DESIGN, MANUFACTURING AND TESTING OF PARACHUTE RECOVERY SYSTEM FOR ALUDRA SR-10 UNMANNED AERIAL VEHICLE (UAV)

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ABSTRACT

Unmanned Systems Technology (UST) Aludra SR-10 Unmanned Aerial Vehicle (UAV) was purposely designed for survey and mapping mission. This study focuses on the design, manufacturing and testing of Parachute Recovery System (PRS) on the Aludra SR-10 UAV. A design work of PRS involving in defining a suitable type of parachute design, parachute compartment, parachute deployment and activation mechanism system. This study was performed by simulation approach (using Computational Fluid Dynamic, CFD) and experimental approach (static drop test and flight test). The evaluation of aerodynamics characteristics using ANSYS software over two types of parachute models (annular and cruciform parachutes canopy) help to determine the most suitable type of parachute design for PRS. The static drop test with on board system (consisted of NI myRio, IMU and GPS) programme using LabVIEW software was performed to evaluate the feasibility of the parachute. Meanwhile, the flight test was conducted to investigate the performance and reliability of PRS at different deployment heights. A baseline annular parachute canopy with 2.41 m of the nominal diameter was selected as the main parachute, which produced highest drag coefficient (1.03). The findings also highlighted the significance of separation and recirculating flows behind studied geometries, which in turn was responsible in producing the drag. Through the static drop test, the selected parachute design provided a predicted terminal descent velocity of approximately 4 m/s with payload of 5kg. This parachute recovery system was able to reduce the impact force at fourth time lower compared to belly landing, from 139.77 N to 30.81 N. The pilot-chute was successful pulled main parachute to free stream and fully inflated in a short time, less than 3 seconds. Most of all, the parachute recovery was able to support and bring the aircraft to a soft and safe landing thus, confirmed its reliability. Interestingly, robust evidence in a prediction of the landing position area using PRS was achieved.

ABSTRAK

Unmanned Systems Technology (UST) Aludra SR-10 Unmanned Aerial Vehicle (UAV) adalah direka bagi tujuan misi kaji selidik dan pemetaan. Kajian ini memberi tumpuan kepada reka bentuk, pembuatan dan ujian Sistem Pemulihan Parasut (PRS) pada Aludra SR-10 UAV. Reka bentuk ini melibatkan kerja untuk menentukan jenis payung terjun yang sesuai, tempat penyimpanan payung terjun, sistem terjun payung dan sistem mekanisme pengaktifan. Kajian ini dilakukan dengan pendekatan simulasi (menggunakan Computational Fluid Dynamic, CFD) dan pendekatan eksperimen (ujian penurunan statik dan ujian penerbangan). Penilaian ciri-ciri aerodinamik ke atas dua jenis model payung terjun (berbentuk nnular dan crucifrm) dengan menggunakan perisian ANSYS menunjukkan bahawa payung terjun berbentuk annuar yang paling sesuai diunakan sebagai PRS. Ujian pelepasan secara statik bersama sistem yang dilengkapi dengan perisian LabVEW digunakan untuk menguji dan menganalisis trajektori payung terjun. Sementara itu, ujian penerbangan telah dijalankan untuk melihat kebolehpercayaan pelaksanaan PRS di Aludra SR-10 pada ketinggian yang berbeza. Payung terjun bebentuk annular dengan agaris pusat kira-kira 2.41m dipilih sebagai payung terjun utama kerana ia menghasilkan pekali seret yang tertinggi (1.03). Simulasi ini menujukkan aliran di sebalik geometri, yang bertanggungjawab untuk menghasilkan daya. Melalui ujian penurunan statik, reka bentuk payung terjun yang dipilih memberikan kelajuan penurunan terminal kira-kira 4 m/s dengan muatan 5kg. Sistem pemulihan payung terjun ini dapat mengurangkan empat kali ganda daya impak semasa mendarat berbanding pendarahan perut pesawat, dari 139.77 N hingga 30.81 N. Pilot-chute berjaya menarik payung terjun utama untuk aliran bebas dan melambung sepenuhnya dalam masa yang singkat, kira-kira 3 saat. Pemulihan payung terjun mampu menyokong dan membawa pesawat ke pendaratan yang lembut dan selamat. Di samping itu, kajian ini dapat memberikan bukti kukuh untuk meramalkan kawasan pendaratan yang menggunakan pemulihan payung terjun.

LIST OF ABBREVIATIONS

AGL	Above ground level
C.G	Center of gravity from the aircraft
CFD	Computational Fluid Dynamic
CTOL	Conventional take-off and landing involving the use of runways
GCI	Grid Convergence Index of the meshing
GSC	Ground Control Station
IMU	Inertial Measurement Unit
LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench
LOS	Line of sight
NI	National Instrument
PRS	Parachute Recovery Systems
PWM	Pulse-width modulation
RANS	Reynolds-averaged Navier-Stokes
SUAV	Small Unmanned Aerial Vehicles
TRANS	Time Reynolds Averaged Navier-Stokes Equations
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
VTOL	Vertical take-off and landing that can take off and land vertically.

LIST OF SYMBOL

μ	Viscosity of air	kg/m.s
Δs	Prism layer thickness (Inflation)	mm
b	Drag coefficient exerted on the aircraft cause by air resistance	-
C_d	Drag coefficient	-
C_l	Lift coefficient	-
d	Drag coefficient exerted on the parachute cause by air resistance and the aircraft	-
D_c	Constructed diameter of parachute	m
D_o	Nominal diameter of parachute	m
D_p	Inflated shape projected diameter of parachute	m
D_T	Total drag of the parachute and the aircraft/load	N
D_v	Spill hole diameter of annular parachute	m
F_{Impact}	Impact attenuation upon landing	N
g	Acceleration of gravity	m/s^2
h	Inflated height of fully inflate parachute	m
H_{Loss}	Altitude loss during inflation process	m
L_{arm}	Cruciform arm’s length	m
L_e	Suspension line length of parachute	m
n	Filled constant of parachute during inflation process	-
q	Dynamic pressure	-
Re	Reynolds number	-
S	Cross sectional area	m^2
t_f	Parachute inflation time	s
V_f	Final velocity of the aircraft	m/s
V_t	Rate of descent during recovery	m/s

w	Cross wind speed	m/s
W_{arm}	Cruciform arm’s width	m
W_{Chute}	Weight of parachute	N
W_{Load}	Weight of aircraft/load	N
W_T	Total weight of the parachute and the aircraft/load	N
ρ	Density	kg/m^3

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INTRODUCTION

1.1 Research background

Unmanned Aerial Vehicle (UAV) is an aircraft with no pilot on board. UAVs can be remotely controlled that can be flown by a pilot at a ground control station, (GCS) or autonomously based on pre-programmed flight plans. Over the past few decades, there have been significant researches and developments of UAVs. UAV can be distinguished from one another in terms of range or altitude, shapes, size, weight, endurance, design approach and missions [1]–[4]. UAV are now gaining high interests from civil and military fields to conduct a mission which includes reconnaissance, surveillance, target tracking, combat and high structure inspection. Moreover, UAVs have different components those are used to perform the mentioned missions and roles [2], [5], [6].

In military field, UAVs have been used not only for reconnaissance and surveillance but also as a target and decoy to simulate the profile of enemy aircraft or missile. Furthermore, UAVs can be employed in various areas including rescue, strike mission and combat for some high-risk missions. Multiple civilian roles have been designed for UAVs to be utilized in civil and numerous commercial applications such as search and rescue, survey, inspection, agriculture, aerial photography and data collection. Besides that, UAVs has also been widely used as experimental platform in various research groups in university and industry in order to develop further technologies [4], [7], [8].

Despite this rapidly grows industry of UAVs technology, safety to people and property remains as the utmost importance. The primary safety for Unmanned Aerial System (UAS) that closely relates to hazardous probability are: 1) a collision between UAV and other airspace users and 2) the controlled or uncontrolled impact of the UAV crash on the ground, hit an object or structure or land on some undesired location [9]. Modern UAVs are equipped with a typically expensive and high technology electronic components. System failures and damage of UAVs whether it is structural or systems damage can be costly. To increase the safety of UAV operation, different types of UAV safety equipment can be adopted includes parachutes, nets, flight termination systems and emergency locator transmitters as recovery system [2], [5], [10].

The process of UAVs recovering is frequently described as the most difficult and critical phases in UAV operations. Proper design of recovery system for UAVs is highly desirable factor to prevent improper landing leads to accidents. However, different technologies for recovering commonly come together with positive and negative attributes. One mechanism that has been studied by several researchers in recent years to address safety concerns for most small type of UAV is by mounting a parachute system onto the aircraft. Not only as primary recovery method, but the parachute system can be the most effective method as a recovery system in the event of a system failure to reduce the risk on the aircraft and its payload.

The ultimate goal of this current research is to determine the feasibility and reliability of Parachute Recovery Systems (PRS) in order to allow small unmanned aerial vehicle (SUAVs) such as Aludra SR-10 UAV safe landing without damage. Thus, a proper development of mechanism and solutions are required to allow vertical descent and horizontal landing of aircraft in preventing the damage on aircraft’s airframe and structure. This study approaches to promote the systematic design technique and process of parachute recovery including the analysis of its performance. Besides, these researches are beneficial to predict the landing area of these aircraft using the parachute recovery system.

1.2 Problem statements

Unmanned Systems Technology (UST) Aludra SR-10 Unmanned Aerial Vehicle (UAV) was purposely designed for survey and mapping mission. In the early designing stage of Aludra SR-10 UAV, this type of unmanned aircraft used skid and belly landing as a recovery method. This type of landing method may encounter a tough landing on hard soil and gravel, producing high impact momentum on the aircraft body. This impact may cause structural or system damage which costly to be repaired. Therefore, this research disclosure was performed in a correlation to enhancements in the field of aircraft safety and implementation of emergency parachute recovery for Aludra SR-10 UAV.

Nowadays, Parachute Recovery System (PRS) are recently used for landing method purposely to replace the belly landing technique. The PRS mechanism are currently applied in numerous tasks in aviation industry and very suitable to be applied as recovery system in small and medium sized unmanned aircraft such as Aludra SR-10 UAV. To date there are various embodiments and concepts correspond to the parachute recovery which are significantly important be considered for the investigation. However, previous studies of the PRS for UAV lack several conceptual and methodological analyses. The criteria includes parachute canopy shape, attachment to the aircraft, deployment compartment, deployment mechanism and others.

There are four shapes of commonly used parachute canopies UAV’s recovery system. These four types of parachute canopies are cruciform, hemisphere, annular and parafoil shape. Different type of parachute design produce different drag forces during descending. The parachute which produce provide a higher drag force will give better performance in parachute recovery system [11], [12]. A significant study of drag force produced by different shapes of parachute can be determined using Computational Fluid Dynamic (CFD).

Upon an activation of the deployment mechanism, the parachute should rapidly deploys away from the storage compartment. The ability to rapidly deploy the parachutes is an important feature for low flying aircraft such as Aludra SR-10 UAV which is necessary in order to minimize the altitude loss. Further investigations are needed to explore the mechanism that allows the parachute to deploy rapidly after being activated. A static drop test could provide a needed information in determining the parachute inflation process and descending behaviour, as well as the minimum deployment altitude.

Mostly, the parachute descends uncontrollably and almost slightly vertically through the air stream. This situation leads to an uncertain landing point. Investigation of the landing area or range is considered as a continuing concern within the parachute recovery performance. The main challenge faced by many researchers is to predetermine the recovery area of an aircraft from the parachute deployment point. An analysis from the flight test data is useful to determine the accuracy of landing area prediction.

Additional weight to the aircraft is an important concept in the most studies. Additional weight is an impact factor that significantly affect the flight performance of UAV which include its stability, slower cruising speeds and reduced aircraft endurance. Therefore, the addition of significant weight from parachute recovery equipment and devices to the UAV should be considered. In this study, the design criteria for these recovery system were set to lift a maximum payload of the aircraft up to a maximum take-off weight (MTOW) of 5 kg.

1.3 Research objectives

This prospective study was designed to investigate the use of parachute recovery as a landing method for CTRM research unmanned aircraft, Aludra SR-10 UAV. The specific objective of this study were

i. To design a suitable parachute for Aludra SR-10 UAV as the Parachute Recovery System (PRS).

ii. To develop and manufacture a complete Parachute Recovery System (PRS) for Aludra SR-10 UAV.

iii. To conduct a static drop test and flight test in order to investigate the performance of the design Parachute Recovery System (PRS).

1.4 Scope of study

To achieve the research objective as discussed in the previous sub chapter, the full scopes of study will be conducted in this research work involves:

i. **Understanding on the use of CFD ANSYS-Fluent software:** The ANSYS Fluent software is CFD software which developed based on Time Reynolds Average Navier Stokes Equations (TRANS). To solve this type equations, there are there elements need to be considered. These three elements are (1) numerical grid generation, (2) numerical scheme used for solving the TRANS (Flow solver), and (3) the turbulence models. The ANSYS software allows various grid model can be implemented (course, medium and fine), various flow solver and various turbulent model can be implemented. Through understanding on ANSYS software helps in solving the flow problems involving parachute.

ii. **Static drop test:** The test was conducted to evaluate a parachute performance through releasing the parachute from altitude of 38 meter above ground level (AGL) under 5kg payload. The on board system measurement unit were designed to evaluate the parachute performance includes the rate of descent and the stress impact. This system consist of NI myRio, IMU and GPS devices were developed using LabVIEW software.

iii. **Manufacturing and installation of PRS:** Installation of PRS into Aludra SR-10 UAV involved only a simple modification to the UAV airframe and system. The detailed mechanism involved in implementing the design of parachute recovery were based on the design evaluation and concept selection in the design process.

iv. **Flight test:** The performance characteristics of PRS included parachute inflation time, descent time taken, deployment distance, PRS reliability and deployment method verification were observed and analysed. The landing distance area during flight test was compared and validated with the mathematical model of prediction landing area.

1.5 Contribution

The design, manufacturing and test the Recovery Parachute System on the Aludra SR-10 UAV represent the research work which will give contribute as follows:

i. Deeper understanding of the Parachute Recovery System (PRS), and also the selection of suitable deployment system and mechanisms for Aludra SR-10 UAV.
ii. Provide a useful knowledge to identify, select and design the suitable type of parachute canopy to be used as parachute for recovery system.
iii. The static drop test procedure represent a suitable test for evaluating the rate of descent parachute and stress impact.
iv. The development of flight testing process gives a real performance of the capability and reliability of parachute recovery system.

1.6 Thesis organization

The overall structure of the study was divided into five chapters.. The first chapter described research background, problem statements, objective and scope of the study. Chapter 2 focused on laying out the theoretical background and previous work by the researchers from the earliest models to the latest models related to the parachute recovery systems. The information was collected from several resources and then was then was reviewed to obtain related data regarding the design requirement and consideration for the parachute recovery.

The third chapter explained the research methodology employed for this study. The methodological approach was performed in this study involved computational simulation and experimental approach. The simulation approach was conducted by Computational Fluid Dynamic (CFD), meanwhile the experimental approach involved a static drop test and an open environment flight test. This chapter described the design methodology approach in the early phase of the design process development, provided with the outline function, set of integrated ideas and concepts.

The fourth section presented the findings of the research, focusing on the three key themes that were (i) computational simulation, (ii) drop test and flight test, and (iii) addresses of each research question in turn. The results obtained from CFD aerodynamic simulation offered an important contribution to the selection of parachute canopy design. The selected parachute undergone a drop test to determine the feasibility and ability to support load during the landing before undertaking into the final testing. In the final test, the flight test assisted in determining mechanical feasibility of the parachute recovery for Aludra SR-10 UAV. Lastly, final chapter summarized the current findings in order to reflect on the extent to which this study was contributed to the parachute recovery study and provided basics idea for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

It is very important to obtain necessities on the subject matter knowledge as can contribute to a proper execution of the research. The concept and modelling technique for this system was also highlighted.

2.2 Recovery system for Unmanned Aerial Vehicle

Recovery are often described as the most difficult and critical phases in UAV operations. The primary function of the recovery system is to land the UAV on a runway, smooth field road, or carrier deck safely. Proper and suitable design of the recovery system for UAVs is highly desirable factor to prevent improper landing that may lead to accidents. There are various types of recovery system that available for the small-to-medium UAVs such as skid or belly recovery, wheeled landing, parachute recovery and vertical-net recovery. However, different technologies for recovering present together with positive and negative attributes [2], [4], [5], [13].

The simplest and less expensive option for the recovery system is skid and belly landing method, where the aircraft's fuselage contacts directly to the ground. This recovery method normally may damage the aircraft's structure due to a sudden impact force thus, increases the maintenance and repairing cost. Therefore, a strong belly structure along with shock absorbers is required to withstand the impact.

A conventional landing is also known as wheeled landing and has been used by many small-to-medium UAVs due to their gentle retrieval and smooth landing. This type of recovery system can protect the aircraft from damage during landing while the landing gear act as a shock absorbent. In addition, the landing gear can provide a more stable support for the aircraft on the ground compared to the skid or belly landing recovery. However, this type of recovery requires a large landing area and cannot be applied when there is no or less availability of adequate landing area.

The parachute recovery is commonly used by a small and air-launched unmanned aircraft as recovery system and also as an emergency flight termination system. Numerous parachute configuration have been designed to have a relatively low rate of descent in order to decrease the damage of aircraft upon the impact toward the ground or water. The landing position of the UAVs after parachute deployment is difficult to be determined due to difficulty of directional to control because it is subjected to the vagaries of the wind. Therefore, the parachute deploys at a very low altitude in order to reduce a drift distance.

Vertical-net recovery is the most commonly used approaches for "zero-length" recovery method. A net is gripped tightly around two balancing poles that are staked firmly onto the ground. This type of recovery system is most desirable because the forces are properly distributed to the entire aircraft, so that the UAV does not get damage. An important criterion of using this type of recovery system is the location of the propeller as it is directly contacted between propeller and net may damage.

Abinaya and Arravind [13] have compared various types of recovery system for the small-to-medium AVs in term of safety, cost, design complexity, operator skill and recovery failure rate. Table 2.1 expresses the rating between four types of recovery methods used by the SUAVs such as skid or belly recovery, wheeled landing, parachute recovery and vertical-net recovery. This rating comparison help is beneficial identify and select an effective recovery design for Aludra SR-10 UAV. Apparently, according to the rating comparison by considering the advantages and disadvantages of every system, the PRS can fulfill the requirement for a successful recovery method. This type of recovery method allows a soft landing even with it is handled by an untrained operator

Table 2.1: Rating of different types of recovery system

Classification	**Skid or belly landing**	**Wheeled landing**	**Parachute recovery**	**Vertical-net recovery**
Cost	Low	High	Medium	High
Safety	Medium	High	Medium	Average
Operator skill requirement	Low	Average	Average	Medium
Design complexity	Low	High	Medium	Medium
Recovery failure rate	Medium	Low	Medium	High

2.3 Characteristic of parachute

Modern designs of parachutes are classified into two categories that are ascending and descending canopies. An ascending canopy is specifically built to ascend and stay aloft as long as possible such as paraglide. In contrast, the descending canopy provides a reduced/ low amount of dragging force. This condition is mainly to slow and maintain a balance of dropping object or person so that the item would remain safe until it reaches the ground [14].

The physics behind deployment parachute is involving the interaction between gravity and air resistance includes several factors such as weight and shape of the parachute. As the aircraft's power supply was cut off, no thrust is produced thus leads to zero thrust acting on the aircraft. An explosive charge is widely used to deploy the parachute in order to slow down the descent rate of the aircraft. Figure 2.1 shows the forces act on the parachute during the recovery system. Since a weight still act on the aircraft, the aircraft immediately falls back to the earth by its weight. Air resistance increases due to a large surface area that is produced by canopy when it is opened. As the aircraft descends, the drag and the weight in opposing forces are produced. The weight (W) is always directed towards the centre of the earth while the drag force (D) is opposed to the motion direction. A stable parachute is descent in equilibrium acceleration between the total drag of the parachute and the aircraft (D_T) and the weight of the load and the parachute assembly (W_T).

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