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LOW-GLIDE PARACHUTE CONTROL FOR AFFORDABLE PRECISION AERIAL DELIVERY

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Abstract

Precision, on-time aerial delivery is a critical component of Objective Force, in terms both of force projection, resupply and sustainment and as an essential component of force protection and survivability. Delivering materiel where, when and as needed allows the Objective Force Warrior to be responsive in the on-time execution of his mission and also agile in changing/evolving battle situations. Finally, precision aerial delivery is key to sustainment with a minimized logistics footprint. Previously, guided airdrop has focused on the development of large-scale parafoil systems. These systems have the potential to provide the accuracy required with delivery from high altitude and large offset distances. The drawback is relatively high cost for each pound of payload delivered. Investigation of alternate approaches is warranted to reduce system costs. The team of the United States Army, Navy and Air Force, along with a number of contractors, is evaluating alternative airdrop technologies under an Army Science and Technology Objective (STO) titled "Deployment Combat Ready Aerial Delivery" and the USAF funded New World Vista-Precision Aerial Delivery (NWV-PAD) program. The NWV-PAD program invested in three areas: 1) Weather, 2) Computed Aerial Release Point (CARP), and 3) Advanced Low Cost, Smart Decelerators. This paper will focus on one low cost decelerator system known as the Affordable Guided Airdrop System (AGAS). A companion paper at this conference will describe linked weather and CARP program.

I. Introduction

The key ideas of the AGAS concept are explained nextThe first step in the precision air delivery process is for the end user to broadcast a supply request that includes information on where and when it is needed on the ground. The request is received by a support aircraft (possibly an UAV), which upon arrival in the vicinity of the assigned drop zone (DZ) drops a wind dropsonde and/or collects in-situ weather from other sources. The wind profile acquired during this drop allows computation of the reference trajectory (RT) and of the Computed Air Release Point (CARP). The delivery aircraft will then be navigated to that point for air delivery of the materiel (payload). Should the wind estimate and calculation of the CARP be perfect and the aircrew able to get the aircraft to this point precisely, then the parachute would fly along RT towards the TA with no control inputs required. However, wind estimation is not a precise science. Furthermore, calculation of the CARP relies on less than perfect estimates of parachute aerodynamics and the flight crews cannot precisely hit CARP for each airdrop mission (especially in case of massive (multiple) deliveries). Therefore, the AGAS Guidance, Navigation and Control (GNC) system is used to correct these potential errors.

The ultimate goal of the AGAS system is to allow delivery aircraft to accurately drop payloads at or above 5500*m*, keeping the aircraft out of the range of shoulder fired ground to air missiles and small arms fire. Another benefit of the system is the ability to pre-address each bundle on the aircraft and to guide the individual bundles to their own pre-programmed TA. Obviously, in order to accomplish these goals, the AGAS system needs to be simple, affordable, durable, and reusable (it should survive multiple drops without any repairs). It should not require major modifications to the standard delivery system's harness or bundle, major modifications to the cargo parachute, or a significant amount of rigger training.

As a result, the AGAS design concept employs a commercial Global Positioning System (GPS) receiver and a heading reference as navigation sensors, an inexpensive guidance computer to determine and activate the desired control inputs, and application of Pneumatic Muscle Actuators (PMAs) developed by Vertigo Inc. to generate control inputs. The navigation system and guidance computer are secured to the existing container delivery system, while PMAs are attached to each of four parachute risers and to the container. Control is affected by lengthening one or two adjacent risers. Upon deployment of the system from the aircraft, the guidance computer steers the system along pre-planned RT. The AGAS concept relies on sufficient control authority to be produced to overcome errors in wind estimation and the point of release of the system from the aircraft. The following subsections briefly discuss the main components of the developed and flight-tested G-12 based AGAS.

II. Parachute

In general, AGAS may be implemented on any circular parachute (a flat circular parachute is one that when laid out on the ground, forms a circle). The G-12 has been used to demonstrate feasibility of the AGAS concept.

III. Control Input System

To provide control inputs for AGAS, Vertigo, Inc. developed PMAs that are braided fabric tubes with neoprene inner sleeves that can be pressurized[1-3]. Upon pressurization, the PMA contracts in length from 7.6*m* to 5.8*m* and expands in diameter. Upon venting it does the opposite. When three of four PMAs are pressurized (filled) and one is activated (vented) this action "deforms" the parachute creating an unsymmetrical shape, essentially shifting the center of pressure, and providing a drive or slip condition. This forces the parachute to glide in the opposite direction of the control action (vented PMA). Two adjacent PMAs can be activated simultaneously.

The volume of the onboard nitrogen tank limits the number of possible fills for all four PMAs to 32 per drop. PMA fill and vent times remain constant 5-6 seconds throughout each drop (regardless of the volume of gas remaining in the tanks).

The PMAs' control system (PCS), also developed by Vertigo, Inc., resides in a specially designed container of 0.4*m* height. It consists of a high-pressure recharge circuit (225*atm*), two 44*atm* accumulator tanks, pressure reduction units, valves, and a low-pressure circuit feeding PMAs (10.2*atm*). Nitrogen rather than helium is used in the latest version of AGAS as it is less-dependent on temperature.

III. CARP and RT computation

Presently as a part of the AGAS effort Draper Labs and Planning Systems Inc. (PSI) developed a highly sophisticated system that provides accurate prognosis of the wind over the DZ to be used for generation of the CARP and the RT.

This laptop based system resides aboard a C-130 carrier aircraft and is linked to the aircraft's data bus. Its software is designed by Draper Labs to produce CARPs and RTs and relies on the best available 3D wind profile generated by PSI's software known as WindPADS (Wind-Profile Precision Aerial Delivery System)[4].

IV. GNC system development

As discussed in Section II the actuation box for PMA's developed by Vertigo is capable of only bang-bang control. Optimal control analysis conducted at NPS suggested that bang-bang is also the optimal control strategy and produced an important concept of an operating angle. This motivated the following basic control concept for AGAS. Since the time-optimal control strategy was shown to minimize the number of actuations for a planar model, this strategy was employed to get the parachute to within a predefined altitude-dependent DZ (defined by inner and outer cones discussed next) and then for the remainder of descent to stay within this area. In addition, this basic strategy was modified to provide robustness to uncertainties in yaw motion due to yaw moments created by activating adjacent PMA's and/or due to yaw sensor errors[5-7].

V. Flight test

The AGAS system was successfully demonstrated during the PATCAD conference held at YPG in September of 2001[8]. To illustrate the difference between non-controlled and controlled parachutes, two standard G-12 and two AGAS (followed by a wind-pack to measure winds) were deployed simultaneously. A total of two drops were conducted. The miss distance for the three AGAS systems released was less than 78*m* as oppose to 140 and 1370*m* for uncontrolled parachutes (see Table 1).

Table 1. PATCAD results

Date	Test Item	Weight (*kg*)	IP miss (*m*)
09/13/01	*WindPack*	21	515.1
	STD G-12	724	512.2
	STD G-12	773	141.9
	AGAS-1	**726**	**76**
	AGAS-2	**726**	**78**
09/14/01	*WindPack*	21	1048.6
	STD G-12	726	1371.6
	AGAS-4	726	55.5

VI. Conclusions

Results presented in this paper showed feasibility of the AGAS concept. A bang-bang control strategy imposed by the PMA hardware was developed to successfully drive AGAS to the DZ within a prescribed circular error in flight tests at YPG. The key to the success of this strategy were concepts of operating angle motivated by optimal control analysis as well as inner and outer cones and hysteresis included to improve performance robustness.

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