U. S. Air Force Concepts for Accurate Delivery of Equipment and Supplies

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For many reasons it is often impractical to land and off-load an aircraft or use conventional parachute delivery techniques to provide logistic support for military troops engaged in combat. This problem of getting supplies and equipment to the point of need involves both resupply and assault phases. Each phase has peculiar characteristics which, in addition to the type and quantity of cargo needed, permit one of a family of aerial delivery systems to provide the necessary support. Descriptions of these systems and their characteristics, which provide a high degree of flexibility in the aerial delivery of cargo, are presented. The impact of new aircraft such as the C-141, C-142, and C-5A on mission versatility and capability are discussed as well as problem areas associated with making more effective use of aircraft capability.

Introduction

In attempting to convey aerial delivery development efforts in a manner other than the usual tabulated listing, an approach was taken which is oriented towards considerations one must make when confronted with a delivery requirement which he feels can be satisfied only through selection of an airdrop technique. Consideration of these factors early in development can greatly facilitate decision-making on hardware configuration.

Background

Our U. S. Army is a mobile, fast-moving force capable of combating today's cold-war sparks around the world on very short notice. This force needs large quantities of food, ammunition, fuel, communication and engineering equipment, and heavy artillery. This capability and associated responsibility depends on the Army using every means of transportation known to man—and in a hurry. This last phrase dictates initial stage movement of most of these items by air. Movement by air, however, does not of itself satisfy the end requirement which is to provide these necessities of combat life within arms reach of the fighting men.

There has been an aerial delivery system of one kind or another since the early days of aviation history, but airdrop as an accepted alternate rather than emergency means of delivery did not really come of age until World War II. The aircraft used, however, were limited in capability to that load which could be ejected from a side door or bomb bay. Acceptance of this mode of delivery led to development of the rear loading cargo aircraft and an airdrop system capable of airdropping loads weighing up to the carrying capacity of the aircraft at altitudes ranging from 700 to 1500 ft, depending on the load size, parachute configuration utilized, and number of aircraft in formation.

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The combined effect of increasing demands on accuracy of delivery and quantity of cargo to be delivered coupled with advancements in aircraft detection and antiaircraft weapons, making this altitude range highly uncomfortable in a combat area, has led to expansion of the entire aerial delivery concept. This expansion has resulted in a family of aerial delivery systems that permit closer attainment of the end goal, that is, cargo delivered at arms length.

Aerial Delivery Altitudes

Expansion of the aerial delivery concept to provide the much needed, better, bigger, broader service can be analyzed easier after a breakdown into altitude ranges. It will be seen that each range or a portion of each range has attributes which, under certain combat environments, would better suit the mission requirement. This breakdown can be accomplished in the following categories: 1) 0 to 20 ft above ground level (AGL), 2) 20 to X ft AGL, 3) X to 1500 ft AGL, and 4) 1500 plus ft AGL. (X is an ill-defined line somewhere between 300 and 500 ft AGL, depending on the operational environment.)

Since many of the factors that lend themselves to discussion of these altitude ranges are based on comparison with the original 700- to 1500-ft technique, discussion of that technique will be made before proceeding further. This method, hereafter referred to as the standard system, is illustrated in Fig. 1. Airdrop is initiated through deployment of 15-, 22-, or 28-ft ringslot parachutes either singularly or in clusters which, upon inflation, develop sufficient force to overcome the load restraint break ties or a mechanical load restraint mechanism to extract

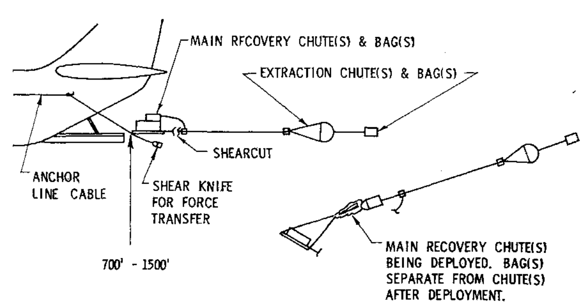


Fig. 1 Standard system.

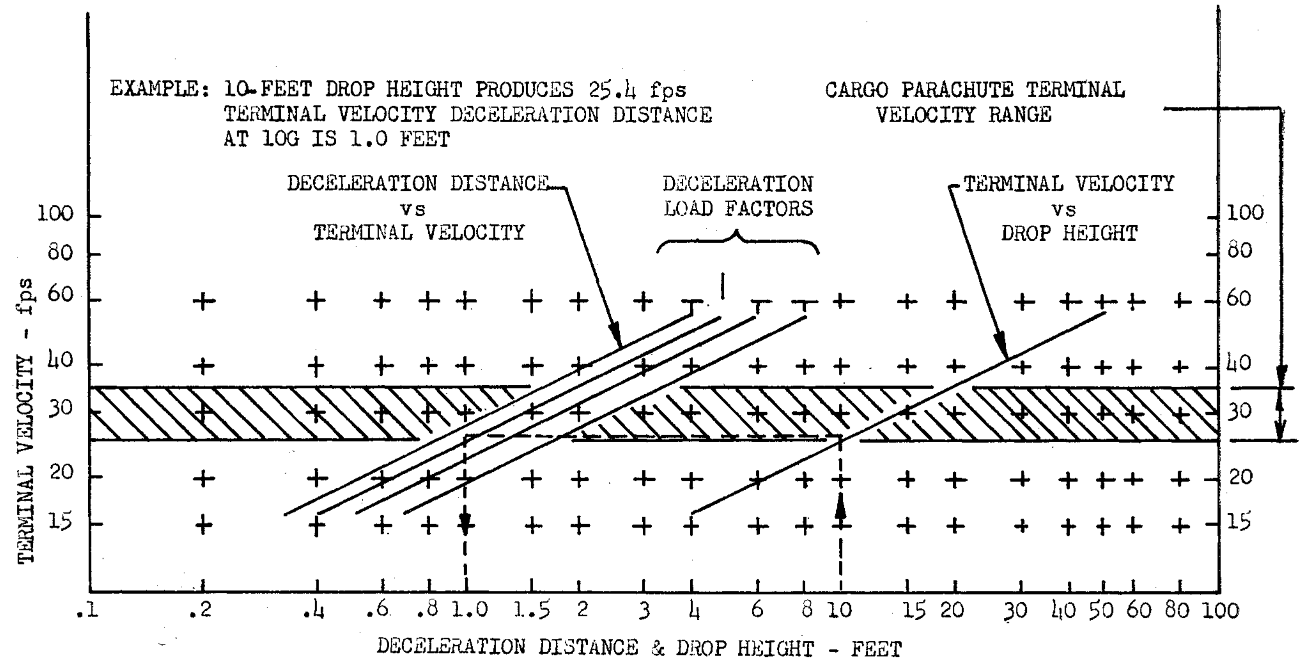


Fig. 2 Deceleration load factor vs free-fall distance.

the load from the aircraft.‡ As the load crosses the ramp, a knife, which is restrained to the aircraft but which has been moving along with the load, cuts through the extraction line near the load. The force from the extraction parachute is thus transferred and used to deploy the 64- or 100-ft-diam solid flat circular main recovery parachute(s). These parachutes provide a controlled descent of the load at 25–30 fps, and are released upon ground impact through relaxation of a force-carrying member. This system can be used to deliver single or multiple loads weighing up to 35,000 lb and has a delivery accuracy in the neighborhood of 500 ft from a predetermined point. Delivery of multiple loads is accomplished by having the first load out extract the extraction parachute for the second load and likewise for additional loads. Deceleration of the cargo at ground impact is accomplished through use of crushable paper honeycomb. Since there is no controlled orientation between the cargo horizontal axes and the direction of travel at ground contact, this system has a practical surface wind limitation of 15 knots. Dropping in higher wind conditions incurs a corresponding risk of load toppling and rolling after impact. A 15-knot wind limitation may not appear too restrictive, but the *USAF Handbook of Geophysics, 1960*, indicates that there is a 90% calculated risk (exceeding 10%) of a steady surface wind of 15 knots with random gusts of 25 knots and occasional gusts to 35 knots over 60% of this continent at least nine months of the year (this excludes the Rocky Mountain Area). These expectations may be considered representative of midlatitude conditions throughout the Northern Hemisphere. Corresponding estimates for the Southern Hemisphere suggest even stronger surface winds.

0 to 20 Ft AGL

This is the altitude range which results in a free-fall velocity corresponding to the impact velocity obtained with the standard system (25–30 fps). Elimination of recovery parachutes reduces load preparation time and increases the weight of cargo delivered to total weight of rigged-load ratio. Cargo rigging and cushioning can be accomplished with hardware developed for use with the standard system. Figure 2 illustrates the relation between the free-fall distance to result in a particular impact velocity and a corresponding vertical deceleration distance required to keep the deceleration load factor within a range dictated by the type of cargo delivered.[2] Aircraft vulnerability to radar detection and wind effect on accuracy of delivery in this altitude range are nil. Susceptibility to ground artillery is low; however, susceptibility to small arms fire is high. Delivery accuracy can be very precise simply because of physical drop-point proximity. For fixed-wing aircraft this range requires a drop zone of sufficient cleared area to permit a flight profile such as that shown in Fig. 3, and the drop zone must be clear enough to allow for the load trajectory during horizontal deceleration.[2]

20 to X Ft AGL

The upper portion of this range X lies somewhere between 300 and 500 ft AGL and is that altitude at which radar detection and ground artillery become a problem. The actual figure is dependent on enemy capabilities. This range offers many of the same advantages as the 0- to 20-ft AGL range with respect to aircraft detection, delivery accuracy, and wind drift. Vertical velocity retardation techniques are required in this altitude range to prevent the deceleration force factor from exceeding allowable load limitations, or else energy absorption materials of prohibitive stroke length must be employed. The cleared area required for fixed-wing aircraft can be much smaller than the 0- to 20-ft AGL range because of flight-profile descent and ascent-area reduction. The cleared area is also smaller because horizontal deceleration can be accomplished throughout the vertical trajectories of the load without imposing a deceleration force factor beyond the load capability.

X to 1500 Ft AGL

Although this range does present the previously discussed standard system problem areas of aircraft detection and vulnerability to ground artillery, it has not been ruled out for potential improvement. Since X is the altitude at which

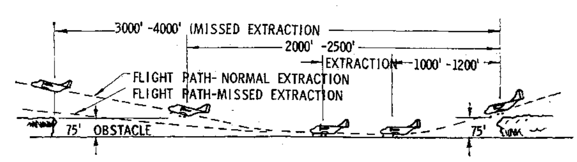


Fig. 3 Low-level flight profile.

‡ See Ref. 1 for descriptions and sketches of the various types of parachutes mentioned in this report.

detection and vulnerability start becoming a problem, then improvement can be accomplished by reducing the upper figure to as near X as possible. Overcoming wind-drift and system repeatability problems would greatly increase delivery accuracy, which is the other main problem area associated with dropping from this range. Large varieties of rigging hardware are already available, and flight profiles in this range are more all-weather oriented than in lower ranges where visual flying characteristics are a practical necessity. This is also the altitude range where airdrop of personnel is accomplished; and, under many situations, cargo and personnel must be dropped from the same aircraft on the same pass over the drop zone.

1500 Plus Ft AGL

This altitude range extends to the flight ceiling of the aircraft, and it is the upper portion of the range where aircraft detection and vulnerability are minimal, which is mainly in consideration. Drifting problems can be overcome by incorporating a built-in glide capability which can be used to resist wind drift and to direct cargo to the intended delivery site. The higher the drop height the greater the horizontal displacement capability. The low potential of visual aircraft contact from the ground coupled with the nonrequirement for visual ground contact from the aircraft make this range suitable for all-weather operation.

Aerial Delivery Systems

An arsenal of delivery systems to take advantage of particular characteristics associated with the various altitude ranges is in the final stages of development. This arsenal will be discussed in order of increasing altitude. In discussing the various delivery system mission characteristics, reference is made to assault, resupply, and special mission-type operations. Almost everyone has his own definition for these operations, so for clarification and consistency the following definitions are used in this report.[2,3]

1) Assault phase: For cargo delivery purposes this phase begins with the delivery of assault forces into an uncontrolled or hostile objective area and ends with delivery of all supplies necessary to support the initial assault forces in attainment of their objective.

2) Resupply phase: This involves large-quantity delivery of supplies necessary for follow-on support of assault phase and continued maintenance of stock levels thereafter. The area of delivery is secure or at least not openly hostile.

3) Special mission: This primarily involves small-quantity delivery to established sites or outposts that may or may not be surrounded by hostile territory. They are primarily resupply missions in nature in that they keep the outposts supplied with whatever is needed for them to continue with their mission.

For portions of this section and those which follow, the following list of abbreviations is provided for ease of reference: container delivery system (CDS), ground proximity extraction system (GPES), low-altitude parachute extraction system (LAPES), and parachute low-altitude delivery system (PLADS).

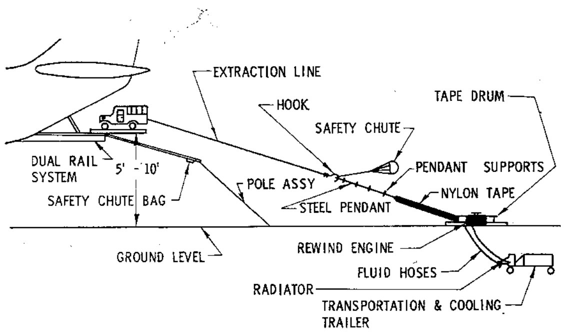


Fig. 4 Ground proximity extraction system.

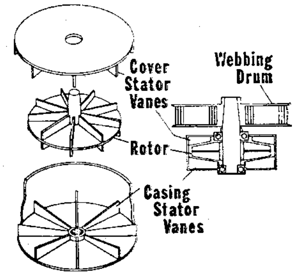


Fig. 5 Ground proximity extraction system energy absorber.

0 to 20 Ft AGL

Two different systems have been developed to take advantage of this altitude range. The ground proximity extraction system involves engagement of a ground station to extract the load, and the low-altitude parachute extraction system uses parachutes to extract the load.

GPES equipment

This system is comprised of an airborne equipment subsystem and a ground equipment subsystem. Figure 4 depicts a GPES delivery. The airborne equipment consists of a manually powered, hydraulically operated, lightweight, folding-pole assembly remotely controlled from a position in the forward portion of the aircraft cargo compartment. In the folded position the pole fits within the aircraft, permitting the ramp and cargo door to be closed. In the open position it extends 7 ft below the lowered landing gear, and all portions of the pole mounting and actuation hardware are below the level of the onboard roller conveyor system, which in itself is only 2.5 in. in height. An extraction hook, which is attached to the end of the pole with a release mechanism and a shear pin backup, is connected by nylon webbing to the cargo. The release mechanism trigger is mounted in the throat of the hook and is actuated upon engagement with the ground station. Actuation of the trigger also releases a latch which closes the throat of the hook and prevents disengagement from the ground station.

The ground equipment consists of an energy absorber and an energy dissipator. The energy absorber (see Fig. 5)[4] consists of a tape drum and a 24-in.-diam water brake mounted in the horizontal plane with the drum keyed atop the shaft of the water brake. Four-hundred twenty feet of 5-in.-wide nylon tape is stored on the tape drum in one-wrap layers. The water brake has a radially vaned rotor with a radially vaned stator on each side of the rotor. A gasoline-driven system is provided for tape rewind after extraction. The tape drum, brake, and rewind engine are mounted on a 4- × 6-ft base plate which is anchored to the ground with five to ten (depending on soil conditions) 3-ft-long aluminum stakes. The energy dissipator is a gasoline-driven cooling system, mounted on a trailer, which is used to lift and transport the energy absorber assembly. The cooling system is connected to the water brake by flexible hose. For delivery of cargo weighing from 2500 to 12,500 lb, two of the energy absorbers are installed on 100-ft centers bracketing the flightpath of the aircraft, and the ends of the nylon tapes are connected by a 75-ft steel cable. For delivery of cargo weighing from 12,500 to 25,000 lb, two additional absorbers are connected to the same cable. Installation time runs about 2 man-hours per energy absorber.

GPES operation

The pole assembly is extended prior to entering the extraction zone, and extraction is initiated when the hook at the end of the pole assembly engages the steel cable connecting

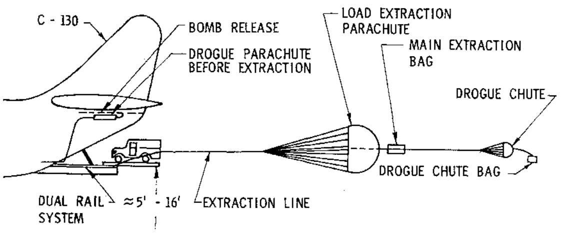


Fig. 6 Low-altitude parachute extraction system.

the energy absorber assemblies. Engagement of the cable also starts unwinding the energy absorber tape which in turn rotates the absorber rotor against the ethylene glycol and water fluid mixture. The fluid flow within the brake is primarily a flow outward between the rotor vanes from the rotor hub toward the rotor rim and, after turning 180°, it flows back toward the hub between the stator vanes. This flow, along with the turbulence within the flow pattern, develops a torque which is transmitted to the tape drum and, in turn, acts as a force resisting the forward movement of the cargo to be delivered.[5] In operation, some 5 sec elapse from the instant the hook contacts the cable until the load is at rest on the ground.

In the event that the hook hits a solid object such as a rock, prior to cable engagement, the hook release mechanism shear pin backup will fail and release the hook without damage. A 27-in.-diam ribless guide parachute attached to the hook deploys automatically upon any hook-pole separation and, in the event of a loose hook, provides a stabilizing force which helps to prevent the hook and extraction line from flailing into the aircraft.

GPES mission characteristics

The GPES is suitable for accurate delivery of large quantities of supplies and equipment to a preselected distribution point where troops and cargo handling equipment are geared to handle large volumes of heavy cargo. It also has potential for periodic resupply to a fixed installation site where accuracy of delivery is a definite requirement. Delivery capacities with this system are a function of the GPES recycle time and the time required to clear the extraction zone. The delivery cycle time can vary upwards from 2 min, which is nominal GPES recycle time, to about 5 min, which is fairly easily obtainable for sustained operation. Since in this altitude range cargo is not protected against high-vertical impact velocities, the GPES insures a proper delivery altitude because of the cable engagement necessity. Likewise, necessary cable engagement insures accuracy of delivery. Accuracy of this mode of delivery is such that a known weight being delivered will come to rest 90% of the time within 25 ft of a predetermined spot, and an unknown weight will come to rest 90% of the time within 50 ft of a predetermined spot.[6] Conversely, however, the necessity of cable engagement means that an aircraft must engage or go around for another pass, that flexibility for delivery site variation is limited to those sites equipped with the GPES equipment, and delivery of additional loads into an extraction zone is dependent on removing the previous load from the zone.

LAPES equipment

Figure 6 depicts a LAPES delivery. The extraction system consists of a tow plate; a 15-ft-diam ringslot drogue parachute; and a 22-, 28-, or 35-ft-diam ringslot extraction parachute used singularly or in combinations depending on the weight of the load to be delivered.

The tow plate is a force transfer device mounted to the aircraft floor near the aft end of the cargo compartment and consists of a 1-in.-diam pin for towing the drogue chute until extraction initiation is desired and a remote actuated spring-powered knife to effect force transfer. The extraction system contains electrically actuated pyrotechnic release devices to release the parachute should an extraction not be desired.

Early work in this altitude range indicated that a special platform would be required to withstand the abuse imposed by the horizontal velocity at impact with the ground. This early work also indicated that special rigging hardware would be required to permit extraction of bulk cargo loads. Solution of both problems has been accomplished through development of a special platform and an extraction line-load attachment briddle. The platform (see Fig.7) is an extruded aluminum modular design similar in cross section to aluminum landing

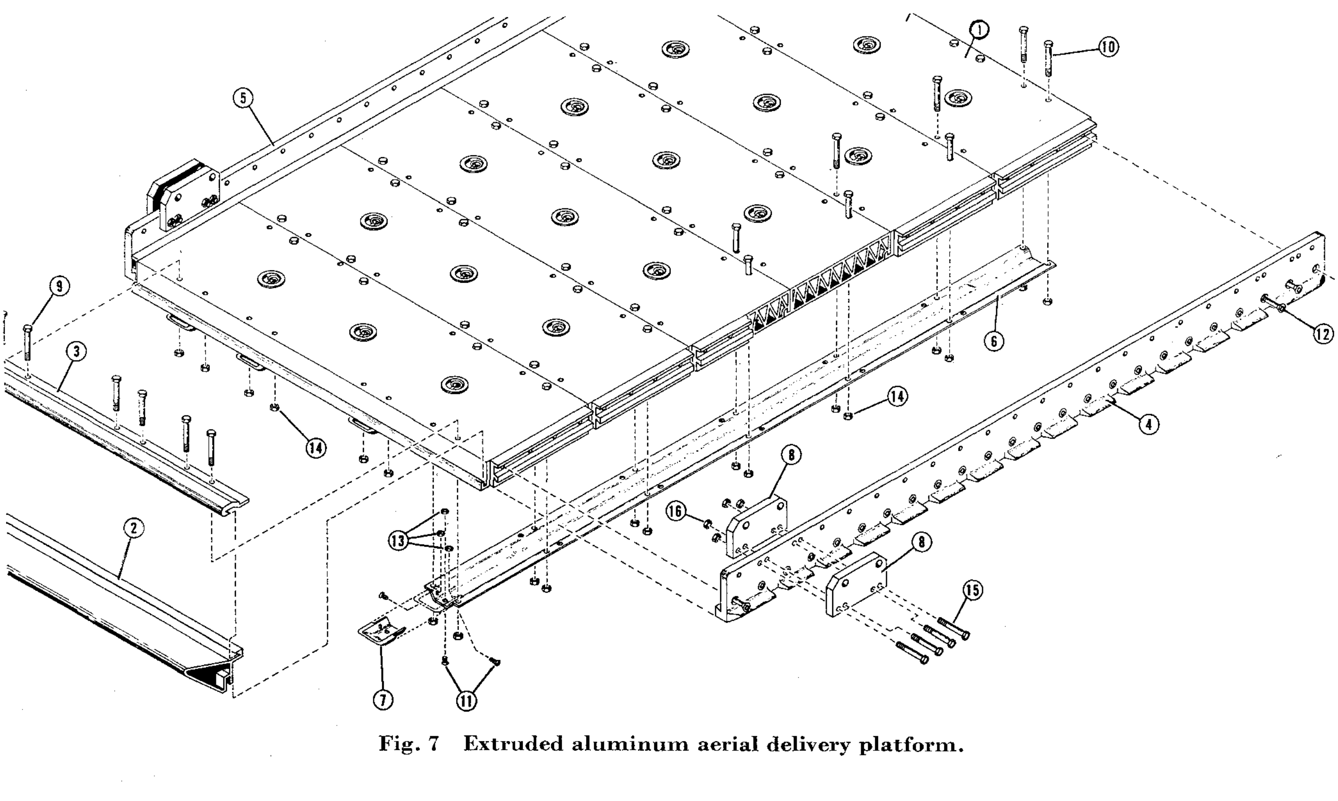


Fig. 7 Extruded aluminum aerial delivery platform.

mat. The modules are 2 × 9 ft and can be assembled into platform lengths of 8, 12, 16, 20, and 24 ft. The extraction briddle is basically a Y-shaped nylon line arrangement where the bottom portion of Y connects into the emergency release device previously mentioned, and the two upper legs of the Y extend along the sides of the load and attach to the sides of the platform near the front of the load. The vertical movement of the briddle at the rear of the load is limited through nylon restraints to the sides of the platform. In addition to providing a way of extracting any load, this briddle arrangement provides a means of controlling the platform attitude at impact with the ground.

LAPES operation

When the aircraft passes through 100 ft AGL upon entering the drop zone, the drogue parachute is deployed and the drogue line is restrained to the tow plate. Force transfer is operator-effected when the aircraft reaches the desired extraction initiation point and when sound signal from a sensitive radar altimeter indicates that the aircraft is at a proper delivery altitude. The drogue line pulls the extraction parachute out of the aircraft which inflates and extracts the load. The drogue parachute line runs through the apex of the extraction parachute and is connected to the main extraction line. The apex or vent of the extraction parachute is secured to the drogue line at a position near that which it has when the canopy is fully inflated. This is done for several reasons: 1) to expedite inflation of the main chutes, 2) to insure that there will at least be some force extracting the load even if the main chutes fail to properly inflate, and 3) to take advantage of the additional force which the drogue parachute can provide during extraction and arrestment. The portion of the drogue line between the apex and confluence point of the extraction parachute becomes the vent control line, as shown in Fig 8. As the extraction parachute is pulled from the aircraft by the drogue and starts to inflate, its initial stage of inflation appears as the reefed shape shown.§ This technique expedites canopy opening in that it presents a shorter length of travel and a smaller volume for that initial mass of air which must reach and fill the cap area to start canopy opening, and it pulls the vent inward, thereby preventing loss of this air. Accelerating opening of the extraction parachutes decreases inflation time by about 1.5 sec which in turn results in reduction of ground distance from force transfer to load rest by roughly 300 ft. The ground distance for loads weighing from 2500 to 35,000 lb delivered in this manner is less than 1000 ft, and the elapsed time from drogue parachute force transfer until the load is at rest on the ground is about 6 sec. Effort is continuing toward increasing unit load delivery capability up to the maximum capacity of the aircraft (52,000 lb for C130).

It is often the case that, say, 20,000 lb of supplies are desired but that because of bulk, odd configuration, materials handling equipment capability, or platform size availability, these supplies are available only in two 10,000-lb loads. Two loads having a combined weight of up to 48,000 lb can be delivered by having the first load out deploy the extraction parachute for the second load. The effects of attaching the second load directly to the first, and perhaps likewise attaching a third or fourth load to get the over-all extraction zone size down to that of a single load, are currently being investigated at a combined weight of up to 50,200 lb.

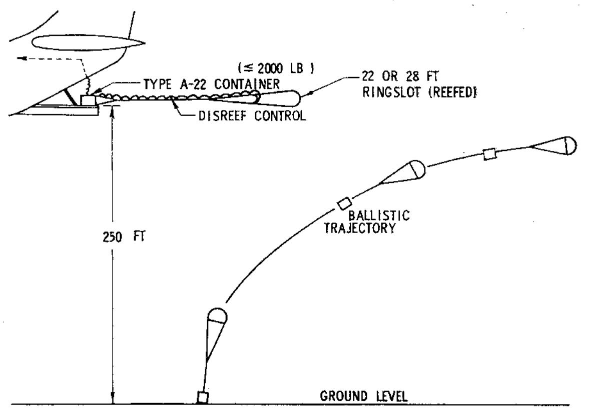


Fig. 9 Parachute low-altitude delivery system.

LAPES mission characteristics

The LAPES is suitable for delivery of supplies and equipment to both permanent and nonpermanent sites on an assault, resupply, or special mission basis. Because of its nonrequirement for a preinstalled ground station, this system has a large volume potential limited only by the pace at which the aircraft can traverse the extraction zone and the ability of any subsequent aircraft crew to deliver its load into the remaining open area. Nondependence on a ground station also permits multiple deliveries from the same aircraft on the same pass and permits considerable en route flexibility in selecting alternate drop zones. Although lack of a ground station has advantages, it also has drawbacks in that accuracy of delivery to a predetermined spot is a function of experience and proficiency which will not be the same with every crew. Likewise, altitude of delivery can be excessive. An operational accuracy determination has not yet been made, but it is estimated that delivery can be accomplished within 150 ft of a predetermined point.

20 to X Ft AGL

As previously stated, X is an ill-defined line somewhere between 300 and 500 ft AGL but will be assumed as 500 ft for discussion of this range. Four different systems have been developed to take advantage of this altitude range: 1) PLADS, 2) CDS, 3) mains extraction system (MES), and 4) high-speed delivery system.

PLADS equipment and operation

Figure 9 depicts a PLADS delivery. As the aircraft is en route to the delivery site the load to be delivered is manually positioned onto the ramp of the aircraft. As the aircraft nears the extraction zone a reefed parachute is deployed and is towed against the load until the desired extraction initiation point is reached, at which time the parachute is disreefed by an electrically actuated pyrotechnic cutter. Inflation of the parachute overcomes the load restraint and extracts the load. The parachutes used at 22- and 28-ft-diam ringslots result in impact velocities of 70 to 90 fps.

This system is a means of delivering, on a single pass, one or two plywood-bottomed fabric supply containers capable of holding from 500 to 2000 lb each. Accuracy of this system,

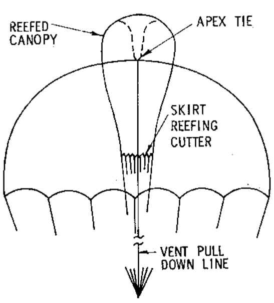


Fig. 8 Vent control 1) without skirt reefing hardware; 2) with skirt reefing hardware.

§ The skirt reefing hardware is not part of Fig. 8 and will be discussed in a later section.

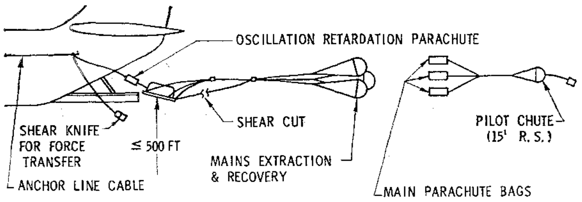


Fig. 10 Mains extraction system.

90% of all loads within 25 ft of predetermined point, is primarily due to the consistent ballistic trajectory taken by the load from the prerequisite 130-knot airspeed and 250-ft delivery altitude.[7]

PLADS mission characteristics

This mode of delivery is primarily for special mission-type operations. The high-impact velocity dictates some special packaging consideration and limits the types of supplies which can be delivered. The plywood-bottomed fabric containers and the unit load-weight limitation permit relative ease of handling both before and after the drop. Delivery on a single pass is limited to two of these containers, and delivery of more than two requires repositioning additional containers on the aircraft ramp and making another pass over the drop zone. Up to 16 containers can be delivered in this manner before having to land and reload. The precise accuracy obtainable with this mode of delivery is dependent on achieving a precise airspeed and altitude at extraction. The containers and the types of supplies delivered in this manner can withstand the rolling and toppling encountered in high-drop winds exceeding 15 knots.

CDS equipment and operation

The CDS is used to deliver up to 12 containers holding from 500 to 1500 lb each. The previously mentioned plywood-bottomed fabric supply containers are loaded onto the aircraft in double rows and can be delivered in any even number up to 12. When the desired extraction initiation point is reached while flying at 300 ft altitude, the aircraft is placed in an 8° pitch attitude, and a 15-ft-diam ringslot parachute is deployed which cuts the nylon webbing restraining those containers to be delivered at that site. Gravity provides the extraction force, and the containers are recovered by two 24-ft-diam spherical canopies which provide a 40- to 50-fps descent rate. Accuracy of the system is such that 90% of the time the first containers out will be within 150 ft of a predetermined spot, and the remainder will be within 300 ft of the first.[8]

MES equipment and operation

Figure 10 depicts a mains extraction delivery. The MES consists of a ringslot parachute which is deployed and towed against an aircraft floor-mounted tow plate. The device previously mentioned under LAPES consists of a pin for towing the drogue line and a remote actuated spring-powered knife. At the desired extraction initiation point, force transfer is effected, and the drogue chute pulls the 64-ft- or 100-ft-diam solid flat circular main recovery parachute(s) from the load and through the cargo compartment. Inflation of these main parachute(s) overcomes load restraint and extracts the load from the aircraft. As the load crosses the ramp a knife which has been moving along with the load, but is secured to the aircraft, cuts through the extraction line and transfers the force of the main parachute(s) to recovery of the load at a descent rate of 25–30 fps. As the load leaves the ramp, an oscillation retardation parachute is deployed from the front of the load which retards movement caused by pendulum effect and permits impact at a very low horizontal velocity. Loads weighing from 2500 to 12,500 lb have been delivered in this manner at altitudes of less than 350 ft, and investigation is continuing on loads weighing up to 35,000 lb. Elimination of the oscillation parachute can be accomplished for system simplification at the expense of increasing the drop altitude approximately 100 ft. Delivery of multiple loads is accomplished by having the first load extract the parachutes for the second load and likewise for a third and fourth load.

An operational accuracy determination has not yet been conducted, but it is estimated that the first load will be in the neighborhood of 150 ft from a predetermined point and that succeeding loads will be at approximately 300-ft intervals. Substituting calibrated force-level break ties in place of the tow plate for system simplification can be accomplished at some degradation in accuracy.

A further altitude reduction of up to another 100 ft is anticipated with this system upon completion of a current vent-control investigation. Figure 8b (with skirt reefing) is illustrative of the configuration being investigated. Previous extraction force-to-weight ratios were in the order of 3.5 to 5 and were considered excessive by personnel associated with the program; use of the skirt reefing keeps this ratio down to a very acceptable 1.5 to 2, and the vent control accelerates canopy opening after disreef. (See foregoing section on LAPES operation for discussion of the vent-control principle.)

A similar vent-control investigation is currently being undertaken using larger, more readily available 100-ft-diam solid flat circular canopies. Results to date with loads up to 10,000 lb and drop speeds up to 150 knots indicate a comparable drop altitude, extraction force-to-weight ratio, and accuracy capability.

MES mission characteristics

This mode of delivery is suitable for use in assault, resupply, and special missions. The weight-range capability of this system covers in excess of 90% of the items needed for an Army Airborne Division; however, the extraction force-weight ratio, without vent control, is higher than that desired for extracting vehicle-type loads. This is the only mode below 500 ft suitable for heavy drop at up to 150 knots. Although dropping at 150 knots instead of 130 knots tends to degrade accuracy, it results in spending 15% less time traversing hot spots likely to be surrounding a drop zone.

As there are no means of assuring proper orientation between the horizontal cargo axes and the direction of travel at ground impact, dropping in surface winds above 15 knots results in decreased load survivability because of toppling and rolling.

High-speed delivery system equipment and operation

Figure 11 depicts a high-speed delivery system in operation. This system is a peculiar cargo delivery system intended for use not with cargo aircraft but with fighter aircraft. The system consists of a cylindrical, finned, aerodynamically

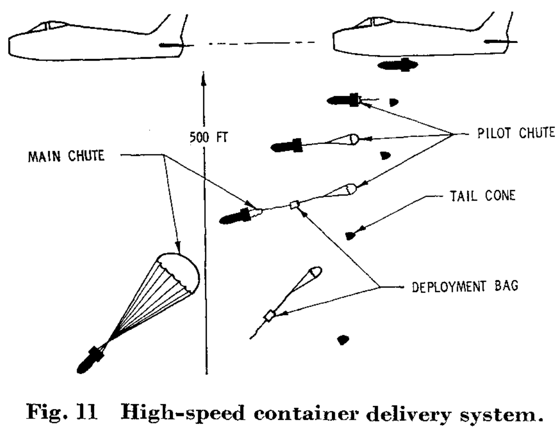


Fig. 11 High-speed container delivery system.

shaped container that is suspended from aircraft external stores racks. At the desired delivery initiation point, the container is dropped from the rack, the tail cone is pyrotechnically separated, and a pilot parachute deploys. The pilot parachute extracts a reefed 34-ft-diam ringslot parachute that decelerates the container and, after disreefing, delivers the container at an impact velocity of 30 to 35 fps. Each container can accept from 100 to 500 lb of supplies, and up to four containers can be delivered simultaneously at airspeeds up to 450 knots from an altitude of 500 ft. An operational accuracy determination has not yet been made, but it is estimated that delivery can be accomplished within 300 ft of a predetermined point.

High-speed delivery system mission characteristics

This mode of delivery can be accomplished by a wide variety of aircraft and is primarily for special missions where urgency of delivery is of prime consideration. This mode of delivery presents a small ground fire target during rapid ingress and egress of hostile or nonsecure drop zones; also, the aircraft can deliver the cargo in conjunction with other missions and reduce the number of occasions where a fighter escort would be requested anyway to provide protection to slower, more vulnerable cargo aircraft. The size of the container is such that two men can maneuver it both before and after delivery. Packing of the container requires special care to insure the center-of-gravity location required for stability during the initial deployment stage. Because of the speed-range capability of the variety of aircraft which can deliver this item, accuracy of delivery is very dependent on pilot experience and proficiency.

X to 1500 Ft AGL

Now new systems have been developed for this range; however, two areas of investigation have been undertaken to permit better use of the range: 1) 25,000- to 35,000-lb airdrop subsystem and 2) standard system refinement.

25,000- to 35,000-lb airdrop subsystem

This effort has consisted of developing parachutes, extraction lines, and extraction line hardware suitable for extracting loads weighing from 25,000 to 35,000 lb at airspeeds up to 150 knots. Two 28-ft-diam ringslot parachutes are used for reliability rather than a single larger parachute to provide the extraction force. Extraction operation and recovery are as in the standard system (see Fig. 1).

Standard system refinement

This effort is being conducted in an improvement with little or no modification of hardware phase and an improvement with modification of hardware phase. The first completed phase involved improving the accuracy through reduction of drop altitude and refinement of the procedure used to compute the extraction initiation point. This effort involved statistical analysis of aircraft approach altitudes and the trajectories taken by both personnel and cargo.

The altitude reduction analysis involved determining probabilities of acceptable impact attitudes and descent rates after various altitude losses, taking into account the probability of the aircraft flying at an exact altitude. As a result of this analysis, previous cargo drop altitudes of 1500 ft for clustered canopies (up to 35,000 lb), 1100 ft for single 100-ft-diam canopies (3500 lb), and 700 ft for single 64-ft-diam canopies (2200 lb)[9] were reduced, respectively, to 1100 (up to 25,000 lb), 900, and 550 ft with a 97% probability of acceptable impact condition. The minimum drop altitude for personnel, based on a 99.99% probability of safe impact condition, could be reduced to 375 ft; but, allowing 250 ft for use of the emergency reserve parachute raises this to 625 ft which is 125 ft less than thought required previously.[10]

The computed air release point refinement involved trajectory analysis to determine the separate effects of wind and forward travel until the load reaches a stable vertical velocity, determination of the wind-drift effect until impact, and development of equations and charts to permit an aircrew to predetermine the desired extraction initiation point. This phase has not been operationally evaluated for accuracy, but it is estimated to be within 200 ft of a predetermined point.

As previously stated, it is often desired to drop both personnel and cargo on the same pass over the drop zone, and the lower the aircraft altitude at drop, the greater the deliver accuracy potential. This brings us to the second phase of standard system refinement, which is to further lower the 1100- and 900-ft cargo drop altitudes to the 625 ft required for personnel. Decreasing parachute inflation time through incorporation of the previously discussed vent-control principle is being investigated with favorable results toward attainment of this objective. This phase also involves investigating the previously mentioned floor-mounted force transfer device for towing the inflated extraction parachute until extraction initiation is desired. This will permit deployment and force stabilization prior to drop time and will reduce the inaccuracy effect due to elapsed time variations presently encountered in these two areas.

1500 Plus Ft AGL

Two delivery systems are being developed for use in this altitude range: 1) steerable parachute airdrop system and 2) high-altitude delivery systems.

Steerable parachute airdrop system equipment and operation

Several steerable systems are currently being evaluated which have lift-to-drag ratios ranging from about 1.7 to about 3. A lift-to-drag ratio of 1.7 means that under a no-wind drop condition the systems will move forward about 1.7 ft for every foot loss in altitude. The parachute is directed towards the desired impact point by a servomotor steering package either deforming the chute or actuating a control surface. The servomotor steering package, which is mounted on the load being delivered, senses its position in relation to a cigarette carton sized ground-based signal transmitter and manipulates the chute accordingly. Cargo being delivered in this manner is packaged in 500-lb-capacity fabric containers or in the same 2000-lb-capacity plywood and fabric containers used for PLADS and CDS. Delivery is accomplished at airspeeds up to 150 knots. An operational accuracy determination has not yet been conducted, but test data indicate that it will be in the neighborhood of 200 ft from the transmitter.

Steerable parachute system mission characteristics

This system is primarily for support of special missions where out-of-sight delivery is desired or required. The gliding capability of this system can be used to overcome wind drift or it can be used to permit delivery to a site offset from the delivery aircraft. Although the homing ability of this system permits high accuracy, it also dictates that a ground station be available at the intended site. The delivery capability of the system is limited per package to 2000 lb, but multiple packages can be delivered on a single pass. This 2000-lb limitation is not based on physical limitations of the system but on lack of requirement for higher capacity.

High-altitude delivery system equipment and operation

This delivery mode consists of a two-stage recovery system to permit delivery of 100 to 1500 lb of supplies at descent rates of 100 fps until just prior to ground impact where parachute disreefing reduces the descent rate to 25–30 fps. Activation of the disreefing is accomplished either by a timed pyrotechnic fuse ignited at aircraft load separation or by a cigarette pack size remote electronic device in the hands of drop point personnel. Drop altitudes up to the aircraft ceiling may be utilized; but since the accuracy is a function of drop altitude, altitudes of 3000 to 5000 ft are utilized with accuracies in the range of 90% of delivered loads within 200 ft of a predetermined spot.[11]

High-altitude delivery system mission characteristics

This mode of delivery is primarily for support of special missions where high-velocity descent is desired to maintain security of the operation. Use of the ground-controlled disreef activator permits a last-minute decision as to whether to recover the load or to allow it to destroy itself at impact in case it is descending towards an enemy-controlled drop point. The ground-controlled mode is limited to delivery of a single load per pass whereas the automatic mode is limited to two loads per pass. Delivery of additional loads requires additional passes over the drop zone.

Systems Comparison

This arsenal of delivery modes presents a very broad capability towards our delivery at arms-length goal; but, as in any arsenal, there is some capability overlap, and a decision as to which item offers the best solution to a particular delivery mission requires consideration of both the mission environment and the mission requirement. For instance, one would not use a dump truck to deliver a letter to the corner post office, but then again he would not hesitate to use this same vehicle to go to the same corner for an emergency medical prescription. Either the supplies requester must provide sufficient information for someone else to decide as to the best delivery technique, or he must analyze the situation himself and request accordingly. One might say that the requester should not be concerned as to the delivery technique utilized so long as he receives his requested supplies. But such is not the case because, in some of the modes (especially those operating below 500 ft), the requester will be expected to provide at least some protection for the delivery aircraft, and he knows that all aerial delivery procedures (with some more than others) are like flags waving to and fro saying, "Here I am," to the enemy; thus, to protect his position he is going to desire one with as small a signature as possible. Both requester and the one responsible for filling the request must at least take into account ramifications of the factors listed below in deciding which delivery mode should be utilized: 1) cargo, 2) drop zone, 3) aircraft availability, 4) logistical impact, and 5) mission versatility.

Defining several qualitative sets of these factors, assigning relative weights, and comparing them with altitude range characteristics, system capabilities and dollars would permit an illustration of how the systems supplement each other. Because of the length and an illustration, a more general type comparison is being presented. This comparison, which is summarized in Table 1, is basically a qualitative type and consists of ranking the systems within an altitude range in regard to each of the factor ramifications, in general, rather than across all the altitude ranges and to a specific set of factors. Three guidelines which must be taken into consideration in interpreting this comparison are: 1) Identical numbers across all four altitudes ranges are not indicative of identical factor comparison, i.e., a 1 in the 0- to 20-ft AGL range is not necessarily comparable to a 1 in the 20- to X-ft AGL range. 2) The lower the ranking number the more nearly the system approaches a favorable factor characteristic, i.e., a 1 for the size-required factor indicates a smaller size requirement. 3) These numbers cannot be converted to a "very good, good, bad" type rating.

The weight deliverable shown for each of the systems is as it applies to the C-130 (except for the high-speed delivery system). (See the New Aircraft Capabilities section below for additional system weight capability information.)

Factor Discussion

Cargo

This factor involves the type and quantity of cargo needed, how it is already packaged, how it can be packaged, its horizontal and vertical impact velocity capabilities, and the urgency with which it must be delivered.

Aircraft availability

This involves consideration of the type(s) of aircraft available to conduct the mission and the proficiency of the available crews to perform under the conditions existing at the drop zone. Since the situation of having one aircraft per delivery request is unrealistic, then this factor also involves consideration of aircraft utilization. All of the systems can utilize the aircraft capability from a floor space and/or weight standpoint in that multiple loads can be carried to the drop site. The ability of a system to deliver this capability in one pass over the drop zone is a measure of system efficiency in making the aircraft available for additional missions. Another efficiency measurement is a comparison of the weight or cube carried onboard the aircraft to the actual weight or cube of the cargo delivered, i.e., rigged weight or cube vs net weight or cube.

Logistical impact

This factor involves consideration of the over-all time required, exclusive of flight time, per unit of cargo delivered. It involves loading the cargo into the aircraft, securing the cargo, and installing any special hardware peculiar to a particular delivery mode. For example, PLADS and CDS require securing of the plywood-based fabric containers, and the GPES requires installation of the pole assembly. This also includes time required for cargo preparation and involves considering the number of canopies, reefing configurations, pyrotechnic devices, electrical circuitry equipment checkout, etc., all of which require special skills and training to employ. It also includes the problems of returning delivery hardware such as platforms, containers, parachutes, extraction lines, electronic packages, etc. to the rigging area for repair or re-use.

Drop zone characteristics

This factor involves ground winds at the drop zone, the drop zone size and physical characteristics, and its location. It also involves consideration of equipment and personnel available at the drop zone for handling delivered cargo, delivery accuracy required, and the security of both the drop zone and its approach corridor(s).

Mission versatility

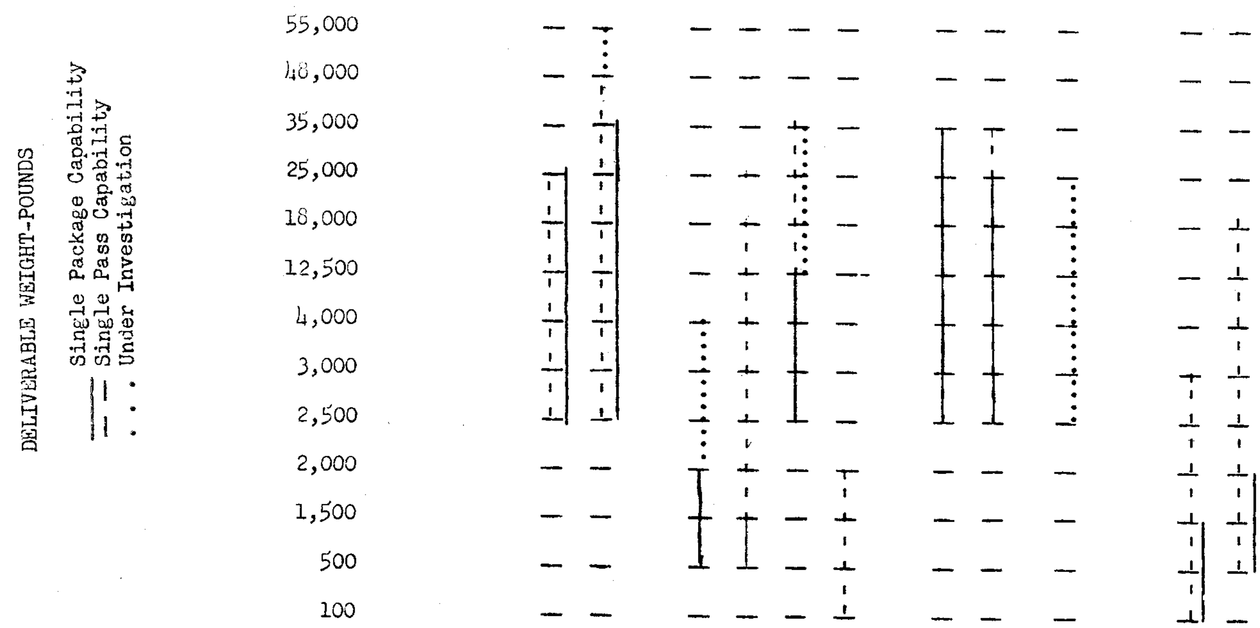
This involves consideration of the ability of the delivery modes to respond to en route changes in delivery destination, whether it be a 100-yd change or 100-mile change, and the ability of the modes to be used for assault, resupply, or special type missions. This factor also involves the ability of the delivery modes to be utilized during nighttime or low-visibility environment and the ability to drop personnel concurrently with cargo.

New Aircraft Capabilities

Introduction of the C-141 aircraft has required updating the standard system hardware to be compatible with the longer cargo compartment (70 ft vs 41 ft), and its load-carrying capability has increased the standard system single pass multiload

Table 1 System capability comparison

COMPARISON FACTORS	0 to 20 ft AGL: GPES	0 to 20 ft AGL: LAPES	20 to X ft AGL: PLADS	20 to X ft AGL: CDS	20 to X ft AGL: Mains Extraction	20 to X ft AGL: High Spd Dlv Sys	X to 1500 ft AGL: Standard System	X to 1500 ft AGL: Std System Refin (Phase I)	X to 1500 ft AGL: Std System Refin (Phase II)	1500 ft plus AGL: High Alt Dlvr	1500 ft plus AGL: Steerable Sys
DROP ZONE											
Size Required	1	2	1	2	2	2	3	2	1	2	1
Impact Accuracy	1	2	1	2	2	3	3	2	1	2	1
Ground Wind Tolerance	2	1	1	1	2	1	1	1	1	2	1
Security Required	1	2	2	2	2	1	1	1	1	2	1
Utilization Obtainable	2	1	2	1	1	2	1	1	1	2	1
AIRCRAFT AVAILABILITY											
Utilization Obtainable	2	1	3	2	1	2	1	2	2	2	1
Crew Proficiency Required	2	1	2	1	1	3	1	1	1	2	1
LOGISTICAL IMPACT											
Aircraft Preparation	2	1	2	2	1	2	1	1	1	1	1
Load Preparation	1	2	2	1	2	3	1	1	2	1	2
Hardware Return to Supply	1	2	2	1	2	2	1	1	1	1	2
MISSION VERSATILITY											
Drop Zone Flexibility	2	1	1	2	2	2	1	1	1	1	2
Drop Zone Visibility Required	2	1	1	1	1	2	1	1	1	2	1
Assault Mission	2	1	NA	1	1	NA	1	1	1	NA	NA
Resupply Mission	1	1	NA	1	1	NA	1	1	1	NA	NA
Special Mission	2	1	1	1	1	1	1	1	1	1	1
Concurrent Personnel Delivery	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes



capability to 70,000 lb. The size and range of the aircraft are such that it is an intertheater type rather than an intratheater type, and the only alternate delivery mode being examined is a CDS for up to 28 containers (68,000 lb).

The size and range of the upcoming C-5A are such that the only airdrop capability warranted is using the standard system primarily as an alternate means of unloading the aircraft in case it cannot land at its destination. This will require upgrading the system to a 50,000-lb single load capability and a 100,000-lb multiload single pass capability. The first thought to obtain this capacity was to increase the size of the present standard system components, but the 145-ft length of the cargo compartment would result in extraction lines weighing upward of 500 lb and their contacting the perimeter of the cargo compartment with extraction parachute oscillations of less than 3°. (C-130 and C-141 extraction parachute oscillations run about 5° to 6°.) These considerations are indicative of the problems that will be encountered with attempting to develop an airdrop capability from this flying warehouse.

Development of rear loading, intratheater V/STOL aircraft such as the XC-142 is at the other end of the cargo aircraft weight capability spectrum. Inherent parachute limitations have required the Army to create specialized airborne units for the conduct of assault operations. This has resulted in the division of parachute operations into phases, with phase I being a parachute assault phase executed by specialized forces and aimed at capture or construction of adequate airbases to permit delivery of the follow-on phase forces. V/STOL cargo aircraft, which do not require prepared strips or specialized forces, will relieve parachute units of the necessity to direct their initial effort toward the security of a base of operation. This will have the effect of giving an airborne capability to any element capable of being air-transported and will permit delivery of follow-on forces and cargo to the site that best facilitates accomplishment of the over-all mission.

The flight-profile capability of this type aircraft permits delivery of supplies without extraction parachutes, without recovery parachutes, with little or no cushioning, and without a material handling crew. The aircraft is flown at 0 to 30 knots in the 0- to 20-ft AGL range with a 5° to 10° pitch attitude; a manual release of the cargo restraint and gravity does the rest.

Conclusion

This arsenal of delivery systems will undoubtedly and hopefully be reduced in quantity not by arbitrary decision but rather by breakthrough in systems currently under development; or there may be entirely new approaches to the problem which will provide a broader range of system abilities without loss of particular capabilities. Current system capabilities such as accuracy and capacity are constantly under investigation for possible improvement to facilitate system combination or elimination. For the time being, however, there is no single system capable of meeting all requirements; and, since no two available systems have identical characteristics, a decision as to which to eliminate, if any, can only be made by the organization which will use these systems based on consideration of the risks and costs involved.

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