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DESIGN OF PRESSURE DEPENDENT AUTOMATIC ACTIVATION DEVICE FOR CARGO PARACHUTES

M.Sc. Thesis by

Burak CİVELEK

Department of Defense Technology

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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DESIGN OF PRESSURE DEPENDENT AUTOMATIC ACTIVATION DEVICE FOR CARGO PARACHUTES"** completed by **BURAK CİVELEK** under the supervision of **ASSOC. PROF. DR. SINAN KIVRAK** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Assoc. Prof. Dr. Sinan KIVRAK

Supervisor

Assoc. Prof. Dr. Mehmet DEMİRTAŞ

Jury Member

Dr. Ramazan KARSLIĞLU

Jury Member

Prof. Dr. Fatih V. ÇELEBİ

Director

Graduate School of Natural and Applied Sciences

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2020, 15 May **Burak CİVELEK**

DESIGN OF PRESSURE DEPENDENT AUTOMATIC ACTIVATION DEVICE FOR CARGO PARACHUTES

ABSTRACT

Operating airdrop missions has a significant role in providing supplies to occupying groups for countries. Airdrop can be used to deliver humanitarian aid to places where the utilization of any other transportation means is impossible, and in emergency situations where replenishment needs to be carried out quickly in military.

In this thesis, initially, the High Altitude Low Opening (HALO) concept will be addressed elaborately and the calculation of the release point will be described, which is very important for the success of the airdrop, then the role of pressure dependent automatic activation device on high altitude airdrop will be introduced. After that, mechanical design and electronic components of the device will be explained and the working principle of the system will be articulated. The objective of this research thesis is to provide an automatic activation device to utilize in high altitude low opening airdrop missions. The device is tested in a laboratory environment and then it is tested in the field by performing real airdrop. The results of these trials are included in this study.

As a result, it has been suggested that a device with an electronic command control unit that is capable to make precise measurements and to transmit commanding signals to actuator quickly, and with a mechanical part which easy to install, does not require disposable parts and can be used repeatedly, can meet the need in this field. Additionally, this system is assumed to have shorter-term training for operators.

Keywords: Airdrop, cargo parachute, automatic activation device, cargo parachute, altimeter sensor.

YÜK PARAŞÜTLERI IÇIN BASINCA DAYALI OTOMATIK AÇMA CIHAZI TASARIMI

ÖZ

Ülkeler için havadan ikmal, etrafı çevrili gruplara ikmal sağlama bakımından büyük öneme sahiptir. Havadan ikmal, diğer ulaşım vasıtalarının kullanımının imkânsız olduğu durumlarda insani yardım malzemesi dağıtmada ve acil durumlarda ikmale ihtiyaç duyan askeri birliklere ikmal sağlamada kullanılabilir.

Bu tezde, başlangıçta Yüksek İrtifa Alçak Açış (YALAÇ) yöntemi detaylı bir şekilde anlatılacak ve havadan ikmalin başarısında büyük öneme sahip olan yük bırakma noktası hesabı açıklanacaktır, basınca dayalı otomatik açma cihazının yüksek irtifa atmalarındaki rolü anlatılacaktır. Daha sonra, tasarlanan otomatik açma cihazının mekanik tasarımı ve elektronik bileşenleri ile çalışma prensibi anlatılacaktır. Bu araştırma tezinin amacı yüksek irtifadan yapılan havan malzeme ikmallerinde kullanılmak üzere otomatik paraşüt açma cihazı tasarlamaktır. Tasarlanan cihaz önce laboratuvar ortamında daha sonra gerçek atmalarda test edilmiştir. Test ve atma denemeleri sonuçları tez içerisinde sunulmuştur.

Sonuç olarak, hassas bir şekilde irtifa tespiti yapan ve hızlı bir şekilde motora komuta veren elektronik komuta kontrol ünitesi ile tek kullanımlık parça içermeyen ve tekrar kullanılabilen, kolayca kurulup kısa süreli eğitim gerektirmeyen otomatik paraşüt açma cihazının, yüksek irtifadan havadan ikmal operasyonlarında kullanılabilir olduğu görülmüştür.

Anahtar Kelimeler: Havadan ikmal, otomatik açma cihazı, yük paraşütü, yükseklik sensörü.

CONTENTS

ABBREVIATIONS

ADC	Analog Digital Converter
AGAS	Affordable Guided Airdrop System
AGU	Airborne Guidance Unit
AGL	Above Ground Level
CARP	Computed Air Release Point
CDS	Container Delivery System
DZ	Drop zone
GPS	Global Position System
HALO	High Altitude Low Opening
IAS	Indicated Airspeed
HARP	High Altitude Release Point
LCD	Liquid Crystal Display
MCU	Micro Controller Unit
MSL	Mean Sea Level
PGA	Programmable Gain Amplifier
PI	Point of Impact
OEF	Operation Enduring Freedom
TAS	True Air Speed

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CHAPTER 1

INTRODUCTION

Airdrop has been a very significant concept for many countries in the world. Decision-makers use this concept on restricted areas where there are no places to land an aircraft or land convoy resupply is either impossible or unsafe. This supply concept can be used for both to deliver humanitarian aid support to natural disaster zones, and combat forces in the battlefield deprived of any needed materials. In this subject, the military side of the airdrop concept will be examined.

In airdrop supply missions there are so many risk factors that must be considered. The most important one is aircraft being vulnerable to enemy's anti-aircraft defense weapons. If aircraft happen to be destroyed or unusable, the situation will not only affect airdrop supply operation but also it will affect all the operations due to having a strategic role. Because of the strategic importance of the aircraft, operation planners have to take the safety of it into account. Therefore, it is mandatory to perform airdrop operation as at high altitudes and from far distances as possible. If the aircraft flies at altitudes above 20,000 feet AGL (Above Ground Level) and up it could hardly be recognized by enemy in daylight [1]. In order to carry out the airdrop mission from farther distances, precision-guided airdrop systems are necessary. However, to execute the mission at high altitudes, affordable systems can be used as well.

The main affordable method is to release the bundle from high altitude free-falling and to deploy the main parachute at a respective low altitude. This method is called "High Altitude Low Opening" (HALO). In this method, aircraft can be protected from at least light anti-aircraft artillery and protect itself from surveillance of the enemy.

The main purpose of this thesis is designing a device, cheap and easy to use, which can be benefitted in high altitude airdrop mission. In this aim firstly the background of the airdrop will be described and problems will be defined.

1.1 Historical Development of Airdrop

The idea of dropping something from air derives from Leonardo da Vinci's sketches in 1495. Firstly, a person with a parachute, which resembles a triangle umbrella, was drawn by Leonardo. After that time, the Montgolfier brothers, who are popular with their design of air balloons which rise via hot air, dropped a sheep from a tower with a parachute that is designed by them too. As a result, this initiative resulted in success and sheep landed the ground safe [2]. The first parachute with a human was produced and demonstrated by physicist Andre-Jacques Garnerin in Paris France on October 22, 1797 [3]. With the enhancement of technology, parachute and the other airdrop equipments have developed and diversified. Thanks to those improvements, countries have started to use this concept in their military operations.

The first airdrop attempt in military history was made by the British in Iraq 106 years ago. Just after the Ottoman Empire entered World War I, at the end of 1914, Britain attacked Iraq by deploying troops. But these attacks failed and the Ottoman forces encircled the Anglo-Indian army under the command of General Charles Vere Ferres Townshend. Upon Mirliva Halil (Kut) Pasha's rejection of surrender offer, the 143-day "Siege of Kut" started on 7 December 1915 and continued until 29 April 1916. The provision of supplies and ammunition to these isolated forces was vital. However, all attempts by road and sea failed. For this reason, the British Headquarters also tried out an attempt that was so unique that day to supply ammunition and food to the forces under siege. It was for the first time that airdrop method was used which is important for military history. Short 184 type 225 hp seaplanes were used in the supply flights between April 15-29, 1916. However, this attempt was unsuccessful again when Ottoman troops shot down these planes with maverick fire. Only a few were able to realize the mission [4]. Figure 1.1 shows an aircraft with a bundle full of flour mounted to its wing, which is intended to drop supplies to troops emplaced in Kut in 1916 [5].

Figure 1.1 An aircraft with a bundle full of flour mounted to its wing, which is intended to drop supplies to troops emplaced in Kut in 1916.

Airdrop operations have gained a strategic role in the World War II thanks to the German paratroopers which jumped on the island Crete on 20 May 1941 [6]. There are lots of significant factors that affect the airdrop operation's success. Those consist meteorological situation, precise calculation of release point, airdrop equipment, training of personnel and more. At the end of the operation because of bad weather and lack of navigation ability German troops suffered heavy losses. Even though heavy losses suffered it was a very important achievement for airdrop in military operations. Thus, it was seen that airdrop operation was an important force multiplier in military operations.

In Normandy landings, referred to as D-Day, over 900 aircraft and 400 gliders were used in June 1944 and as far as known 13,000 paratroopers and tons of supply material dropped from aircrafts. About ten percent of the airborne troops despite bad weather and inadequate navigation landed at the desired drop zone (DZ) [7]. However, great advantage of providing uninterrupted support to sections behind enemy lines expose the importance of the airdrop operation on the battlefield.

Since the Second World War, airdrop methods have been used in many operations. During the Vietnam War, During Operation Just Cause in Panama on December 20, 1989, during Operation Desert Shield and Desert Storm, 1991, different types of airdrop methods were utilized efficiently in operations to have an upper hand on the battlefield [7].

In the 2000s, in addition to military operations, airdrop was started to be used in humanitarian operations.

Following the attacks on September 11, 2001, the United States launched an operation to exterminate Al Qaeda and destroy the Taliban in Afghanistan. As a strategic part of this operation which referred to as Operation Enduring Freedom (OEF), the US wanted to illustrate Afghan people that this operation is not towards Afghan people but towards Al Qaeda. For this purpose, the US used airdrop to deliver humanitarian aid for Afghan people. The goal of providing humanitarian aid to the Afghan people largely failed. Most of the food packages got unusable because they smashed the ground causing the content to become unusable [8]. It was understood that many factors should be considered when performing high altitude airdrop.

In 2014, the Turkish Armed Forces used airdrop method to subsidize Libyan people with humanitarian aid. 14 tons of food and medical materials were reached to intended drop zones in this operation which was carried out with two Turkish military aircrafts. The operation was successfully completed, but this operation was carried out at low altitude, because of that reason aircrafts were targeted by terrorist groups and thanks to the superior maneuverability of the pilots, the planes were saved from being plunged down at the last minute. Figure 1.2 shows some Turkish newspaper headlines [9-10]. In this way, the importance of high altitude airdrop was once again recognized.

After this brief overview of historical development, this research thesis will move into why high altitude is crucial for airdrop operations.

HABER TURK

19 Eylül 2011 PAZARTESİ GÜCÜ ÖZGÜRLÜĞÜNDE Fiyatı: 50 Krş

Yardım uçağına uçaksavar atışı

Başbakan'ın talimatıyla Libya'ya havadan insani yardım atan Türk kargo uçağına uçaksavarlarla ateş açıldı, şans eseri isabet olmadı

PARAŞÜTLE 14 TON

C-130 ve C-160 askeri kargo uçakları, önceki sabah 14 ton gıda yardımını paraşütle atmak üzere Libya'nın Bingazi kentinden havalandı. C-130, Nijer sınırı yakınında Katrub'un güneyine yardımı bırakıp döndü.

KADDAFİ GÜÇLERİ Mİ?

C-160'a ise Sirte yakınında Waddan'a yardımı attıktan sonra, uçaksavar ateşi açıldı. Pilot hızla rota değiştirip yükseldi. Uçak isabet almaktan kurtuldu. Ateş açanların Kaddafi güçleri olup olmadığı araştırılıyor. 31'de

Türkiye'yi ve insanları çok seviyoruz

POSTA

TÜRKİYE'NİN EN ÇOK SATAN GAZETESİ

19 EYLÜL 2011 PAZARTESİ www.posta.com.tr HAFTA İÇİ 45 KURUŞ (Kıbrıs'ta 1 TL)

September 2011

Libya'ya yardım götüren Türk uçağına saldırı

KILPAYI KURTULDU

Türk Hava Kuvvetleri, 1974 Kıbrıs Barış Harekatı'ndan beri ilk kez havadan paraşütle yardım malzemesi attı.

Libya'daki mülteci kamplarına havadan insani yardım ulaştıran Türk Hava Kuvvetleri'ne ait C-160 kargo uçağına uçaksavarla ateş açıldı. Türk pilotlar uçaksavar mermilerini görünce anında manevra yaparak uçağı isabet almaktan kurtardı. Saldırı 30 saniye daha geç başlasaydı uçak kurtulamayacaktı

ERDOĞAN EMİR VERMİŞTİ

Başbakan Erdoğan, Libya ziyareti sırasında bölgedeki mülteci kamplarındaki dramı öğrenince harekete geçmiş, Türk yetkililere mültecilere yardım edilmesi talimatı vermişti. Türk Hava Kuvvetleri'ne ait C-130 ve C-160 tipi iki kargo uçağı 14 ton gıda malzemesiyle önceki gece Ankara Etimesgut Askeri Hava Üssü'nden havalandı. Uçaklar sabaha karşı Bingazi'ye indi. Bingazi'den yeniden havalanan C-130 tipi uçak, yardım malzemesini Nijer sınırındaki kampa paraşütle atıp döndü.

YÜKLÜ OLMAMASI KURTARDI

C-160 tipi uçak da yardım malzemelerini Kaddafi'nin memleketi Sirte'ye yakın Waddan bölgesine bıraktı. Dönüşte C-160 tipi uçağa uçaksavarla ateş açıldı. Mermileri son anda fark eden Pilot Binbaşı Murat Mocan son anda yaptığı manevrayla uçağı kurtardı. Saldırı 30 saniye daha geç olsa, mermiler karşıdan görülemeyecek ve uçak büyük olasılıkla isabet alacaktı. Ayrıca uçak yüklüyken saldırıya uğrasaydı pilotun ani manevra yapması da mümkün olmayacaktı. Mustafa KELEŞ-Haluk YAVUZHAN/AA

Figure 1.2 Some Turkish newspaper headlines

1.2 Characteristics of Airdrop

We have mentioned above that air supply carries certain risks on the battlefield. In situations which airdrop is inevitable, it is of great importance that decision-makers know the characteristics of the airdrop. Knowledge of the methods and types of airdrop affects the result of the operations either in a positive or negative way. Decision-makers have to choose the most appropriate method and type of airdrop according to DZ's location, enemy threat on the land, size and weight of the required payload and type of the parachutes. However, the ultimate goal of the operation should be to ensure that the requested supplies arrive at the right place at the right time in an utilizable condition. The airdrop methods and types are described below.

1.2.1 Methods of Airdrop

There are three methods for releasing loads from an aircraft. These are described below [11].

- **Extraction.** This method is preferred for the release of platform loads from aircraft. Firstly the extraction parachute release from the aircraft and then it pulls the airdrop platform. With the help of that force of extraction, airdrop platform leaves the aircraft.

- **Door load.** It is the load that is below 226 kg and thrown out of the paratroop exit door. This method generally covers the material that the paratrooper will first need after landing. Just as the paratrooper, the static line of the door load is connected to the aircraft and the parachute of the load is opened upon leaving the aircraft.

- **Gravity.** The cargo or loads are connected to the aircraft by a column. It is referred as release door. When approaching the DZ, the plane raises its nose a little and the entire weight lean against this column. At the calculated release point loadmaster cuts the door and free the load. The main parachute is deployed by a static line connected to the aircraft.

1.2.2 Types of Airdrop

Airdrop resupply is classified into three types. These are described in more detail below [11].

- **Free-drop.** This type of airdrop is preferred only for materials that will not lose its physical integrity (such as leaflets, clothes) when dropped to the ground or in the event of compulsory situations. No parachute or similar device is used to slow down the descent velocity of the load. The load descends at a rate of 130 to 150 feet per second.

- **High-velocity.** To protect from enemy anti-aircraft weapons this is indispensable for aircraft to fly as at high altitudes as possible. This type can be applied in two ways. Either the parachute opens as soon as it leaves the aircraft or opens at a low altitude.

Opening the main parachute at high altitude causes the load to be affected by wind and weather conditions. Other than this, high-altitude airdrop utilizes a small drogue parachute that creates sufficient resistance to hold the load in a vertical position and stabilized during its free-fall. At the predetermined altitude, with the help of automatic activation device, the drogue parachute pulls the main parachute open.

- **Low-velocity.** This type of airdrop is most widely used in all air supply operations. Since the load is attached to the aircraft with a static line, the parachute of the cargo is deployed as soon as it leaves from aircraft and load gently descends to the ground. Depending on the type of parachute and the weight of the load, it can be connected to up to eight parachutes to slow down the descend rate of drop.

1.3 Literature Review

1.3.1 Requirement of High Altitude Airdrop

As mentioned earlier, the most significant threat to aircraft which is used for airdrop is basic anti-aircraft weapon. Simple air defense weapons pose a greater threat to aircraft than radar-guided missiles and other enemy aircrafts. The emplacements of those portable weapons may not be found before the airdrop operation. They are affordable and easily usable weapons. The threat of anti-aircraft weapons has obliged us to try out for high altitude missions. Although high altitude airdrop protects the aircraft from enemy threats, it has its disadvantages. A bundle connected with an unguided ballistic parachute that is released at high altitude is susceptible to effects of wind and weather conditions. Drifting in the air the load may fall into unwanted areas or even into the enemy's hands instead of the targeted area. In this operations, the probability of the load falling into the hands of the enemy is worse than falling into undesired places. This will expose the position of the friendly troops to be assisted and cause a great loss of prestige as well. In order to eliminate these problems, either precision guided airdrop systems or HALO concept should be utilized.

1.3.2 Precision Guided Airdrop Systems

Precision guided airdrop systems is a self-directed parachute system using Global Position System (GPS) signals to land to the desired point. This system uses ram air type parachute as a dome, analyzes the data via the guiding unit and navigates the parachute making use of servo motors in order to lower to point of impact. Thanks to smart systems, both aircrafts are protected from enemy threat and the required material reaches the desired location safe. It includes expensive and complex systems such as the command control unit, the task planner, and the routing system [12].

These systems have been widely used in armies all around the world since 2001. In addition, it is seen that their areas of usage will increase in the future. The need for precision airdrop systems in the area of operation cannot be denied. In addition to the emphasis of delivering these substances to the unit that needs replenishment materials in the area of operation, protecting the aircraft from the threat of the enemy is of great importance when considering the overall operation.

First airdrop facilitating a steerable parachute was done by Kane in the early 1960s [13]. In this study, round-type parachutes were used. The endeavors to steer round-type domed parachutes continued in the following years. The most common and widespread one of these studies is The Affordable Guided Airdrop System (AGAS) [14]. In this study, the main lifting risers of the round- type parachute are pulled with the help of the pulling arms, therefore the shape of the dome changes for a period and thus the guidance of the system is provided.

In 2000s, the development of sensor and positioning technology has enabled the load to be dropped at high altitudes and from further distances with an accuracy of 25 to 150 meters on the target. As a result of these developments, precision airdrop systems became widespread rapidly and their areas of usage have expanded. For instance, the U.S. Department of Defense have undertaken extensive efforts in smart parachute systems under the name “Joint Precision Airdrop System” [15].

In addition, many countries have been conducting research on precision guided airdrop systems. NATO has prioritized these systems and has been working on smart parachute systems in order to protect the aircraft in instances performed at high-altitude and to prevent the payload fall into unwanted hands [12].

1.3.2.1 Structure of the System

The system consists mainly of three main parts; these are dome equipment, intelligent steering system and load being transported. The dome is equipped with a ram air type parachute dome because it is easy to steer. The wing consists of the upper and the lower layers which are made of less air-permeable nylon fabric. It consists of rectangular forms called cells between two layers. The front edge of the wing is open. The air entering through the cell openings cannot escape from the back and maintains wing shape. There are holes in the inner walls of the cells. These holes allow air to pass between the cells and keep the parachute in balance. By pulling the guide ropes connected to the wing ends of the parachute, the shape of the dome can be changed and parachute can be navigated [16]. In intelligent systems, servo motors perform the routing process via command control device. These servo motors change the shape of the dome by shortening or extending the steering line of the parachute and allow the parachute to move in the desired direction [12]. In precision guided parachutes there is an Airborne Guidance Unit (AGU) between the load and the dome. The canopy is placed on the AGU at 4 points via the risers. The integrated structure of the system is shown in the Figure 1.3 [17].

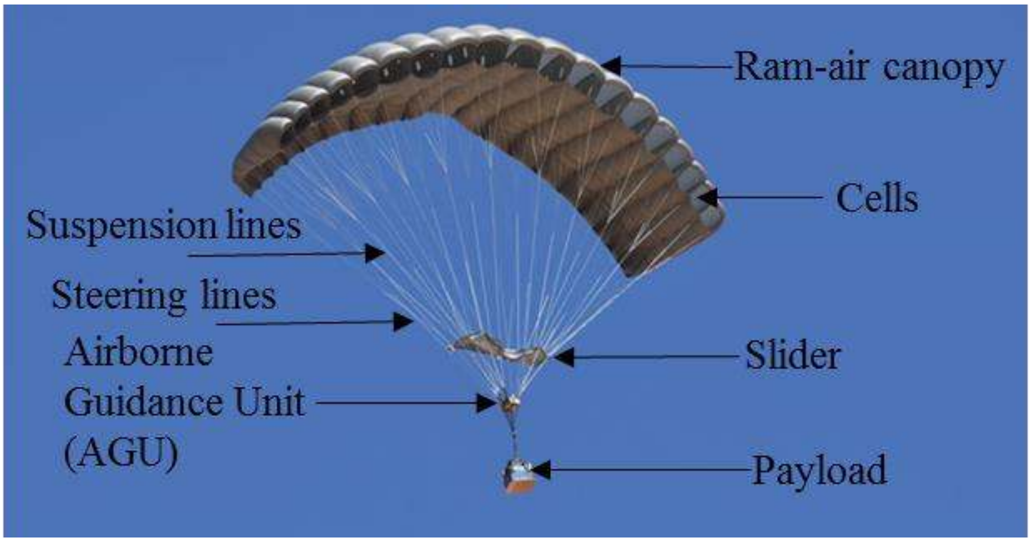

Figure 1.3 The integrated structure of the system

1.3.2.2 Working Principle of the System

As previously described, ram air type parachutes glide by penetration of air into the cells and are guided by steering lines. Steering lines are controlled by guidance unit. The AGU includes a navigation and guidance system, a flight control system and an actuator hardware.

The guidance algorithm designates the possible trajectory depending on the current situation estimates. First of all, a possible path is drawn between the coordinate of the point of impact typed in the system and the current coordinate given by the GPS module. This route, which is specified in accordance with the aerodynamic structure of the parachute, is updated with the current altitude and wind corrections which are imposed by sensors. The system tries to stay within the trajectory by making maneuvers. In order to provide a soft touch and to prevent damage to the payload, it is positioned against the wind in the final approach and lands into the wind. Path profile for precision guided airdrop shown in Figure 1.4 [18].

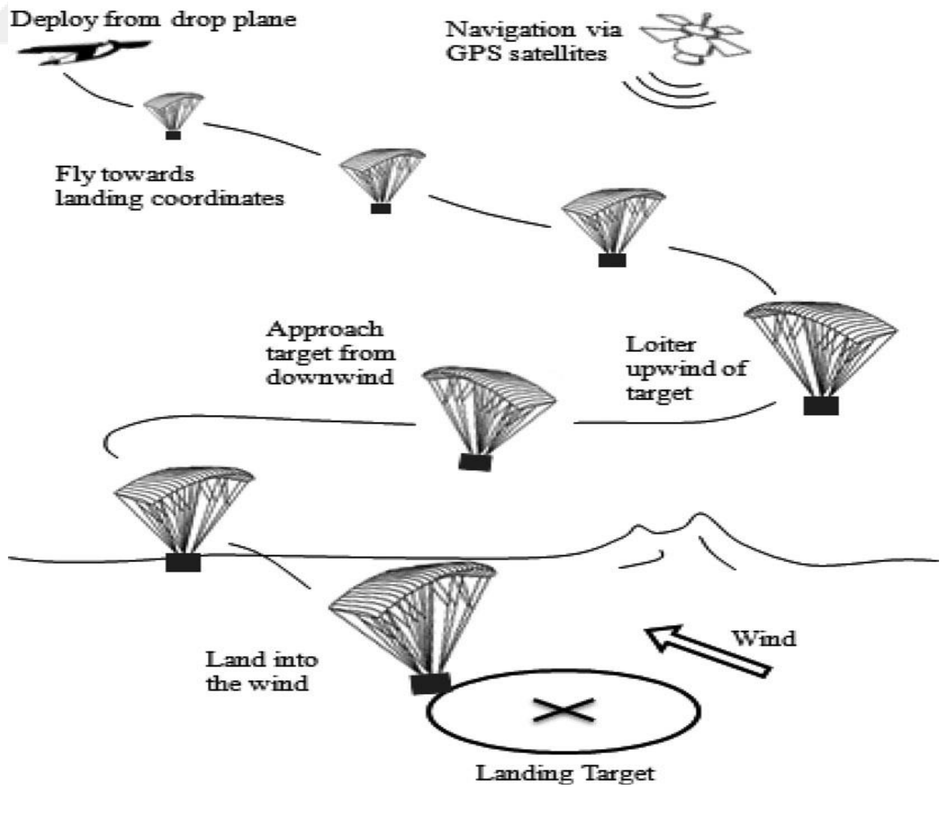

Figure 1.4 Path profile for precision guided airdrop

1.3.3 High Altitude Low Opening (HALO) Concept

Research and development of existing airdrop systems is focused on reducing threats to aircraft and costs with cheap disposable systems for military or humanitarian airdrop missions. Due to the expensive cost of precision guided airdrop systems, ballistic cargo parachutes should be used with regard to the HALO concept. These HALO systems are much cheaper than precision guided airdrop systems [19]. It is thought that the load thrown using the HALO concept costs 2 dollars per pound [20]. This is quite inexpensive compared to precision guided systems. The HALO concept is a two-step high altitude airdrop method. The first step is the section where the load falls free with the help of drogue parachute after leaving the aircraft. The second step is the slow-descend section referring to the period between where the main parachute deploys and the load reaches the desired point [21]. The descending trajectory line must be straight as possible as with the aim of the load being minimally affected by the wind in order to hit the target. At an appropriate altitude, the main parachute should be deployed to minimize impairment. To achieve this goal, an automatic opening mechanism is needed which is fast and accurate.

1.3.3.1 Structure of the System

Various cargo containers and parachute types can be used in high altitude airdrop. But basically all the components of the system are the same. The system has a drogue parachute that allows stable free fall. This drogue parachute is connected to the load with an automatic activation device by a bridle (1). It is also attached to the main parachute by another bridle (2). The bridle (1), which is taut during the free fall, is the one which is connected to the load by routing the automatic opening device. As for main cargo parachute, it is connected to the payload by cotton columns and also connected to drogue parachute with the bridle (2). The payload is secured by shock-absorbing honeycombed material and placed on the standard platform. Schematic design of structure of the system is shown in the Figure 1.5.

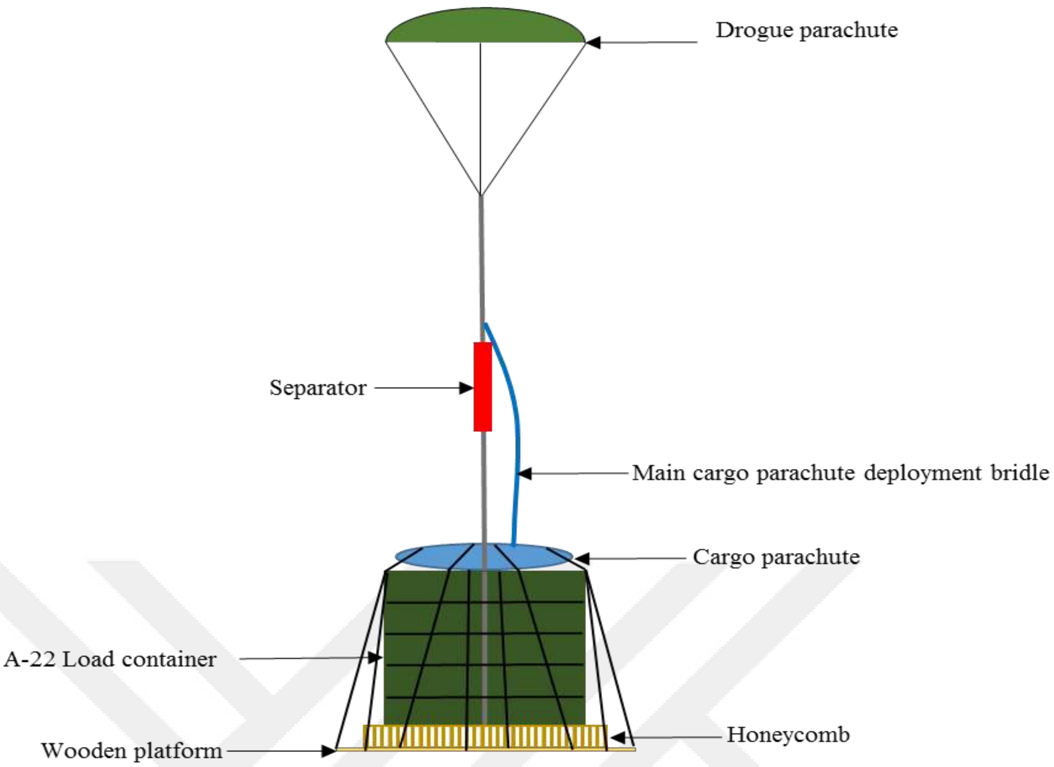

Figure 1.5 Schematic design of structure of the system

1.3.3.2 Working Principle of the System

HALO system that we have developed could be used with all standard army parachutes and equipment, including the 15 ft and 28 ft ring-slot parachutes and 68 inch pilot chutes as a drogue parachute. Containers or platforms are rigged with a relatively small and durable stabilization parachutes which, when inflated, are used to achieve a high-velocity rate of fall, 65-250 ft/sec., to a selected altitude where a barometric sensing device actuates a timing device and cutter to deploy a larger Cargo parachute [22]. The 68 inch drogue parachutes shown in Figure 1.6. The aim of these parachutes is to stabilize the cargo until it reaches the actuation altitude where main canopy deploys. When payload is dropped at high altitudes, the drogue parachute opens immediately with the help of static line which is connected to the plane after leaving the aircraft. This small parachute keeps payload stable during the free fall. If the balance parachute is not used in the HALO concept, the load falls unevenly during free fall, turning its sides to all directions unpredictably. As a result, at the time of main parachute deployment, the opening direction of it may not face the direction as it should face upwards. In addition, there may be difficulties in opening the main cargo parachute at the desired altitude.

Figure 1.6 68 inch drogue parachutes

When the desired altitude is reached, the automatic activation device commands and releases the drogue parachute. The released drogue parachute pulls instantly the main parachute stripping it from its deployment bag and allows it to be filled with air. When the main parachute is fully opened, the drogue parachute is separated from the main parachute and continues to decrease in altitude with main parachute deployment bag. The main parachute lands to the ground with the payload and is released from the payload through the release apparatus to prevent the load from being dragged. Operating principle of the system is shown in Figure 1.7.

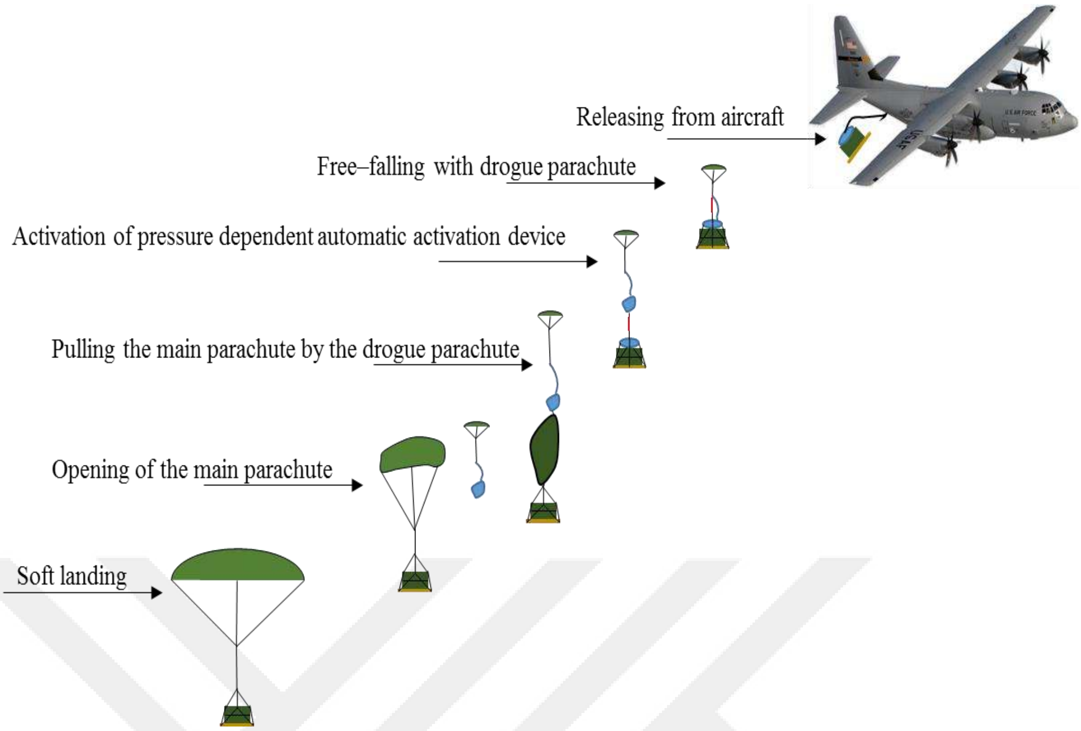

Figure 1.7 Operating principle of the system

1.4 Description of the Problem

Airdrop operations are preferred only under certain circumstances. Generally used only when there is no way to land supply via any other transportation means. Except for humanitarian aid areas, it should not be forgotten that the areas, which are chosen for drop zone, are open to enemy threats. In order to protect the aircraft from enemy threats, it is crucial to release the load as high and far from DZ as possible. Therefore, at the present time, precision guided airdrop systems have started to be developed. However, these systems are often more expensive than the dropped material. In addition to these systems that continue to evolve, high altitude airdrop by protecting the aircraft can eliminate this disadvantage. To perform a successful high altitude airdrop mission, accurate release point calculation and opening mechanism that smoothly opens the main parachute at the desired altitude are required. Otherwise, the mission fails.

1.5 Scope and Purpose

The scope of the research thesis will center around pressure dependent automatic activation device design, software, tactical use, and how to perform a successful high altitude airdrop. The goal of the research thesis is to accomplish stable HALO operations without dependence on foreign sources. This device is designed for the training and operations of high altitude airdrop made within the Turkish Armed Forces. The device is intended to be used repeatedly without the need to replace parts and to be easily prepared by the user for the next mission.

CHAPTER 2

UTILIZATION OF PRESSURE DEPENDENT AUTOMATIC ACTIVATION DEVICE IN HALO CONCEPT

2.1 Examples of Pressure Dependent Automatic Activation Devices in Parachute Systems

The automatic opening device is a device that enables the quick opening of the reserve parachute in case of emergency. Current automatic opening devices are designed for use in personnel parachutes. This device is activated if the parachutist loses conscious after exiting the plane, during the free fall and cannot open the parachute at the desired altitude.

Working principle of these devices depends on pressure reading. With the help of pressure sensor, altitude and fall rate is acquired. The altitude and falling rate are calculated according to the difference between the two atmospheric pressure values recorded in predetermined time intervals. This data is all acquired without user intervention [23]. Nowadays electronic sensor barometers are preferred instead of diaphragm barometers. In addition, some systems are completely mechanical and not relying on batteries, squibs or pyrotechnic devices, while some systems are fully electronic. Today, electronic systems are generally preferred. Mechanical systems consist of manual altitude adjustment console, pressure sensing diaphragm, spring-link pull mechanism and steel wire. Example of mechanical type opening devices are in the Figure 2.1 [24]. The system operates at the preset altitude and the opening of the parachute is provided by the spring system which pulls the pin.

Figure 2.1 Example of mechanical type opening devices

Electronic systems consist of a battery, a cutter, adjustment monitor and control unit. Example of electronic devices are Figure 2.2 [25]. The computer sends cutter a signal when it is time to activate the deployment of main parachute. The cutter fires and cuts the enclosed loop which is normally designed to prevent the main parachute being released from the load and activated.

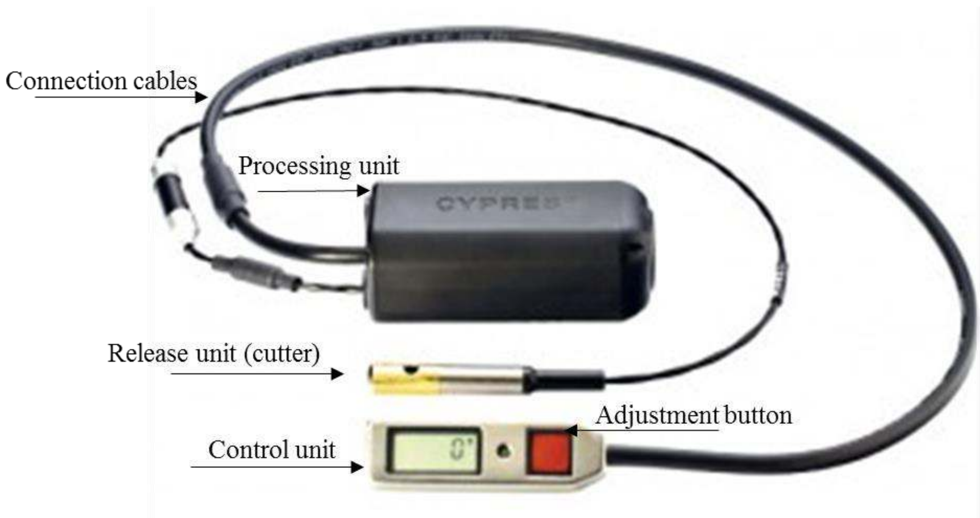

Figure 2.2 Example of electronic devices

2.2 Calculating of High Altitude Release Point

In airdrop operations, there are two methods of calculating release point for unguided cargo parachutes. The first is “Computed Air Release Point” (CARP) and the second is calculating of “High Altitude Release Point” (HARP) [22].

The CARP solution is based on average parachute ballistics and fundamental dead-reckoning principles. That makes below-mentioned calculations para-scientific. The HARP is not more than being a CARP solution except a third vector (High velocity, free fall vector) involved. HARP diagram shown in Figure 2. 3 [22]. This vector accompanies the overall course in the air between stabilization point and actuation point. These types of airdrop operations are generally performed with two-stage actuation mechanisms (The second is likely to be a barometrically actuated release parachute: main canopy) though some Container Delivery System (CDS) airdrop operations can be readily carried out involving one-stage actuation only: without a stabilization parachute.

The distance between the actuation and deployment altitudes is assumed to be 500 feet unless a given ballistics data is available.

Small stability fluctuations of the aircraft after release and slight difference on the uniformity of loads will not be accounted in the HARP compute. If one think these may hamper the end result, he must make sure the aircraft is steady during release and loads are rigged soundly.

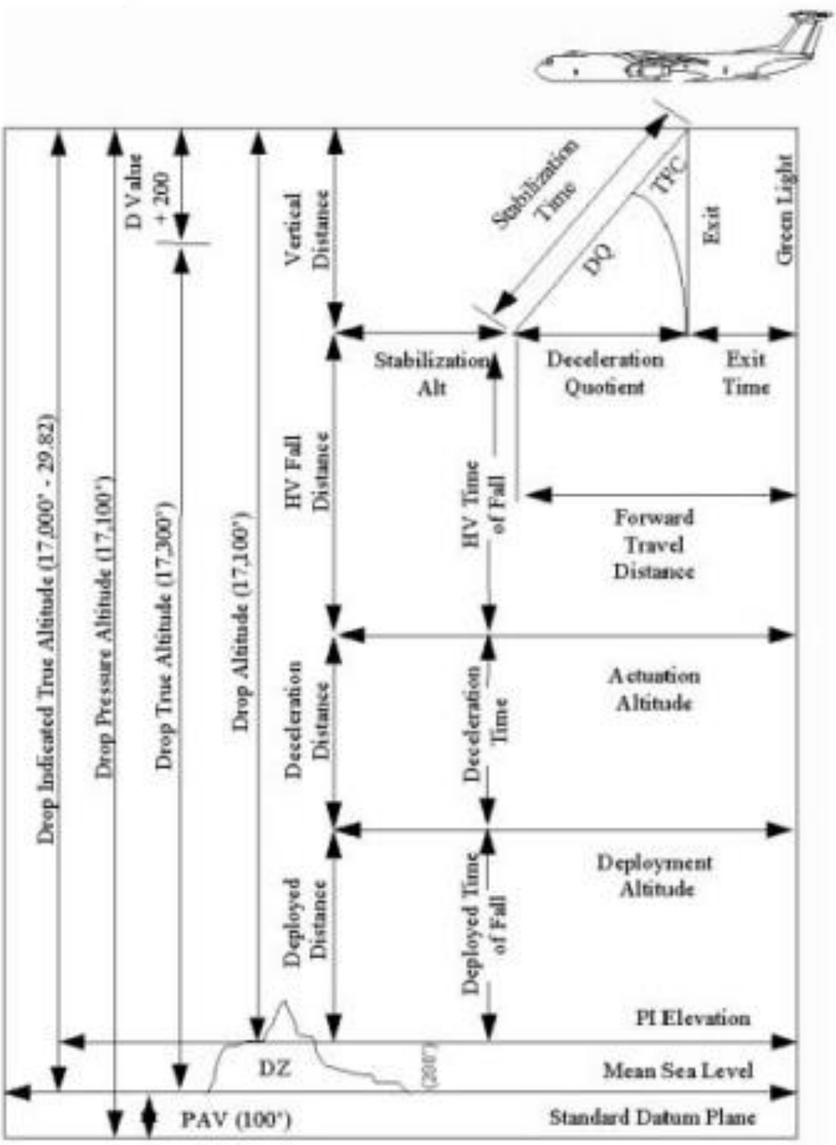

Figure 2.3 HARP diagram

The points to be considered while performing the HARP calculation are as follows.

Warning-1: All resultant wind speed and aircraft airspeed values should be averaged and summed up vectorially. If changes in wind speed and direction are taken into account, and calculations are reiterated continuously until release point, maximum accuracy in the result could be obtained. To achieve this purpose, air delivery experts and airborne mission commanders may assist the pilot and be ready to give directions along the way.

Warning-2: Pressure altitude variation between local mean sea level and standard datum plane is ignored in computations. Therefore, temperature dependent altitude variations between standard datum plane related altitudes and local mean sea level related altitudes are ignored as well.

Warning-3: Delayed releases must be accounted by adding the acquired delayed distance (groundspeed * delayed period of time) to the point of impact along the direction of aircraft heading. This calculation is not included below.

Warning-4: Do not predetermine a deployment altitude that would damage the load and the parachutes, refer to parachute ballistics.

Warning-5: If the surface winds are known, airdrop decisions will be based solely on surface wind limitations. If not, the aircraft commander will decide on whether to execute the airdrop or not.

2.2.1 High Altitude Release Point Computations

a. Drop True Altitude is the drop altitude, above mean sea level, in feet.

b. Point of Impact (PI) Elevation is the drop zone altitude, above mean sea level, in feet.

c. Drop Altitude is the drop altitude, above PI, in feet. C is obtained by subtracting b from a.

d. Actuation True Altitude is the altitude of actuation of an automated opening mechanism (with a barometric setting or a timer), above mean sea level, in feet.

e. Actuation Altitude is the actuation altitude, above PI, in feet. E is obtained by subtracting d from b.

f. Deceleration Distance is the vertical distance between actuation altitude and deployment altitude of main canopy, in feet. F is obtained by subtracting g from e. This information should be obtained from parachute ballistic data and used to determine the actuation altitude after settling over the deployment altitude value. Then a reverse-calculation should be carried out.

g. Deployment Altitude is the altitude of full deployment of main canopy, above PI, in feet. This altitude must be determined by the aerial delivery expert and the pilot regarding military tactics, desired accuracy of the airdrop and parachute ballistic data.

h. Deployed Rate of fall is the rate of descent of the parachute when it is fully deployed, in ft/sec., obtained from parachute ballistic data.

i. Deployed Time of fall is the period elapsed while deployment altitude is being covered, in seconds. I is obtained by dividing g by h.

j. Deceleration Time is the period elapsed while the deceleration distance is being covered, in seconds, obtained from parachute ballistic data.

k. Total Time of Fall is the period elapsed from actuation point to PI. K is obtained by adding i to j.

l. Deployed Wind is the vectorial average of wind values and directions at actuation and PI altitudes. These values can be elicited through open source.

m. Deployed Drift Effect is the total drift incurred by the load when the main canopy is fully deployed, in meters. M is obtained by dividing the product of multiplying (l and k) to 1.94. (1.94 is the constant to convert wind speed unit (knot) to the metric system.)

n. Vertical Distance is the distance covered between the times of the load exiting the aircraft and reaching the stabilization altitude, in feet, obtained from parachute ballistic data.

o. Stabilization Altitude is the altitude when the stabilization of the load is secured due to the stabilization parachute above PI in ft. O is obtained by subtracting n from c.

p. High Velocity Fall Distance is the distance covered between stabilization and actuation altitudes, in feet. P is obtained by subtracting e from o.

q. High Velocity Rate of Fall is the rate of descent of the stabilized load when stabilization parachute is fully deployed, until the actuation altitude, in ft/sec., obtained from parachute ballistic data.

r. High Velocity Time of Fall is the period elapsed while the high velocity fall distance is being covered in seconds. I is obtained by dividing p by q.

s. Time of Fall Constant is the period elapsed while vertical distance is being covered, in seconds, obtained from parachute ballistic data.

t. High Velocity Total Time of Fall is the period elapsed from the load exiting the aircraft and reaching the actuation point, in seconds. T is obtained by adding r to s.

u. Ballistic Wind is the vectorial average of wind values and directions at drop and actuation altitudes. These values can be elicited through open source.

v. High Velocity Drift Effect is the total drift incurred by the load when the stabilization parachute is fully deployed, in meters. V is obtained by dividing the product of multiplying (t and u) to 1.94. (1.94 is the constant to convert wind speed unit (knot) to the metric system.)

w. True Air Speed (TAS) is the speed of the aircraft relative to the drop altitude wind, in knots, effected by air density and aircraft geometry as well. We here do not want to dig into these details. Interested reader may search through open source and obtain true airspeed by doing the calculations himself, or use an embedded calculator facilitating air density value, aircraft type, drop true altitude and the indicated airspeed (IAS), which is 130 knots for container deliveries and 140 knots for heavy equipment deliveries mostly. Anyway, this value can’t be ignored or replaced by indicated airspeed.

x. Course is the predetermined path through drop zone of the aircraft, in degrees. This altitude must be determined by the aerial delivery expert and the pilot regarding military tactics and the desired accuracy of the airdrop.

y. Drift Correction is the correction of the course by ballistic wind, in degrees. It could be vectorially calculated by hand, or by an embedded calculator on open source.

z. Heading is the true course of the aircraft, in degrees. Z is obtained by adding x to y. It could be elicited through open source, or by hand calculation skipping v.

aa. Groundspeed is the speed of aircraft relative to the ground, in knots. It could be vectorially calculated by hand, or by an embedded calculator on open source. Calculations require ballistic wind direction and value, heading and true air speed.

bb. Exit Time is the elapsed time from “green light” until first load exits the aircraft, in seconds, obtained from the parachute ballistic data.

cc. Deceleration Quotient is the elapsed time from the moment the load is seen unattached from the aircraft to the stabilization point, in seconds, obtained from the parachute ballistic data.

dd. Forward Travel Time is the elapsed time from “green light” to the stabilization point, in seconds. It could be obtained from parachute ballistic data or it is obtained by adding cc to bb.

ee. Forward Travel Distance is the distance covered while forward travel time is progressing, in meters. EE is obtained by dividing the product of multiplying (aa and dd) to 1.94.

ff. Usable Drop Zone Length is self-explanatory, predetermined by aerial delivery experts considering military tactics, drop zone features and possible directives of ground personnel.

gg. Usable Drop Zone Time is self-explanatory, needed to designate how many discrete loads could be delivered to drop zone before exceeding.

hh. How to Plot Release Point:

Steps:

Step 1. The operator should mark or underline l, m and u, v and ee.

Step 2. Then he should start from the last, and move from PI to u direction for u addition ee.

Step 3. Secondly, he should move from (where he is at) to l direction for m.

Step 4. Finally, he draws a straight line between PI and where he is at last, measure the distance vectorially and mark the release point. (Optional: specify geographic coordinates of that point.)

2.3 Application of the System on Load Containers

2.3.1 Preparation of Cargo Parachutes

Cargo parachutes of various sizes and types are used for airdrop in armies from all around the world. The type of cargo parachute to use is determined according to methods of the airdrop and weight of the bundle. In this thesis study, G-12 D model cargo parachute has been used which is quite eligible for A-22 load containers.

The G-12 D model cargo parachute weighs 125 lbs. and has a diameter of 64 feet. The total layout length is 87.7 ft. Maximum payload capacity is 2,200 lbs. 1.1 oz. PIA-C-7020, type I ripstop nylon parachute cloth is used in manufacturing of the parachute [26].

After this general information given for the recognition of the parachute, it will be mentioned how to pack the parachute without going into detail. Parachute must be packed with a total of 7 staff. Firstly the parachute is brought to the proper layout position. The vent lines are wrapped with a cotton cloth and attached to a fixed hook. The clevis at the end of the suspension lines is connected to a tension device and tension is applied. Suspension line groups are separated into two groups and a line separator is positioned between those groups. Just as it is for the suspension lines, the canopy gores are folded into two groups. With the help of a large pedestal fan, canopy is inflated to fold properly. After folding, canopy and suspension lines are tied with type 3 cotton thread, beginning 5 ft above the skirt and in 5 ft. intervals along the remaining canopy length. Suspension line groups are tied beginning 10 ft. below the skirt and in 10 ft. intervals along the remaining length of suspension lines. The parachute is recovered from the tension device. And then starting from the top, it is stowed in deployment bag. After securing the flaps on the deployment bag, suspension lines are tied on retaining strap loops. Covering cloth is placed on top of the strap loops and fixed by 80 pound thread. By connecting the drogue parachute and making the final arrangements, the parachute is made ready for mounting on the payload [27]. Respective steps of the process are shown in Figure 2.4 below.

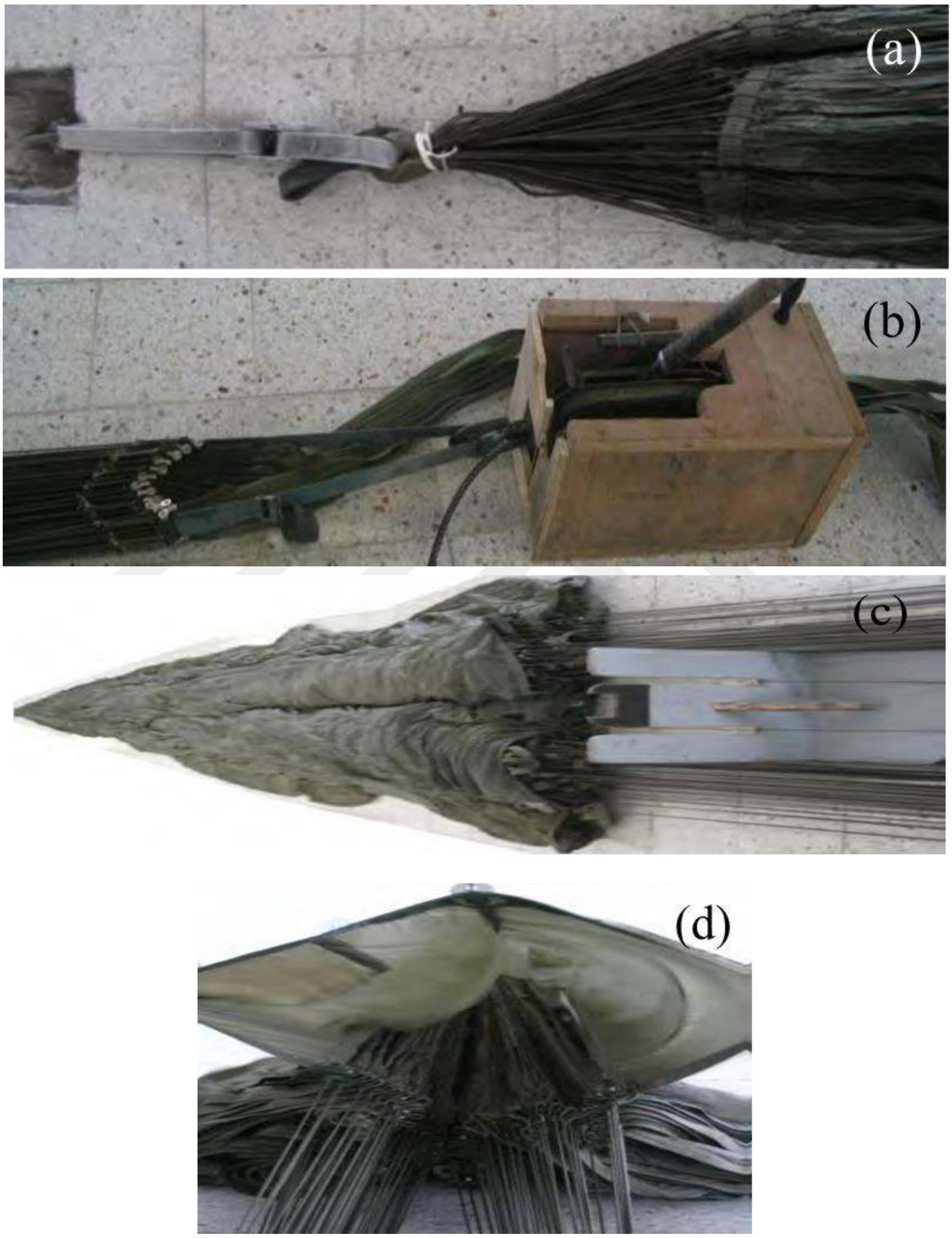

Figure 2.4 Preparation of cargo parachute

(a) Canopy vent lines wrapped and secured, (b) Application of tension, (c) Line separator positioned between suspension line groups(d) Inflating for proper folding,

Figure 2.4 (continued): Preparation of cargo parachute, (e) Tying canopy, (f) Tying suspension lines (g) Stowing the canopy in deployment bag, (h) suspension lines tied on retaining strap loops, (i) Suspension line stowage completed, (j) Packing completed

2.3.2 Preparation of Load Containers

A-22 standard load container (122 cm 136 cm) is used in the trial sessions of this thesis. It has a 2,200 pound load capacity. The A-22 container is referred by worldwide operators as two different types, German and American. This difference are due to slight changes in size. Dimensions of the American A-22 load container is 122 cm to 136 cm. Dimensions of the German A-22 load container is 110-122 cm. The type of the container depends on the type of the aircraft used for airdrop operation. The height of the prepared load should be min 30 inches and max 59.8 inches. All the experiments conducted during trial sessions of this thesis were made within these standards.

The layer forming the floor of the container is a wooden skid constructed from ¾ -inch thick sheet of plywood. First, standard web out of the columns is weaved on the standard skid to support the load afterwards. The cover of A-22 is laid over the web. Sufficient shock absorbing material is placed on this cover. This shock absorbing material is generally referred to as "honeycomb". A mesh is knitted with enough columns and placed on the shock-absorbing material. While placing these columns, enough care must be taken to make them pass each other’s under and over alternately. The material to be packaged is uniformly stacked and the cavities between the packages are filled with shock absorbing material. After the material is placed, the ends of the columns are joined and tightened by their buckles. Cover canvas is wrapped over the load and fastened with type 3 thread. Preparation of load container shown in Figure 2.5. A 3-feet extension column is connected to the web via a clevis at the one end and to a parachute releasing device at the other above the load. Parachute releasing device is used for preventing the load from dragging after drop. The top loop of the G-12 D cargo parachute is connected to the link ring of the 68-inch pilot chute [28]. The automatic opening device which is the subject of the thesis is assembled together with the three ring system.

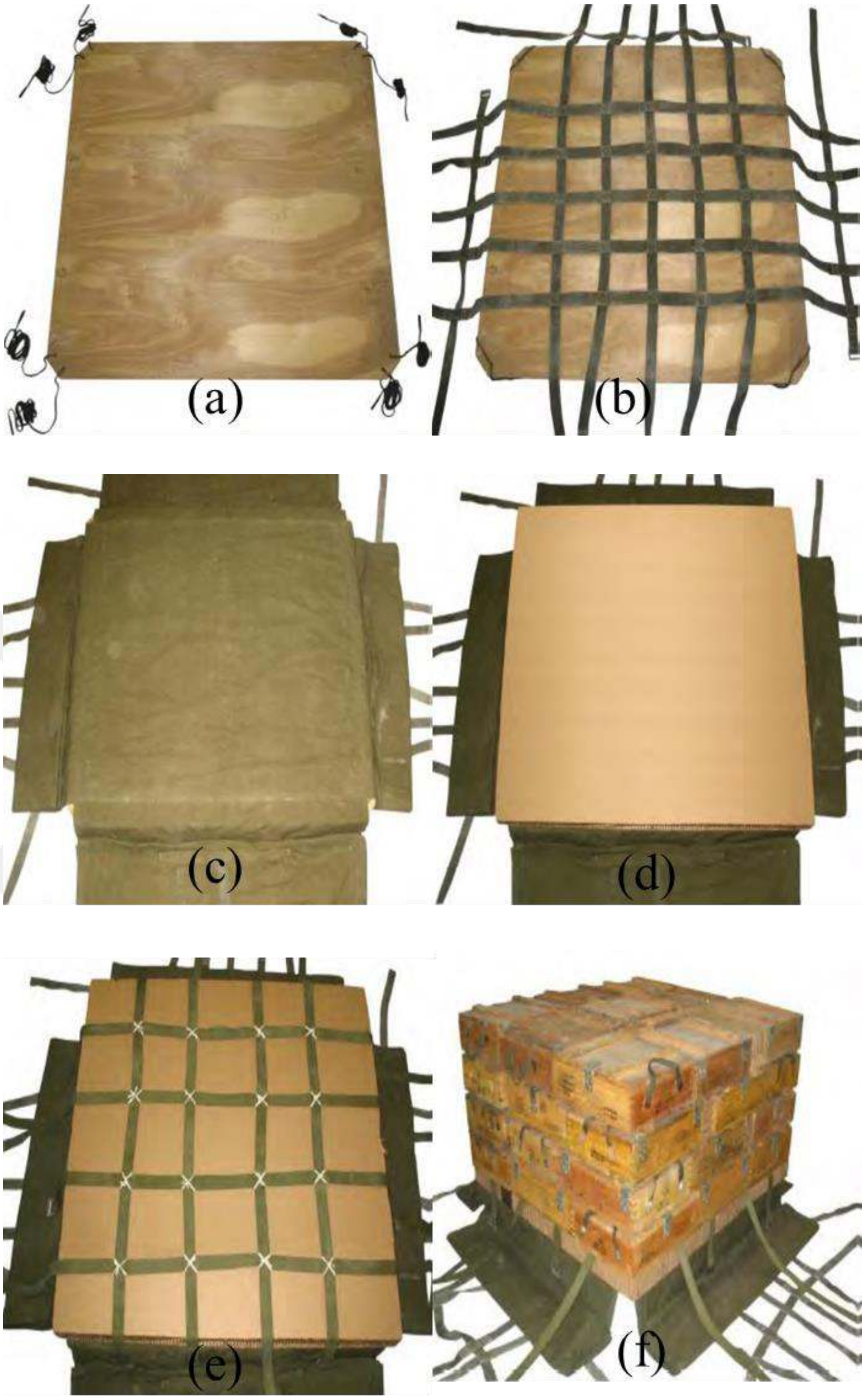

Figure 2.5 Preparation of load container

(a) Skid prepared, (b) Support web placed, (c) Cover on web, (d) Honeycomb positioned on cover, (e) Mesh of columns prepared, (f) Load positioned on mesh,

Figure 2. 5 (continued): Preparation of load container (g) Load wrapped by columns, (h) Load wrapped by cover web, (i) Cargo parachute attached to container

2.3.3 Three Ring Parachute Release System

The three ring release system is widely employed by military and sportive free fall parachutists. There are a few different variations of the three ring system. Although the basic principle is the same in all of them, the area of usage and the dimensions of the rings vary. It is seen that the first patents of the systems that are similar to those used today are based on the years of 1958 [29]. The patent of three rings with different diameters passing through each other which is first integrated into parachute systems, date to 1982 [30].

In three ring release system, as shown in Figure 2.6, largest ring is attached to body harness. Intermediate ring and smallest ring are attached to riser web. Smallest ring goes through only the intermediate ring, the intermediate ring goes through only the big ring. The system has a closing loop which goes through the smallest ring. Rings are threaded through each another and locked into place by a cable. When cable is pulled out there is nothing holding the loop so the loop gets free and then the smallest ring gets through intermediate ring and gets free, and then the intermediate gets through the biggest ring and the system gets free at last. Under emergency conditions, it is critical for a parachutist to get released from the main parachute and under these circumstances time is of the pith. In addition, when the parachutist lands into water, or upon a tree, or is dragged by an overwhelming wind on the ground, the ability to get released immediately from the parachute may be vital. For these reasons, the use of the three ring system in personnel parachutes has developed and become widespread. In this thesis, three ring release system has changed and modified and adapted to the cargo parachutes. The modified three ring release system is shown in Figure 2.7.

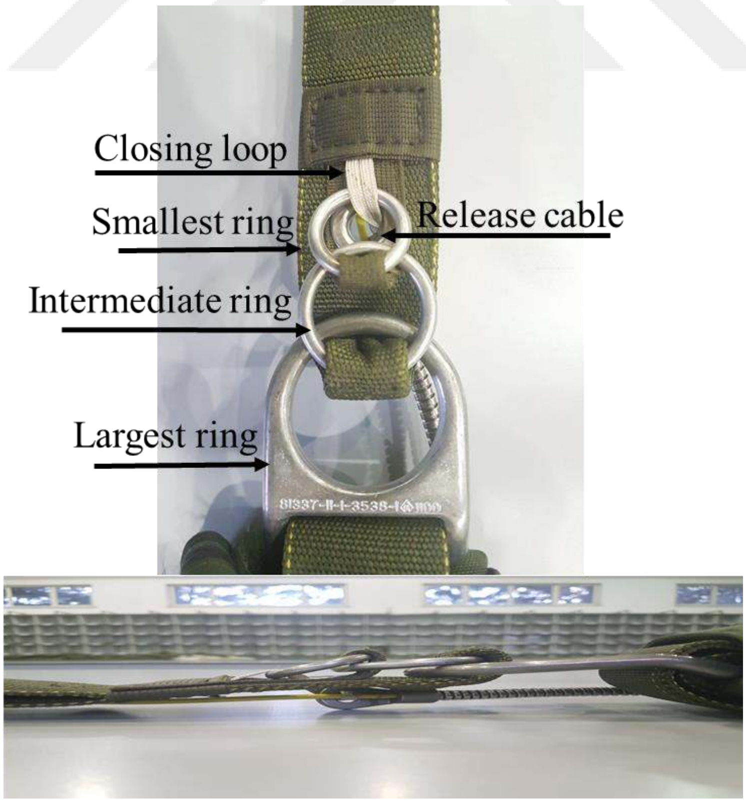

Figure 2.6 Three ring release system

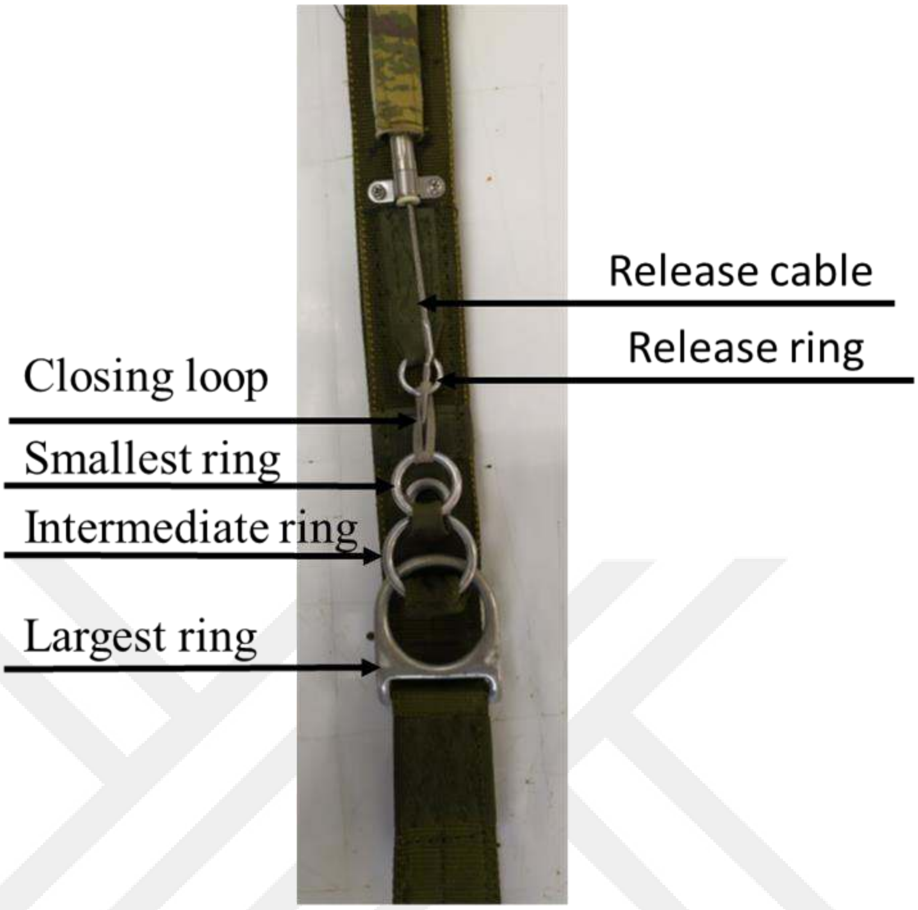

Figure 2.7 The modified three ring release system

2.3.4 Mounting of the Device

The automatic activation device must be connected with the three ring system and be placed as such that it does not interfere with the opening of the main cargo parachute, preferably between the drogue parachute and the payload. The desired ongoings of the system is based on the proper integration of the automatic activation device and the three ring system. This integration must also be properly mounted to the entire system.

In an attempt to facilitate what needs to be done, it should be aimed that the device be mounted in a simple way. For this purpose, the device and three ring system ought to be emplaced on a portable column. This column has connecting hooks which are located at both ends. The connection hook on the device end of the column is connected to the web which wraps the payload for the drogue parachute to release it at the time of activation. The connecting hook at the other end of the column is also connected to the drogue parachute. At this point where the device's column is connected to the drogue parachute, the opening bridle of the main cargo parachute is also connected. Since the device's column is shorter than the main parachute opening bridle, the main parachute opening bridle will not be pulled and the main parachute will not open until this column gets out of process when the activation of automatic activation device is triggered.

The device is placed in a pocket, sewn on the column, in which only the device can fit. A transparent cover is provided in the area where the display of the device is located in order to turn on and off, and set the device easily. The contraction rope lie out through the hole at the end of this pocket and passes through the protective sheath until the three ring system. The pin placed at the end of steel contraction rope, which is assumed to pass through the closing loop, is enclosed by an additional layers of fabric to prevent involuntary and indirect activation which could be caused by possible outside jolts. The device and the modified three ring system which is mounted on the column are shown in Figure 2.8, the device which is mounted on the load is shown in Figure 2.9. Schematic design of modified structure of the system is shown in Figure 2.10.

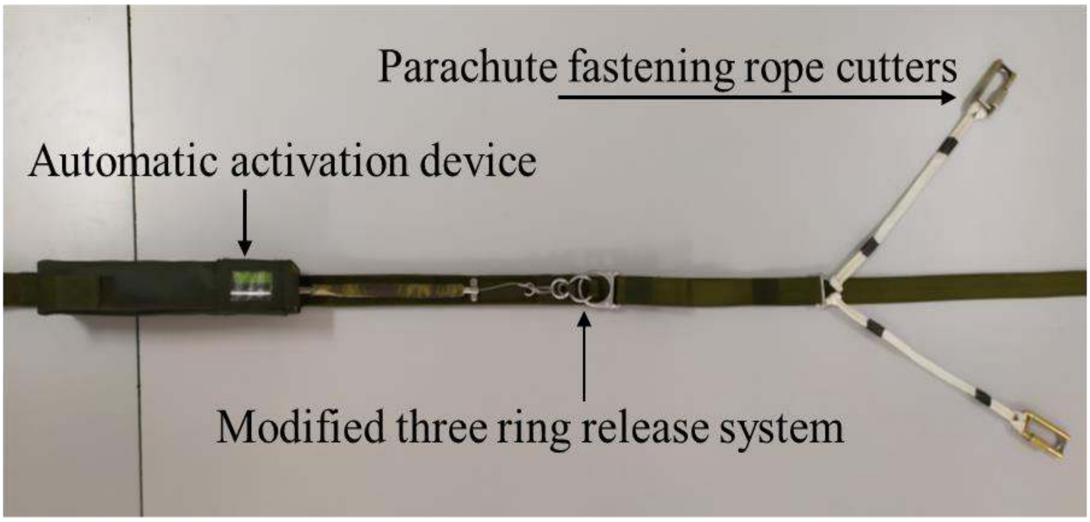

Figure 2.8 The device and the modified three ring system which is mounted on column

Figure 2.9 The device which is mounted on load

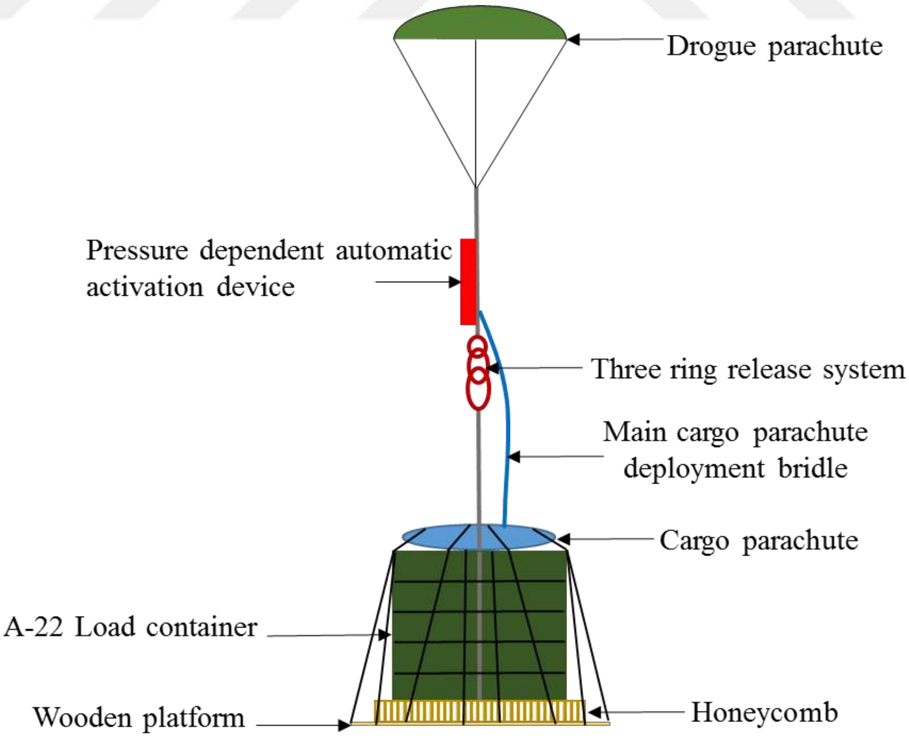

Figure 2.10 Schematic design of modified structure of the system

CHAPTER 3

PRESSURE DEPENDENT AUTOMATIC ACTIVATION DEVICE

3.1 Working Principle of the Device

The pressure dependent automatic activation device has an electronic detection, and command and control unit. Despite this electronic structure, this system is also capable to work mechanically by the help of its mechanical actuator. The electronic part of the device consists of a battery, a trigger motor, a command and control unit, a small monitor, and a sensor. The device senses the altitude by means of the barometer sensor which is activated by the command and control unit. The mechanical part of the device consists of pull spring, steel cable, and lock mechanism. The pressure dependent automatic activation device consists of the hardware components shown in Figure 3.1. The device should not require a pyrotechnic device that needs to be replaced after each use. The system can be reset and used, so it does not cost extra. Since the housing is made of cast aluminum, it is not damaged in impacts.

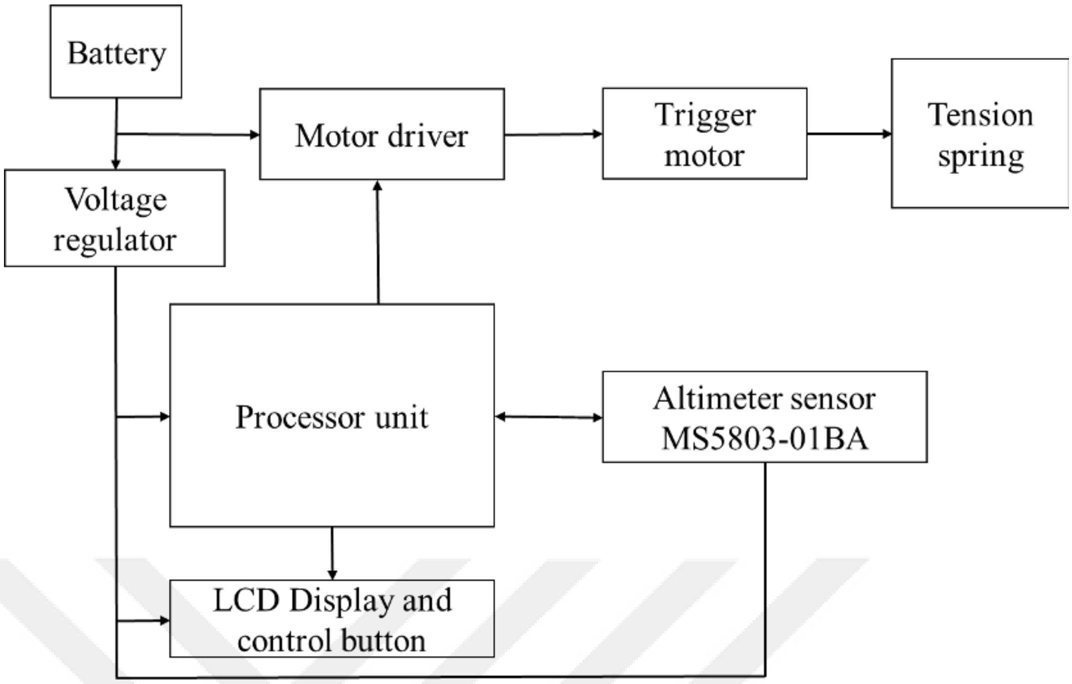

Figure 3.1 Block diagram of the device

The device is powered by a 12 volt battery. Voltage regulator works to level off the voltage for smooth operation of processor unit, Liquid Crystal Display (LCD) monitor and altimeter sensor. The trigger motor retracts the mechanism lock and releases the tension spring by the command given by the processor when the necessary activation conditions are met. The processor unit calculates altitude using the information received by the altimeter sensor and also checks the overall operation of the device. The processor unit communicates with the MS5803-01BA altimeter sensor over the I^2C data line. The LCD monitor and control button block allows the device to be turned on and off, and the test and fault status is displayed. After the test process has passed successfully, the processor unit stores the ground altitude value in its memory when it is turned on. Activation conditions of the device and software algorithm will be examined in detail in the following sections.

The most important part of the device is the sensor that detects altitude. Detailed examination of the sensor used has been made in the following sections. The sensor, by computing pressure difference which is calculated within one millisecond of intervals of readings, determines the altitude of the load, which is in free fall. The altitude at which the main parachute is to be opened and the altitude of the DZ are typed to system before commencing the mission. The monitor and control buttons of the device are used for this purpose. After the load has been released from the aircraft, the device reports the altitude to the command control unit until it reaches the desired altitude. When the desired altitude for main parachute to deploy is reached, the command and control unit sends a signal to the trigger motor. The trigger motor, which receives the signal, is deactivated the locking system that holds the tension spring in place. With the retraction of the latch bolt, the released spring pulls the cable and free the three ring system. At the end of this rapid process, the bridle between drogue parachute and the payload is dissolved and the drogue parachute is released. The drogue parachute strips out of the payload and begins to pull the main parachute. After deploying the main parachute, it continues to wane in altitude carrying deployment bag of cargo parachute and automatic activation device.

3.2 Tactical Use

The device is mounted on the load container to be thrown at the desired altitude as described in the previous sections. After mounting, it is turned on and battery status of the device is checked. After the time of turning on, it counts down from 10 whilst performing a hardware check, and later on indicates that it is ready. After the hardware check, the system starts and the monitor displays the altitude of the current area. After set up, the buttons is protected against accidental pushes. The device has two different altitude settings. The first is registered to the device as drop zone altitude. If the altitude of the DZ is not introduced by the user, the device assumes the altitude read is the DZ altitude. The second altitude setting is registered to the device as activation altitude. If the second setting is not introduced as well, the device add an 1100 ft plus DZ altitude to determine activation altitude. After registering settings to the device, the protective cover of the monitor is sealed. After the final checks are made, the load is properly connected to the aircraft and made ready for airdrop.

When the aircraft is over activation altitude which is determined by aircrew according to CARP ft AGL, it fulfills the first operating condition. If the operation is canceled and the landing is likely before the load is released from the aircraft, it is recommended that the device be switched off. After a regular release, the second activation condition is achieved and the processor unit activates the trigger motor to pull the pin holding the three ring system.

3.3 Design of the System

3.3.1 Mechanical Part

Total weight of the device is 1700 gr. It is 31 cm long, 6.5 cm high and 5.5 cm wide. Products such as squibs or pyrotechnic explosives have not been used in the moving part of the device. Instead, it is designed with a spring-operated mechanism that pulls the pin which keeps the three ring system locked. In this way, it is made available for re-use and no new parts are needed for additional reiterations. The spring mechanism is actuated by the trigger motor. A 5 cm difference of length between the tensioned and loose condition of the spring is sufficient for the device to function. Aforementioned 5 cm distance is the length required for the pin to release the three ring system and a proper transition to loose condition. Overall, the spring in question should ensure two conditions: it should have high spring constant (it shouldn't easily be set by pulling to tensioned state), and the distance between the tensioned and loose conditions must be no lesser than 5 cm.

The main body of the device is made of aluminum material. In this way, the electronic component of the device is protected from the effect of static electricity. In addition, aluminum is a lightweight and easy-to-process material. The transmission device is designed to transfer the power of the trigger motor to the lock tongue. This transfer device is connected to the lock tongue by means of the rotary shaft. The lock tongue ensures that the release latch, which makes the tension spring stop taut, maintain at an installed state. When the spring is tensioned, the small pin located at the device-end of the spring changes the position of the release latch. The release latch make a transition to the other side of the lock tongue. A steel wire is located inside the spring seat. This steel wire is connected to the pin which releases the three ring system. When the spring is released and gotten into loose state, it pulls the steel wire and the steel wire pulls the pin to release the system. The Solidworks CAD model of the device with mechanical components is shown in Figure 3.2. The prototype of the device shown in Figure 3.3.

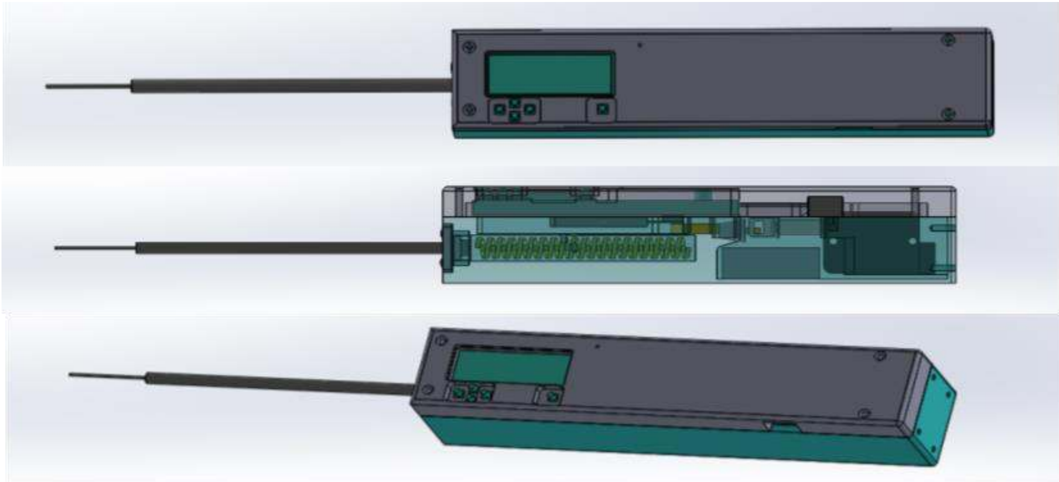

Figure 3.2 The Solidworks CAD model of the device

Figure 3.3 The prototype of the device

3.3.2 Electronic Part

The electronic part of the device consists of battery, trigger motor and electronic card. The electronic parts of the device operate with a 12 v 850 mAH li-po battery as mentioned in the previous sections. The battery can supply energy for 17 hours with the device running. Standard central lock engine used in vehicles has been chosen as the trigger motor. The reason for choosing this engine is its simple logic and durability. In addition, the engine used has a pull thrust of 5 kgf.

The electronic card is consisted of a motor driver, on-off key, 2 * 16 LCD screen, adjustment keys, processor and sensor. VNH2SP30 - 30A mini Arduino Motor driver board has been chosen as motor driver. STM32F103C8T6 board has been chosen as processor. Electronic card of device is shown in Figure 3.4. MS5803-01BA has been used as altimeter sensor. Detailed information about the most important component, the sensor, is presented below.

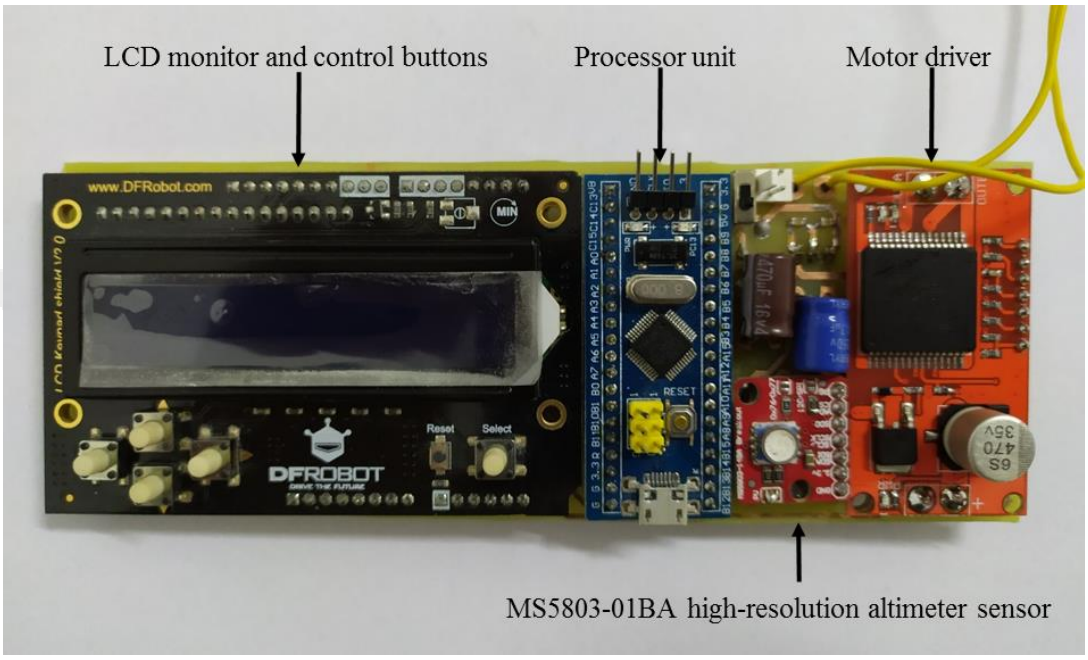

Figure 3.4 Electronic card of device

3.3.2.1 High Resolution Altimeter Sensor

The most significant part of the electronic component of the device is the altimeter sensor. For this reason, in order to avoid bugs during operation, the MS5803-01BA high resolution altimeter sensor is used in this device.

The pressure range of the sensor is between 10 mbar and 1300 mbar, precision measurements can be made in this range. It has Analog Digital Converter (ADC) 24 bit of resolution, in this way we can read the pressure value with a sensitivity of 0.012 mbar. The sensor makes measurements based on temperature. It can be read at 25°C degree with sensitivity of ±1.5 mbar. If the temperature is between -20°C and + 85°C, altimeter can be read with a sensitivity of ±2.5 mbar. It transmits the data to the processor at 8.22 ms after sensing the pressure value. It detects the temperature in the range of -40 to + 85 °C degrees with 0.8 degree sensitivity. This temperature value is computed by the sensor itself and included in the altitude calculation. It has max +4.0 supply voltage. Operating supply voltage is between min 1.8 v and max 3.6 v. İn this device the supply voltage 3.3 v because the device's processor runs at 3.3 v. The deforming temperature limits of the sensor are -40°C to +125°C degrees.

The altimeter sensor consists of a piezo-resistive sensor. The piezo-resistive sensor generates a certain electricity according to pressure changes. The sensor manipulates the data to Multiplexer (Mux) to reduce the number of data into one. The data equivalent current is amplified by the Programmable Gain Amplifier (PGA) and sent to the Analog Digital Converter (ADC). Analogically detected data becomes digital and sent to digital interface. With the help of digital interface, communication with the Micro Controller Unit (MCU) is provided, and digital interface sends the detected data to the MCU for processing. Activated sensor is shown in Figure 3. 4.

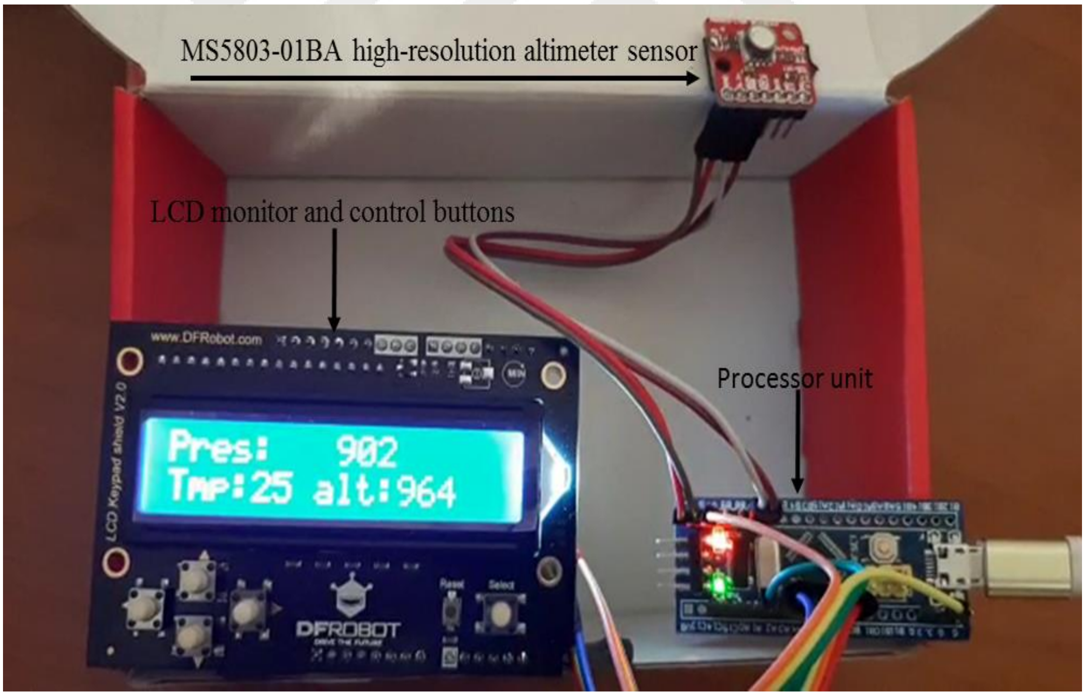

Figure 3.5 MS5803-01BA high-resolution altimeter sensor

3.3.2.2 Software Algorithm

When the device is turned on, firstly the processor controls the sensor and hardware. If it encounters a problem, it reports an error. If there is no problem, it checks the battery and shows the battery status.

After the checking, the menu is displayed on the screen. The menu consists of six options. When selected, these display current altitude, activation altitude (adjustable), drop zone altitude (adjustable), self-check, engine-test and confirmation options. In the current altitude tab, the altitude of the location of the device is reflected on the screen.

The second option is the adjustment of the activation altitude. If no changes are made in this section, activation altitude is accepted as 1100 feet AGL. In incremental values of 25 ft, one can adjust new activation altitude value.

The third option is drop zone altitude. If no changes are made in this section, the altitude of the area where the device is switched on is considered as the drop zone altitude. In incremental values of 25 ft, one can adjust new drop zone altitude value.

The fourth option is the option that allows the device to check itself again. This option is used when it is desired to have the initial hardware and battery control done which is performed when the device is turned on. It is recommended to perform this action before releasing the cargo from aircraft as a last check.

The fifth option is the test engine option. Before the device is mantled onto the load, it is used to check the functionality of the trigger motor and the spring mechanism. After the device spring mechanism is manually set up, the operation of the mechanical parts of the device is checked by this option.

The last option is the confirmation option. When this option is pressed for 5 seconds, the device starts measuring altitude to self-activate at the desired activation altitude. Once this option is selected, the device is ready for airdrop. If the task is canceled, pressing the confirmation button for 5 seconds will return to the menu and the altitude reading will be ended. Thus, the cancellation button is the same button that is used for confirmation. Adjusted values are not erased and therefore can be readily available for an instant future use.

The device needs two conditions to be realized so as to be activated following its approval.

The first condition is realized when the device rises above 1000 ft. above the sum of drop zone altitude and activation altitude. When the aircraft reaches this height, the first activation condition is met. To determine the current altitude in question, the altitude value is read 50 times, the highest and lowest values are discarded and the remaining values are averaged. Thus, the risk of errors is eliminated.

The second condition to be realized is reading the drop zone altitude plus the activation altitude. While calculating the activation altitude value in question, the altitude value is read 10 times, the highest and lowest values are discarded and the remaining values are averaged. In this way, instant reading errors are avoided. The reason why the frequency of readings is decreased by one to fifth is that the time required for 50 readings is more than that of 10 readings. As the elapsing time (in the magnitudes of milliseconds) is more important while the cargo is descending to its activation altitude, namely, as no delay could be affordable due to the activation at an undesired altitude, the frequency of readings is diminished. This delay may cause confusion in the HARP compute.

Software is written via MikroC programming language and software algorithm is shown in Figure 3. 6.

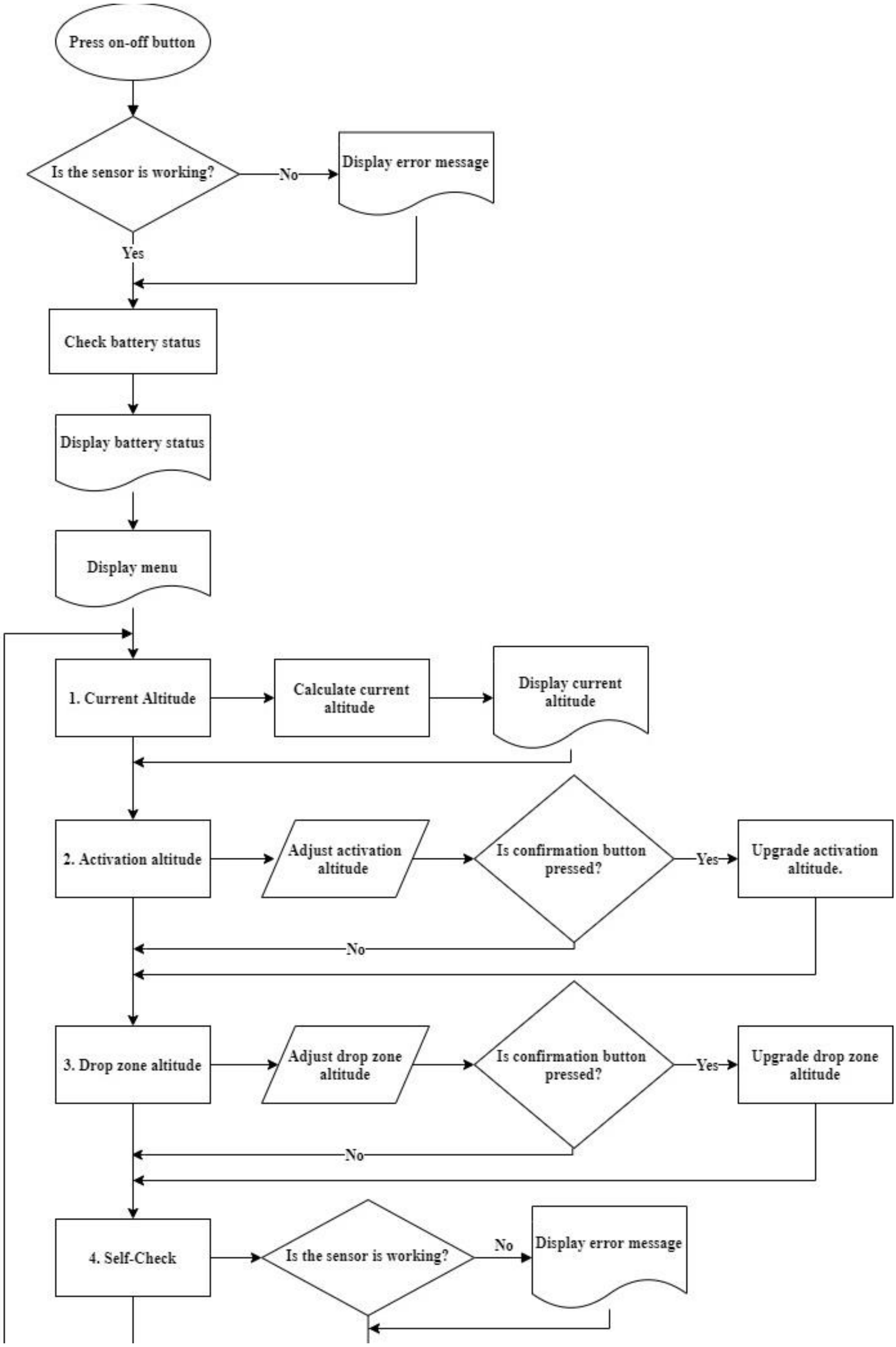

Figure 3.6 Software algorithm

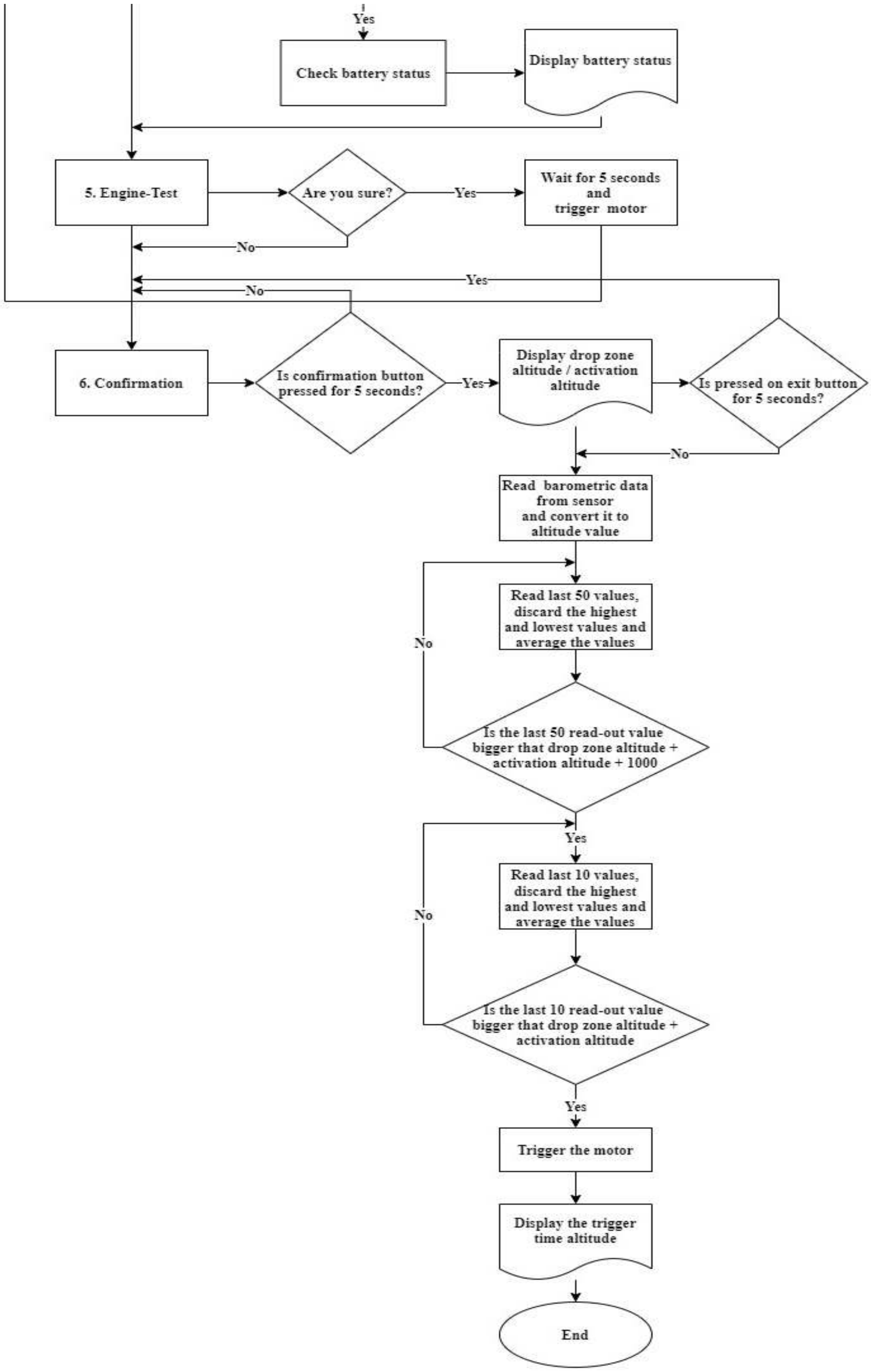

Figure 3.6 (continued): Software algorithm

CHAPTER 4

EXPERIMENTS AND ANALYSIS OF THE RESULTS

4.1 Laboratory tests

Tests were carried out in the air data test system where the desired pressure and temperature values can be adjusted for true conditions to before the device is tested in real airdrop. The air data test system used in the tests is the ADT403 model of the DRUCK brand.

In the tests of the pressure depended automatic activation device, 25,000 ft altitudes has been chosen as the upmost limit. This altitude value has been selected because it is suitable for high altitude airdrop operation. The performance of propeller aircrafts decrease due to the lack of air density at altitudes higher than the selected altitude. The temperature range has been dwelled upon between -20°C and +20°C degrees. These values are preferred because they are close to real airdrop conditions.

Two different test groups were created in laboratory tests and five attempts were made in both test groups. In the first test group, the operability of the device was tested by changing the activation altitude. In the second test group, the effect of temperature changes on the device were observed.

4.1.1 First Test Group

In the first five tests, the temperature was kept constant at room temperature. In addition, the altitude of the aircraft and the drop zone altitude were not changed. In these tests, only the activation altitude of the device was changed. Two goals have been aimed by this study, to check how the device's software works and to monitor how the change of activation altitude affects the reliability of the device. In order to simulate the free fall phase, the period to be covered per 1000 ft. was assumed to be 4.3 seconds. It was calculated according to the free fall speed of load container, which is approximately 70 meters at most per second.

In the first test, activation altitude 600 ft. (AGL) and drop zone altitude 2786 ft (MSL) were registered into the device. The altitude at which the device releases from the aircraft was introduced into the system as 25,000 ft. It was observed that the device was activated at 3258 ft (MSL) after 93.3 seconds, descending through every 1000 ft. in 4.3 seconds.

All things being equal except for the activation altitude which were selected as 600, 1100, 1500, 2000 and 2500 respectively. According to these activation altitude values, it was observed whether these changes in the activation altitudes have a significant deviational values on when the device launched activation.

As the activation altitudes change from one trial to another, Free fall periods also change receiving the values 91.1seconds, 89.3 seconds, 87.4 seconds, and 85.1 seconds alternately and accordingly. First air data tests are shown in Figure 4.1. The test's results are shown in Table 4.1.

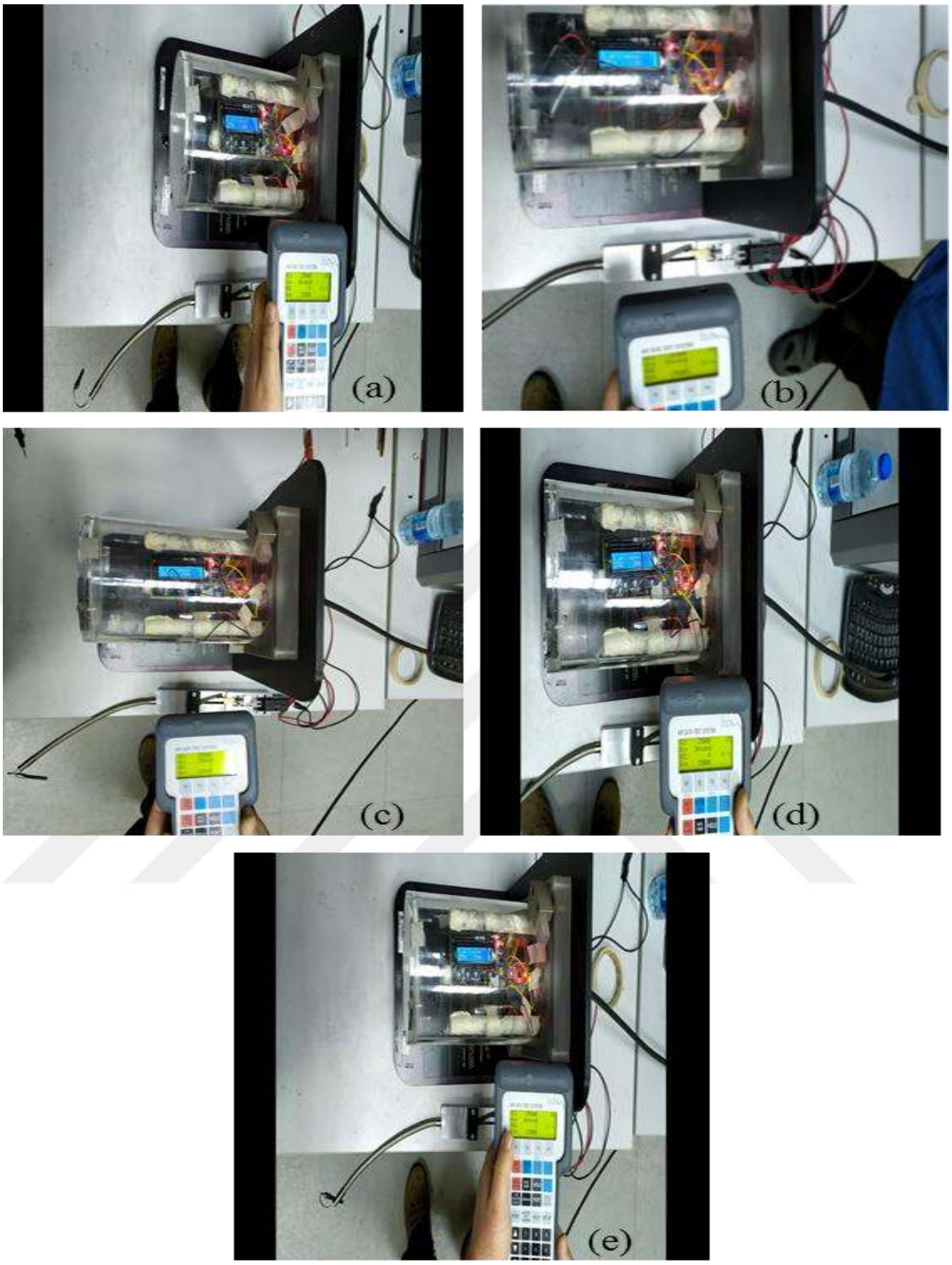

Figure 4.1 First air data test group

Table 4.1 Results of the first test group

	Release Point (ft)	DZ (ft)	Temperature (°C)	Activation Altitude (ft) (Desired)	Activation Altitude (ft) (Actual)	Activation Altitude Difference (ft)
1	25000	2786	24	3386	3258	128
2	25000	2786	24	3886	3812	74
3	25000	2785	24	4285	4214	71
4	25000	2782	24	4782	4671	111
5	25000	2789	24	5289	5204	85

As a result of the tests, it has been observed that the device was activated at the desired altitude with an average deviation of 93.8 ft. In the following part, the effects of changing temperature will be studied.

4.1.2 Second Test Group

In the second part, five tests were carried out at temperatures varying between -20°C and +20°C degrees in order to see the effects of changing temperature on the operational of the device.

In these tests, the altitude of the aircraft release point 25000 ft. was registered into the system. DZ and the activation altitudes was defined as 2789 ft (MSL) and 1100 ft

(AGL) respectively. As it is in the previous tests, in order to simulate the free fall phase, the period to be covered per 1000 ft. was assumed to be 4.3 s.

In the first test, test temperature was set as -20°C degrees. Activation altitude 1100 ft and drop zone altitude 2789 ft were registered into the device. The altitude at which the device releases from the aircraft was introduced into the system as 25000 ft. It was observed that the device was activated at 3760 ft. after 91.3 seconds, descending through every 1000 ft. in 4.3 seconds.

All things being equal except for the temperature which were selected as -10, 0, 10 and 20 respectively. According to these temperature values, it was observed whether these changes in the operation temperatures have a significant deviational values on when the device launched activation. Second air data tests are shown in Figure 4.2. The test's results are shown in Table 4.2.

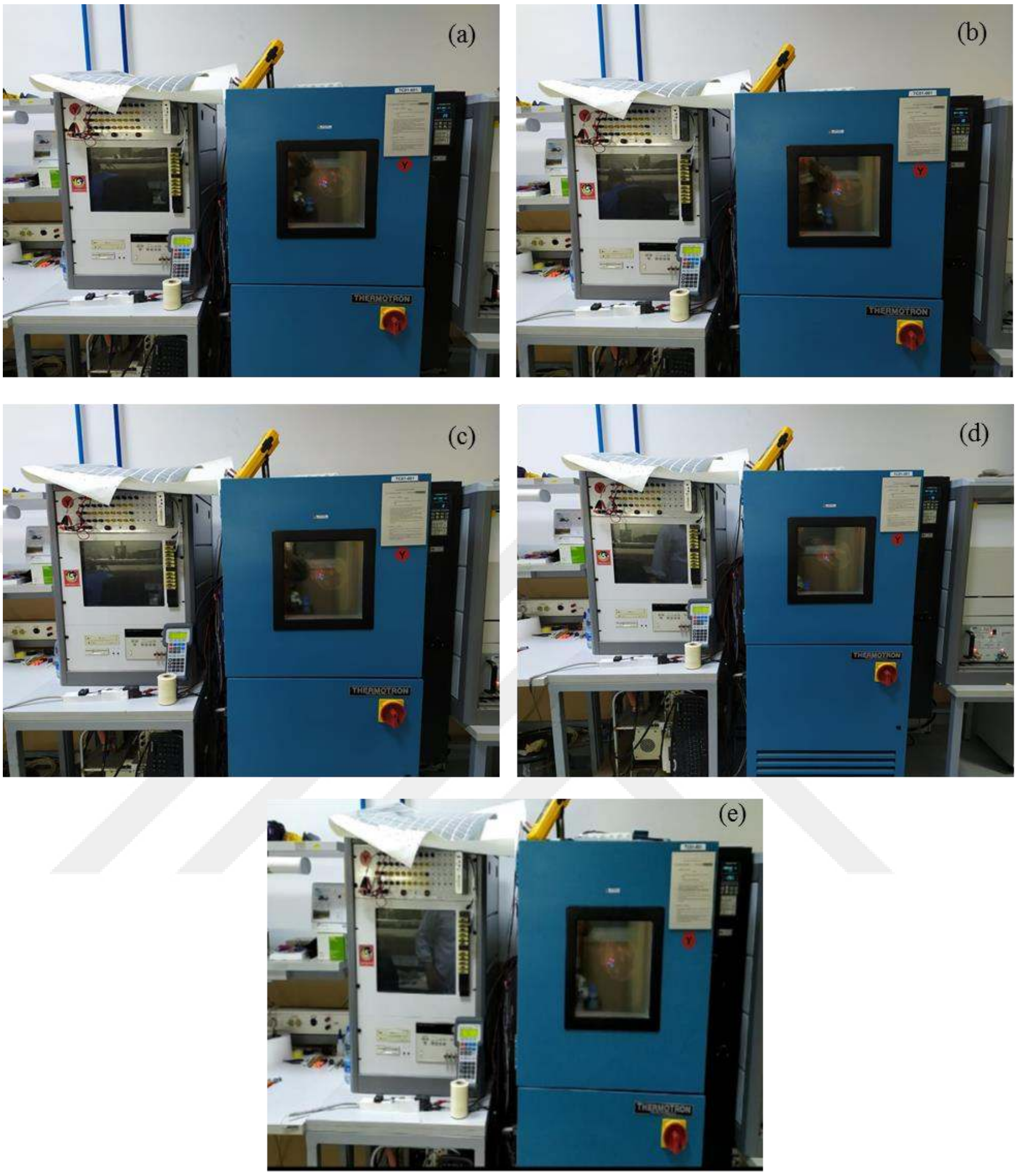

Figure 4.2 Second air data test group

Table 4.2 Results of the second test group

	Release Point (ft)	DZ (ft)	Temperature (°C)	Activation Altitude (ft) (Desired)	Activation Altitude (ft) (Actual)	Activation Altitude Difference (ft)
1	25000	2789	-20	3889	3760	129
2	25000	2786	-10	3886	3808	78
3	25000	2782	0	3882	3797	85
4	25000	2785	+10	3885	3767	118
5	25000	2786	+20	3886	3957	71

As a result of the tests, it was observed that there is no deviation on activation altitude that can be correlated with temperature changing that was between -20°C and 20°C degrees. Therefore, it could be said that temperature change has no effect on the reliability of the device.

4.2 Airdrop Experiments

Two real airdrop experiments were conducted with CN-235 cargo aircraft by using A-22 standard load container and G-12 D cargo parachute.

First airdrop was carried at 5000 ft AGL (8485 ft MSL). DZ altitude was 3485 ft (MSL). Air temperature was observed as +10°C degrees at the DZ and 7°C degrees at 5.000 ft. Activation altitude was set as 1600 ft AGL. Deployed wind at drop zone was observed as 1 kt from 270 degrees. Ballistic wind from release till parachute deployment altitude was observed as 3 kt from 220 degrees. The aircraft course was 270 degrees.

By taking all the information mentioned above into account, release point has been calculated to be 340 m away from reference impact point at an azimuth angle of 95 degrees.

Load was released at the calculated release point and thanks to the camera and external altimeter which were mounted on the load, it was observed that the system was activated at 1600 ft AGL. Payload was dropped successfully to a point which is 40 meters from 270 degrees with reference to PI. The phases related to first attempt has been shown in Figure 4.3.

Figure 4.3 The phases related to first airdrop

Second airdrop was carried at 10000 ft AGL (13485 ft MSL). DZ altitude was 3485 ft. Air temperature was observed as -2°C degrees at the DZ and -6°C degrees at 10.000 ft. Activation altitude was set as 1600 ft AGL. Deployed wind at drop zone was observed as 6 kt from 80 degrees. Ballistic wind from release till parachute deployment altitude was observed as 10 kt from 100 degrees. The aircraft course was 270 degrees.

By considering all the above-mentioned information, release point has been calculated to be 709 m away from reference impact point at an azimuth angle of 92 degrees.

Load was released at the calculated release point and thanks to the camera and external altimeter which were mounted on the load, it was observed that the system was activated at 1600 ft AGL. Payload was dropped successively to a point which is 70 meters and 270 degrees from the desired impact point. The phases related to second airdrop attempt has been shown in Figure 4.4. Experiment results are shown in Table 4.3

Figure 4.4 The phases related to second airdrop

Table 4.3 Results of the real airdrop experiments

	Release Point (ft)	DZ (ft)	Activation Altitude (ft)	Deviation Distance (m)
1	5000	3485	1600	40
2	10000	3485	1600	70

Airdrop attempts have been successfully completed with an average deviation of 55 meters from the desired impact point. Correct prediction of the magnitude and direction of the wind to which the load is exposed throughout the whole duration of the fall, is critical for successful dropping of the load upon the desired impact point. Also, respective higher values on release altitude selections may result in higher deviations between the desired PI and actual drop point as the much higher the duration of wind exposition means the higher instability in the calculation since these calculations are not all-scientific but merely approximations.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As a result of the research, it was concluded that the HALO airdrop concept with a stable and easy-to-use automatic opening device can be used to protect the aircraft from the threat of the enemy. Due to the high cost and complex structures that can cause malfunctions, it is seen that precision guided airdrop systems cannot be preferred in every airdrop operation and this gap can be closed with HALO concept.

In HALO concept, the main cargo parachute is deployed by automatic cutting devices based on time count-down. However, counter-based systems do not yield accurate results in deploying the main parachute at the desired altitude. Devices designed to deploy reserve personnel parachutes in case of emergency contain expensive and disposable parts. In order to overcome all these problems, a new design has been made by combining an electronic detection and command system with a mechanical deployment mechanism. In addition, the device is easy to use and does not require much training.

In this thesis, an automatic activation device has been successfully designed, mounted, and full-scale tests have also been carried out. Laboratory tests on the air data test system concluded that the device is able to operate at a maximum altitude of 25,000 ft and at a temperature range of minimum -20°C and temperature. The designed device is involved in a trial airdrop which contains A-22 cargo container and single G-12 D type cargo parachute. Payload weights from 1,500 to 2,000 lbs. were airdropped from 5,000 ft and 10,000 ft AGL using a 68-inch drogue parachute and landed safe. Drop accuracy in real airdrop tests was generally within a circle of 40 m or 70 ft using reliable HARP calculation data. It is considered that if the lower base geometry of the load is designed to be the way than can be least affected by the wind, the drop accuracy can be further improved by minimizing glide ratio during free fall. It is suggested accuracy calculation programs should be downloaded on aircraft in the future to improve the accuracy of HALO precision airdrop systems. The more frequent wind and temperature information which are input data to HARP calculation is loaded into the aforementioned calculation programs that update the release point instantly and accordingly, the more accurate results might be obtained. Because, manmade and paper and pencil calculations cannot be updated in a tiny time that an airdrop operation may require.

It has been evaluated that the device designed in this study can be used not only in high altitude airdrop operations but also in unmanned aerial vehicles, rocket systems and various systems that require altitude-based input to activate itself or one of its components.

Our published articles on the use of pressure-dependent automatic activation devices [31] and precision-guided airdrop systems [32] have been quickly accepted and reached high reading levels in a short time. It indicates that relevance to this issue is very high.

5.2 Recommendations

The recommendations regarding the pressure dependent automatic activation device are presented below considering the results of this study.

Countries using airdrop should focus on high altitude airdrop and provide training on this issue. In addition to the necessity to work on the smart parachute systems, research should be made on various pressure depended automatic activation devices for the HALO concept, which is much cheaper and provides enough safety against enemy threats. It should be recalled that the opening device, which is designed to be used in high altitude low opening airdrops, should provide simple use and be easily mounted on the load as well; should not require complicated training to benefit from it.

In addition to simple use of the device, in the case of an aircraft incapable of automatically calculating the release point, personnel should be trained to become capable of performing this calculation accurately and precisely, and this should be emphasized on their training rehearsals. In these trainings, both airdrop experts and aircraft crew should be trained together.

If the possible benefits of the system from civilian aspect are investigated in detail, it could be even deducted that it may provide fundamental advantages in non-military missions.

Furthermore, this system can be mounted on target air vehicle in any rocket test. If the target cannot be hit by the rocket being tested, it may be provided that it does not require an additional landing software and hardware system for landing and it can be provided to descend to the ground by opening its parachute without damaging any civil constructions or living beings. Because these target systems should be designed as cheap as possible to meet only the needs. The parachute landing systems designed as described in this thesis are perfect for such rocket targets. Additionally, this system is also mountable to the rockets to make them land to the ground safe and sound without detonation if the option of neutralizing it is out of consideration.

REFERENCES

[1] Benney, R., Barber, J., McGrath, J., Noetscher, G., McHugh, J., Tavan, S. The Joint Precision Airdrop System Advanced Concept Technology Demonstration, 18th AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar. Retrieved February 17, 2020, from AIAA database. 2005.

[2] Parfit, M., *"Letting Us Down Gently: The Art of the Parachute", Smithsonian.* p. 58. August 1990.

[3] Siegel, N., "Legacy of Flight," *Aviation History.* p. 74. September 1998.

[4] Ertaş M. Y., Kılıçaslan H., Ortaylı İ. "*Kutü'l Amare 1916 Olaylar, Hatıralar, Raporlar*", (3th Ed.). Kronik Kitap, İstanbul, ISBN9752430044, 2018

[5] Schlenoff, D., 1916 Aerial Resupply Invented, Retrieved February 15, 2020, from https://blogs.scientificamerican.com/anecdotes-from-the-archive/aerial-resupply-invented-1916/#. August 12, 2016.

[6] Klumpp, R. A. *Strategic Brigade Airdrop: Past, Present, Future?* Graduate Research Paper, Graduate School of Logistics and Acquisition. Air Force Institute of Technology. Wright-Patterson AFB, OH. November 1996.

[7] Military Airlift Command, office of History. *Anything, Anywhere, Anytime: An Illustrated History of the Military Airlift Command, 1941-1991.* Scott Air Force Base, IL: Headquarters Military Airlift Command, May 1991.

[8] Harmon, C., "Point Paper on C-17 Humanitarian Airdrops," HQ, AMC/DOKT. Scott AFB, IL. 11 April 2002.

[9] Yardım uçağına uçaksavar atışı. Habertürk, p.1. 2011, September 19.

[10] Kılpayı kurtuldu. Posta, p.1. 2011, September 19.

[11] US Department of the Army Airdrop of Supplies and Equipment in the Theater of Operations. (FM 10-8). 1969.

[12] Wuest, M. R., & Benney, R. J. Precision Airdrop (Largage de précision). Nato Research And Technology Organization Flight Test Techniques Series, (*24*), 1-62. December 2005.

[13] Kane, T., Dicken, H. K., & Buehler,C. R. A Homing Parachute System. Research Report, Sandia Corp., 1-37. 1961.

[14] Brown, G., Haggard, R., Almasssy R., Benney, R., & Dellicker, S. The Affordable Guided Airdrop System (Agas). American Institute of Aeronautics & Astronautics AIAA-99-1742, 316-325. l999.

[15] Benney, R., Barber, J., Mcgrath, J., Mchugh, J., Noetscher, G., & Tavan, S. The New Military Applications of Precision Airdrop Systems. American Institute of Aeronautics & Astronautics AIAA 7069, 1–16, 2005.

[16] Lingard, J. S. The Performance and Design of Ram-Air Gliding Parachutes. Royal Aircraft Establishment Technical Report TR 81103, 1981.

[17] Guided Precision Aerial Delivery System. (n.d.). Retrieved from https://airborne-sys.com/product/firefly-military-cargo-delivery-parachute/

[18] Cacan, M. R., Scheuermann, E., Ward, M., Costello, M., & Slegers, N. Autonomous Airdrop Systems Employing Ground Wind Measurements for Improved Landing Accuracy. IEEE/ASME Transactions on Mechatronics, (*20)*, 6, 3060–3070, 2015.

[19] Johnson, J. G., Kaminer, I. I., & Yakimenko, O. A. Hardware Integration of Parachute Guidance, Navigation, and Control for the Affordable Guided Airdrop System (AGAS) Master's Thesis, Naval Postgraduate School. 2001.

[20] Sadeck, J., Riley, J., Desabrais, K. J., & Lee, C. Low Cost HALO Cargo Airdrop Systems. 20th AIAA Aerodynamic Decelerator Systems Technology

Conference and Seminar. Retrieved February 17, 2020, from AIAA database. 2009.

[21] Henry, M., Lafond, K., Noetscher, G., Patel, S., Pinnell, G. Development of a 2,000-10,000-Lb Improved Container Delivery System. Technical Paper U.S. Army Natick Soldier Research, Development and Engineering Center, 2009.

[22] US Air Force Instruction. Flying Operations Computed Air Release Point Procedures (AFI 11-231). 2005.

[23] United States Patent. Pressure Dependent Release Device for a Parachute (Patent Number: 4,858,856). United States; 1989.

[24] Parachute Automatic Sensing and Activation Devices. (n.d.). Retrieved from https://www.fxcguardian.com/

[25] Automatic Activation Devices. (n.d.). Retrieved from https://www.cypres.aero/

[26] G-12 Cargo Parachute Assembly. (n.d.). Retrieved from https://www.millsmanufacturing.com/products/g-12-parachute/

[27] US Department of the Army Air Force and Navy. Unit And Intermediate Direct Support (Ds) Maintenance Manual Including Repaır Parts And Specıal Tools List For Parachute, Cargo Type: 64-Foot Diameter, Model G-12d (10-1670-281-23P). 1990.

[28] US Department of the Army. Airdrop of Supplies Rigging Containers (FM 10-500-3). 1996.

[29] United States Patent. Parachute Release Mechanism (Patent Number: US2845241A). United States; 1958.

[30] United States Patent. Means for Releasably Attaching Strands (Patent Number: US4337913A). United States; 1982.

[31] Kivrak, S., Civelek, B., Arabaci, H. Pressure-Dependent automatic activation device at the high altitude low opening airdrop missions. International Journal

of Engineering Science and Computing (IJESC), (*9*), (Issue 6) 23026-23031. 2019.

[32] Kivrak, S., & Civelek, B. A Review on the precision guided airdrop systems. International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS), (*VIII*), (Issue I) 13-17. 2019.

CURRICULUM VITAE

PERSONAL INFORMATION

Name Surname	**: Burak CİVELEK**
Date of Birth	**: 15.09.1987**
Phone	**: +905555532015**
E-mail	**: civelek.burak2@gmail.com**

Photo

EDUCATION

High School	**: Kuleli Military High School**
Bachelor	**: Turkish Military Academy**
Master Degree	**: Defense Technology**

WORK EXPERIENCE

Ministry of National Defense

TOPICS OF INTEREST

- Aviation
- Electronics Engineering