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[Snowflake] Yakimenko, O., Slegers, N., Bourakov, E., Hewgley, C., Bordetsky, A., Jensen, R.,

Mobile System for Precise Aero Delivery
with Global Reach Network Capability

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Abstract—**This paper discusses the current status of the development of the mobile aerial delivery system to be further employed in a variety of different applications. High accuracy of the developed system enables its use in precision troop resupply, precise sensors placement, urban warfare reconnaissance and other similar operations. This paper overviews the overall system architecture and components of the developed aero delivery system itself and then proceeds with describing the current status of integrating it with an advanced deployment platform, unmanned aerial system, to achieve mobility and autonomy of operations. The paper also discusses some other systems in development pursuing similar goals and reviews some novel applications that become possible with the developed aerial delivery system.**

I. INTRODUCTION

THERE is a need to develop different-weight autonomous aero delivery parafoil-based systems, including micro a light weight (MLW) system for delivery of 10…150 lbs and a ultra light weight (ULW) system for 250…700 lbs payloads.[1] These systems could play a vital role in and provide aerial delivery of therapeutics, medical equipment, combat care kits, combat critical care systems, expendable re-supply items for biological detection systems, prophylaxis, and robot/sensor/psyop systems. They are supposed to be deployed from high altitudes and large standoff distances (to keep aircraft and aircrew out of harms way), and an airborne guidance unit should guide them to the predetermined target with the anticipated accuracy threshold of 50 meters and 150 meters, for MLW and ULW systems, respectively.[1] Moreover, these aerodynamic decelerator systems (ADSs) should fit into existing architecture and be able to be deployed from manned fixed and rotary wing aircraft platforms and select unmanned aerial system (UAS).

The recently developed Snowflake ADS[2-5] falls into the category of MLW systems and because of its advanced guidance, navigation and control (GNC) algorithms concept, involving networking, has superb potentials.

This paper overviews the content and performance of the developed Snowflake ADS and presents the current state of integrating it with another advanced system – Arcturus T-20 UAS to achieve the goals set for MLW systems. To this end, Section II provides a brief description of the Snowflake ADS / Arcturus UAS system, followed by Section III overviewing other similar products in the development by other teams. Section IV briefly discusses the directions of further research based on the unique capabilities of the developed system. The paper ends with conclusions.

II. DESCRIPTION OF THE SNOWFLAKE ADS

In 2008 the Aerodynamic Decelerator Systems Center (www.nps.edu/ADSC), being supported by the U.S. SOCOM, presented a miniature prototype of autonomous ADS, Snowflake, developed by the team of researches from the Naval Postgraduate School and University of Alabama. The fully deployed Snowflake ADS in flight is shown in Fig.1a. It consists of a Pelican 4"×8"×10" payload container with the GNC unit inside it (Fig.1b). The wingspan of a fully deployed two-skin canopy is 4.5' and its chord is 2.1'. The dry weight of the original system is only 4.3lbs. The GNC unit consists of avionics and control actuators. The avionics include three accelerometers, gyroscopes and magnetometers, a global positioning system and barometric altimeter, integrated on a single circuit board.[2]
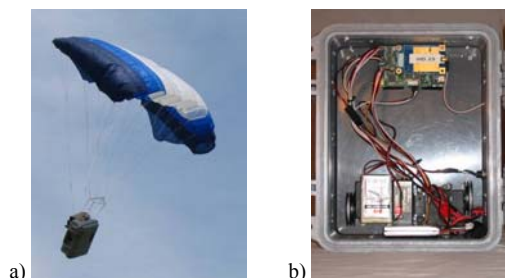

Fig. 1. Snowflake with a fully deployed parafoil (a) and avionics bay inside a Pelican 1200 case (b).

In its original design the Snowflake ADS is capable of carrying additional 1…3 lbs of a payload and exhibits the

following performance: the descend rate of 12ft/s, forward speed of 14kts, glide ratio of 2, and minimum turning radius of about 50ft. The original Snowflake ADS was developed to be deployed manually by throwing it out of the window of general aviation aircraft, helicopter, or deployment ramp of a transport aircraft. The person who deploys it has to push the button on the side of a Pelican container (charge the deployment mechanism) and throw it out (there is no static line / lanyard).[2]

The user has to define (upload) a target location beforehand and upon release Snowflake ADS steers towards it autonomously, tracking the inertial trajectory as shown in Fig.2. The precision placement algorithm to control the system during all phases is based on the model predictive control.[3] Snowflake GNC allows landing at any predetermined direction including into the wind for soft landing.
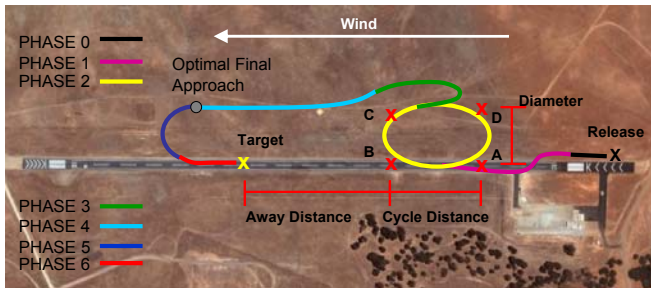

Fig. 2. Guidance strategy.

To mitigate the effect of unknown and constantly changing ground winds, the terminal guidance algorithms employ continuous (real-time) reoptimization of the final turn.[3] As pointed in Ref.4 this is a unique feature that distinguishes Snowflake's GNC from that of all other known systems. But this is not the only novel idea Snowflake utilizes to achieve an unprecedented accuracy. The Center for Network Innovation and Experimentation (CENETIX) (cenetix.nps.edu/cenetix) introduced another novelty, networking, enabling communication between multiple descending ADSs, ground weather stations and operator/user, who can reside anywhere in the world (global reach).[5] The current network / communication architecture is presented in Fig.3.

The portable ground target weather stations (Fig.4a), based on the portable Kestrel 4000 weather station, were developed to measure ground winds and uplink them to the descending Snowflakes-N (N stands for the networking version). In its current design a primary mode for the weather station to communicate with the descending Snowflake-N is via miniature computer and 900MHz FreeWave radio module residing in a Pelican case 1150 nearby (Fig.4b). In this case, the weather station talks to the computer using a Bluetooth interface.

The Snowflake-N payload can also include the standard Blackberry 8310 cell phone, which communicates with the autopilot via Bluetooth-Serial module. That allows sending and receiving packages of data via the AT&T

GSM network / Internet to the situational awareness (SA) server located at NPS. The portable ground weather stations in this case can also include a Blackberry / Bluetooth module bundle allowing them to be clients of the network as well.
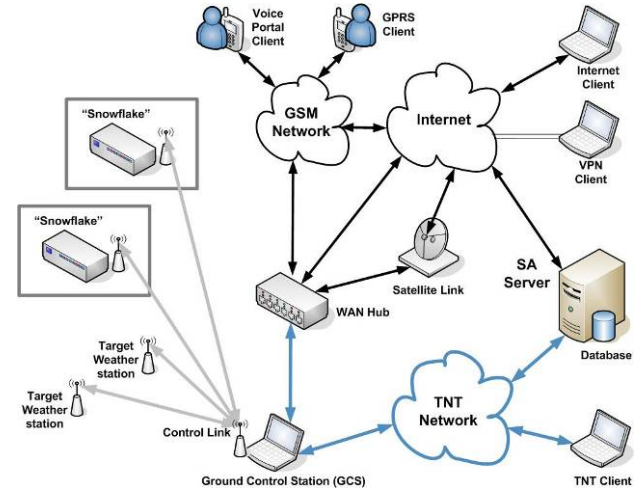

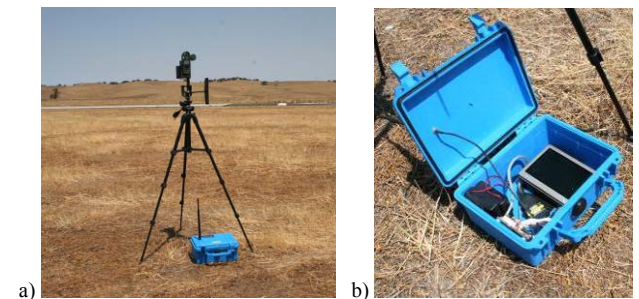Fig. 3. The Snowflake communication architecture.

Fig. 4. Portable weather station on the vane (a) and its computer / communication set (b).

Lastly, the operator/user can interfere at any moment via computer (Internet), via GSM handheld, or via voice portal to change any mission parameters.

Originally developed for the single purpose of communicating with the target weather stations to enable better touchdown accuracy of the Snowflake ADS, the developed architecture allows doing much more and some of these new capabilities, e.g. dynamic target reassignment from a distant location via the phone or Internet were explored and tested already.[5]

The accuracy of the Snowflake system achieved in numerous drops at Camp Roberts, CA and Yuma Proving Ground, Yuma, AZ is of the order of ~25m circular error probable (CEP), i.e. twice as accurate as the current requirement to MLW systems. With upcoming tests in September of 2009 the touchdown accuracy is expected to decrease down to about 15m CEP, which is the lower bound for the cheap sensors Snowflake ADS employs.

The current development of the Snowflake ADS includes integrating it with the UAS in order to deliver a

complete, self-contained mobile combat system for precise aero delivery with global reach capability. To this end, the Arcturus T-20 UAS (www.arcturus-uav.com) presents an ideal deployment platform. The T-20 UAS is ArcturusUAV's newest and largest vehicle (Fig.5). With a 17' wingspan, this Tier II class vehicle offers the ability to carry up to 65lbs of payload in excess of 16 hours. It is powered by a versatile 10 horsepower 4 stroke engine offering smooth, quiet (!) and efficient power. With most of the fuel carried in the wings, T20 has a massive payload bay measuring 11½"×11½"×34" clear, with more available. Avionics are carried in the aft portion of the fuselage.

Fig. 5. Atcturus T-20 UAS.

The T-20 features molded modular construction for ease of parts replacement. The live skin hinging system ensures control surface integrity and low maintenance. The T-20 is pneumatically launched and belly landed. This allows the vehicle to operate from austere unimproved locations. No runway is needed to fly. A replaceable belly skid absorbs the abrasion and is changed in minutes. Any reasonably level open space is all you need to operate. A retracting sensor gives a full 360 deg unobstructed field of view.

Compared to the old design, the new Snowflake box intended to be used with T-20 UAS (Fig.6a) is manufactured from a carbon-fiber composite material and happens to be much lighter than the old system, which was housed inside a heavy Pelican 1200 case. The size of the new system coincides with the size of the inner compartment of the Pelican 1200 case. This new design can now be used in the same manner as the previous design, but it can also be a part of a bigger payload container as shown in Fig.6b.

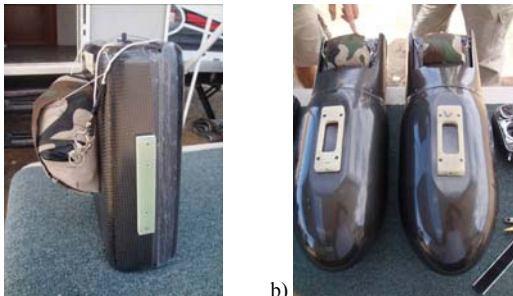a)   b)

Fig. 6. New Snowflake avionics enclosure (a) and a payload pod (b).

In the case of small payload (sensors, meshcards / network nodes) the inner payload bay of Arcturus T-20 UAS can host up to a dozen Snowflakes. The larger containers (Fig.6b) are hung under the wing as shown in Fig.7. The preliminary tests of this new design showed a safe release of Snowflake containers. More tests are expected in October of 2009.

Upon completion the system will we demonstrated at Precision Airdrop Technology Conference and Demonstration (PATCAD) at the U.S. Army Yuma Proving Ground. For the sake of comparison some other ADSs falling into MLW and ULW system category are discussed next.
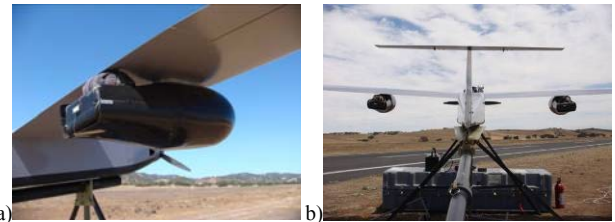

a)   b)

Fig. 7. Snowflake ADS under the wing of Arcturus T-20 UAV (a) and a complete ready-to-go system at the launch catapult.

III.   OTHER MLW AND ULW SYSTEMS

There are several other companies developing systems similar to that of Snowflake ADS / Arcturus UAS. A brief description of these systems is presented below.[1]

The U.S. Army Quick-MEDS (QM) precision guided delivery system by Dynetics, Inc. (www.dynetics.com) (Fig.8) is designed to deliver critically needed supplies to troops from the Outlaw UAS (www.griffon-aerospace.com/outlaw.html). The empty pod weight goal is 10lb and the total payload weight is not to exceed 40lbs. The QM incorporates onboard GPS with an inertial navigation system that triggers an auto-release when over the target, allowing the UAS to operate at safe altitudes. The QM releases autonomously, guides to a point directly over the intended recipient, and deploys a circular (uncontrolled) parachute to decelerate the pod prior to ground impact.

Fig. 8. Dynetics Quick-MEDS system.

Compared to Snowflake ADS / Arcturus UAS the QL has several drawbacks:

- Small standoff distances at deployment (there is no parafoil),
- Uncontrollable parachute that may result in a low accuracy if deployed higher than 300ft above the ground,
- Single package per system,
- Pusher aircraft limiting deployment capabilities,
- No intention / need for taking advantage of networking with other agents.

The Atair's Onyx Micro Light (Onyx ML) delivery system (www.atair.com/onyx) (Fig.9a) is a precision airdrop system designed to address the requirements of the Joint Precision Airdrop System MLW (JPADS-MLW) system of the Joint Medical Distance Support and Evacuation (JMDSE) program for delivering medical resupply and casualty support payloads, sensors, or robots weighing between 10 and 150 pounds from a variety of manned and unmanned platforms and systems. The intention is to deploy it from the long endurance autonomous powered paraglider (LEAPP) developed under contract with DARPA (Fig.9b).

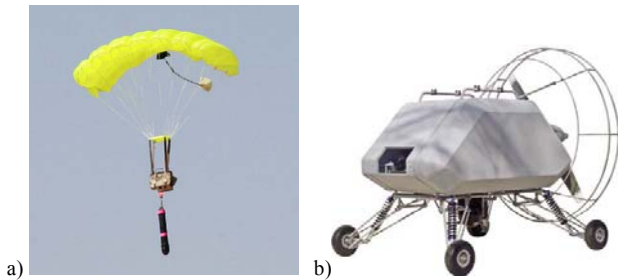a)   b)

Fig. 9. Onyx ML with mock sensor payload release canister (a) and powered paraglider LEAPP (b).

Compared to the Snowflake ADS / Arcturus UAS this system has:
- Moth mode control for a parafoil that limits an accuracy and prevents landing into the wind for soft landing,[4]
- Single package per system,
- Low-speed deployment platform,
- No intention / need for taking advantage of networking with other agents.

STARA's guided parachute Mosquito (www.stara.biz) is another reusable ADS designed to accurately deliver payloads weighing between 1 and 150 pounds within 50 meters of a pre-programmed GPS impact point (Fig.10). It currently comes in three weight categories, 30lbs (40ft^2 canopy), 60lbs (80ft^2 canopy) and 130lbs (150ft^2 canopy). They all employ the same 12"×10"×2" airborne guidance

Fig. 10. STARA's Mosquito sensor delivery system.

unit (AGU), which relies on GPS only and weights about 10lbs.

This system is expected to be deployed from a Tigershark UAV (www.microuav.com/tigershark.html) (Fig.11b), and for the purpose of accommodating light weight resupply bundles was repackaged into the MDS3 form factor (called "Provider").

Fig. 11. Tigershark UAV.

To our knowledge this system has the following features:
- Upon arrival to the vicinity of the target the actual payload is being released under a round canopy opening right before above the surface of the ground, while the parafoil flies away, i.e. no soft landing (into the wind) is available,
- Single package per system,
- Relatively low range for the deployment platform, deteriorated by using an external not aerodynamically sound suspension,
- The necessity to have a runway to operate UAS from.

To summarize, it seems that the concept the authors of this paper are trying to put forward, i.e. multiple networking packages intended to soft land into the wind, and being deployed from an aerodynamically perfect UAS requiring no runway is a novel concept worth further development. Upon completion, based on its features / performance it can be used in a variety of new applications as described next.

IV.   FURTHER DEVELOPMENTS

As described above the developed Snowflake system features not only precise payload delivery but also features landing into the given direction. Combined with a capability to re-compute the inertial trajectory as often as needed this allows attempting landing Snowflake onto a friendly or even hostile moving platform.[6] The difference between two is that in the first case the platform and Snowflake(s) can be controlled collaboratively assuming that they share all information between themselves, while in the second case the Snowflake will need to rely on its own sensors to estimate platform's motion.

In addition to Snowflake ADS unique capability of delivering supplies with high accuracy in hostile and hazardous environment, the system could also be used as an innovative "node" of ad hoc self-forming tactical network. On one hand, it is a slowly descending aerial node, which is capable of receiving data from the unattended sensors, once it gets in the range of wireless link, and sending information out through manned-

unmanned network-on-the-move, before hitting the ground.

On the other hand, it is a perfect platform for bringing in nuclear radiation or chemical sensors close to the source, which otherwise is inaccessible to Special Forces operators. While collecting and feeding data out, remotely controlled Snowflake could also bring new set of disposable unattended sensors for the next step of data collection.

Several Snowflake ADS gradually descending in geographically distributed areas would enable largely distributed in time and space networking capability with sensors and small unit operators.

The remotely-controlled parafoil could be an individual temporary node or a hub for a short-term aerial-ground network. Placing a small base station in Snowflake ADS payload would allow having highly undetectable wireless cell physically existing within 2…4 seconds of burst transmission. Then another cell or cluster pops-up 10…15 miles away from the source to receive this information temporary stored in UAV, air balloon, or ground vehicles relaying tactical information across network-controlled battlefield. Several parafoils during the descent could comprise a short-term mesh for reaching further into the area without network coverage.

V.   CONCLUSIONS

This paper presented a current state of the development of a mobile system for precise aero delivery with global reach, consisting of Arcturus T-20 UAS and Snowflake ADS. With more tests expected to occur in September-October of 2009 this system features unprecedented accuracy of sensors delivery, impressive endurance of flight, capability to deploy up to a dozen ADSs at once. Combined with its mobility, versatility, robustness it poses a unique combat tool that can be used in a variety of tactical scenarios. This system is expected to be demonstrated among dozen of other systems at the 5th biennial PATCAD to take place at the U.S. Army Yuma Proving Ground on October 19-23, 2009.

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