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IDGA's @DefenseInsider, Chris Archer, investigates the enhancement of SOF operational capabilities via UAV pinpoint payload delivery. Professor Oleg Yakimenko, Dept. of Systems Engineering, Naval Postgraduate School explores the various approaches to precise aerial payload delivery and highlights the various ways SOF could expand their operational capabilities.

Briefly explore the current state and various approaches of precise aerial payload delivery

Up until recently (say a decade ago) there was a problem of precise delivery of supplies to ground troops or humanitarian payload to disastrous areas. Upon deployment at high altitudes (to keep an airplane and its crew out of harms way) common high-altitude high-opening (HAHO) aerial payload delivery systems (PDS) based on relatively inexpensive unguided circular parachutes, like T-10, G-12 and others, were at the mercy of unknown winds, which resulted in up to 50% of payload being lost (meaning that a touchdown error exceeded a radius of a zone where payload could potentially be retrieved.). Even if the winds were known, it was impossible to deploy HAHO PDS at exactly the so-called computed air release point (a couple of seconds delay in releasing HALO PDS from a transport aircraft flying at 150 knots at 35,000ft or a 3-5% inaccuracy of estimating a current altitude above the ground would result in a large touchdown error as well). That was always a problem. It is somewhat similar to the problem of improving accuracy while deploying bombs (except that a parachute descent rate is 7-15% of that of a freefall bomb's speed). The only solution to the later problem found during the World War II was to deploy bombs not from a horizontal flight but from diving, which increases the aiming time and absolute speed of a bomb. In fact, that 70-year old solution suggested one modern approach to improve an accuracy of aerial payload delivery via better unknown winds penetration. I am talking about high-altitude low-opening (HALO) systems. These one- or two-stage systems take advantage of a ballistic or nearly ballistic (controlled) descent with a total speed well exceeding that of the variable winds until they are very close to the ground when the main chute deploys. For example, this approach is realized in Strong Enterprise's Screamer and Atair Aerospace's ONYX systems as well as in the high-altitude sonobuoy employment system from a P-8A multi-mission maritime aircraft.

Surely such systems rely on: a) a good estimate of an altitude above the ground (to deploy a main chute), and b) good knowledge of the winds (to be deployed within the area they can potentially reach a target). These days, variable sensors (mainly differential GPS and baroaltimeter) solve the first problem, and in order to have a good prediction (model) of the winds versus altitude the mission planner (MP) was developed. This MP developed by the US Army Research, Development and Engineering Command a decade ago within the joint (US Army and US Air Force) Precision Air Drop (JPAD) program, was a serious step forward towards a better precision and served its purpose very well.


Steerable AGAS

To fight yet remaining uncertainties a very elegant solution, allowing slightly disturbing a shape of a common circular canopy was found and realized in the so-called affordable guided airdrop system (AGAS). This system proved to be quite effective and even with a 1:1 glide ratio was able to improve touchdown accuracy down to less than 300ft.

Cardinally new solution though relies on a usage of guided parafoil, aerodynamic cell structure, which is inflated by the wind. Compared to a simple round canopy, a parafoil parachute has greater steerability / control and with a typical glide ratio of around 3:1 will glide further, i.e. may be released farther away from an intended point of impact. Touchdown accuracy of these systems depend on a perfection of guidance, navigation and control (GNC) system realized in their onboard controllers. The airborne guidance unit (AGU) of all today's systems, like Sherpa (by MMIST), Spades (by Dutch Space), Panther (by Pioneer Aerospace Corp. / Aerazur), GigaFly/MegaFly/Firefly/Microfly (by HDT Global / Airborne Systems), carry some kind of empirical guidance algorithm, based on the estimated PDS performance and online estimates of the winds, and producing the guidance commands to steer towards a target remaining upwind, and performing a flare just before landing to reduce a descent rate. In fact, that's exactly what skydivers do (much more effective than guided cargo parafoils though). Another known approach, realized on lighter cargo systems like Mosquito by STARA Technologies, assumes steering towards a target and then entering a sharp spiral all way down around an imaginary line extending from a target upwards.

Tell us about ‘Blizzard’?

First of all, let me say that we are not in the business of designing parafoil’s canopies so we cannot possibly compete with their manufacturers. However what we have a certain expertise is in designing GNC algorithms. So our initial intention was to demonstrate that with the advanced GNC approaches existing systems can reduce the touchdown accuracy from the required 300ft all way down to 30ft. As you noticed from the discussion above, other systems utilize A G U rather than A GNC U, i.e. the “navigation” and “control” parts are missing. I think the desire was to make their controllers as simple as possible, so they only rely on GPS sensors. In fact, the cost of a complete INS/GPS unit is only around $200, so there is no reason why they cannot be employed instead of just GPS. Of course utilization of INS/GPS requires more accurate modeling of the PDS, but it is well worth it. To keep the story short our AGNCU does not drop N and C. It utilizes target motion estimation to know a PDS position relative to a possibly moving target, well-established landing patterns of an aircraft, optimal control theory to constantly re-optimize the final turn maneuver in real-time, model predictive control to accurately track a reference trajectory. It can also benefit from a better current surface winds modeling using data provided by a handheld ground weather station or already descended (dummy) PDS.

Landing onto a moving target

To prove the concept we utilized all our ideas on a miniature home-built Snowflake PDS and tested it under different-size canopies at Camp Roberts and the US Army Yuma Proving Ground deploying it from a general aviation aircraft, helicopter, and transport aircraft. To date we have performed about 200 drops and demonstrated a predictable performance of 30 ft circular error probable (CEP), with 95% of payload delivered within 3CEP, and landing into the wind or with any other desired heading onto a stationary and slowly moving target. These 30 ft are of the order of an accuracy of a cheap GPS receiver, so to achieve even a better performance and make our system independent of GPS we recently started incorporating video data that can be provided by a cheap onboard camera.

While an adaptive AGNCU we developed can be utilized by any other (heavier) system leading to significant improvement of its performance, we proceeded with the development and testing of even more advanced concepts and created a mobile autonomous high-precision PDS (MAPDS) that may have a variety of novel applications even within its ultra small weight (in its current configuration – up to 50lbs). We partnered with the Arcturus UAV and based on their superb Tier II class T-20 platform created our “Blizzard”. Arcturus T-20 unmanned aerial vehicle is equipped with the autopilot and optical sensors to find and track targets, and is capable of carrying up to 100 lbs of payload in excess of 16 hours. It is powered by a versatile 10 horsepower 4 stroke engine offering smooth, quiet and efficient power. This UAV can carry two large payload pads under the wind and/or multiple smaller Snowflakes in its massive payload bay measuring 11½”×11½”×34”.


Blizzard PDS with two Snowflakes under the wing

Mission planning, launch / recovery operations and passing any necessary information to / from Blizzard airborne components is handled by the ground mission command and control center (MC^{2}C). Another optional component of Blizzard is a miniature ground weather station (GWS). All components (MC^{2}C, UAV, PDS, GWS) are networked to support a global-reach capability, providing the most current data to a situational awareness display, and enabling communication with the descending system from anywhere in the world via computer (Internet), GSM handheld, or voice portal to dynamically reassign target or change any other mission parameter.

The Blizzard MAPDS utilizes a retracting high performance gimbal featuring a full 360° un-obstructed field of view, direct drive brushless motors for increased stabilization performance, integrated global positioning system (GPS) receiver plus three-axis inertial measurement unit for standalone operation that eliminates the need for vehicle mounting calibration, and integrated image processing board. Blizzard’s gimbal provides a continuous pan and tilt of +40° / -220° with a 200°/sec slew rate and 0.023° pointing. The Cobham’s receiver uses spatial diversity to overcome fades and multipath and enhance video quality and while its miniature microwave standard definition video transmitter coupled with a 2Watt variable efficiency power multiplier allows transmitting the encrypted video stream taken by the camera down to MC^{2}C for up to 50 miles with 5Db margin. The system works with the smallest angle of line-of-sight clearance above the ground, and for short-range operations (less than 15 miles) allows non-line-of-sign operations inside canyons, around the hills and tall buildings (urban operations).

Target assignment can be accomplished in several ways. First, the coordinates of the target(s) can be entered into the system during the pre-flight checks or in flight via the MC^2C or from anywhere in the world via the Internet. Another scenario is that the coordinates of the target are computed automatically by choosing any point within the image. Finally, the target coordinates can be transmitted from the ground with the help of the target GWS. This optional Blizzard component not only allows transmitting the coordinates of the delivery point itself, but also provides a very cheap and yet effective way of increasing accuracy of payload delivery by measuring and transmitting the ground winds. This palm-size device needs to be mounted at the desired target location, and may be deployed either with a vane, if a soft landing is needed, regardless the delivery direction, or without it if a certain delivery direction is preferable (in the mountains). Day or night the requested payload will be delivered right to the target.

In addition to Blizzard PDS 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 SOF 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 Snowflakes 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’s payload pod 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.

Highlight the various ways SOF could expand their operational capabilities through advanced pinpoint placement and wireless sensor networks

By definition, special operations forces (SOF) are one of the nation's key penetration and strike forces able to respond to specialized contingencies across the conflict spectrum with stealth, speed, and precision. Blizzard is all about it. Stealth – the sensors and network components are deployed from nowhere (from the skies). Speed - it does not take much effort to launch Blizzard from any unprepared location and rapidly deliver multiple payloads within 400-mile range. Precision – 30 ft is the best precision among all existing systems. I think it is quite easy to imagine the usefulness of such a system in many of SOF core missions:

- Combating Terrorism and Counterproliferation - Imagine how effective the developed Blizzard PDS can be in covertly deploying ground nuclear, biological and chemical sensors in the areas otherwise unreachable. Not only can you plot a single sensor, but even a grid of sensors which would provide a much better picture of a potential threat. If needed, a canopy and payload pod can be produced from a decaying material and a sensor could destruct itself after unlinking information back to a flying UAV. On the contrary, such a sensor could be equipped with a solar battery and provide valuable information for days. The payload can carry a small ground robot that can carry these sensors into the caves or other closed environments. Recall the recent Fukushima Daiichi nuclear disaster – would it be good to be able to accurately place a grid of sensors right by / on / inside reactors without jeopardizing people's lives?

- Special Reconnaissance – again, you can deploy ground sensors where otherwise you could not reach. For example, we had a proposal to deliver sensors to a tropical forest floor or even between canopy layers. Other applications we are working on are delivering an autonomous ground robot which could provide a video link or even disarm an improvised explosive device (IED) spotted from a UAV.

- Direct Action – you can support short-duration strikes and other small-scale offensive actions by enhancing SOF mobility by delivering necessary supplies on schedule to precise locations. That also includes delivering urgently-needed medical supplies to wounded warriors (the scenario we have demonstrated during our experiments several times already). Another application would be establishing network coverage. Imagine deploying network components covertly (at night) before the strike!

- Military Information Support Operations – precise delivery of PSYOP materials (leaflets). By the way, this was one of the first applications of parafoil-based aerial delivery systems: the SnowGoose UAV (CQ-10A) is an application of MMIST's powered Sherpa, self-propelled autonomous PDS.
- Induce or reinforce foreign attitudes and behavior favorable to the U.S. or friendly nation objectives by planning and conducting operations to convey information to foreign audiences to influence their emotions, motives, objective reasoning, and ultimately the behavior of foreign governments, organizations, groups, and individuals.

Obviously precise delivery would also be very useful in SOF collateral activities like humanitarian assistance to supplement or complement the efforts of host nation civil authorities or agencies to relieve or reduce the results of natural or man-made disasters. Think for example of 2010 Haiti earthquake.

The DoD has been scrutinized for spending money on science projects that target hypothetical future wars rather than giving deployed forces what they need…a defense magazine article stated that 'innovation is not helpful if it is not assisting troops at war' – how would you respond? What research is being conducted at the NPS that aids the SOF effort?

I would agree with this statement. Following the systems engineering approach a need for the new system and the maturity of the required technologies should first be carefully analyzed. The article you are citing follows with "an 80-percent solution that can be available in months is better than a perfect outcome that could takes years or decades to achieve". In our particular case we offer a solution (30 ft accuracy of payload delivery) which is available today (actually it was available two years ago, when we demonstrated our system at the Precision Airdrop Technology Conference and Demonstration in the US Army Yuma Proving Ground, Yuma, AZ). Some of the latest requests for new payload delivery systems however still ask for a 300-ft accuracy. Our entire point is that the technology is here already. You just need to marry good canopies that exist with advanced GNC approaches that exist too. By the way, the same article "10 Technologies the Military Needs for the Next War," puts robot pack mules that would relieve soldiers of lugging food, ammo and heavy batteries onto the most needed technologies. Well, another way would be to simply deliver these goods to a certain (precise) location at a certain time. So the technology we are talking about is in need and can be considered as (an existing!) alternative or a supplement to those robot pack mules.

To answer the second part of your question I need to refer to the well-established Tactical Network Testbed (TNT) experimentation events that NPS conducts quarterly in cooperation with the USSOCOM. Three times a year these two-week events take place 100 miles South of Monterey, at Camp Roberts, CA, and once a year, in February, at Avon Park, FL. These TNT venues facilitate a collaborative working relationship between Government, academia, and industry to promote the identification and assessment of emerging and mature technologies for the primary goal of accelerating the delivery of technology discoveries to enhance SOF capability needs. This program started almost a decade ago and since then it provides unique interdisciplinary graduate education experience for NPS students and research opportunities for NPS faculty in which the latest technologies, concepts of operation, and human systems integration are evaluated for SOF applications in a field environment.

Another related program initiated in 2009 is Research and Experimentation for Local and International Emergency and First-responders (RELEIF). RELIEF is field environment focused on developing and testing and humanitarian assistance and disaster response technologies and processes. It leverages existing technologies, addresses challenges related to both domestic and international crisis response, and catalyzes collaborative activities across local, federal, and non-governmental sectors.

Finally, the NPS's Consortium for Robotics and Unmanned Systems Education and Research (CRUZER) was established just a year ago with the aim to provide a collaborative environment and community of interest for the advancement of unmanned systems education and research endeavors across the Navy, Marine Corps and Department of Defense. Some of research topics within this initiative are also dedicated to support different SOF missions.

Oleg Yakimenko received his B.Sc. and M.Sc. degrees in Computer Science / Controls Engineering and in Aeronautical Engineering from the Moscow Institute of Physics and Technology, Moscow, Russia in 1984 and 1986, respectively. In 1988 he received his second M.Sc. degree in Operations Research from the Air Force Engineering Academy, Moscow, Russia. In 1991 he received his first Ph.D. degree from this academy specializing in optimal control theory and aeronautical engineering. In 1996 Dr. Yakimenko received his second Ph.D. (Dr.Sc.) degree from the Russian Academy of Sciences for his work in the area of operations research as applied to fighter aircraft operations. By 1996 Dr. Yakimenko had progressed through the all professorial ranks at the Air Force Engineering Academy and since 1998 has been working for the Naval Postgraduate School, Monterey, CA. His research interests include orbital and atmospheric fight mechanics; optimal control, guidance, navigation and control of manned and unmanned vehicles; avionics, and human factors. He is an author of over two hundred publications in the areas of his interests and several textbooks. Dr. Yakimenko is an Associate Fellow of AIAA and a Fellow of the Russian Academy of Aviation and Aeronautical Sciences.