Design and Development of a New Cargo Parachute and Container Delivery System

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Abstract

The U S Army Soldiers Systems Center, Product Manager Force Sustainment Systems at Natick, MA was tasked with the development of a new low cost Container Delivery System (CDS). The program plan was to develop a new airdrop container, a High Velocity parachute and a Low Velocity parachute as alternatives to existing CDS components. Current CDS is used to support missions that provide water, food and supplies to areas unreachable by other means or to quickly provide these items on the spot for military operations. In actuality, very few airdrop items are returned for reuse and only in training does reuse occur. The High Velocity parachute and a Low Velocity parachute use the same basic design principles to keep the costs as low as possible. The container has been simplified in construction and is still able to perform its mission. These designs are based on using a high tear resistant, low cost, woven, polypropylene material. New materials and methods to produce a low cost parachute were investigated during this program. This led to examining the basic premise of parachute design and to challenge some of these basic concepts to see if the labor costs could be reduced through a simpler design and using standard, low cost, commercially available material. These concepts eliminate reinforcement of the canopy and use the inherent strength of low cost, canopy stock width material, along with a slower opening design to withstand the high parachute opening shock. The suspension lines are tied directly to the canopy material, reducing the number of suspension lines and eliminating the labor associated with sewing them on. This innovative parachute design is new in both geometry and method of construction. This is a modified cross parachute design that uses several strips of fabric that cross the other fabric at 90 degrees and are spaced so that crown vents are created to increase the geometric porosity and reduce opening shock. The number of suspension lines are reduced using this new design. The standard 26 ft Ringslot High ‘V’ chute has 26 lines compared to the new 12 line design. The G-12 cargo parachute has 64 compared to the new 20 line design. The fabric runs from one side of the parachute over the top to the other side without a break in the fabric so as not to create weak points at junctions. c. Stitching is kept to a minimum by only sewing the edges of the wide material at their edges where they intersect the other fabric that crosses at the crown and at the ends. Fabrication can be accomplished by non parachute makers such as tent or sail makers. A low cost slider is used on the high velocity, high altitude parachute to further reduce opening shock. As a result, the cost is reduced by approximately 60% of the present inventory items and at the same time decent rate is reduced by 4% to 12%. Testing to date has been successful with the High Velocity chute and the container having completed all formal testing and are accepted for their intended use of loads up to 2,200 pounds and altitudes up to 25,000 feet. The Low Velocity chute has shown that it can deliver 2,200 pounds with a rate of decent of 25 feet/second and is now being tested in its final configuration before entering formal testing. This paper describes the new container and the design of the two new parachutes and discusses airdrop test results.

I. Introduction

For many years the U S Army and other world governments have used A-22 containers to deliver miscellaneous items of supplies and equipment by means of cargo airdrop. The items are delivered by either High-Velocity or Low-Velocity parachutes and from C-130 or C-17 aircraft. Up to 40 containers with up to 2,200 pounds each can be delivered by this method. This method of airdrop is known as the Container Delivery System (CDS) and has proven itself to be an effective way to deliver supplies measuring no more than 4 ft x 4 ft x 4 ft and weighing between 501 lbs and 2,200 lbs. The A-22 container is placed on a plywood skidboard and several layers of energy-dissipating honeycomb are used under the A-22 to attenuate the ground impact shock and protect the supplies. High-Velocity airdrop has a descent rate of 70 to 90 ft/sec; for Low-Velocity the descent rate is 28.5 ft/sec or below.
During Operation Provide Promise in Bosnia, United States (U.S.) Forces delivered aid using over $31 million of standard airdrop equipment with no equipment recovered, clearly identifying a need for a low cost one-time use CDS alternative for airdrop missions of this type.

II Low Cost Airdrop System (LCADS) Requirements

The LCADS will provide an efficient low-cost aerial delivery capability for the full spectrum of Army operations to include combat re-supply missions, Stability and Support Operations (SASO), and Military Operations Other Than War (MOOTW). The LCADS creates a low-cost means of addressing the logistical re-supply needs found in those ambiguous situations residing between peace and war, such as peacekeeping and peace enforcement operations, as well as humanitarian relief operations and support to domestic authorities. LCADS is comprised of three items: the Low Cost Container, Low Cost High-Velocity Parachute, and Low Cost Low-Velocity Parachute. All components are simple in design, maintenance, operation, and potential refurbishment, thus generating low development and lifecycle costs and minimizing materiel lead times, and come pre-packaged from the manufacturer.

The LCADS must be designed so that it cost less than current system, thus reducing mission costs. The intent of this system is to create a low-cost system that can deliver supplies at a cost that is less than 55% of current systems. A maximum suspended load weight of 2200 lb load capacity will allow supplies that typically weight between 501 and 2,200 lbs to be delivered to intended recipients on the ground. Supplies must be delivered to a specific point on the ground where they can be recovered and used to support the full spectrum of military operations or humanitarian relief efforts. High velocity (the ability to rapidly descend through winds) is required to attain delivery accuracy when delivery aircraft must fly high over the target due to terrain, weather, or ground threat. During high velocity airdrops, a descent rate of no greater than 90 feet per second is desired so that a load can be rigged to survive the force of impact. It is nearly impossible to rig an airdrop load to survive an impact greater than 90 feet per second. During low-velocity airdrops, a descent of no greater than 28.5 feet per second is desired so that a load can be rigged to survive the 19G force of impacting the ground.

The LCADS must be compatible with Army and Air Force air and ground support platforms and simultaneous air-droppable from standard U.S. Air Force cargo aircraft and special operations, NATO, and other services aircraft.

LCADS must be capable of being deployed at current CDS release altitudes: for High-Velocity airdrop of between 1,250 feet above ground level (AGL) to 25,000 feet mean sea level (MSL) and 500 to 1,250 feet AGL for Low Velocity airdrop.

The LCADS must have a probability of successful airdrop completion without the occurrence of a system abort that makes the airdropped load non-mission capable after ground impact of at least 0.92.

III Low Cost A-22 Container (LCC)

The Low Cost Container is a low-cost alternative to the A-22 cargo container. The LCC is designed for single use air delivery and will not be recovered. It will be used to contain standard CDS operational loads ranging in weight from 501 to 2,200 lbs. It will be airdropped at aircraft speeds of up to 150-KIAS at altitudes of 501 to1,200-ft AGL and 15,000 to 25,000-ft MSL. Weight 10 lbs; dimensions approx 48-inx48-in base, four approx 7-ft long sidepieces (approximately the same as the A-22).

The LCC shown in Figure 1 is made of 2-in polypropylene webbing stitched in a simplified version of the A-22 cargo bag, with a standard D-ring at the apex of each of its four “crow’s foot” shaped sides and a standard friction adapter on each of the 2 restraining straps. The LCC is placed on top of the energy dissipater material. The sides of the container are laced together around the load (a load of 4 water drums is shown in Figure 1). The LCC is tied to the skid and the parachute is tied to the ‘D’ rings of the LCC.

Both High-Velocity and Low-Velocity airdrops using the LCC were conducted to assess the operational effectiveness and suitability for U.S. Army use. Rigged loads weighed from 501 to 2,200 lbs at airspeeds of 140 to 150 knots from C-130 and C-17 aircraft. Airdrops were conducted at an altitude of 25,000 feet for High-Velocity airdrop and 1,200 feet for Low-Velocity airdrop. The LCC met all the design criteria and its performance equaled that of the standard A-22 containers.
IV Design of the High-Velocity Parachute

A. Materials

Several materials were evaluated for the High Velocity parachute canopy material: nylon, non-woven polyesters, polyethylene scrim films and woven polyproplyenes. The woven polypropylene was determined to be the most suitable. Polypropylene is a polymer that derived from the processing of crude oil and natural gas. A weave of 24 x 11 strips were used for the High-V design. This material is widely used as a geo-textile to build silt fences, and in road building and repair as a stabilizer and separator. It has the advantage of low cost combined with high tear resistance, elasticity, tenacity and the best porosity for this chute design. Nylon sells for $2 to $5 per square yard where as the 3.5 ounce woven polypropylene is selling from $0.20 to $0.50 per square yard. Tests showed the woven polypropylene to have a tear resistance over 3 times stronger than a similar weight of nylon material. These qualities led to a new design that used more material, yet allowed for simplification of the design, so that the labor to make the parachute and the overall costs were lower. It is estimated that the use of this material for parachutes when stored will last up to 20 years.

The High V parachute uses twelve 3/8” diameter ropes that tie on to the canopy. This reduced number of suspension lines means that stronger lines were required. Three ply twisted rope was selected because of its low cost and good elastic properties.
B. Construction

Low cost is achieved by constructing a parachute with the least amount stitching and the fewest suspension lines resulting in reduced manufacturing time. The High-Velocity parachute uses 12 suspension lines, rather than the 26 lines of the 26-ft ringslot parachute. This is accomplished by using the material itself to distribute the load over the 3-foot wide leg material. A sleeve is created at both ends of each panel by folding the end over and sewing it to itself. The suspension line is threaded through the sleeve and knotted in place. The other end of the suspension line (Figure 2) is tied to the container. The only stitching on the canopy is where the edges of each panel intersect the other panels at 90 degree angle. The total amount of stitching on the High V canopy is 128 feet as compared to the 420 feet for the 26-ft ringslot. Stitching is performed by a 4-needle cable stitch machine.

C. Detail of Design

This design evolved from the cross parachute. Building on the cross chute’s simplicity of design and fabrication, the legs of the cross parachute were broken up into three separate panels and spaced apart to create four vent holes in the crown and vertical slots in the legs. This distance was empirically determined to provide the best geometric porosity and to reduce the opening shock. The relatively high tenacity polypropylene warp fibers run from one side of the parachute to the other side. The fibers are gathered together and attached to the suspension line that is tied thru the sleeve.

The three suspension lines for each side of the chute are tied on to the corresponding rings on the container to save the cost of the attaching clevis. An ‘X’ shaped load spreader is made from 1 ¼” nylon webbing. Each three lines are routed thru each corresponding webbing end and attached with 80 lb cotton. The spreader is added to the lines 3 feet above the container to provide a wide confluence point and essentially extend the container attaching points and eliminate the extensions used on the A-22 container. A simple ‘X’ slider is used to further reduce opening shock and to provide control of badly deployed chutes.
V Design of the Low-Velocity Parachute

Figure 3. Low ‘V’ Parachute

A. Materials

A 2.7 ounce woven polypropylene was selected for this design, which has the same properties as the material used in the High-V parachute.

A 5/16” nylon three-ply twisted rope was selected because of its low cost and good elastic properties. The Low-V parachute design reduces the number of suspension lines from 64 to 20 lines.

B. Detail of Design

The same basic design principles are used in the Low-V parachute as the High-V parachute. Ten strips of machine woven material at 7.33 feet wide are cut to 90 feet long. Five panels are crossed with the five more panels and sewn at the edges on the crown. They are spaced apart and crossed at 90 degrees to create sixteen vents in the crown (Figure 3) to increase geometric porosity and reduce opening shock. This is a greater challenge than the High-V parachute because the suspension line forces must be transmitted from a single point to spread over the 7.33 foot wide panel material. Also packing and unfolding such wide panels is difficult and was only achieved through several trials of packing and reefing methods. Stitching was performed by a 4-needle cable stitch machine. The same method of attaching the lines to the canopy was as the High-V by forming sleeves at the end of the panels for the lines to be tied too.

The five suspension lines for each side of the chute are attached to snap hooks. The four snap hooks are used to quickly attach to the four corresponding ‘D’ rings of the container. An ‘O’ ring is used around the suspension lines 5 feet above the container to provide a single confluence point and essentially extend the container’s risors attaching points and eliminate the extensions used on the A-22 container.

Testing showed that to achieve our goal of being .92 reliability that a hem organizer/reefing system was need to prevent parachute damage during a bad deployment. The skirt of the parachute was connected together at the attachment point where the suspension lines attach to the canopy to prevent the possibility of a skirt inversion which allows one or more legs to move outside of the skirt to inflate on their own which causes unsymmetrical inflation and chute damage. Several reefing designs have been successfully tested to date: slider, reefing line with break ties and permanent ties attaching the legs together.
C. “Chute First” Parachute Deployment

It was decided to use “Chute First” parachute deployment instead of the present G-12 pilot chute deployed. This accomplishes three things: saves the cost of the 68” pilot chute, eliminates the trailing static lines from the aircraft and provides better low altitude performance. A low cost deployment bag design shown in Figure 7, attached to a A-22 load, was made from the same material as the canopy. The bag is a simple design that is open at one end and at the opposite end has a hole in which the ‘O’ ring is attached to the bag. The suspension lines are thread thru the ‘O’ ring from inside the bag. The excess lines are folded in the bottom of the bag and the canopy is folded on top of the lines. A static line is attached to the apex of the canopy. The bag is attached to the load with a 5 foot 9/16” tubular tied to the ‘O’ ring. Cotton break ties hold the parachute on the load. The other end of the static line is attached to the aircraft anchor cable with a break tie. The static line during deployment shown in Figure 4,pulls the canopy out of the bag and then the static line detaches from the aircraft anchor cable when the break tie is broken.
VI High ‘V’ Airdrop Testing at The Yuma Proving Grounds

A. Test Conditions

A total of 61 CDS with the Low Cost Hi-V Parachute were dropped for Phase 2, which include 25 single CDS and 36 CDS in mass deployment formation. On C-130 aircraft, 20 instrumented-singles and one pass of 16 CDS (a full stick) were dropped. On C-17 aircraft, 5 instrumented-singles and one pass of 20 CDS (half of a full stick), one CDS of which was instrumented, were dropped. Initially, 20 CDS were to be dropped from the C-17 as well as from the C-130 aircraft All drops were conducted from 25,000 ft mean sea level (MSL) at airspeeds between 130 and 150 knots-indicated-airspeed (KIAS) on Mohave Drop Zone at Yuma Proving Ground. Most of the DT CDS were rigged with the LCADS LCC due to a low supply of standard A-22 containers. Single drops were weighted to the maximum CDS weight of approximately 2200 lbs. Mass deployment drops contained CDS with weights ranging from 500 to 2200 lbs. Instrumented CDS were equipped with strain links and PDAS for gathering opening force data and utilized optical tracking ground cameras to record time-space-position information for obtaining the velocity at impact. Mass deployment drops were observed to note any air starvation caused by neighboring canopies. Low-Cost Hi-V data were compared post-drop with data gathered for the 26-Ft RS canopy during Phase 1

B. Kineto Tracking Mounts (KTM)

The dynamic performance for all of the LCADS loads was measured using optical trackers called KTM. Dynamic performance includes altitude losses, descent rates, and trajectory reconstruction. Each KTM has a precision-toolled stabilized tracking mount with azimuth and elevation encoders which are sampled along with Coordinated Universal Time (UTC) once every video or camera frame. These data were coded onto the edge of each video frame. The KTM mounts each have four independent camera stations which can support a mix of 70-mm, 35-mm, and video cameras. At a minimum, three KTM are used to record the drops in order to generate Time, Space Position Information (TSPI) data. The video tapes are read after the drops. The video reading station is equipped with a decoder and video reading software. The decoder allows the edge data (time, azimuth and elevation) to be read with each video frame. Calibration targets are used to determine the scale of video pixels to radians, which are known as “Reader Constants.” The Reader Constants give the conversion needed to calculate the azimuth and elevation of any pixel on the video screen, which is referenced to the center of the payload. Each test object is read to an individual file which contains time, azimuth, elevation, x counts (pixels), and y counts. Once these data files are created, they are processed to provide the TSPI solution. The processing is conducted using YPG-developed software which first reads-in each data file and uses the computed Reader Constants to produce the angular measurement to the test object. The software takes each measurement at a corresponding time to compute
TSPI by calculating the nearest intersection of each angular measurement. A sliding filter smoothes the output of TSPI and the program allows for rotation and translation of the output, if required.

C. Strain Links

Strain links were used to measure opening shock on the LCADS loads. The strain links consist of a metal “dog-bone,” full-bridged strain patch and amplifier. The output from the strain links was recorded on the Portable Data Acquisition System (PDAS) recorder. PDAS is a ruggedized, self-contained microcontroller-based data logger which provides up to eight channels of 12-bit resolution 0-5 volts, direct current (vDc) analog input, as well as a logic level switch input for event flagging. It has 2 Mb of non-volatile memory, which allows for up to 4 minutes of recording four channels at 1000 Hz sample rate. After recording, ASCII text data or binary data can be downloaded to a personal computer (PC) via an RS-232 connection. The amplified strain link output is 0-5 vDc, which is what PDAS digitizes and records. The voltage data are converted to force (pounds) by using a “K-factor” determined by the YPG Calibration Laboratory, and are unique to each link. To compute opening shock, the channel at each time interval is plotted, from which the maximum strain link force is determined. This maximum force experienced is divided by the suspended weight of the load. This gives opening shock in “G’s” (acceleration due to the earth’s gravity: 32.2 ft/s² or 9.81 m/s²).

D. Video

Ground-to-Air video was recorded using a stabilized KTM mount. A high-speed lens, 250 frames per second, was also used on the mount as a means of slow-motion tracking of the opening sequence of every LCADS drop. Onboard video cameras were placed to capture three main views: First Motion, Ramp, and Overall. The First Motion camera shows the initial movement of the CDS bundle and any interaction the bundle might experience on the inside of the aircraft. The Ramp camera points out the ramp door and down, to give a view of the initial canopy opening sequence. The overall camera was mounted further towards the cockpit but points towards the ramp, giving an overall view of each CDS bundle exiting the aircraft.

E. Descent Rate

An example of a plot for a Low Cost Hi-V CDS dropped from high altitude (25,000 ft MSL) is shown in Figure 8. Three lines of data are plotted together: uncorrected velocities or raw data, data corrected to standard day conditions, and data corrected to standard day sea level conditions per drop altitude. These lines depict the CDS load exiting the aircraft, experiencing the opening force from the canopy, and trying to reach a steady state velocity until ground impact. (The highest rate of descent is actually shown negative, as the Z-axis is defined as “up”.)
F. Opening Shock.

The Low-Cost Hi-V Canopy must withstand opening shock in order to keep the payload attached and secure. Opening shock data were recorded using strain links attached through the suspension line groups of the canopy risers, recorded by PDAS. From a Total Force plot of these data, the maximum strain link force at one instant was determined. A sample plot of strain link data, Total Force versus Elapsed Time, is shown in Figure 9. The data set for each DT drop was plotted and given a “sanity” check to make sure the data were good before picking out the peak opening force. The check includes looking at the plot trends before and after opening force. Prior to opening force, the strain link force should be zero as the load is still at rest on the aircraft. Any small peaks before opening force are either the load beginning to exit the aircraft or possibly external electromagnetic noise. After peak opening force, the strain links should show a force equal to the suspended weight of the load, total rigged weight minus the weight of the canopy, within 1 percent of full scale of the strain link used. Strain link data that did not meet these checks were deemed bad data.
FIGURE 9. OPENING SHOCK OF THE HIGH ‘V’ PARACHUTE

G. CONCLUSION

The LCADS Low-Cost Hi-V Canopy met the objectives of all subtests and is suitable for operational testing. All LCADS DT Phase 2 Low-Cost High-V Canopies were verified for field readiness condition prior to airdrop. The Low-Cost High-V Chute met the load capacity criteria of 2200 pounds (lbs), is compatible with U.S. Air Force (USAF) cargo aircraft, is operationally suitable to be dropped from 25,000 ft, can survive ground impact at high velocities, is capable of delivering a serviceable load in greater than 13-knot ground winds, and meets the specifications of 0.92 reliability at 80 percent confidence and 0.85 probability of airdrop completion without the occurrence of an Essential Function Failure.

VII References