A Review on the Precision Guided Airdrop Systems

Burak CİVELEK*, Sinan KIVRAK
Yıldırım Beyazıt Üniversitesi, Keçioren, Ankara, Turkey
Corresponding author: Burak CİVELEK

Abstract: **- Airdrop is necessary in many areas around the world where there are no places to land an aircraft or where grand convoy resupply is either impossible or unsafe. Moreover, airdrop allows delivery of both humanitarian and combat forces to battlefield in a quick way. However, the rapid development of technology brings precision airdrop systems into the table. Compared to the old technology non-precision systems, precision airdrop systems allow the aircraft to gain the possibility to drop loads from high altitudes. It is very difficult to see or hear the aircraft from the ground when precision airdrop systems are released from a height above 20,000 feet AGL (Above Ground Level), which provides a great advantage.[1] This literature review about general discussion of precision airdrop systems article begins with examination of the main canopy. Then it discusses how the system works.**

Keywords: **Airdrop, Precision systems, Guided systems, Control method**

I. INTRODUCTION

Current air supply systems are mostly inaccurate, and limited in difficult weather conditions. Furthermore, the existing equipment usually requires the aircraft to pass through the drop zone at low altitudes, sometimes more than once before achieve the drop, which poses great risk to valuable aircrew and aircraft.Air supply is usually used when there is no land supply.[2]

The work of the guided airdrop systems was pinned by Kane using a modified dome-type parachute in the early 1960s.[3] In 2000's developments in detection and guidance technology like as GPS (Global Positioning System) and wind detecting precision airdrop systems will allow loads to be dropped from more than 30,000 feet altitudes, with offset capabilities of 10 km from the desired point of impact and with 25 to 150 meters accuracy.[4]

In last decade, there has been an extreme increase in the use of precision airdrop systems. For instance, the U.S. Department of Defense made a lot of research projects about precision airdrop systems under the name of "Joint Precision Airdrop System" and great investments in this subject.[5].

Precision airdrop system has highly developed after 2001 and it will probably be more widespread in operational areas in the predictable future. Many nations are carry out some program about precision guided airdrop systems, and more will start to fund such systems because these are requirements to be used in theater of war. In addition, NATO has given priority to these systems in order to supply air from a higher altitude and to avoid deliveries from falling into the unwanted places.[6]

In 2014 a video has released in social media by the Islamic State. In this video, in the vicinity of the Syrian border town of Kobane, a number of a series of US-based ammunition boxes which attached to an unauthorized round type cargo parachute was shown by the ISIS militant. He says they were dropped by US forces and had been intended for the YPG. John Kirby, the Pentagonpress secretary, made a statement acknowledging that this weapon's palette was one of the 28 palettes dropped into the PYD and fell into the wrong place.[7][8]The Pentagon blamed the unpredictable wind factor. This event emphasizes how much the possibility of error, including GPS-guided systems used by the Air Force, is present.[9]

It is obvious that sensitive-guided systems are needed; while these systems protect the aircraft and its crew against hazards from the ground at the same time increase the accuracy of the drop point.[10]

Modern technologies have enabled many new innovative airdrop methods to be implemented. In order to reduce the risks that prevent the application of the precision airdrop systems is being enhanced to improve accuracy by taking into account the profile and accuracy of the wind.[11]

The Precision Airdrop system is an important system designed to provide critical equipment to soldiers in combat areas where conditions change quickly and hard to guess. This system supports logistics operations using aircraft to supply materials and equipment in more than one location on a single task. Although these places are hostile or limited areas, the sensitivity of the system allows to provide logistics to the desired point.[12]

II. EXAMINATION OF THE MAIN CANOPY

Main canopies consist of two separate concepts. When examining basic structures, round as shown in Fig. 1 and ram-air as shown in Fig. 2 can be classified as two parachutes. Round parachutes are less maneuverable and slower than ram-air canopies. Ram-air canopies, allow for smoother landings, despite having higher maneuverability and smaller surface area. Commonly ram-air type parachutes are used in Precision Airdrop systems. Whereas the biggest advantage of round parachutes is production cost.[13]

Fig. 1 - An example of round parachute

Fig. 2 - An example of Ram-air parachute

Ram-air type parachutes provide high accuracy in airdrop from long distances and high altitudes, but their use is disadvantageous because of the cost associated with each load delivered. Therefore, alternative approaches to reduce system cost have been sought. The army of United States, the Boeing Company and the Vertigo team have worked for alternative air supply systems. These studies contain the improvement of the Affordable Guided Airdrop System (AGAS). This project contain low production cost command control, guidance system and navigation in airdrop systems. The main target of the AGAS project is to place the command control system in the G-12 and G-11 model round type classic load parachutes and the standard load container called A-22. The concept of design contains application of a Global Positioning System (GPS) module and direction sensors, a routing unit that detects and applies control data. Also the implementation of Pneumatic Muscle Actuators (PMAs) to the guidance. The navigation system and steering module are connected to the standard load platform. The PMAs are connected to the four main lift columns of the load parachute and the parachute is directed through them. Shown in Fig. 3.[14]

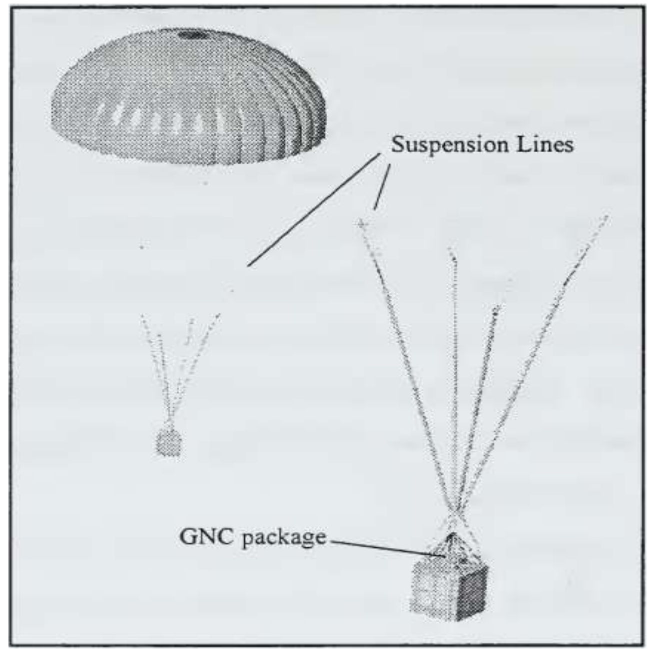

Fig. 3 – Affordable Guided Airdrop System

Standard, non-steerable parachutes show forward movement with some pull. With wind measurements, it is sufficient to compensate for wind deflections. The system can be steered with a GPS-controlled steering system mounted on the load.[13]

Experiments have shown that, in general, the sensitivity of AGAS, which has a load of 500 lb, is higher than that of an AGAS with a load of 2.200 lb.[15]

In order to design a transport system capable of carrying 2,000 to 10,000 lb loads, a department in U.S. Army known as Natick Soldier Research, Development and Engineering Center (NSRDEC) cooperated in coordination with the Joint Improvised Explosive Device Defeat Organization (JIEDDO).This system aims to reach the target with a standard round type parachutes with an accuracy of 400 m when released from a height of 24,000 feet Mean Sea Level (MSL).This program is named as The Joint Improvised Explosive Device Defeat Organization developed the 10K Improved Container Delivery System (JIEDDO 10K ICDS).

The program has used a few different systems. The most common system used High Altitude Low Opening systems (HALO) system primarily uses a drogue parachutes to lower to 1,500 feet AGL. At this altitude, the device called the automatic cutting device is triggered and the main parachute is opened and a soft decrease is achieved.[16]

Precision airdrop systems are also use either a ram-air or round parachute. The Screamer is the systems developed by Strong Enterprises with RoboTek Engineering, Inc with use two type of parachute.[17].This system include the Airborne Guidance Unit (AGU), aviation electronics and software. This system is a pattern of High Altitude Low Opening airdrop system. This system uses a 650 feet ram air parachute that has been adjusted to the target it means ‘controlled’ parachute,G-11 cargo parachutes are opened at an altitude which is predetermined and does not exceed the target. Screamer also includes a small platform, including parachutes and AGU.[18]

Ram-air type parachute is an air vehicle that can move manned or unmanned with its attack and trailing edge, unlike the round type parachutes. The ram-air parachute contains a canopy made of fabric with a top and bottom surface, also a plurality of inwardly aligned cells arranged longitudinally. These cells are similar to those of the aircraft wing structure, creating longitudinal channels that allow air flow through the cell ports on the edge of the canopy attack. There is no space at the edge of the canopy. In this way, the air entering the cell mouth is kept in the canopy and the parachute is kept in the air. With the braking ropes connected to the wing of the canopy, the parachute is guided. During the landing, the braking ropes are used to ensure that the edge of the attack meets the wind and a slow landing is performed.[19]

Although more expensive to manufacture than round type parachutes, ram-air parachute are more preferred because they have the possibility of both lateral and longitudinal movement by utilizing their ability to enter the wind.[20]

The use of ram-air parachutes ensures safe loading and removal from high altitude. Today, depending on the GPS navigation more than 100 m high accuracy is achieved. As a result of various trials, it was shown that this precision landing was technically appropriate with ram-air parachute.[12]

This system takes less time to prepare and to rigging the parachute. The system include actuators, sensors, and an airborne guidance unit which processing power. The airborne control and command unit is connected to the parachute braking lines and suspended between the parachute and the load. The electromechanical subcomponents of the system are: two 1.5 hp brushed servo motors, motor driver, 900Mhz RF modem. microprocessor, dual-channel GPS, and three 12VDC sealed lead acid batteries. Two batteries supply 24VDC to the actuators, the third source supplies power to the electronics. [5]

III. TRAJECTORY CONTROL OVERVIEW

If the load is not lowered to the desired point, it means that an error has occurred. These errors are usually explained by the distance between the target point and the point at which the load falls and an angle or (x, y) according to the drawn axis. The resulting faults may be caused by troubles at the calculated drop point, route error followed in the air, throwing team fault, aerodynamics of the load, or unpredictable winds.[21]

On a simple level, the guidance algorithm plans the route based on the current situation estimates. In addition to atmospheric winds, the navigation algorithm uses GPS metrics to estimate the position, speed, direction and head angle of the parachute. The control algorithm uses GPS data to enable the parachute to remain in the calculated trajectory. A precision airdrop system can be successfully generated by the creation of a new adaptive control scheme and the development of guidance diagrams using a radio frequency signal beacon.[20]

In round type of guided airdrop systems, the airborne guidance unit is primarily provided to take the wind and weather conditions in real time with various methods. The unit draws a trajectory based on wind forecast and GPS data. System’s calculated trajectory shown in Fig. 4.[22]

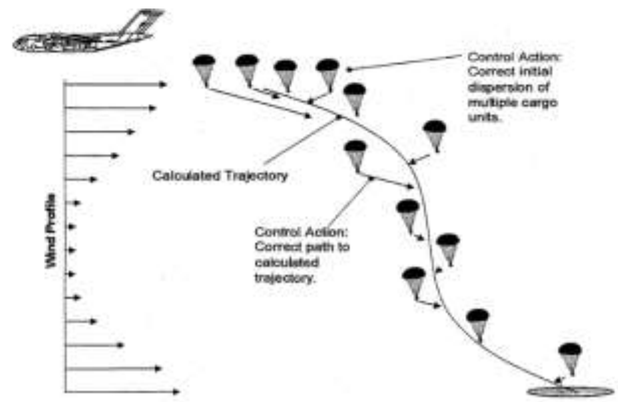

Fig. 4–System’s calculated trajectory

Theoretically, the wind is known for precisely and if the parachute is opened at the desired drop point, with a good modeling, the system can reach the desired target without any control command. However, because unpredictable effects occur, the system undergoes a deviation from the calculated path due to varying weather conditions. The system ensures that the parachute ropes are stretched and loosened to stay on the calculated trajectory. The guidance concept is shown in Fig. 5.[22]

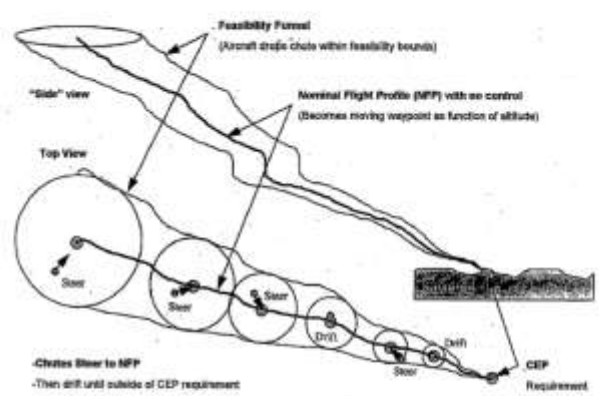

Fig. 5 – Airdrop Guidance Concept

In ram-air type of guided airdrop systems the most important factor affecting the performance of system in a healthy landing is the direction and speed information of the landing zone's wind information is fully known in real time.[23],[24].

Ram-air type systems do not have a pre-calculated trajectory. After the system is released in the aircraft, it moves to the coordinates of the landing zone. It makes maneuvering in the air according to the distance to the final approach angle to the target. In order to prevent damage to the load and soft landing, the system confronts the wind and descends into the wind. In summary, the system consists of three basic principles. First of all is going to the target, secondary is loiter, and last one is landing maneuvers according to the wind.[25]

Existing system guidance, navigation and control (GNC) algorithms utilize the loiter phase to perform current air wind information.[26]

General flight profile for current ram-air type airdrop shown in Fig.6.[27]

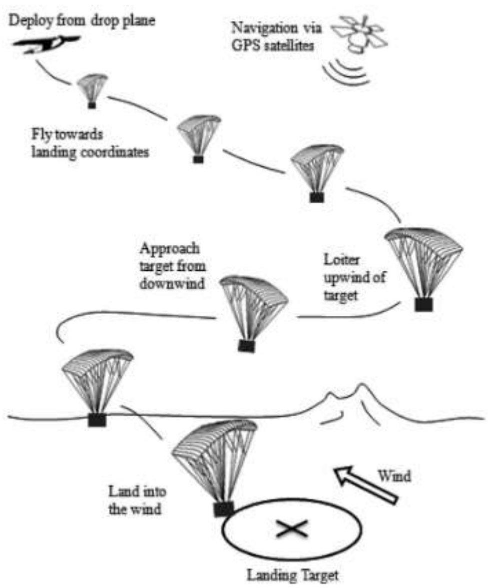

Fig. 6 –General flight profile for current ram-air type airdrop

Efforts to accurately estimate the atmospheric conditions for perfecting the ram-air type parachutes should focus on near-ground winds. Accurate calculation of ground wind intensity and direction are the most important source of minimizing the damage to the load by minimizing the impact speed by allowing the system to descend in the opposite direction to the wind.[27]

In the absence of a well-designed control algorithm, it is impossible for the ram-air type system to follow the planned trajectory. For the design of the control algorithm, the basic dynamic characteristic of the system must first be tested and known. Doing real airdrop tests is the most accurate method to measure it, however, actual airdrop tests can be restricted due to their large budget, accident risk and need for a long period of time. Numerical models derived from theoretical calculation and mathematical simulation, design and verification of GNC algorithms as well as stability in flight data and statistics can be used to figure out these limitations. For this reason, command algorithms are one of the most important requirements for pathmonitoring of guided airdrop systems. Recently, numerous entrepreneurs and scientists have conducted several studies to control guided airdrop systems.[28]

In[28],J. Xiong examines error equations based on linear time variables of a parachute system and utilizing the traditional proportional derivative (PD) control for pathway following control. In [29], Costello and Slegers implemented a prescience control method for analyzing the movement of a parachute system for very limited conditions. In [30]-[31]-[32]The researchers were used in the study of active disturbance rejection control (ADRC) method, although the control system lacked a tight convergence and robustness analysis.

But simulation and experimental results clearly indicate that without doing real airdrop tests, the credibility of the constructed model and the preferred control method is not fully achieved.[33]

IV. CONCLUSION

Since 2001 Precision airdrop has developed rapidly. Its use in military operations and humanitarian operations will become widespread in the coming period. The requirement for precision airdrop is undeniable. It is important to protect the aircrafts and their crew against any threat from the drop zone and to prevent them from being damaged. In addition, in the rapidly changing operational environment, the supply materials needed should be delivered to those who need them in the shortest way and in the right way.

Airdrop should not be seen as a simple replenishment system. The US Airdrop accident, which was experienced in 2014 and reflected in the press, caused a great resonance in terms of the quality of duties in the world public opinion. Every successful airdrop finds a great place in the press and social media. The successful airdrop is also perceived as a full power show, as the failed airdrop affects the country's reputation.

As could be seen from the benefits discussed above, having capabilities to use national precision airdrop systems is vital for all nations as well.

The ram-air type parachute is preferred since it can be guided further in the investigated studies. Due to their high costs, the existing precision airdrop systems are generally not available in the operational area. However, the installation of cheap propeller systems and GPS systems into the classical airdrop system can be made smart. In doing so, paramotor operating principles can be used. In this way this new system can change the course of airdrop in the field of operation.

Regardless of the parachute dome or steering system, the most important aspect of producing intelligent systems is the airborne guidance unit. Designed systems can be tested with many modeling techniques and control methods. In this way, the cost of real trials with high cost is saved.

REFERENCES

[1]. R. Benney, J. Barber, and J. McGrath, "The joint precision airdrop system advanced concept technology demonstration," 18th AIAA Aerodyn. Decelerator Syst. Technol. Conf. Semin., pp. 1–13, 2005.
[2]. Airdrop of Supplies and Equipment (FM 4-20.116 / To 13c7-1-13). .
[3]. R. Kane, M. T., Dicken, H., and Buehler, "'A Homing Parachute System,' Tech. rep., Sandia Corp., Albuquerque, N. Mex., 1961. [8]."
[4]. J. W. Wegereef, "Precision airdrop system," Aircr. Eng. Aerosp. Technol., vol. 79, no. 1, pp. 12–17, 2007.
[5]. R. Benney, J. Barber, J. Mcgrath, J. Mchugh, G. Noetscher, and S. Tavan, "the New Military Applications of Precision Airdrop Systems," Aiaa, no. September, pp. 1–16, 2005.
[6]. M. R. Wuest and R. J. Benney, Precision Airdrop (Largage de précision), vol. 323, no. December. 2005.
[7]. "https://www.theguardian.com/world/2014/oct/22/isis-us-airdrop-weapons-pentagon Ewen MacAskill, and Martin Chulov in Beirut Wed 22 Oct 2014." .
[8]. "https://www.cbsnews.com/news/isis-we-have-our-hands-on-weapons-ammo-air-dropped-by-u-s/ CBS/AP October 21, 2014,."
[9]. ……...https://www.washingtonpost.com/news/checkpoint/wp/2014/10/21/u-s-accidentally-delivered-weapons-to-the-islamic-state-by-airdrop-militants-allege/?noredirect=on&utm_term=.ccb93b7d316a By Dan Lamothe October 21, 2014."
[10]. "Carrabba, P., THE RIGHT PLA CE AT THE RIGHT TIE- An Analysis of High Altitude Airdrop and The Joint Precision Airdrop System. Graduate Research Paper, Graduate School of Engineering and Management. Air Force Institute of Technology. Wright-Patterson AFB, ."
[11]. B. Gilles, "Precision Aerial Delivery System," pp. 1–8, 2003.
[12]. A. L. Brinkley, M. Engineering, S. A. Simonson, D. R. Cohn, and A. F. Henry, "by Certified by by," 1994.
[13]. J. G. Johnson, I. I. Kaminer, and O. A. Yakimenko, "Monterey , California THESIS," no. September, 2001.
[14]. S. Dellicker and J. Bybee, "Low cost parachute guidance, navigation, and control," 15th Aerodyn. Decelerator Syst. Technol. Conf., no. c, pp. 51–65, 1999.
[15]. D. S. Jorgensen and M. P. Hickey, "The AGAS 2000 precision airdrop system," Proceeding of Infotech, pp. 26–29, 2005.
[16]. M. Henry, K. Lafond, G. Noetscher, S. Patel, and G. Pinnell, "DEVELOPMENT OF A 2 , 000-10 , 000-LB IMPROVED," no. April, pp. 0–10, 2010.
[17]. T. Strong, McGrath, "The Screamer Airdrop System for Precision Airdrop of1,000 and 4,000 kg Class Payloads."
[18]. G. N. J.Barber, "Instrumentation for the Assessment of Parafoil Performance, AIAA paper 2005-1611 presented at the AIAA Aerodynamic Decelerator Systems Conference, May 23-26, 2005, Munich, Germany."
[19]. "https://www.explainthatstuff.com/how-parachutes-work.html." .
[20]. M. R. Cacan, "Adaptive Control of Autonomous Airdrop Systems in Degraded Conditions Adaptive Control of Autonomous Airdrop," PhD Thesis, Georg., no. December, 2016.
[21]. S. P. Dillenburger, J. K. Cochran, and V. R. Cammarano, "Minimizing supply airdrop collateral damage risk," Socioecon. Plann. Sci., vol. 47, no. 1, pp. 9–19, 2013.
[22]. G. Brown, R. Haggard+, and R. Almas$, "THE AFFORDABLE GUIDED AIRDROP SYSTEM (AGAS)."
[23]. K. Kelly and B. Pena, "'Wind study and GPS dropsonde applicability to airdrop testing,' presented at the 16thAmer. Inst.Aeronautics Astronautics Aerodynamic Decelerator Syst. Technol. Conf., Boston, MA, USA, 2001."
[24]. N. S. M. Ward, M. Costello, "'Specialized system identifica- tion for parafoil and payload systems,' J. Guidance, Control, Dynamics, vol. 35, no. 2, pp. 588–597, 2012."
[25]. M. Ward and M. Costello, "Adaptive Glide Slope Control for Autonomous Airdrop Systems," 2012 Am. Control Conf. Fairmont Queen Elizab., pp. 2557–2562, 2012.
[26]. "Calise, A., and Preston, D., 'Swarming/Flocking and Collision Avoidance for Mass Airdrop of Autonomous Guided Parafoils,' Journal of Guidance, Control, and Dynamics, Vol. 31, No. 4, 2008, pp 1123--1132."
[27]. M. R. Cacan, E. Scheuermann, M. Ward, M. Costello, and N. Slegers, "Autonomous Airdrop Systems Employing Ground Wind Measurements for Improved Landing Accuracy," IEEE/ASME Trans. Mechatronics, vol. 20, no. 6, pp. 3060–3070, 2015.
[28]. J. Xiong, "Research on the Dynamics and Homing Project of Parafoil System. Changsha, China: Nat. Univ. Defense Technol., Oct. 2005."
[29]. N. Slegers and M. Costello, "'Model predictive control of a parafoil and payload system,' J. Guid., Control, Dyn., vol. 28, no. 4, pp. 816–821,."
[30]. Z. X. L. L. Jiao, Q. L. Sun, X. F. Kang, Z. Q. Chen, "'Autonomous homing of parafoil and payload system based on ADRC,' J. Control Eng. Appl. Informat., vol. 13, no. 3, pp. 25–31, Sep. 2011."
[31]. Y. P. H. J. Tao, Q. L. Sun, P. L. Tan, Z. Q. Chen, "'Active disturbance rejection control (ADRC)-based autonomous homing control of powered parafoils,' Nonlinear Dyn., vol. 86, no. 3, pp. 1461–1476, Nov. 2016."
[32]. Y. P. H. J. Tao, Q. L. Sun, P. L. Tan, Z. Q. Chen, "'Au- tonomous homing control of a powered parafoil with insufficient alti- tude,' ISA Trans., vol. 65, pp. 516–524, Nov. 2016."
[33]. J. Tao, Q. Sun, H. Sun, Z. Chen, M. Dehmer, and M. Sun, "Dynamic modeling and trajectory tracking control of parafoil system in wind environments," IEEE/ASME Trans. Mechatronics, vol. 22, no. 6, pp. 2736–2745, 2017.