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The AGAS 2000 Precision Airdrop System

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The requirement for airdropping critical military and relief supplies from high altitude has existed since the advent of long-range, ground-based, anti-aircraft armaments. Aircrews understandably want to fly above the threat of anti-aircraft fire when operating in hostile environments. Advances in just the past five years in navigation, guidance, and control electronics based on the Global Positioning System (GPS), and improvements in the measurement and forecasting of in-situ winds have made the active control of cargo parachutes a relatively affordable and reliable method of compensating for wind drift. Where a ballistic (uncontrolled) round parachute cargo resupply system delivered from high altitude might drift thousands of meters off target, modern autonomously controlled cargo parachute systems can compensate for winds aloft and command the parachute to within a few tens of meters of the designated target. One such system is the 2,000-lb class Affordable Guided Airdrop System – AGAS 2000. Unique among precision airdrop parachute systems, AGAS 2000 integrates a relatively inexpensive autopilot controller with a military inventory round cargo parachute and inventory cargo sling assembly to convert a standard one-ton cargo delivery system into a precision airdrop system. AGAS 2000 can deliver a one-ton payload to within 211 m circular error probable (CEP) of its target when its programmed mission profile is based on forecast winds and to within 38 m CEP when based on a current wind profile provided by a system such as the Air Force's Precision Airdrop System (PADS).

I. Introduction

THE US Army includes in its definition of precision airdrop, "systems that enable safe and accurate delivery of supplies, equipment, vehicles, or personnel from high altitudes. These include autonomous parachute systems (capabilities exist over a wide range of payload weights), mission planning tools, weather forecasting and sensing systems, personnel navigation aids and related integrated communication systems."[1]

AGAS 2000 is one such precision airdrop system, combining a commercial autopilot controller and mission planner with a standard 64-ft diameter G-12 cargo parachute and A-22 Container Delivery System (CDS). AGAS 2000 has demonstrated full compatibility with the US Air Force Precision Airdrop System (PADS), a portable wind profile generator and guided airdrop system mission planner.

The development of AGAS 2000 has been well documented.[2-4] This paper focuses on its concept of operation (CONOPS) in a tactical environment, its compatibility with the new Air Force airdrop mission planner (PADS), and current plans to expand AGAS to a range of systems for payloads from 200 to 10,000 lb using a common system architecture.

II. AGAS 2000 Classification

The US Army and Air Force's Joint Precision Airdrop System (JPADS) program comprises a common mission planner – the Precision Airdrop System – linked to guided parachute systems. The Army has broken precision airdrop systems into four weight classes: "extra light" for payloads up to 2,200 lb, "light" for payloads up to 10,000 lb, "medium" for payloads up to 30,000 lb, and "heavy" for payloads up to 60,000 lb.[5]

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AGAS 2000, which is essentially a “precision CDS,” operates with payloads ranging from 500 to 2,200 lb. Because AGAS is fully integrated with PADS, AGAS 2000 falls into the JPADS Extra Light classification.

III. AGAS 2000 Function

Figure 1. AGAS 2000 Rigged for Flight.

Ground troops routinely receive bulk supplies of ammunition, food, and water using the Container Delivery System (CDS). The supplies are mounted on a wooden skid board and covered with a tarpaulin before being wrapped in a webbing net. This configuration is designated the CDS A-22. The supply bundle rolls off the rear ramp of a military cargo aircraft and descends by cargo parachute. The standard CDS A-22 bundle weighs between 250 and 2,200 lb. AGAS 2000 is essentially an enhancement to the standard CDS that allows for deployment and precise delivery from altitudes significantly higher than the low-altitude thresholds required for precise ballistic delivery. AGAS 2000 functions on the principle of canopy riser slip. The suspension lines on a G-12 cargo canopy are segregated into four equal groups, each line group terminating in a link to a length of fabric webbing called a riser. In conventional use, the four risers are attached to the top of the A-22 CDS so that the payload is suspended from the G-12 canopy in flight. When the CDS is configured for precision airdrop, an AGAS Autonomous Guidance Unit (AGU) – a 30 in × 30 in × 8.5 in box containing the Flight Control Unit (FCU), riser control hoists, batteries, etc. – is tied down flush to the top of the 48 in × 48 in CDS (Fig. 1).

Figure 2. AGAS 2000 in a Commanded Riser Slip.

Each of the G-12 parachute risers is replaced with a long, narrow riser made of Kevlar webbing and each of these four risers is routed through a corner guide slot in the AGU cover and wound onto a hoist spool. During AGAS 2000 flight, onboard hoists are autonomously commanded to lengthen or shorten a single riser or two adjacent risers. This asymmetric change in riser length causes a distortion in the shape of the canopy skirt (Fig. 2). This shape change causes an overall asymmetric distortion of the otherwise round parachute canopy. The G-12 parachute is an aerodynamic bluff body that is statically unstable when descending vertically, meaning that there is a destabilizing pitching moment about the system’s center of gravity that causes the parachute to oscillate in a planar or coning motion. By asymmetrically distorting the canopy, the flow field around the canopy is changed. The resulting change in pressure distribution creates a differential lift that causes the canopy to seek its statically stable angle of attack. Using riser displacement or “riser slip” to change the shape of the canopy, the G-12 can be commanded to “glide” with a horizontal-to-vertical glide ratio as high as 0.6:1.[6] By changing the length of a single riser or two adjacent risers, the G-12 parachute can be commanded by the AGAS 2000’s bang-bang controller to translate or “fly” in any one of eight cardinal and ordinal directions.

IV. Concept of Operation

The basis for all precision airdrop is twofold – delivery beyond the region of threat to the aircraft engaged in the airdrop operations and compensation for the effects of wind.

A. Operational Employment

Because AGAS 2000 is an autonomously guided delivery system, multiple loads can be programmed for delivery to a single landing zone – “many on one” (Fig 3). This would be a suitable CONOPS for the massive resupply of a single military unit or the delivery of relief supplies to a densely populated area.

Conversely, individual units or multiple units can be programmed for delivery to widely separated landing zones – “one-on-many” and “many-on-many,” respectively. In the many-on-one case, the pilot flies toward a Calculated Air Release Point (CARP) and release his “stick” of CDSs targeting the release of the middle unit on the

CARP. In the one-on-many and many-on-many cases, the pilot will fly to a series of CARPs, releasing a single CDS or group of CDSs at subsequent CARPs.

B. Wind Profiling and CARP Calculation

Figure 3. Four AGAS 2000 Programmed for the Same IP.

In standard airdrop operations using unguided round parachutes, an air release point is calculated based on the known aerodynamic performance of the parachute system (including altitude loss to canopy full deployment, downrange tracking during canopy deployment and trailover to vertical descent, and parachute system steady-state drag area) coupled with the estimated wind profile. This Calculated Air Release Point is the position in inertial space from which the airdropped load is calculated to “drift” onto the impact point (IP), the designated point of intended landing. With perfect knowledge of the wind profile over the entire ballistic trajectory, the load would land precisely on the IP if released exactly at the CARP.

Regardless of the gliding characteristics of the precision airdrop system parachute – whether “low-glide” like the AGAS 2000 G-12 parachute or “medium-glide” like a ram-air inflated parafoil – all precision airdrop systems depend on the knowledge of the in-situ wind field. The ability to translate horizontally or “glide” gives a parachute cargo delivery system the inherent ability to correct for delivery offsets from the CARP and course drift due to errors in calculated wind profiles.

Wind varies in space and time, making exact knowledge of wind velocity along a particular trajectory impossible. However, various methods of measurement and analysis are available to aid in estimating wind. Wind profiles for the intended target area can be developed from two sources of wind data. Near real-time wind data can be collected from a windsonde deployed over the target, or a wind forecast file for the drop zone can be downloaded from the Joint Air Force and Army Weather Information Network (JAAWIN) web site. Regardless of source, the wind data are loaded into a mission computer, which then merges the wind data with the desired target coordinates, release altitude, and payload weights, and generates a unique flight trajectory for each payload. The mission computer also generates a CARP based on the drop aircraft’s deployment speed, run-in heading, and the payload trajectories. After the trajectories are generated, they are uploaded from the mission computer to the AGAS flight computers using a wireless serial data link. During the payload’s descent, the AGAS flight computer monitors its current position and altitude, compares these to the planned flight trajectory, and commands riser slips that will drive the payload toward the programmed flight trajectory (Fig. 4).

1. *Commercial Mission Planner*

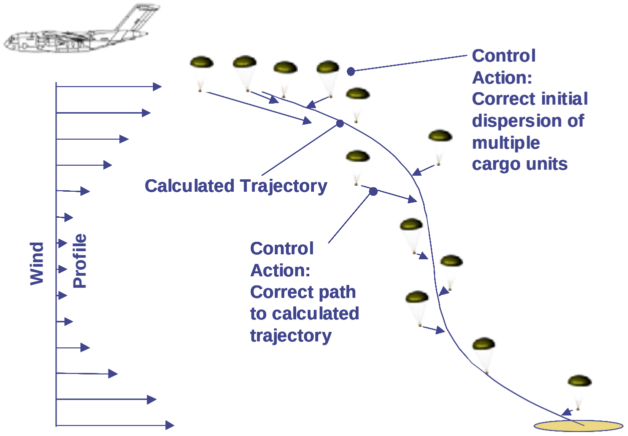

Figure 4. Mission Profile.

From its inception, AGAS has comprised a commercial windsonde and a pressure-ruggedized laptop mission computer and flight planning software initialized and executed through a Graphical User Interface (GUI) (Fig. 5). The windsonde consists of a GPS receiver and a serial data transceiver that broadcasts the windsonde’s position and altitude once per second to the AGAS mission computer, which is carried onboard the drop aircraft. When the windsonde has reached the ground, the mission computer operator generates the trajectories for the payloads and transmits them to the systems using a FreeWave wireless data link.

Each AGAS flight computer records flight data during descent that can be retrieved after the system is recovered. The information is sampled and recorded once per second. These mission data are useful in determining how well the systems are performing and for determining the cause of any system inaccuracy, especially when the units are deployed with forecast wind trajectories. Each sentence in the data file contains the following information:

- System ID number
- Universal Time Code
- Current system latitude and longitude
- Current system altitude
- System orientation
- Magnetic variation for the current position
- Target latitude and longitude for the current system altitude

2. PADS Mission Planner

AGAS 2000 is also fully compatible with the US Air Force's new Precision Airdrop System (PADS). As described in Ref. 7, the portable PADS supports ground and in-flight high-altitude airdrop mission planning for ballistic and autonomously guided cargo parachute delivery systems (Fig. 6). In flight, the PADS laptop computer is connected to a portable UHF radio receiver that is connected to one of the airdrop aircraft's bottom UHF antennae to receive real-time in-situ wind data from GPS dropsondes hand-launched from the airdrop aircraft. The integrated 802.11g wireless interface on the commercially available PADS laptop computer communicates the mission file to the AGAS 2000 AGU while in the aircraft's cargo bay. When PADS is used, the reference trajectory is loaded directly from PADS to the AGAS flight computer; the AGAS mission computer is not needed.

Figure 5. Commercial AGAS Mission Computer.

C. AGAS Programming

Programming the flight computer prior to loading AGAS 2000 on the drop aircraft is a simple matter of transferring a baseline mission profile to the AGU from the mission computer. The user interface for the commercial AGAS mission planner and the PADS mission computer is similar. The mission profile is derived from a mission file that includes modeled wind field information, system identification number, payload weight, release altitude, aircraft run-in heading, and latitude and longitude of the target point of impact. When using PADS to derive a mission profile, other information that differentiates AGAS from other delivery systems is also input. This includes identification of the AGU, parachute, and payload type.

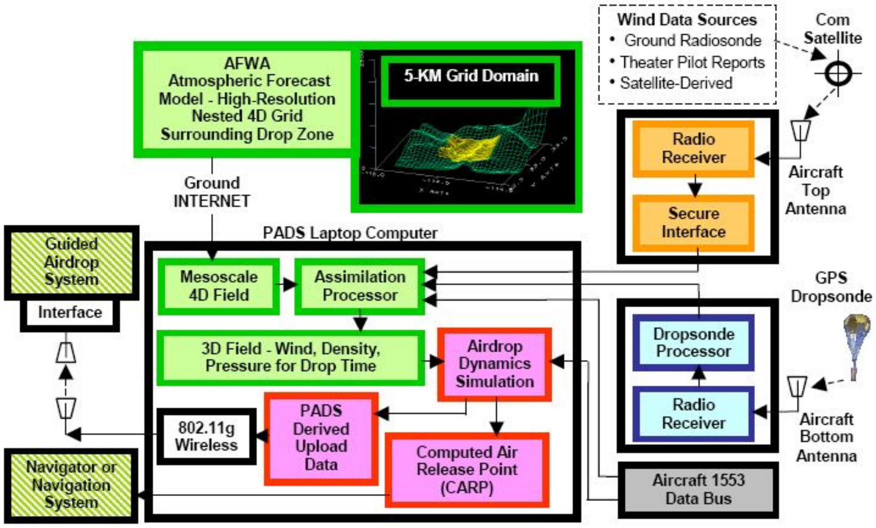

Figure 6. Precision Airdrop System Architecture and Top-level Function (from Ref. 7).

D. AGAS Rigging

As a CDS enhancement, AGAS 2000 requires minimal training and no modifications to rigging, ground handling, or aircraft cargo bay facilities and equipment. Rigging of AGAS 2000 relies largely on standard G-12 and A-22 CDS procedures. Riggers are taught to mount the AGAS 2000 AGU to the A-22 and rig the G-12 parachute to the AGU.

V. Performance

A. Key Performance Parameters

Brown and Benney[8] provide a detailed analysis of what the US Army and Air Force consider to be the key system performance parameters for all types of precision-guided aerial delivery systems. The intrinsic performance parameters that bring value to a guided aerial delivery system are accuracy, reliability, payload capacity, and safety of the drop aircraft. These parameters relate directly to getting a given payload on the ground accurately.

1. *Threat Avoidance*

Cargo resupply operations are not generally undertaken where air-to-air threats are known to exist. Brown and Benney go on to summarize the ground-to-air threats to cargo aircraft from operating over hostile territory. The most potent of these are IR-guided man-portable air defense systems (MANPADS) and radar-guided surface-to-air missiles (SAMs). The threat posed by radar-guided anti-aircraft weapons reaches above 20,000 ft AGL but known SAM threats are typically eliminated before cargo aircraft enter the airspace. MANPADS, on the other hand, have worldwide proliferation and are difficult to neutralize given their light weight and portability. However, their effectiveness is essentially limited to 15,000 ft AGL. Therefore, by flying above 15,000 ft AGL, the threat to aircraft safety from MANPADS is greatly reduced.

2. *Terminal Accuracy*

The most obvious Key Performance Parameter for a precision-guided aerial delivery system is landing accuracy. In this regard, a round “low-glide” parachute – where the maximum achievable ratio of system lift to drag or “glide ratio” is something less than 1:1 and the intrinsic glide ratio is 0:1 – has certain inherent advantages over a ram-air-inflated “medium-glide” parachute such as a parafoil – with an intrinsic system-level glide ratio of perhaps 2 or 3:1. (System-level glide ratio, or more correctly the ratio of the horizontal release point offset to the release height above the target, is a derived rather than a key performance requirement. A particular threat or operational scenario would be required to derive such an offset requirement. For the vast majority of deployment scenarios contemplated, operation above the MANPADS threat environment is considered adequate to ensure aircraft safety.)

Low-glide systems use a glide-on-command approach that reverts to a ballistic trajectory except when horizontal velocity is needed. There is no “forward” body axis direction. Control is not by “steering” of an always-forward moving body, but by modulation of the magnitude and direction of the lift vector. Medium-glide systems, on the other hand, steer by turns that are initiated by skidding and continue to skid in a fully developed turn (under-banked compared to a coordinated turn) to a degree determined largely by system mass and canopy loading. The advantage of AGAS 2000’s bang-bang control onto any one of eight ordinal and cardinal headings without the need to steer is that the system can quickly correct for the errors in wind data near the ground where their effects are more severe than at higher altitudes because there is less time to correct.

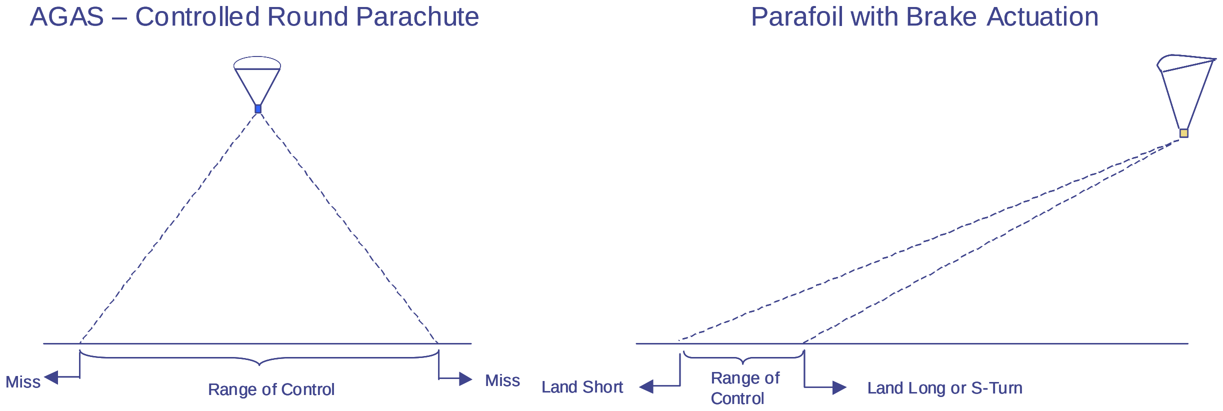

Figure 7. Range of Control for AGAS 2000 vs. Guided Parafoil Airdrop System.

Vertical control, by which is meant control of the path angle to affect the longitudinal location of the point of impact, also has a variety of forms. Low-glide systems using glide-on-command do not distinguish between lateral and vertical control. The fact that the flight path of AGAS 2000 is nearly vertical (normal to the target plane) is an advantage in the terminal phase. Medium-glide systems use a variety of control laws that lengthen the path in order to effectively reduce glide ratio, for example by adjusting the base-final turn point or by flying ‘S’ turns. Some systems also apply “brakes” by deflecting both steering lines together. Vertical errors therefore become amplified landing errors with medium-glide approach angles. AGAS 2000, on the other hand is virtually insensitive to errors in IP elevation given that its terminal descent is essentially vertical (Fig. 7).

B. AGAS 2000 Demonstrated Performance

As documented in Ref. 4, AGAS 2000 underwent an extensive series of demonstration and validation testing during the yearlong period leading up to and through the delivery of the first five production-representative systems to the US Army in April 2005. Of the 39 missions flown during this period, fourteen AGAS 2000 were programmed to fly trajectories based on JAAWIN forecast wind data and 25 were flown with updated trajectories using data gathered from a windsonde dropped over the target shortly before deployment.

The demonstrated accuracy of the fourteen units flown using forecast wind generated flight trajectories is 211 m Circular Error Probable (CEP). In these flights, the latest recorded wind profile on which the forecast was based was typically more than 12 hours old. When flown with a programmed trajectory based on current windsonde data, the demonstrated accuracy of 25 AGAS 2000 flights improves to 38 m CEP. This performance is considered representative of the performance that AGAS 2000 can be expected to achieve when deployed operationally with the Air Force's PADS missions planner.

Figure 8. Four AGAS 2000 Deployed from a C-130 Hercules.

A detailed discussion of all the testing performed during this period is contained in Ref. 4. The results of these demonstrations are briefly summarized here.

1. Forecast Wind Generated Flight Trajectory Deployments

The ability to employ AGAS 2000 when only forecast wind data are available to generate the planned flight trajectories greatly enhances the system's flexibility by allowing its use with aircraft that are not equipped with PADS.

The first deployment of AGAS using forecast wind generated flight trajectories occurred in December 2004 at US Army Yuma Proving Ground. Prior to each system deployment, a forecast wind data file was downloaded from JAAWIN and loaded into the AGAS mission computer. The flight trajectories were generated and loaded into the system hours before the mission execution time. To permit post-test analysis of the accuracy of the forecast wind profiles, a windsonde was deployed on each mission and its data recorded by a ground station so that engineers could compare the actual winds at the drop zone to the forecast.

These first tests (Fig. 8) were flown at an altitude of 17,500 ft MSL. On the first day, multiple AGAS 2000 were deployed in a single pass. All of the systems demonstrated reasonable landing accuracy. A review of the flight data from a typical system from that deployment series shows that the forecast wind generated flight trajectories for the systems were fairly close to those generated from near-real time windsonde data, especially close to ground level where precise knowledge of the wind becomes critical. The system was able to achieve proximity to the flight trajectory early on in the descent. However, about midway through the descent, when the winds were predicted to continue with a northerly component, the windsonde showed that the winds below this altitude were actually from the south. The AGAS 2000 unit had sufficient drive performance to overcome these discrepancies and achieve an accurate landing.

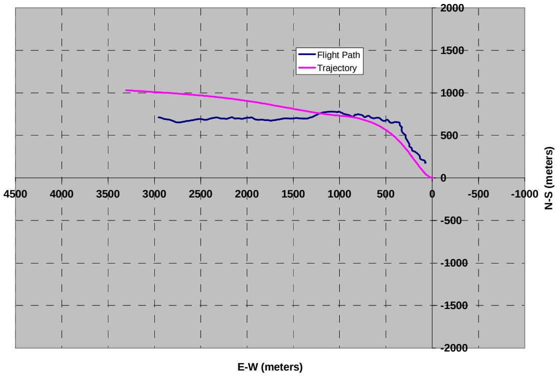

Figure 9. Actual Track vs. Planned Track Using Degraded Forecast Winds.

The day after these deployments, another load of AGAS 2000 was deployed using forecast winds. The weather conditions over the drop zone had deteriorated since the previous day and the wind intensity had picked up. The forecast was for a steady wind out of the northwest from drop altitude to the ground, but the graph of the windpack generated flight trajectory revealed that the winds had shifted so that they were actually out of the west. The ground track of the AGAS 2000 unit shown in Fig. 9 shows that the system was able to maintain close proximity to the flight trajectory during its initial descent, but the control authority of the unit was not sufficient to completely overcome the difference in the winds, and it landed northeast of the target. Conversely, AGAS 2000 achieved its most accurate landings during the final day of deployments, with one unit landing about three meters from the target (Fig. 10).

Figure 10. AGAS 2000 Lands 3 m from IP.

In March 2005, AGAS 2000 was demonstrated for the US Army 82nd Airborne Division at Fort Bragg in North Carolina. Four AGAS 2000 payloads were ballasted to different weights in order to provide some vertical separation between the payloads during descent, since they were all programmed to land at the same coordinates. All four systems were programmed with forecast wind generated flight trajectories, and all four achieved reasonable accuracy, landing on the drop zone in a cluster.

2. *Windsonde Generated Flight Trajectory Deployments*

The majority of AGAS 2000 missions flown to date have been with windsonde generated flight trajectories. Weather conditions have varied widely throughout these deployments, but the system has still managed to achieve a high level of accuracy. The first series of demonstrations with a production-representative AGAS 2000 using a windsonde was in June 2004. These deployments were from a C-123 Provider flying at 10,000 ft AGL. Identically weighted CDS payloads, all programmed with the same target coordinates and windsonde-generated trajectories, were deployed near-simultaneously on a single pass. A plan view of the flight paths of a typical deployment from this test series is shown in Fig. 11. In this graph the pink line represents the “ideal” trajectory generated by the windsonde. The blue line shows the actual flight path of the unit. The AGAS unit steers toward the trajectory and eventually achieves proximity to the planned flight trajectory. The system then makes minor position corrections to maintain this proximity for the remainder of the descent.

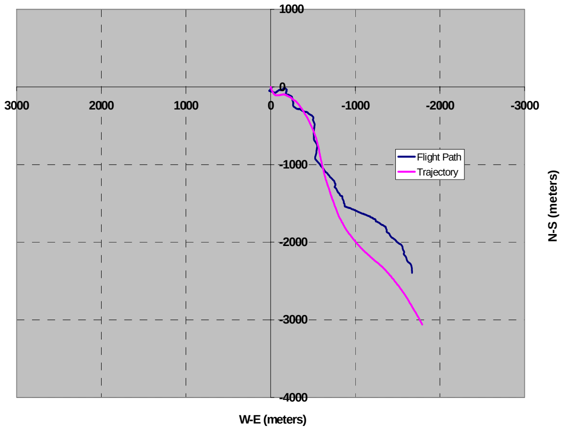

Figure 11. Typical Performance in Strong and Steady Wind Conditions.

Another series of deployments, performed in July 2004, shows how well AGAS 2000 can maintain proximity to the flight trajectory when the wind profile recorded by the windsonde and the actual winds over the drop zone are nearly identical (Fig. 12). In this deployment, the unit flies onto the planned flight trajectory early on in the descent and then makes many small corrections to maintain this proximity and ultimately lands very close to the target.

During this and the previous series, the payloads were all ballasted to the same weight and had the same rate of descent. The result was that on several occasions the canopies of adjacent systems would bump into one another as the systems descended in a tight group (Fig. 13). In one instance, one of the parachute canopies partially deflated after flying through the wake of another parachute, descended past the leading system, and then re-inflated inside the other parachute canopy. The two systems flew as one, with each AGU controlling its own riser set, and the combined system landed within of few meters of the target. However, this event did point to the requirement for some form of payload de-confliction when simultaneously deploying multiple AGAS 2000 of identical all-up weight.

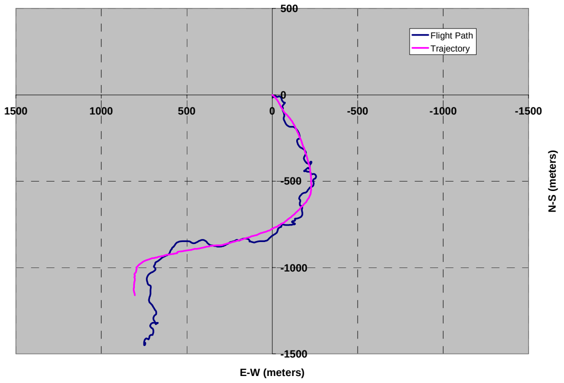

Figure 12. Typical Performance in Highly Variable Wind Conditions.

In February 2005, additional AGAS 2000 deployments were performed, but this time ground-support engineers also collected forecast wind information. Multiple payloads were deployed simultaneously by a C-123 from 10,000 ft AGL using windsonde-generated flight trajectories. A storm front had just moved through the area immediately prior to these deployments and the wind conditions were changing constantly throughout the series, especially from 1,000 ft AGL to the ground. The forecast wind information that was collected during these demonstrations was used to generate forecast trajectories for comparison to the windsonde trajectories. The results show that there can be large discrepancies between the two trajectories and that using the windsonde to measure near-real time wind profiles to

Figure 13. Two AGAS 2000 Flying the Same Planned Trajectory Come Into Contact.

generate the planned flight trajectory substantially improves overall system accuracy. An example of this is shown in Fig. 14. Here the actual AGAS 2000 flight path is shown in blue, the windsonde-generated flight trajectory that it was driving to is shown in pink. The yellow line represents the flight trajectory the system would have been driving to if the forecast winds were used as the wind data source.

3. *Summary Performance Data*

Demonstrated AGAS 2000 performance clearly indicates the link between system accuracy and knowledge of the winds over a given drop zone. In certain weather conditions, AGAS 2000 can use forecast wind generated planned flight trajectories with little if any degradation in overall system accuracy, but when weather conditions are rapidly changing, the fidelity of the forecast winds is degraded. This has a direct effect on the accuracy of AGAS 2000.

The PADS mission computer has a more sophisticated trajectory generating algorithm and, over time, it is expected that system-level accuracy using PADS-generated trajectories based on forecast winds will improve. At the same time, there is a significant advantage to deploying a windsonde over the drop zone to generate the most accurate wind profile possible for the generation of the planned flight trajectory. This is clearly illustrated when the impact points of all the flights discussed above are plotted on the same chart (Fig. 15). The pink triangles represent system deployments performed using windsondes to generate the flight trajectories and the blue squares represent system deployments performed using forecast winds to generate the flight trajectories. Use of current winds to generate AGAS 2000 trajectories results in an 82% increase in overall system accuracy over the use of forecast winds.

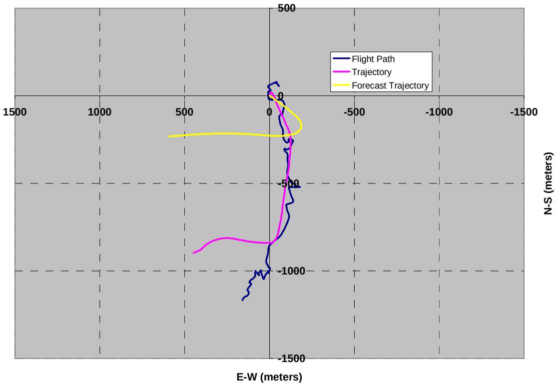

Figure 14. Forecast and Windsonde Generated Wind Profiles Can Vary Substantially.

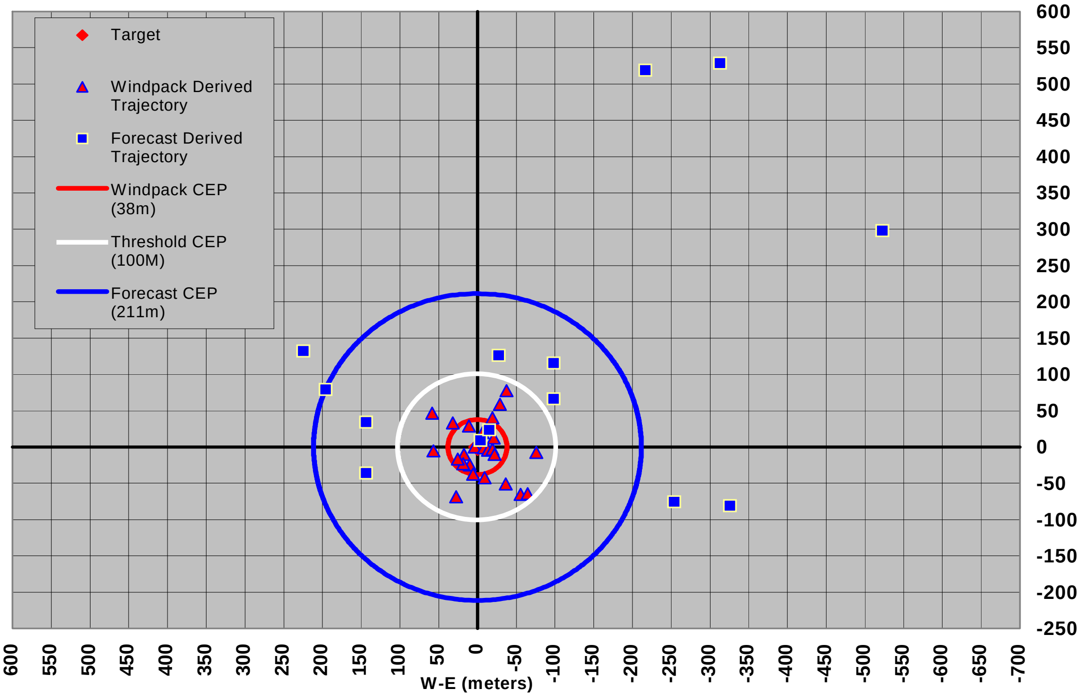

Figure 15. Results of 35 AGAS 2000 Flights With and Without Windsonde Data

VI. Future AGAS Development

AGAS 2000 is now a fully supported commercial off-the-shelf precision airdrop system. It provides a reliable means to accurately deliver payloads in the 500 to 2,200-lb weight range. AGAS 2000, incorporating the A-22 CDS, can be used to deliver loads considerably lighter that the rated capacity of a G-12 cargo parachute, however there is an accompanying degradation in performance. First, the lag time in response to a commanded riser slip increases slightly as the ratio of payload weight to canopy surface area – canopy loading – decreases. Hence, an AGAS 2000 with a 2,200 lb payload is slightly more responsive to commanded riser slips than an AGAS 2000 with a 500 lb payload. In addition, the more lightly loaded the canopy, the slower its rate of descent and the longer the flight time. That means that errors in the programmed wind profile have longer to propagate. The result is that, overall, an AGAS 2000 with a 2,200-lb payload will demonstrate slightly better terminal accuracy that an AGAS 2000 with a 500-lb payload. This problem is overcome by dropping lighter payloads with proportionately smaller parachutes.

A. Lower Weight Capacity AGAS

The AGAS architecture is totally compatible with any round canopy parachute system and has proven itself during development testing to be most effective with solid cloth parachutes whose canopy shapes generate highly destabilizing pitching moments at zero degrees angle of attack (i.e., parachutes that tend to oscillate or cone to a high degree in ballistic flight). Flat circular canopies including the 64-ft diameter G-12 cargo parachute used on AGAS 2000, the 28-ft diameter C-9 personnel parachute, and the 24-ft diameter T-10R troop reserve parachute have shown themselves in AGAS development testing to be highly suited to autonomous riser slip control.

Vertigo is also experimenting with the 35-ft diameter flat extended skirt T-10 troop canopy as a candidate for a 500-lb class AGAS. The flat extended skirt canopy is characterized by a flat circular (or, more accurately, polygonal) surface to which is added an extension in the form of an annular flat ring. This tailoring has the effect of flattening the curvature of the inflated canopy at the skirt. The aerodynamic effect is an increase in drag and a reduction in the slope of the pitching moment coefficient curve at zero degrees angle of attack. This has been shown in preliminary testing to increase the command-response time constant and to reduce the maximum glide ratio for solid cloth canopies of this type. Early system-level testing has shown, however, that the T-10 does have sufficient control authority to make it well suited to AGAS.

Under contract to the US Army Natick Soldier Center, Vertigo is currently developing a smaller and lighter AGAS AGU that will be fully compatible with the T-10, C-9, and T-10R parachutes. This AGU is being built around same FCU used in AGAS 2000 but incorporates smaller and lighter riser hoists, AGU housing, and AGU frame. The T-10R and C-9 can easily accommodate loads up to 300 lb, and the T-10 has been proven to be an effective cargo parachute for payloads up to 500 lb, making an "AGAS 500" the first logical extension of the AGAS family of products. AGAS 500 should be ready for transition to commercial production by Capewell in late 2005.

B. Higher Weight Capacity AGAS

Moving up to the "JPADS Light" classification – 2,200 to 10,000 lb rigged weight – there are two available canopies that could extend the weight range of AGAS: the inventory 100-ft diameter G-11 cargo parachute and the 137-ft diameter triconical parachute that was designed for use in a cluster of six parachutes to deliver loads of up to 60,000 lb from the C-17 Globemaster.[9] The G-11 has a 5,000 lb capacity and the 137-ft triconical cargo parachute is rated for loads up to 10,000 lb.

Under the same Natick Soldier Center contract, Vertigo is currently preparing for a C-123 deployment of the existing AGAS 2000 AGU with a G-11 parachute and a 4,000-lb payload. The only change required to the existing AGU is a reprogramming of the motor control processor with longer throws for the 100-ft diameter G-11. If the performance of the flat circular G-11 proves similar to the G-12, terminal accuracy performance should be only slightly less than AGAS 2000. Calculations show that the electromechanical hoists in the AGAS 2000 AGU should easily handle a 4,000-lb payload. If the test results are positive, Vertigo will identify the modifications required to accommodate G-11 payloads up to 5,000 lb and, with Capewell, develop a plan for qualifying an "AGAS 5000." This will include qualification with the Army's new Enhanced Container Delivery System (ECDS). It also opens the way for scaling up AGAS capacity to 10,000 lb – "AGAS 10000" – using an enhanced AGAS 5000 AGU and 137-ft diameter triconical parachute.

C. AGAS P^{3}I and Derivatives

In addition to extending the family of AGAS products to accommodate payloads ranging from 200 to 10,000 lb, engineers at Vertigo, Capewell, and the Natick Soldier Center are also working on enhancements to the current AGAS 2000 design as well as extending the AGAS concept to more specialized requirements.

1. *Pre-planned Product Improvement*

AGAS is undergoing continuous product improvement, adding features that can generally be retrofitted to existing fielded hardware. Currently, the existing military specification AGU batteries are being replace with sealed lead-acid batteries that are at once lighter, smaller, less expensive, and longer lasting. The current AGAS 2000 AGU weighs 169 lb. Engineers and component suppliers are prototyping and evaluating aluminum frames, composite housings, and lighter hoists, all in an effort to drive weight out of the system.

2. *Military GPS*

The next generation AGAS FCU will include an extra serial data port for integration of a military GPS receiver. A commercial GPS receiver will remain an integrated component of the FCU electronics and will have its own dedicated serial data connection, but during system start-up and initialization, the FCU computer will check the GPS receiver serial data line to see if there is a signal indicating that the military GPS receiver is connected. If it is, this data line will be used exclusively for the mission. The commercial GPS receiver will be ignored.

3. *Ground Release Mechanism*

Also being evaluated is a concept for the autonomous release of two adjacent parachute risers after the AGAS 2000 lands in high-wind conditions. This will allow the parachute to deflate, thereby preventing it from dragging the payload across the drop zone. The AGAS 2000 AGU already has the ability to command riser release. This study focuses on the architecture of an integrated sensor suite that will only trigger riser release in the presence of at least two mutually exclusive environments to ensure the parachute is released only after landing and then only in high-wind conditions.

4. *Special Operations Forces Version*

US Special Operations Forces have expressed an interest in an expendable, very lightweight AGAS AGU that can be used to deliver supplies in the 200 to 800 lb weight range. Their interests extend to issues including hardware transformation. Work on the current Natick Soldier Center program is highly relevant to this mission.

5. *Training System*

AGAS 2000 has proven itself to be very rugged, making it well suited to repeated use in training exercises. Turnaround time is only about 30 minutes longer than the time to inspect, repack, and rig a conventional G-12 CDS. However even that can be quite time consuming when the goal is to maximize the number of training missions in a fixed time. The G-12 is a large parachute and the one-ton CDS bundle requires a forklift to move it around the riggers' loft.

On the other hand, AGAS 500 with a 24-ft T-10R canopy and a 150 lb payload (Fig. 16) would make an ideal training system, permitting multiple drops in a single day from almost any aircraft with a cargo carrying capability, and mirroring in all respects the mission planning and programming required for all weight classes of AGAS, from 200 to 10,000 lb.

Figure 16. Prototype AGAS 500's T-10R Covers Target IP in Development Test.

In addition, engineers are developing the architecture for a video-game-like mission simulator for use with either PADS or the commercial AGAS mission planner. Historically, human error has been the major cause of large landing errors. The AGAS simulator will require all the input steps of a real mission and, when performed properly, will result in landings with a few meters of the target.

VII. Summary

The Affordable Guided Airdrop System (AGAS) 2000 takes a conventional Container Delivery System (CDS) and converts it from a ballistic cargo delivery system to a precision guided airdrop system, well suited to operational deployment at altitudes well above the threat posed by ground-to-air weapons. AGAS 2000 is in this regard a "smart" CDS, outperforming even low-altitude-delivered conventional CDS (Fig. 17).

The effectiveness of this method of aerial resupply was demonstrated at the Precision Airdrop Technology Conference and Demonstration (PATCAD) 2003, and AGAS 2000 has evolved to a commercially available, fully supported precision airdrop system. Its use of inventory parachutes and payload containers and rigging makes it the least expensive of any precision aerial delivery system in its weight class. The use of inventory airdrop equipment also minimizes training requirements and limits any impact on logistics burden.

Given a common flight control and mission architecture, AGAS is suited for integration with round parachutes of various diameters and with inventory and custom payload slings, containers, and platforms to create a range of systems for payloads from 200 to 10,000 lb. AGAS 500, designed for payloads weighing 200 to 500 lb, is scheduled for transition to production in late 2005.

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Figure 17. Four AGAS 2000 (Two Already Down) Land On Traget.