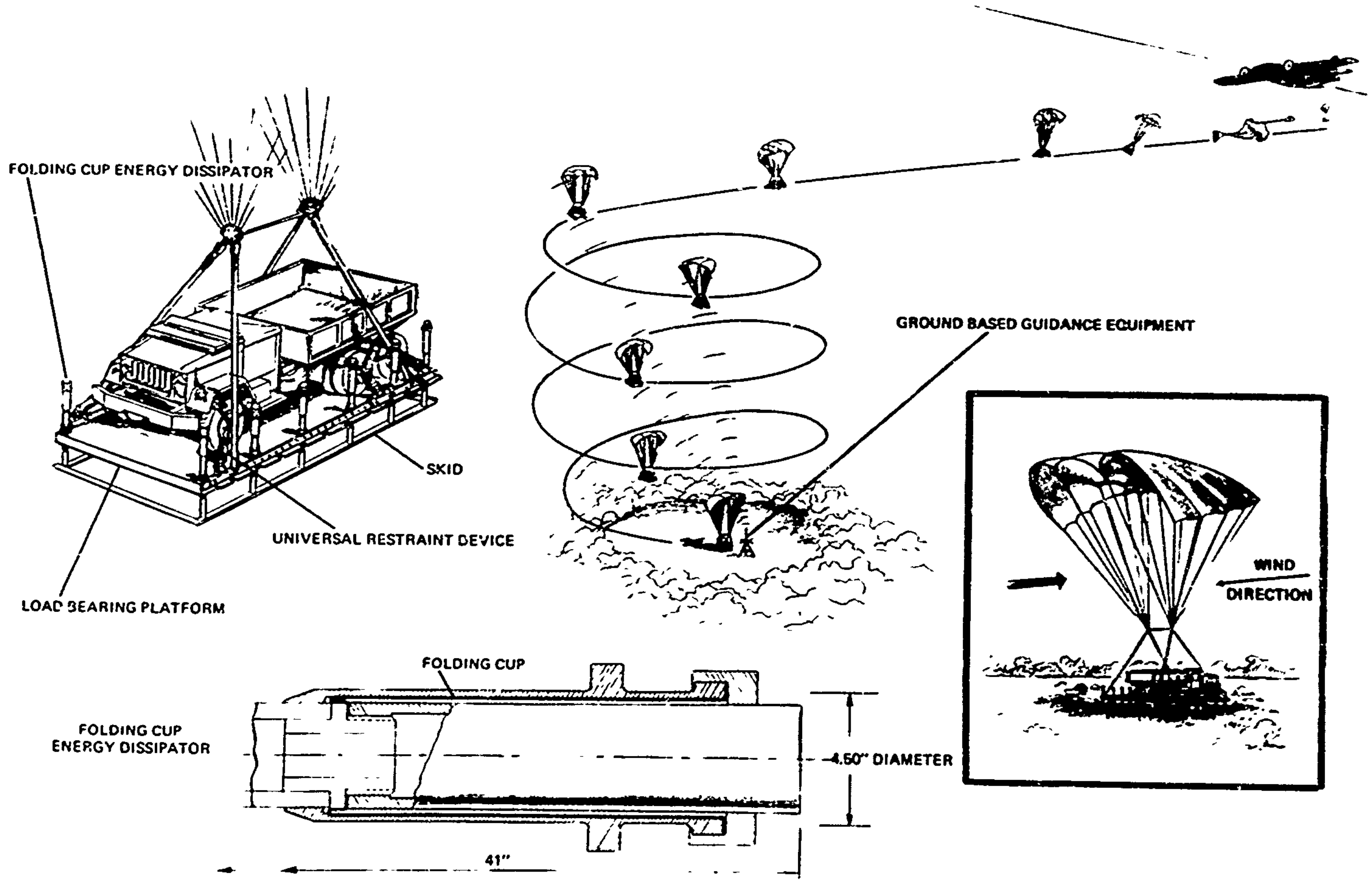
MODIFIED PRADS CONCEPT

FIGURE 48



BERTIN AIR BAG CONCEPT

FIGURE 49



GLIDING SYSTEM CONCEPT

FIGURE 50

the idea of a mechanical universal restraint device that is used on all five (5) concepts.

The principal variation between the five (5) concepts is the means of dissipating the kinetic energy in the loads assembly at touchdown. Five different principles are employed. They are the following:

1. The "skirt jet" principle
2. A modified PRADS principle
3. The "sky hook" principle
4. The Bertin Air Bag system
5. The folding cup energy dissipator

All of these with the possible exception of the Bertin air bag system are designed to provide a soft-landing. It may be possible to modify the Bertin Air Bag decelerator to accomplish a soft-landing but as currently designed it will not provide this capability. The chief interest in this concept is the high wind landing capability that is claimed by Bertin. Three (3) of these energy dissipating principles employ rocket power to decelerate the airload to a velocity at or near zero at touchdown. Rocket power is used because it is a highly efficient source of energy and its release is ammenable to precise control. The concept variations deal with the manner the rocket power is applied. The folding cup energy dissipator can be applied to a number of concepts but in the concepts chosen for evaluation it is applied only to a glider concept.

The concepts chosen for evaluation were the following:

1. Standard rigging system as currently used for cargo air drop.
2. Skirt jet principle used with a reinforced load bearing platform and universal restraint devices.
3. PRADS system modified to achieve a soft landing and using universal restraint devices to attach the cargo to a load bearing platform.
4. The sky hook impact attenuation technique used with a load bearing platform and universal restraint devices.

5. The Bertin air bag principle using a load bearing platform with universal restrain devices and modified to provide a soft landing.

6. The folding cup energy dissipator attached to a load bearing platform and using universal restraint devices and a parafoil decelerator which is guided or controlled electronically.

The concepts based on the skirt jet, sky hook, and Bertin air bag principles use the same type and number of parachutes employed in current airdrop systems. The PRADS system uses parachutes of smaller size and number and the rockets are relied upon to decelerate the load to a safe landing. The gliding system replaces the parachutes with a parafoil, parasail or some other suitable glider equipment.

Features characteristic to each of the concepts are listed in the following summaries. Information required in the analyses is also included with these summaries.

1. Standard Airdrop System

The standard rigging system consists of lashing the load to a modular platform with cotton or nylon straps and using paper honeycomb between the load and the platform to dampen the landing impact. Some cargoes can be suspended on load-bearing platforms but in most cases the cargo is suspended directly from parachutes with the platform acting as a load spreader or retainer for the honeycomb.

Vehicular cargoes require extensive preparation by trained or closely supervised personnel so that the vehicle will not be damaged from the 15-20 g landing deceleration. Considerable skill and judgement is required to prepare and secure vehicular loads in order to prevent damage.

Parameter	Load Class				
	Under 5,000 (lb)	5,000-10,000 (lb)	10,000-15,000 (lb)	15,000-20,000 (lb)	Over 20,000 (lb)
Weight of Rigging	1500	2000	2700	3200	3750
Rigging Time (M.H.) w/chute	5.9	7.7	17.8	19.0	28.4
Rigging Time (M.H.) w/o chute	3.4	3.9	11.5	11.5	19.65
Approximate Number of Rigging Components	200	450	750	750	1050
Rigging Component Costs; w/parachutes	1900	4000	7200	8600	11,500
System Development Costs	None - Currently Operational				
System Development Time	None - Currently Operational				
Current Status	Operational				

2. Skirt Jet Soft Landing Concept

This system consists of securing the load to a load-bearing platform with a quick tie down method similar to the Universal Restraint Device. No honeycomb and very little vehicle preparation are necessary because a soft landing is supplied by small retro rockets mounted inside the platform. An accurate ground sensor (possibly a mechanical probe) is necessary to initiate the rockets. Four to six restraint devices, depending upon the nature of the load, which require very little effort to apply, would be attached after the vehicle is driven onto the platform. De-rigging would also be fast and simple and all equipment except the rocket motors will be reusable. The rocket motor would be serviced with standard tools as part of the recovery or maintenance program.

The standard number of recovery parachutes are required but they will be attached to the platform instead of the load. Maintenance will be reduced somewhat by the elimination of paper honeycomb and tie down straps but the level of skill involved in maintenance may increase due to the sophistication of the rockets and ground senor.

Parameter	Load Class				
	Under 5,000 (lb)	5,000-10,000 (lb)	10,000-15,000 (lb)	15,000-20,000 (lb)	Over 20,000 (lb)
Weight of Rigging	1875	2505	3645	4165	4735
Rigging Time (M.H.) w/chute	3.59	5.02	9.88	11.13	15.02
Rigging Time (M.H.) w/o chute	1.09	1.27	3.63	3.36	6.27
Approx. Number of Rigging Components	110	200	260	280	350
Rigging Component Costs; w/o parachutes	2395	2980	4330	4850	5630
System Development Costs	2.8 Million				
System Development Time	7 - 10 Years				
Current Status	Some Feasibility Studies Completed.				

3. Sky Hook Soft Landing Concept

The Sky Hook system consists of a load bearing platform, fast-operating tie down devices similar to the Universal Restraint device, and a rocket powered decelerator system initiated by an accurate ground sensor. The load bearing platform is expected to weigh about 70 lbs. per foot and 4 to 6 restraint devices would be required which weigh about 30 pounds each. The cargo and parachutes are connected through a pulley system and rockets are used to accelerate them toward each other near touchdown, resulting in a net cargo velocity which is near zero with respect to the ground. Calculations based on concept analysis and tests of the current PRAD system indicate that approximately twenty pounds of propellant is needed per 1000 pound of cargo. Additional weight will result from the mounting and pully structure.

The rigging time should be less than the PRAD system because the rockets are much smaller. It should be possible to design the system to use reuseable rocket motors. The rockets, ground sensor, pulley and mounting system will increase the amount and skill level of maintenance but the storage and shipping space requirements will be decreased by the elimination of honeycomb.

Parameter	Load Class: Under 5,000 (lb)	5,000-10,000 (lb)	10,000-15,000 (lb)	15,000-20,000 (lb)	Over 20,000 (lb)
Weight of Rigging					
Rigging Time (M.H.) w/chute	4.44	6.17	12.53	13.98	19.27
Rigging Time (M.H.) w/o chute	1.94	2.42	6.28	6.48	10.52
Approximate number of Rigging Components	100	200	250	275	350
Rigging Component Costs; w/o Parachutes	3195	4680	6730	8350	10,030
System Development Costs	2.8 Million				
System Development Time	7 - 10 Years				
Current Status	Concept Stage				

4. PRADS Soft Landing Concept

This system is very similar to the PRAD system currently being developed except that the rocket power must be adjusted and controlled to decelerate the airdrop load to a velocity at or near zero at touchdown. Parachutes of a smaller size are used and rocket power is used to decelerate the load to a safe touchdown velocity.

A load-bearing platform would be used to which the cargo is attached with tie-down devices similar to the Universal Restrain units. The platform would weigh about 70 pounds per foot and one 60 pound rocket per 1000 pound of drop load would be sufficient to lower the decent velocity to or near zero.

Rigging time will be lessened by reducing the requirement for preparing vehicular loads, eliminating preparation of the honeycomb and using quick tie down arrangements such as the Universal Restraint Device. Attaching the rockets will increase the rigging time, but the net savings will be significant.

An accurate ground sensor will be needed to initiate the rockets. The system currently planned will have such a sensor but to accomplish a soft landing the accuracy requirement may be more severe.

Parameter	Load Class				
	Under 5,000 (lb)	5,000-10,000 (lb)	10,000-15,000 (lb)	15,000-20,000 (lb)	Over 20,000 (lb)
Weight of Rigging	2150	3060	4480	5280	6130
Rigging Time (M.H.) w/chute	4.04	5.44	12.50	13.08	19.04
Rigging Time (M.H.) w/o chute	2.79	3.57	8.93	9.33	14.77
Approximate Number Of Rigging Components	100	200	255	275	340
Rigging Component Costs; w/o Parachutes	3495	7180	11.180	14.850	18.430
System Development Costs	1.55 Million				
System Development Time	4 to 6 Years				
Current Status	This System Without the Soft Landing Feature Has Progressed Through Exploratory Development.				

5. Bertin Air Bag System

This system concept is based upon extending the capability of the double air bag impact attenuator currently used on the Bertin "Atterroglisseur" in order to achieve a soft landing. Air bags of appropriate design would be fitted to a load bearing platform and use of fast acting mechanical or hydraulic restraint devices would simplify rigging and derigging and reduce the time for these operations. Limited tests conducted by Bertin indicate that the system is currently feasible for landing decelerations of 15-20 g's but this must be reduced if a soft landing is to be achieved. The weight of the air bag systems should be between 100-800 pounds for loads between 1000-25,000 pounds.

The high wind landing capability claimed for this system is of considerable interest. The storage volume and maintenance of the system will be adjusted by eliminating honeycomb and tie-down straps and adding the air bag energy dissipator. The system will be totally reusable and repacking the air bags will almost by necessity, be part of the recovery procedure rather than the rigging procedure. Capability in high wind conditions will be extended considerably because of the air curtain effect of the energy dissipating system.

Parameter	Load Class				
	Under 5,000 (lb)	5,000-10,000 (lb)	10,000-15,000 (lb)	15,000-20,000 (lb)	Over 20,000 (lb)
Weight of Rigging	1950	2910	4030	4880	5430
Rigging Time (M.H.) w/chute	3.80	5.27	10.61	11.86	16.26
Rigging Time (M.H.) w/o chute	1.30	1.52	4.36	4.36	7.51
Approximate Number of Rigging Components	125	250	500	500	500
Rigging Component Costs; w/o Parachutes	3010	4490	6540	8210	9880
System Development Costs	2.69 Million				
System Development Time	6 - 9 Years				
Current Status	Feasibility of Landing at 15 - 20 g's Has been Confirmed by Limited Tests. The Feasibility of Modifying The Design to Achieve a Soft Landing Has Not Been Established.				

6. Gliding Descent Systems

These systems would use a parafoil, parasail or some similar gliding device whose glide path can be remotely controlled. A soft landing would be provided by equipping a load bearing platform with a mechanical energy dissipator such as a folding cup and skids. This scheme becomes feasible due to the guidance capability since the platform can now be oriented to make the skids effective. A vehicle drive-on capability would exist and tie down could be accomplished with the Universal Restraint Devices.

A guidance system would be required and this increases the weight and complexity of the system. A highly favorable feature of this system is its ability to land in high wind situations since guidance can orient the landing path into the wind.

The rigging time for the parafoil compared to the parachutes might be favorable since the volume is appreciably reduced. Overall these systems are more complex due to the guidance feature and an increase in the amount of maintenance can be expected.

Parameter	Load Class				
	Under 5,000 (lb)	5,000-10,000 (lb)	10,000-15,000 (lb)	15,000-20,000 (lb)	Over 20,000 (lb)
Weight of Rigging	2470	3366	4850	5490	6120
Rigging Time (M.H.) w/chute	2.60	3.12	6.46	6.76	10.20
Rigging Time (M.H.) w/o chute	1.31	1.52	4.36	4.36	7.52
Approximate Number of Rigging Components	100	200	260	280	345
Rigging Component Costs; w/o Parachutes	3540	4330	5620	6470	7200
System Development Costs	3.15 Million				
System Development Time	8 - 10 Years				
Current Status	Limited Tests of Gliding Systems Have Been Performed By The Air Force				

C. Analysis of Candidate Systems

An analysis of the candidate systems plus the current airdrop system was made using the methods discussed in Section V.A.2. Analyses were made with and without the parachutes. Parachutes are used to lower the load in most of the concepts and were not actually considered as being a part of the rapid airdrop loads preparation study. For this reason an analysis was made ignoring the parachutes so that a true evaluation could be made of the effect of the different concepts on the preparation time. Two of the concepts, however, depart from the conventional parachute descent system and it is more meaningful in evaluating them to include the parachutes. The PRADS system uses parachutes of small size and relies upon rocket power to perform an appreciable part of the function of decelerating the airload to a safe touchdown velocity. The smaller parachutes are easier to pack and some time is saved, but this is offset by the necessity to install the rockets. It is not a fair evaluation to charge the rocket installation time without crediting the savings in parachute preparation time, hence, the parachutes have been included in one of the evaluation schemes. The gliding systems replace the parachute with alternate style equipment and the rigging times can be significantly different. It is proper, therefore, in evaluating this concept to include the parachutes in the preparation time.

In Figures 51 through 62 the results of the analyses for the six (6) different concepts are presented. The data and work sheets used to generate these analyses are rather extensive and are not included in this report. This information has been organized, however, into a set of notes delivered to Natick Laboratories with this report. Table 7 provides a summary of the individual concept evaluations which is useful in comparing the characteristics of the different approaches.

One additional explanation regarding the rating of the current system is necessary. It will be noted that a double rating is shown. Since the system is operational it scores a perfect mark for development cost, dvelopment time and potential (risk). So that its merits from a rigging standpoint can be compared to the undeveloped systems, an average score for these three categories was arbitrarily assigned and the scores using these arbitrary values are shown in parenthesis.

Load Class Weight Factor U_j → Parameter	Load Class Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.	Adjusted Parameter Value $\ell_i = \Sigma(U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	.550	.127	.150	.150	.023			
Rig-Derig Time	.750	.650	.150	.100	.000	.533	.30	.160
Complexity	.533	.333	.200	.200	.200	.400	.20	.030
Development Cost	1.00 (.300)	1.00 (.300)	1.00 (.300)	1.00 (.300)	1.00 (.300)	1.00 (.300)	.10	.100 (.300)
Development Time	1.00 (.450)	1.00 (.450)	1.00 (.450)	1.00 (.450)	1.00 (.450)	1.00 (.450)	.10	1.00 (.045)
Capability	.670	.670	.670	.670	.670	.670	.03	.054
Potential (Risk)	1.00 (.600)	1.00 (.600)	1.00 (.600)	1.00 (.600)	1.00 (.600)	1.00 (.600)	.07	.070 (.042)
Component Cost	.850	.650	.300	.200	.000	.625	.06	.033
Maintenance	.560	.500	.500	.500	.500	.538	.05	.027
Weight	.572	.750	.781	.810	.824	.670	.04	.027

$S = \Sigma_i (W_i)(\ell_i)$ → .656 (.449)

(xxx) Ratings are high in these parameters because the system is operational. Average values have been arbitrarily assigned for comparison with undeveloped systems.

STANDARD SYSTEM EVALUATION - WITH PARACHUTES

Figure 51

Load Class Weight Factor U_j → Parameter	Load Class: Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.	Adjusted Parameter Value $\ell_i = \Sigma(U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	.550	.127	.150	.150	.023			
Rig-Derig Time	.850	.850	.400	.400	.050	.697	.30	.209
Complexity	.533	.333	.200	.200	.200	.400	.20	.080
Development Cost	1.00 (.300)	1.00 (.300)	1.00 (.300)	1.00 (.300)	1.00 (.300)	1.00 (.300)	.10	.100 (.030)
Development Time	1.00 (.450)	1.00 (.450)	1.00 (.450)	1.00 (.450)	1.00 (.450)	1.00 (.450)	.10	.00 (.045)
Capability	.670	.670	.670	.670	.670	.670	.08	.054
Potential (Risk)	1.00 (.600)	1.00 (.600)	1.00 (.600)	1.00 (.600)	1.00 (.600)	1.00 (.600)	.07	.070 (.042)
Component Cost	.950	.900	.850	.800	.750	.902	.06	.054
Maintenance	.560	.500	.500	.500	.500	.538	.05	.027
Weight	.572	.750	.781	.810	.824	.670	.04	.627

(xxx) Ratings are high in these parameters because the system is operational. Average values have been arbitrarily assigned for comparison with undeveloped systems.

$S = \Sigma_i (W_i)(\ell_i)$ → .721 (.558)

STANDARD SYSTEM EVALUATION - WITHOUT PARACHUTES

Figure 52

Load Class Weight Factor U_j → Parameter	Load Class: Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.	Adjusted Parameter Value $\ell_i = \Sigma(U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	.550	.127	.150	.150	.023			
Rig-Derig Time	.800	.800	.450	.350	.100	.665	.30	.200
Complexity	.865	.800	.732	.732	.600	.811	.20	.162
Development Cost	.312	.312	.312	.312	.312	.312	.10	.031
Development Time	.473	.473	.473	.473	.473	.473	.10	.047
Capability	.820	.820	.820	.820	.820	.820	.08	.066
Potential (Risk)	.620	.620	.620	.620	.620	.620	.07	.043
Component Cost	.550	.420	.050	.000	.000	.363	.06	.022
Maintenance	.437	.437	.437	.437	.437	.437	.05	.022
Weight	.400	.667	.679	.737	.766	.535	.04	.021
							$S = \Sigma_i(W_i)(\ell_i)$ →	.614

SKIRT JET CONCEPT EVALUATION - WITH PARACHUTES

Figure 53

Load Class Weight Factor U_j → Parameter	Load Class Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.	Adjusted Parameter Value $\ell_i = \Sigma (U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	.550	.127	.150	.150	.023			
Rig-Derig Time	.950	.950	.750	.750	.550	.883	.30	.265
Complexity	.865	.800	.732	.732	.600	.811	.20	.162
Development Cost	.312	.312	.312	.312	.312	.312	.10	.031
Development Time	.473	.473	.473	.473	.473	.473	.10	.047
Capability	.820	.820	.820	.820	.820	.820	.08	.066
Potential (Risk)	.620	.620	.620	.620	.620	.620	.07	.043
Component Cost	.800	.750	.600	.550	.450	.658	.06	.039
Maintenance	.437	.437	.437	.437	.437	.437	.05	.022
Weight	.400	.667	.679	.737	.765	.535	.04	.021
						$S = \Sigma_i (W_i)(\ell_i)$ →		.696

SKIRT JET CONCEPT EVALUATION - WITHOUT PARACHUTES

Figure 54

Load Class Weight Factor U_j → Parameter	Load Class					Adjusted Parameter Value $\ell_i = \Sigma(U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.			
	.550	.127	.150	.150	.023			
Rig-Derig Time	.750	.700	.300	.200	.000	.577	.30	.173
Complexity	.934	.800	.734	.677	.600	.841	.20	.168
Development Cost	.250	.250	.250	.250	.250	.250	.10	.025
Development Time	.421	.421	.421	.421	.421	.421	.10	.042
Capability	.820	.820	.820	.820	.820	.820	.03	.066
Potential (Risk)	.500	.500	.500	.500	.500	.500	.07	.035
Component Cost	.500	.200	.000	.000	.000	.300	.06	.018
Maintenance	.563	.437	.375	.375	.375	.486	.05	.024
Weight	.360	.637	.650	.712	.742	.500	.04	.020
							$S = \Sigma_i(W_i)(\ell_i)$ →	.571

SKY HOOK CONCEPT EVALUATION - WITH PARACHUTES

Figure 55

Load Class Weight Factor U_j → Parameter	Load Class					Adjusted Parameter Value $\ell_i = \Sigma(U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.			
	.550	.127	.150	.150	.023			
Rig-Derig Time	.900	.850	.600	.600	.350	.791	.30	.237
Complexity	.934	.800	.734	.677	.600	.841	.20	.168
Development Cost	.250	.250	.250	.250	.250	.250	.10	.025
Development Time	.421	.421	.421	.421	.421	.421	.10	.042
Capability	.820	.820	.820	.820	.820	.820	.08	.066
Potential (Risk)	.500	.500	.500	.500	.500	.500	.07	.035
Component Cost	.700	.550	.350	.200	.000	.537	.06	.032
Maintenance	.563	.437	.375	.375	.375	.486	.05	.024
Weight	.360	.637	.650	.712	.742	.500	.04	.020

$S = \Sigma_i(W_i)(\ell_i)$ → .649

SKY HOOK CONCEPT EVALUATION - WITHOUT PARACHUTES

Figure 56

Load Class Weight Factor U_j → Parameter	Load Class: Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.	Adjusted Parameter Value $\ell_i = \Sigma (U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	.550	.127	.150	.150	.023			
Rig-Derig Time	.800	.700	.300	.250	.000	.611	.30	.183
Complexity	.934	.800	.734	.677	.600	.841	.20	.168
Development Cost	.750	.750	.750	.750	.750	.750	.10	.075
Development Time	.527	.527	.527	.527	.527	.527	.10	.053
Capability	.840	.840	.840	.840	.840	.840	.08	.067
Potential (Risk)	.700	.700	.700	.700	.700	.700	.07	.049
Component Cost	.500	.150	--	--	--	.322	.06	.019
Maintenance	.563	.437	.375	.375	.375	.486	.05	.024
Weight	.245	.558	.574	.642	.675	.404	.04	.016
							$S = \Sigma_i (W_i)(\ell_i)$ →	.654

PRADS CONCEPT EVALUATION - WITH PARACHUTES

Figure 57

Load Class Weight Factor U_j → Parameter	Load Class: Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.	Adjusted Parameter Value $\ell_i = \Sigma (U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	.550	.127	.150	.150	.023			
Rig-Derig Time	.850	.800	.500	.450	.100	.715	.30	.215
Complexity	.934	.800	.734	.677	.600	.841	.20	.168
Development Cost	.750	.750	.750	.750	.750	.750	.10	.075
Development Time	.527	.527	.527	.527	.527	.527	.10	.053
Capability	.840	.840	.840	.840	.840	.840	.08	.067
Potential (Risk)	.700	.700	.700	.700	.700	.700	.07	.049
Component Cost	.700	.300	--	--	--	.423	.06	.025
Maintenance	.563	.437	.375	.375	.375	.486	.05	.024
Weight	.245	.558	.574	.642	.675	.404	.04	.016
							$S = \Sigma_i (W_i)(\ell_i)$ →	.692

PRADS CONCEPT EVALUATION - WITHOUT PARACHUTES

Figure 58

Load Class Weight Factor U_j → Parameter	Load Class: Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.	Adjusted Parameter Value $\ell_i = \Sigma(U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	.550	.127	.150	.150	.023			
Rig-Derig Time	.800	.700	.350	.300	.050	.668	.30	.200
Complexity	.734	.734	.734	.667	.600	.721	.20	.144
Development Cost	.250	.250	.250	.250	.250	.250	.10	.025
Development Time	.421	.421	.421	.421	.421	.421	.10	.042
Capability	.820	.820	.820	.820	.820	.820	.03	.066
Potential (Risk)	.600	.600	.600	.600	.600	.600	.07	.042
Component Cost	.500	.150	.000	.000	.000	.294	.06	.018
Maintenance	.624	.562	.500	.500	.500	.576	.05	.029
Weight	.360	.588	.636	.675	.721	.486	.04	.019

$S = \Sigma_i (W_i)(\ell_i)$ → .585

BERTIN AIRBAG CONCEPT - WITH PARACHUTES

Figure 59

Load Class Weight Factor U_j → Parameter	Load Class: Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.	Adjusted Parameter Value $\ell_i = \Sigma(U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	.550	.127	.150	.150	.023			
Rig-Derig Time	.900	.900	.700	.700	.450	.829	.30	.249
Complexity	.734	.734	.734	.667	.600	.721	.20	.144
Development Cost	.250	.250	.250	.250	.250	.250	.10	.025
Development Time	.421	.421	.421	.421	.421	.421	.09	.062
Capability	.820	.820	.820	.820	.820	.280	.08	.066
Potential (Risk)	.600	.600	.600	.600	.600	.600	.07	.042
Component Cost	.700	.550	.350	.200	.000	.502	.06	.030
Maintenance	.624	.562	.500	.500	.500	.576	.05	.029
Weight	.360	.588	.636	.675	.721	.486	.04	.019
							$S = \Sigma_i (W_i)(\ell_i)$ →	.646

BERTIN AIRBAG CONCEPT - WITHOUT PARACHUTES

Figure 60

Load Class Weight Factor U_j → Parameter	Load Class Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.	Adjusted Parameter Value $\ell_i = \Sigma (U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	.550	.127	.150	.150	.023			
Rig-Derig Time	.850	.800	.550	.550	.250	.742	.30	.223
Complexity	.667	.667	.667	.667	.667	.667	.20	.133
Development Cost	.250	.250	.250	.250	.250	.250	.10	.025
Development Time	.263	.263	.263	.263	.263	.263	.10	.026
Capability	.750	.750	.750	.750	.750	.750	.08	.060
Potential (Risk)	.600	.600	.600	.600	.600	.600	.07	.042
Component Cost	.550	.400	.200	.000	.000	.383	.06	.023
Maintenance	.437	.375	.312	.312	.312	.389	.05	.019
Weight	.025	.492	.522	.623	.675	.263	.04	.010
							$S = \Sigma_i (W_i)(\ell_i)$ →	.561

GLIDING SYSTEM CONCEPT - WITH PARAFOIL

Figure 61

Load Class Weight Factor U_j → / Parameter	Load Class: Under 5000 Lb.	5000-10000 Lb.	10000-15000 Lb.	15000-20000 Lb.	Over 20000 Lb.	Adjusted Parameter Value $\ell_i = \Sigma (U_j)(\lambda_{ij})$	Parameter Weighting Factor W_i	Parameter Score $S_i = (W_i)(\ell_i)$
	.550	.127	.150	.150	.023			
Rig-Derig Time	.900	.900	.650	.650	.400	.814	.30	.244
Complexity	.667	.667	.667	.667	.667	.667	.20	.133
Development Cost	.250	.250	.250	.250	.250	.250	.10	.025
Development Time	.263	.263	.263	.263	.263	.263	.10	.026
Capability	.750	.750	.750	.750	.750	.750	.08	.060
Potential (Risk)	.600	.600	.600	.600	.600	.600	.07	.042
Component Cost	.650	.600	.450	.400	.300	.568	.06	.034
Maintenance	.437	.375	.312	.312	.312	.389	.05	.019
Weight	.025	.492	.522	.623	.675	.263	.04	.010
							$S = \Sigma_i (W_i)(\ell_i)$ →	.593

GLIDING SYSTEM CONCEPT - WITHOUT PARAFOIL

Figure 62

TABLE 7. SUMMARY OF CONCEPT EVALUATIONS

Parameter	Standard System		Sky Hook		Skirt Jet		PRADS		Bertin Air Bag		Gliding System	
	With Chute	w/o Chute	With Chute	w/o Chute	With Chute	w/o Chute	With Chute	w/o Chute	With Chute	w/o Chute	With Chute	w/o Chute
Rig-Derig	.160	.209	.173	.237	.200	.265	.183	.215	.200	.249	.223	.244
Complexity	.080	.080	.168	.168	.162	.162	.168	.168	.144	.144	.133	.133
Development Cost	.100 (.030)	.100 (.030)	.025	.025	.031	.031	.075	.075	.025	.025	.025	.025
Development Time	.100 (.045)	.100 (.045)	.042	.042	.047	.047	.053	.053	.042	.042	.026	.026
Capability	.054	.054	.066	.066	.066	.066	.067	.067	.066	.066	.060	.060
Potential Risk	.070 (.042)	.070 (.042)	.035	.035	.043	.043	.049	.049	.042	.042	.042	.042
Component Cost	.038	.054	.018	.032	.022	.039	.019	.025	.018	.030	.023	.034
Maintenance	.027	.027	.024	.024	.022	.022	.024	.024	.029	.029	.019	.019
Weight	.027	.027	.020	.020	.021	.021	.016	.016	.019	.019	.010	.010
TOTAL SCORE	.656 (.449)	.721 (.568)	.572	.649	.614	.696	.654	.692	.585	.646	.561	.593

Review of the evaluation summary indicates some distinguishing characteristics between the concepts. The following features have been observed. All the concepts score higher than the standard system because of the improvements expected in the rigging time and the complexity of the new systems. The three rocket powered soft landing concepts score the highest with the PRADS system receiving the highest rating. The PRADS system scores higher than the skirt jet and sky hook because it has been partially developed which provides a higher score in the development cost, development time and potential (risk) categories. If this advantage is taken away, both the skirt jet and sky hook outscore the PRADS system. The reason for this is that these two concepts are designed specifically to solve the rapid airloads preparation problem whereas the PRADS system is an adaptation of a system that was designed for another purpose.

The complexity of both the Bertin air bag and the gliding concepts cause them to suffer in the ratings. The complexity of these systems not only reflects a low score for this parameter but also reduces the score in several other categories resulting in lower overall ratings. However, from a rigging standpoint alone, both of these concepts score very well.

VI. CONCLUSIONS AND RECOMMENDATIONS

A number of conclusions and recommendations can be made which result from the investigations and evaluations performed during the study. The following is a list of conclusions that the findings of this investigative study appear to support.

- There is considerable justification for the development of a series of load bearing platforms. This style platform is essential to any soft landing system, but in addition a number of advantages would accrue to current rigging practics. Some of these advantages are:

  a. The parachutes could be attached to the platform rather than the load which would simplify this rigging operation somewhat;

  b. The use of alternate style lashing arrangements such as the Universal Restraint device proposed herein could be considered; and

  c. Load handling and installation on the aircraft would be enhanced by the greater stiffness of the load bearing design.

- The development of a soft landing capability appears to be essential for any significant advance toward a rapid airdrop loads preparation capability. The soft landing concept makes the drive on, drive off goal for vehicular loads a feasible proposition. It reduces the restraint requirements making the use of ideas such as the Universal Restraint device feasible approaches and it greatly simplifies the task of preparing vehicles for airdrop.

- Several means of achieving a soft landing capability are available. The rocket assisted concepts are attractive because large amounts of quick energy is made available for rapid deceleration of the loads to a safe landing velocity.

- The Bertin air bag system provides the much desired high wind landing capability, but the feasibility of extending its capability to provide a soft landing capability has not been established.

- The gliding system concepts provide the high wind landing capability in addition to the soft landing features but the complexity of this system reduces its attractiveness. Also control of mass airdrops with the guidance system may present an insurmountable problem.

- Containerization of vehicular loads does not appear to be a feasible proposition. This is a useful technique, however, for supply type loads.

The following list of recommendations is offered based upon the findings of this study.

- The development of a series of load bearing platforms should be considered. This style of platform is required for any rapid airdrop loads preparation solution. In the meantime, this type of platform would benefit current rigging practices.

- Planning should be started to obtain a soft landing capability. The soft landing potential of the PRADS system should be investigated in the development program planned for this concept. The sky hook principle could also be investigated readily by modifying units of current airdrop equipment. A rocket and pulley system could be added without great difficulty and a simple mechanical ground sensor could be used to initiate the rockets. Investigation of other soft landing approaches should be continued by study and analysis.

- A modest program to define the requirements for a soft landing should be initiated. A need exists to substantiate or redefine the assumption made herein that a 5 g deceleration force at touchdown would constitute a soft landing.

- The possiblity of modifying the Bertin air bag principle to achieve a soft landing capability should be studied. If the high wind landing capabilities of this system are true, the addition of a soft landing feature would provide a system with excellent rapid rigging properties and the broadest air-drop capabilities of all the systems considered.

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