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# THE PERFORMANCE OF CARGO AIRDROP SYSTEMS USING G-12E PARACHUTES: STATISTICAL DETERMINATION OF MINIMUM ALTITUDE

by

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February 1995

Final Report

March 1993 - November 1994

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In order to reduce the exposure of aircraft to hostile fire, the U.S. Air Force is interested in dropping cargo from the lowest possible altitude above ground level. Using trajectory data from previous airdrop system testing, this report statistically determines the minimum altitude above ground level (AGL) from which airdrop systems (comprising clusters of two to three G-12E parachutes) may safely deliver cargoes up to 5000 pounds. The methods used to compute variables of interest, such as system tension and system orientation, are presented. To support this statistical analysis, intervals were defined based upon clearly discernible events. This led to a reexamination of so-called "functional phases," used by the airdrop community. Some phases were found unsuitable for statistical purposes. To resolve this problem, "process intervals" were defined based upon clearly discernible process states or events. Based upon the limited data available, it was found that G-12E airdrop systems can safely deliver cargoes of up to 5000 pounds when released from aircraft at an altitude of approximately 300 feet AGL.

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# Preface

The purpose of this report is to determine if cargo airdrop systems comprising G-12E parachutes can deliver cargoes of less than 5000 pounds from an altitude above ground level (AGL) of 300 feet.

The U.S. Air Force is especially interested in dropping cargo from the lowest possible altitude AGL in order to reduce the exposure of aircraft to hostile fire. One system which addresses this need is the Low Altitude Retro-Rocket System (LARRS), which is designed to deliver cargoes from 300 feet above ground level (AGL).

If the G-12E airdrop systems can deliver loads from 300 feet AGL then the high expense of the LARRS airdrop method for cargo weights below 5000 pounds can be avoided.

To determine if the existing G-12E airdrop systems can be delivered from 300 feet AGL (without damage) the trajectory data from previous tests conducted at Yuma Proving Grounds were statistically analyzed.

To statistically analyze the data it was found necessary to define process intervals based upon clearly discernible events. The definition of such intervals led to a re-examination of so-called "functional phases," used by the airdrop community. It was found that some such phases are unsuited for statistical purposes because they overlap. Instead, "process intervals," based upon clearly discernible events were defined. These intervals concern a particular process through which the airdrop system must pass in order to perform its function. The inflation process is one such interval, which is clearly described in Theo Knacke's 1992 edition of the "Parachute Recovery Systems, Design Manual."

The limitations of this statistical determination of minimum altitude and other measures of performance, such as precision and accuracy, are discussed. Based upon the limited data available, it was found that the G-12E airdrop systems can potentially deliver cargoes of up to 5000 pounds from an aircraft altitude 300 feet AGL.

This work commenced in March 1993 and was completed in November 1994.

**PERFORMANCE OF CARGO AIRDROP SYSTEMS USING G-12E PARACHUTES:**

**STATISTICAL DETERMINATION OF MINIMUM ALTITUDE**

# INTRODUCTION

## Background

The U.S. Air Force wants to airdrop cargo at low altitudes in order to reduce aircraft exposure to hostile fire. The lowest altitude above ground level (AGL) at which an aircraft can deliver cargo without impact damage is the minimum altitude. Lower altitudes AGL will likely result in destruction of the cargo.

One system which appears capable of satisfying this need is the Low-Altitude Retro-Rocket System (LARRS) which was designed to deliver cargo from aircraft flying at 300 feet AGL.

## Purpose

However, because the LARRS is relatively expensive, it may be more cost effective to use the G-12E family of airdrop systems for cargoes of less than 5000 pounds. This possibility is based on the assumption that clusters of two or three G-12E parachutes can deliver their cargoes from approximately 300 feet AGL.

The purpose of this report is to determine if conventional G-12E parachutes (pulled-down vents using centerlines) can deliver cargo without impact damage from 300 feet AGL.

## Technical Approach

Rather than performing experiments on the G-12E family of airdrop systems, I used trajectory data acquired from previous testing to analyze performance. Environmental conditions prevailing at the time that data were acquired are unknown; i.e., these data were not obtained from a controlled experiment. However, statistical analysis can still be used to determine the average and the variation in airdrop system performance over certain — yet-to be-defined — intervals.

This statistical approach to determining the performance of airdrop systems is supported by defining certain intervals using clearly discernible events which become apparent when analyzing trajectory data* When this approach is rigorously applied it leads to a re-examination of the functional phases presently used by the airdrop community to describe parachute performance.

The analysis presented here was greatly enhanced by studying computer images captured from video tapes of the subject tests. In particular, system dimensions measured during the inflation process were compared with trajectory data to obtain a better understanding of parachute system performance.

* Clearly discernible events are noted when a variable of interest peaks or displays a maximum or minimum slope, or when it is plotted versus another variable, such as time.

Some problems were encountered in determining the time interval between the greenlight (beginning of extraction) and the load transfer event because time codes displayed on the video images were often blurred.* This particular time interval is of some concern because the cargo could land before the actuation delay timer of the parachute release has timed out. Should this be the case, the operational minimum altitude may need to be increased.

## Scope

This report describes the methods used to analyze the performance of G-12E airdrop systems using existing trajectory data. The objective is to develop a rational method whereby the minimum altitude loss may be determined, i.e., to determine if the cargo reaches its first minimum speed with an altitude loss of approximately 300 feet or less. Should this be the case, then these systems should be considered a viable alternative to the LARRS for the lower weight ranges. This would lead to substantial cost savings for development, manufacture and maintenance of future airdrop systems for cargo weights of less than 5000 pounds.

The methodology used in this report will support other studies where the performance of airdrop systems is to be determined in a rational manner.

## Related Work

Similar analyses of trajectories were conducted by Edward Giebutowski[1] and later by Steven Kunz.[2] This report expands the data base of airdrop system performance characteristics by including airdrop systems that comprise clusters of two to three G-12E parachutes.

*The only drops where this information could be obtained from video recordings were #0-052, where the time from extraction to load transfer was found to be 3.957 seconds, and #0-056, where the time was found to be 4.0845 seconds.

# DEFINITIONS

In the 1991 report by S. Kunz,[2] the cargo speed was plotted versus time to show that the occurrence of the first minimum cargo speed is a clearly discernible event. This new investigation extends previous findings by refining the statistical method used to assess parachute performance. By using clearly discernible events to mark the beginning and end of certain intervals of interest, the interval level of measurement[3] is achieved so that the full power of standard parametric statistical methods may be applied to compare similar systems or processes. In fact, because the intervals obtained from trajectory data are obtained from physical measurements, the researcher may be justified in applying even more powerful statistical tests, such as the coefficient of variation.

It is quite fortunate that several clearly discernible events, obtained through the analysis of trajectory data, can support such an approach. Definitions and Figure 1, depicting the airdrop method which were presented in the above referenced report by Kunz are repeated here for convenience.

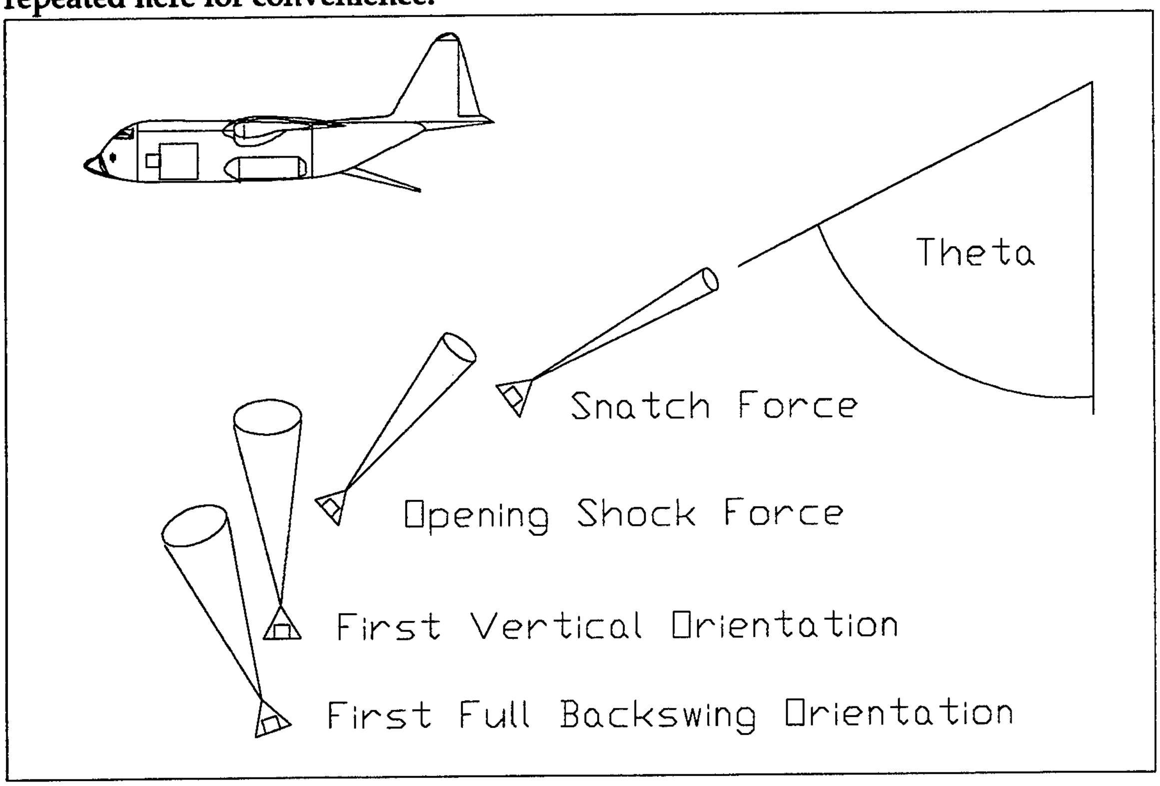


**Figure 1:** G-12E Airdrop Method

## Previous Definitions

**System Vertical Angle** is the angle between the axis of symmetry of the parachute system and the line radiating from the center of the earth. The system vertical angle for a single canopy is shown as theta in Figure 1. As the cargo is being extracted from the rear of the aircraft, the system axis is nearly horizontal, i.e., the system axis is aligned with the longitudinal axis of the aircraft. The system vertical angle, theta, therefore starts with a value of –90 degrees and approaches zero as the system orientation approaches vertical.

**Backswing Angle** is the value of the system vertical angle just after the system has passed through its first vertical orientation, when the system vertical angle, theta, first becomes positive.

**First Full Backswing Angle** is a clearly discernible data point when the vertical angle is plotted versus altitude loss or time. It occurs sometime after the system passes through its first vertical orientation, when the rate of change of theta becomes zero, i.e., when the system has momentarily ceased rotating.

**First Minimum Cargo Speed** is a clearly discernible data point when the cargo speed (magnitude of the velocity) is plotted versus altitude loss or elapsed time. This is the point where the cargo speed reaches its first minimum with respect to earth. For the G-12E airdrop systems studied in this report, that point occurs at about the same time that the first full backswing occurs.

**Altitude Loss** is the distance between the altitude of the cargo at the time of extraction (greenlight), and the altitude of the cargo at a particular later time of interest.

**Minimum Altitude** is the altitude loss at the time that the cargo reaches its first minimum speed.*

## Discussion of Functional Phases

The performance of airdrop systems begins with the extraction of the cargo (and recovery parachutes) from the rear of the aircraft and ends when the cargo impacts the earth.

In order to simplify the analysis of airdrop system performance, Irvin Industries[4] first proposed that parachute performance be divided into the functional phases: deployment, inflation, deceleration, descent, and termination. Unfortunately these definitions are not well suited to support statistical analysis of parachute performance because they overlap, e.g., the cargo is undergoing deceleration during both the deployment and the inflation phases so defined.

John Watkins uses the term "key points" to define phases in the trajectory of a personnel parachute.[5] These "key points," however, are to some extent determined visually, e.g., the "first vertical" orientation, or the "fully inflated" canopy.

Another approach, described on page 5-67, of Theo Knacke's 1992 edition of the "Parachute Recovery Systems Design" manual[6] subdivides parachute inflation into

*~~Minimum Altitude was previously defined as the vertical distance between the altitude of the cargo at the time it is~~ extracted from the aircraft and the altitude at the time the system reaches "equilibrium." The use of the word "equilibrium," in this regard led to some confusion so this new definition is proposed.

intervals called "opening phases." These opening phases, are nonoverlapping intervals, which begin and end with the occurrence of certain events. He defines the canopy filling time as the interval from line stretch to the first full open canopy.

Theo Knacke rationally defines canopy filling time by plotting drag-area-versus-time curves on page 5-45 of his manual without recourse to visual information. These curves are obtained by first dividing the measured instantaneous force by the instantaneous dynamic pressure and plotting this ratio vs time.

Using trajectory data I computed a similar ratio—the specific tension vs the square of the cargo speed. This ratio does indeed display a relative maximum just before the cargo reaches its first minimum speed. Thereafter, other peaks were noted, which indicate that this ratio is quite sensitive to local updrafts or thermals. A comparison of this plot with video images indicates that the flat circular canopy of a typical airdrop system fully inflates shortly before the occurrence of the first minimum cargo speed.

It is only possible to identify intervals of interest from trajectory data alone when clearly discernible events or data points exist. Whether these intervals are called "functional phases," or "process intervals" is immaterial. The phrase "process interval" and the word "phase" are interchangeable.

By emphasizing the concept of "process interval" instead of the "functional phase" our attention is shifted away from the purpose of the phase to the set of actions affecting the process. Because Theo Knacke already uses clearly discernible points to define the "opening phase" we may also view it as a "process interval." *

The statistical method used to determine the overall performance of parachutes treats time intervals in the same manner as other process variables, namely statistically. Clearly, identical parachutes do not always open in the same time. Such a statistical approach is similar to, but not as severe as, the mathematical definition of shock time histories by means of "ensemble statistics" described by Kelly and Richmond[7] because the method recognizes that the time duration for each process interval also varies from trial to trial. All process variables including time itself are to be treated in the same statistical manner.

## Supporting Definitions

Extraction phase starts at greenlight when the cargo is extracted from the rear of the aircraft by means of extraction parachute(s). During extraction, the line connecting the center of mass of the cargo to the center of the extracting parachute is approximately horizontal, i.e., the system vertical angle, theta, is approximately –90 degrees.

* By defining parachute performance as a process, we may exploit the existing definitions and methods already apparent in the disciplines of "quality control" and "statistical process control," i.e., we may improve the performance of airdrop systems through the application of such methods.

It is to be noted that process intervals may be further subdivided by using sensors to detect events that cannot otherwise be discerned from trajectory data or observed from video images. For example, the process interval called parachute deployment, which begins with load transfer and ends when the main canopies have been fully extended, can be subdivided by using a sensor to detect the very instant that the canopy bags are pulled off the platform. In this way we may assess the performance of airdrop system components such as load transfer devices, or reefing line cutters. The time-base of the motion detector must, of course, be synchronized with the time-base used for trajectory data if we are to know the altitude of the system when such events occur.

**Main Parachute Deployment** phase starts when load transfer begins, i.e., when the extraction parachute is disconnected from the cargo platform. This phase begins when the main recovery canopies are pulled out of their bags and ends when the peak snatch force occurs — indicating that the canopies have been fully extended.*

**Parachute Opening** phase starts when the peak snatch force occurs and ends when the peak opening shock force occurs.** With the occurrence of the peak opening shock force, the canopy is clearly open, but not yet fully inflated or filled.

**Stabilization** phase begins with the occurrence of the peak opening shock force and continues as the canopies continue filling and the system passes through its first vertical orientation. It ends when the cargo reaches its first minimum speed — at about the same time that the system reaches its first full backswing orientation.***

This new definition of stabilization is based upon an analysis of trajectory data and examination of video images of the system just after the occurrence of the peak opening shock force. This definition of stabilization is not in agreement with the one in the Computed Air Release Systems Procedures Manual.[8]

**Final Descent** begins when the cargo reaches its first minimum speed. Thereafter it descends at nearly constant speed while displaying pitching oscillations similar to that of a pendulum. Analysis of these oscillations shows that they decrease slowly over a number of cycles.****

* Other methods may be used to deploy the recovery canopies, such as the canopy-first, lines-first, or the sleeve deployment method. Using simple sensors, such as load cells, the "peak snatch force," can be detected, indicating that the canopies have been fully extended.

** This would be a subinterval of what Theo Knacke calls **canopy filling time**, which begins with line stretch (peak snatch force) and ends when the canopy is fully inflated or filled. He describes the more complex opening of reefed parachutes by simply dividing the process into two subprocesses or phases. The first phase he calls a reefed filling time, and the second phase he calls an unreefed filling time, which he denotes by $T_{f1}$ and $T_{f2}$, respectively. I note that the reefed opening phase clearly ends with the occurrence of a peak opening shock force when a "reefed stabilization" phase begins. It is terminated by cutting the reefing line, beginning what Knacke calls the "disreefed opening" phase.

*** Watkins has already noted that inflation is sometimes interrupted by wake recontact called "post-inflation collapse," causing the system to fall a greater distance before reaching its first vertical orientation, and also that some parachutes "did not fully inflate until after they had reached first vertical" orientation.

**** Analysis of trajectory data indicates that each family of airdrop systems displays its own unique pitching oscillation frequency and damping coefficient. The smaller clusters (one to three canopies) display higher frequencies and little damping, whereas the larger clusters (four or more canopies) display lower frequencies and significant damping. When pitching oscillations abruptly increase in strength it is believed that the energy source driving this process is the result of changing winds or wind shear.

## Discussion of Equilibrium

Previously, equilibrium was defined as the state of the system (parachute and cargo) as the cargo nears terminal velocity and after the system reaches a vertical orientation.[9] Here the word "equilibrium" has been reserved for the classical definition of dynamic stability.*

The discipline of dynamical systems analysis defines "equilibrium" as a point in the phase-plane diagram representing the state of a dynamic system. Briefly, when a stable system is displaced slightly from its equilibrium point, the system will return to equilibrium. In the case of an unstable system the equilibrium point acts as a repeller, i.e., the trajectory will normally depart from such a point.

*It was found that the stability of a system can be most easily understood by plotting the time differential of a system variable versus the variable itself to observe its phase-plane behavior. This approach, used to study the behavior of the system vertical angle, supported an examination of the effects of winds upon system orientation. It was found that changing winds cause the system to suddenly pitch from its vertical orientation, and that such oscillations soon die out. This fact suggests that the simple parachute system is fundamentally stable with regard to pitching oscillations — after the occurrence of the first minimum cargo speed. Using video to study the early inflation process, when the system orientation is far from vertical, the canopy can often be seen to partially collapse, or to suffer what is called "wake recontact," whereas after stabilization such wake recontact is rarely observed.

# METHOD OF ANALYSIS

## Description of Trajectory Data

Trajectory data files of G-12E airdrop tests, obtained from Yuma Proving Grounds, support the analysis of the behavior of these G-12E systems, and the statistical determination of minimum altitude loss.

The data were obtained by tracking the payload using several earth-fixed optical cameras. Personnel at Yuma Proving Grounds used triangulation to compute the position of the center of mass of the suspended load as a function of time in earth-fixed (x-y-z) coordinates, where the z-axis is in alignment with the gravitational vector of the earth, and the x-axis and the y-axis, represent the west-to-east and the south-to-north directions.

Each data file (ASCII format) from Yuma Proving Grounds displays the position, speed, and acceleration of the cargo along three earth-fixed axes as a function of time; however, only the position was actually measured, the speeds and accelerations having been computed from position data.

Yuma Proving Grounds uses polynomial regression to smooth position data prior to aligning the earth-fixed x-axis with the line of flight of the aircraft at greenlight, i.e., at the moment when extraction of the cargo begins.

## Computation of Process Variables

From trajectory data certain process variables may be computed to analyze the physical behavior of parachute systems. One variable of particular interest is the computation of the tension, $\tau$, between the cargo and the parachute system. This tensile force, a vector, can be computed using equations based upon Newton's laws, when the weight of the cargo (including platform) is known.

### The Tension Vector

The tension vector represents the tensile force connecting the cargo to the parachute system through the confluence point. The component of the tension that is acting in the x/z-plane can be computed by ignoring the acceleration of the cargo along the y-axis. Computing the tension component along the x-axis (horizontal axis along which gravity does not act), we have:

$$\tau^*\mathrm{Sin}(\Theta) = -M_s{}^*d^2x_s/dt^2.$$

The computation of the component of the tension that acts along the z-axis is computed by adding the specific force due to gravity to the computed acceleration of the cargo along the z-axis:

$$\tau^*\mathrm{Cos}(\Theta) = M_s{}^*(d^2z_s/dt^2 + g_s).$$

The component of the tension acting in the x/z-plane is then simply the magnitude of the vector composed of these two components.*

$$\tau = -M_s*((d^2x_s/dt^2)^2+(g_e+d^2z_s/dt^2)^2)^{1/2}. \quad (1)$$

where:

$\tau$ = estimated tension between cargo and canopy
$M_s$ = mass of the suspended load
$x_s$ = position of the cargo along x-axis
$z_s$ = position of the cargo along z-axis
$g_e$ = gravitational constant on earth

## System Orientation

The best estimate of the system orientation is the angle of the tension vector with respect to the gravitational attraction vector (local vertical) in the x/z-plane. Called $Theta_x$ ($\Theta$), it is computed as:

$$\Theta_x = \arctan(-(d^2x_s/dt^2)/(g_e+d^2z_s/dt^2)). \quad (2)$$

The other system orientation angle, $\Theta_y$, is computed in a similar fashion.

* ~~This estimate of the tension is justified after the occurrence of opening shock, when the cargo is so much smaller than the~~ canopy, i.e., when the tension produced by the canopy system is much greater than the drag force acting upon the cargo. By ignoring cargo drag we can assume that the net force acting upon the cargo is simply the vector sum of the tensile force acting upon the cargo and the canopy and that force due to gravity.

## Physical Insights

### Specific Tension

When the previously defined tension vector is divided by the scalar value of the suspended mass, the resultant vector is called the specific tension, specified in units of feet*second$^{-2}$. By studying the specific tension we have reduced the study of parachute behavior to the study of its kinematics. Note that we may at any time multiply the specific tension by the suspended mass to obtain the actual tensile force. This supports the comparison of airdrop systems with different loadings (pounds per square foot of canopy), but here we choose to simplify the analysis within each similar airdrop system. For example, the peak specific tension can be used to divide the airdrop process interval in two by noting that this peak is a clearly discernible event when the specific tension is plotted versus time, as shown in Figure 2.

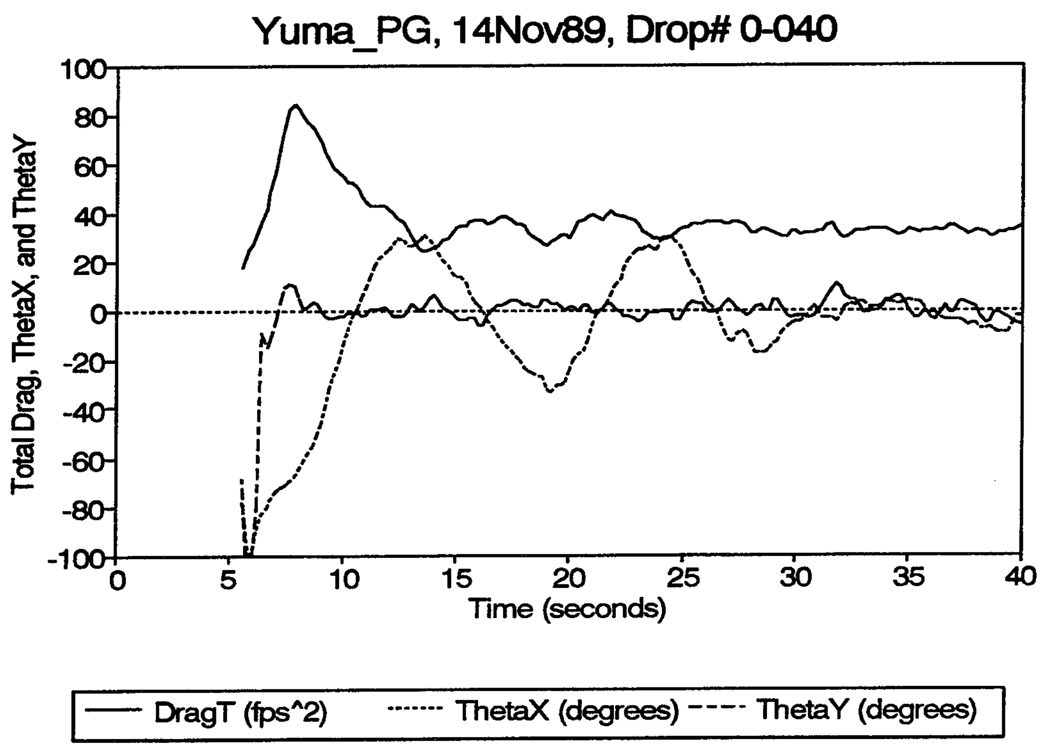


**Figure 2:** Specific Tension versus Time

### System Vertical Angle

The method of determining system orientation used in the previously referenced report (see page two) concerning parachute pitching oscillations by Giebutowski was based upon a visual determination of the location of both the cargo and the center of the canopy from films. The line connecting these two points was used to describe the system vertical orientation. This approach was subject to error not only due to normal measurement errors but also because the location of the so-called "center" of a canopy or canopies is not at all obvious when visually determined.

The previously described method of computing the system orientation physically corresponds to the orientation of the tension vector passing through the confluence point. In general one should expect the tension vector to point to the center of pressure of the canopy. The direction of this tension vector can momentarily differ with that of the the axis of symmetry defined by Cockrell on page 4, of his 1987 publication[10] to the extent that the canopy is distorted through asymmetric loading.

Figure 3 is an example of the application of this computed estimate of system orientation. It compares the computed system vertical angle with the horizontal speed of the cargo along the x-axis. It compares drift (due to the effect of local windspeeds) with system pitch (due to the effect of local wind shear). The horizontal displacement of the equilibrium point from zero is physically interpreted as the effect of horizontal winds, i.e., the cargo is drifting with respect to earth. The vertical displacement of the equilibrium point from zero is interpreted as the effect of wind shear upon the system orientation.

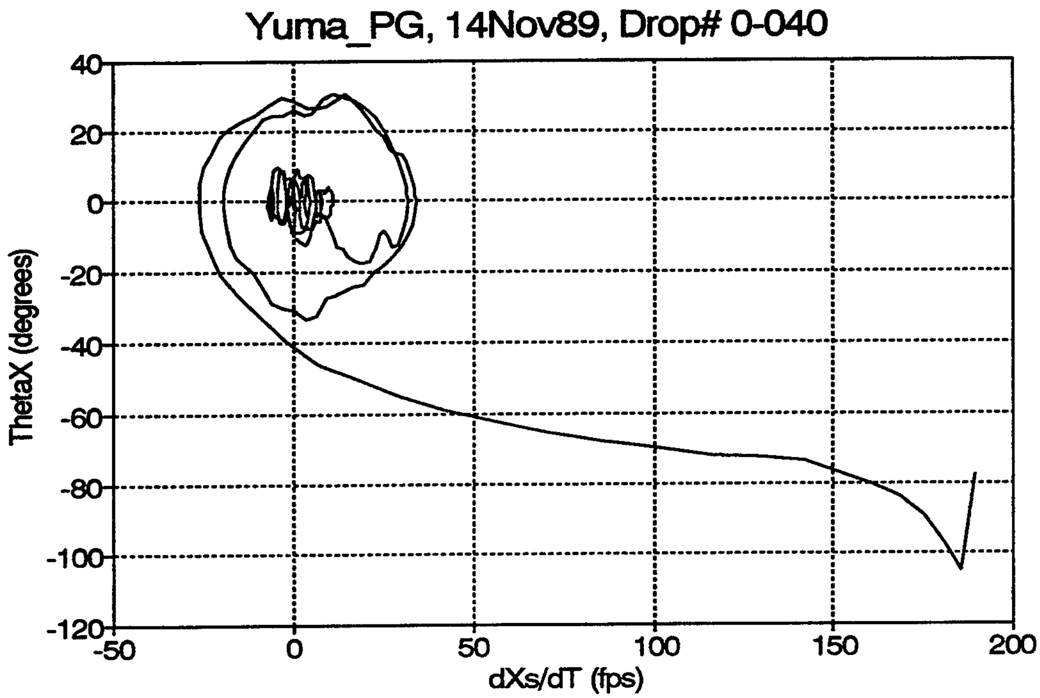


**Figure 3**: System Vertical Angle vs Horizontal Cargo Speed

The computed system vertical angle also serves to define the orientation of airdrop systems that comprise parachute clusters, where the location of the center of pressure is the result of all canopies acting at different angles upon the system confluence point. The fluctuation of this center of pressure for clusters of parachutes can be physically interpreted as the realignment of the canopies during system rotation.

Thus the method of computing the system vertical angle, in addition to being rational, also obviates the expense of tracking the location of several canopies in time.

## Statistical Method

### Altitude Loss

The altitude loss of the cargo from greenlight to the occurrence of the first minimum cargo speed, was determined from trajectory data acquired from Yuma Proving Grounds, Yuma, Arizona, for G-12E airdrop systems with two to three parachutes. These data form the basis for a statistical determination of the average and the standard deviation of the altitude loss for a group of similar G-12E airdrop systems, called a statistical ensemble. The minimum altitude loss statistic was obtained by plotting the cargo speed versus altitude, locating the point where it reaches its first minimum, and noting the altitude loss at that point. The following graph, displaying the cargo speed and the elapsed time from greenlight, vs the altitude loss, is typical.

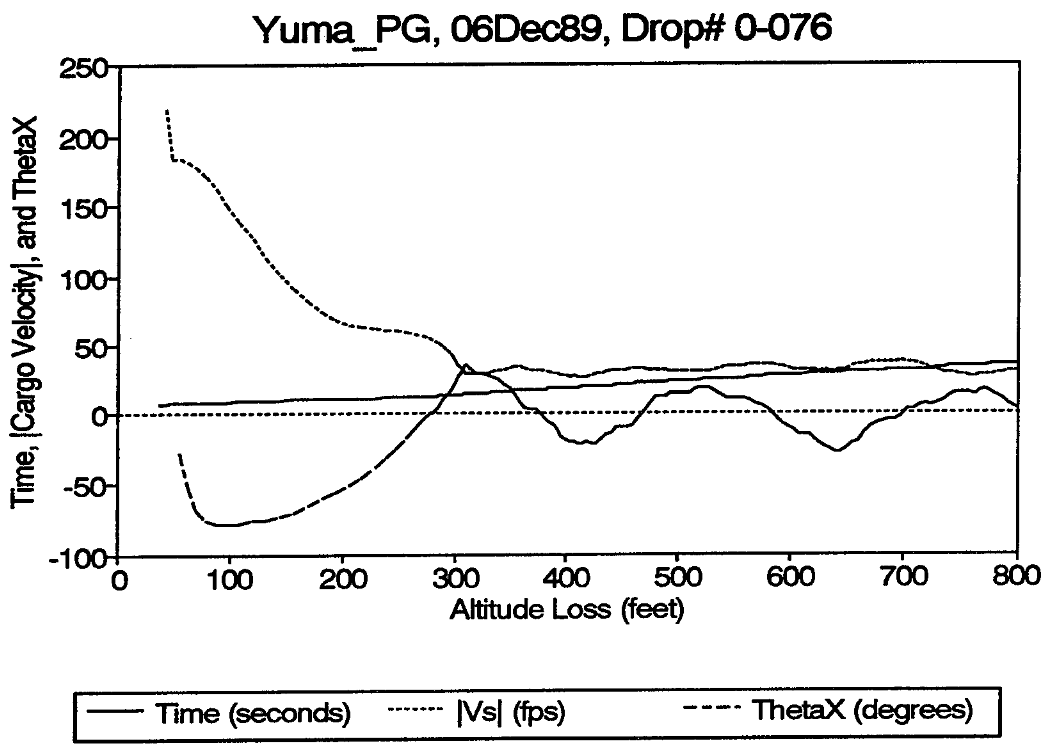


**Figure 4:** Cargo Speed and System Vertical Angle vs Altitude Loss

Obtaining the minimum altitude statistic was greatly facilitated by using the following magnified version of the previous graph.

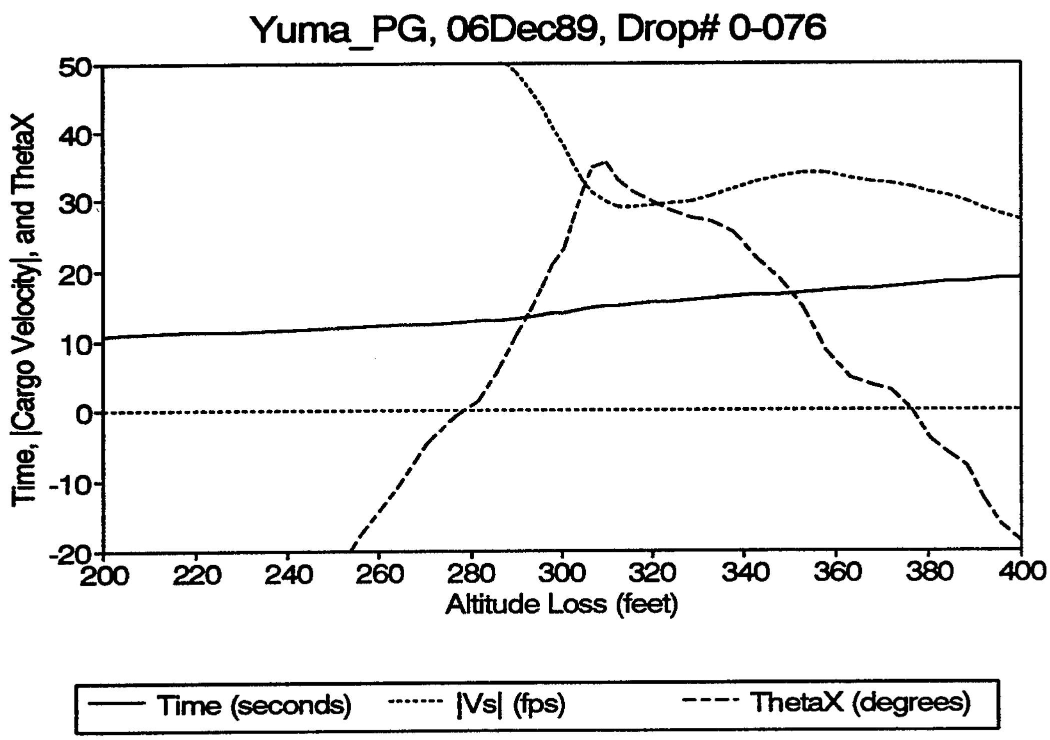


**Figure 5**: Magnified Version of Figure No.4

The first minimum cargo speed can be seen to nearly coincide with the occurrence of the first full backswing orientation of the system. Preceding this point, the cargo speed is decreasing rapidly. Since the minimum cargo speed also represents the minimum kinetic energy, the steepness of the curve just before this point suggests that landing the cargo a little early will result in impact damage or even destruction of the cargo.

**Elapsed Time**

The same approach was used to determine the time that elapsed from greenlight until the cargo speed reaches its first minimum. This statistic was obtained because there is concern that the cargo could land before the canopy release mechanism has been activated.

## Assumptions

By assuming that the statistic is normally distributed as was done during the previous analysis of the G-11 family of airdrop systems, we can compute the mean and the standard deviation and draw conclusions about the variability in the altitude loss of G-12E airdrop systems.

The following ogive plot (empirical cumulative distribution function) was used to determine the extent to which the data for a certain ensemble (G-12E airdrop systems that comprise cargo with suspended weights of 2250 pounds, delivered at a cargo speed of 140 knots) is normally distributed.

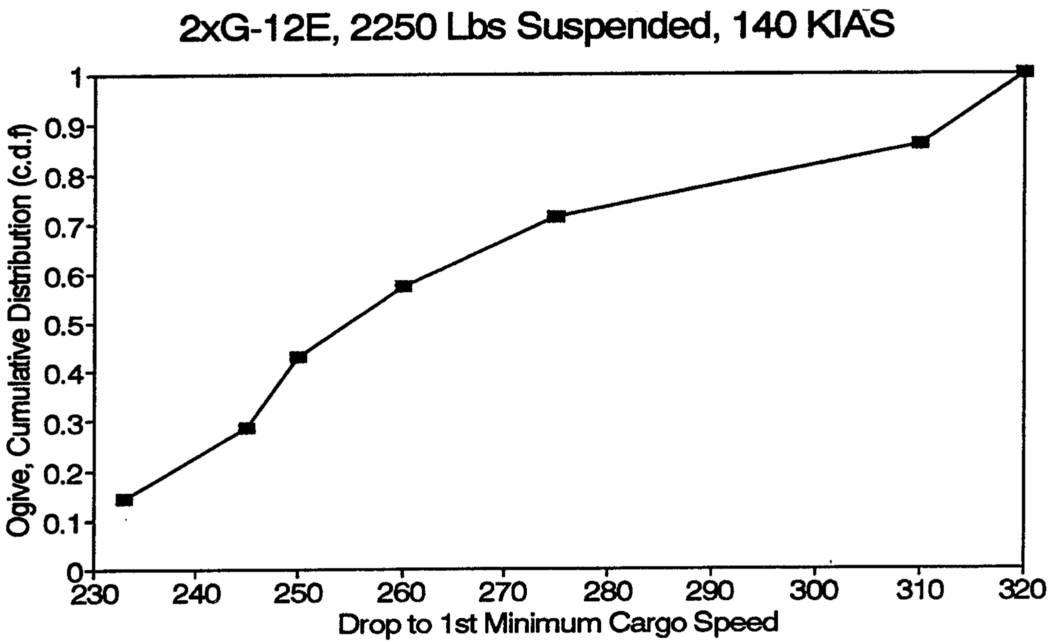


**Figure 6:** Ogive of Minimum Altitude for Clusters of Two G-12Es

This curve differs somewhat from the s-curve to be expected for normally distributed data. This means that the standard deviation computed from these data, and hence the safety factor added to the average altitude loss, is only approximately correct.*

The application of safety factors to the average minimum altitude based upon the computed standard deviation is based upon the assumption that the conditions on page 19 of Siegel[3] have been met. In particular, the observations must be drawn from normally distributed populations, which the above ogive plot does not support. It appears that at least 10 trials for each statistical ensemble are needed to gain confidence that the performance statistic of interest is in fact normally distributed, so that safety factors may be properly applied.

*It is by adding a safety factor to the average minimum altitude loss that the variation in process of each airdrop system is accounted for and the probability of damage is limited to those few systems whose performance falls outside the normal range for that group. At the present time the minimum safety factor is determined by adding twice the dispersion (standard deviation) of the minimum altitude to the mean of the same statistic.

# THE QUALITY OF AIRDROP SYSTEMS

The quality of any system can be defined in terms of its ability to satisfy the needs of the user. In the case of airdrop systems, this can be defined in terms of the precision and accuracy with which cargo can be delivered to a desired location. The mean error or offset provides a measure of accuracy, while the precision of such an operation is the fluctuation of this error about the mean. The standard deviation, then, is a measure of precision.

This statistical definition can be used to quantitatively describe the accuracy, an important measure of airdrop system performance, namely: deliver cargo from an aircraft to an intended point or target on the earth.

The probability that this objective can be achieved, i.e., that the cargo will fall close to that point, or within an acceptable distance from it — without suffering impact damage — is dependent on the processes* which follow:

Current Weather Conditions
Weather Measurement Methods
Carp Computations
Navigation Aids
Pilot/Navigator Judgment
Airdrop Equipment Performance.

This report, based upon the analysis of trajectory data provides insight into the overall system performance after greenlight. It concerns only the last item of the list.

# LIMITATIONS

The analysis of trajectory data indicates only the extent to which altitude loss is clustered about a mean. This supports the determination of precision or repeatability, but not accuracy. The analysis predicts the range within which similar airdrop systems can be expected to land but, the analysis cannot predict the distance between the point of intended delivery and the point of actual impact.

To determine the precision and accuracy (quality) of the airdrop method, it would be necessary to analyze the performance of the complete system. The overall performance depends not only upon the performance of parachute systems but also upon the preceding processes in the above list.

# RESULTS

The G-12E trajectory data were divided into statistical ensembles first by grouping the data according to the number of canopies and next by grouping the data according to the weight of the cargo. The speed of the aircraft at the time of extraction (greenlight)

*Here the word process means a system of causes produced by an inanimate object or device, human intervention, or natural phenomenon due to the environment, such as weather.

should also be considered when a wide range of aircraft speeds during extraction are noted. The greenlight statistics and the cargo weight data can be found in the appendices for clusters of two and also for clusters of three G-12E parachutes.

## Clusters of Two G-12E Parachutes

The interpretation of the following statistical data is outlined here for the first data set, i.e., for clusters of two G-12E parachutes. The interpretation of the statistical data for clusters of three G-12E proceeds in a similar manner.

Two different ensembles are shown in each table. The first ensemble concerns systems delivering 2250 pounds of suspended weight. The second concerns suspended weights of approximately 3500 pounds.

## Peak Drag Statistics

Table 1 displays system data for that point in the trajectory where the peak drag force occurs. The first statistic of note is the altitude loss from greenlight to the occurrence of peak tensile force. This statistic shows an average of 105.2 feet, a dispersion of 41.3 feet and a relative dispersion of 39.3 percent.

Table 1.

Statistics at Peak Drag for Clusters of Two G-12E Parachutes

Cargo Trajectory Data
Data at Peak (specific) Drag Force

| Date | Drop# | #Chutes | Altitude Loss (feet) | Cargo Speed (fps) | Elapsed Time (seconds) | Peak Drag (fps^2) | Backswing (degrees) |
|---|---|---|---|---|---|---|---|
| 15Nov89 | 0-049 | 2 | Not Available | | | | |
| 30Nov89 | 0-071 | 2 | 68.9 | 100.4 | 7.4 | 74.6 | -74.3 |
| 20Oct89 | 0-017 | 2 | 144.7 | 102.0 | 9.0 | 76.1 | -68.5 |
| 16Nov89 | 0-053 | 2 | 73.0 | 108.9 | 7.0 | 82.5 | -70.1 |
| 20Oct89 | 0-016 | 2 | 131.0 | 96.0 | 6.8 | 85.2 | -68.2 |
| 20Oct89 | 0-019 | 2 | 176.4 | 71.4 | 9.2 | 75.0 | -59.2 |
| 20Oct89 | 0-018 | 2 | 72.5 | 97.0 | 8.6 | 74.0 | -71.0 |
| 16Nov89 | 0-052 | 2 | 70.1 | 117.1 | 7.8 | 81.0 | -70.2 |
| | Average: | | 105.2 | 99.0 | 8.0 | 78.3 | -68.8 |
| | Dispersion: | | 41.3 | 13.2 | 0.9 | 4.1 | 4.3 |
| | % Dispersion: | | 39.3 percent | | 11.3 percent | | |

| Date | Drop# | #Chutes | Altitude Loss (feet) | Cargo Speed (fps) | Elapsed Time (seconds) | Peak Drag (fps^2) | Backswing (degrees) |
|---|---|---|---|---|---|---|---|
| 28Dec89 | 0-123 | 2 | Not Available | | | | |
| 28Dec89 | 0-124 | 2 | Not Available | | | | |
| 20Nov89 | 0-058 | 2 | 102.7 | 96.3 | 9.2 | 87.2 | -76.9 |
| 30Nov89 | 0-070 | 2 | 100.0 | 100.0 | 7.6 | 82.5 | -61.1 |
| 30Nov89 | 0-068 | 2 | 108.9 | 125.1 | 6.4 | 85.2 | -76.3 |
| | Average: | | 103.9 | 107.1 | 7.7 | 85.0 | -71.4 |
| | Dispersion: | | 3.7 | 12.8 | 1.1 | 1.9 | 7.3 |
| | % Dispersion: | | 3.6 percent | | 14.8 percent | | |

Note that for the first ensemble, the elapsed time from greenlight to the occurrence of the peak tensile force shows an average of 8.0 seconds, a dispersion of 0.9 seconds, and a relative dispersion of 11.3 percent.

## Minimum Altitude Statistics

Table 2 displays the state of process variables for two different payload weights (ensembles) for that point in the trajectory where the first minimum cargo speed occurs.

Table 2.

Statistics at First Minimum Cargo Speed for Clusters of Two G-12E Parachutes

| Date | Drop# | #Chutes | Weight: Gross (lbs.) | Weight: Suspended (lbs.) | Data at the First Minimum Cargo Speed: Altitude Loss (feet) | Elapsed Time (seconds) | Cargo Speed (fps) | Backswing Angle (degrees) |
|---|---|---|---|---|---|---|---|---|
| 15Nov89 | 0-049 | 2 | 2520 | 2250 | Not Available | | | |
| 30Nov89 | 0-071 | 2 | 2520 | 2250 | 233.0 | 11.8 | 20.0 | 28.0 |
| 20Oct89 | 0-017 | 2 | 2520 | 2250 | 320.0 | 14.0 | 27.1 | 24.3 |
| 16Nov89 | 0-053 | 2 | 2520 | 2250 | 245.0 | 12.3 | 38.3 | 35.0 |
| 20Oct89 | 0-016 | 2 | 2520 | 2250 | 275.0 | 11.8 | 30.0 | 22.9 |
| 20Oct89 | 0-019 | 2 | 2520 | 2250 | 310.0 | 14.2 | 22.1 | 25.0 |
| 20Oct89 | 0-018 | 2 | 2520 | 2250 | 250.0 | 13.4 | 27.1 | 22.1 |
| 16Nov89 | 0-052 | 2 | 2520 | 2250 | 260.0 | 13.6 | 33.8 | 30.0 |
| | Average: | | | | 270.4 | 13.0 | 28.4 | 26.8 |
| | Dispersion: | | | | 30.7 | 1.0 | 5.9 | 4.2 |
| | % Dispersion: | | | | 11.4 percent | 20.8 percent | | |
| | with safety factor | | | | 331.9 | | | |

| Date | Drop# | #Chutes | Gross (lbs.) | Suspended (lbs.) | Altitude Loss (feet) | Elapsed Time (seconds) | Cargo Speed (fps) | Backswing Angle (degrees) |
|---|---|---|---|---|---|---|---|---|
| 28Dec89 | 0-123 | 2 | 3537 | 3267 | Not Available | | | |
| 28Dec89 | 0-124 | 2 | 3537 | 3267 | Not Available | | | |
| 20Nov89 | 0-058 | 2 | 3770 | 3500 | 290.0 | 14.4 | 22.1 | 28.3 |
| 30Nov89 | 0-070 | 2 | 3770 | 3500 | 230.6 | 12.0 | 31.4 | 18.2 |
| 30Nov89 | 0-068 | 2 | 3770 | 3500 | 283.2 | 11.1 | 24.5 | 22.5 |
| | Average: | | | | 267.9 | 12.5 | 26.0 | 23.0 |
| | Dispersion: | | | | 26.5 | 1.4 | 3.9 | 4.2 |
| | % Dispersion: | | | | 9.9 percent | 15.1 percent | | |
| | with safety factor | | | | 321.0 | | | |

Of particular note is the altitude loss of the first 2250 pound ensemble from greenlight to first minimum cargo speed. The ensemble shows an average of 270.4 feet, and a dispersion of 30.7 feet. The relative dispersion is 11.4 percent.

Based upon these statistics, the minimum altitude after adding the minimum safety factor from greenlight is approximately 331.9 feet for the first ensemble of clusters of two G-12E parachutes.

## Clusters of Three G-12E Parachutes

**The interpretation of statistical data in Tables 3 and 4 proceeds in the same manner as outlined previously for clusters of two G-12E parachutes.**

### Peak Drag Statistics

Table 3.

Statistics at Peak Drag for Clusters of Three G-12E Parachutes

Cargo Trajectory Data
Data at Peak (specific) Drag Force

| Date | Drop# | #Chutes | Altitude Loss (feet) | Cargo Speed (fps) | Elapsed Time (seconds) | Peak Drag (fps^2) | Backswing (degrees) |
|---|---|---|---|---|---|---|---|
| 20Nov89 | 0-056 | 3 | 171.7 | 83.4 | 9.0 | 88.0 | -60.8 |
| 20Nov89 | 0-057 | 3 | 151.9 | 85.1 | 9.2 | 91.6 | -66.0 |
| 20Nov89 | 0-055 | 3 | 153.5 | 80.0 | 8.6 | 82.7 | -64.2 |
| 20Nov89 | 0-054 | 3 | 182.5 | 73.9 | 9.4 | 90.1 | -60.2 |
| | Average: | | 164.9 | 80.6 | 9.1 | 88.1 | -62.8 |
| | Dispersion: | | 12.8 | 4.3 | 0.3 | 3.4 | 2.4 |
| | % Dispersion: | | 7.8 | percent | 3.3 | percent | |
| 14Oct89 | 0-038 | 3 | 77.4 | 103.9 | 7.2 | 89.1 | -70.1 |
| 14Oct89 | 0-040 | 3 | 81.8 | 106.8 | 7.8 | 84.7 | -67.6 |
| 14Oct89 | 0-041 | 3 | 104.2 | 84.3 | 8.2 | 87.1 | -63.8 |
| 14Oct89 | 0-039 | 3 | 127.0 | 94.2 | 7.4 | 94.3 | -65.5 |
| | Average: | | 97.6 | 97.3 | 7.7 | 88.8 | -66.8 |
| | Dispersion: | | 19.8 | 8.8 | 0.4 | 3.5 | 2.4 |
| | % Dispersion: | | 20.3 | percent | 5.0 | percent | |
| 28Dec89 | 0-125 | 3 | | | | | |
| 30Nov89 | 0-072 | 3 | 99.4 | 112.1 | 8.0 | 91.1 | -73.0 |
| 28Dec89 | 0-126 | 3 | 149.3 | 91.8 | 8.4 | 91.5 | -66.4 |
| 30Nov89 | 0-069 | 3 | 112.4 | 131.6 | 7.6 | 93.9 | -73.9 |
| | Average: | | 120.4 | 111.8 | 8.0 | 92.2 | -71.1 |
| | Dispersion: | | 21.14 | 16.25 | 0.33 | 1.24 | 3.34 |
| | % Dispersion: | | 17.6 | percent | 4.1 | percent | |
| 06Dec89 | 0-073 | 3 | 100.7 | 131.2 | 8.2 | 84.5 | -76.9 |
| 06Dec89 | 0-074 | 3 | 43.4 | 114.3 | 8.8 | 97.8 | -77.5 |
| 06Dec89 | 0-075 | 3 | 119.0 | 113.0 | 7.6 | 93.6 | -76.5 |
| 06Dec89 | 0-076 | 3 | 131.7 | 112.7 | 9.8 | 89.3 | -75.0 |
| | Average: | | 98.7 | 117.8 | 8.6 | 91.3 | -76.5 |
| | Dispersion: | | 33.8 | 7.8 | 0.8 | 4.9 | 0.9 |
| | % Dispersion: | | 34.2 | percent | 9.4 | percent | |

## Minimum Altitude Statistics

Table 4.

Statistics at First Minimum Cargo Speed for Clusters of Three G-12Es

| Date | Drop# | #Chutes | Altitude Loss (feet) | Elapsed Time (seconds) | Cargo Speed (fps) | Backswing Angle (degrees) |
|---|---|---|---|---|---|---|
| | | | Data at the First Minimum Cargo Speed | | | |
| 20Nov89 | 0-056 | 3 | 313.0 | 13.8 | 18.3 | 38.3 |
| 20Nov89 | 0-057 | 3 | 306.0 | 14.4 | 18.3 | 23.3 |
| 20Nov89 | 0-055 | 3 | 293.0 | 13.6 | 13.3 | 28.3 |
| 20Nov89 | 0-054 | 3 | 312.0 | 14.2 | 17.0 | 24.2 |
| | Average: | | 306.0 | 14.0 | 16.8 | 28.5 |
| | Dispersion: | | 8.0 | 0.3 | 2.0 | 6.0 |
| | % Dispersion: | | 2.6 | 12.2 percent | | |
| | Minimum AGL: | | 321.9 | | | |
| 14Oct89 | 0-038 | 3 | 230.0 | 11.9 | 17.0 | 37.0 |
| 14Oct89 | 0-040 | 3 | 240.9 | 12.6 | 11.7 | 29.2 |
| 14Oct89 | 0-041 | 3 | 240.0 | 13.1 | 11.4 | 27.1 |
| 14Oct89 | 0-039 | 3 | 275.0 | 12.0 | 15.8 | 31.7 |
| | Average: | | 246.5 | 12.4 | 14.0 | 31.2 |
| | Dispersion: | | 17.0 | 0.5 | 2.5 | 3.7 |
| | % Dispersion: | | 6.9 | 17.7 percent | | |
| | Minimum AGL: | | 280.5 | | | |
| 28Dec89 | 0-125 | 3 | Not Available | | | |
| 30Nov89 | 0-072 | 3 | 283.2 | 12.8 | 27.0 | 28.0 |
| 28Dec89 | 0-126 | 3 | 305.0 | 13.6 | 18.8 | 22.5 |
| 30Nov89 | 0-069 | 3 | 299.0 | 12.2 | 30.0 | 23.6 |
| | Average: | | 295.7 | 12.9 | 25.3 | 24.7 |
| | Dispersion: | | 9.19 | 0.57 | 4.76 | 2.37 |
| | % Dispersion: | | 3.1 | 18.8 percent | | |
| | Minimum AGL: | | 314.1 | | | |
| 06Dec89 | 0-073 | 3 | 312.0 | 14.7 | 36.7 | 34.2 |
| 06Dec89 | 0-074 | 3 | 268.0 | 15.4 | 29.5 | 12.5 |
| 06Dec89 | 0-075 | 3 | 327.0 | 13.4 | 29.2 | 33.3 |
| 06Dec89 | 0-076 | 3 | 314.0 | 15.1 | 29.2 | 32.5 |
| | Average: | | 305.3 | 14.7 | 31.1 | 28.1 |
| | Dispersion: | | 22.3 | 0.8 | 3.2 | 9.0 |
| | % Dispersion: | | 7.3 | 10.3 percent | | |
| | Minimum AGL: | | 349.8 | | | |

# CONCLUSIONS

Airdrop performance analysis in Table 5 is a summary of system statistics at the occurrence of the first minimum cargo speed for G-12E parachute clusters.

Table 5.

Statistical Summary of G-12E Airdrop System Performance

| Statistical Ensemble | Altitude Loss (feet) | Elapsed Time (seconds) | Cargo Speed (fps) | Vertical Angle (degrees) |
|---|---|---|---|---|
| | Data at the First Minimum Cargo Speed | | | |
| **2ea. G-12E Parachutes (2250 pounds average suspended weight)** | | | | |
| Average: | 270.4 | 13.0 | 28.4 | 26.8 |
| Dispersion: | 30.7 | 1.0 | 5.9 | 4.2 |
| % Dispersion: | 11.4 | 20.8 percent | | |
| incl. safety factor: | 331.9 | | | |
| **2ea. G-12E Parachutes (3500 pounds average suspended weight)** | | | | |
| Average: | 267.9 | 12.5 | 26.0 | 23.0 |
| Dispersion: | 26.5 | 1.4 | 3.9 | 4.2 |
| % Dispersion: | 9.9 | 15.1 percent | | |
| incl. safety factor: | 321.0 | | | |
| **3ea. G-12E Parachutes (2115 pounds average suspended weight)** | | | | |
| Average: | 306.0 | 14.0 | 16.8 | 28.5 |
| Dispersion: | 8.0 | 0.3 | 2.0 | 6.0 |
| % Dispersion: | 2.6 | 12.2 percent | | |
| incl. safety factor: | 321.9 | | | |
| **3ea. G-12E Parachutes (2175 pounds average suspended weight)** | | | | |
| Average: | 246.5 | 12.4 | 14.0 | 31.2 |
| Dispersion: | 17.0 | 0.5 | 2.5 | 3.7 |
| % Dispersion: | 6.9 | 17.7 percent | | |
| incl. safety factor: | 280.5 | | | |
| **3ea. G-12E Parachutes (4968 pounds average suspended weight)** | | | | |
| Average: | 295.7 | 12.9 | 25.3 | 24.7 |
| Dispersion: | 9.19 | 0.57 | 4.76 | 2.37 |
| % Dispersion: | 3.1 | 18.8 percent | | |
| incl. safety factor: | 314.1 | | | |
| **3ea. G-12E Parachutes (5000 pounds average suspended weight)** | | | | |
| Average: | 305.3 | 14.7 | 31.1 | 28.1 |
| Dispersion: | 22.3 | 0.8 | 3.2 | 9.0 |
| % Dispersion: | 7.3 | 10.3 percent | | |
| Minimum AGL: | 349.8 | | | |

The average minimum altitude, before adding a safety factor, for the clusters of two G-12E parachutes was found to be less than 300 feet.

For lightly loaded systems that comprise three G-12E parachutes, the average minimum altitude (without an added safety factor) was found to exceed 300 feet by only 6 feet. The other clusters of three G-12E parachutes reached stability in less than 300 feet.

The peak opening force divides airdrop system performance into two distinctly different intervals. In the interval from greenlight to the occurrence of the peak opening force (tension) we are primarily concerned with the process of parachute deployment when all manner of devices such as transfer devices, reefing lines, and various timing devices come into play. After this point the system rapidly approaches its final descent velocity when it's trajectory is strongly affected by the local wind field.

Improvements in the first interval will be obtained through refinement of the classical methods and devices used by airdrop.

The improvement in the second interval will be obtained through an improved understanding of the effects of winds upon parachute trajectories. This is especially true with regard to the effects of wind shear upon parachute trajectories.

# RECOMMENDATIONS

Clusters of both two and three G-12E parachutes reached stability in approximately 300 feet. Based upon the limited information available from the LARRS program, there is no reason to believe that it could equal or improve upon this performance. For this reason the G-12E family of airdrop systems should be considered as a viable alternative to the LARRS for suspended weights of less than 5000 pounds.

Because experimentation is expensive, it would be advisable for the Army and Air Force to coordinate their efforts in the improving airdrop system performance by jointly developing the statistical method to be used in determining the quality of the airdrop systems.

In general there is no need to integrate all experiments into one effort. When it can be demonstrated that the variation in process intervals is normally distributed, it will, in general, be possible to determine the average and the standard deviation of each subinterval quite independently of preceding and succeeding intervals. For example, it should be possible to measure the time interval of the actuation delay timer of the parachute release on the ground. Likewise, the Air Force should be able to conduct assessments of navigation aids quite independently of airdrop testing. When the results of such experiments indicate that the error in the data is normally distributed, the variance in the overall performance of the airdrop system can be predicted using analysis of variance (ANOVA) techniques.

A statistical approach to the evaluation of airdrop system performance can support a rational, economical program for improving the quality of the airdrop systems, leading to more reliable support of the soldier in the field and, more recently, humanitarian relief efforts.

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# Appendix A

# Data for Clusters of Two G-12E Parachutes

Table A-1.

Weight Data for Clusters of Two G-12E Parachutes

| Date | Drop# | #Chutes | Weight Gross (lbs.) | Weight Suspended (lbs.) |
|---|---|---|---|---|
| 15Nov89 | 0-049 | 2 | 2520 | 2250 |
| 30Nov89 | 0-071 | 2 | 2520 | 2250 |
| 20Oct89 | 0-017 | 2 | 2520 | 2250 |
| 16Nov89 | 0-053 | 2 | 2520 | 2250 |
| 20Oct89 | 0-016 | 2 | 2520 | 2250 |
| 20Oct89 | 0-019 | 2 | 2520 | 2250 |
| 20Oct89 | 0-018 | 2 | 2520 | 2250 |
| 16Nov89 | 0-052 | 2 | 2520 | 2250 |

| Date | Drop# | #Chutes | Weight Gross (lbs.) | Weight Suspended (lbs.) |
|---|---|---|---|---|
| 28Dec89 | 0-123 | 2 | 3537 | 3267 |
| 28Dec89 | 0-124 | 2 | 3537 | 3267 |
| 20Nov89 | 0-058 | 2 | 3770 | 3500 |
| 30Nov89 | 0-070 | 2 | 3770 | 3500 |
| 30Nov89 | 0-068 | 2 | 3770 | 3500 |

Table A-2

Aircraft (Greenlight) Data for Clusters of Two G-12E Parachutes

| | | | Aircraft Data: Airspeed | | Trackspeed | Altitude |
|---|---|---|---|---|---|---|
| Date | Drop# | #Chutes | Target (kias) | Target (fps) | Actual (fps) | Actual (feet) |
| 15Nov89 | 0-049 | 2 | 140 | 236.3 | Not Available | |
| 30Nov89 | 0-071 | 2 | 140 | 236.3 | 255.5 | 1020.8 |
| 20Oct89 | 0-017 | 2 | 140 | 236.3 | 272.8 | 1078.6 |
| 16Nov89 | 0-053 | 2 | 140 | 236.3 | 253.9 | 1098.2 |
| 20Oct89 | 0-016 | 2 | 140 | 236.3 | 263.0 | 1093.2 |
| 20Oct89 | 0-019 | 2 | 140 | 236.3 | 256.2 | 1083.1 |
| 20Oct89 | 0-018 | 2 | 140 | 236.3 | 261.8 | 1058.9 |
| 16Nov89 | 0-052 | 2 | 140 | 236.3 | 248.9 | 1057.8 |
| | Average: | | | | 258.9 | 1070.1 |
| | Dispersion: | | | | 7.2 | 24.7 |

| Date | Drop# | #Chutes | Target (kias) | Target (fps) | Actual (fps) | Actual (feet) |
|---|---|---|---|---|---|---|
| 28Dec89 | 0-123 | 2 | 140 | 236.3 | Not Available | |
| 28Dec89 | 0-124 | 2 | 140 | 236.3 | Not Available | |
| 20Nov89 | 0-058 | 2 | 150 | 253.2 | 257.0 | 1032.0 |
| 30Nov89 | 0-070 | 2 | 140 | 236.3 | 271.5 | 997.8 |
| 30Nov89 | 0-068 | 2 | 140 | 236.3 | 271.0 | 1029.0 |
| | Average: | | | | 266.5 | 1019.6 |
| | Dispersion: | | | | 6.7 | 15.5 |

# Appendix B

## Data for Clusters of Three G-12E Parachutes

Table B-1.

Weight Data for Clusters of Three G-12E Parachutes

| | | | Weight | |
|---|---|---|---|---|
| ****************** | | | ***************** | |
| Date | Drop# | #Chutes | Gross (lbs.) | Suspended (lbs.) |
| 20Nov89 | 0-056 | 3 | 2520 | 2115 |
| 20Nov89 | 0-057 | 3 | 2520 | 2115 |
| 20Nov89 | 0-055 | 3 | 2520 | 2115 |
| 20Nov89 | 0-054 | 3 | 2520 | 2115 |
| | | | | |
| 14Oct89 | 0-038 | 3 | 2520 | 2175 |
| 14Oct89 | 0-040 | 3 | 2520 | 2175 |
| 14Oct89 | 0-041 | 3 | 2520 | 2175 |
| 14Oct89 | 0-039 | 3 | 2520 | 2175 |
| | | | | |
| 28Dec89 | 0-125 | 3 | 5310 | 4905 |
| 30Nov89 | 0-072 | 3 | 5405 | 5000 |
| 28Dec89 | 0-126 | 3 | 5310 | 4905 |
| 30Nov89 | 0-069 | 3 | 5405 | 5000 |
| | | | | |
| 06Dec89 | 0-073 | 3 | 5405 | 5000 |
| 06Dec89 | 0-074 | 3 | 5405 | 5000 |
| 06Dec89 | 0-075 | 3 | 5405 | 5000 |
| 06Dec89 | 0-076 | 3 | 5405 | 5000 |

Table B-2

Aircraft (Greenlight) Data for Clusters of Three G-12E Parachutes

| | | | Aircraft Data Airspeed | | Trackspeed | Altitude |
|---|---|---|---|---|---|---|
| Date | Drop# | #Chutes | Target (kias) | Target (fps) | Actual (fps) | Actual (feet) |
| 20Nov89 | 0-056 | 3 | 150 | 253.2 | 257.5 | 1044.1 |
| 20Nov89 | 0-057 | 3 | 150 | 253.2 | 259.9 | 1046.0 |
| 20Nov89 | 0-055 | 3 | 150 | 253.2 | 259.0 | 1019.2 |
| 20Nov89 | 0-054 | 3 | 150 | 253.2 | 260.0 | 1038.0 |
| | Average: | | | | 259.1 | 1036.8 |
| | Dispersion: | | | | 1.0 | 10.6 |
| 14Oct89 | 0-038 | 3 | 140 | 236.3 | 265.9 | 1094.8 |
| 14Oct89 | 0-040 | 3 | 140 | 236.3 | 264.8 | 1126.2 |
| 14Oct89 | 0-041 | 3 | 140 | 236.3 | 258.0 | 1123.6 |
| 14Oct89 | 0-039 | 3 | 140 | 236.3 | 267.3 | 1078.1 |
| | Average: | | | | 264.0 | 1105.7 |
| | Dispersion: | | | | 3.6 | 20.1 |
| 28Dec89 | 0-125 | 3 | 140 | 236.3 | | |
| 30Nov89 | 0-072 | 3 | 140 | 236.3 | 253.6 | 1007.3 |
| 28Dec89 | 0-126 | 3 | 140 | 236.3 | 231.7 | 1066.7 |
| 30Nov89 | 0-069 | 3 | 140 | 236.3 | 273.6 | 1003.5 |
| | Average: | | | | 253.0 | 1025.8 |
| | Dispersion: | | | | 17.11 | 28.94 |
| 06Dec89 | 0-073 | 3 | 150 | 253.2 | 261.8 | 1035.8 |
| 06Dec89 | 0-074 | 3 | 150 | 253.2 | 267.7 | 1094.6 |
| 06Dec89 | 0-075 | 3 | 150 | 253.2 | 263.8 | 1059.6 |
| 06Dec89 | 0-076 | 3 | 150 | 253.2 | 262.3 | 1076.9 |
| | Average: | | | | 263.9 | 1066.7 |
| | Dispersion: | | | | 2.3 | 21.7 |

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