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THE AFFORDABLE GUIDED AIRDROP SYSTEM (AGAS)

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ABSTRACT

This paper presents an overview of the Affordable Guided Airdrop System (AGAS). AGAS is a low cost, high altitude, deployable airdrop system that will be autonomously controlled via an onboard Guidance, Navigation & Control System (GN&C). The AGAS consists of a round parachute that is controlled via four pneumatic muscle actuators (PMAs) which are connected between the system's payload and risers. The AGAS concept is being developed under the US Air Force New World Vistas Precision Aerial Delivery (NWV-PAD) program that is jointly managed by the US Air Force Office of Scientific Research (AFOSR) and the US Army Soldier and Biological Chemical Command, Soldier Systems Center (Natick). AFOSR and

Natick have teamed with The Boeing Company and Vertigo Inc. to demonstrate the AGAS concept. A scaled system was demonstrated in September and November 1998 and is currently scaling up to a standard container delivery system (CDS) payload (A-22 container with 2200 pound capacity). This paper presents the current state of development of the AGAS and provides experimentally obtained performance data on the scaled system. The paper also discusses the applications for the AGAS system in the context of the NWV-PAD program and introduces the Guidance Navigation and Control (GN&C) system concept, which will utilize commercial off-the-shelf (COTS) components.

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APPLICATION

Controllable airdrop systems have matured significantly with the introduction of Global Positioning System (GPS) technology. There are many applications for such systems that are of interest to the Department of Defense (DoD) which include "precision delivery" of equipment and supplies. Controllable parafoils and semi-rigid wing technologies have dominated this application area and both of these technologies provide the added benefit of relatively significant aircraft offset distances for system deployment, which equates to some increase in aircraft survivability. However, the current costs of these higher glide technologies are large when compared to the equivalent payload capacity AGAS cost estimates. The AGAS system is intended to fill a technology void between these higher glide systems and current high altitude, high opening, ballistic systems while potentially offering an increase in accuracy. The AGAS system is one program within the overall NWW-PAD program. A brief outline of specific parts of the overall NWW-PAD program and the relationship they have towards complementing the AGAS will be presented next.

OVERVIEW OF NWW-PAD PROGRAM

The NWW-PAD program's primary objective is to explore technologies that have the potential of improving the accuracy of high-altitude airdrop while maintaining a low system cost. Based on a variety of studies regarding the major sources of

high-altitude airdrop accuracy, the NWW-PAD government team determined that investment in three primary areas should have the most potential of achieving the NWW-PAD objectives with the potential of a high return on investment. The three areas are: 1) improved computed aerial release point (CARP) technologies, 2) advanced wind sensors and wind models, and 3) advanced decelerator concepts. The NWW-PAD program has made investments in these three areas. The goal is to perform an integrated demonstration of these technologies in FY01. The key elements of AGAS and their relationship with aircraft-based sensors and data are illustrated in Figure 1.

A typical airdrop scenario with AGAS starts with executing wind/weather models over a grid area that includes the drop zone and use these predictions in the improved CARP (a PC based algorithm) to determine the first approximation to the CARP in space (prior to or just after take-off). On route, the CARP is improved with near-real-time wind estimates over the drop zone. These may come from a variety of sources, to include: A) the 1553 bus on the aircraft that carries estimates of winds encountered by the aircraft; B) drop sondes that may be dropped periodically on route to the drop zone; and C) advanced wind sensors such as LIDAR and/or radar measurements on route. The CARP/Trajectory algorithm is used to determine a "best wind estimate" based on all or some combination of these wind inputs, and to determine the release point (green light) by back-

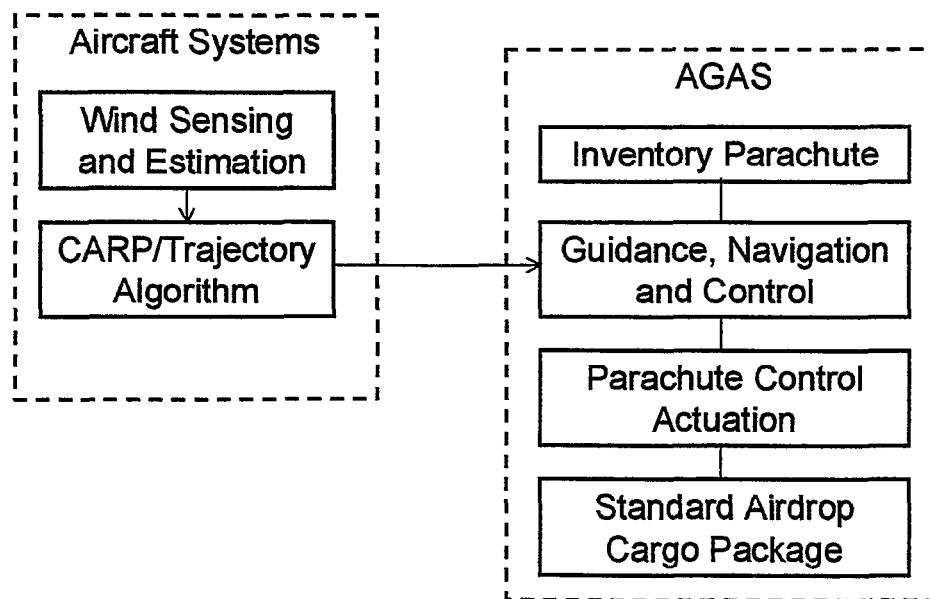


Figure 1 System Component Block Diagram

calculating the trajectory of the loads from the drop zone. This provides an updated release point location to the navigator/pilot. Just prior to green light, the predicted trajectory, current GPS signal, wind estimation, etc. is uploaded to the AGAS GN&C unit. Once the CARP signals a green light, the deployment sequence is started and (for the current program) no further communication with the loads will take place.

Once the parachute deploys and opens, the AGAS GN&C corrects the system's trajectory if it is drifting from the preset "nominal" trajectory (Figure 2). The GN&C logic will perform a minimal quantity of "steering" inputs to keep the system on the preprogrammed trajectory. AGAS will have the ability to autonomously guide multiple loads to different drop zones from one sortie or put all or some loads on the same drop zone.

The horizontal velocity required of the guided system is not related to the wind velocity, but rather to the accuracy of the input wind profile data. The guided system will need only to generate a horizontal velocity somewhat greater than the average error in the wind velocity data.

(Theoretically, if the airdrop system could be modeled exactly, the winds are known with perfect accuracy and the parachute opens exactly at the calculated air release point (CARP), then no control action is necessary.) This reduced horizontal velocity requirement creates an opportunity for other than high glide systems that may be more affordable and yet have high terminal accuracy.

SYSTEM DESCRIPTION

The technique of controlling round canopies has been used for years by soldiers and smoke jumpers who jump round chutes into generally unprepared drop zones. This is accomplished by jumpers pulling down on risers to "slip" the parachute horizontally and is usually performed to avoid other jumpers and obstacles, or to minimize the relative horizontal velocity of the system in winds just prior to ground impact. AGAS uses a similar technique with pneumatic muscle actuators (PMAs) to cause and to control the slip or "drive" of the parachute. The AGAS flight configuration and method of rigging the PMAs is illustrated in Figure 3.

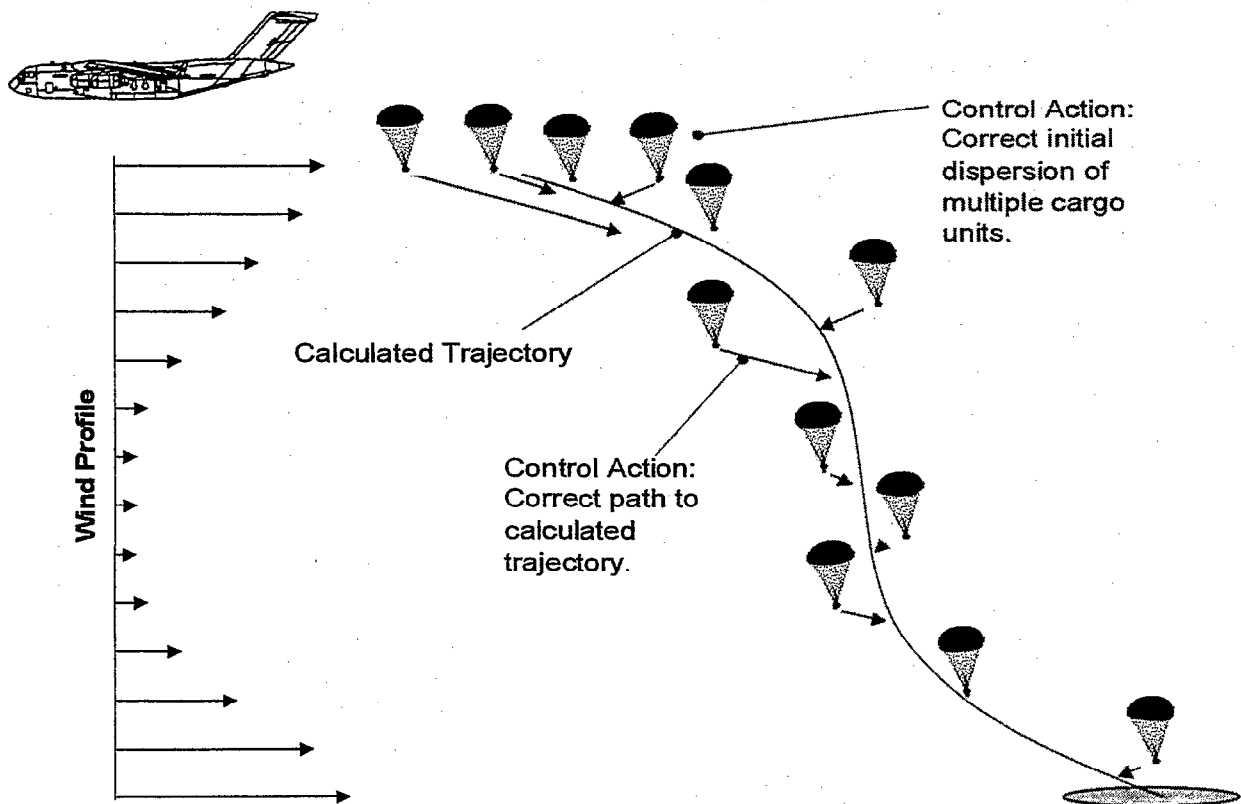


Figure 2 Mission Profile

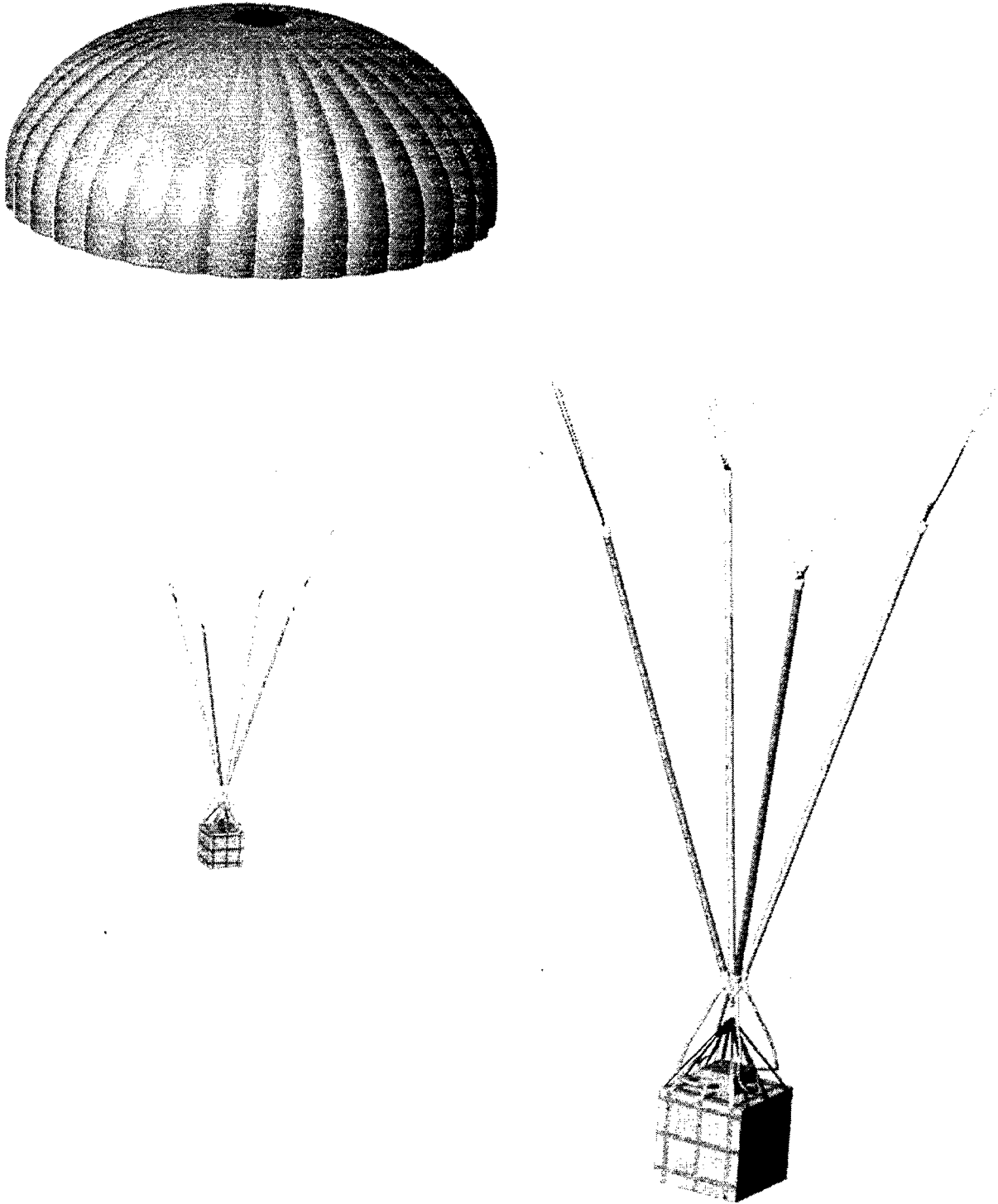


Figure 3 AGAS Flight Configuration and a Close Up of the Control Rigging

The no-glide AGAS control state is with all PMAs contracted (pressurized). When horizontal velocity is needed, one PMA or two adjacent PMAs are vented and extend to cause the desired parachute shape change. Early tests showed that this was more effective than starting with all extended and causing drive by contraction.

The AGAS system has the advantage of having no "predetermined" forward direction due to the symmetry of the system. This is expected to provide an increase in drop zone accuracy (as compared to equivalently sized parafoil systems) as the system will be capable of descending vertically over the desired ground impact point and minimize the affect of relatively poor accuracy of the vertical component of GPS. The full scale AGAS will utilize standard military airdrop inventory which will include: the G-12 canopy (a 64-foot constructed diameter flat circular) and the A-22 container (the standard US Army resupply container which is essentially a 4-foot cubed box with a payload capacity of up to 2200 pounds).

a similar device was described in a patent document for a mining application (Pierce U.S. 2,211,478) (Figure 4).

A PMA is a braided fiber tube that contracts in length and expands in diameter when pressurized. The contraction is quite forceful when compared to a piston-in-cylinder of the same diameter, (in fact 20 or more times more forceful at the same pressure), and a contraction stroke of up to 40% of the original length is obtainable. A more complete description of PMA characteristics is found in "A New Pneumatic Actuator: Its Use in Airdrop Applications".¹ Figure 5 shows the uninflated PMAs as installed on a scaled system.

The particular characteristics that recommend PMAs for use as AGAS actuators are:

- efficient packing and reliable deployment,
- high specific power, and
- low manufacturing cost.

PNEUMATIC MUSCLE CHARACTERISTICS

Pneumatic Muscle Actuators (PMAs) have been known, in concept, since at least 1940 when

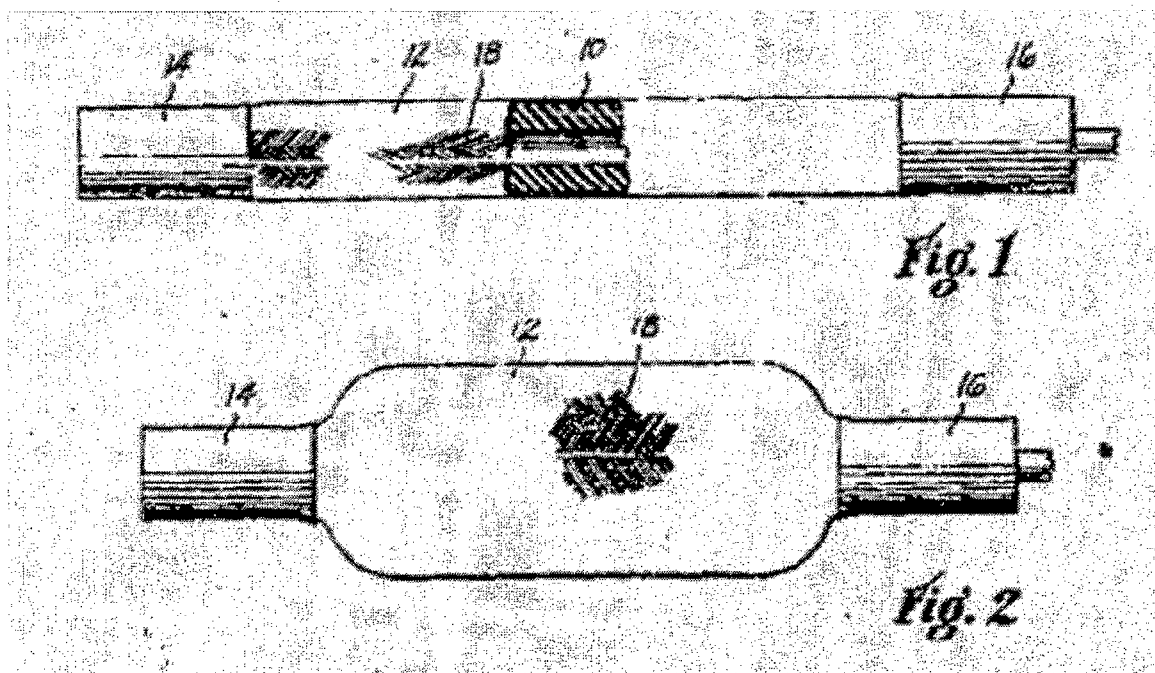


Figure 4 1940 Patent Drawing of Pneumatic Muscle



Figure 5 PMA Installation

TESTING

To demonstrate the concept, a scaled version of the AGAS system has been designed and tested with its four PMAs being activated via radio control from the ground. Figure 6 shows the scaled system which consists of a C-9 parachute (28 foot constructed diameter flat circular canopy), four PMAs (each is 10 feet long when uninflated and 1 inch in diameter), and an instrumented payload weighing approximately 300 pounds. Drop tests were conducted at Lake Elsinore, California (August 1998) and Yuma Proving Grounds (September and November 1998).

The YPG tests were complimented with instrumentation and data recording devices that monitored system dynamics, actuator commands, and wind profile (RAWIN and ground based LIDAR). The instrumentation suite is further described in "Low Cost Parachute Guidance, Navigation and Control".² Other data was collected through the use of drop sondes, a calibrated companion system with the same rate of decent (but not controlled), ground balloon launches and ground based LIDAR for wind measurements. Initial sizing of the PMAs for these tests were determined by manually changing the lengths on single and double riser set under a C-9 canopy. The trajectory and a measurement of the length of the riser length change were recorded to estimate both when the onset of collapse in the leading edge occurs, and a first estimate of system performance (lift to drag ratio).

Figures 7 and 8 show typical data from flight tests. The velocity data has been filtered to remove short-period canopy oscillations. Our best estimate of the wind has been removed. Figure 7 shows the response to the action of a single PMA. An initial glide ratio (approximately 0.3) is apparently due to motion induced by the oscillations as well as an imperfect wind estimate. Upon control input, the glide ratio clearly increases by approximately 0.4 to 0.5 demonstrating the performance achievable by this technique. A response time of approximately 5 seconds was observed. Figure 8 shows the response to the simultaneous action of two adjacent PMAs. The video obtained during these tests highlighted collapse of the leading edge of the canopy with action of two adjacent PMAs. There does not appear to be an increase in performance by actuating two with the exception of additional heading resolution of eight possible control states rather than four.



Figure 6 Flight with One PMA Extended

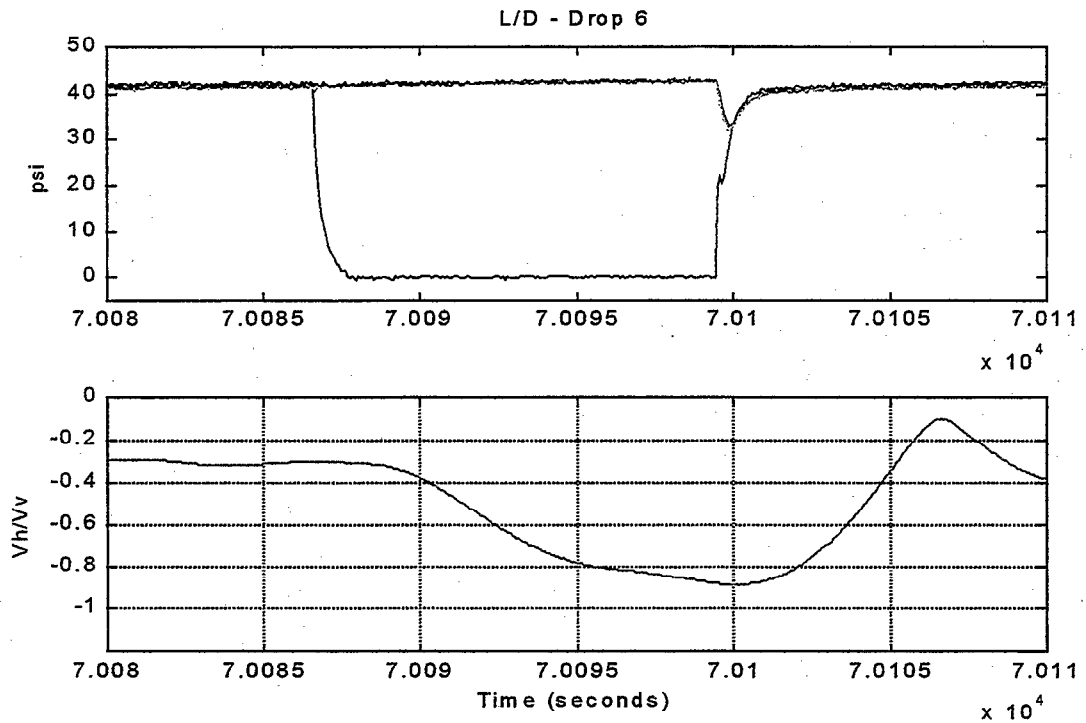


Figure 7 Response to Single Actuator

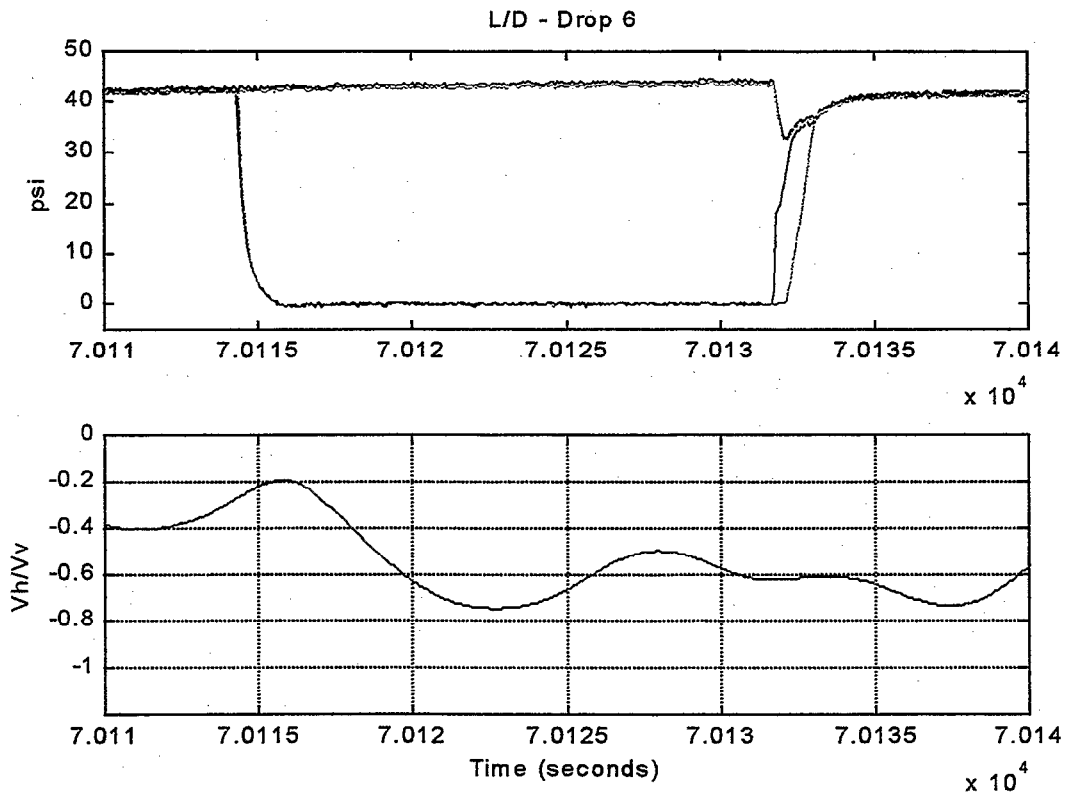


Figure 8 Response to Two actuators

GUIDANCE, NAVIGATION AND CONTROL

The AGAS steering mechanism flies the parachute to a nominal flight profile (NPF) rather than being guided directly to the delivery point. This means that a trajectory from the airdrop release point to the delivery point is initially computed based upon a measured wind profile and stored in the airdrop package guidance unit. As the package is descending, the estimated deviation from the trajectory is calculated. Steering commands are applied to the standard non-glide parachute to give the capability of trajectory correction. The process is illustrated in Figure 9.

The AGAS Guidance, Navigation and Control (GN&C) system employs commercial off the shelf (COTS) components to configure a rugged, affordable, low risk Guidance Control Unit (GCU). The GCU receives initialization, drop zone aimpoint, and nominal trajectory data prior to air drop and, following GPS acquisition, outputs steering commands to the Pneumatic Muscle Actuator (PMA) valve controllers.

Figure 10 illustrates the AGAS GN&C components and interfaces required. The GCU employs commercial PC/104 modules installed in a standard PC/104 aluminum enclosure. The core of the GCU is a 386SX single board computer with 2 Mbytes of flash memory that will be programmed in C using a software developer's kit provided by the manufacturer. Navigation is accomplished with a C/A code GPS receiver, mounted on a GPS Carrier Card, and using an active GPS antenna. An electronic compass is used to determine the parachute orientation for a steering reference. Two modules, an R104-88 Relay Output board and a power supply, round out the guidance components. For test data recording, a 512MB hard drive is mounted on a hard drive adapter.

The computer interfaces with the GPS receiver and valve driver cards via the PC/104 Bus, and with the hard drive using the on board IDE interface and a ribbon cable. It interfaces with the compass using one of two on board serial communication ports (UARTs). Power is distributed to each of the modules via the PC/104 Bus.

An AGAS simulation will be developed using pre-existing diagrammatic programming tools. Figure 11 illustrates the organization and major modules of the proposed AGAS simulation. The

simulation will be updated to reflect parachute response data from flight testing as that data becomes available from opportune testing.

Unit testing of the GN&C software is accomplished within the simulation environment. Integration and functional testing of the manually coded software and the full up software build will be conducted on a single board. Functional testing of the GCU complete with the GPS receiver, electronic compass, GCU battery pack and valve controllers will be conducted before flight testing.

CURRENT STATUS OF PROGRAM AND ANTICIPATED FOLLOW ON EFFORTS

The results summarized here were produced in the first year of the planned multi-year NNV-PADS program. The scaled C-9 system demonstrated large oscillatory motions during uncontrolled descent, but these motions were reduced during control inputs and the transition to glide. In the prototype scaled tests, the system appeared to demonstrate a maintainable L/D of at least 0.4. The performance of the system under a G-12 is expected to improve based on US Army experience with G-12 ballistic systems compared to the C-9 system.

The goal of this program is to demonstrate controllability of a CDS system and to conduct an integrated demonstration in 2001. The goal is not to maximize L/D of the system or to glide near leading edge collapses. The concept of riser slips for control could be expanded to many other canopy types and improved system performance is expected for some canopies. However, the goal of this program is to utilize existing US Army inventory systems to minimize cost/training and not to invest in new canopy systems. The C-9 tests have given the team confidence in the concept and the design of the G-12 system is underway.

A series of drop tests at YPG are planned for the spring of 1999 with a G-12 system with varying riser lengths to assist in simulation and GN&C development. These tests will also assist the team's understanding of the affect of riser slip length on L/D when the concept is scaled. These tests also plan to look at the potential of utilizing a proportional control capability with the PMAs as an alternative to the C-9 on-off control tests.

Other low L/D (known as "semi-ballistic") concepts are also being explored in the NMV-

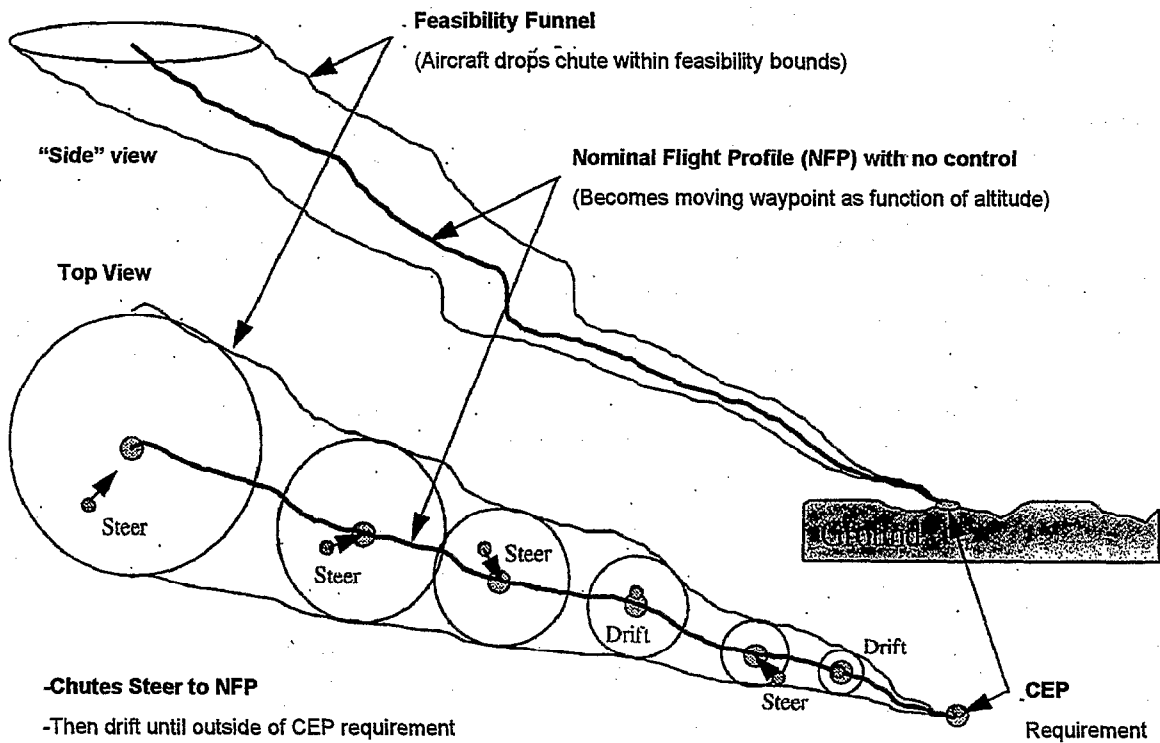


Figure 9 Airdrop Guidance Concept

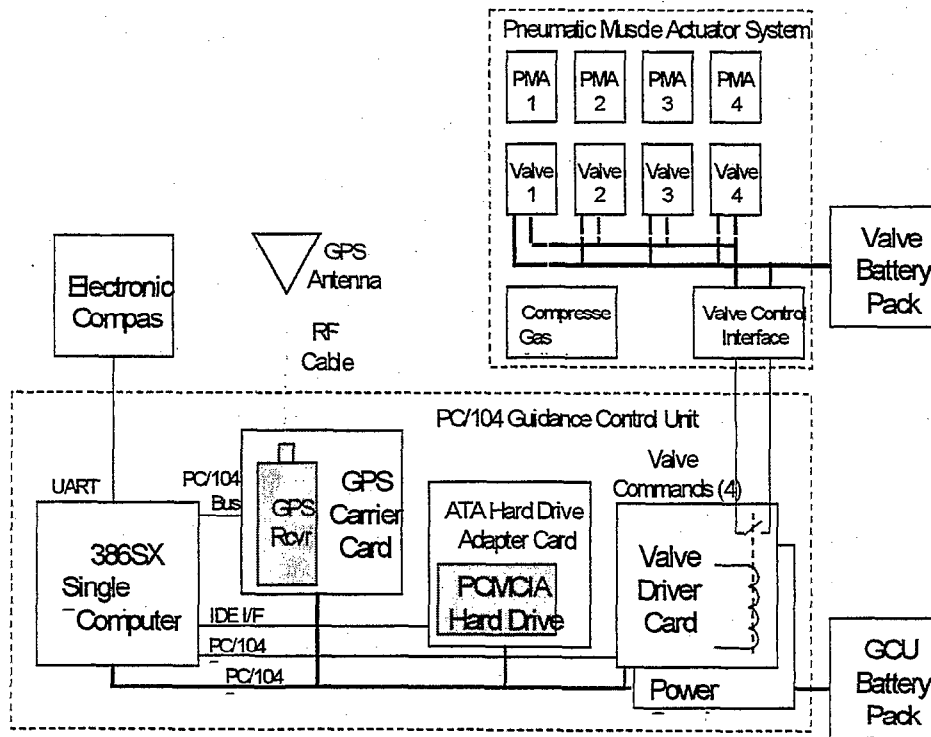


Figure 10 AGAS Flight Test GN&C Components and Interfaces

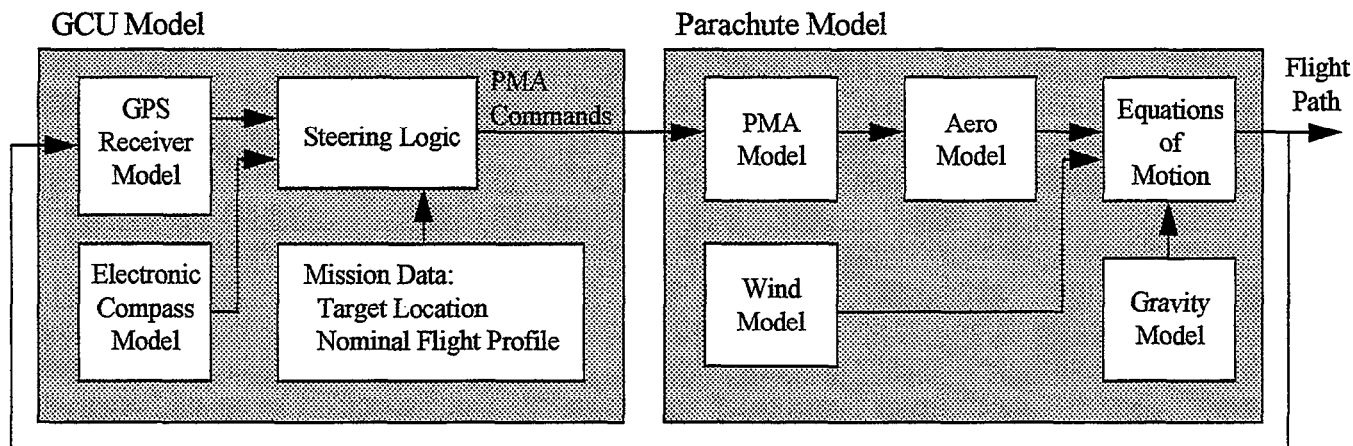


Figure 11 AGAS Simulation

PAD program through complimentary research on high performance computer modeling that couples computational fluid dynamic and structural dynamic finite element software to predict airdrop system performance. The C-9 AGAS system has been modeled with a structural dynamic finite element code referred to in "Controllable Airdrop Simulations Utilizing a 3-D Structural Dynamic Model."³ The 1999 goal is to demonstrate a radio controlled 2200 pound AGAS system. If the work is continued, the plan is to incorporate an onboard GN&C system and conduct autonomous flights in 2000.

The NWV-PAD program hopes to demonstrate an integrated (with onboard winds and digitized CARP communicating with the AGAS unit) demonstration in 2001 with an impact Circular Error Probable (CEP) of less than 100 meters.

CONCLUSIONS

This paper has presented the current state of development for the Affordable Guided Airdrop System (AGAS). This system is being developed as part of the US Air Force NWV-PAD program. A scaled AGAS system has been designed, constructed and tested with a full suite of instrumentation. The system has been successfully drop tested many times and has resulted in excellent data and system characterization for GN&C development. System performance estimates have confirmed a GN&C system architecture utilizing all COTS components. The scaled AGAS experimental results are encouraging and have resulted in a continuation of the program to test a full scale (2200 pound system) later this year.

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