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HIGH-SPEED CONTAINER DELIVERY SYSTEM (HSCDS): TRADE-OFF DETERMINATION

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13. ABSTRACT *(Maximum 200 words)*

In order to resupply containers at higher airspeeds and from lower altitudes, the High Speed Container Delivery System (HSCDS) program was initiated in 1990. This system will be designed to airdrop from the C-17, MC-130, and other capable aircraft from up to 250 knots indicated airspeed (KIAS) and as low as 300 feet above ground level (AGL). In November 1991, a Trade off Determination (TOD) was started by Natick to be conducted simultaneously with the Trade off Analysis (TOA) being prepared by the U.S. Army Quartermaster School. The TOD was prepared in-house; whereas, the TOA was performed by a contractor (American Power Jet). The HSCDS consists of three separate subsystems; therefore, the TOD was prepared accordingly. The results of the TOD indicated that: 1) Breadboard prototypes of rigid and cargo net containers need to be designed, constructed, and tested before one concept is chosen over the other. 2) A 40 to 50 foot diameter flat circular solid cloth parachute that utilizes a lower porosity canopy material near the apex seems to be the most promising alternative for the main recovery subsystem. 3) Aerodynamic (parachute) method of extraction/ejection of containers seems to have the most potential for success.

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PREFACE AND ACKNOWLEDGEMENTS

This report is the first deliverable of the Concept Formulation Package (CFP) described in Army Regulation 71-9. It identifies the full range of materiel possibilities for a new aerial delivery container system for the United States Army, and establishes bands of performance and system characteristics that can be achieved in the time available. The new system must provide the capability to airdrop supply containers from U.S. Air Force cargo aircraft flying at 300 foot altitudes and 250 knot airspeeds.

The authors wish to thank Mr. Bob Rodier, Mr. Hank Antkowiak, Mr. Peter Van Buren and Mr. Matti Harm, of the Airdrop Systems Division, Aero-Mechanical Engineering Directorate for their technical advice and expertise concerning containers, parachutes and airdrop operations, MSGT John Hayes, of the USAF Mobility Center, for his technical advice and expertise concerning Air Force loadmaster issues, and Mr. John Redgate, of the Information Management Directorate, for his assistance in editing and formatting the report.

SUMMARY

The High-Speed Container Delivery System (HSCDS) airdrop development program addresses the U.S. Army's need for a system to airdrop containerized equipment and supplies (up to 2,200 pounds per container) from U.S. Air Force cargo aircraft flying at high airspeeds (up to 250 KIAS) and low altitudes (300 feet AGL or lower).

First, all plausible technical approaches for the system were described. The system was broken down into three critical components or subsystems; the **container subsystem**, the **main recovery subsystem**, and the **extraction/ejection subsystem**. Technical approaches were presented one subsystem at a time. Additionally, bands of performance, advantages and disadvantages were presented for the different alternatives. Finally, the most promising technical approaches were recommended for further study.

Container Subsystem

The current A-22 cargo bag will not be able to withstand the parachute opening shock forces expected to occur at increased airspeeds. Also, the A-22 is not designed to withstand the large lateral force that must applied to the containers by high-speed extraction subsystem. This large force will be required to eject or extract the containers off the level aircraft floor at a rapid rate in order to reduce dispersion of the containers on the drop zone. A variety of options and trade offs were presented for the HSCDS container dimensions, types of construction and impact mitigation techniques. It was recommended that new containers that have a 2,200 pound capacity, a 48 by 48 inch base, and a construction of either a rigid box or an improved cargo net design be designed and tested.

Main Recovery Subsystem

The current Container Delivery System (CDS) can be airdropped by two different modes; low velocity (LV) and high velocity (HV). The terms LV and HV refer to the terminal (stabilized) velocity at which the containers descend under the canopy rather than the aircraft airspeed. LV CDS containers have a terminal descent rate of between 14-27 fps. High velocity CDS containers descend at between 41-90 fps, and they are generally used to airdrop containerized items that are not very sensitive or are easily damaged. The standard low velocity recovery subsystem is a flat circular, 64 foot diameter, solid canopy parachute. High velocity CDS are rigged with a 26 foot ringslot main recovery parachute. A study was conducted to establish an optimal rate of descent range for all HSCDS. This would eliminate the need for both a high and low velocity system. Different designs, types, sizes and quantities of main recovery parachutes were studied in relation to their ability to meet the low altitude, high-speed performance criteria. Based on these studies, the optimal main recovery subsystem appears to be single flat circular, solid cloth parachute with a diameter of 40 to 50 feet. The main parachute should be deployed by a pilot parachute which is itself deployed by static line. It was also recommended that new types of breakaway static lines be investigated for use with the new pilot chute. Concept testing should also be conducted with various cluster

configurations of 28 foot heavy duty ringslot extraction parachutes. This will provide data on a type classified item that has possibilities for use in the subsystem.

Extraction/Ejection Subsystem

CDS containers are now extracted from the aircraft floor by the force of gravity. While the aircraft maintains a level flight path, it pitches up its nose, by changing the flap settings on the wings, creating a 6 to 8 degree deck angle. The containers are then released and are forced to roll off the aircraft ramp by gravity. This method cannot be accomplished at higher airspeeds since the aircraft can not achieve a sufficient deck angle without gaining altitude. In order to extract/eject loads at up to 250 knots indicated airspeed (KIAS), new equipment and/or techniques must be developed. The numerous alternatives that were examined were grouped into four categories; stored energy ejection, electromechanical ejection, gravity extraction, and aerodynamic extraction. Based on subsequent analyses, the aerodynamic (parachute) extraction method appears to have the most potential for success. A towplate system should also be incorporated into the subsystem in order to achieve greater drop accuracy.

Conclusion

The TOD process has identified most, if not all, of the possible alternatives within the three major subsystems. Through this process, the direction of the HSCDS program has been established. Based on the results of this TOD and the Trade Off Analysis (TOA), generated by the Combat Developer, the next Concept Formulation Package (CFP) document, the Best Technical Approach (BTA), will be completed. The BTA will discuss in more detail the technical attributes of the most promising alternatives, to include detailed cost trade-offs among the alternatives.

HIGH-SPEED CONTAINER DELIVERY SYSTEM (HSCDS): TRADE OFF DETERMINATION

1.0. INTRODUCTION

1.1. Mission Need

The High-Speed Container Delivery System (HSCDS) airdrop development program addresses the U.S. Army's need for a system to airdrop containerized equipment and supplies (up to 2,200 pounds per container) from U.S. Air Force cargo aircraft flying at high airspeeds (up to 250 KIAS) and low altitudes (300 feet AGL or lower). This need is consistent with a Military Airlift Command (MAC)/Training and Doctrine Command (TRADOC) Memorandum of Agreement (MOA) which states that future airdrop systems for personnel, vehicles, equipment and supplies will be deployed at lower altitudes and higher airspeeds. In addition, the United States Special Operations Command (USSOCOM) has expressed interest in the low and fast resupply capability for Special Operations use.

1.2. Predecessor System

The current CDS container (the A-22) can deliver up to 2,200 pounds (suspended weight), can be airdropped individually or in mass, and can be airdropped on single or multiple drop zones. The primary mission aircraft now used to deliver CDS are the C-130 and the C-141. Up to 16 containers (2,328 pounds each with the parachute; total of 37,248 pounds) can be airdropped at 140 KIAS in a single pass from the C-130 aircraft. As many as 40 containers (total weight limited to 65,800 pounds or 1,645 pounds per container, or only twenty eight 2,328 pound containers) can be airdropped at 150 KIAS in a single pass from the C-141 aircraft. The current CDS containers are extracted by gravity (they roll off the cargo floor rollers when the aircraft obtains a nose-up attitude).

The current CDS can be airdropped in two different modes; low velocity (LV) and high velocity (HV). The terms LV and HV refer to the terminal (stabilized) velocity at which the containers descend under the canopy, not the aircraft airspeed. CDS rigged for LV is made up of the A-22 aerial delivery container; the G-12E parachute system, which is a 64 foot diameter flat circular solid canopy with a 57 foot centerline pull-down vent; and paper honeycomb for ground impact shock mitigation. The A-22 container is comprised of a nylon sling assembly for parachute attachment and load bearing, and a canvas cover for load confinement and environmental protection. A 48 by 48 inch piece of 3/4 inch plywood is used for a skidboard in conjunction with the A-22. LV CDS containers have a terminal descent rate of between 14-27 fps.

High velocity CDS descend at between 41-90 fps, and are generally used to airdrop containerized items that are not very sensitive or easily damaged. There are several reasons for using HV CDS. One is that HV CDS is less expensive than LV. Another is to improve point of impact (PI) accuracy when the aircraft must fly at higher altitudes (above 1,000 feet). The containers are less susceptible to wind drift due to their increased descent rate. CDS rigged for HV is similar to LV with the following exceptions: a 26 foot high velocity cargo parachute or a 22 foot extraction parachute is used in lieu of the G-12E, the plywood skidboard is 1 inch thick, and five to seven layers of honeycomb are used in lieu of the two layers used for LV.

1.3. Background

The HSCDS program is the second phase of the two-phase Enhanced Container Delivery System (ECDS) program. The first phase (referred to as the interim system) was conducted to reduce the minimum drop altitude from 600 feet to 300 feet AGL at current airspeeds. Since the interim ECDS was to be compatible with the developmental Centerline Vertical Restraint System (CVRS), the container was modified to be compatible with that system.

The interim program maximized the use of existing materials to satisfy the requirements. The main recovery parachute was changed from the G-12D to the G-12E, which permitted the airdrop altitude to be lowered to 300 feet AGL. The interim ECDS was adopted and authorized for use in December 1989.

The high-speed phase of the program, initiated in January 1990, is aimed at satisfying the 250 KIAS requirement. The increase in delivery airspeed to 250 KIAS introduces significant technical challenges that must be met.

1.4. Market Surveillance

Market surveillance suggests that nondevelopmental item (NDI) systems, that would meet the full range of HSCDS requirements, do not exist commercially, nor in other U.S. or foreign military services inventories. However, maximum consideration will be given to NDI components and commercially available technology as contributors to the overall materiel solution. Modification/adaptation of existing materiel (e.g., A-22 cargo container, existing military parachutes, existing extraction subsystems, etc.) will be preferred to developmental subsystems/components, if the performance of the modification/adaptation successfully contributes to meeting the system requirements. In those areas where NDI, or modification/adaptation of existing materiel can not be utilized for the system, it is proposed that a suitable materiel solution be developed. For the purposes of this Trade-Off Determination (TOD), the NDI approach will not appear when discussing the overall system or subsystems (based upon the above mentioned market survey). This will accelerate the TOD process and decrease the cost incurred from examining infeasible alternatives.

1.5. Trade-Off Study Approach

The first objective of this report is to describe all plausible technical approaches, demonstrating that each of the recommended approaches to be considered are ready for engineering rather than being experimental.

The HSCDS has been broken down into three critical components or subsystems; the **container subsystem**, the **main recovery subsystem**, and the **extraction/ejection subsystem**. Technical approaches will be presented one subsystem at a time. Trade-off studies presented here will discuss each area individually; however, the effects of a subsystem approach on another subsystem, or on the overall system, will be discussed where appropriate. Bands of performance, advantages and disadvantages will be presented for each of the alternatives.

Finally, technical approaches will be recommended that have the possibility of meeting of the requirements of the O&O Plan within reasonable bands of performance, cost and schedule.

2.0. CONTAINER SUBSYSTEM

The current container consists of the A-22 cargo net/bag, paperboard honeycomb and a plywood skidboard. The existing container (herein referred to as the A-22) is not designed to withstand the increased parachute opening forces that will be experienced when airdropped at 250 KIAS. Also, the A-22 configuration does not provide positive restraint of the cargo to the plywood skid. Extreme shift of the cargo relative to the skidboard will occur if the A-22 is to be extracted by parachute. Moreover, load shift relative to the skid during existing CDS training operations has been reported, especially when the aircraft is conducting flight maneuvers in simulated combat conditions. If the containers must be extracted with an extraction parachute, the current A-22 design will not withstand the extraction force (i.e., the load may experience shifting during the extraction phase). The A-22 can be moved by forklift prior to airdrop, by inserting the tines into gaps in the honeycomb (if the gaps are present). If there are no gaps in the honeycomb, the A-22 is stored on top of 4 foot lengths of 4 inch by 4 inch lumber to facilitate forklifting. After airdrop, however, any forkliftability is lost, since the honeycomb crushes and the wood block technique is not feasible on the drop zone.

These problems will require the container to be substantially modified or replaced with a developmental container. As part of the effort to meet the requirements for the container, the load capacity and dimensions of the container will be analyzed and optimized. In addition, simplifying and speeding up the rigging and derigging of the container are important design goals.

2.1. Container Dimensions

The A-22 container has a cargo carrying area of 48 inches wide, 53 inches long and 66 inches high. However, with the introduction of the CVRS, the length of the A-22 skid was reduced to 48 inches. Even though the A-22 bag has a base of 53 inches, it is not normally rigged longer than 48 inches. The maximum overall height of the A-22 rigged on honeycomb and with the parachute attached on top of the load is 83 inches. The A-22 can be doubled (48 by 96 by 66 inches) to accommodate larger equipment, such as AHKIO Sleds (88 inches long), snowmobiles (104 inches long), and bulk plywood or lumber resupply loads (usually 96 inches long).

2.1.1. Width of Container

The parameter that dictates this dimension is the aircraft rail system. For CDS operations on board the C-130, MC-130 and C-141, the airdrop side rails and the CVRS are utilized to create two rows, 48 inches wide each. For the C-17 aircraft the airdrop side rails and the logistics rails are both used in lieu of the CVRS. A dimensional analysis was made on the interface between the rail system and the base of the container. The analysis suggests that the base width design value should be 48.00 +.25/-.00. The base width dimension of the container is a fixed parameter, and as such, no alternative dimensions (other than alternative tolerances to optimize interface with the rail systems) need be considered. It is important to note that if the 48 inch dimension is too short, there is a possibility that the skid would not engage both the aircraft rail and the center rail. This is critical since in that case there would be no vertical restraint on the container. If the base width is too wide then the container will either not fit into the aircraft or it will jam upon loading or exit. Using the A-22 system, the plywood skid is cut in the field by hand. There exists a great risk right now that the plywood skid will be out of tolerance, which will invite these problems to occur. If a replacement skid or rail interface is to be designed, the 48 inch dimension and it's associated tolerance must be held firm to alleviate this problem.

2.1.2. Length of Container

There are two logical alternatives available for the container length.

2.1.2.1. Maintain 4 Foot Length. This approach will assure compatibility with all loads currently airdropped in the A-22 or double A-22 containers. It will also allow more containers to be dropped per aircraft than using a longer container, providing more flexibility of loads for multiple DZs. However, the 48 by 48 inch footprint of such a container is inherently unstable upon ground impact.

2.1.2.2. Longer Container. This approach maintains the width of 48 inches while making the length longer than 48 inches. In general, a longer container has the following **advantages**: more stable during ground impact (less likely to tip over), accommodates longer loads without the necessity to double the container, accommodates more equipment per container, standardizes all CDS loads to one size if no doubling is required, requires fewer parachutes per full stick of containers since there will be fewer containers in each stick (these will ease rigging burden for parachutes, and container rigging), fewer parachutes per stick are likely to reduce air starvation between parachutes, fewer containers per stick will reduce the number of bundles to recover on the DZ for a given amount of equipment. This approach has the following **disadvantages**: since the maximum weight of the longer containers would be increased to 2,910 pounds, the main recovery parachute subsystem would become more complex and difficult to design (this complexity is due to the increase in range of weights to 6 to 1), reduces the capability to airdrop limited amount of equipment per drop (the amount of materiel contained in one long container may be more than is needed for a given unit), longer and heavier (2,910 pounds) containers will be significantly more difficult to manhandle on the drop zone (i.e., roll container over to prepare for MHE or derigging). The CDS Dimension and Capacity Study done in 1986 suggested a length of 60 inches to accommodate ammunition pallets, which can be up to that length. However, to accommodate double size loads a length of 96 inches could be considered.

> NOTE ON AMMUNITION PALLETS: *Before ammunition pallets, rigged without being broken down, can be airdropped they must be certified. In most cases the ammunition is broken down and packaged for airdrop to promote survivability of the rounds or missiles. The orientation of the rounds/missiles in the ammunition pallet, in general, are different than their orientation when packaged in an A-22 for airdrop. The cost for certification of one ammunition pallet for airdrop exceeds $100,000. The*

process is also very time consuming, since obtaining rounds/missiles and good fragility data is many times difficult. Therefore, since the driver to go to a 60 inch (or longer) container is so that ammunition pallets can be airdropped, then the associated certification costs and program delays must be considered. The additional cost would exceed $3,000,000 and the time required to certify the pallets would be at least 3 years. The certification effort could be conducted separate from the R&D program, and therefore, would not necessitate a 3 year program delay.

2.1.3. Height of Container

CDS containers are rigged at various heights depending upon the equipment or supplies in the A-22. There currently is a height restriction on CDS loads of 83 inches, including the parachute. It is understood that this restriction is imposed due to the possibility of container static lines being fouled with the static line retriever cable during the drop. Also, there is concern for load stability in the aircraft and on ground impact if the container is too high.

2.1.3.1. Shorter. It is possible to consider restricting the container to less than 83 inches to improve stability, however, this would significantly reduce the cargo volume per container unless it was made longer.

2.1.3.2. Taller. Increased height would allow more volume per container. However, stability would become a significant problem unless the length was increased. If the static line retriever cable was totally eliminated as a technique for releasing the containers then the height restriction could be relieved.

2.1.3.3. Fixed Height. Regardless of exactly what the container is, the concept of maintaining a fixed height has the following **advantages**: load uniformity in aircraft is desirable when considering aerodynamically extracting the loads one against the other, makes a rigid container design easier to achieve. The **disadvantages** include the need to square out or fill in gaps on loads to make each load fit in a fixed height cargo area.

2.1.4. Weight of Container

2.1.4.1. Status Quo. Maintain maximum rigged weight of 2,328 pounds (582 lbs/linear foot). This approach will be consistent with the present restraint criteria in the aircraft. All rate of descent simulations and models for the various current and alternative recovery parachutes would still be valid. The recovery of the cargo on the drop zone would probably be easier and not require as much materials handling equipment.

2.1.4.2. Increased Maximum Weight. Increase the maximum rigged weight beyond the 582 lbs/linear foot limit.

Advantages. Some heavy ammunition loads (see note on page 6) would be able to be rigged without being broken down (although most ammunition pallets are already less than 2,200 pounds). The overall logistics flow and the time to rig these heavy ammunition containers may be significantly reduced if they can be loaded without breaking them down.

Disadvantages. The CVRS currently has a maximum rating of 582 lbs/lin ft in the vertical direction. This limits the rigged weight of a four foot (length) container to 2,328 pounds and a five foot container to 2,910 pounds. In order to increase the rigged weight beyond the existing limit, a new CVRS would have to be fielded by the USAF or additional vertical restraint would have to be applied to each container. Since the current CVRS was developed to eliminate vertical restraints straps, placing additional restraints on the container will defeat the purpose of the CVRS.

2.2. Construction of Container

The alternatives for container construction can be grouped into two categories: rigid type and cargo net type. There are further variations/alternatives in materials and construction within these categories. Several approaches are summarized herein:

2.2.1. Modified A-22

Modify existing A-22 design with the following: additional suspension straps to take up the parachute opening loads, new rigid skidboard with tiedown provisions, ratchet devices to connect the A-22 to the skid more positively, and D-rings sewn into the A-22 webbing for attachment of skid straps to A-22.

Advantages. Similarity with existing A-22 design will simplify training requirements. Probably the lowest cost solution. Could modify existing containers in the field which would expedite fielding and eliminate the need to phase out the old A-22. New method of tying bag to skid will greatly improve load shift relative to the skid.

Disadvantages. A-22 does not provide resistance to cargo shift within the container. Does not dramatically reduce rigging/derigging requirements. Ratcheting down on the A-22 webbing is not supported by the A-22 webbing. After storage and transportation the A-22 loosens up and will require retightening of the skid straps. If this is done the parachute opening forces will be transmitted to the skid. These forces will require a stronger skid, therefore requiring additional cost and weight for the skid. Does not provide forkliftability after airdrop.

2.2.2. Developmental Cargo Net Type

This approach leverages on the basic concept of the A-22 container. However, considering the fact that the A-22 was designed in the early 1950's, this approach would take a fresh look at every aspect of this type of container -- the cargo cover, the webbing net/sling assembly, the suspension webs, the skidboard and the load/skidboard restraint method.

Paperboard honeycomb will be used for impact mitigation. Heavy-duty ratchet buckles will be integrated into the cargo net webbing to improve the container's ability to resist load shift relative to itself and the honeycomb beneath the net. State-of-the-art materials handling and cargo restraint equipment will be used and will provide for non-complex and quick rigging/derigging. A rigid type skid with tiedown provisions will replace the plywood skid. Use of standard military webbing and hardware will be maximized, except in those cases where doing so degrades container performance or is not cost effective. Could be doubled for items longer than 48 inches.

Advantages. The container is lighter weight than a rigid box type and will be easier for one person to move around for storage. Ratchet devices allow for a very tight fit of the cargo and will reduce load shift. If design is similar to the 463L cargo net it will provide familiarity and some degree of standardization among Army and Air Force systems. Container could be used as a logistics container, as well as an airdrop container. Cargo net design will take up parachute opening forces easier than a rigid wall type since the webbing will yield more.

Disadvantages. May require a cargo bag inside the net for bulk supplies, although it is conceivable that the net could contain such supplies without a bag. Rigging a cargo net with buckles and ratchet devices may be more time consuming than a rigid walled container. May not restrain the cargo positively during extraction phase as well a rigid type.

2.2.3. Rigid Container

The cargo carrying area for this approach will be a rigid walled container. The material construction could be double wall extruded aluminum, composite, high-strength polymer, or some other material that meets the performance requirements. The container will have collapsible or separable walls for storage and to facilitate loading the container. A new skid with tiedown provisions will be connected to the container with webbing straps that have ratchet buckles.

Advantages. Permanent forklift capability can be designed into the rigid base. Rigid wall design will be very simple to load/rig. A cargo cover shall not be required for this design, since the rigid container itself shall provide total load confinement, as well as basic protection from the environmental elements (i.e., rain, snow, etc.). Gaskets could be used to provide a weather tight container for storage outside (without honeycomb prerigged or with honeycomb inside). Separable walls facilitate manportability, and make storage of empty containers take up less volume. Separable parts also permit replacement parts rather than replacing an entire container (saves on O&S costs). Could store rigid parts outside rather in warehouse. Rigid design will make extraction of load easier. No cargo shift within container. Skid straps will not loosen as easily as a net design (may not need to be tightened). [Note: One inch polyester straps are a good alternative for the skid ties since the elongation of polyester is much less than that of nylon.] Can be used as a logistics container as well as an airdrop container. Could be doubled for items longer than 48 inches.

Disadvantages. Rigid pieces will be heavy compared to a cargo net design. Rigid parts may not be a durable as cargo net (but this remains to be demonstrated). Investment cost will be more than cargo net type; however, a life cycle cost analysis may prove to justify expense. Fixed size does not lend itself to odd shaped or varying sized loads. Requires squaring or filling in gaps prior to closing the container (however, this is required to some degree with cargo net types as well).

2.3. Positioning of Shock Absorbing Material

There are several alternatives that will be discussed concerning this issue. Each approach is applicable for use with a cargo net, rigid wall or modified A-22 design container (unless noted otherwise). It is also assumed that paper honeycomb will be used for shock absorption. However, the material developer is aware of a thermoplastic urethane honeycomb sheet material with similar characteristics to paper honeycomb. This material will cost more per sheet than paper honeycomb; however, it has memory and will, therefore, be reusable. Thermoplastic urethane sheets will be evaluated during the test program.

2.3.1. Honeycomb on Bottom

This is the traditional approach, which includes a skidboard under the honeycomb. The skid allows the honeycomb to be held in place under the load, provides a smooth surface for the container to roll on, interfaces with the aircraft rails to constrain the load vertically and keep it in line during loading onto and exiting from the aircraft. If provisions are designed in the container, it can be tightly secured to the skid for improved flight restraint (reduced load shift). It will be difficult to totally eliminate load shift (especially during the extraction phase). The main parachute would be attached to the top of the container.

2.3.2. Honeycomb Inside Container

This primarily applies to the rigid type container. With the honeycomb inside the container, any concerns for load shift would be totally eliminated, and the container would be well suited for extraction. If a rigid container were to have a dual role as a logistics container, then logistics loads could not be easily converted to airdrop loads (would require unpacking, inserting honeycomb and then repacking). It will also be difficult to inspect the condition of the honeycomb, and to replace the honeycomb.

2.3.3. Honeycomb on Forward Side

The paper honeycomb would be mounted (possibly with webbing and a thin sheet of plywood) to the side surface of the container, which would be facing forward in the aircraft. In this scenario there is no need to rigidly envelope the honeycomb. Once the container exits the ramp of the aircraft it would rotate into proper orientation and impact the ground on the honeycomb. This idea could be applied to the cargo net container as well. This concept would require a reduction in the number of containers that could be loaded in the cargo bay, since the honeycomb on the side would take away as much as 18 inches per container.

2.3.4. Honeycomb on Top

By placing the honeycomb on top of the container, shifting of the container cargo can be significantly reduced. The center of gravity would be closer to the floor of the aircraft; therefore, the load itself would also be less prone to shift. This can reduce the incidence of loads jamming in the rail system and enhance crew safety in the cargo compartment. The honeycomb can be easily replaced if damaged at the rigging site, in transit, or at the departure airfield. The rigging of the container and the deployment sequence would be more complex and possibly more susceptible to malfunctions. The container would have to flip 180 degrees in order to land on the honeycomb. This may require the parachute riser assembly to pass beneath the container and possibly come in contact with the roller conveyor system.

3.0. MAIN RECOVERY SUBSYSTEM

The recovery subsystem is responsible for decelerating the payload to a reasonable rate of descent and orienting the system so that it impacts the ground as close to vertical as possible. When designing a new recovery system, the two most important characteristics to be considered are the type and the diameter of the parachute. These attributes affect descent velocity, oscillation of the system, opening forces, life-cycle costs, and other factors. These properties have all been considered in the following discussion.

3.1. Parachute Type

There are many different types of decelerators, most of which have very specific applications. Guide surface parachutes are very good for stabilizing loads when used as pilot or drogue chutes. Annular parachutes have very good drag characteristics, but are not reliable at high deployment speeds. Conical parachutes have qualities very similar to flat circular solid parachutes, with slightly better drag and stability drag characteristics than a flat circular. Other decelerators (e.g., ballutes, rotafoils, vortex rings, parafoils, etc.) are designed for very different applications (e.g., supersonic speeds, guided delivery, etc.), are very expensive to manufacture, and are not desirable candidates for HSCDS.

A market survey was conducted on existing parachutes. This study revealed that there are currently no cargo parachutes available which could survive the high deployment velocities and lower the payload at an acceptable rate of descent. The results of the survey are found in the Sandia Report, paragraph 2.2. The parachutes that are currently used for cargo airdrop will not survive the high opening forces experienced at 250 knots.

The parachutes best suited for cargo airdrop recovery applications are solid cloth, ribbon, and ringslot types. Their proven performance in the field, and relatively low cost make them attractive concepts. Based on their high potential for meeting the requirements, these types of parachutes have been analyzed in terms of their feasibility as a main recovery parachute for HSCDS. It should be noted that cruciform or cross parachutes also have good utility for cargo airdrop, however, they were not analyzed in great detail during this TOD. The use of cross parachutes for this application may be a valid consideration if other types of chutes fail to meet performance and cost requirements.

3.1.1. Solid Flat Circular

This type of parachute is constructed with multiple triangular gores of solid cloth and it has a vent or hole in the apex of the canopy. The canopy can be laid out flat on the ground, thus its name "flat". Its design is the basis for most types of circular parachutes.

Advantages. They are simple and economical to construct, handle, and inspect. They have been in use as cargo airdrop parachutes for decades and have a very high reliability factor. While most of the larger cargo parachutes (G-12 and G-11) are not constructed for high-speed applications, a heavy-duty solid flat circular parachute, very similar to the G-12, has survived successfully during test drops at 240 KIAS with a payload of 1,900 pounds.

Disadvantages. There is very little data available for high-speed applications of solid flat circular parachutes. The C-9 personnel parachute has been used to deploy 200 pounds at 275 knots, but larger cargo parachutes generally are used at deployment velocities not exceeding 150 knots. Large solid canopies have been reported to perform at 275 KIAS [10], however, the parachutes used were extended skirts and were reefed.

3.1.2. Ringslot

The canopy is constructed with wide concentric cloth strips with intervening slots. Ringslot parachutes are typically constructed of a flat or conical shape. They have been used for aircraft landing deceleration, extraction of airdrop platforms, and for high velocity airdrop container loads.

Advantages. Ringslot canopies can survive higher deployment velocities than solid ones built with similar materials. Their method of construction makes them very sturdy parachutes and are more affordable than ribbon chutes.

Disadvantages. Drag characteristics of the ringslot parachute are not as good as those of a solid canopy of comparable size. Ringslot parachutes are generally slower to open that solid cloth canopies, which would lead to greater altitude loss before inflation.

3.1.3. Flat Circular Ribbon

This canopy is a flat circular design which consists of concentric ribbons, usually two inches in width, supported by smaller vertically spaced tapes and radial ribbons at the gore edges. Gores are triangular and dimensions are determined in the same manner as for a solid flat circular parachute.

Advantages. This parachute has excellent stability and lower opening forces than solid canopies. In general, ribbon parachutes are more sturdy than ringslots and solid cloth canopies of similar scale, although this is primarily a function of material strength.

Disadvantages. Drag characteristics of the ribbon parachute are not as good as those of a solid canopy of comparable size. Ribbon parachutes are generally slower to open than solid cloth canopies, which would lead to greater altitude loss before canopy inflation. Manufacturing costs are greater than those of a solid canopy design.

3.2. Number of Parachutes

Clusters of parachutes are commonly used when air-dropping equipment on platforms. A payload of 35,000 pounds may require up to eight 100-foot diameter canopies to lower it at a reasonable rate of descent. Smaller payloads (like CDS) are generally recovered using a single canopy; however, both clusters of smaller parachutes or a single recovery parachute were also considered as alternatives for container airdrop.

3.2.1. Single Canopy - No Reefing

Advantages. The opening reliability of a single canopy is very high regardless of the type of parachute. Stowing single canopies into their deployment bags is relatively simple. Logistically, it is easier to maintain one canopy per load than multiple canopies.

Disadvantages. With only one canopy on a load, any malfunction will probably damage or destroy the payload. In order to achieve a desired rate of descent, the single canopy would be larger than the individual canopies used in a multiple-parachute recovery system. Larger canopies are more difficult to recover on the drop zone and are generally more expensive to purchase. When several bundles are being airdropped at the same time, it is likely that they will be of widely varying weights. This could lead to container collisions during the descent phase, since the heavier payloads could be descending much faster than the lighter ones.

3.2.2. Clusters of Small Main Parachutes

Utilize one specific type and size chute for all drops. As the payload increases, additional chutes will be rigged on the load, thereby creating clusters of small main canopies for heavier containers (e.g., 600 to 1000 pound loads have one chute, 1000 to 1500 have two chutes, and 1500 to 2200 pound loads have three chutes).

Advantages. This method will permit the descent rate of all containers to be more uniform. This is advantageous since the number of honeycomb layers can remain constant (or nearly constant) for each load regardless of the container weight. Load survivability is easier to enhance when the descent rate is consistent. Also, reduces the load interference problem experienced when one load descends up to twice as fast as another. If one parachute in a cluster fails to open properly, there is a better chance that the payload may survive than there would be with a single canopy recovery system.

Disadvantages. Clusters will probably require riser extensions which will impede the low altitude performance of the system. However, if the chutes are very small the fact that they open very fast may compensate for this problem. Multiple canopies have a tendency to steal air from each other, which will cause an inconsistency in parachute opening time (and thus the low altitude capability). Rigging will be more complex with multiple bags and riser extensions. Will require more parachutes to be packed per load, although the chutes will be smaller and easier to pack. If multiple chutes were to be packed in a single D-bag; rigging complexity would be dramatically increased. The logistics of having several different D-bags each packed with different numbers of parachutes is less flexible than each chute in a separate D-bag.

3.2.3. Single Recovery Parachute with Variable Reefing

The recovery parachute could be reefed to different diameters, depending on the weight of the container. The parachute would have several reefing lines of different size rigged each time it is packed, with the reefing lines coded by color. When attaching a parachute to a container, a chart in the rigging manual would identify to the rigger which lines to cut. Either all of the lines will be cut or one specific line will not be cut. A hardware link could be used to disconnect the proper lines rather than destroying them for each drop.

Advantages. This method would combine the advantages of delivery by both single and clustered parachutes. A consistent rate of descent could be maintained, regardless of container weight, as well as the high reliability of single canopy opening. Would be simpler to rig than multiple parachutes.

Disadvantages. The possibility of cutting the wrong reefing lines exists. Rigging multiple reefing lines for each canopy would add time to the parachute packing process.

3.3. Parachute Diameter

Variations in parachute diameter and type may greatly affect the performance of the system. The most important performance parameters for HSCDS are opening forces, oscillation, altitude loss and descent velocity. The final design must be capable of performing at 250 knots, but performance at 130 knots is also desirable. Trajectory simulations were run to determine the performance characteristics over a range of canopy diameters. The trajectory program calculates the path of the payload and canopy from the time of main canopy stretch until payload impact, as a function of time. When the diameter was varied, care was taken to assure that a consistent set of initial conditions for starting each new trajectory calculation was maintained.

Given a solid cloth parachute diameter, a parachute weight was estimated by taking the parachute canopy area and multiplying it by a constant of 0.0441 lb/ft^2. This constant was derived from typical solid parachute weights and areas. (The 43 foot diameter ribbon parachute which was considered has a known weight of approximately 160 pounds.) Knowing the weight of the main parachute, and assuming full free-stream dynamic pressure, a pilot parachute drag area and, hence, constructed diameter, may be calculated. These calculations assume a solid pilot parachute with a drag coefficient of 0.8. Knowing the constructed diameter of the pilot parachute and assuming a static line deployment of the pilot, the time to deploy and fill the pilot parachute can be estimated.

Once the pilot parachute is filled, the deployment process of the main parachute can be modeled. This was done for the 38 foot diameter parachute using the LINESAIL code, which was written at Sandia National Laboratories. The relative velocity of the pilot parachute/main bag assembly with respect to the container can be determined. Using this data, an average deployment acceleration of 325 feet/sec^2 was used to estimate the time required to achieve main canopy deployment after pilot parachute deployment and filling. Adding the time for pilot parachute deployment and filling to the time for main canopy deployment yields an estimate of the total time from container exit to main canopy stretch. Using the time to main stretch, and basic free-body diagrams, the reduction in the container horizontal velocity and the increase in container vertical velocity can be estimated. These velocities, along with the container altitude at main canopy stretch, are required as input to the two point mass trajectory code (TWOBODY).

The TWOBODY results are summarized in Tables 3.1, 3.3 and 3.4. Both "stable" and "unstable" models for the main parachute were studied. For the "stable" case, there is always a force attempting to restore the parachute to zero angle of attack if perturbed away from that state. In the "unstable" case, there is no force to restore the parachute to a zero angle of attack when perturbed until the angle becomes large. The "unstable" case generally results in larger degrees of backswing, but, also in less altitude loss to first vertical. It was presupposed that the "unstable" model is a better simulation of a solid cargo parachute than the "stable" model. Therefore, the "unstable" results are presented in this report. The stable results were reported in the Sandia Report, Section 3.1.5.

3.3.1. Opening Forces

Parachute opening forces are highly dependent upon deployment velocity. In theory, as velocity increases, the force increases with its square. For example, if the velocity doubles, the force quadruples. Smaller canopies open quicker, when the velocity is higher. Larger canopies take a longer time to stretch, so the velocity is lower when it inflates, but its larger area contributes greatly to the opening force.

Table 3.1. Theoretical Parachute Opening Force vs. Parachute Diameter

Parachute diameter (ft)	Parachute type	Theoretical Maximum Force 130 KIAS	Theoretical Maximum Force 250 KIAS
38	solid	7,654	25,344
43	ribbon		18,189
45	solid	7,889	26,260
50	solid		24,864
55	solid		24,928
60	solid		24,350
64	solid	7,839	24,049

Limited experience has shown that trajectory codes will predict higher opening forces than are actually measured at 250 KIAS. For example, in Oct 91, two A-22 containers were airdropped from an MC-130 traveling at 240 KIAS. Opening force data was obtained on each of the main recovery parachutes, which were MC-1150 (64 foot solid cloth) parachutes.

The results of those tests are as follows (the measured forces were only 70-75% of the predicted):

Table 3.2. Opening Force Data for the MC-1150 Parachute at 240 KIAS

Rigged Weight of Container (pounds)	Measured Opening Force (pounds)	Predicted Opening Force (pounds)
1,820	13,350	18,116
1,920	13,500	18,908

3.3.2. System Oscillation

The angle of the container vertical axis with relation to the ground vertical axis is the oscillation angle. The maximum oscillation angle obtained just after the container swings through the "first vertical", is called the maximum backswing (since it is usually the largest oscillation angle during the descent). The optimal oscillation angle at the time of ground impact is 0 degrees. The larger the angle at ground impact, the greater the probability of damaging the cargo, and the greater the propensity for the container to roll over on the ground. The following table provides the maximum backswing angle for various size and type of main parachutes. It must be noted that the ground impact angle will be less than this angle for most of the chutes since the container will have gone through a number of oscillations before falling 300 feet.

Table 3.3. Theoretical Max. Backswing Angle vs. Parachute Diameter

Parachute		Maximum Backswing Angle (degrees)	
dia. (feet)	type		
		130 knots	250 knots
38	solid	2	3
43	ribbon		5
45	solid	9	6
50	solid		17
55	solid		29
60	solid		40
64	solid	*	32

* Indicates that system had not reached a maximum backswing before impact.

At 250 knots, parachutes greater than 50 feet in diameter are significantly more unstable than smaller diameter chutes. The large volume of the air mass in the canopy associated with the larger chutes is the primary cause of this instability. Slotted parachutes of comparable size would tend to be more stable. Although the maximum backswing is generally larger at high-speeds, the canopies 45 feet and under are predicted to have a maximum backswing of less than 10 degrees. The 45 foot canopy actually performs better at high-speed than low, according to the trajectory code prediction. This study suggests that a main canopy diameter of 45 feet or less will provide for a very small and controlled ground impact angle (especially when compared to the current 64 foot diameter chute).

3.3.3. Altitude Loss

The altitude loss to first vertical is a measure of how far the container falls below the delivery aircraft before it orients itself vertically below the main canopy for the first time. A container payload should always reach first vertical prior to impacting the ground to maximize load survivability.

Table 3.4. **Theoretical Altitude Loss vs. Parachute Diameter**

Parachute Diameter (Feet)	Parachute Type	Altitude Loss to First Vertical (Feet) 130 KIAS	Altitude Loss to First Vertical (Feet) 250 KIAS
38	solid	251	182
43	ribbon		208
45	solid	244	154
50	solid		154
55	solid		156
60	solid		161
64	solid	300	166

The trajectory code predicts that meeting the 300 foot altitude requirement, at 250 KIAS, should not be a problem for any of the canopies in the above table.

3.3.4. Descent Velocity

The nature of container airdrop makes the descent velocity issue a complex one. Since there is such a wide range of weights (500 to 2,200 pounds) a single fixed-size parachute will produce a range of descent rates. The current G-12 parachute (used for low velocity), for instance, yields a range of between 14 and 27 fps. The 26 foot ringslot parachute results in 41 to 76 fps, and the 22 foot ringslot results in 48 to 90 fps (both used for high velocity). This must be kept in mind during any analysis of container airdrop descent rates.

3.3.4.1. Two Descent Modes. Maintain two modes of dropping containers (LV and HV).

Advantages. Concept has been used for years. It allows existing CDS loads to be rigged with the existing (or similar) honeycomb configurations (this assumes that the same descent velocities as existing LV and HV are maintained).

Disadvantages. The container and its contents would be required to survive both HV and LV ground impact. This would add complexity to the container design, thus adding technical risk to the container design effort. It would require two sets of significantly different rigging procedures (increase the number of paper honeycomb configurations) adding to the logistics burden on riggers. Two or more different types of main parachutes would be required unless reefed versions or clusters were used for the HV mode. Increasing the number of main chutes increases the logistics burden, especially when considering prerigged contingency loads. It also adds complexity, risk and, therefore, cost to the 250 knot main parachute design effort. Loads (2,200 pounds) dropped HV with current honeycomb configurations experience 125 g's or more (since the honeycomb bottoms out) as compared to less than 40 g's for LV drops.

In order to reduce the ground impact shock levels for HV drops (2,200 pound containers) to 40 g's, as many as 14 layers of honeycomb (42 inches) is required. This amount of honeycomb is not feasible due to space and center of gravity concerns. Bottoming out of hone nb is a very unpredictable condition where the g levels experienced can be very severe. The appropriate number of layers of honeycomb should be used to avoid this situation. It is not desirable to have more than five layers of honeycomb (due to space considerations). If a 2,200 pound load hits the ground on 44 by 44 inch sheets of honeycomb the shock will be 38 g's. In order to decelerate this load to 38 g's with a maximum of five layers of honeycomb, it can not be descending faster than 46 fps (see Table 3.5). The cost of dropping at 25-30 fps and 70-90 fps for 2,200 pound loads are higher than dropping at intermediate descent rates (see Appendix A, Estimated Cost Per Airdrop vs. Main Canopy Diameter).

Table 3.5. Honeycomb Layers vs. Descent Velocity

Layers of Honeycomb Required to Avoid Bottoming*	1	2	3	4	5	6	7	8	9	10
Descent Velocity at Impact (fps)	20.6	29.1	35.6	41.1	46.0	50.4	54.4	58.1	61.7	65.0

* assumes 2,200 pound load, impacting on a 44 by 44 inch sheet of paper honeycomb

3.3.4.2. Single Descent Mode. A single mode that descends under canopy (or canopies) at some intermediate velocity range (e.g., 30-50 fps) for all airdrops. In this case the appropriate amount of honeycomb would be used to reduce the impact shock to acceptable levels.

Advantages. Simplifies numerous logistics concerns, especially the fact that only one mode of rigging will be required (this will greatly simplify and reduce costs for contingency stocks). Front-end analyses indicate that this approach is cost effective (see Appendix A, Estimated Cost Per Airdrop vs. Main Canopy Diameter) if the proper size parachute is chosen. Eliminates the need to train two methods. Only need one set of Computed Air Release Point (CARP) data.

Disadvantages. More honeycomb per drop (more than LV CDS) will be required, however, studies indicate that the maximum number of layers can be maintained at between 4 and 5.

3.3.4.3. Free-Fall Method. This method would not require any decelerator at all. The containers would simply be extracted from the aircraft and allowed to fall at their terminal velocity.

Advantages. This method may be more economical, since the cost of the main canopy could be eliminated. Rigging procedures would also be greatly simplified.

Disadvantages. While the cost of the recovery parachute would be eliminated, this savings would probably be offset by the cost of the enormous amount of honeycomb that would be required to deliver a load without exceeding survivable ground impact shock levels. The amount of honeycomb would add far too much size to the system, making it impossible to fit the required amount of containers into the aircraft. The question of what are acceptable "g levels" during ground impact (to ensure load survivability) must be quantified before any serious consideration of free drop can be made. If extremely high g levels (e.g. 500 g's) can be experienced, then it may be plausible. Another consideration is to have an air bag inflate upon load exit (activated by a static line) that would envelope the load and mitigate the impact energy. In addition to these difficulties, the orientation of the payload at impact could not be controlled.

3.4. Other Main Recovery Subsystem Concepts

3.4.1. Lifting Pilot Parachute

In this concept a lifting pilot parachute is used to deploy the main recovery parachute. The idea being that the recovery parachute would be deployed closer to the level of the delivery aircraft to reduce the altitude loss during main parachute deployment. This would be possible since the pilot parachute would travel in the upward direction during the main parachute deployment. Additional details concerning this concept are found in the Sandia Report, paragraph 2.8.4.

Advantages. A lifting pilot parachute would reduce the altitude lost during deployment of the main recovery parachute.

Disadvantages. Upon further consideration, it was realized that using the lifting pilot parachute would only result in a cross-wind deployment of the main parachute -- an undesirable option. Cross-wind deployments are avoided whenever possible due to problems with line sail and canopy damage. Indeed, once the main had been extracted out of the bag, the free-stream velocity would tend to restore the parachute to a position immediately down stream of the container, negating any gain anticipated from the lifting parachute. Also, maintaining the proper orientation for the pilot would be, and has proven to be in other cases, very difficult. If the parachute is not aligned properly the lifting effect will not occur.

3.4.2. Precursor/Stabilization Parachute

This concept is one developed and implemented by the Soviets on their heavy equipment drops. When large parachutes are used on heavy equipment drops, there is some time while the parachutes are being deployed that the load is essentially in free-fall and subject to tumbling. By placing a small parachute, which inherently deploys much faster, inside the suspension lines of the main recovery parachute, several advantages can be realized. This concept shows promise for systems with large main parachutes. However, it has been estimated that the proper size for a recovery parachute to minimize system life cycle cost is 35-45 feet. Additional details concerning this concept are found in the Sandia Report, paragraph 2.8.5.

Advantages. Upon deployment, the small parachute deploys and fills very quickly, stabilizing the load. It can provide for some initial deceleration of the load, thereby reducing the operational requirements for the main parachute. If positioned correctly, it is also possible that the small parachute can provide some aid for inflation of the larger main.

Disadvantages. It is doubtful that this concept will have much to offer for a system which utilizes a 35-45 foot diameter parachute. However, the concept should be kept in mind if larger parachutes are considered later in the program. The impact of this system on drop zone length requirements is expected to be insignificant.

4.0. EXTRACTION SUBSYSTEM

Current CDS containers are extracted by gravity (they roll off the cargo floor rollers when the aircraft obtains a nose-up attitude). However, due to the high airspeeds that HSCDS must be delivered at, alternative concepts for removing the containers from the aircraft have been studied. The various alternatives have been grouped into four categories: gravity extraction, aerodynamic extraction, stored-energy ejection and electromechanical ejection.

In generating concepts for extracting or ejecting containers, several factors were considered, including: the length of drop zone used (distance traveled between green light and when the last container exits the aircraft), extraction subsystem rigging complexity, logistics burden, and cost.

It has been assumed that a program goal should be that the drop zone (DZ) required to deliver a full stick HSCDS at 250 KIAS be no longer than the DZ required for a full stick at 150 KIAS. However, since this may prove to be unachievable, the maximum amount of DZ required, beyond the current DZ requirements for full sticks, must be identified (e.g., not to exceed 130% of current DZ usage requirements). However, this issue must be clarified by the Combat Developer in the Trade Off Analysis (TOA).

4.1. Gravity Extraction

4.1.1. Level Flight Gravity Extraction

The level flight method is the current means that CDS containers are dropped from the C-130 and C-141 aircraft. While maintaining a level flight path, the aircraft sets its flaps in order to obtain a deck angle of between 6 and 8 degrees of the horizontal. As the aircraft approaches the designated release point, "green light" is called and a cut knife connected to the static line retriever cable cuts the webbing restraint gate on the aft end of the containers. Once the gate is cut, gravity forces the containers to roll out of the aircraft.

Advantages. This technical approach has been used for decades and the procedures for its use are found in FM 10-500-3, MAC Reg 55-40, MAC Reg 55-130, MAC Reg 55-141, and numerous other sources. Training, rigging, computed air release point (CARP) and flight procedures will be similar to existing methods. No ancillary extraction or ejection equipment would have to developed or utilized to remove the containers from the aircraft. Therefore, this approach is inherently less complex than other extraction or ejection techniques.

Disadvantages. The static line retriever/cut knife technique produces inconsistencies in the time from green light to first container exit. As a result, the ability to accurately airdrop CDS onto a Point of Impact (PI) is reduced using this technique. It is impossible for pilots to achieve the exact deck angle on each drop, further reducing accuracy. Airdropping at increased airspeeds (250 KIAS) with this technique will require much longer drop zones than low speed drops (130-150 KIAS). At high airspeeds, the C-17 aircraft will not be capable of achieving level flight path deck angles of 6 to 8 degrees. The achievable deck angles for high-speed airdrop from the C-17 vary widely, depending on the airspeed and the aircraft's gross weight (see Appendix B, Maximum Deck Angle vs. Airspeed for the C-17 Cargo Transport). The maximum achievable deck angles for the MC-130 aircraft (at high airspeeds) are comparable to that of the C-17. Small deck angles (less than 3 degrees) also will be very difficult for the pilot to maintain and could possibly result in containers rolling back into the aircraft.

Since the deck angle at higher airspeeds will be reduced, the amount of time required for all containers to exit the aircraft (exit time) will be increased (see Appendix C, Exit Times for Gravity Extraction of Containers). Increased exit times combined with higher airspeeds will require very long drop zones (for full sticks of 16 and 40 containers, the required DZ lengths will be up to more than **three** times as long as those currently required at 150 KIAS). Based on these facts, gravity extraction at 250 KIAS is not feasible.

4.1.2. Automated Gate Cutting Device

Gravity extract the containers exactly the same as previous concept except, in lieu of the retriever cable, use an automated device to cut the webbing restraint (release) gate. The device would be a computer controlled, solenoid activated gate release, with a manual override capability.

Advantages. Same as previous concept. In addition, provides for a more predictable gate release thereby improving DZ accuracy. Using the guillotine knife method, the variation in gate cut time can be as much as 2 seconds, which will be nearly eliminated with this method. Theoretically, this will reduce the required DZ length by 800 feet over the previous concept. Does not destroy webbing gate for each drop, which would save on expendable item costs. An automated gate release mechanism such as this has been developed by the Douglas Aircraft Corporation and has been tested with some degree of success. The Air Force is planning to incorporate this mechanism into normal CDS operations from the C-17, and perhaps from other cargo aircraft.

Disadvantages. Similar to previous concept.

4.1.3. Automated, Mechanized Release Gate

This system would replace the current web release gate with an individually controlled mechanized gate located at each container station. Each release gate could be preprogrammed and remotely controlled from any location in the aircraft. See ADL Report, pages 40-43, for details concerning this concept. This approach would have the same effect of the programmable center rail system that was considered in lieu of the CVRS.

Advantages. Same as Level Flight Gravity Extraction concept. Moreover, containers could be automatically reconfigured for multiple drop zones. Release of the containers could be remotely controlled. A more positive release could be attained; therefore, the release would be more consistent and predictable. The forward restraint buffer board and the release gate assemblies would not be required if these devices or the programmable center rail were installed. Eliminates need for in-flight rerigging of loads between drops or due to in-flight changes in mission plans. Actuation could be performed from the cockpit, thereby freeing up the loadmasters to complete other duties.

Disadvantages. Same as Level Flight Gravity Extraction concept . Also, this concept would be very expensive when compared to the present system. It introduces additional logistical and maintenance requirements.

4.1.4. Gravity Extraction with Pull-Up Maneuver

The pull-up maneuver is different from the level flight method in that the aircraft will physically nose up its flight path in lieu of, or in addition to, obtaining a deck angle. This method is not currently used since the required deck angles can be achieved at the lower airspeeds. However, it was evaluated during the CDS Accuracy Enhancement Study done in 1987.

Advantages. Same as Level Flight Gravity Extraction concept. Also, it would induce a greater effective deck angle, thereby permitting faster exit times for gravity extraction at high airspeeds.

Disadvantages. Same disadvantages as Level Flight Gravity Extraction concept. Additionally, a pull-up maneuver would cause the aircraft to gain altitude while air-dropping the containers, which would increase the vulnerability of the aircraft. A pull up of over 10 degrees will be required to reduce the required DZ length to within the current systems length requirements. This will cause the aircraft to gain in the vicinity of 300 to 500 feet of altitude for sticks of 16 and 40 containers, respectively. Testing at low speeds in 1987 demonstrated that "pilots could not consistently perform the (pull up) maneuver and call the release. This procedure resulted in the widest variance of exit time and airdrop dispersion."

4.2. Stored Energy Ejection

The concept of stored energy ejection is based on the principle of storage of mechanical, electrical, pneumatic, kinetic, potential, or other forms of energy in order to release it over a short period of time which will propel containers out of the aircraft. It is assumed that each of these concepts will eject the containers over a horizontal aircraft deck. Detailed descriptions of these concepts are found in the ADL Report, pages 48-59 and 90-91, and each of them is abstracted herein.

4.2.1. Rocket Motor Propulsion

A rocket motor similar to an ejection seat motor is attached to the skidboard of each container to propel it aft and out.

Advantages. Stored energy is portable and would perform well with respect to container acceleration.

Disadvantages. This alternative would cause an unacceptable level of safety/fire hazards.

4.2.2. Long Compressed Spring

Energy is stored in a helical compression spring. The spring would be "cocked" and propel the containers aft when released.

Advantages. This alternative would provide a positive displacement of the containers.

Disadvantages. Implementation would be complex and expensive. Depending on the size of the spring, there may not be enough room for the system.

4.2.3. Aircraft Carrier-type Catapult Ram

Containers would be ejected by a hydraulically- or pneumatically-powered ram. Energy would be stored in an air tank or accumulator.

Advantages. A large amount of energy could be stored. The force application can be continuous throughout the stroke. Accumulators are commercially available.

Disadvantages. It would be technically difficult to design a ram for this application. Ram would require a large amount of space in the aircraft. A cable and pulley system may also be required for implementation.

4.2.4. Airbag Ejection

Containers would be ejected by an airbag positioned forward of the stick. The airbag would be inflated in the same manner as those in automobiles.

Advantages. This system would be portable, provide a simple interface with the aircraft and containers, and be easily actuated. It would be much safer than a mechanical or motor-driven system.

Disadvantages. The ejection force applied may not be continuous. Velocity and acceleration rates may be of unacceptable reliability. The airbag may be prone to damage from sharp objects. The overall dynamic performance is expected to be unacceptable.

4.2.5. Power Spring

This alternative is similar to the long compressed spring; however, each container would have its own spring for ejection. Each container would be driven by an engaging lever. The spring may be wound by a small electric motor and mechanically released.

Advantages. The springs are commercially available, relatively compact, and may be wound automatically or manually.

Disadvantages. The ejection force applied may not be continuous. The system would be expensive (40 units per aircraft). The interface with the aircraft would be complex.

4.2.6. Telescoping Cylinder with Accumulator

Containers are ejected by a long telescoping hydraulic cylinder. Energy is stored using hydro-pneumatic accumulators.

Advantages. Energy storage method can store large amounts of energy in a small volume. This system can be easily actuated.

Disadvantages. The equipment will be complex and expensive. There would not be any available space for this system. There may be a problem rigging for multiple drop zone airdrops.

4.2.7. Pneumatic Cylinder with Slider Mechanism

Containers are ejected by a cable-driven driver powered by a small hydraulic or pneumatic piston in a long cylindrical bore. Energy is stored in a hydro-pneumatic accumulator or air tank.

Advantages. A high amount of energy can be stored and applied continuously to the load. A good dynamic container performance can be achieved. Aircraft power requirements would be low.

Disadvantages. The accumulator would probably occupy the forward-most container position in the aircraft. Sealing of the piston would be critical, especially if hydraulic. The system may be difficult to configure for multiple drop zones. The interface between the cylinder and the aircraft would be somewhat complex.

4.2.8. Sled Ejection Powered by Hydraulic Motor

This alternative is based on the same concept used in the Motor Operated Sled Ejection System (MOSES), but it would be powered by an accumulator-driven hydraulic motor, rather than an electric motor.

Advantages. The hydraulic motor should improve ejection performance. There is a high energy storage capability. Interface with the aircraft would be simple and there would be a centralized power source.

Disadvantages. The forward most container position would be used for the system. The equipment required may be heavy and difficult to handle.

4.2.9. Torsion Bar

Energy would be stored by the elastic wind-up of a torsion bar.

Advantages. The concept is simple and there would be a high energy storage for a small angular deflection.

Disadvantages. This alternative would be extremely heavy. It would be sensitive to single component failures and there is no available space for the components. It would probably be an expensive system.

4.2.10. Trailing Rocket Motor

A rocket motor is deployed from the ramp and attached to trailing cable. The rocket motor is remotely ignited a safe distance from the aircraft by trailing electrical leads.

Advantages. The rocket motor has a high storage capability. There would not be any interface problems with the aircraft. The unit would be lightweight and portable.

Disadvantages. The system may be expensive. This concept has a high technical risk. The concept is unproven in any other capacity.

4.2.11. Sequential Release Mechanism

Each pair of containers are ejected by compression springs placed between them. They may be sequentially released for container selectability.

Advantages. Container selectability would be very good.

Disadvantages. There is no surface on the container to properly bear the spring loads. There is no method to initially compress the springs. A complex release mechanism would be required. There would not be a continuous load application. Concept has a high technical risk.

4.2.12. Gas-filled Cylinder

Containers would be ejected by propulsion using a gas-filled cylinder. There may either one cylinder per container or one per stick. The cylinder may be activated electronically or manually. The cylinder would be reusable.

Advantages. Portable, high capacity compact source of power would be available and be continuously applied to the load. There would not be any fire hazards present. The aircraft would not have to be reconfigured. The containers could be rapidly ejected.

Disadvantages. Special handling of the gas-filled cylinder may be required. The system would require an interface with the containers. The size of the cylinder to eject one container would take up too much space to be practical.

4.2.13. Rollers with Torsion Springs

Special cylindrical rollers powered by torsion springs would eject the containers. Energy input to the springs would be electrically or manually delivered.

Advantages. Aircraft power requirements would be low.

Disadvantages. There may not be any available space for large springs. The containers would be prone to slippage during initial acceleration.

4.3. Electromechanical Ejection

Electromechanical ejection concepts are based on the principle of container ejection by a mechanical apparatus powered by an electromechanical device such as an electric motor. Details of these concepts are found in the ADL Report, pages 59-72 and 92-93. However, a synopsis of these concepts follows.

4.3.1. Electrically Powered Rollers

Containers would be ejected by electrically powered rollers similar to those currently used in the KC-10 aircraft.

Advantages. Containers can be selected electronically. Concept would use the existing USAF roller design.

Disadvantages. Aircraft would have to be modified with rollers. Loads may not be extracted consistently. Cost would probably be expensive.

4.3.2. Pneumatic-Powered Rollers

Containers are ejected by the use of pneumatically powered rollers mounted in contact with the existing roller system. The source of the power may be a compressor, air tank, or aircraft engine bleed air. Small air motors would directly power each powered roller required.

Advantages. This system can interface with the cargo roller system with little or no modification. Commercially available air motors are compact enough to mount below the aircraft roller level. Rollers will be capable of a "free wheel" as well as a powered mode. The source for the pressurized air can be remote.

Disadvantages. The system would be fairly complex. It would require a large volume of pressurized air. Unit torque for small motors is small.

4.3.3. Skidboard Edge - Contact Rollers

Containers would be ejected by a series of electric motor driven rollers mounted near the aircraft rail system. The rollers would rotate about their vertical axis and engage the skidboard by friction.

Advantages. Components are commercially available. Containers could be remotely selected multiple drop zones.

Disadvantages. There is no space in the aircraft to install the motors. Each container would require its own motor/roller assembly. It may decrease the size of the container space, thereby reducing the capacity of the container. This system may not easily interface with the aircraft floor or rail system. The cost of this system would be expensive.

4.3.4. Vertical Axis Conveyor

Containers would be ejected by a low profile, vertical axis conveyor which runs along two pulleys or sprockets. The height of the conveyor would be less than the aircraft roller height and the conveyor would be either a continuous belt or a chain with fittings which would engage the skidboard. Loads would be selected manually.

Advantages. Aircraft interface could be accomplished using the existing tiedown ring provisions. The system would have a remote driver and may be powered electrically or hydraulically. It can be used with a stored energy method.

Disadvantages. A large power source would be required. Skidboards would have to modified. Positive continuous ejection may be difficult to maintain.

4.3.5. Toothed Roller Conveyor

The ejection of the containers would be accomplished by a series of electrically-powered toothed rollers. The rollers would engage a compatible indent in the skidboard.

Advantages. Loads can be selected electronically. The containers could be displaced positively.

Disadvantages. There is no available space for the roller power source. Skidboards would have to be modified to accommodate the rollers. Positive continuous ejection may be difficult to maintain.

4.3.6. Ballscrew Drive

Containers are ejected by electrically-powered ballscrews and "pushers." One long ballscrew and motor would be installed for each stick of containers. When activated, the ballscrew would rotate at a very high rate of Rpm's and force the pushers aft. The pushers are in contact with skidboards and will force the containers aft.

Advantages. There will be a positive container displacement and a continuous load application. The power source is remote and there would be minimal aircraft interface.

Disadvantages. The Rpm's required to eject the containers would be extremely high. A power source would be needed. This system may present some safety hazards.

4.4. Aerodynamic Extraction

Extraction by aerodynamic means is another possibility for the extraction subsystem. As the current method of extraction for platform airdrop, it is already proven technology. There is also the possibility that parachutes and extraction lines already in use may be integrated into a new extraction system. There is presently a system called the High-Speed Low Level Airdrop System (HSLLADS) which is used on the MC-130 aircraft for delivery of up to 2200 pounds in a single pass at 250 KIAS. The HSLLADS uses a stored energy ejection technique to propel the containers off the ramp using a bungee cord sling. During a test program conducted in 1987-88 by the Special Missions Operational Test and Evaluation Center (SMOTEC) some work was accomplished to upgrade the capacity of the HSLLADS to 4,400 pounds, and to investigate the possibility of aerodynamic (parachute) extraction of the containers at 250 KIAS. A reefed version of the 15-foot ringslot extraction parachute was used as the drogue (tow plate was used), and an attempt to extract by mains with the G-12E parachute (reefed) was made. Testing was done at various airspeeds up to 250 KIAS. The test showed that these parachutes were damaged at airspeeds above 200 KIAS. The program was canceled. This test demonstrated that existing airdrop parachutes (even if reefed) are not designed to withstand the high-speed aerodynamic environment. Existing ribbon parachutes may be better suited for use as drogue and extraction chutes. Solid cloth and ringslot chutes made of heavier duty materials than existing airdrop parachutes are also feasible approaches.

4.4.1. Free-Fall Energy Extraction

This concept involves deploying an extraction parachute from the overhead pendulum release, which is towed behind the aircraft from the tow plate. The aftmost container would be connected to the extraction line. At green light, the chute would extract the aftmost container only. Once that container begins to free-fall off the ramp, a connecting line or strap (which joins it to the next container on board the aircraft) extracts the next container. Each of the containers in a stick would in turn pull out the next container and so on until the stick is completely removed from the aircraft. After extraction, the containers would be separated from each other by cutting the connecting line. The cutter could be actuated from the static line or from a lanyard connected to the main canopy which would delay the cut. Also considered was the concept of allowing the containers to remain connected throughout the airdrop to reduce container dispersion. In this case the strap would have to be long enough to permit the main chutes to open. If the containers remained connected, the main chutes, once deployed, would provide an additional extraction force on the remaining containers. There are several alternatives considered for the connecting strap material. Specifically considered were nylon webbing and bungee cord. This concept is described in detail in the ADL Report, pages 72-76. Additional discussions of using nylon connecting straps and bungee cord with this concept are found in the Sandia Report, paragraphs 2.8.6 and 2.8.8.

Advantages. The same size extraction parachute could be used on each drop, regardless of the total number of containers being extracted for that drop. The extraction chute would be small enough so that it could be towed from the tow plate. Thus, a separate drogue chute would not be required.

Disadvantages. There are significant technical risks associated with actual dynamic behavior of the container as it exits the aircraft. This uncertainty would require an in-depth analysis due to the safety considerations of the aircraft. The cutter system (if used) may be somewhat complex in operation. Increasing length connecting straps or bungees would have to be used for containers stationed forward in the aircraft. In-flight mission changes would be very complex, if not completely unfeasible. Studies completed using both the bungee and webbing type connecting straps indicate very long exit times for multiple containers (see Sandia Report, paragraph B.6).

4.4.2. Multiple Container Train Method

In this concept, groups of containers are bundled together into "trains" with a sling. Each train is extracted by its own extraction parachute. As the aftmost container reaches the end of the ramp, the sling is cut or released, and the containers continue to roll out under their own momentum, independent of each other. A pilot parachute is static line deployed as the container falls away from the aircraft. Each container employs its own main recovery parachute. Additional details concerning this concept are found in the Sandia Report, paragraph 2.8.1.

A spreadsheet was set up to calculate the length of drop zone used based upon the number of containers in each train, distance from the aft end of the most aft container to the rear edge of the ramp, time to deploy and inflate each extraction parachute, and maximum allowable container velocity. For a maximum allowable extraction velocity of 88 feet/sec, a deployment time of 1.25 seconds, 5 containers per train, and a ramp length of 10 feet, the drop zone used is estimated to be approximately 4,400 feet.

Advantages. A group of containers can be extracted by using only one extraction parachute (or one cluster of parachutes). The containers are separated upon exit, thereby enhancing the deployment of the recovery parachutes. The basic techniques for this system are already established. With this concept, the extraction force can be tailored through variable reefing of the extraction parachute. The containers should not experience the tumbling problem, as is the case with the current gravity driven CDS.

Disadvantages. A drogue parachute has to be sized smaller than the maximum tow force that can be exerted on an aircraft. Since the extraction parachute has to be large enough to extract as many as 40 containers (93,000 pounds), a small drogue must deploy the extraction parachute(s). To extract 40 containers, the extraction force will be very large (at least 60,000 pounds) and will have to be allowed to build up gradually. Since the locking rails can not be used for CDS, break lashings of some type must be used to let the extraction chutes deploy, fill and build up the desired force prior to initiating extraction. Rigging the break lashings may be a time-consuming task for the loadmaster. A pendulum release may be required to deploy the drogue. If containers in the adjacent sticks are slung together, lateral forces induced by the sling upon extraction may cause binding against the centerline vertical restraint system which could cause the load to stick. These lateral loads could be countered by inter-container shims or spacers between the adjacent sticks.

NOTE: *In lieu of the belly band, a pusher mechanism could be devised that rests on the rollers and allows the extraction line to be attached in the center to eliminate the binding moment concerns of a sling extraction on each stick. This concept is best employed if the number of containers to be dropped per pass is limited to even numbers only. However, by adding an additional truss member, a pusher could be devised that extracts only one stick.*

4.4.3. Simultaneous Extraction Method

This concept is similar to the multiple train method except that all of the containers to be dropped per pass will be extracted with one extraction parachute (or a cluster of parachutes). The extraction parachute(s) is deployed and initially acts on all the containers in the stick at once to accelerate them to a prescribed velocity. The connecting sling is then cut or released and the containers coast out of the cargo bay. Critical to this concept is the ability to accelerate the stick to an adequate velocity which will assure extraction of all of the containers from the aircraft. This whole system can be considered as being very similar to the gravity system currently in use. The difference is that the containers are all accelerated under a consistent force (however, the force will vary as the extraction parachute gains relative velocity) until the desired velocity is reached. At this time the extraction parachute would be released from the containers, and the containers would travel under their own momentum off the ramp of the aircraft (they will slow down due to friction on the rollers and the rail system). If the extraction velocity is not large enough and the extraction force is cut away early, friction becomes a major problem. However, if the extraction velocity is large (e.g., 80 fps) and the extraction force is cut away later, the contribution of friction is relatively small. The containers that exit the ramp prior to the release of the extraction line would have their static lines deployed directly off the extraction sling. The remaining containers would deploy static lines off the anchor line cable. Additional details concerning this concept are found in the Sandia Report, paragraph 2.8.9.

A spreadsheet was used to calculate the length of the drop zone used at 250 knots, varying extraction ratios and extraction velocities. Extracting at 1 g would yield an exit velocity of over 30 feet/second, requiring a drop zone length of 1,235 feet. This is very short compared to the other concepts considered. An extraction parachute on the order of 20 feet in diameter would be required to produce a 44,000 pound (20 containers at 2,200 pounds each) extraction force at 250 knots. This spreadsheet assumed that the extraction force had to be cut away before the first container exited off the ramp, and thus the exit velocity did not exceed 30 fps. If the force was maintained until the stick reached 80 fps, then the drop zone used will be significantly reduced from the 1,235 feet predicted by the spreadsheet.

Advantages: This concept seems very promising. In addition to the relatively short length of drop zone used, it seems like it could lend itself well to the required 18 second inter-drop zone rerigging goal. The extraction parachute could actually be a cluster of smaller parachutes, with the possibility of tailored reefing. This combination could provide for a very large range of extraction forces to accommodate 1 to 20 containers per drop.

Disadvantages: If the extraction force is released too early, the exit times for the remaining containers will be unpredictable. If the extraction force is maintained until the extraction velocity is 80 fps, the exit times will be very predictable. However, the containers will be very close together and could experience interference between containers or their respective main recovery parachutes. However, the legitimacy of this concern is uncertain.

4.4.4. Multiple Towplates

This concept is identical to the container train method with the exception of using a separate towplate on each side of the aircraft. The towplates would be centered between the center rail and the appropriate outboard rail.

Advantages. Loads could be more easily configured into individual sticks for multiple drop zone requirements.

Disadvantages. Loads may not be able to be dropped simultaneously from each side of the aircraft. This would double the length of drop zone used for airdropping 40 containers. Adding an additional towplate to the aircraft is an expensive and logistically difficult task.

4.4.5. Interval Container Sling

In this concept, one extraction parachute is used to extract all the containers for a given drop zone. The containers are extracted at fixed intervals through the use of a special sling. The containers are initially positioned immediately adjacent to one another in the cargo bay of the aircraft. Upon releasing the extraction parachute, the sling engages the aftmost container and starts to accelerate it to the maximum allowable extraction velocity (V_{max}). Slack in the sling permits only the aftmost container to be accelerated. The slack is sized such that the sling between the aft most container (first to exit aircraft) and the next (second) container goes taught at the same time the first container reaches V_{max}. The extraction parachute must then slow down to zero velocity (relative to the aircraft) as the second container begins to accelerate from rest. The sling is designed so that the first container is free to continue to move aft at V_{max}. This results in the first container moving relative to the sling. As the container reaches the end of the ramp it falls down out of the sling and deploys the pilot parachute for the recovery system via a static line to the aircraft. This process continues until the last container is accelerated up to V_{max}. The sling flies free from the aircraft and will likely fall in the drop zone if large enough numbers of containers are dropped. This concept allows the containers to exit the aircraft at controlled intervals with the intention of minimizing the interference problem observed between the last few containers in the current gravity system. Additional details concerning this concept are found in the Sandia Report, paragraph 2.8.2.

A spreadsheet was set up to predict the length of drop zone used. Drop zone lengths ranged from 1,880 feet up to 3,472 feet, depending on distance between last container to the end of the ramp, the extraction ratio (extraction force/weight of containers), and sling length between containers.

Advantages. The extreme advantage of this concept is that the containers exit at intervals which will help minimize the interference between recovery parachutes of adjacent containers as is observed with the current gravity extraction system.

Disadvantages. One drawback to this concept is the snatch loads associated with the sling when the slack runs out and the sling goes taught. At this time, a container is free to continue to move out of the cargo bay, but the extraction parachute must momentarily be stopped and then begin to accelerate with the next container. This snatch force can be reduced by increasing the slack length of the sling. By doing so, the size of the parachute would have to be reduced to avoid exceeding the maximum extraction velocity. The sling design must be such that containers are free (or freed) to move aft after they are accelerated to the desired extraction velocity. This may require some release mechanism on the sling that would be actuated when the slack length goes taught. Containers in the rear of the aircraft would require shorter slings than those in the front of the cargo bay, which could create additional rigging complexity and logistics complications. The recovery parachutes are to be deployed via a pilot parachute which is static line deployed from the aircraft. If the static lines are to be of the nonbreakaway type, routing of the static lines to avoid interference of the sling with the pilot parachute will be important.

4.4.6. Extraction by Recovery Parachute

This concept relies upon using the main recovery parachute to also extract the container. The extraction of the containers is very serialized. That is, a container in the stick cannot begin to be extracted until the prior container has been completely extracted and has deployed the next main parachute. The interval between containers being extracted is governed by the extraction velocity, the length of the recovery system and the initial inflation time for the recovery parachute. Additional details concerning this concept are found in the Sandia Report, paragraph 2.8.3.

An extraction parachute (in this case the main recovery parachute) must also be deployed some distance behind the aircraft to avoid being fouled by the aircraft's wake. Time will be required to deploy the risers and the main parachute for this distance. If the container is considered to move aft relative to the aircraft at the maximum extraction velocity (88 feet/sec) and the deployment distance is considered to be 50 feet, the time for deployment to canopy stretch would be 0.6 seconds. Adding the deployment time to the filling time yields a total time of 1.8 seconds.

Advantages. The advantage to this concept is that the recovery parachute is inflating while the container is extracted from the aircraft. This will help reduce the altitude loss during the airdrop process.

Disadvantages. Successive containers require longer and longer risers to reach from the recovery parachute, through the cargo bay, to the container. This increases the overall height of the recovery system after it deploys and turns over, thereby counteracting the earlier gains in loss of altitude. Considering that the container should be extracted before the canopy is completely filled and calling on experience, from which it is known that it takes approximately 1 second to extract a 3000 pound payload with three 64 foot diameter main parachutes, it seems likely that a 1-1.5 second interval would be expected. Using this range of values for 20 containers gives a drop zone length ranging from 8440 to 12,660 feet, an extremely large drop zone.

4.4.7. Interval Sling of Container Trains Method

This concept combines ideas from both the Simultaneous Extraction and the Interval Container Sling concepts. An interval extraction sling is used in conjunction with an extraction parachute to extract trains of containers. Additional details concerning this concept are found in the Sandia Report, paragraph 2.8.10.

Advantages. The results look quite favorable, seemingly the result of taking advantage of benefits of both concepts. Using 4 trains of 5 containers each at 250 KIAS, calculated drop zone lengths do not exceed 1,750 feet in the worst instance. Snatch forces will not be a problem, since the differential velocities between the extraction parachute and containers are relatively small.

Disadvantages. The system would be more complicated to rig than the Simultaneous Extraction concept, especially for multiple drop zones or in-flight rigging changes. Many of the same disadvantages of the Simultaneous Extraction and the Interval Container Sling concepts are inherent with this concept. The drop zone used would be less than the Interval Sling Method. However, it would be longer than that used for the Simultaneous Extraction Method (with extraction velocity of 80 fps).

5.0. CONCLUSIONS

5.1. Container Subsystem

The container subsystem has to be able to meet the restraint requirements in the aircraft, extraction force requirements, parachute opening shock requirements, and the landing force requirements. The existing A-22 cargo bag may be able to meet the restraint and landing requirements, but it can not meet the extraction force and opening shock requirements without substantial modifications. The modifications to the A-22 will add complexity to the rigging and derigging of the containers. Therefore, a new start approach or a new start that maximizes the use of existing materials is the recommended approach for the container.

Both a rigid and a cargo net container have legitimate advantages and disadvantages. However, before one type can be chosen over the other, it is recommended that breadboard prototypes of both the rigid and improved cargo net type containers be designed, constructed and tested. The cargo net design has significant advantages over the rigid concept in terms of container weight, storability, maintenance and unit cost. Therefore, if the cargo net container fares well during the technical demonstration, especially in the areas of in-flight restraint and load shift during parachute extraction, the improved cargo net type will be recommended for inclusion in the Engineering and Manufacturing Development program.

5.2. Main Recovery Subsystem

In order for HSCDS to meet the 250 KIAS and the 300 foot drop altitude requirement, a new main recovery subsystem will likely be required. This TOD suggests that solid cloth materiel solutions for the recovery subsystem are ready for engineering and that the associated developmental risks are not high. Ribbon, cross and ringslot parachutes should not be considered as candidates for the main recovery parachute unless or until significant problems are encountered with a solid cloth canopy design and test program.

A flat circular solid cloth construction parachute that utilizes a lower porosity canopy material near the apex, seems to be the most promising alternative. This is based upon computer simulations and will not be verified until a prototype is constructed and tested. The use of a single canopy is preferred to a cluster of canopies. The diameter of a smaller canopy will have a direct relationship to the performance of a cluster. If smaller canopies are selected for main recovery, clustering will enable the use of the same canopy over a wide range of suspended weights. Variable reefing is recommended for a single main recovery parachute.

Prototypes should be constructed and tested using the MC-130 aircraft and the C-17 when it becomes available for use. A new pilot parachute should be identified or developed to meet the high-speed requirement.

5.3. Extraction/Ejection Subsystem

The current method of extraction (level flight gravity) cannot be achieved at airspeeds above 150 KIAS. A new start or new start using some existing materials will have to be pursued.

The stored-energy and electromechanical ejection methods that were studied either will not adequately fulfill the requirements, require unacceptable modifications to the aircraft, require an excessive amount of power, are too large to fit within the confines of the cargo compartment, and/or will be too expensive. High-speed gravity extraction can not be achieved unless the aircraft is permitted to gain altitude during the airdrop. Of the four alternatives explored for load extraction, the aerodynamic (parachute) method has the most potential for success. Certain aspects of parachute extraction of containers have been demonstrated in testing by SMOTEC [9].

The use of a towplate system should be strongly considered for use with an aerodynamic extraction subsystem, since it will enhance the delivery accuracy, especially at the higher airspeeds.

Although light duty ribbon parachutes would perform very well for 250 KIAS towing and extracting, ringslot parachutes constructed with heavier duty materials than the existing ringslot extraction parachutes are the most attractive. Ringslots can be constructed for significantly less cost than ribbons. Riggers are more accustomed to packing ringslot and solid parachutes than ribbon chutes. However, two new airdrop systems, the 42,000 pound Low Altitude Parachute Extraction System (LAPES) and the High-Speed Airdrop Container (HISAC), either have introduced, or will soon be introducing, ribbon parachutes into the inventory.

5.4. Program Direction

The TOD process has identified most, if not all, of the possible alternatives within the three major subsystems. Through this process, the direction of the HSCDS program has been established. Based on the results of this TOD and the Trade Off Analysis (TOA), generated by the Combat Developer, the next CFP document, the Best Technical Approach (BTA), will be completed. The BTA will discuss in more detail the technical attributes of the most promising alternatives, to include detailed life cycle cost trade-offs among the alternatives.

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-92/050 in the series of reports approved for publication.

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APPENDIX A.

Estimated Cost per Airdrop versus Main Canopy Diameter

APPENDIX A. Estimated Cost per Airdrop versus Main Canopy Diameter

When designing an aerial delivery resupply container, one of the most critical concerns is to ensure that the cargo is in useable condition after the container impacts the ground. The survivability of the load is contingent on the impact shock level that the cargo experiences. There are two primary variables that effect the shock level; descent velocity (which varies with the type and size of the main canopy) and impact mitigation (which varies with the type and size of the shock absorbing material). Since the state-of-the-art shock absorbing material for airdrop applications is paper honeycomb, we will use it for this analysis. Research into alternatives (polyethylenes, polyurethanes, air bags, etc.) has failed to demonstrate a material that performs as well as paper honeycomb.

A trade off study of main canopy size versus estimated cost per airdrop has been made herein. The cost per airdrop will only consider the cost of the variables; the main canopy and the paper honeycomb.

Current LV CDS descend between 14-28 feet per second (fps) under canopy and impact onto two full sheets of honeycomb. Containers fully loaded (2,200 pounds) experience approximately 40 g's upon ground impact during LV drops. This is calculated using:

$$G = \frac{A\ S_a}{W} - 1$$

Where S_a is the crushing strength of paper honeycomb (6,300 psf), W is the weight of the container (2,200 pounds) and A is the area of honeycomb (44" x 44" sheet in ft^2). Since the existing CDS loads survive this condition, any new system should reduce ground impact shock on 2,200 pound containers to 40 g's or less. For a given area of honeycomb, however, as the weight of the container decreases the ground impact shock actually increases (see Figure A-1). For example, existing six hundred (600) pound LV CDS containers impacting the ground on full sheets of 44" x 44" honeycomb experience 140 g's. For this study, we will consider container weights of 1,100 and 2,200 pounds and that 75 g's and 40 g's respectively will be experienced on ground impact (based on Figure A-1).

Predicated on recent procurement data obtained from TROSCOM the following unit costs were derived:

Paper Honeycomb = $ 1.02/ft^3
Solid Canopy Cost = $ 0.64/ft^2
Ring Slot Canopy Cost = $ 1.56/ft^2

The number of times the main parachute can be reused before it is discarded or before it's repair costs equal the canopy's original value must be qualitatively analyzed since no statistical data has been gathered on the subject. Based on discussions with senior Army Chief Warrant Officers a relationship between canopy diameter and reuseability was established and is illustrated in Figure A-2, Cargo Parachute Reuses vs. Diameter (Estimates). It should be emphasized that these are merely estimates based upon the experience of a several senior CWOs in the airdrop field.

First we varied the diameter of solid cloth canopies with a 2,200 pound payload. The estimated cost per airdrop vs. canopy diameter for solid cloth and ringslot canopies and a 2,200 pound load is illustrated in Figure A-3. Figure A-4 depicts the same relationships for 1,100 pound containers.

The results clearly estimate that for a given canopy diameter a solid cloth main parachute will have lower life cycle costs (cost per drop) than a ringslot.

> NOTE: THIS LIFE CYCLE COST ASSUMES THAT THE AIRDROP EQUIPMENT IS RECOVERED AFTER EACH DROP (I.E., TRAINING ENVIRONMENT). COST DURING COMBAT OPERATIONS (ASSUMING THE AIRDROP EQUIPMENT WILL NOT BE RECOVERED) WILL BE MUCH HIGHER PER DROP AND FOR THIS ANALYSIS WILL BE DOMINATED BY THE PARACHUTE COST

For 2,200 pound loads the study estimates that solid parachutes between 30 and 50 foot diameters are the most economical ($28 to $33 per drop). The ringslot parachute diameters that yield the lowest costs per drop ($47 to $49 per drop) are 30 to 40 feet. The study estimates that for the same 2,200 pound load, current LV CDS costs for the parachute and honeycomb per drop are approximately $71.00. This indicates that there is the potential to reduce the cost per drop (for the chute and honeycomb only) by more than 100% over the current LV CDS.

Moreover, a 2,200 pound load dropped in the current high velocity CDS mode (28 foot ringslot and 7 layers of honeycomb) results in approximately $25.00 per drop. However, this drop results in a much higher g loading on the container since the honeycomb will "bottom out". The resulting deceleration on the load is undefined, being contingent on the stiffness of the cargo being dropped. However, the deceleration will exceed 100-140 g's, much higher than the 40 g's that we assumed for other cost estimates. To reduce the g levels to 40 for HV CDS drops it will require 13 layers of honeycomb, which will increase the cost per drop to approximately $46. It will also not be feasible to use that much honeycomb due to the amount of space it will take up, and the fact that the resultant higher center of gravity of the container is not desirable.

In summary, this analysis suggests that 30 to 50 foot diameter solid cloth main recovery parachutes are the most cost effective for use with "heavy" (2,200 pound) CDS loads. In general solids are more cost effective than ringslot parachutes, even for the lighter loads. However, an interesting note is that utilizing the off the shelf 28 foot heavy duty extraction parachute for loads under 1,100 pounds will result in a cost per drop of about $22. Since this chute already is in the inventory and is currently used as a main recovery chute for 500 pound loads at 250 KIAS (HSLLADS), the feasibility of using it with 1,000 pound loads at 250 KIAS should be investigated. It is entirely possible that the increased forces may damage the 28 foot ringslot.

Using one size parachute for loads above 1,100 pounds and a smaller main chute for "light" CDS loads appears to be an attractive concept. First it may be possible to use an existing parachute for "light" CDS loads at 250 KIAS.

Additionally, using a smaller chute for light loads will increase the descent velocity for those loads, thus maintaining a more uniform descent velocity for all drops. For example, the descent velocity using a 40 foot diameter solid canopy will be 22 fps for a 600 pound load and 43 fps for a 2,200 pound load. If we use a 28 foot ringslot for a 600 pound load the descent velocity will be 37 fps. If the descent velocities are more uniform, the likelihood of interference between two loads during the descent phase will be reduced.

It also makes sense to reduce the area of honeycomb used for "light" loads to reduce the impact shock on the load.

Figure A-1. Impact Deceleration vs. Container Weight

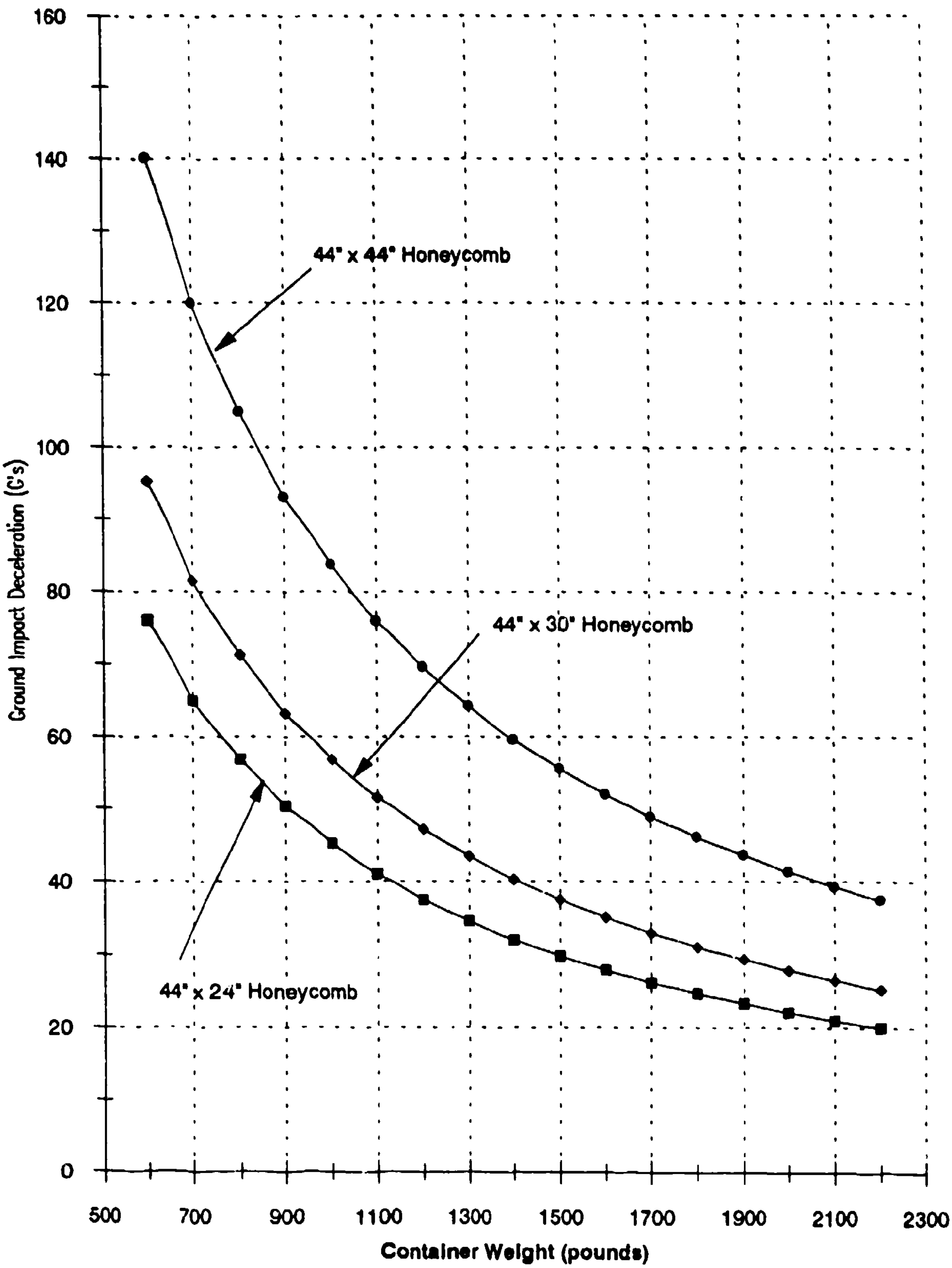
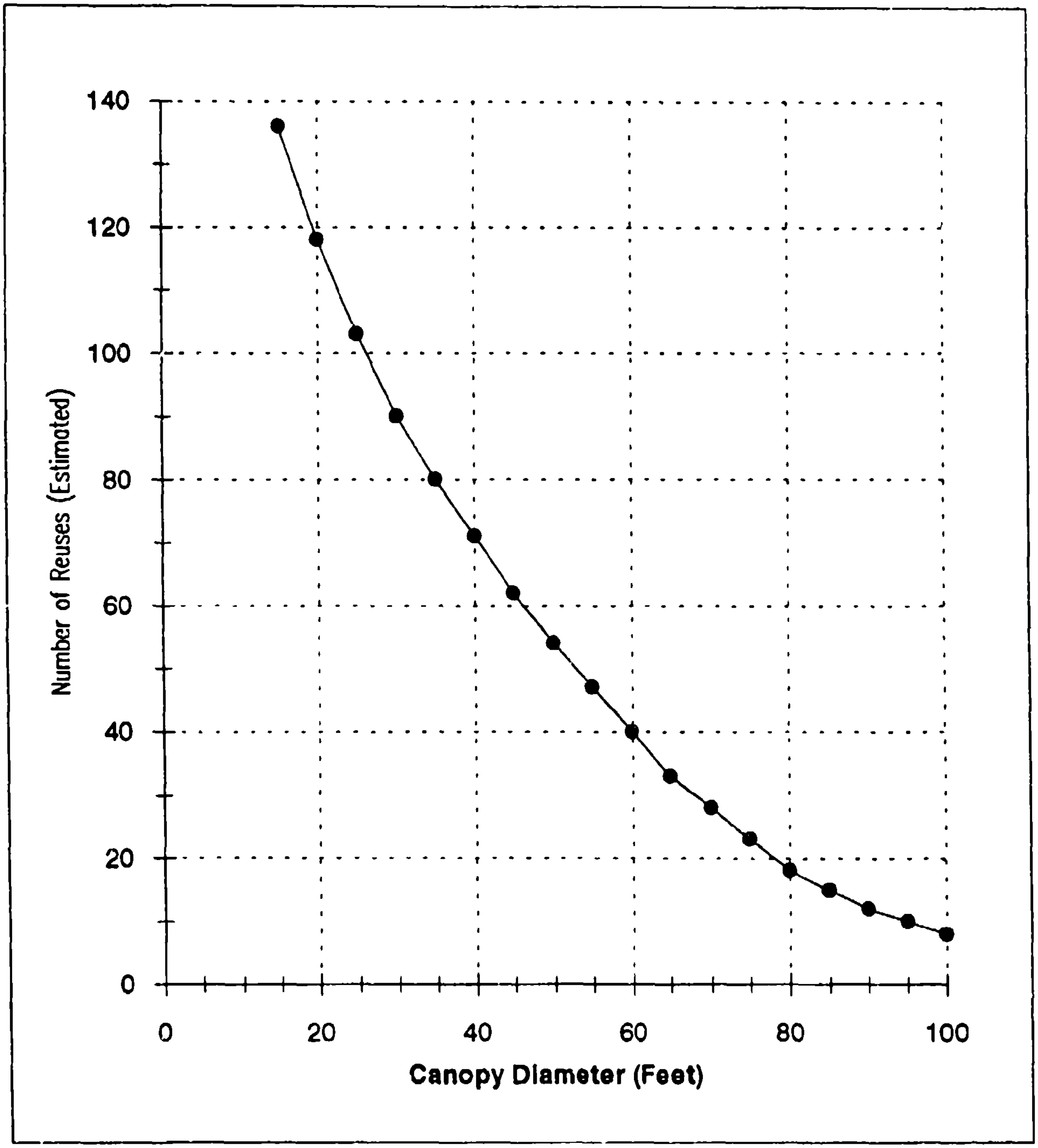


Figure A-2. Cargo Parachute Reuses vs. Diameter (Estimates)



* Reuses before repair costs equal canopy value or canopy is discarded.
Numbers are estimates based on discussions with senior CWOs in the airdrop field.

Figure A-3. Est. Cost per CDS Drop vs. Canopy Diameter (2,200 pound load)

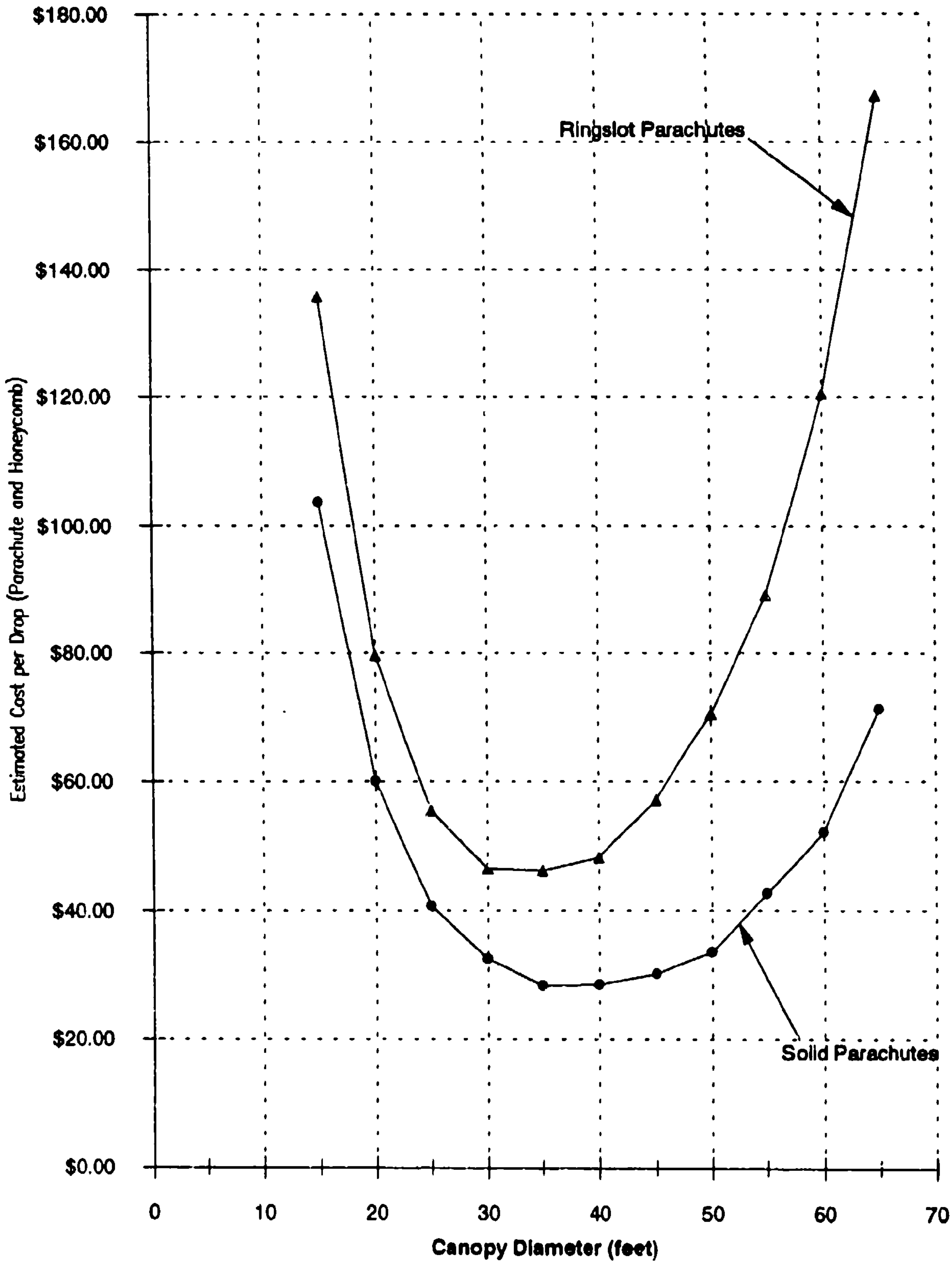
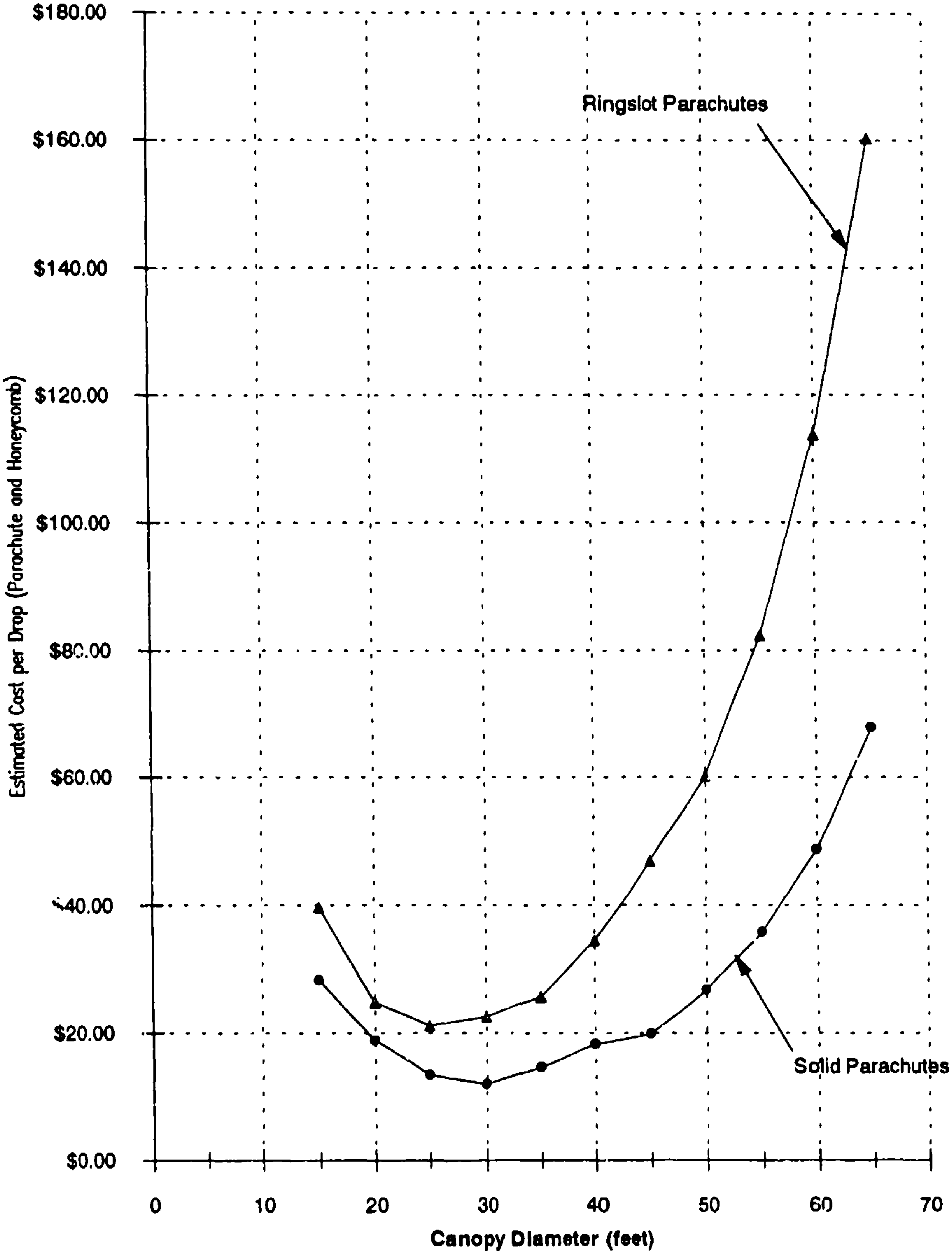


Figure A-4. Estimated Cost per CDS Drop vs. Canopy Diameter (1,100 pound load)



APPENDIX B.

Maximum Deck Angle vs. Airspeed for the C-17 Aircraft

APPENDIX B. Maximum Deck Angle vs. Airspeed for the C-17 Aircraft

This summary is based on information obtained from the C-17 System Project Office (SPO) on C-17 maximum achievable deck angle vs. airspeed. Flight Path Angle vs. Equilibrium Airspeed charts have been generated by the SPO for various flight parameters. These charts were formulated based on wind tunnel and computer modeling. By utilizing these charts the maximum achievable deck angle at high-speeds (235 to 250 KIAS), while maintaining level flight can be predicted. This information is critical for determining if high-speed CDS airdrop from the C-17 can be done by gravity extraction. Based on a preliminary review, flying with the slats and flaps retracted (clean wing) will permit the maximum deck angle at high-speeds. Aircraft gross weight significantly affects the achievable deck angle at level flight.

Table B-1 was generated for various airspeeds (200, 220, 235 and 250 KIAS), comparing deck angle to gross aircraft weight. Figure B-1 is a graphical representation of Table B-1. All information assumes a level flight path and a clean wing. For low altitude flight, the equilibrium airspeed (KEAS) is, for all intents and purposes, equal to the indicated airspeed (KIAS), and that assumption has been made in this analysis. Current CDS airdrop at low speeds (140-150 KIAS) is conducted from C-130 and C-141 with between a 6 and 8 degree deck angle.

Table B-1. Maximum Deck Angle for the C-17 vs. Airspeed

Gross Weight (lbs)	Maximum Deck Angle (Degrees)			
	200 KIAS	220 KIAS	235 KIAS	250 KIAS
283,000	3.9	2.9	2.3	1.5
300,000	4.3	3.3	2.5	1.8
350,000	5.4	4.1	3.4	2.7
400,000	6.6	5.1	4.1	3.4
450,000	7.5	5.9	5.0	4.0
500,000	8.7	6.7	5.8	4.8
539,000	9.5	7.4	6.5	5.4

Maximum deck angles at airspeeds above 200 KIAS are dramatically effected by the gross weight of the aircraft. For the C-17, the following weight data was obtained:

Table B-2. C-17 Aircraft Weight Breakdown

Airframe Gross Weight	275,000 pounds
Aircraft Fuel (maximum)	176,000 pounds
Maximum CDS Cargo Load	93,000 pounds
Maximum Total Gross Aircraft Weight (40 CDS, 170,000# Fuel)	539,000 pounds
Minimum Total Gross Aircraft Weight (1 CDS, 5,000# fuel)	283,000 pounds

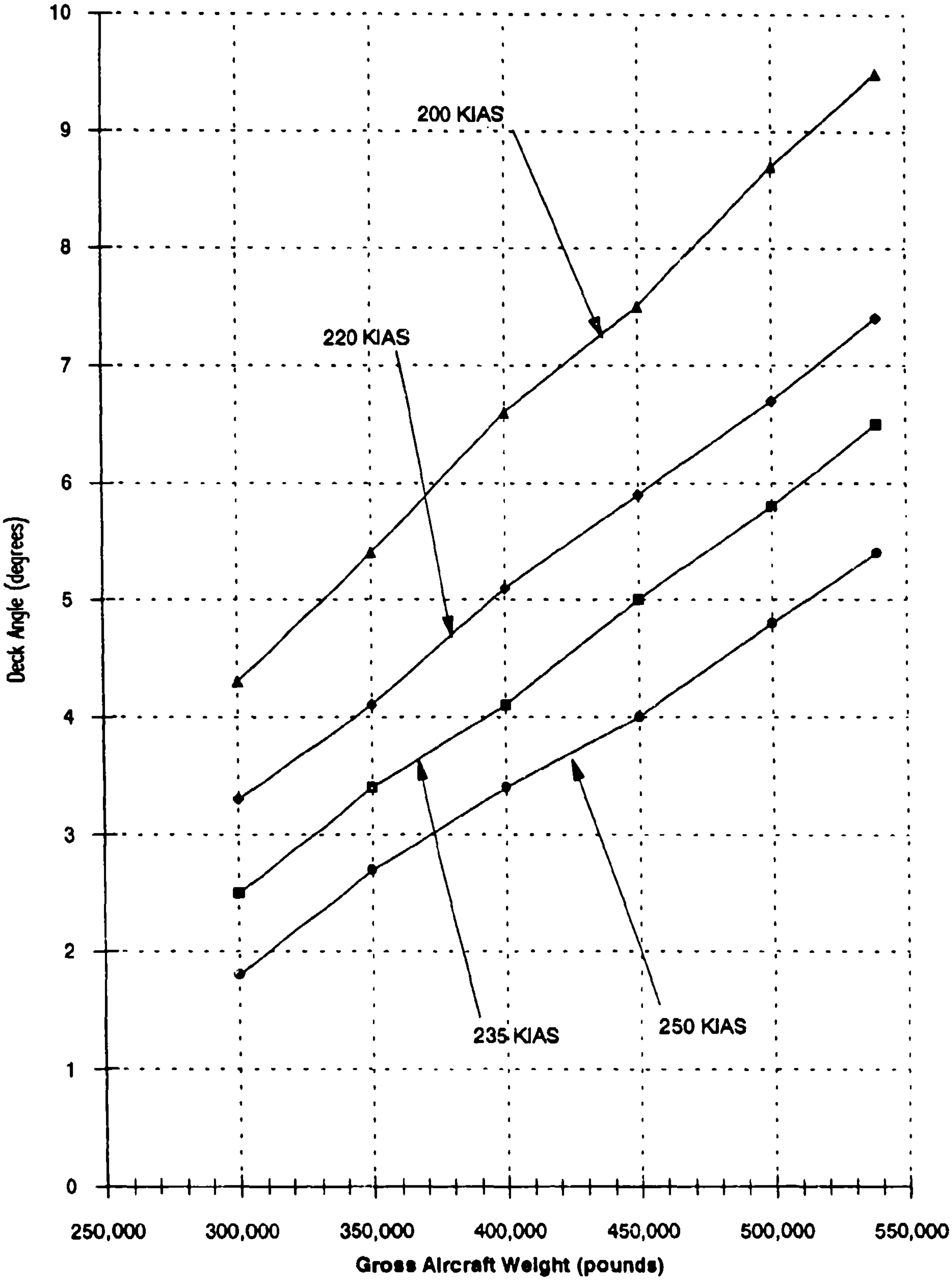
It is a safe assumption that airdrop missions will usually be conducted with about "a half a tank of gas", since fuel will be used getting to the Drop Zone (DZ) and returning back from the DZ. So if we assume the majority of CDS drops will be conducted at between 330,000 and 430,000 pounds total aircraft weight, the maximum achievable deck angles for each airspeed are as follows:

Table B-3. Range of Achievable Deck Angles vs. Airspeed (C-17)

Airspeed (KIAS)	Maximum Deck Angle (degrees) (assuming 330 to 430k aircraft weight)
200	5 to 7
220	3-1/2 to 5-1/2
235	3 to 4-1/2
250	2 to 3-1/2

Clearly, at above 200 KIAS the C-17 will not be able to achieve the 6 to 8 degrees deck angle that the C-130 and C-141 do for low speed CDS airdrops. At 200 KIAS, it is close, but one must consider that if the aircraft is lightly loaded the maximum deck angle will be reduced to about 4 degrees. Even if the 6 to 8 degrees was achievable it will require a much longer drop zone than a 150 KIAS drop from the same deck angle. Therefore, a very large deck angle is required at high-speeds to get the cargo out of the aircraft as quickly as possible.

Figure B-1. C-17 Maximum Deck Angle vs. Aircraft Gross Weight



APPENDIX C.

Exit Times for Gravity Extraction of Containers

APPENDIX C. Exit Times for Gravity Extraction of Containers

The force of gravity on the container is contingent upon the aircraft deck angle and the friction in the floor rollers. First we must ascertain the friction forces in the rollers.

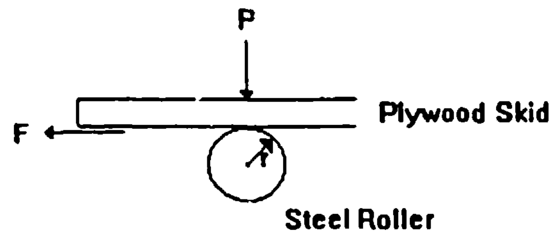


Figure C-1. CDS Skid on Aircraft Rollers

The coefficient of rolling friction $K_r = K / r$, where K is the coefficient of friction between plywood and steel. From page 3-28 of Marks' Handbook [16], K for wood on wood is 0.02, and for steel on steel K is 0.002. K for wood on steel is somewhere between these two values. For this analysis we will assume K for wood on steel is 0.015 and neglect the effect of friction in the roller bearings. The radius of the rollers varies for each aircraft. The K_r for each aircraft is therefore estimated to be:

Table C-1. Coefficient of Rolling Friction of Aircraft Floor Rollers

Aircraft	Radius of Cargo Floor Roller (inches)	Coefficient of Rolling Friction, K_r
C-130	1.125	0.013
C-141	0.9375	0.016
C-17	0.9375	0.016

To be conservative (since we neglected bearing friction) we will use $K_r = 0.016$ for this analysis.

The free body diagram for a container being gravity extracted looks like this:

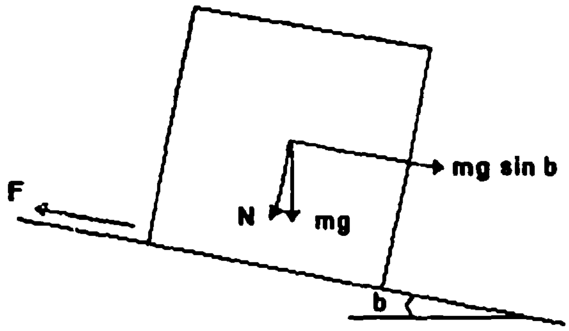


Figure C-2. Free Body Diagram of Container Rolling out of Aircraft

Before the container begins to roll the sum of the forces in the x direction is zero:

$$mg \sin b - 0.016\, mg \cos b = 0$$

Solving yields: $\tan b = 0.016$ or $b = 0.92$ degrees

Therefore, the container will begin to roll once a deck angle of 0.92 degrees is achieved.

After the container begins to roll, the sum of the forces in the x direction follows:

$$mg \sin b - 0.016\, mg \cos b = ma$$

$$a = 32.2\,(\sin b - 0.016 \cos b)$$

Therefore, the acceleration due to gravity of a container on the aircraft rollers is independent of the container's mass and solely dependent upon the effective deck angle. The following table summarizes this acceleration of a container vs. the effective deck angle.

Table C-2. Container Acceleration vs. Effective Deck Angle

Deck Angle	Acceleration (fps/s)
1	0.05
2	0.61
3	1.17
4	1.73
5	2.29
6	2.85
7	3.41
8	3.97
9	4.53
10	5.08

Figure C-3. Gravity Extraction of 16 Containers: High vs. Low Speed

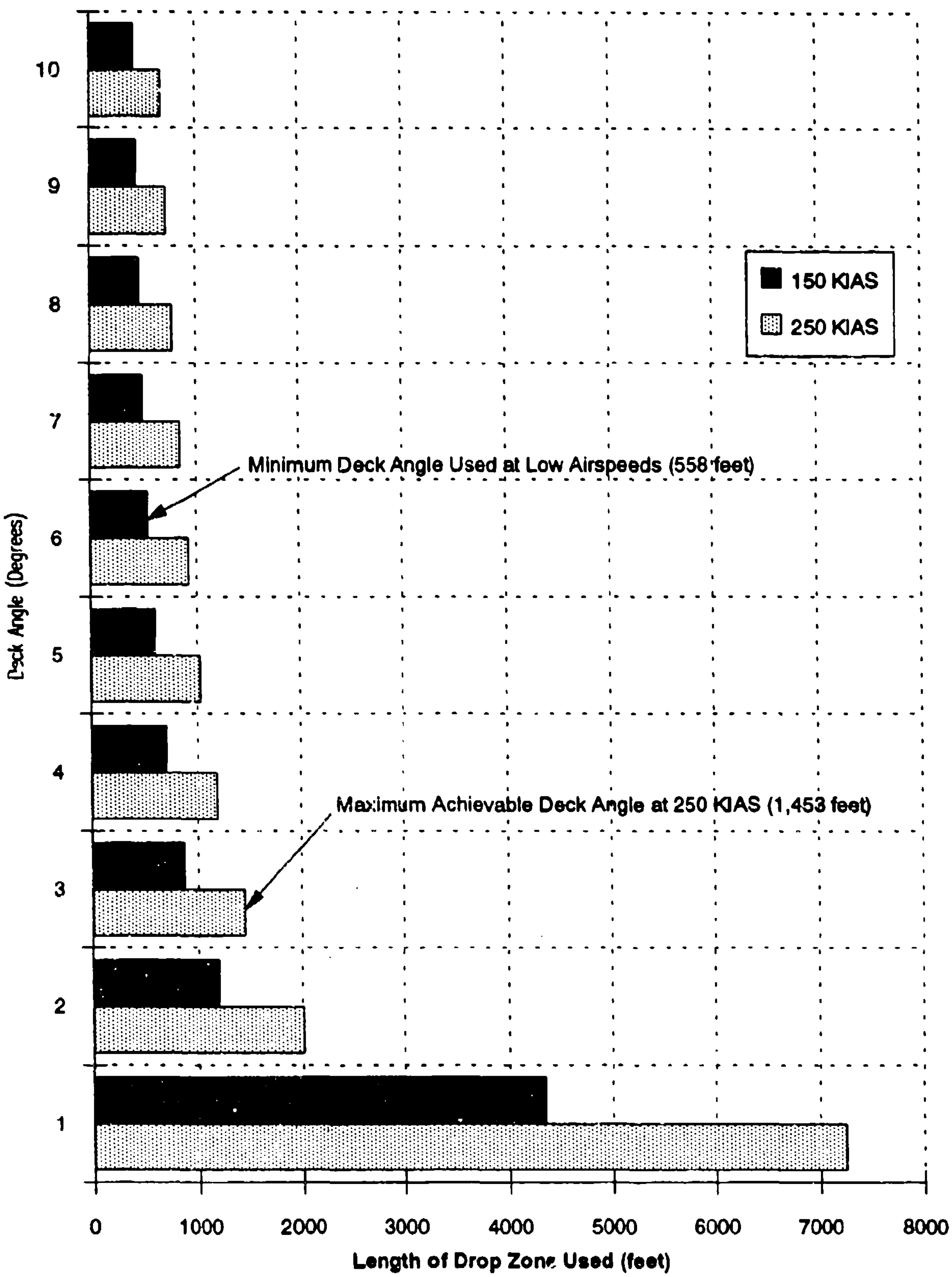
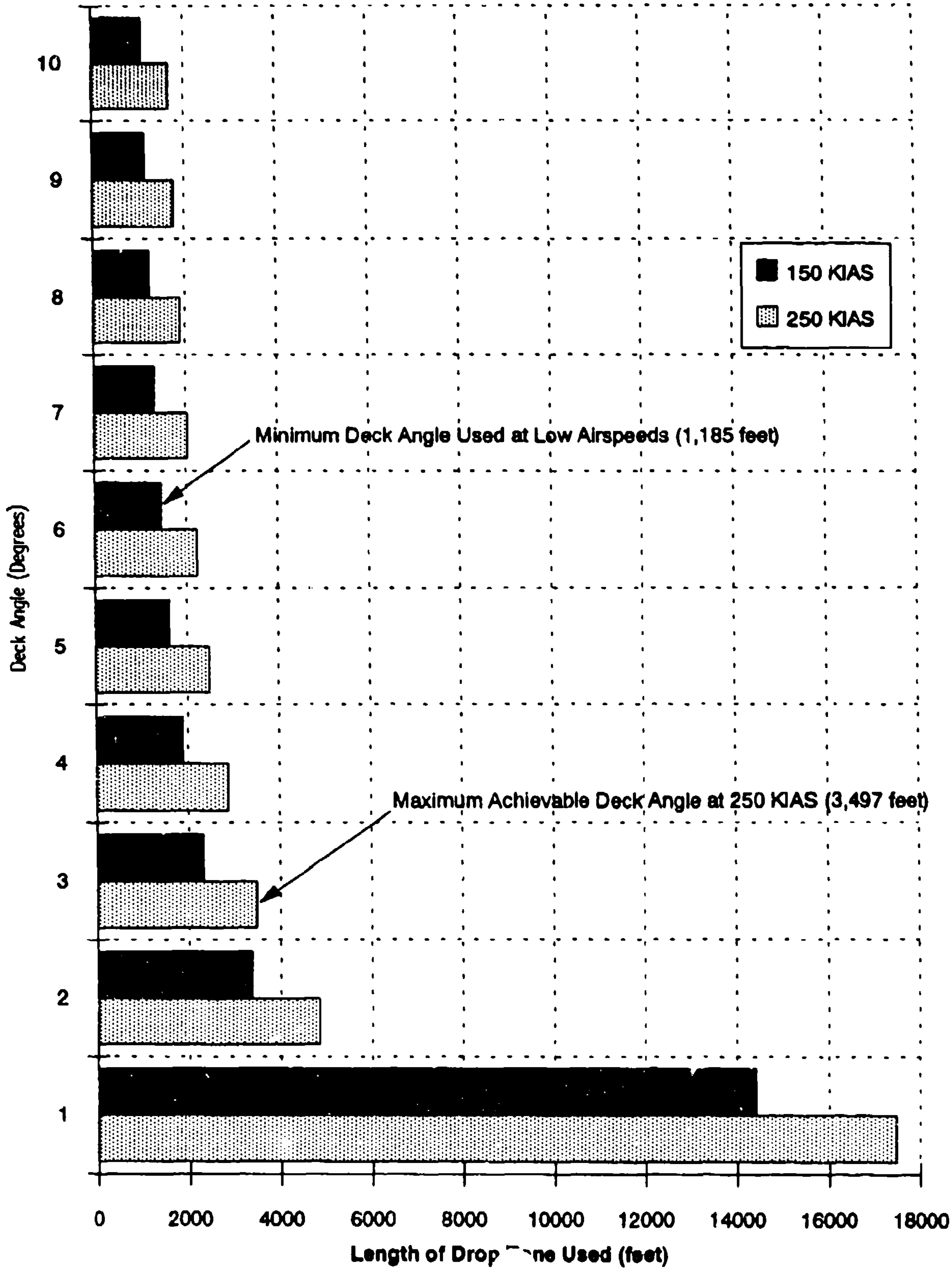


Figure C-4. Gravity Extraction of 40 Containers: High vs. Low Speed



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