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AIRDROP ERROR ANALYSIS

Gene A. Petry

Aeronautical Systems Division
Wright-Patterson Air Force Base, Ohio

June 1975
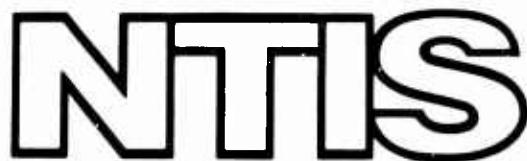
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AIRDROP ERROR ANALYSIS

Directorate of Crew and AGE Engineering (ENC)
Delivery and Retrieval Branch (ENCMD)

June 1975

TECHNICAL REPORT ASD-TR-75-8

Final Report for Period December 1973-August 1974

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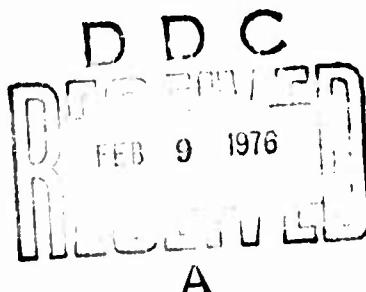
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Current procedures that are used to determine the correct release point for airdrop are contained in the multi-command Air Force Manual 55-40, "Computed Release System Procedures," dated 4 November 1971. The dispersion of airdrop loads about the desired impact point that results when these procedures are used is much greater than desired. There are many factors affecting the airdrop dispersion. It is the objective of this report to identify those significant factors that contribute to the overall airdrop impact error and, where possible, recommend procedures for incorporating improvements. (Cont)

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20. (Cont)

The present Computed Air Release Point (CARP) manual was used as a baseline in conducting this study. It is acknowledged that the manual is continually being updated and is currently under revision. However, the anticipated revisions are not expected to invalidate the relative comparisons and findings made herein. Indeed the intent of this report is to recommend that the applicable findings be incorporated in subsequent revisions. One desirable outcome of a study such as this is an airdrop model that enables a comparison of different factors. Refinement of the model with actual data can provide a method of predicting ballistic data for inclusion into the CARP manual. This study first considered all known significant factors affecting airdrop and grouped these factors in a fashion that would lead to an orderly evaluation. A logic diagram was prepared for these factors and a discussion as to the impact upon the airdrop accuracy was made. A sensitivity analysis of known factors was made to determine which ones should be further analyzed in more detail. From the analysis, models were developed. It was found that some basic calculation steps in the CARP solution are in error and can be corrected. The largest single factor contributing to airdrop error results from wind drift. If the resupply area is unsuitable for an aircraft to land for offloading, and an airdrop accuracy of 100 yards circular error average (CEA) is required, there are two possible delivery options: (1) use a steerable gliding system, (2) use the Low Altitude Parachute Extraction System (LAPES). Operational airdrop systems do not provide an accuracy of 200 yards CEA when dropped from 1000 feet or higher above the ground. As the airdrop altitude increases, so will the impact error.

FOREWORD

The findings contained in this report were prepared in response to airdrop accuracy problems encountered in operational use of the Container Delivery System (CDS) from altitudes above 1000 feet. Mr. Petry conducted this study effort while assigned to the Delivery and Retrieval Branch of the Mechanical Support Division, Directorate of Crew and AGE Engineering, Deputy for Engineering, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

The objective of this report was to identify those significant factors that contribute to the overall airdrop impact error and, where possible, recommend procedures for incorporating improvements.

This effort was accomplished under Project AFSD0157, Intermediate Wind System, for the period of December 1973 to August 1974.

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SECTION I

BACKGROUND

Aerial delivery from aircraft in flight must necessarily be considered an integral part of logistic programming for the military missions of today and the future. Because air transportation is inherently faster than any other mode, it is advisable to use aerial delivery to transport men, equipment, and supplies from the Zone of Interior and other places on earth to points of threatened or demonstrated crisis. Also, with the concept that future battlefields will call for highly mobile and widely dispersed military units, it is reasonable to assume that these units may depend almost entirely on aerial delivery which may come from bases far removed from the scene of combat. Landing the cargo plane in the areas to be supplied is an obvious solution. However, this means of supply involves costly airfield construction, cost of landing and takeoff, and aircraft maintenance. Also, landed aircraft present a vulnerable target. It is evident, then, that aerial delivery subsystems, properly developed as a normal means of supply, may be the only and most cost effective solution. An airdrop subsystem must provide a capability to drop accurately within the required zone, under all conditions of weather and terrain, and provide operational reliability to prevent damage to the equipment delivered. Accuracy refers to the capability of an airdrop subsystem to deposit the load at a predetermined spot on the ground from an aircraft over the drop zone. The most important element that detracts from accuracy is wind drift during descent. At present, a method known as Computed Air Release Point (CARP) is used in determining the point at which airdrop of paratroopers or equipment should be released in order to impact on the desired area. This method can rely upon an aircraft which precedes the delivery aircraft to the drop zone and determines wind velocity at drop altitude. This information is relayed to the delivery aircraft and used in the computation of the proper release point. In this method no consideration is made for wind magnitude or direction changes below drop altitude. This shortcoming can seriously affect the accuracy of high altitude drops, because of the probability of changing wind conditions below drop altitude. One way to overcome the resultant inaccuracies from wind is to increase the rate of descent of the supplies and equipment being dropped. This increased rate of descent tends to reduce the effect of varying wind conditions that may exist in a particular area. The increased rate of descent carries with it, however, more stringent energy absorption requirements at impact. Then, too, accuracy is not dependent upon rate of descent alone. The means of extracting or ejecting aerial supply equipment or bundles from the aircraft must be positive, so as to establish a firm basis from which to compute exit time. The deployment time of the retarding device should be constant; and finally, before the entire aerial delivery subsystem can effectively be utilized, an accurate method is required to locate the release point in space relative to the desired impact point.

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SECTION II

PROBLEM DISCUSSION AND ANALYSIS

1. CARGO AIRDROP DESCRIPTION

Cargo airdrop involves all types of air-to-ground delivery of equipment and supplies for airdrop from cargo aircraft. This report will address loads weighing 500 pounds to 35,000 pounds dropped from altitudes up to 20,000 feet above the ground. Two types of equipment airdrop will be discussed in detail:

a. High velocity delivery of certain items of supply requires that the rigging of airdrop containers with an energy dissipator attached to the underside of the load and a stabilizing device such as a ring-slot parachute attached to the top of the load. The stabilizing device is designed to minimize oscillation of the load and create just enough drag to stabilize the load during descent so that it will land on the energy dissipator. Loads of 500 to 2200 pounds are normally delivered in this fashion. The gravity ejection method is usually employed for single and multiple loads.

b. Low velocity drop is delivery of various items of supply and equipment by the use of cargo parachutes. In those cases where the load is rigged on platforms, an extraction parachute system is used to extract the load from the aircraft. The initial action of the extraction parachute force is to remove or release the restraint which secures the load in the aircraft cargo compartment (Figure 1). The load is then extracted from the cargo compartment. Once the load is out of the aircraft, the extraction line is released from the load and the extraction parachute force is then diverted to deploy the main recovery parachutes. The recovery parachutes inflate and lower the cargo to the ground at a terminal impact velocity of approximately 25 feet per second. Figure 2 gives the drop cycle for the low velocity Container Delivery System (CDS).

2. FACTORS AFFECTING AIRDROP ACCURACY

a. The multi-command Manual 55-40 provides the foundation for worldwide employment of the CARP for airdropping of personnel and equipment from Air Force aircraft. Figure 3 provides a pictorial representation of those factors involved in the CARP solution under a no wind condition. The CARP method does include provisions to account for an assumed constant wind drift effect. A review of the literature for other technical efforts related to CARP provided very limited information. SEM-TM-65-13, "Lowering the Drop Altitudes and Updating the CARP for the C-130," addressed the problem of accuracy of delivery for the standard heavy delivery technique. Based upon ninety-one drops, it was determined that a minimum of 1100 feet was required for clusters of G-11As to reliably deploy and inflate.

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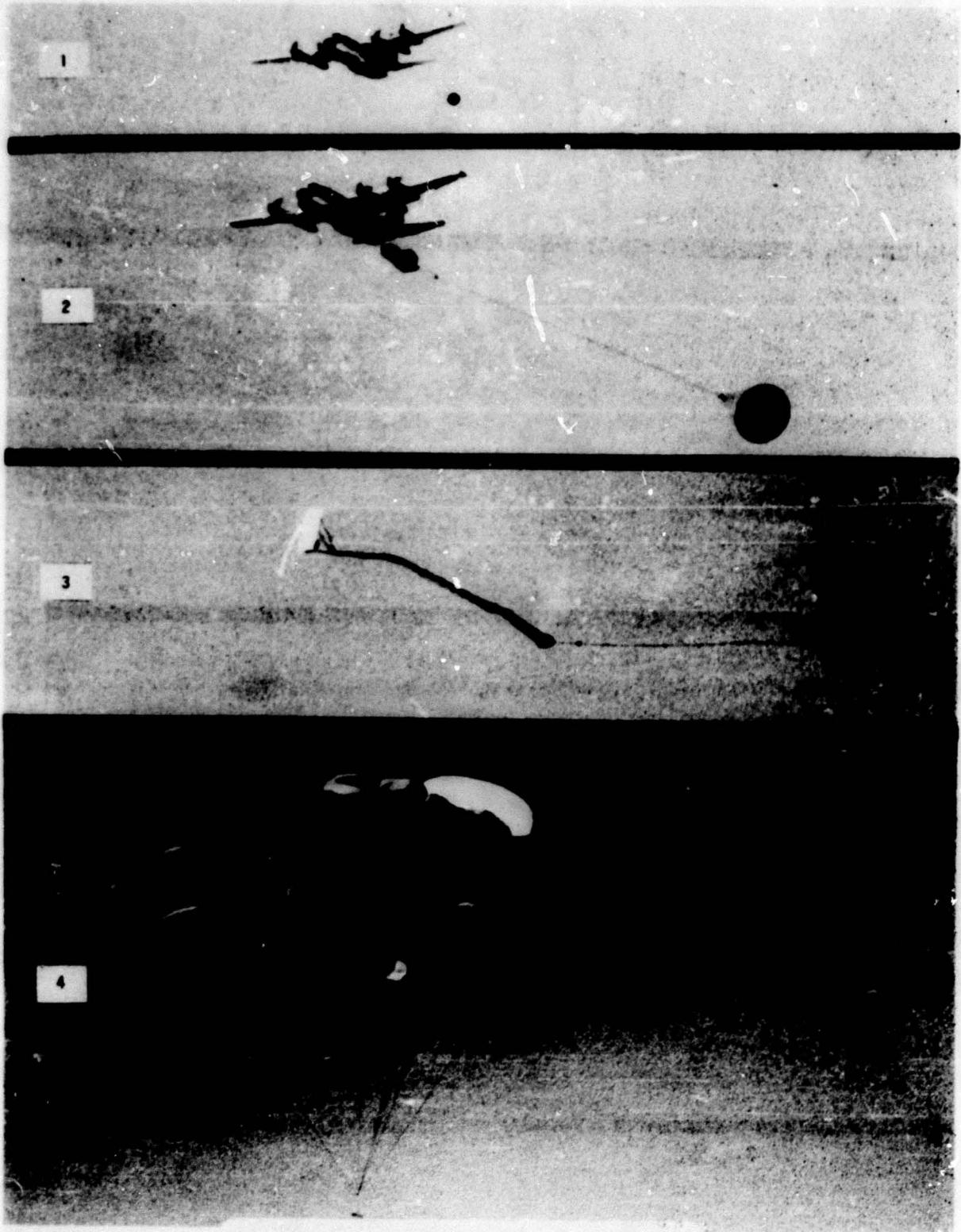
Figure 1   EXTRACTION CYCLE OF
HEAVY AIRDROP

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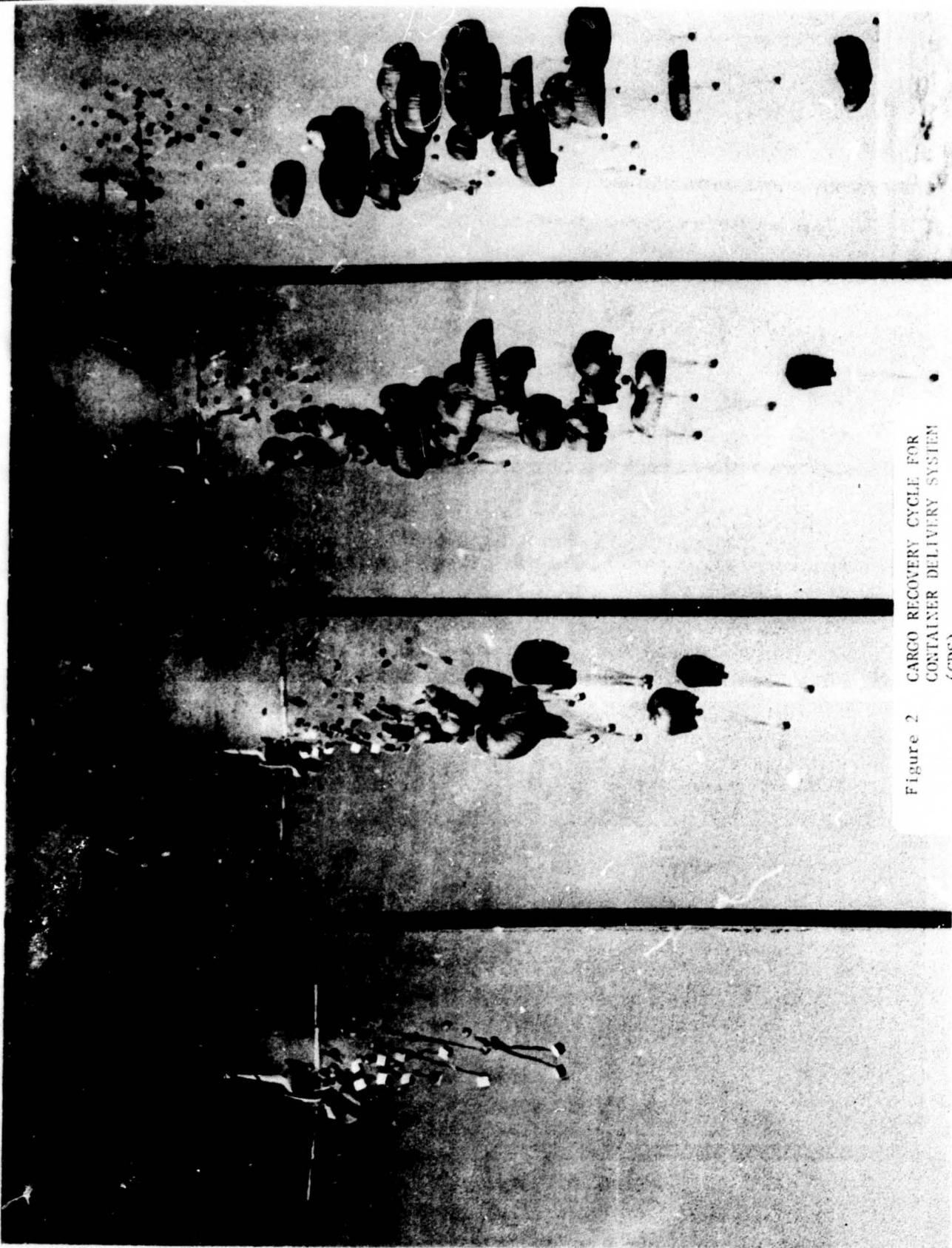
Figure 2   CARGO RECOVERY CYCLE FOR
CONTAINER DELIVERY SYSTEM
(CDS)

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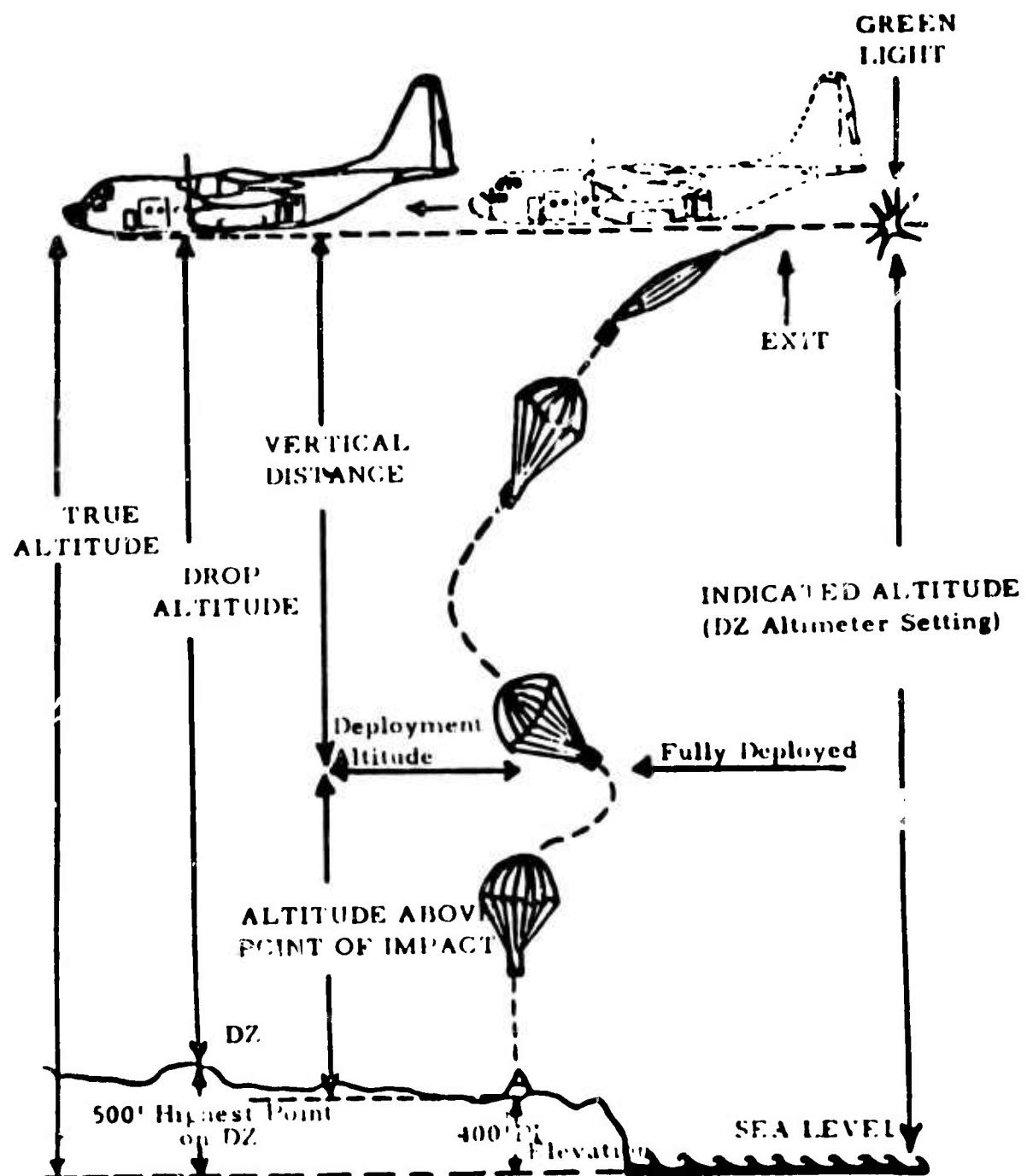
Figure 3. CARP vertical diagram

b. The United States Army Natick Laboratories' Technical Report 73-55-AD, "High Level Container Airdrop System," by A. L. Farinacci and D. B. Bruner, developed a model for dropping container loads weighing up to 2200 pounds from high levels and landing them with a high degree of single-drop accuracy. Their computer model considered the effect of given wind profiles, but did not consider the variation in parachute deployment initiation, opening time, etc.

c. In conducting this airdrop analysis, an effort was made to identify all those factors that contribute to the overall error. The resultant error will be composed of all component errors. To be able to predict an overall error for airdrop, the error distribution of each factor contributing to the error must be known.

d. Based on a technical review of the literature for airdrop, the following list contains most of the significant factors that would affect airdrop accuracy. Many of these factors are interrelated.

    (1) Load weight.

    (2) Parachute size for both the extraction and recovery parachutes.

    (3) Airspeed.

    (4) Drop altitude.

    (5) Density related to temperature, pressure, and altitude.

    (6) Position of the load in the aircraft.

    (7) Total time of fall (TTF).

    (8) Time of fall constant (TFC).

    (9) Rate of fall (RF).

    (10) Forward travel distance (FTD).

    (11) Forward travel time (FTT).

    (12) Wind velocity.

    (13) Location of impact point (IP) on the ground.

    (14) CARP relative to IP.

    (15) Human error.

    (16) Mechanical error (instruments, parachutes, etc).

3. LOGIC FLOW CHART

a. In an effort to relate the listed factors in a manageable fashion, a flow chart was prepared with the factors grouped in a logical manner (Figure 4). The assumption is made that the gross error of the load in landing near the impact point is primarily the result of three contributing factors: (1) aircraft position error, (2) ground position error, and (3) trajectory error. Aircraft positioning error results when the navigational system is such that the computed air release point in space cannot be accurately located. The Adverse Weather Aerial Delivery System (AWADS) is required to locate the CARP within approximately $\pm$ 100 yards when airdropping 700 feet above the ground. The positioning error probably increases with drop altitude, however, the actual error is unknown. The error in locating the correct ground position will also contribute to the overall error. Certain geographical locations are mapped far more accurately than others. Knowing where the desired impact point is located relative to the CARP is most important. For lack of substantive data, this study assumed that the maximum error resulting from either the ground positioning error or aircraft positioning error could be a maximum of 100 yards each.

b. The trajectory error results from numerous factors, some of which can be reasonably predicted and others for which very little data is available. The CARP Manual 55-40 is one such attempt to treat the significant trajectory factors. Parachute performance and equipment failures contribute errors that are hard to quantify. Fortunately, available test data from actual airdrops indicate that these two factors contribute a small amount to the overall error when compared to other variables. The wind error contributes the largest proportion of the overall error and is the most difficult to accurately predict. Both the speed and changing direction of the unknown wind adds to the error. Some of the reasons for the wind error are as follows:

   (1) Wind velocities were taken some time before the drop and have changed at drop time.

   (2) Only drop altitude winds are known and are utilized.

   (3) Only ground winds are known and are utilized.

   (4) Wind velocities are not available.

c. The calculation error results from the factors of Total Time of Fall (TTF) and Forward Travel Distance (FTD) as computed in the CARP manual. The FTD is the distance the load travels relative to the ground during the time it takes the load to exit the aircraft, travel through the trajectory and reach a vertical equilibrium velocity. The significant variable factors affecting the FTD are as follows:

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Figure 4 ERROR FLOW CHART
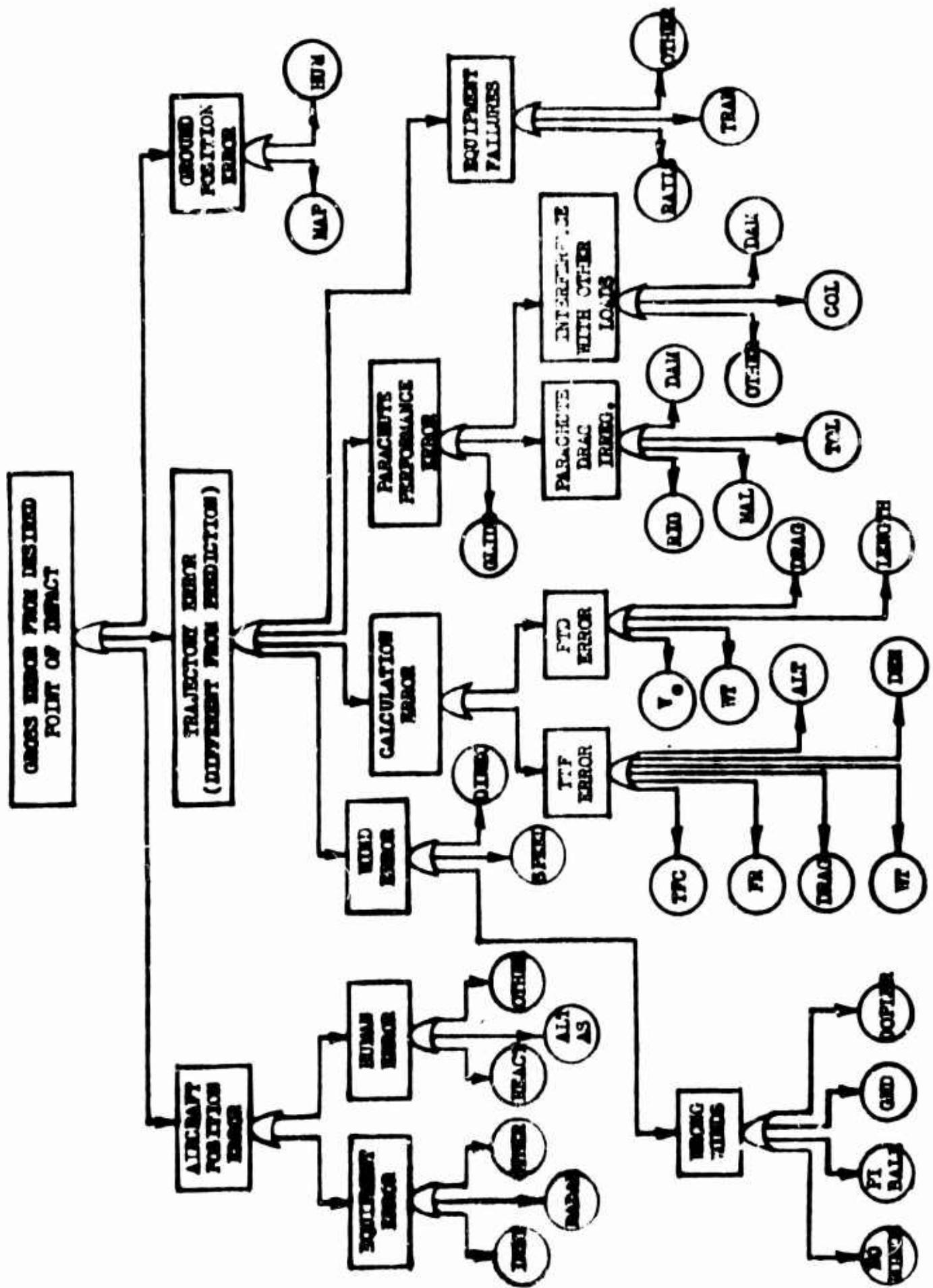
(1) Load weight.

(2) Size of extraction parachute.

(3) Airspeed.

(4) Position of load in the aircraft.

(5) Length of extraction line.

(6) Number and size of recovery parachutes.

(7) Density.

d. Depending on the method of airdrop, some or all of the above factors will contribute to the FTD. Regardless of the airdrop method, a specific FTD for each load at given drop conditions is required to be known and each respective FTD will vary significantly as the drop conditions change. A review of the Parachute Ballistic Data of the CARP manual reveals that the values for the FTD within a given method of airdrop do not take into account all the above factors.

e. The Total Time of Fall (TTF) is significant to the error if there are effective winds. Under a no-wind condition, the load should fall vertically (assuming no gliding) and only the FTD is required as an input to the CARP. When winds are prevalent, failure to account for them will result in large drift errors. Some of the factors affecting the TTF are as follows:

(1) Load weight.

(2) Rate of fall (parachute size).

(3) Density.

(4) Time of fall constant (TFC).

(5) Temperature.

(6) Load drag.

(7) Forward travel distance (FTD).

(8) Altitude.

(9) Recovery parachutes.

4. SENSITIVITY ANALYSIS OF CONTRIBUTING FACTORS TO THE TRAJECTORY ERROR FOR CDS

a. In an effort to determine which of those factors listed in paragraph 3.c contribute the largest amount of error to the overall error, a sensitivity analysis was made. The first sensitivity analysis was made for the container delivery system using a 28 foot ring slot parachute for high velocity drop from both 10,000 feet and 20,000 feet. A 2,000 pound bundle was assumed as the standard weight load. First, an arbitrary 10% deviation for each factor was assumed. Each factor was allowed to vary, one at a time, and the resultant error calculated (Figure 5). All other factors except the one under evaluation were assumed to remain constant. The calculations as given in the CARP manual were used in this comparison. Column 2 of Figure 5 represents the resultant for the assumed 10% error of each variable. It becomes immediately apparent that some of the factors are insignificant. The third column represents a more realistic estimation of the maximum error for each variable. The basis for the estimated maximum error was the technical literature, experience factors, and expert opinion. Even though the estimated maximum error is not exact, the resultant errors in columns 4 and 5 clearly indicate the significant factors that contribute the largest portion to the total error. A discussion of each major factor for the CDS from high altitude with a 28 foot ring slot parachute is given as follows:

(1) Density error results when allowances are not made for the changing density with altitude. The CARP manual utilizes a constant rate of fall to determine the time of fall. At high altitudes above the drop zone a given load falling at an equilibrium velocity will fall appreciably faster than prior to impact. The equilibrium velocity will decrease with loss of altitude due to increasing density. Density changes can be accounted for by several methods. An approximation that is satisfactory for altitudes up to 20,000 feet was used in this study.

$$\rho = \rho_o \, e^{-\left(\frac{0.297\,h}{1000.0}\right)}$$

$$\rho_o = 0.0023769 \,(slugs/ft^3)$$
$$h = altitude \ (ft)$$

Daniel O. Dommash
Airplane Aerodynamics 1967
Pitman Publishing Corp.

(2) Load weight variations also contribute significantly to the overall error. The CARP manual for CDS does not take into account the variation of load weight with a given parachute configuration. Technical orders for CDS show loads of 1400 to 2200 pounds with the 28 foot ring slot parachute. Load weight can be accounted for by utilizing the equilibrium velocity equation:

$$V_e = \sqrt{\frac{2w}{\rho \, C_D S_o}}$$

$$w = load \ weight \ (lbs)$$
$$C_D S_o = drag \ area \ (ft^2)$$
$$\rho = density \ (slugs/ft^3)$$

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ERROR FACTORS	IP MISS (YDS) 10% ERROR	EST MAX ERROR (%)	MISS FROM IP (YDS) FROM MAX ERROR	
			@ 10,000 ft	@ 20,000 ft
Load Weight	83	25	250	515
Drag Area	80	10	80	80
Density	80	20	195	611
Temperature	82	6	15	
Pressure		2		
Airspeed	46	5	23	
Altitude	170	2	40	40
Reaction Time	2	10	3	3
TOTAL TIME OF FALL				
Rate of Fall	75	10	75	
Forward Travel Time	40	25	80	
Wind				
Speed	150	30	460	920
Direction	140	± 30°	520	1040

Figure 5   CDS ERROR FACTORS

Combining this with the density equation above, an equation for time of fall taking into account the density and weight variations can be developed resulting in useful curves to determine time of fall (Figure 6). It should be noted that both density and load weight error are nullified under a no wind condition where the load falls vertically.

(3) The velocity of the wind is by far the most sensitive of all the parameters and is probably the most difficult factor to correctly predict. Both the speed and direction contribute to the error. Coupled with the problem of not being able to predict the wind velocity at a given altitude is the changing velocity versus time. One way to apply the effects of a known wind is to utilize an integrated wind or an equivalent wind that will produce the same drift displacement as the existing wind conditions would. A Wind-Finding Drop Sonde is being developed to have the capability of providing an integrated wind. This effort may alleviate the wind velocity problem in the future.

(4) The forward travel time (FTT) is another significant variable. The time it takes for the load to clear the aircraft from various positions in the aircraft is included as part of the FTT. The CARP manual generally provides for one position within the aircraft. An exception is the container delivery system where three different positions are given. Other factors that affect the FTT were given previously.

(5) With the following four basic equations, the forward travel time can be approximated for each load at any position within the aircraft for given assumptions.

$$V_e = \left[64.4 \, \Delta S (\sin\theta - \mu\cos\theta)\right]^{1/2}$$

$$\Delta t = \frac{V_e}{32.2(\sin\theta - \mu\cos\theta)}$$

$$\tfrac{1}{2}\rho\, C_D\, S_o\, V^2 = -m\,\frac{dv}{dt}$$

$$\frac{d\theta}{dt} = -\frac{g\cos\theta}{V}$$

V_e = exit velocity (ft/sec)

θ = deck angle (degrees)

ΔS = load position (ft)

Δt = exit time (sec)

ρ = density (slugs/ft³)

V = load velocity (ft/sec)

C_D = drag coef

S_o = drag area (ft²)

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TIME OF FALL FOR HIGH ALTITUDE AIR DROPS

FIG 6.   TIME OF FALL (SECS)
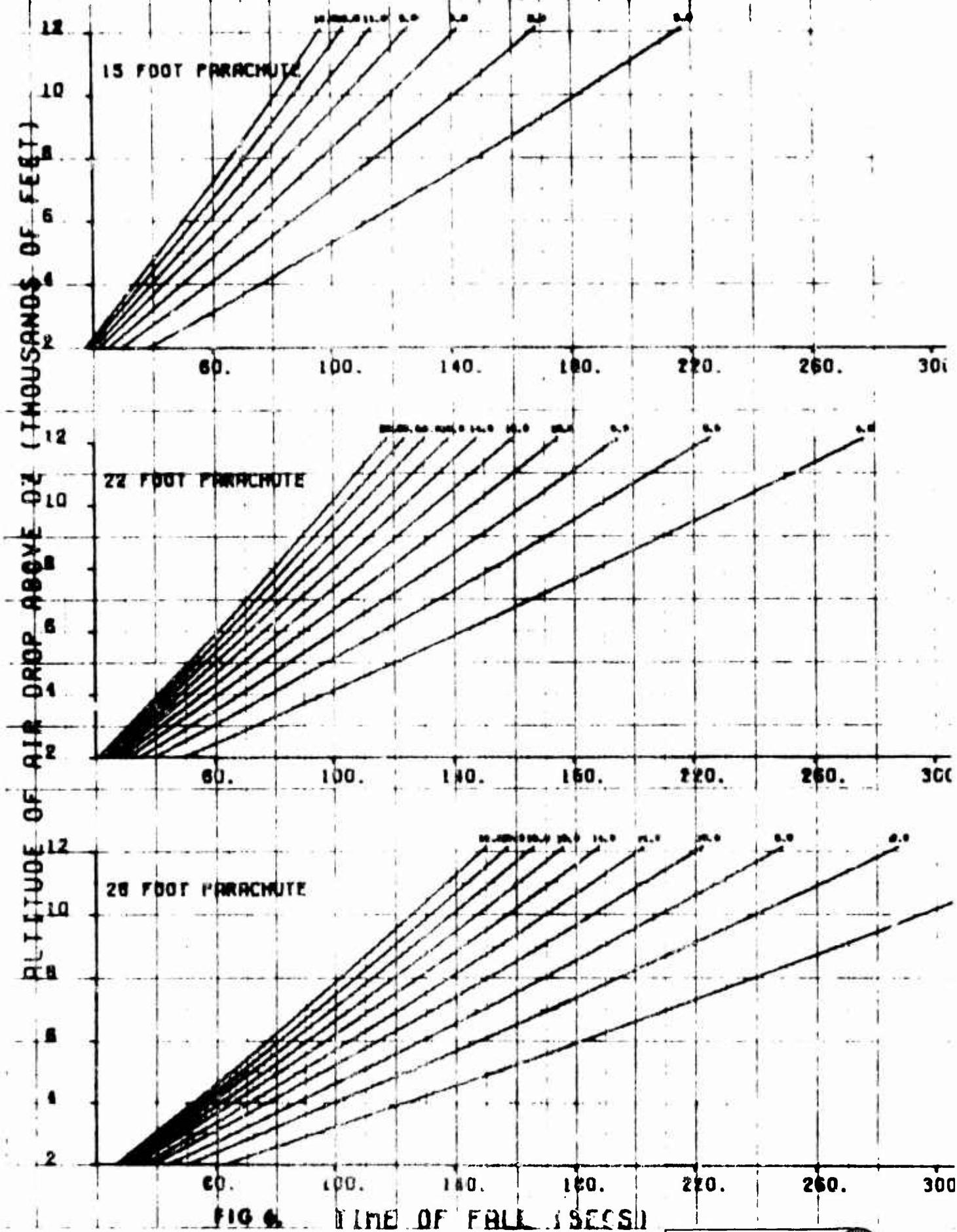
b. From the sensitivity analysis of the factors affecting CDS, the four most significant factors are examined in detail because of their respective large contributions to the overall impact error. Those factors that contribute less than 100 yards error were not examined in detail because of the assumed fact that both the aircraft positioning and ground positioning error will be at least 100 yards. An effective way of relating the four major contributing factors with each other is a plot of total time of fall versus wind velocity (Figure 7). The total time of fall includes the forward travel time and the time of fall. The effective wind velocity is assumed to be a resultant or equivalent to a constant wind velocity for the duration of the drop. This plot can be used in two ways. It can be used to show the drift effect for a given resultant wind for a total time of fall. This drift effect represents the amount of offset required in the CARP to account for the resultant wind. The sensitivity of the wind effect is clearly shown from this figure. For instance, if a resultant 15 knot wind occurs during a high velocity CDS drop from 10,000 feet (~135 second time of fall) and the wind effect is ignored, then an approximate 1150 yard impact error could be expected from wind drift alone. This plot can also be utilized for error analysis. If, for instance, we know the tolerances on a predicted wind for a given TTF, then we could determine the maximum error from the wind and thereby adjust the drop zone (DZ) size as required. Likewise, if we know the TTF error that could exist for a given wind condition, then the drift error can be determined. Figure 8 has included TTF bands for various methods of CDS deliveries.

c. From the discussion of the four major contributing factors one could postulate a maximum error resulting from these four factors. Figure 9 depicts a possible maximum error for CDS from 10,000 feet and 20,000 feet. The maximum ground and aircraft position errors were assumed to be 100 yards respectively. The parachute ballistic error includes the FTD and TF errors. The wind error is assumed to be a resultant velocity that causes drift until the load impacts.

5. SENSITIVITY ANALYSIS OF CONTRIBUTING FACTORS TO THE TRAJECTORY ERROR FOR HEAVY AIRDROP

a. When evaluating significant factors for heavy airdrop, the same factors that were considered for CDS will also be applicable here. However, the magnitude of error each factor contributes will change. The fact that the drop altitude is 1100 feet above the ground will considerably reduce the total time of fall. The position the load occupies in the aircraft becomes more significant for heavy airdrop, especially when conducting airdrop from long cargo compartments such as the C-141 and C-5A (Figure 10). Load exit times can vary by a factor of four, which will result in large errors if these exit times are not accounted for. Since two different types of parachutes are utilized (extraction and recovery parachutes) (Figure 11A), in heavy airdrop, new sources of error are introduced because of the irregular deployment and filling times for large clusters of parachutes (Figure 11B). Published technical reports provide good analytical

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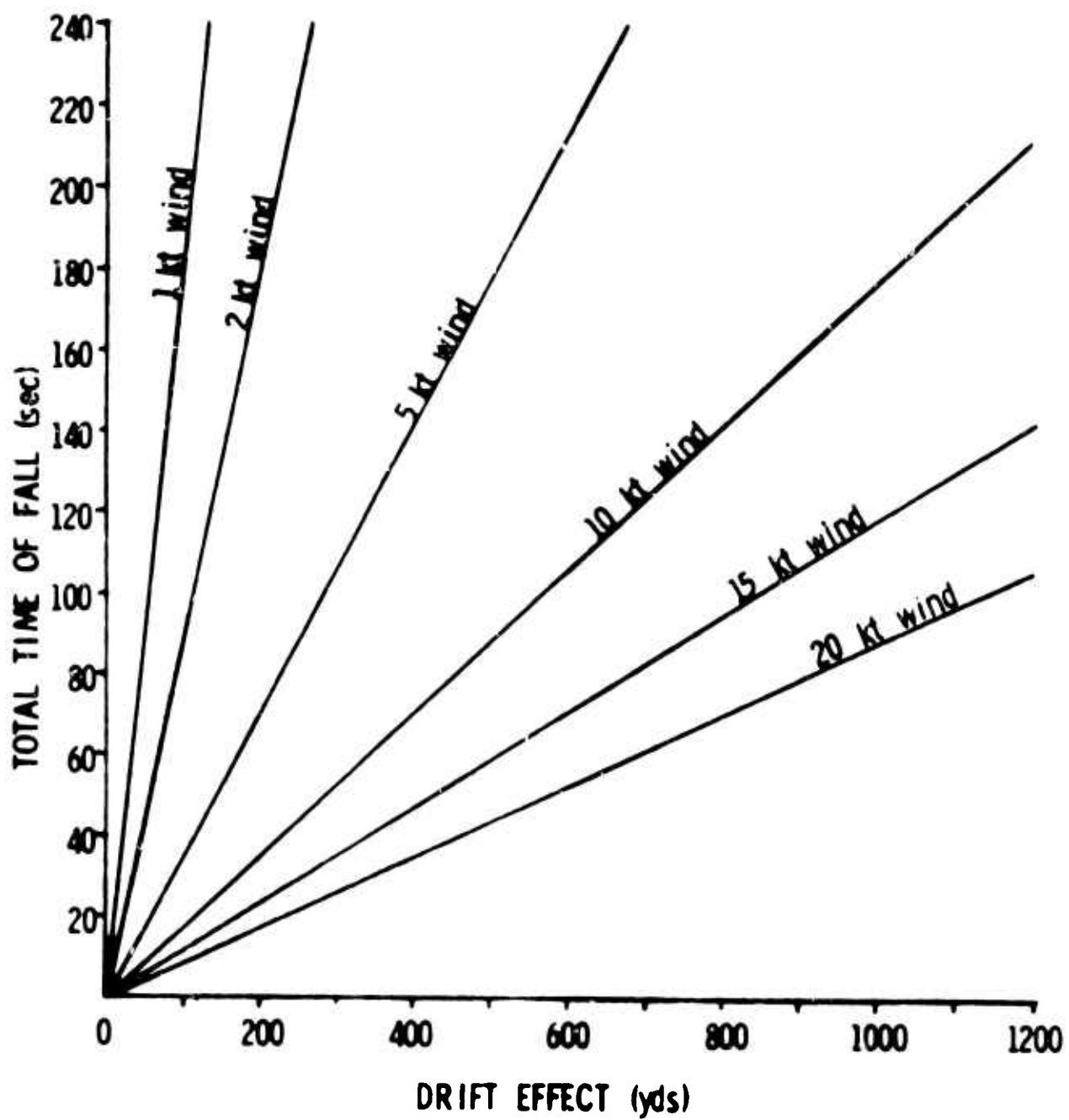
Figure 7 WIND DRIFT EFFECT vs TIME OF FALL
FOR CDS HIGH VELOCITY DROP
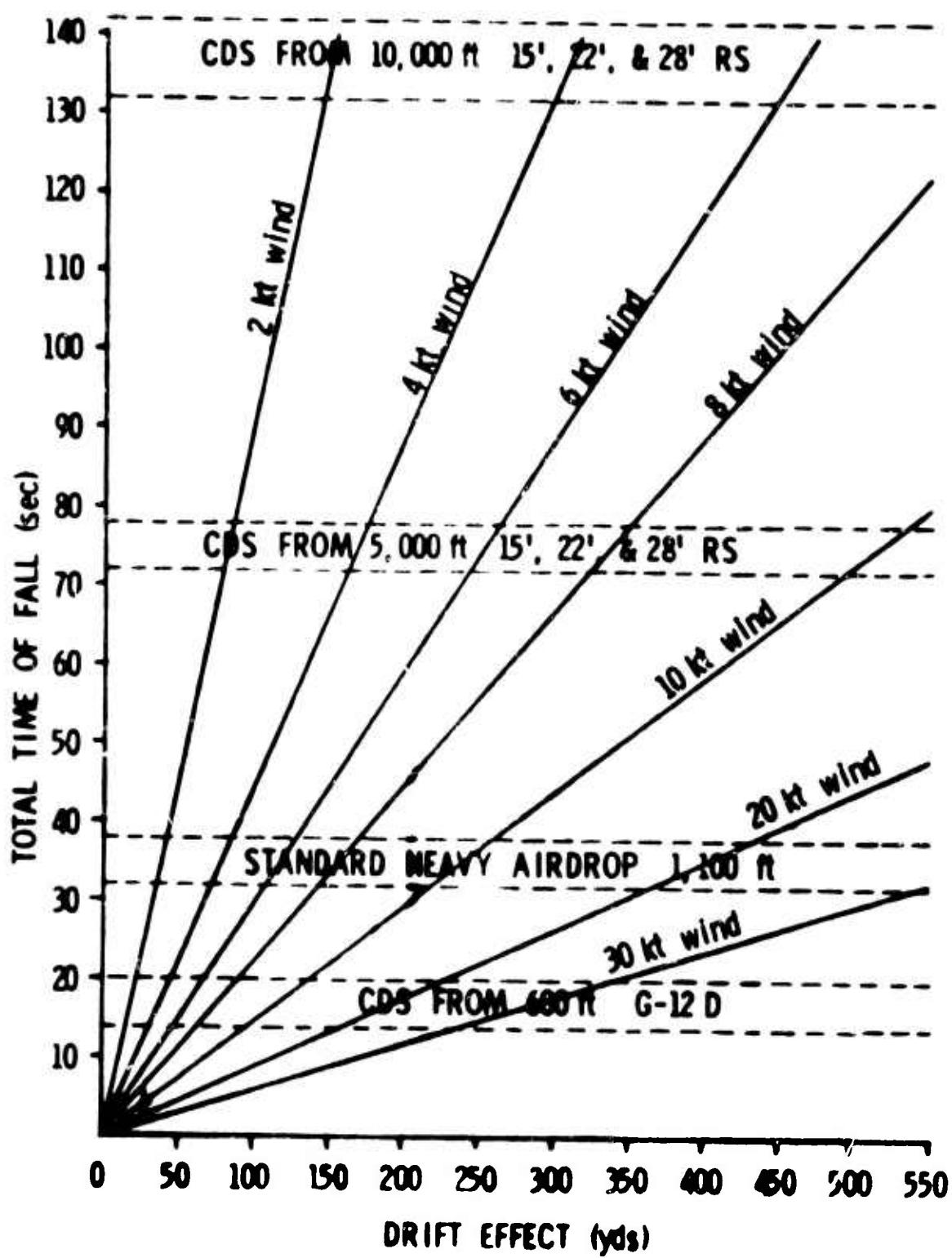
Figure 8 WIND DRIFT EFFECT & TOTAL TIME OF FALL

	CDS from 10,000 ft	CDS from 20,000 ft
GROUND & AIRCRAFT POSITION ERROR	200 yd	200 yd
PARACHUTE BALISTICS ERROR	200 yd	400 yd
WIND VELOCITY ERROR	300 yd	600 yd
MAXIMUM ESTIMATED ERROR	700 yd	1200 yd

IMPACT POINT
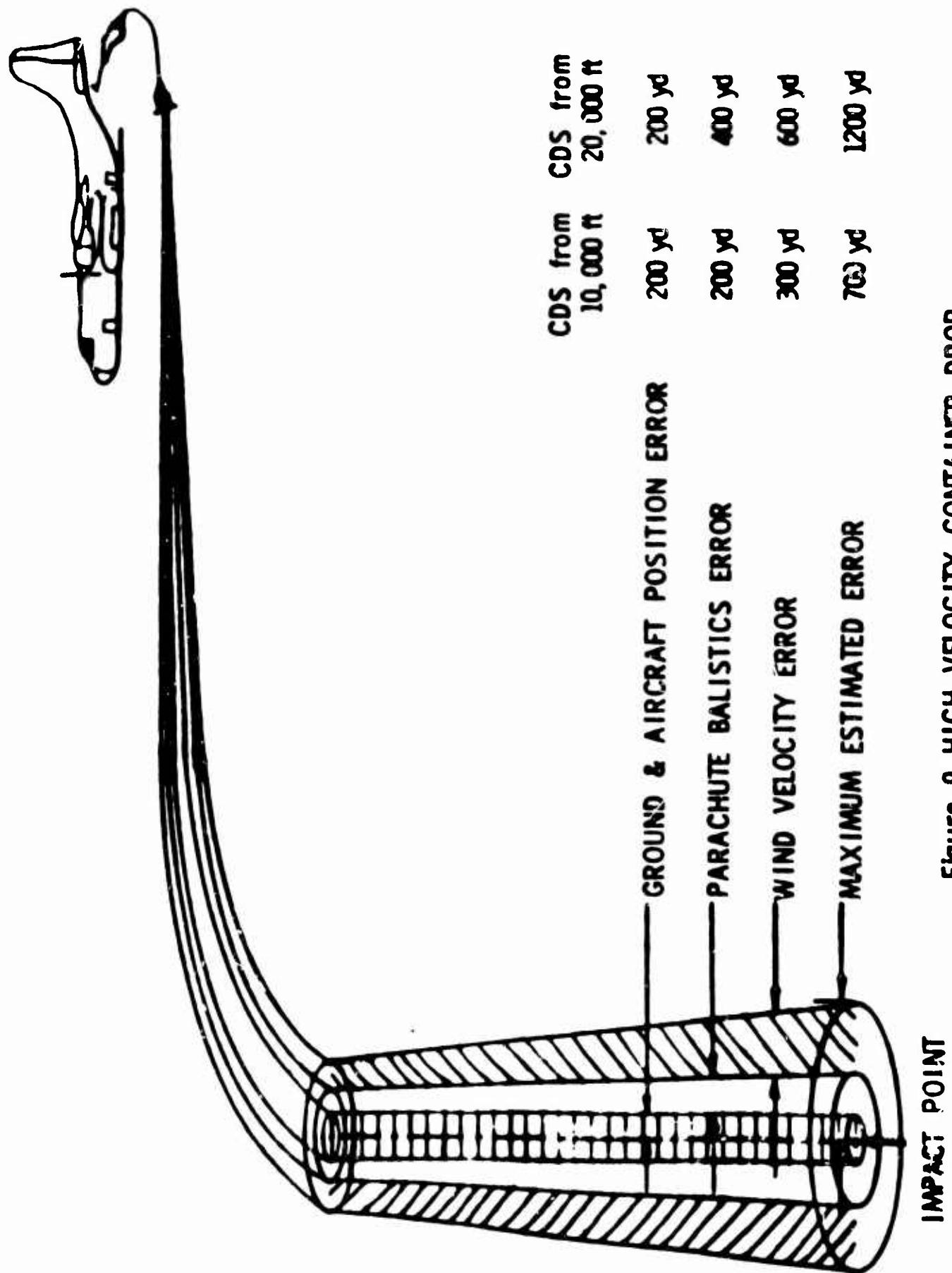
Figure 9 HIGH VELOCITY CONTAINER DROP

C-130

C-14i

C5A

60'

i70'

215'
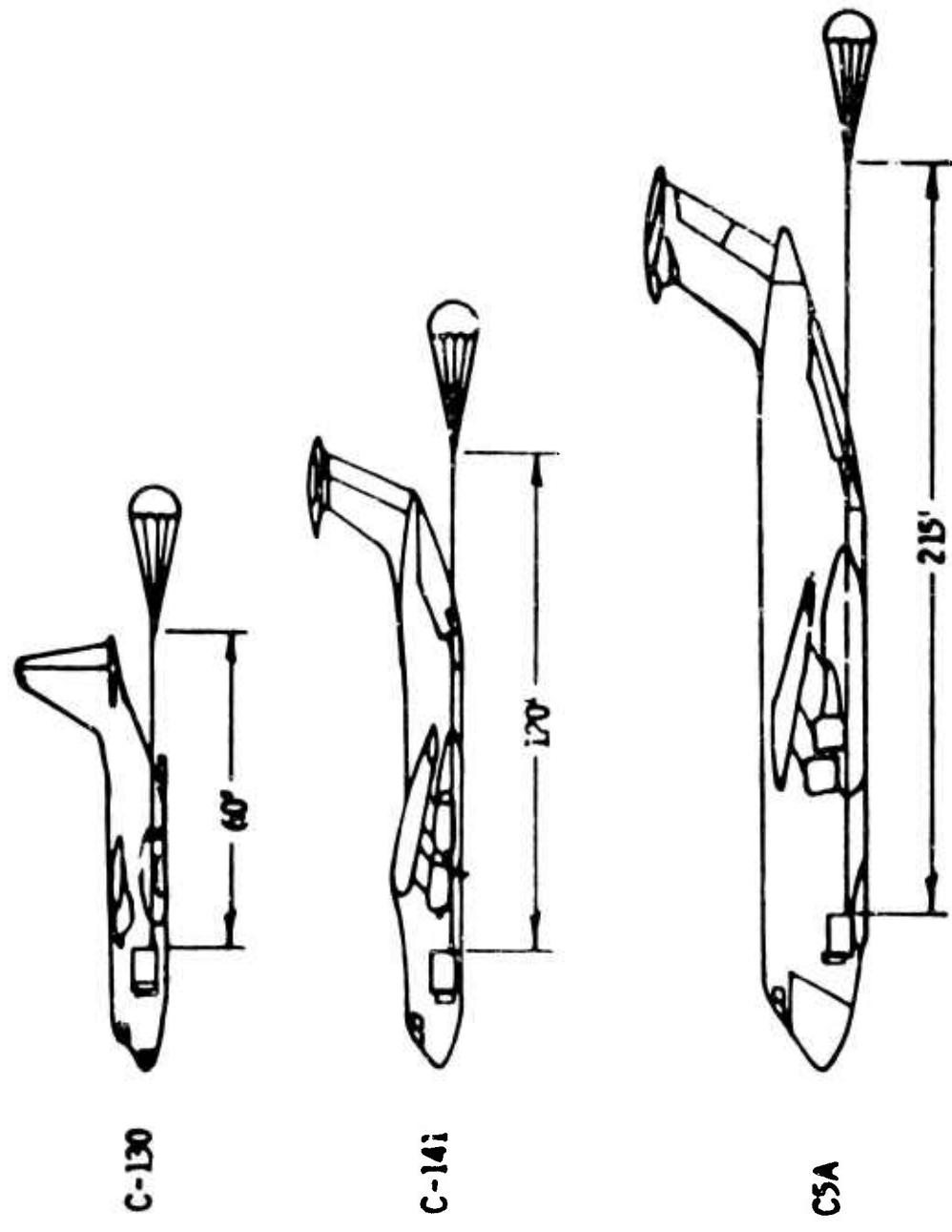
Figure 10 COMPARATIVE SIZES OF CARGO A/C

RAMP
OPEN

PENDULUM
RELEASE

FORCE
TRANSFER
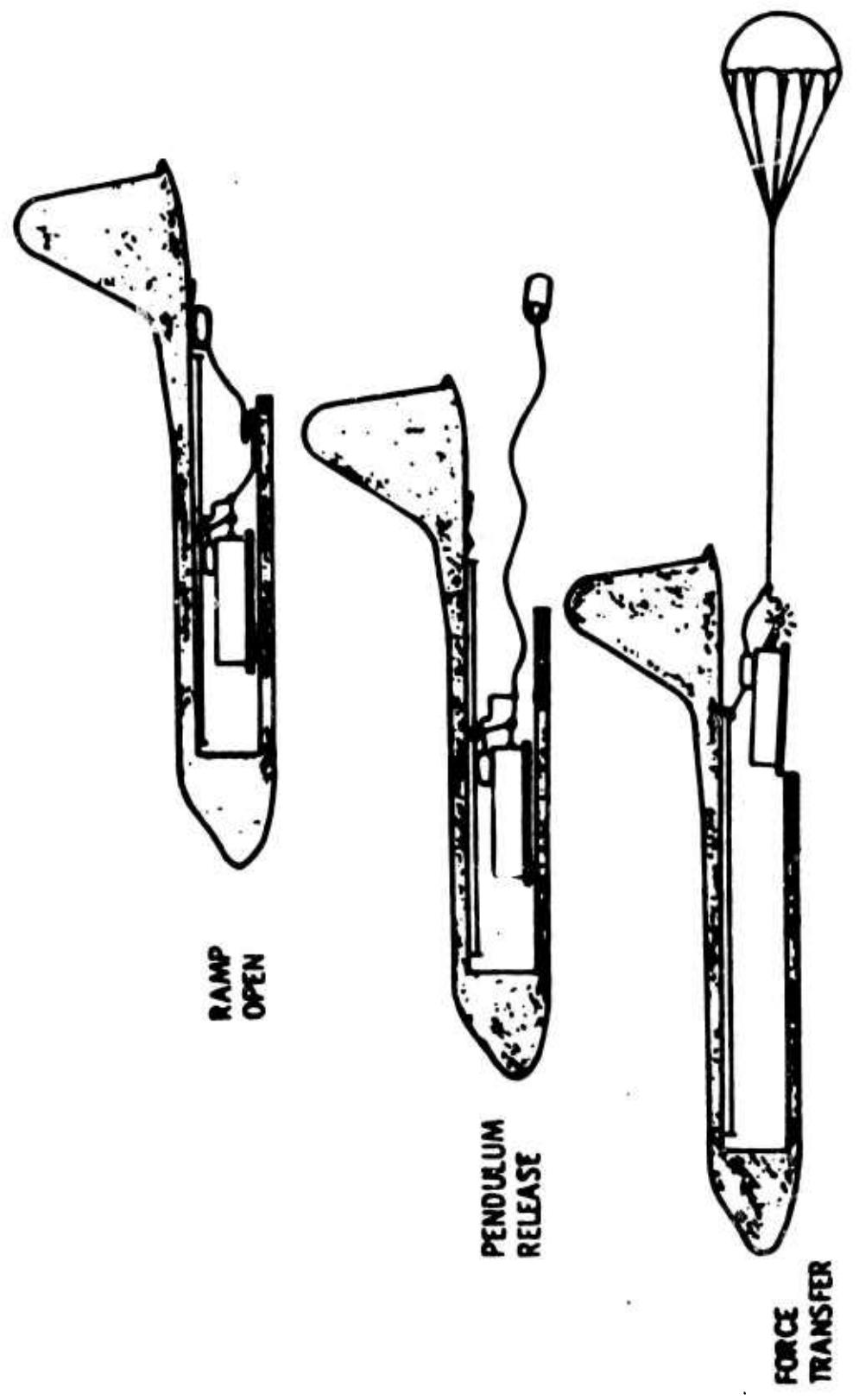
Figure 11A   EXTRACTION CYCLE

Figure 118 **CARGO RECOVERY CYCLE**

~ 1000 ft.
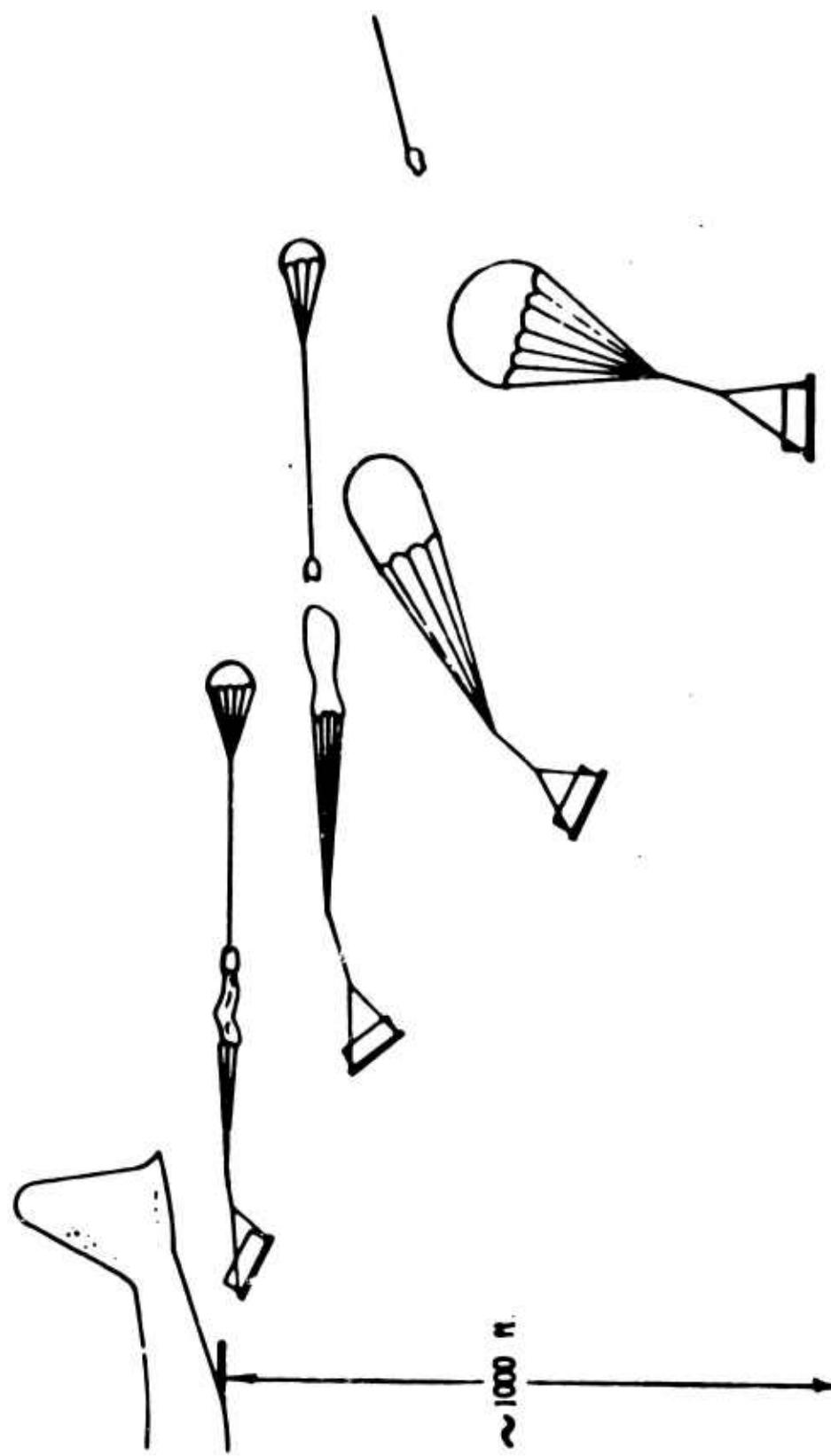
solutions to take into account the apparent mass theory, the differential movement of the load relative to the parachute and the respective trajectories of the load and parachute. However, when clustered recovery parachutes are used, most of the published techniques are inadequate to account for the irregular and unpredictable opening of the clustered configuration. Until analytical methods are developed and proven for clustered configurations, it will be necessary to rely upon empirical relations developed from test data. This study uses empirical relationships developed from the C-5A test and evaluation program.

(1) The estimated maximum error resulting from not considering both the density and weight variations is much lower for heavy airdrop than for CDS drops at high altitude. This is due to the fact that the density changes have little effect on the overall error in the 1100 foot increment. The CARP manual does take into account the different rates of descent for different weight loads for a given parachute configuration for heavy airdrop. Therefore, the density and weight factors contribute a small amount to the overall error.

(2) The forward travel time is a very significant contributing factor. The CARP procedure only gives two FTT values for the entire load spectrum when using G-11A recovery parachutes. Some of the basic parameters affecting the FTT are:

        (a)   Load position in aircraft.

        (b)   Load weight.

        (c)   Extraction parachutes.

        (d)   Recovery parachutes.

        (e)   Airspeed.

        (f)   Force transfer method.

        (g)   Altitude.

Due to these factors, each load under a given set of conditions will have a specific FTT that will vary appreciably from the values given in the manual. The variation of the FTT for all possible conditions can vary as much as 300% versus 11% variance given in the CARP manual. Both empirical and analytical relationships were utilized to determine the effects of the above parameters.

SECTION III

AIRDROP MODELS

1. CONTAINER DELIVERY SYSTEM MODEL

Container delivery system for both high velocity and low velocity drops usually involves an A-22 container loaded with 500 to 2200 pounds of equipment or supplies. These individual bundles are then loaded (up to 16 bundles for the C-131 aircraft) in two rows within the aircraft. An aft release gate provides final restraint just prior to drop initiation. Either a small extraction parachute is deployed that pulls cut knives through the release gate or the retrieval winch is used to pull the cut knives. After the release gate is severed, the CDS bundles roll rearward with respect to the aircraft due to the aircraft deck angle and the aircraft acceleration. The bundles then free fall until the recovery parachute deploys and decelerates the load to an equilibrium velocity rate. Under the influence of winds, the load will drift an amount equal to the product of the total time of impact times the integrated wind velocity. In developing the equations of motion and subsequent model, many assumptions have been made to allow for useful and workable model. The first assumption for the CDS is that the deck angle of the aircraft remains constant during the load exit. For small numbers of bundles this assumption is generally valid. However, as the total weight of the combined bundles approaches the maximum aircraft payload capability, the deck angle will be a function of time. One method to handle this problem is to assume some average deck angle during the ejection phase. This average deck angle can be obtained from test data. The CARP manual only allows for the computation of the first bundle out of the aircraft regardless of the number dropped. Even for large numbers of containers, the deck angle will change very little by the time the first bundle exists. It would appear to be very useful if one could compute a CARP for the first bundle out, the middle bundle out, and the last bundle out. The CARP for the drop would then be based upon the middle bundle and the CARP computation for the first and last bundles could be utilized to determine the drop zone (DZ) size requirements or to determine the maximum number of bundles that could be delivered into a given DZ. For the model developed below, two degrees of freedom are assumed to establish the position of the load relative to the ground and an overall constant drift effect is assumed. As shown in the sensitivity analysis, for a large total time of fall, the wind velocity is the most sensitive variable and one of the least predictable. Complex methods have been presented to forecast the changing wind velocities. To be practical, a method is required to compute an integrated wind effect, that is, a resultant wind that will cause the same drift as changing winds would cause. The model developed herein assumes that an integrated wind is available for the CARP. A total time of fall is required based upon actual conditions. The CARP manual method of determining TF by dividing the rate of descent into the vertical distance of the drop is not adequate since the load has a higher descent rate at altitude versus the rate of

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descent at impact. Figure 12 depicts such a model. The time the aircraft
arrives at the CARP corresponds with t_o. The time from t_o to t_1 represents
the initiation (green light) at the CARP until the load exits the aircraft.
Only the effect of gravity is assumed to cause the load to exit. Time t_1 to
t_2 represents the time the load free falls after exit until the recovery
parachute deploys. During this time, the drag area of the bundle plus
the force of gravity are acting on the bundle. Time t_2 to t_3 represents
the inflating time of the recovery parachute. The $C_d S_o$ of the parachute
is assumed to increase exponentially. Time t_3 to t_4 represents time of
full inflation with the opening shock force applied. Time t_4 to t_5
represents the time the load travels through the trajectory until it is
~ 85 degrees with respect to the flight path (assumed to be vertical
at this time). The forces acting on the load are the drag forces of the
parachute and bundle and the force of gravity. The drift effect on the
load is from t_o to t_f. An effective wind velocity of the drop is
assumed to be known. This model assumes a point mass system relative
to the load.

2. STANDARD HEAVY AIRDROP MODEL

Heavy airdrop generally implies that loads weighing 2500 to 35,000
pounds are rigged on airdrop platforms and are extracted from the air-
craft with extraction parachutes (Figure 13). One or more platforms can
be delivered on the same pass in a sequential fashion, where the extrac-
tion parachute for each load is attached to the load behind it inside the
aircraft. As each load is extracted, the extraction parachute for the
succeeding load is deployed with this sequence continuing until all loads
leave the aircraft. As each load exits the aircraft, a force transfer
is accomplished whereby the extraction force is release from the load
and the force of the extraction parachutes is then utilized to deploy
the main recovery parachutes. This force transfer is accomplished by
the use of cut knives or a mechanical force transfer. After the load
exits the aircraft, it free falls with an induced rotation caused by
gravity as it crests over the teeter rollers of the aircraft ramp. The
free fall and rotation continue until the main recovery parachutes are
fully deployed and commence to inflate. As the inflation force reaches
a significant force (1000 pounds), it either contributes to the load
rotation or counters the gravity induced rotation, depending on the time
at which the force is applied. The load rapidly decelerates as the
recovery parachutes inflate, and has generally reached an equilibrium
velocity by the time the load is descending vertically. After equilibrium
velocity is reached, the load then descends vertically unless there is an
effective wind. In developing the equations of motion, empirical data
have to be used for several events. When the cargo aircraft reaches
the CARP, the aerial delivery system is initiated and the extraction para-
chute is released from its receptacle in the rear of the cargo compart-
ment. The size of the extraction line, the size of the extraction para-
chute, and the airspeed of the aircraft all affect the time duration
required for the extraction parachute to deploy into the airstream and

DRAG EQ $-1/2 \, \rho \, C_b S_o \, V_o^2 = m\frac{dv}{dt}$

GRAVITY $\dot{\theta} = -\frac{g\cos\theta}{V}$ (57.3)

WIND EFFECT $\uparrow V$ - DRIFT EFFECT

$F = g\sin\alpha$

$[t_0 \, t_1]$ C_dS_o of bundle only   (exit)
$[t_1 \, t_2]$ C_dS_o of parachute increased exp   (freefall)
$[t_2 \, t_3]$ C_dS_o of parachute increased exp   (inflation)
$[t_3 \, t_4]$ 1.05 x drag force for opening shock   (shock)
$[t_4 \, t_5]$ C_dS_o of parachute remains constant (transition)
$[t_5 \, t_6]$ Drift effect knowing effective wind   (wind)
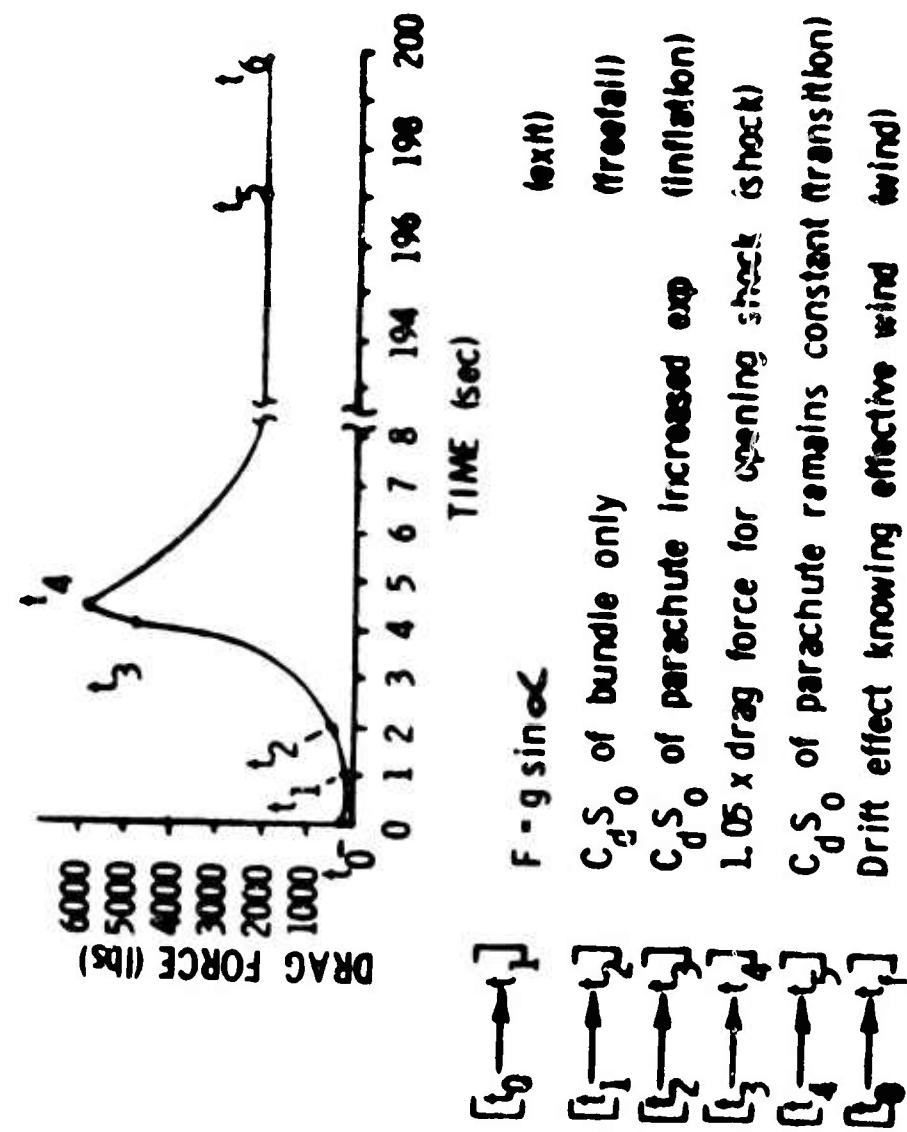
Figure 12 COMPUTER MODEL FOR THE CONTAINER DELIVERY SYSTEM (CDS)
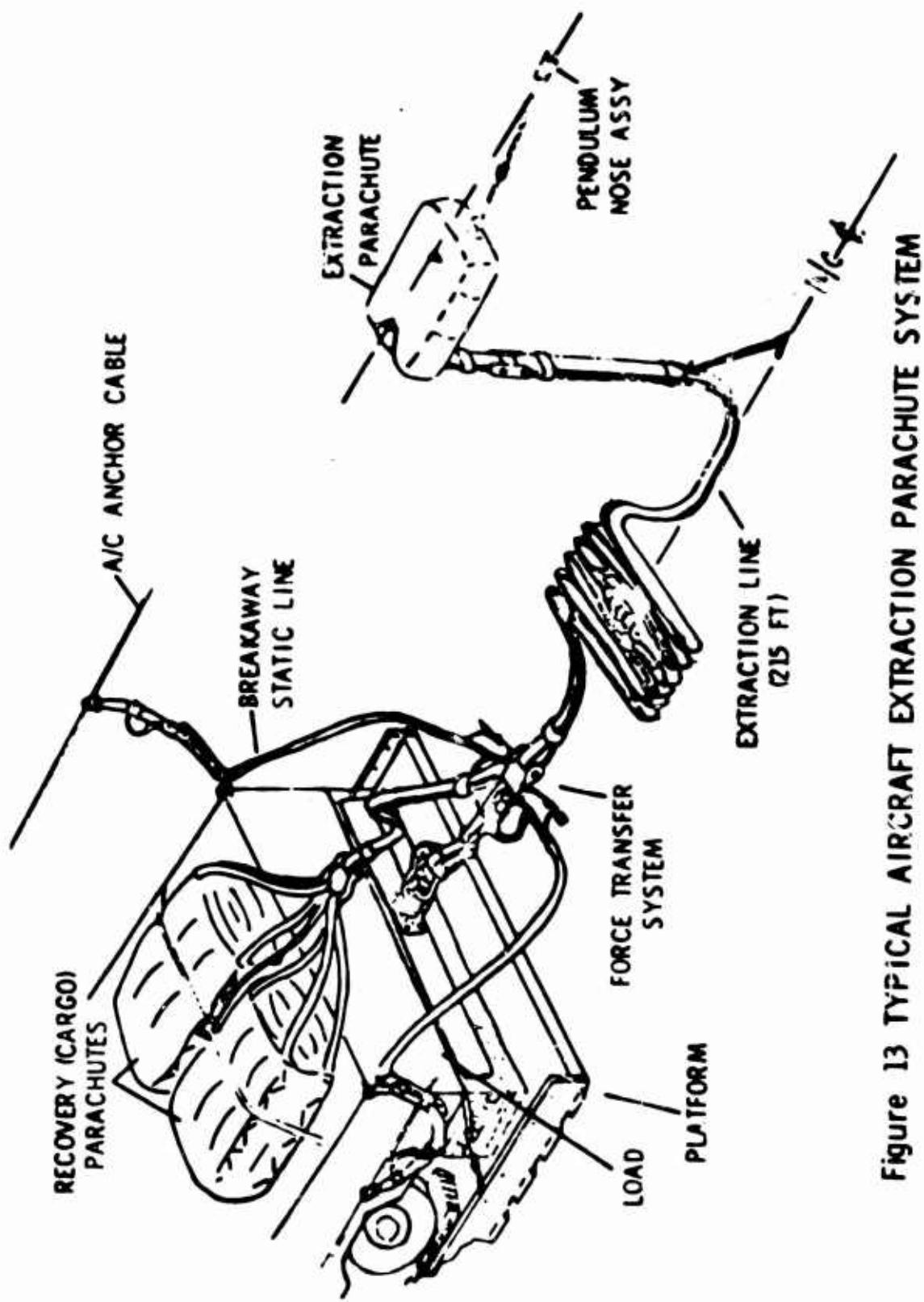
Figure 13 TYPICAL AIRCRAFT EXTRACTION PARACHUTE SYSTEM

develop sufficient force to unlock the aircraft pressure locks. The
pressure locks are usually set to restrain the load within the aircraft
with a force equal to one-half of the load weight. The actual extraction
of the load commences when the aircraft locks unlock and the load is free
within the aircraft. Figure 14 shows a generalized force time history of
a typical inflation of an extraction parachute. An approximation can be
made that will greatly simplify the analysis. Figure 15 shows an assumed
force time history based on an assumption that at lock release, the
extraction parachute is fully deployed and developing maximum force. As
shown in this figure, additional extraction energy is assumed in the
beginning; however, due to exponential force decay, the assumed force
curve will cross below the actual force curve. Based upon actual data
evaluation, the two hashed areas are approximately equal. Furthermore,
both areas are small compared to the total area under the curve from t_1
to t_2. With this assumption, the following equations can be developed:

w = load wt. (lbs)

g = 32.2 ft/sec

ρ = 2.24 x 10^{-3} slugs/ft^3

V_w = relative wind velocity (ft/sec)

V_p = A/C velocity (ft/sec)

V_e = exit velocity (ft/sec)

$$\frac{1}{2}\rho C_D S_O V_w^2 = \frac{w}{g} V \frac{dV}{dS}$$

$$C_1 S = 1 - \left[\ln \frac{V_p - V_e}{V_p}\right] + \frac{V_p}{V_p - V_e}$$

$$C_1 = \rho \frac{C_D S_O}{2m}$$

FROM THE ABOVE WE CAN DETERMINE THE EXIT VELOCITY AT LOAD EXIT.

TIME PREDICTION

also $F = m\frac{dV}{dt}$

$$C_2 = \frac{1}{C_1}$$

$$\frac{1}{2}\rho C_D S_O V_w^2 = \frac{w}{g} \frac{dV}{dt}$$

t_e = time for load to exit (sec)

$$t_e = -C_2\left[\frac{1}{V_e - V_p} + \frac{1}{V_p}\right]$$

WE CAN NOW FIND THE EXIT TIME FOR THE ABOVE CONDITIONS.

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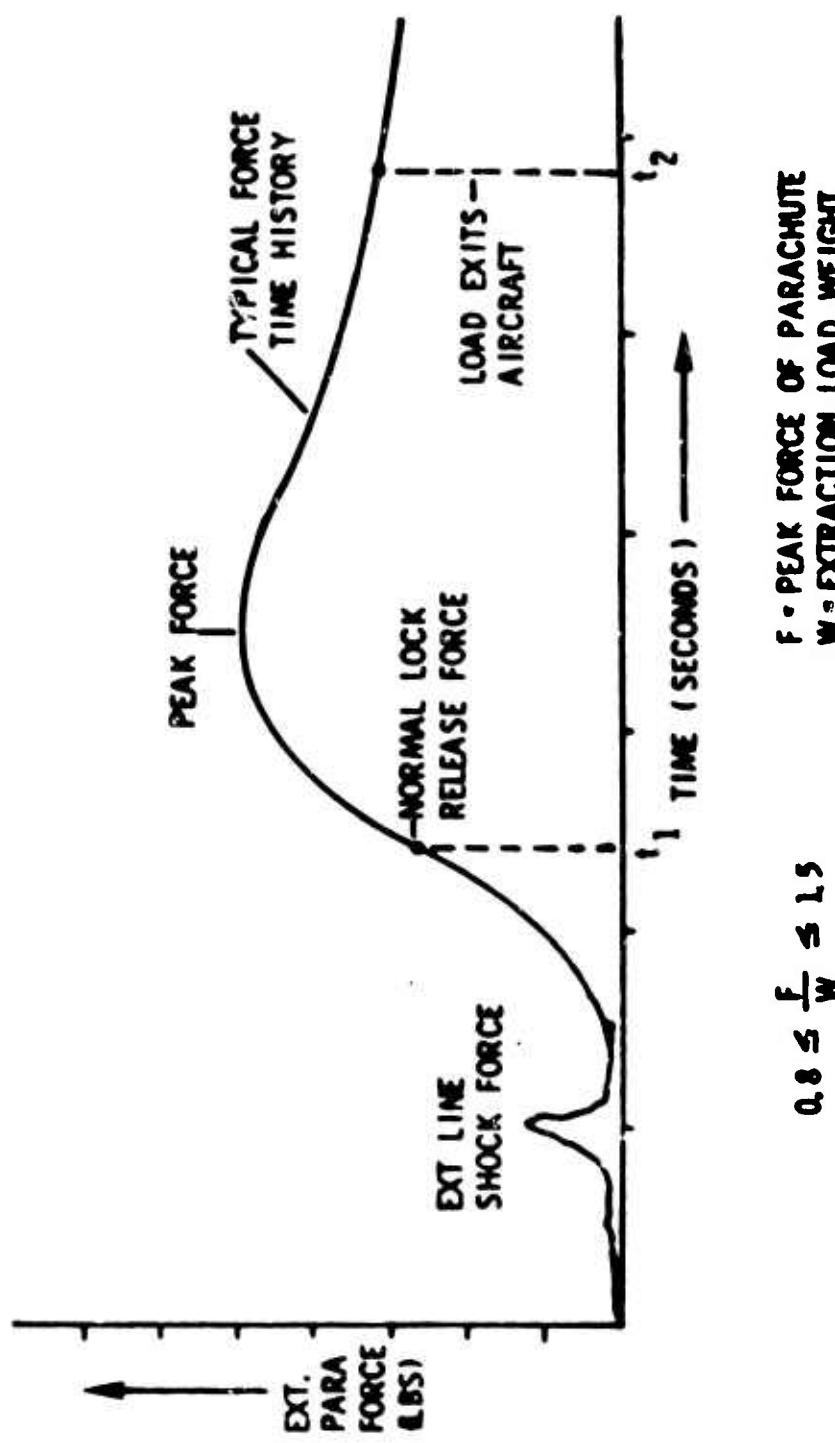
Figure 14 EXTRACTION RATIO
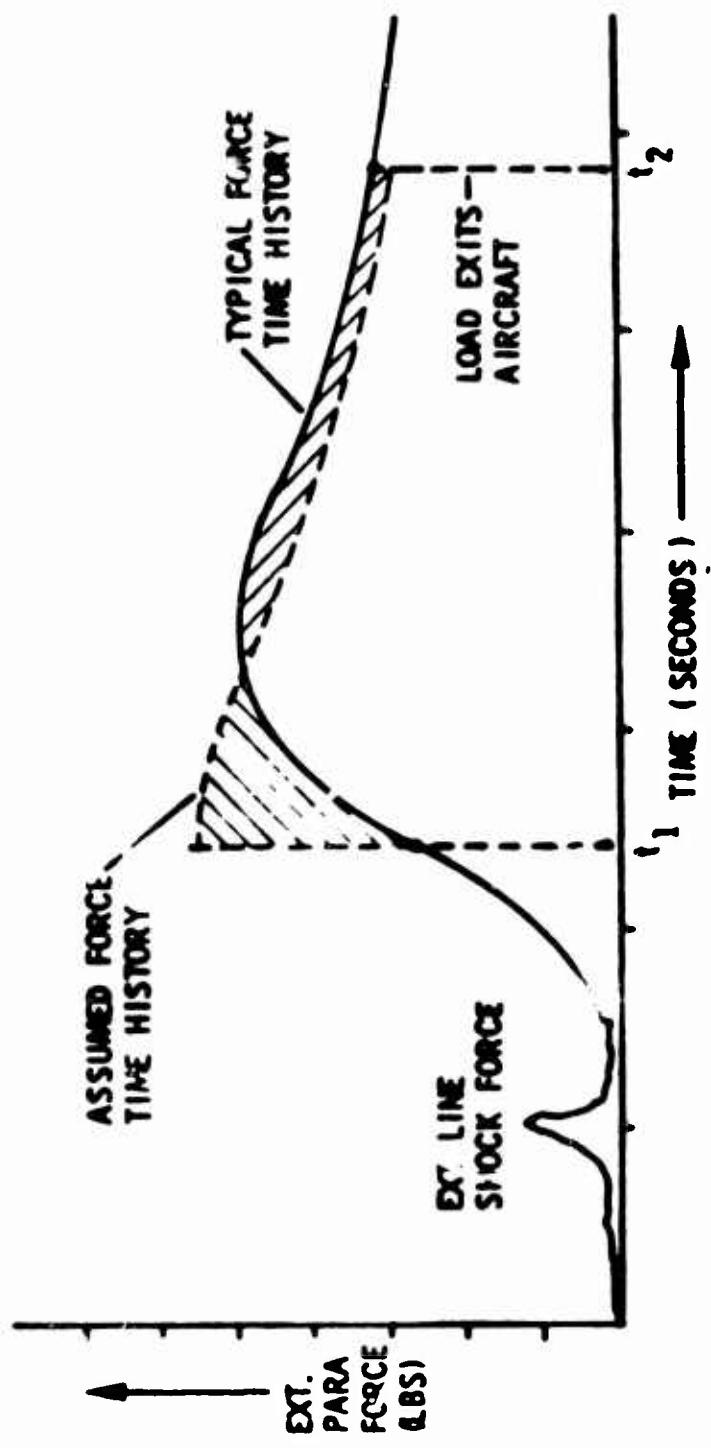
Figure 15 PREDICTED EXTRACTION RATIO

SECTION IV

CONCLUSIONS

a. The inability to accurately predict the wind velocity results in the largest contribution to the overall airdrop error.

b. The error resulting from the unknown winds can be reduced by decreasing the time of fall. The maximum feasible improvement would be predicated upon the amount of increased equilibrium velocity that could be achieved for a given system.

c. It is estimated that the smallest practical total time of fall from 20,000 feet will be $\sim$ 100 seconds for CDS.

d. For the container delivery system, the FTD or FTT does not contribute a significant amount of error when compared to other error sources. For standard heavy airdrop, the FTD error becomes more significant primarily because of the length of the aircraft floor.

e. The total time of fall (TTF) is computed with many parameters. The CARP manual does not take into consideration either load weight or density variations.

f. Operational airdrop systems do not provide an accuracy of 200 yards circular error average (CEA) when dropped from 1000 feet or higher above the ground. As the airdrop altitude goes up, so will the airdrop error.

g. Operational airdrop requirements for 100 yards CEA are neither realistic nor economically feasible for mass delivery or resupply from high altitude.

h. If an aerial delivery accuracy of 100 yards CEA is required, there are three possible methods:

    (1) Air land and offload (high vulnerability).

    (2) Steerable systems (high cost, low weight capability).

    (3) LAPES (high weight, low cost, but low altitude only).

i. The lack of specific and documented requirements in the airdrop area has resulted in proliferation of methods, techniques, and hardware that only solve very obscure requirements. Identifying a requirement around specific equipment generally results in expenditure of scarce resources without satisfying a basic performance requirement.

SECTION V

RECOMMENDATIONS

a. Recommend the operational commands (within DOD) identify and document their airdrop requirements in terms of performance.

b. An accuracy statement should be a part of the performance requirements.

c. An accurate method of predicting the wind velocity should be developed.

d. Accurate data should be obtained for all existing airdrop systems to determine the respective impact accuracy of each system.

e. The next update of the CARP manual should incorporate weight density corrections for high altitude drops.

f. The Army and Air Force should jointly develop a program that would identify current aerial delivery capability, determine the most feasible approach to improve and simplify existing capability. and prepare a joint development project for future development.