R79-112

AIAA PAPER No. 75-1386

DEVELOPMENT OF A HIGH-LEVEL CONTAINER AIRDROP SYSTEM

by
GEORGE A. BARNARD
U.S. Army Natick Development Center
Natick, Massachusetts
WALTER L. BLACK
AAI Corporation
Cockeysville, Maryland
and
FRED W. HAWKER
Payne, Incorporated
Annapolis, Maryland

AIAA 5th Aerodynamic Deceleration Systems Conference

ALBUQUERQUE, NEW MEXICO/NOVEMBER 17-19, 1975

DEVELOPMENT OF A HIGH–LEVEL CONTAINER AIRDROP SYSTEM

George A. Barnard*
US Army Natick Development Center
Natick, Massachusetts

Walter L. Black*
AAI Corporation
Cockeysville, Maryland

Fred W. Hawker*
Payne, Inc.
Annapolis, Maryland

Abstract

This paper reports the development of a system for airdrop, from high altitudes, of bulk supplies to military units. It details a computer-trajectory-simulation study which led to the conclusion that an airdrop system to achieve a 200 m CEP from 3050 meters altitude was feasible. The subsequent design and evolution of such a system are described, with particular attention to the practical solution of dynamic-stability problems manifested during test. The latter part of the paper covers the early development of a follow-on system designed to fulfill a new requirement for equal accuracy from 7600 meters altitude. The new system's evolution is shown, from preliminary design, through early half-scale flight tests, static and dynamic wind-tunnel tests, and a 6-DOF computer simulation intended to establish the dynamic-stability limits of the new design. Plans for the future development of the system are described.

I. Introduction

Repeatedly in the past ten years, it has proved necessary to supply besieged garrisons by airdrop techniques, with ever-increasing losses to antiaircraft weapons. Early attempts to develop airdrop from high altitudes were abandoned due to high costs and the lack of any system for positioning the drop aircraft with sufficient accuracy.

An aircraft navigation system, the Adverse Weather Air Delivery System (AWADS), capable of locating the drop aircraft, with respect to the drop zone, within 100 meters, is now in existence. Given this capability, the Air Force developed a system, based upon timed disreef of the recovery parachute, with which high-level airdrop was again attempted. The system proved less accurate than was hoped for, however.

At this point, Natick Development Center launched a program to achieve the necessary capability while avoiding the defects of the previous systems. The initial step was to define the problem, rather than to assume the general form of the system desired, a priori, as in all previous attempts. Specifically defined were: the load (one metric ton), the accuracy required (200 m CEP), and the drop altitude required (3,050 m). The AAI Corporation contracted to define broadly the system required to cope with the constraints. The system was to be called: High-Level Container Airdrop System (HCLADS).

II. Defining the HLCAD System

Method

Information was acquired and analyzed on both operational and experimental systems employed in container cargo airdrop operations to determine which designs and procedures might be suitable for high altitude airdrop. This part of the study led to the conclusion that the procedures employed in the current (standard altitude) Container Delivery System (CDS), up through cargo release, were suitable for high altitude operations. This was fortunate, for it minimized the impact that the high altitude system would have on operational procedures. It was further concluded that equipment of the sophistication of the AWADS was essential for computing and flying to the proper air release point. This system, using wind data at the drop altitude, which it senses along with other necessary data, iteratively determines a Computed Air Release Point (CARP). This enables the pilot to fly to the proper release point with an estimated accuracy of 100 meters.

Employing these procedures and equipment the containers can be released into the airspace at the proper point. The remaining task is to enable the containers to traverse the airspace without being carried off-course by unknown winds. The approach centered on equipping the standard cargo sling, termed an A-22 container, with a two-stage parachute arrangement with the first stage designed to arrest container tumble caused by tip-off during release and to provide stable aerodynamic flight at minimum drag. The second or recovery-stage parachute was to be deployed at the least height above ground level that would assure time for deceleration to a safe touch-down velocity.

Performance of numerous configurations was analyzed by computer simulation. A three-dimensional trajectory model was employed which was capable of computing the effects of wind vectors that vary in magnitude and direction as a function of altitude. The output from the computer was given as a function of time and consisted of the distance traveled, velocity and acceleration of the cargo for each coordinate with respect to a ground-fixed origin. Parachute position was also given in the same coordinate system plus the line tension between the parachute and cargo.

Wind Profiles

The wind conditions were input to the model as boundary conditions, so for meaningful results it was necessary to make these inputs represent real world conditions as nearly as possible. After considerable search a body of wind data, taken at the Eastern Test Range[1], was located that provided the type information required. These data included 112 cases of soundings taken over an eight-month period, and giving wind direction and magnitude at 25-meter intervals. Eight cases were eventually selected from this body of data for use in the trajectory simultations. Most of these cases were selected because they represented a particularly-adverse condition such as the greatest variation in magnitude or direction. A plot of Wind Case No. 50 shown in Figure 1 is a plot of a typical wind profile.

*Member, AIAA

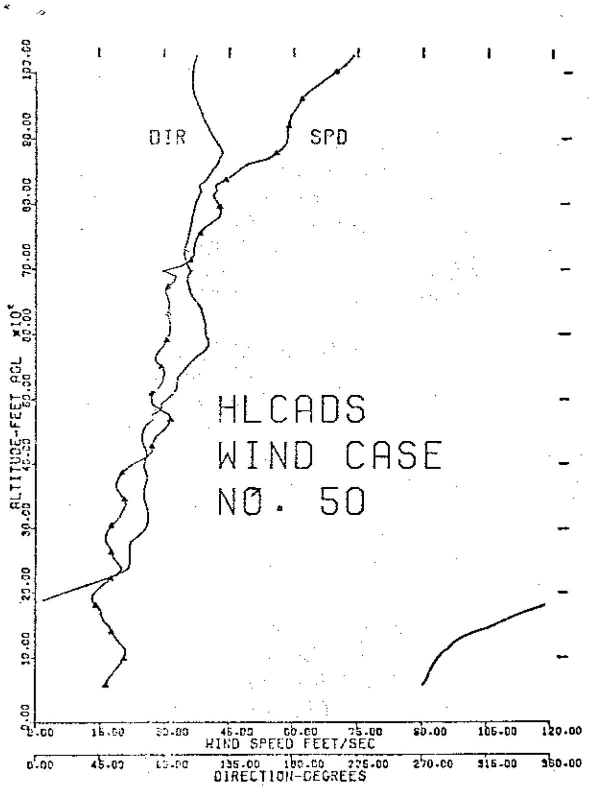


Figure 1 - Typical Wind Profile

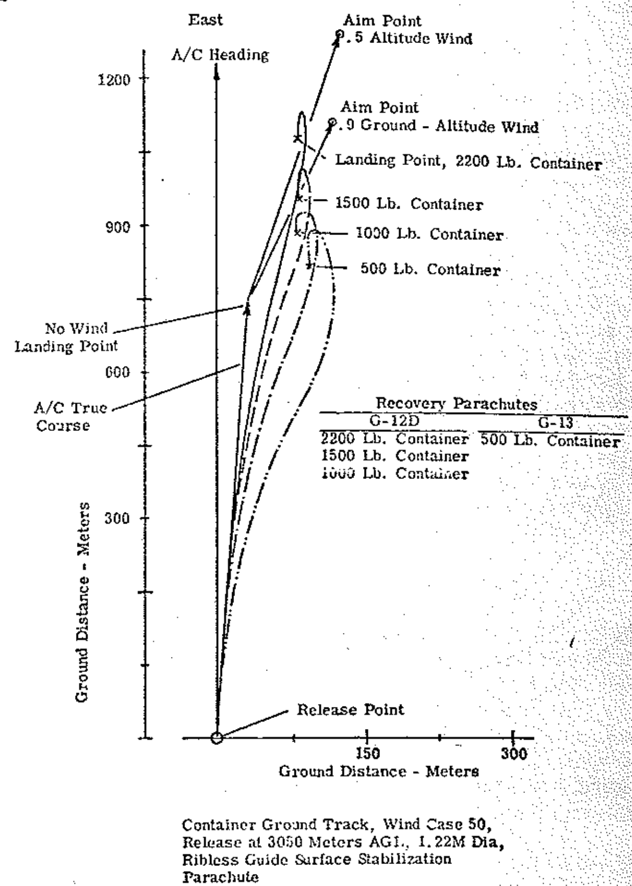
Results

Ballistic coefficients of the hypothetical containers were altered by changing their weight and parachute configuration. Trajectories for each design were computed using the selected set of critical wind conditions. The ground track, or the trace of a vertical line from the cargo on the ground, was the result of interest. A typical set of ground track plots is shown in Figure 2.

The study revealed, as suspected, that the most critical factor from an accuracy viewpoint was the unknown wind profile. This is most clearly evident for the case of a design with an assumed reefing arrangement such as shown in Figure 3. The accuracy of such a system was rendered unsatisfactory by wind effects as illustrated in Figure 4. Satisfactory accuracy, however, was indicated for systems using a two-stage arrangement where the first stage parachute was as small as possible consistent with stabilization needs. Such a system is characterized by a terminal velocity some three times that for a disreef system.

Recommended Configuration

Final recommendations specified a separate 1.22 meter-diameter ribless guide-surface first stage parachute. This gave a peak descent velocity of 75 meters per second. It was further recommended that a G-12D second-stage parachute be used on containers weighing 450-kg or more and a G-13 parachute on the lighter cargoes. Deployment of this second-stage parachute should occur at 150 to 230 meters above ground level. A height sensor carried on the container controls this deployment point. A plot showing the predicted impact pattern of a one metric-ton container dropped with a set of varying wind conditions is shown in Figure 5. These



Container Ground Track, Wind Case 50, Release at 3050 Meters AGL, 1.22M Dia, Ribless Guide Surface Stabilization Parachute

Figure 2 - Typical HLCADS Trajectories

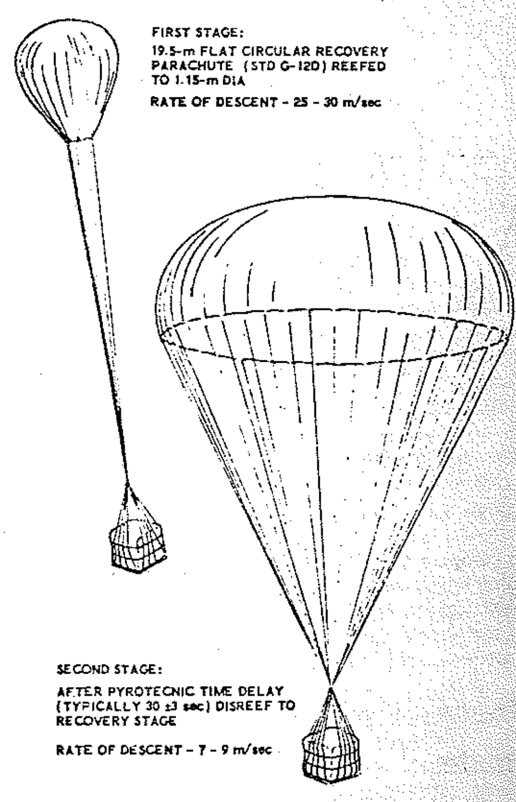


Figure 3 - Early Delayed-Disreef System

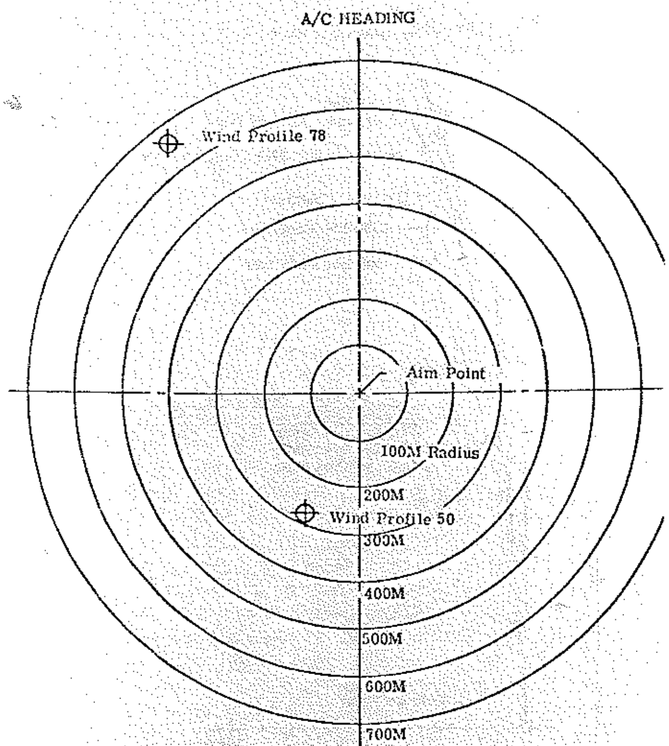
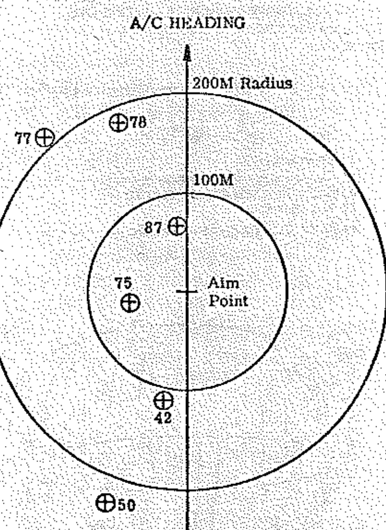


Figure 4 - Impact Accuracy, Disreef System



Circular Impact Pattern Using Altitude Wind, 4 Ft. Dia. Ribless Guide Surface Stabilization Parachute, 2200 Lb. Cargo

Figure 5 - Impact Accuracy, HLCADS

results give a computed CEP of 140 meters. The computed air release point employed the wind at drop altitude only; therefore, these results represent the accuracy that can be expected in a real world airdrop operation. Complete results of this study are given in Reference 2.

III. Evolving and Testing the HCLAD System

Actual Configuration

The next technical problem was to embody the defined characteristics in a real system, providing for low drag, aerodynamic stabilization, staging, and parachute recovery. It turned out to be possible to accomplish all these functions without radical innovations. First, the basic cargo, without any parachutes deployed, proved to have a terminal velocity of 98 meters per second. A small parachute, sufficient to provide static stability, would reduce this only to the requisite 75 m/sec. The AAI study recommended a 1.22 meter ribless guide-surface parachute for this purpose, on the basis of wind-tunnel data. In practice, it developed that the 1.73 meter octagonal pilot parachute which was already part of the existing system, gave adequate stability and a terminal velocity of 74 m/sec, close enough and much cheaper.

The parachute-recovery function was complicated by the fact that the necessary first stage velocity exceeded the critical opening velocity of the recovery parachute, necessitating use of a vent-control line which facilitated the opening process but multiplied the opening shock. The standard G-12D recovery parachute and A-22 cargo sling were found capable, however, of sustaining the opening shock loads, if new equipment was used.

Dynamic Stability

Testing revealed that the high first-stage velocity imposed a significant dynamic problem: Cargoes are almost always statically unbalanced, and so, when suspended, have a static angle of attack which may be large enough to lie in the range of aerodynamic instability. (Stability characteristics of an unstabilized, half-scale model A-22 container load are shown in Figure 11). The resulting unstable moment will, of course, increase with the square of the velocity. Moreover, the principal dynamic axes are usually misaligned sufficiently to promote coupling of the various modes of motion. The practical result of this is that the cargoes tend to oscillate and spin (sometimes violently) under their stabilization chutes. Solutions to the dynamic instability problem were worked out by cut and try in the course of flight tests on the National Parachute Test Range in El Centro. (The configuration evolution is shown in Figure 6.) The load stability was improved by providing a second cargo sling so as to permit four-point suspension in the first stage as well as in the recovery stage. Stability may also be improved by lengthening the drogue riser to put the drogue clear of the extreme turbulence immediately aft of the cargo. This, however, results in the risers of adjacent loads tangling when they are released simultaneously. (It should be understood that, in airdrop operations, an entire aircraft is emptied of such loads in a single pass, in a manner not unlike that of a dump truck.) The solution was to provide a two-section riser. The first section, 1.5 meters long, is deployed along with the drogue, by static line. The second section, 3 meters long, is initially "S"-folded with its ends secured together by a 250-kg break tie which permits its deployment to form a total 4.5-meter riser when the drogue pull exceeds 250-kg. The concomitant time delay allows adjacent loads to separate.

The cargo is suspended from the drogue riser by the four webs of the outer cargo sling. The connection is a webbing loop which carries a cartridge-actuated cutter. Staging occurs when the cutter is fired, severing the loop and thus permitting the four outer suspension webs to fall clear while transferring the drogue pull to the recovery-parachute deployment line. The recovery parachute then suspends the cargo by the inner cargo sling in the conventional manner.

Staging may be initiated by any of several developmental devices which include timers, barometric-pressure sensors, and ground-proximity radars.

The resulting configuration is usable, involves all standard equipment, but has the distinct disadvantage of being quite

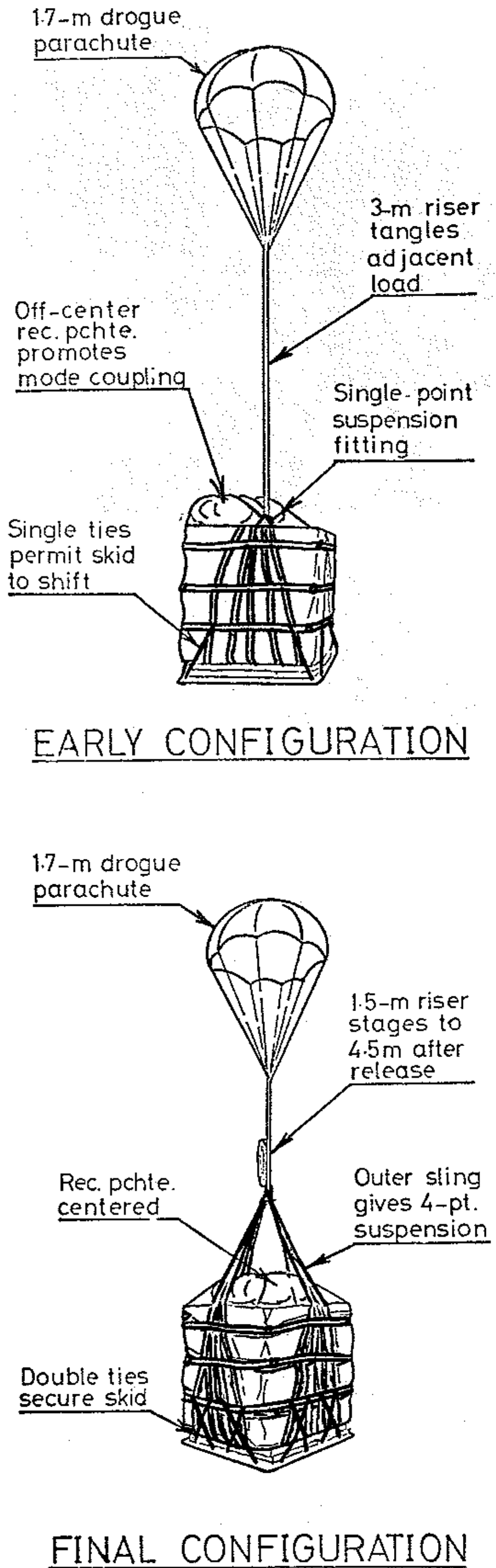


Figure 6 - Evolution of HLCADS Configuration

complicated to rig. The tests were conducted jointly by the Army and the Air Force, and are reported in Reference 3. The final configuration represents a blend of Army and Air-Force ideas.

IV. New Altitude Requirement

At this point in the development, an entirely new requirement was imposed. As a result of the appearance of shoulder-fired guided missiles on the battlefields of Southeast Asia, the Air Force determined that it would now be necessary to airdrop from 7600 meters in the combat environment. The new requirement necessitated an entirely new development program, since the previous (3050 m) requirement taxes the limits of the configuration already developed. It was determined that the first-stage terminal velocity to achieve the still-required 200 meter CEP from 7600 meters must be at least 127 meters per second, based on an extrapolation of the previous AAI study. There was some question, whether such a velocity was feasible at all. It was decided, in view of the evident difficulty of meeting the new requirement quickly, to continue development of the system already in work to provide an early capability and to be known as Interim HLCADS. Concurrently, we would commence development of the new system, to be known as,Ultra HLCADS.

V. Defining the UHLCAD System

The nature of the cargoes to be dropped had not changed, which is to say that the new container must still be more-or-less cubical in form. Experience with the Interim HLCAD System had shown the necessity for special attention to dynamic and aerodynamic stability. The parachute-recovery stage was now to be complicated by the much-greater kinetic energy of the first stage, thereby requiring an intermediate parachute stage or some form of opening-shock attenuation.

The initial contract program called for preliminary design (Phase I) of a first-stage aerodynamic configuration, wind-tunnel tests (Phase II) to establish aerodynamic characteristics (including damping) of this configuration, and a computer simulation of its motion in six degrees of freedom, as affected by anomalies, static and dynamic imbalance, and the like (Phase III).

Design Phase

Payne, Inc., of Annapolis, Maryland proposed a configuration, using a low-drag forward fairing and a stabilization device (called an "in-plane" stabilizer) like a square version of the flare stabilizer used on certain reentry bodies. This configuration is shown in Figure 7. Early in the development, it became evident that it would be advisable to verify the aerodynamics of several variations of this design. The aerodynamic verification of the proposed designs was accomplished in two steps: first, dynamically-scaled models for airdrop testing and second, models for wind-tunnel testing were constructed. Both of the tests used half-scale models.

The dynamic and wind tunnel models were designed and built by Payne, Inc. The Army, through its facilities at Natick Development Center, provided the support and experience needed to accomplish the dynamic tests (i.e. helicopters, recovery crew, drop zone, etc.). The wind tunnel models were tested in the University of Maryland's 2.36 by 3.36-meter subsonic wind tunnel facility (Glenn L. Martin Institute) during November 1974 and January 1975.

The purposes of the two types of testing were:

1. Achieve the greatest possible flexibility in the design phase of the development so that needed aerodynamic changes could be recognized and made before the design was "cast in concrete".

2. Investigate dynamic stability of the designs.

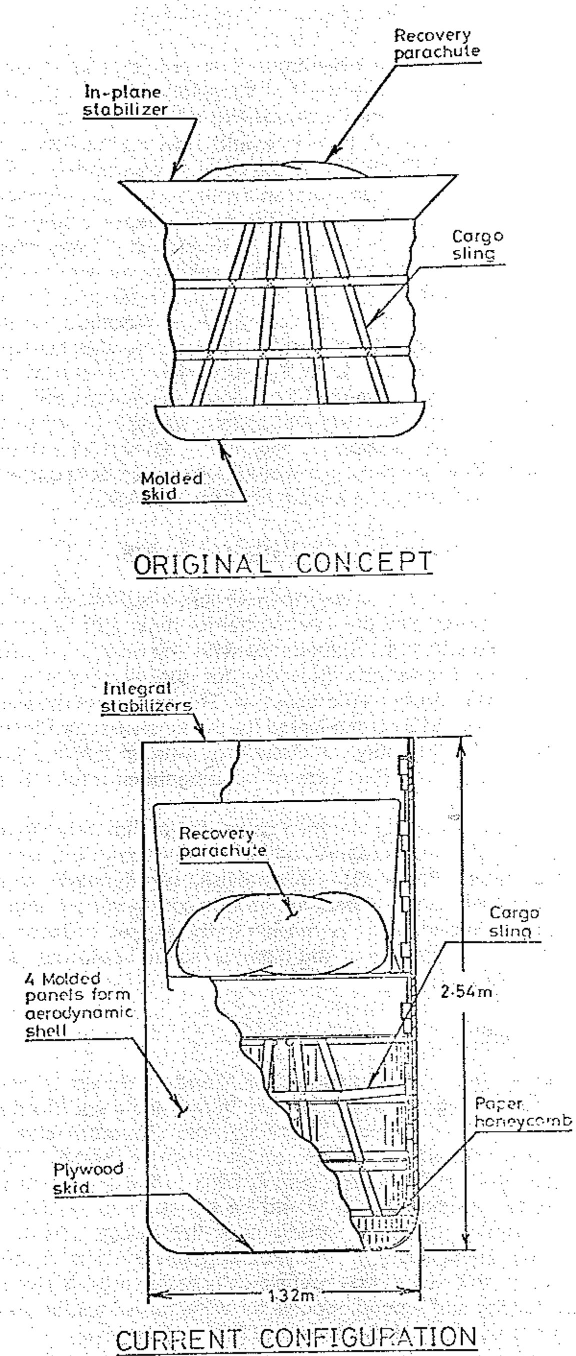


Figure 7 - Evolution of Ultra-HLCADS Configuration

3. Check the feasibility of parachute deployment from the proposed designs.

4. Measure aerodynamic coefficients of various proposed configurations.

Airdrop Tests

Two series of airdrops of half-scale models of the UHLCADS (dynamically scaled by Froude criteria) were conducted at Ft. Devens, Massachusetts. The drops were from 600 meters from UH-1 helicopters with the side doors removed. The models weighed 142-kg each, without the 11-kg T-10 recovery parachute. The first series models were configured with rounded noses and flared stabilizers (Figure 8).

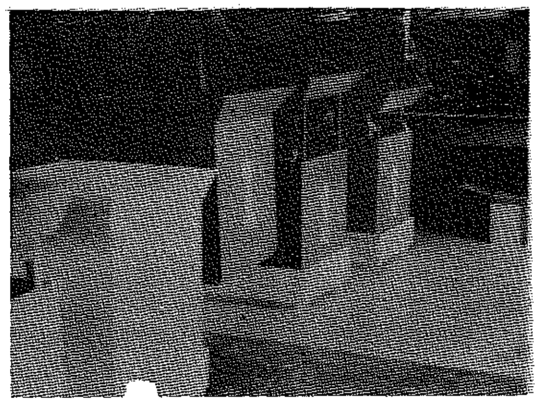


Figure 8 - UHLCADS Half-Scale Drop-Test Models First Series

They were dropped from the helicopter at an angle of attack corresponding to 90° from the design angle at which the optimum drag and best stability characteristics exist. Movies of each trajectory were recorded. The results of the first test series showed that the flare stabilization concept left something to be desired in the area of dynamic stability. Therefore, a second series of half-scale models was constructed having lift-type stabilizers somewhat similar to a bomb tail. The noses had carborundum-grit transition strips to simulate full-scale Reynold's number. These drop tests were conducted under conditions similar to the first series. The launch attitude of the models was changed to nose-forward. (In the operational mode the initial attitude will be nose-into-the-wind, with an initial tip-off pitch rate.)

The new design proved dynamically stable and very clean. One recovery parachute failed to deploy, giving a chance to time the test item into the ground and so estimate its drag coefficient at 0.36, later confirmed by wind-tunnel test.

Wind Tunnel Tests

There were two series of wind tunnel tests. The first series tested the same configurations that were air-dropped the previous month plus several new ones that were designed to correct the instabilities apparent during the initial drops. A typical test model is shown in Figure 9. The second test series

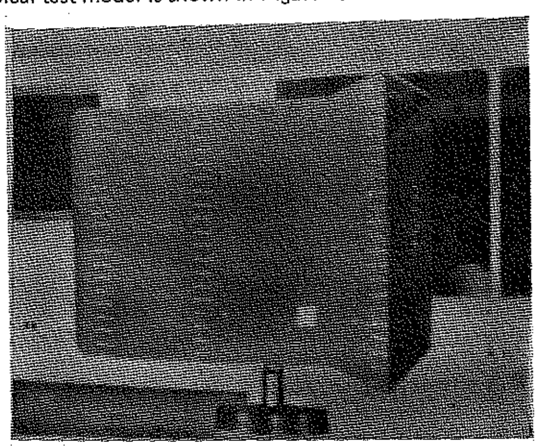


Figure 9 - UHLCADS Half-Scale Wind-Tunnel Model First Series

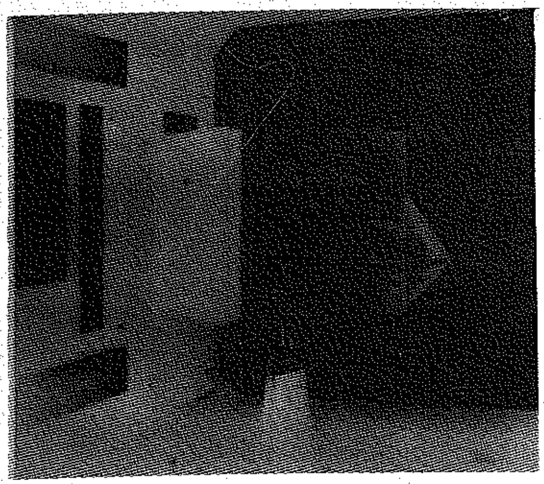


Figure 10a - Standard A-22 Container
Half-Scale Wind-Tunnel Model

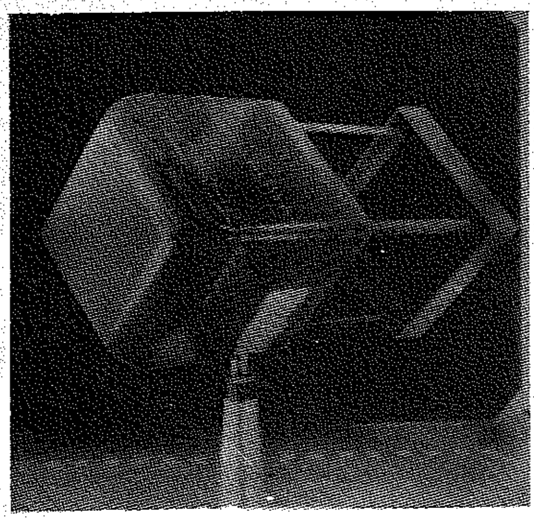


Figure 10b - UHLCADS Half-Scale Wind-Tunnel Model
Second Series

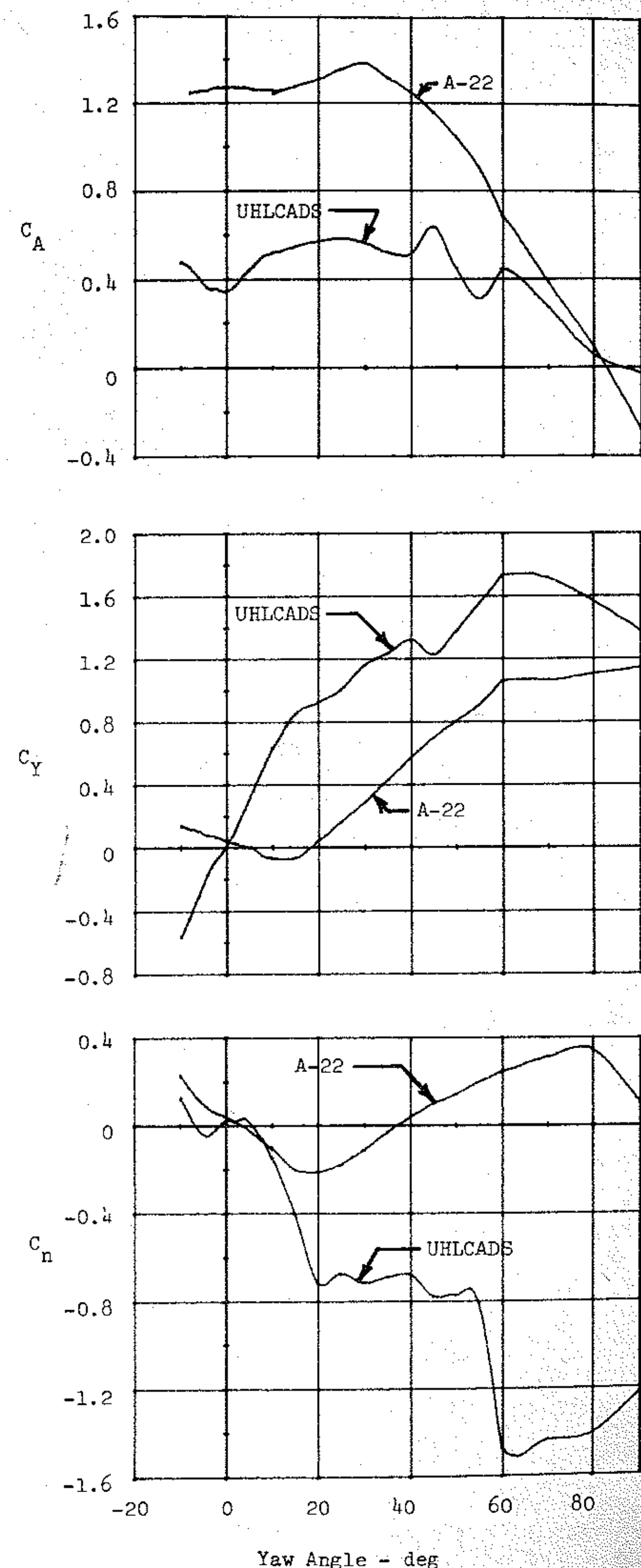


Figure 11 - Typical Wind-Tunnel Data
Second Series

concentrated on specific optimization of the design that had proven successful during the second airdrop. Aerodynamic characteristics of a standard A-22 container were measured for comparison. Test models are shown in Figure 10. The half-scale model tests consisted of standard yaw sweeps from -10° to 180° at fixed roll and pitch angles. The balance data were recorded digitally for both wind and body axes. Damping characteristics were determined by a timed, free-oscillation technique.

The wind tunnel tests evaluated the following:

1. The forces and moments of the candidate designs.
2. Yaw damping of the optimum configuration.
3. Pressure distribution over the nose.

The results confirmed the estimate of the clean-configuration drag coefficient; the static stability was found to be adequate.

Typical wind-tunnel results for the current UHLCADS configuration are compared to those for a standard A-22 container (without drogue) in Figure 11.

The current UHLCADS configuration displays two stable trim points, one on either side of zero yaw, according to the wind-tunnel data. This is related to the interaction between the base flow and the stabilizing surfaces. It has been established that single-point stability may be restored by adding the recovery parachute pack to the base of the cargo, as illustrated in Figure 7. The axial-force coefficient indicated at zero yaw confirms the drop-test value and corresponds to a terminal velocity of 170 meters per second at MSL, in full scale.

The wind-tunnel tests also yielded measured pressure distributions on the nose fairing. These confirm that the large drag reduction arises from thrust forces on the fairing and that the fairing also generates substantial destabilizing moments at non-zero angles of attack. This is what overpowered the "in-plane" stabilizer and required the change to a "bomb-tail" stabilizer.

Results of the yaw-oscillation tests indicate a yaw (and pitch) damping coefficient of -0.14 ± 0.07 sec/radian for the current UHLCADS configuration.

Motion Simulation

The third and final phase of Payne's Inc. work on this project is to use the results of the tests in Phase II as input to a six-degree-of-freedom computer simulation of the first-stage trajectory. The main objective of this effort is to establish the tolerable degree of mass assymmetry consistent with stability. Additionally, it should predict the effects of tip-off and of wind shear. At this writing, the effort is still in progress and no results are yet available.

VI. Future Plans

Assuming that the final results of the Payne, Inc. study are as encouraging as they have been, future plans include full-scale airdrop tests of the first-stage configuration and development of a parachute recovery system which may involve either:

1. An intermediate parachute stage or

2. Opening shock attenuation by means of some form of controlled reefing.

In either case, it will be necessary to develop a staging device which will provide for the period between initiation and completion of the recovery function.

In military operations the Ultra HLCAD System will give field commanders the opportunity to provide accurate resupply airdrops from whatever altitude suits the tactical situation without prohibitive losses of aircraft or materiel.

Although the results of this development may well be useful in other areas, its technical interest lies principally in the application of a rational engineering approach to an area which historically has been dominated by ad-hoc procedures and "cut and try" design.

Acknowledgements

The assistance of the personnel of the University of Maryland's (Glenn L. Martin) subsonic wind tunnel facility is deeply appreciated. Also, the comments and criticism of Dr. Jewel B. Barlow of the University's Aerospace Department have been invaluable.

The help and consultation of Mr. Edward J. Barnicle of Army Natick Development Center and Mr. Carl B. Mihlbachler of Air Force Systems Command, in the evolution of the Interim HLCADS configuration, are gratefully acknowledged.

References

1. Scoggins, J. R. and Susko, M.; **FPS-16 Radar/Jimsphere Wind Data Measured at the Eastern Test Range;** NASA TM X-53290; George C. Marshall Space Flight Center, Huntsville, Alabama; 9 July 1965.

2. Farinacci, A. L. and Bruner, D. B.; **High-Level Container Airdrop System**; Technical Report 73-55-AD; Army Natick Laboratories, Natick, Mass.; March 1973.

3. Krizauskas, J., Massey, W. N. and Morrison, R. L.; **Development and Evaluation of a Two-Stage, High-Altitude Container Airdrop System;** AFFTC-TR-74-32; Air Force Flight Test Center – Edwards Air Force Base, California; November 1974.