Design and Analysis of Recovery Net Landing for UAV ALUDRA MR-01

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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DESIGN & ANALYSIS OF RECOVERY NET LANDING SYSTEM FOR ALUDRA MR-01

ABSTRACT

This report discusses the final analysis and finite element analysis (FEA) of chosen topic, which is **Design and Analysis of Recovery Net Landing for UAV ALUDRA MR-01**. The objective of this research is to design analysis recovery net landing system for ALUDRA MR-01 with maximum take–off weight 40kg which capability to landing with safely. The aim of this study is to analysis and simulates; recovery net landing system for ALUDRA MR-01, determine the critical location on net during aircraft landing impact, define the minimum diameter of net can sustain from impact energy UAV and to determine the recovery net landing can sustain the ALUDRA MR-01 MTOW 40kg with safely. This report is divided into a few main sections for clarify and easier reference. There are Introduction, Literature Review, Methodology, Conceptual Design, Detail Design and Conclusion and Recommendation. The introduction part will helps the reader to have a general view on what are Recovery System and the reasons recovery net landing had been selected by ALUDRA MR-01. The body of this report will further explain all the literature review and research that being done before regarding the same field of interest. These chapter discusses about two parameters; maximum take – off weight of the aircraft and recovery system that is used in UAV industry. The methodology part will explain on how the sequence will take place in order to complete this project within one year duration. Result and discussions shall discuss on the FEA modelling based on different of position the load are applied on recovery net. The results will give the different value of maximum stress by different nodes. In the end this project will be able to define the minimum diameter of net can sustain from impact energy UAV. The ALUDRA MR-01 with maximum take–off weight 40kg had capability to landing Fulmar recovery net landing system which design for MTOW 20kg with safely.

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LIST OF ABBREVIATIONS

<u>Notation</u>

ANSYS Parametric Design Language (APDL)

Computer aided engineering (CAE)

Commercial off-the-shelf (COTS)

Degree of Freedom (DOF)

Document Control Department (DC)

Finite Element Analysis (FEA)

Ground control station (GCS)

Maximum take-off weight (MTOW)

Unmanned System Technology (UST)

Unmanned aerial vehicle (UAV)

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

1.1.1 Recovery System for ALUDRA MR-01 UAV

Unmanned System Technology (UST) has grown humbly since its establishment in 2007 under the directive of Dato' Sri Najib Tun Razak. His mission is to locally produce unmanned aerial vehicle for homeland, military, surveillance of borders and commercial applications. Pioneering in UAV (unmanned aerial vehicle), UST has produced a few aircraft for high range distance as well as for small-range distance.

Currently UST is in progress of developing an aircraft that will be used for medium-range distance which is named, ALUDRA MR-01. Its complete production is estimated to be at the end of year 2015. MR in its name is the abbreviation for medium range. MR-01 is referred as the first UAV aircraft of medium-range category to be produced by UST. ALUDRA MR-01 is expected to have a maximum range of 100 km and MTOW (maximum take-off weight) of 40kg. There had any range of MTOW in industry less than of 90kg (40kg – 90kg) such as Aerolight UAV which MTOW is 40kg, S4 Ehecatl MTOW 54kg and Bora UAV MTOW 85kg [1, 2, 3].

The recovery system method of an unmanned aircraft is by the function of an external operator on the ground. The function of recovery to stop the motion of UAV by absorbing the landing force energy during a landing time. This ALUDRA MR-01 uses launcher in take-off. Whereas, recovery net landing is selected to be the mechanism of recovery for this aircraft. Recovery net is runway independent, thus it is suitable to be used in small total land area as Malaysia. As stated by (Wikipedia, 2012), Malaysia currently covers 329 847 km land area, which 67% of its total is actually consists of rivers, mountains and lumpy lands [4]. Different landforms may affect the searching of runway for landing of aircraft. Furthermore, some existing runway may not full fill the requirement of safe landing due to bumpy and damaged land surface. To avoid damages and ruins to the aircraft during conventional landing, landing net is a better mechanism to be used for ALUDRA MR-01. The existing recovery net previously was utilized for aircraft Fulmar UAV. Suitable with its short-range capability, the recovery net was designed to be compatible with it that possess MTOW of 20 kg. Hence, modifications are required to increase its capability in used for ALUDRA MR-01.

1.1.2 Finite Element Analysis (FEA)

In mechanical design some form of strength analysis is usually required as part of the design process. Traditionally this has been done by simple engineering calculations, but as product performance becomes more important and as design become more complex so these simple methods have become inadequate. According to Mottram, Shaw defined with the increase in computational capacity and the availability of software that can predict loading for complex geometries and material behaviour so there has been an explosion in the use of finite element method (Mottram J.T., 1996) Generally there are two types of analysis that currently used in industry: 2-D modeling and 3-D modeling. 2-D modeling preserves simplicity and the analysis can be run on a relatively normal computer, the result tends to yield less accurate. However 3-D modeling advantage is it can produces more accurate results. For this project model, author chooses to use 3-D modeling for purpose to gain the accurate results. In simulation had been determine to selected analysis type as static (steasy-state) for purpose of simplicity [5].

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

The existing recovery net in UST was previously used for aircraft Fulmar. Suitable with its short-range capability, the recovery net was designed to be compatible with it that possess MTOW of 20 kg. Therefore had been done simple calculation to conduct progress analysis but it is uncompleted. Hence, modelling and design simulation required to be done as the current specification to achieve the safety level required for ALUDRA MR-01 that has expected MTOW of 40 kg.

1.2.2 Significant of the Project

This research will focus on the net of the recovery system. The analysis will be carried out by using ANSYS APDL software. The expected detailed that will be collected by the end of the project are the critical location on net of aircraft landing, maximum value of stress and the minimum diameter of net success to sustain the impact energy UAV . The data collections from this research are able to provide reference for the researcher in the future in order to achieve their respective objective. The methodology and timeline of the project also was arranged in proper documentation thus provide the future researcher better view to plan their research.

1.3 OBJECTIVE OF STUDY

The main objective of this project is to determine the recovery net landing can sustain the ALUDRA MR-01 MTOW 40kg with safely; maximum take –off weight 40 kg. In order to expedite and save the cost a study on current landing net that have been used for fulmar UAS. Therefore, some data need to be carried out with current landing net to meet the objective which is come out from analytical analysis and simulation.

- Design analysis recovery net landing system for ALUDRA MR-01
- Determine the critical location on net during aircraft landing impact

- Define the minimum diameter of net can sustain from impact energy UAV
- Determine the recovery net landing can sustain the ALUDRA MR-01 MTOW 40kg with safely.

1.4 SCOPE OF STUDY

These are the scope of study that needs to be done in order to achieve our objective;

- Study on design current recovery landing net (Fulmar UAS).
- Determine the impact kinetic energy by the recovery system.
- Modelling of static simulation in ANSYS APDL.

Figure 1: Fulmar failed to land with safely

1.5 RELEVANCE OF THE PROJECT

The scope of the project is covering to determine the recovery net landing can sustain the ALUDRA MR-01 MTOW 40kg with safely. Most of the methods use in the project is related to the ANSYS programming task. The programming work done can be easily detected if any error or mistakes happen in the program command. The critical locations on net during aircraft landing impact are able to be calculated by using the developed model only by performing few data of experiments. The data generated and analyse by the software are accurate and consistent. The result that be generated is consistent and reliable and still in acceptable error ranges [5].

1.6 FEASIBILITY OF THE PROJECT WITHIN TIMEFRAME AND SCOPE

The expected achievements for this project for the FYP 1 period are:

- Data gathering and review of topic related.
- Study on design current recovery landing net (Fulmar UAS).

For FYP2 time period, the programming model been expected to be fully develop. The aspect of data will be focusing on the following details:

- Critical location on net during aircraft landing impact
- Minimum diameter of net can sustain from impact energy UAV

The project planning is feasible with the time frame have been given and the scope of the project also stay within the range of achievable.

CHAPTER 2

LITERATURE REVIEW

2.1 RECOVERY SYSTEM

The air vehicle which is not fitted with landing gear required recovery system in replaced of conventional landing. The main function of recovery system is to decelerate and catch UAV safely by absorbing landing force energy. By applying increasing impulsive force, the recovery net will slow down the UAV during landing time. Other than recovery landing net, other recent technology of recovery system in UAV industry includes skyhook, arresting line, and parachute [6]. Every UAV will use any recovery system that is suitable in their operation, space compartment in UAV frame, as well as geography during flight test.

2.2 MAXIMUM TAKE-OFF WEIGHT (MTOW) AND RECOVERY MECHANISM OF UAVS

This chapter discusses about two parameters had been selected existing UAV. The parameters are maximum take – off weight of the aircraft and recovery system that is used in their landing situation. Special requirement, geographic limitation, cruising speed and any other factors may affect the selection of mechanism recovery; however maximum take-off weight is likely to be a parameter that is suitable in comparing this parameter among the UAV

2.2.1 Landing Net & MTOW: 19.5kg

Figure 2: KillerBee KB-2 landing net

The Bat formerly known as the KillerBee. It was designed and developed jointly by Northrop Grumman and Swift Engineering [7]. The Bat primary mission is commercial applications such as traffic monitoring, agriculture, pipelines and power lines. The long-endurance KillerBee performance the maximum speed is 201km/h. Its service ceiling is 4,600m. The maximum endurance of the UAV is 15 hours, while its maximum take-off weight is 19.5kg. Its huge capacity provides space for commercial off-the-shelf (COTS) payloads and systems. The UAV captures real-time intelligence data (audio and video) across large distances and transmits it to the ground control station (GCS) through a satellite communication data link. The KillerBee is designed to be launched from an AAI Shadow unmanned aerial system (UAS) launcher which does not require a runway and can be retrieved through nets. During operation its ensures that the UAV was directed into the centre of the net rather than striking the supports or missing the net altogether and striking the ground. Secondly is to abrupt deceleration, even if the UAV did contact the net centre which severely damaged the UAV. The net hooks in the nose allow the aircraft to land in a conventional retrieval net.

Figure 3: Before UAV landing

Figure 4: During UAV landing

2.2.2 Skyhook & MTOW: 22kg

Figure 5: ScanEagle

ScanEagle is a short range unmanned air vehicle developed by Insitu company [8]. ScanEagle missions an intelligence, surveillance and reconnaissance *(ISR*) and civil applications include escorting operations such as sea-lane and convoy protection. One of the example product from ScanEagle is *X-200 ScanEagle HFE-Carb*, an unmanned reconnaissance aircraft. The maximum weight of this UAV is 22 kg while its empty weight is 13.5 kg. It can collect video images almost inaudibly at various altitudes. The air vehicle can operate at speeds between 80km/h and 126km/h and the cruise speed is 90km/h in level flight. The vehicle achieves a maximum rate of climb of 150m/min to a maximum altitude of 4,880m or 16,000ft.ScanEagle has a range of 1,500 km and endurance of more than 28 hours. The system consists of a ground control station (GCS), 6 aircraft, a launcher and a retrieval system. The aircraft (UAV) is controlled from the ground station. The recovery system for ScanEagle is based on the proven SkyHook recovery system developed by Insitu, originally for the SeaScanUAV. ScanEagle is not fitted with landing gear to take-off on land or naval vessels as the air vehicle is catapult launched from a pneumatically operated wedge launcher with a launch velocity of 25m/s. The SkyHook retrieval system uses an arresting or snagging line suspended from a 15.2m boom. The air vehicle is flown directly to approach the snagging line and a hook installed in the air vehicle's wingtip is caught on the line.

2.2.3 Runway or catapult launcher & MTOW: 40kg

Figure 6: Aerolight

Aerolight is a close range unmanned aerial vehicle (UAV) designed and manufactured by Israel-based Aeronautics Defence Systems for the Israel Air Force and the US Navy. The performance Aerolight can fly at a maximum speed of 185km/h. The cruise speed is 92km/h. The range is 150km. The UAV can loiter in air for a maximum of four hours [1]. The UAV can perform training, intelligence, surveillance, target acquisition, gunfire adjustments and reconnaissance missions. It can acquire real time data and transmit it to the ground control station (GCS) through a satellite communication data link. Designed to suit both military and civil operations, the Aerolight can take-off from a runway or catapult launcher and be recovered through a parafoil recovery system. The UAV can execute wide range of missions including border and coastal patrol, battle damage assessment and situational awareness. The Aerolight can be quickly assembled or dismantled and is easily converted for different mission types. It can operate both day and night even in difficult weather conditions. Being a medium-size UAV, it can be easily carried on ground vehicles, helicopters and maritime vessels.

2.2.4 Runway & MTOW: 54kg

Figure 7: S4 Ehécatl

The S4 Ehécatl is an unmanned aerial vehicle developed and manufactured by Hydra Technologies of Mexico which except for its infrared thermal sensor system, is the first of its type to be completely designed and manufactured in Mexico [2]. The aims to provide safety for human lives in hazardous zones. The S4 Ehécatl is an aerial unmanned surveillance system whose development began in 2002. Its principal market is directed towards providing security and surveillance capabilities in support of the Armed Forces, as well as civilian protection in hazardous situations. Because of its small size and unmanned nature, it can enter dangerous zones without being detected. The system was designed for military and civilian use, including the Mexican Armed Forces. It has a maximum velocity of 90 knots, with a maximum operating ceiling of 4,572 meters (15,000 ft) in height. It can take-off from higher altitudes than 2,438 meters (7,999 ft). It provides mode techniques for any type of weather or terrain. All data is integrated by General Dynamics Advanced Information Systems. The S4 model has a wingspan of 3.7 meters (12 ft), and MTOW of 54.43 kilograms (120 lb), including a payload of 9.07 kilograms (20 lb). It has a flight autonomy of 8 hours at the cruising speed of 38 knots.

2.2.5 Runway or parachute & MTOW: 85kg

Figure 8: Bora UAV

BORA Unmanned Aerial Vehicle System is developed and tested by VESTEL in 2010 as a training aircraft. BORA can be easily assembled and disassembled on the field, it gives the feature of easy handling and use. This feature makes Bora a perfect candidate for flight testing of developed products in the field of aviation [3].

BORA System has a better performance than its competitors in his class by providing high-altitude, long endurance and redundant avionics and it has flexible avionics and payload configuration. BORA System and all sub-units are designed by VESTEL. BORA autopilot have been developed as part of the VESTEL autopilot family and it can use all communication channels and has the ability to communicate with avionics software libraries to be tested. The UAV will be take off by runway fully autonomous or launcher fully autonomous. While the recovery system runway autonomous parachute autonomous and controllable. It can take-off from higher altitudes than 18 ft. The BORA model has a wingspan of 4.6 meters, and MTOW of 85 kilograms, including a payload 3 kg with Parachute and10 kg without Parachute. It has a flight autonomy of 5 hours at the cruising speed of 95 km/hour.

2.2.6 Arresting gear & MTOW: 148kg

Figure 9: AAI RQ-7 Shadow

The RQ-7 Shadow unmanned aerial vehicle (UAV) is used by the United States Army and Swedish Army for reconnaissance, surveillance, target acquisition and battle damage assessment [9]. Take offs are assisted by a trailer-mounted pneumatic launcher which can accelerate the 375 pound aircraft to 70 knots (130 km/h) in 50 feet (15 m) recovered with the portable arresting gear similar to jets on an aircraft carrier. The empty weight of RQ-7 Shadow is 84 kg and the gross weight is 170 kg. The RQ-7A is3.40 m long and has a wingspan of 3.89 m with a 327 lbs (148 kg) max take-off weight. The aircraft's endurance ranged between 4 to 5.5 hours depending on mission. Recovery arresting gear using a tail hook mounted on the aircraft catches an arresting wire connected to two disk brake drums which can stop the aircraft in less than 170 feet (52 m) [10]. The force of the forward motion of the landing aircraft is transferred to a purchase cable which is routed via sheaves to the arresting engine, located in a machinery room below the flight deck or on either side of the runway. The arresting engine brings about a smooth, controlled stop of the landing aircraft. At the completion of the arrestment, the aircraft arresting hook is disengaged from the deck pendant, which is then retracted to its normal position.

2.3 FINITE ELEMENT ANALYSIS (FEA)

2.3.1 Application of FEA

ANSYS is a finite element method analysis code which is very popular in the engineering field because of its functionality. ANSYS software allows engineer to construct computer models of structure, machine components or systems; apply operating loads and other design criteria; and study physical responses, such as stress levels, temperature distributions, pressure, etc. [5]. It permits an evaluation of a design without having to create and distinguish multiple prototypes in testing. The ANSYS program can create do the modelling and simulation works for any items in our everyday life such as computer, stand-fan, cupboard, the simulation of machining process and others. The basic idea behind the finite element method is to construct a structure from a finite number of elements, as will demonstrated, these elements will be one, two or three dimensional. These nodes define the elements that discretize the continuum; forces are transmitted by these nodes from one element to the next. The forces acting at the nodes are uniquely defined by the displacements of these nodes, the distributed loading acting on the element, and its initial strain. To find the stresses, strains and displacements within the interior of the element, simple displacement functions (the assumed simple displacement distribution) with nodal displacements as the primary unknowns are used to provide a means of interpolation.

$$\{F^e\} = [k]\{\delta^e\} \tag{1}$$

In which $\{F^e\}$ is the nodal force vector and $\{\delta^e\}$ is the nodal displacement vector containing the element degrees of freedom. The symmetric, positive definite, matrix $[k]$ is the element stiffness matrix. According to Natalie Doyle (Doyle, 2010) [11], the net recovery system could be represented by a three dimensional version of modelling, which could be simulated in various computer software such as Matlab and Ansys. The finite-element techniques steps are finite elements modelling, types and properties for model different parts, the definition of material properties, parameter definition, loading, boundary and initial value definition, common interfaces definition, and control parameter definition. ANSYS Mechanical ANSYS Parametric Design Language (APDL) is to recreate mathematically the behaviour of an actual recovery net landing system. This model comprises all the nodes, elements, material properties: Nylon, real constants, boundary conditions to represent the physical system. Defined the model as 3-D solid analysis models for thick structures in 3-D space. That has neither a constant cross section nor an axis of symmetry [5].

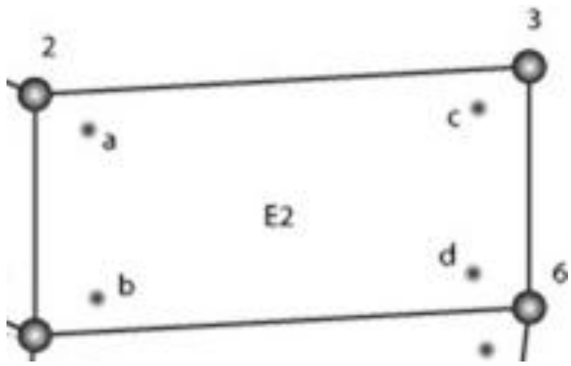


Figure 10: Example of Element 1 (Node: a, b, c, d)

Nodes a, b, c, d had defined as with coordinate systems each used for a different purpose. The types of coordinate system are global and local coordinate systems, display coordinate system, nodal coordinate system, element coordinate system, and the results coordinate system. This project will apply the element coordinate system to determine the direction of orthotropic material properties, applied pressures and results (stress and strains) for that element. All element coordinate systems are right-handed orthogonal systems. For 3-D solid elements, the element coordinate system is usually parallel to the global Cartesian system. Finite Element Analysis (FEA) mesh is solved the program calculates the Degree of Freedom (DOF) results at each integration point in each element. For most meshes that is at the corner of each element. DOF is functions to calculate the derived values and usually stress and strain for each node.

2.3.2 Project Parameters and Assumptions

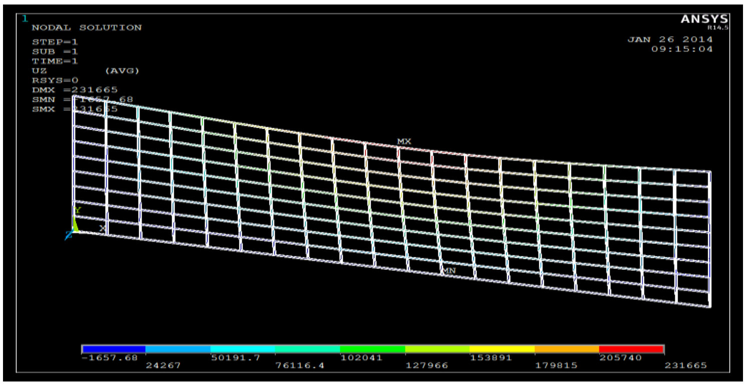


Figure 11: Impact Energy Distribute on the Net

The boundary conditions to simulate the conditions during the landing time where aircraft UAV trap on the landing net all the mass from impact will be transfer to the surface of net. The boundary conditions used for this continuing model are being shown as follows:

Table 1: Parameters and value for initial and boundary condition

Parameters	Value
U, ROT on Nodes (x,y,z fix position)	0
Impact Load	1510.37 J
Diameter, ϕ (centroid)	0.004m

The element type of this project is BEAM188 where is suitable for analysing slender to moderately stubby/thick beam structures. The element is based on Timoshenko beam theory which includes shear-deformation effects [5]. The element provides options for unrestrained warping and restrained warping of cross-sections. The element is a linear, quadratic, or cubic two-node beam element in 3-D. BEAM188 has six or seven degrees of freedom at each node. These include translations in the x, y, and z directions and rotations about the x, y, and z directions. A seventh degree of freedom (warping magnitude) is optional. This element is well-suited for linear, large rotation, and large strain nonlinear applications. The element includes stress stiffness terms, by default, in any analysis with large deflection. The provided stress-stiffness terms enable the elements to analyse flexural, lateral, and torsional stability. Elasticity, plasticity, creep and other nonlinear material models are supported.

2.4 RECTILINEAR KINEMATICS

The kinematics motion of a particle is characterized by specifying at of the particle's position, velocity, and acceleration. There are three kinematics equation in constant acceleration which can be integrated to obtain formulas that relate acceleration *(a_c),* *velocity (v), distance (s),* and time (*t*). The kinematics equations are:-

$$a_c = dv/dt,$$
$$v = ds/dt,$$
$$a_c ds = v\,dv. \qquad (2)$$

Constant acceleration have divide by three scope which are velocity as a function of time, position as a function of time, and velocity as a function of position. Firstly, equation velocity as a function of time is $v = v_0 + a_c t$. This equation have been derive by integrate $\int_{v_0}^{v} dv = \int_0^t a_c\, dt$ where assuming that initially $v = v_o$ when $t = 0$. Next, equation position as a function of time is $s_0 + v_0 t + \frac{1}{2} a_c t^2$. This equation have been derive by integrate $\int_{s_0}^{s} ds = \int_0^t (v_0 + a_c t)\, dt$ with assuming that initially $s = s_o$ when $t = 0$. There are few steps to derive the velocity as a function of position. Either solves for *t* in equation $v = v_0 + a_c t$ and substitute into $s_0 + v_0 t + \frac{1}{2} a_c t^2$. On other way, assuming that initially $v = v_o$ at $s = s_o$ and integrate $= a_c\, ds$. Therefore, the new equation is $v^2 = {v_0}^2 + 2a_c\,(s - s_0)$. Acceleration of particle after the time interval; **a** is constant acceleration or in the case of bodies moving under the influence of standard gravity **g** is used [12].

2.5 NEWTONS SECOND LAW

There is another theoretical method of calculating acceleration due to gravity. Theoretically, bodies allowed to fall freely were found to fall at the same rate irrespective of their masses. The velocity of a freely falling body increased at a steady rate such as when the body had acceleration. This acceleration due to gravity can determine by use the principe of Newton's Second Law of Motion [13]. Newtons Second Law of motion states that acceleration is proportional to the ratio of force to mass;

m = mass of object
g = acceleration due to

.

$$F = ma \quad = \quad a = \frac{F}{m}$$

Figure 12: Newtons Second Law Equation

CHAPTER 3

RESEARCH METHODOLOGY

3.1 PROJECT ACTIVITIES

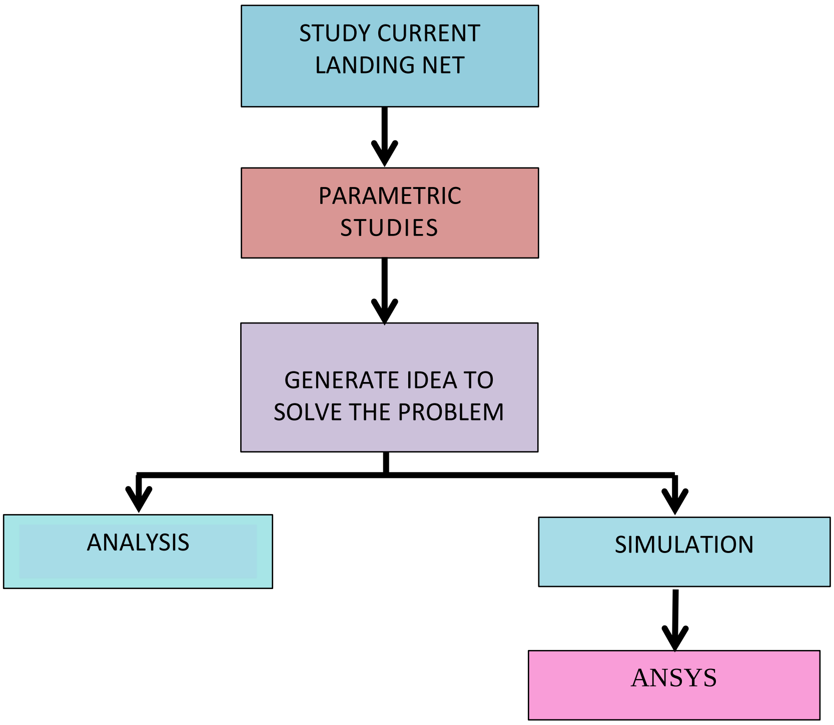


Figure 13: Project progress of Design Recovery Net for ALUDRA MR-01

To meet understanding of current landing net I have learn the equipment's/tools of fulmar landing net. Besides that, learn how to setup landing net from manual operation book and also get guide and explanation from staff UST. In parametric study, I have learned the mechanism concept of current recovery landing net in order to understand the problem of Fulmar UAV.

3.2 REVIEW OF PREVIOUS

- Documentation Review

To study the current landing net which design for fulmar UAS, I got some info from Document Control Department (DC) and found the book untitled *Fulmar System* and *Recovery net for fulmar landing system preliminary conceptual design and analysis that* provided me with the following documents;

From that document, I got step-by-step procedure of processes to setup landing net that is commonly performed in the operation section of UST. I also learnt about tools of landing net and type of rope been used.

- Person-to-person

From informal conversation with staff from UST, i gain information on the details of the project I am undertaking. Persons involved have past experiences in the flight test Fulmar operation tasks in UST. I also got the chance to discuss with technicians who are already familiar with the project flow.

They are reported few problems that arise during the landing Fulmar UAV (MTOW 20kg). If the recovery net was set up too tight between both poles, Fulmar UAV will rebound after impact with the net and fall on the ground. Therefore, to solve this problem have need to meet the solution of recovery Fulmar landing net for ALUDRA MR-01.

3.3 KEY MILESTONES

The milestones showed as synchronization point which is major milestones mark the transition of a project from one phase to another until the last week.

Week / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project Work Continues						Mid - Sem Break									
Submission of Progress Report															
Project Work Continues															
Pre-SEDEX															
Submission of Draft Report															
Submission of Dissertation (soft bound)															
Submission of Technical Paper															
Oral Presentation															
Submission of Project Dissertation (Hard Bound)															

Figure 14: Milestone Project Design and Development Recovery Net landing System for ALUDRA MR-01 (WEEK 1 –WEEK 14)

3.4 GANTT CHART

For assign this project I prefer to use timeline with Microsoft Office Project. The duration of my timeline is 20 May 2013 until 13 December 2013 followed by Final Year Project (FYP1 & FYP2) duration. Prepare timeline that may provide concise details on project conduction as we can define the duration of each task and sub tasks, the date each task starts and ends.

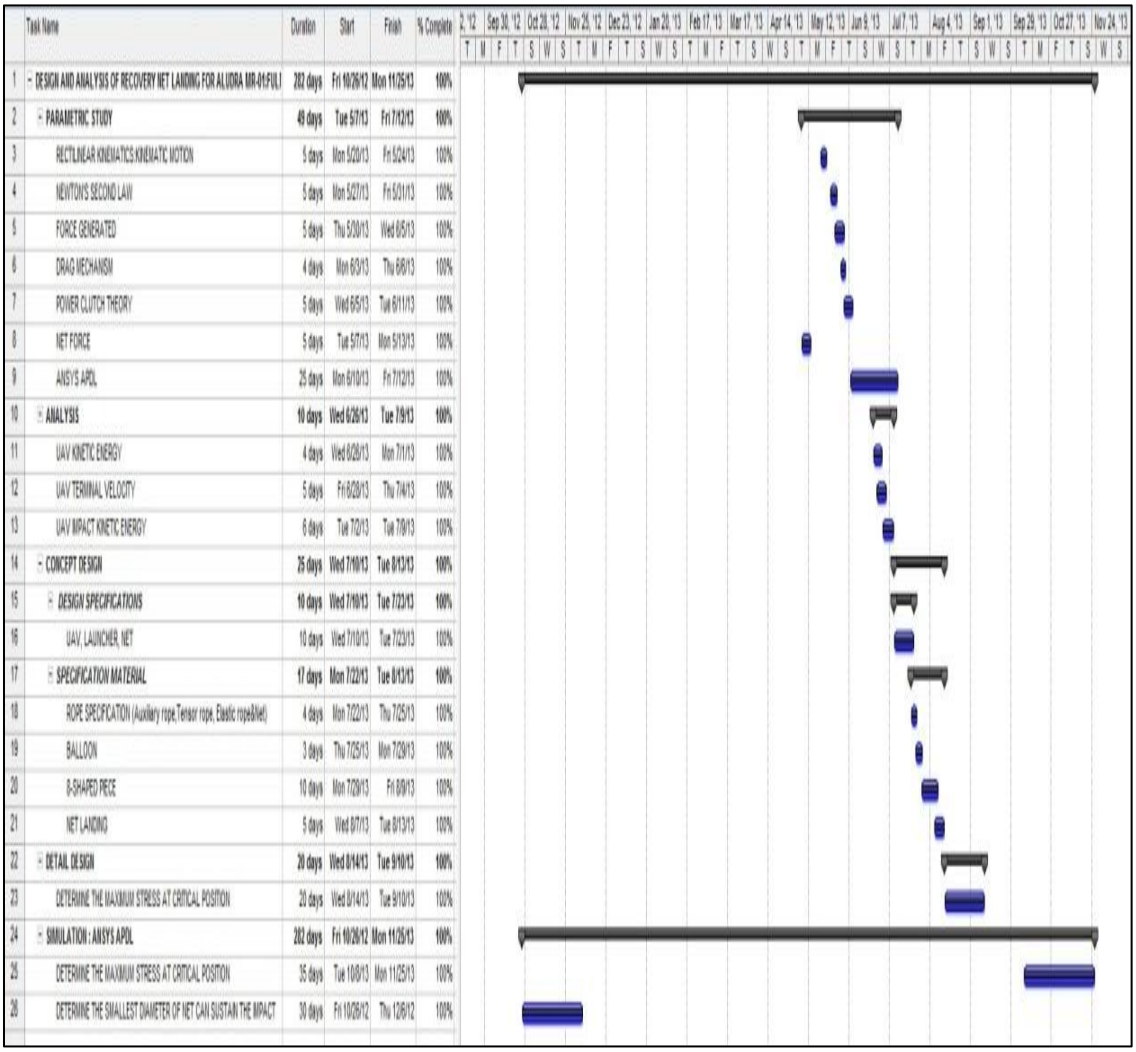


Figure 15: Timeline Project Design and Development Recovery Net landing System for ALUDRA MR-01 (20 May 2013 until 13 December 2013)

3.5 LANDING ACCELERATION

Previous chapter in literature review, the author have discussed the theory of *Rectilinear kinematics* (kinematic motion) and had derived equations from the fundamental equations of motion [12]. This principle use to explain the kinematic motion of UAV initial from take-off until landing. Thus, Figure 16 shown the kinematic motion of UAV and there are 3 differences situation of UAV during flight test. The UAV uses launcher in take-off as what we can see at part I. While, between take off at part I to part II the UAV will jumped on the air as high as it could. After take-off, UAV in a steady flight mode at part III which mean UAV in Autopilot system. Part IV is the position before aircraft landing on net and lastly at part V the aircraft will landing on the net and end the flight forcedly.

$$a = \frac{v-u}{t} \ (6) \quad v = u + at \ (7) \quad s = ut + \frac{1}{2}at^2 \ (8) \quad v^2 = u^2\, 2as \qquad (3)$$

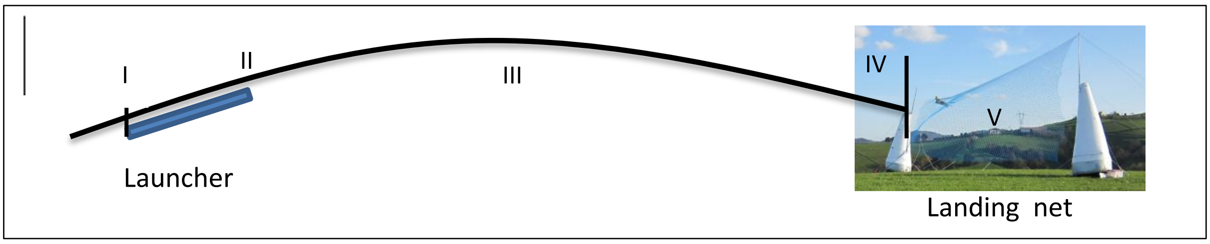


Figure 16: Kinematic motion of UAV

The department have decided the UAV landing speed on the net to 60 knots (30.87 m/s).

3.6 ENERGY ABSORBED BY THE RECOVERY SYSTEM

When landing net hit by UAV, all the force will be transferred around the point UAV landing and stopped by the recovery net. Additionally the impact velocity of the UAV and the take-off weight were used to calculate the energy that must be absorbed by the recovery system.

By use data collection of maximum take-off weight and UAV landing speed we can determine the force generated by UAV landing.

Based on Kinetic Energy stored in the UAV;

$$E_k = \frac{1}{2} m \times {V_i}^2 \tag{4}$$

In this case, where E_k is the Kinetic Energy stored in the UAV [J], m is the take-off weight of the UAV [kg] and V_i is the impact velocity of the UAV [m/s]. Based on engineering specifications of the ALUDRA MR-01, the positive g_{limit} occurs at 5g [11].

$$V_i = UAV\ landing\ speed\ \times g_{limit} \tag{5}$$

$$V_i = 30.9 m/s \times 5g$$

$$V_i = 1515.65 m/s$$

3.6.1 UAV Impact Kinetic Energy

Table 2: Parameters and value for UAV condition

Properties	Value
UAV mass,m	40kg
UAV speed,V	1515.65m/s
Frontial area,A_f	0.2827m^2
UAV aerodynamic drag Coefficient,Cd	0.027
Height above ground,h	13m
Gravitational,g	9.81
Density of air, ρ	1.22kg/m^3

Determine UAV terminal velocity:

$$w = \frac{2mg}{ACd} \tag{6}$$

$$w = \frac{2(40)(9.81)}{(1.22)(0.2827)(0.027)}$$

$$w = 290.31 m/s$$

Determine UAV impact kinetic energy [14]: The height above ground will justify as 7m for ensure require the maximum impact of UAV

$$u\,(h) = \sqrt{\omega^2 - (\omega^2 - v^2)\exp(-\rho ACdm^{-1}h)} \tag{7}$$

$$u\,(h) = \sqrt{228122.7}$$

$$u\,(h) = 1510.37\,J$$

CHAPTER 4

CONCEPTUAL DESIGN

To achieve the objectives of this project a conceptual design method based on interviews and surveys have been conducted among the staffs in UST. With their adequate experiences, knowledge and skills, the author have collect the data which will support the finding. The conceptual design phase is where the basic questions of configuration arrangement, sizing and weight, and performance are answered. These data would also serve as baseline assumptions throughout the design and optimization process of the current recovery net system. The following table 3 is the finding and data gathering for current Fulmar recovery landing net;

Table 3: Design specifications and value of component used

NO	EQUIPMENT	PROPERTIES	DESCRIPTION	VALUE
1.	ALUDRA MR-01	Aircraft	Span	4.00m
			Length	2.50m
			Height	0.60m
		Design Weight (operation)	Maximum Take-Off Weight (MTOW)	40.00kg
			Maximum Landing Weight (MLW)	40.00kg
			Take-Off speed (60 knots)	30.90m/s
			Landing speed(60 knots)	30.90m/s
2.	Launcher	L (m)	Length of launcher	6.00m
		h_s (m)	Height of stand	0.54m
		h_i (m)	Initial height	1.17m
		d_{is} (m)	Distance between starting to stand	3.45m
		Θ (^{o})	Angle of launcher	10.35m

3.	Net	L	Length	13.50m
		W	Width	6.25m
		m	Total mass of net	17kg
		Material	Nylon	-

4.1 TOOLS DESIGN SPECIFICATION

4.1.1 Specification of Rope

There are many type of materials for ropes which are from natural fibres and artificial fibres. Natural fibres made from sisal, manila, hemp, and cotton. This natural fibres is not generally used on rescue vessels. While, artificial fibres had made from polypropylene, nylon, polythene, polyester and certain proprietary materials [15].

❖ Auxiliary rope

- Material: Nylon Fibre
- Diameter: 7mm
- Sub operation: Safety net, holding-down, pulling loads
- Strength: High tensile strength and used for dragging and lifting, braiding, high tenacity, abrasive resistance and low shrinkage
- Placed in fulmar landing net as function for adjust and tying 8 shaped piece and fixing the net on the ground. By pull the auxiliary rope the force will be change the position of 8 shaped piece were also change the position of balloon and landing net [16].
- Design specification;

Table 4: Auxiliary Design Specifications

Diameter, mm	Weight 1 m, g, at most	Breaking load, kgf, at least	Elongation at 80 kg, %, at most
5.0	20	650	5
6.0	25	750	5
7.0	40	950	5
8.0	45	1050	5

❖ Tensor rope

- Material: Artificial fibre
- Diameter: 5mm

- This rope will hold the mass landing net by fixing ends rope on the ground [16].

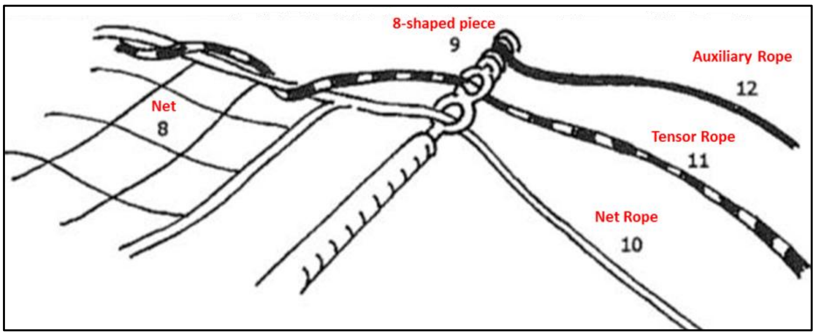
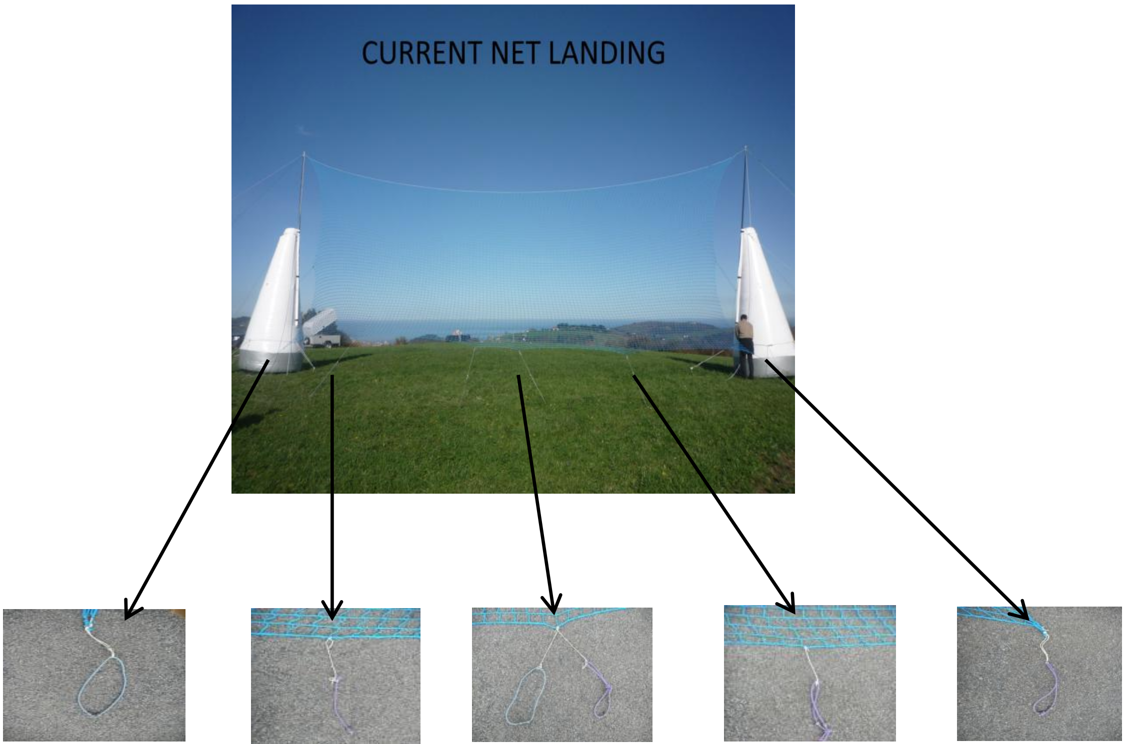


Figure 17: Auxiliary, Tensor rope and Net

❖ <u>Elastic tensors</u>

- Also known as Bungee cord
- Material: Rubber
- Diameter: 9mm
- Incapable to being stretched where the bottom of the net has to be bended toward the direction where the UAV comes from.



F

igure 18: Elastic rope that fixed on ground

❖ Net rope

- Material: Nylon
- Diameter: 4mm
- The rope is directly from the net and it function for adjust the position of landing net only.

Figure 19: 8- Shaped Piece tools

4.1.2 Specification of 8-Shaped Piece

- Material : High steel
- At landing net the 8 shaped piece were functions for hold the 3 type of rope which are auxiliary rope, tensor rope and net rope [16].

Figure 20: Balloon

4.1.3 Specification of Balloon

- Material : Rubber and latex
- As landing net support mechanism during UAV landing.

4.2 MODELLING OF CURRENT RECOVERY LANDING NET

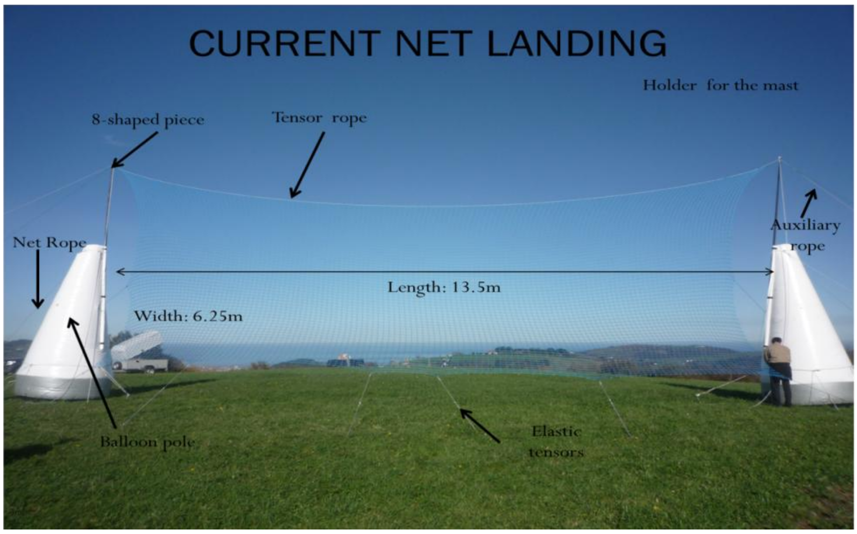


Figure 21: Current Net landing

Current Fulmar landing net are attached with net rope, tensor rope and auxiliary rope which both side are located at the top side inside the 8-shaped piece [16]. To install the balloons attach in the ropes provisionally to the ground, deflate one of the balloons then insert the 8-shaped piece in the tip off the mast. The bottom of the net attach with elastic tensors which has to be bended toward the direction where the UAV comes from and fix the ends to the ground. The current design have no mechanism been use accept the 8-shaped piece and stability on the balloon used.

During the landing time where aircraft UAV trap on the landing net all the mass from impact will be transfer to the surface of net but this concept of current landing net unsustain absorb the force energy from UAV. This landing net had been used for Fulmar UAV which MTOW is 20kg. To meet the objective which is to design recovery landing net system for ALUDRA MR-01 with maximum take–off weight 40 kg, some modification of net recovery system need to carried out to ensure ALUDRA MR-01landing with safety level as required for an aircraft.

4.3 FORCE GENERATED OF CURRENT FULMAR LANDING NET

Assume the aircraft land at centre of the net. The kinetic energy had spread at all rope. Every rope had equal energy. This flow impact force had flow at every point A, B, C, D, E, F and G. Actions had been taken to clarify the value of Fulmar force generated as the landing time. The reason is to upgrade the landing net design for Fulmar UAV to give better range against absorbance impact of UAV. In this calculation to get landing acceleration we assume that the Fulmar take-off speed is similar 60 knots (30.90 m/s) with ALUDRA MR-01. The lengths of launcher still constant it is because the same launcher has been used.

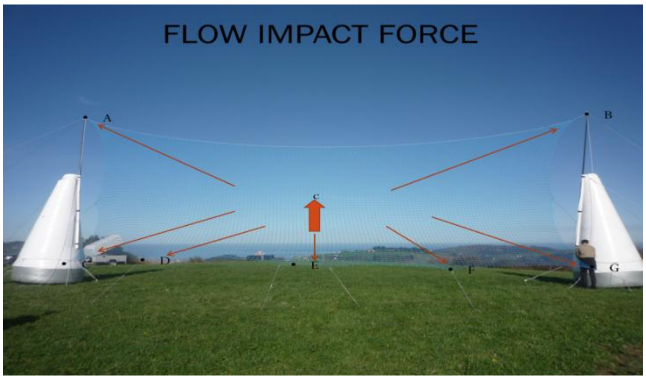


Figure 22: Multi impact force distribution

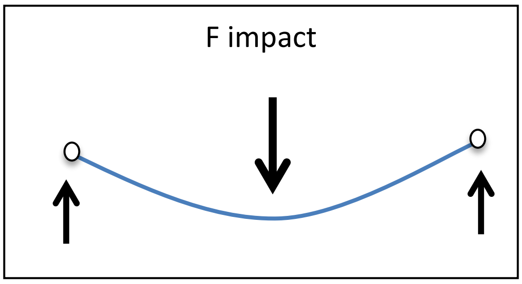


Figure 23: Top view of landing net during impact

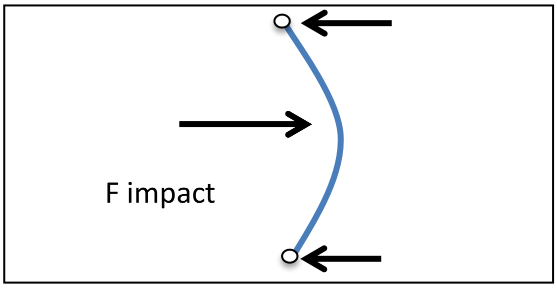


Figure 24: Side view of net

CHAPTER 5

DETAIL DESIGN

5.1 A PROCESS FOR FINITE ELEMENT ANALYSIS A STRUCTURE

In this part, the data such as parameter and equation and that will be used and related to the development of the stress physical model been gathered. For the purpose this project to determine the maximum stress. The data and parameter are as follows:

5.1.1 Parameter and its value used in APDL for FEA of Recovery Net Process

Table 5: Parameters and its Values for Simple Size Recovery Net

Properties	Value
Total of nodes	200
Element on horizontal	0.1m
Element on vertical	0.075m
Simple size of net	19m x 9m

Figure 25: Nodes and Element part

5.1.2 Define Element Type, Material model, Nodes and Element for Nylon Recovery Net Properties

Table 6: Parameters and its Values for Nylon Recovery Net Properties

Properties	Value
Element type	BEAM188
Material model	
▪ Poisson ration (PRXY)	0.39
▪ Elastic Young (EX)	2e-9 Pa
▪ Coefficient of friction (MU)	0.3
▪ Strain	7.8e-5 N/m^2
▪ Stress	6e-5 N/m^2
Diameter, ϕ (centroid)	0.004m

5.1.3 Apply Boundary Condition Part

Table 7: Parameters and its Values for Apply Boundary Condition

Properties	Value
U,ROT on Nodes (x,y,z fix position)	0
Total Impact load	1510.37J
Impact load per node	378J

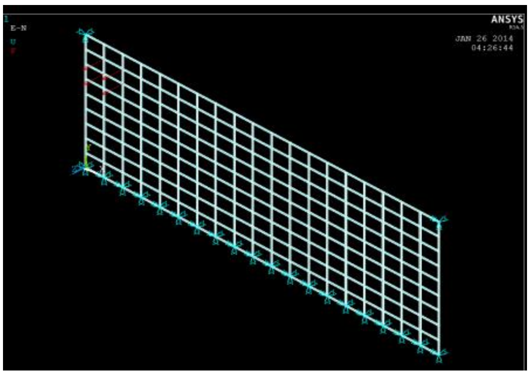


Figure 26: Showed fix nodes area

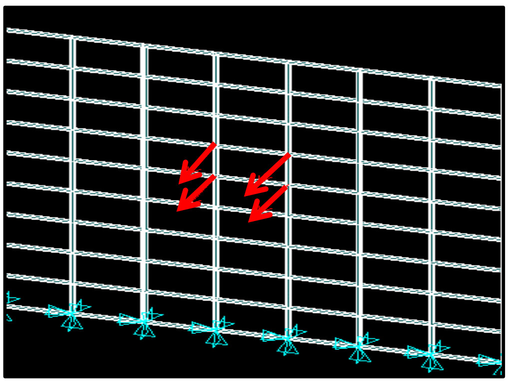


Figure 27: Apply load at selected position

5.1.4 Solve Part

For this part by using the plot result Nodal Solu will gain the more accurate result. As showed at Figure 28.

Table 8: Plot Results and List Result

Properties
Contour Plot Nodal Solu DOF solution Z-Component

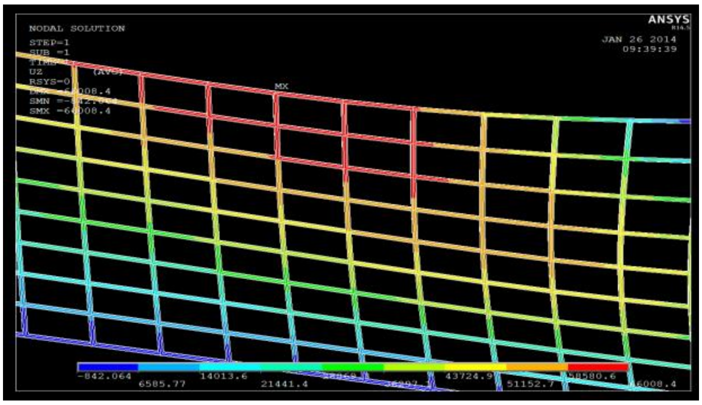


Figure 28: Results had showed the stress distribution

CHAPTER 6

RESULT AND DISCUSSION

6.1 STRESS ANALYSIS

For stress analysis of single load of this research the writer need to study and understand the APDL application to determine the location for applied the load. The ANSYS program will select the nodes to apply the impact load during the nose aircraft landing. The contour plot of single load had showed in Figure 28, 29, 30, 31 and 32.

Figure 29: Position of Case 1 until to Case 27

6.1.1 Contour Plot Result

The variation of colour in the contour plot shows the stress distribution at the work piece caused by the impact. The colour order of highest stress to the lowest stress is from red to blue area. The stress variation can be interpreting respect to the stress scale display. There are all contour plot with different position case 1 until case 27 had showed in Figure 30, 31, 32, 33 and 34.

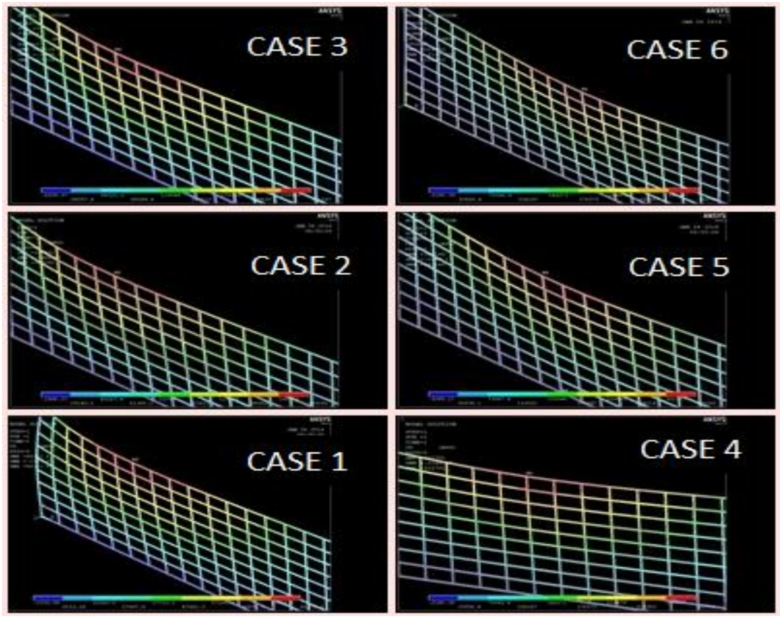


Figure 30: Case1 until Case 6

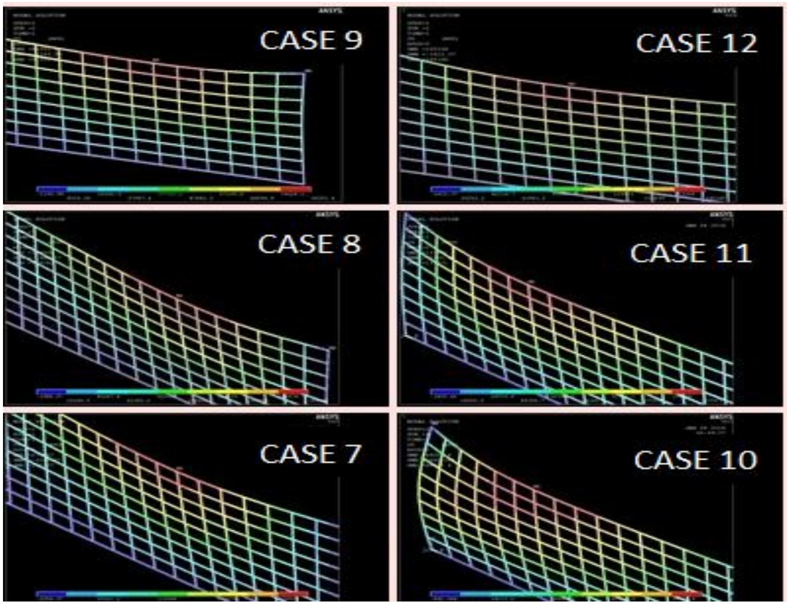


Figure 31: Case7 until Case 12

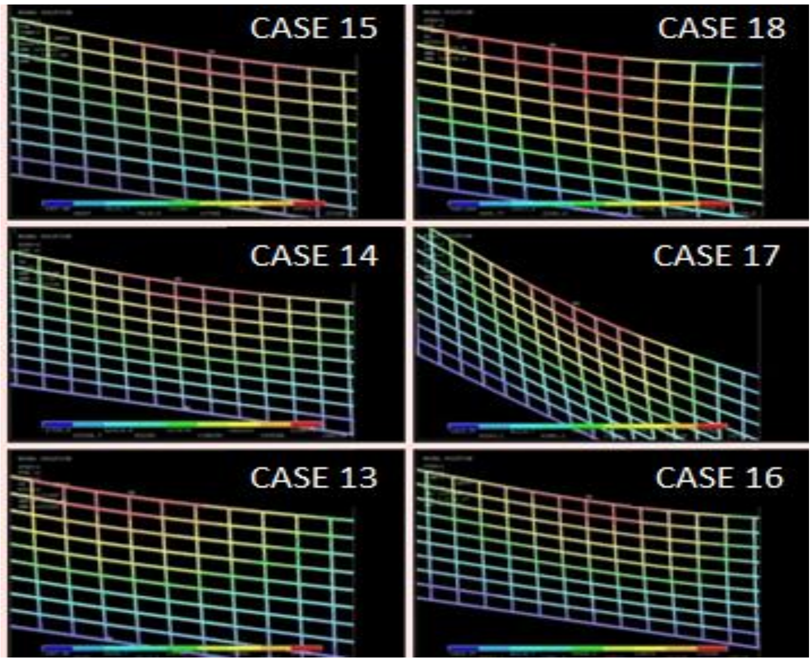


Figure 32: Case13 until Case 18

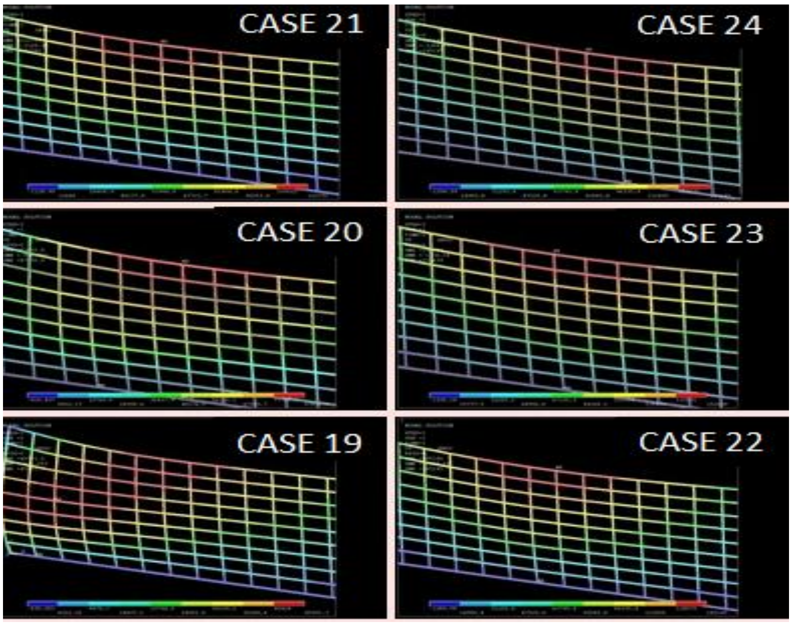


Figure 33: Case19 until Case 24

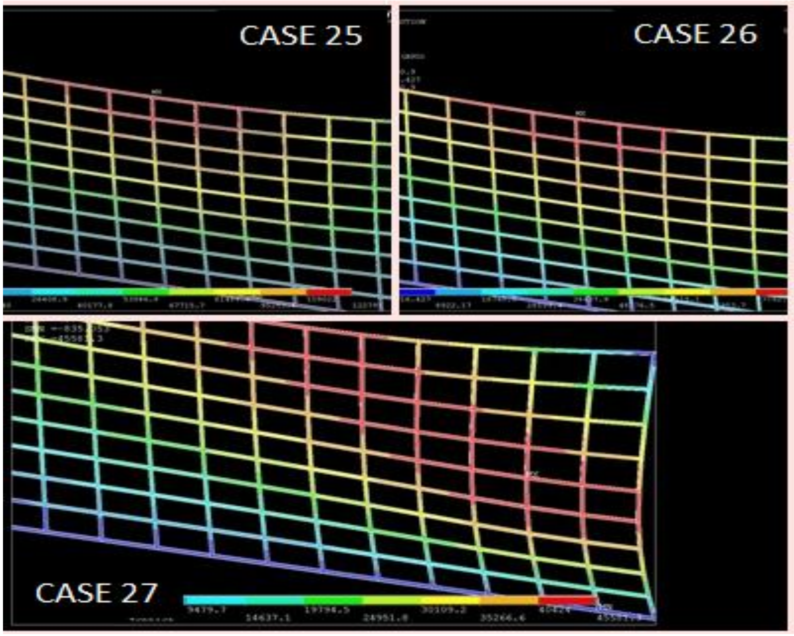


Figure 34: Case25 until Case 27

6.2 THE MAXIMUM STRESS OF ALL CASES

The contour plot and nodes plot for every data been showed in following table. From the contour plot we can analyze the stress distribution in the model by referring to the scale of stress provided. The cases that reach the highest stress are Case 19 and Case 27 which have the same value 455, 150 N/m^2

Table 9: Maximum stress by nodal solution per node

CASE	NODE	MAX VALUE (N/m^2)
CASE 1	187	85,973
CASE 2	188	187,130
CASE 3	188	268,790
CASE 4	189	321,140
CASE 5	190	338,410
CASE 6	192	321,140
CASE 7	193	268,790
CASE 8	193	187,130
CASE 9	194	85,973
CASE 10	187	65,848
CASE 11	188	137,420

CASE 12	189	194,330
CASE 13	190	230,670
CASE 14	190	243,160
CASE 15	191	230,670
CASE 16	192	194,330
CASE 17	193	137,420
CASE 18	194	65,848
CASE 19	103	455,150
CASE 20	188	87,354
CASE 21	189	122,340
CASE 22	190	144,600
CASE 23	190	152,070
CASE 24	191	144,600
CASE 25	192	122,340
CASE 26	193	87,354
CASE 27	118	455,150

6.3 THE MINIMUM DIAMETER OF NET CAN SUSTAIN FROM IMPACT ENERGY

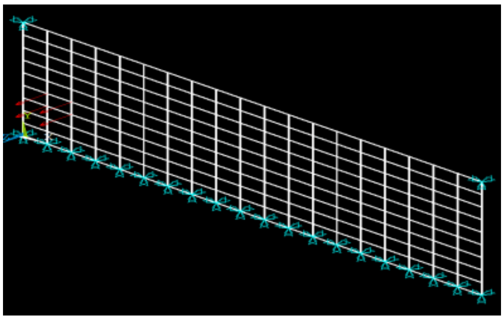


Figure 35: Apply load at case 19 position

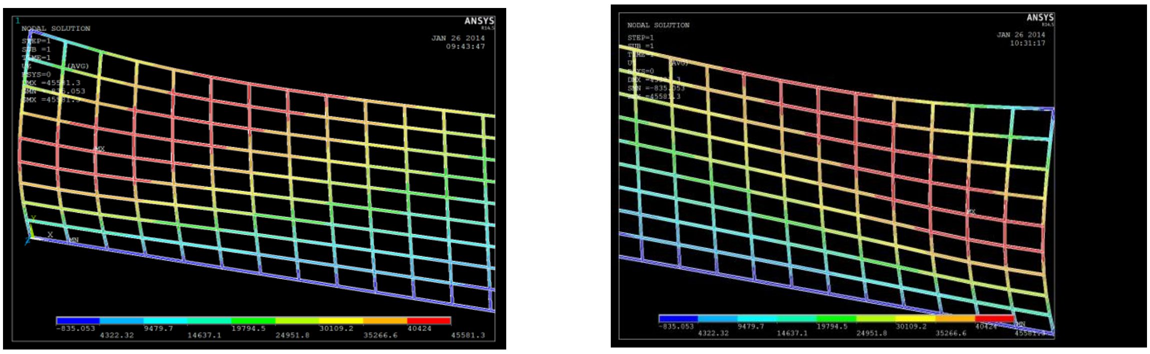


Figure 36: Case 19 & Case 27 with maximum stress 455,150 N/m^2

After required the value of maximum stress during impact distribution, for the next stage can defined minimum diameter of net can sustain from UAV impact. This analysis used the value of maximum stress at both case 19 & 27; 455,150 N/m^2.

Assume the node at 103 and 118 will give the same result because it is symmetric. Select the node 103 for apply the load impact; the data of maximum stress follow by different diameter had showed in Figure 28, 29, 30, 31 and 32.

Table 10: Varies of diameter net

DIAMETER, m	NODE	MAX VALUE (N/m^2)
0.001	103	721 596.0
0.002	103	459 222.0
0.003	103	143 830.0
0.004	103	45 515.0
0.005	103	18 647.0
0.006	103	8994.9

The tensile strength ultimate for nylon = 60Mpa

$$60x10^6 \ N/m^2$$

$$600\ 000 \ N/m^2$$

$$45\ 515 \ N/m^2 < 600\ 000 \ N/m^2$$

This comparison between values of maximum stress compare with value of tensile strength ultimate for Nylon properties [15]. The value of tensile strength ultimate for nylon; it is greater than the current maximum stress 45 515 N/m^2.

CHAPTER 7

CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

This ANSYS APDL had come out the result of maximum stress at critical location on net during aircraft landing impact. Also had define the minimum diameter of net can sustain from impact energy UAV. From the analysis, the result show that the current diameter recovery net; 0.004m which have maximum stress 45 515 N/m^2; it is smaller than the tensile strength ultimate for Nylon properties 600 000 N/m^2 [15]. Therefore, we had achieved the main objective to design recovery net landing for ALUDRA MR-01 (40kg) with safety level during UAV landing. By prove with simulate or analysis have done to current Fulmar net landing; MTOW 20kg is compatible with ALUDRA MR-01 that has expected MTOW of 40 kg. This FEA model should be validated by comparing the results with the result from actual experiment using the same process to require the accurate results. . In the future, the recommended work for future researcher is to reconfirm the data obtained from this project.

7.2 RECOMMENDATION

As suggestion for future works this project should be conduct in actual testing by using the drag mechanism equipment. (Suggestion: Spin lock**.** In order to decrease the impulse from the impact of ALUDRA MR-01 with recovery net on UAV landing, the force from UAV landing acceleration which is transfer to the tension of the rope need to be experience the drag mechanism. The energy from the force will be transfer to the drag energy.

7.2.1 Modelling of New Concept Recovery Landing Net

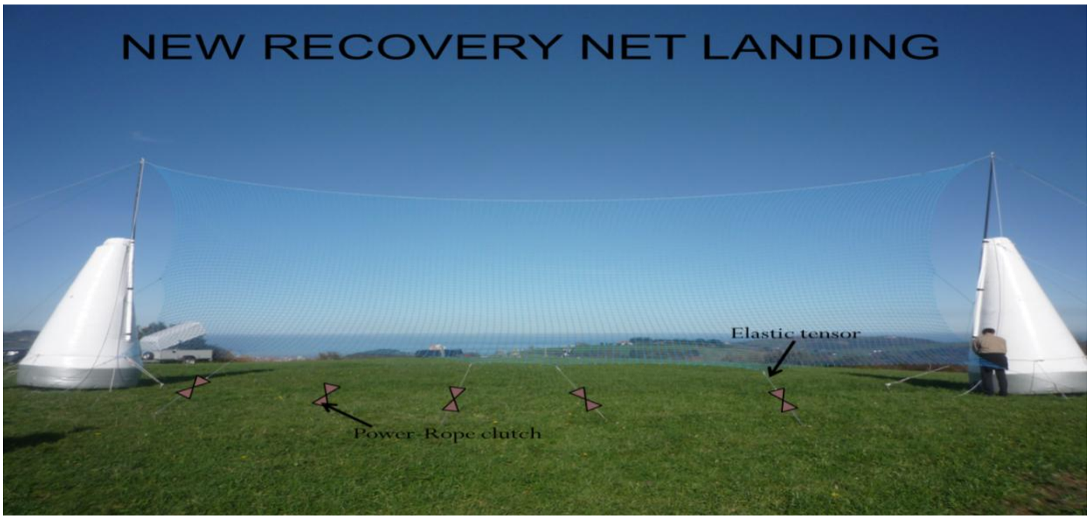


Figure 37: Design Concept New Recovery Net landing

In this design concept for new landing net, author will apply the power rope clutch and require a higher safe working load and more advanced release mechanism. From simulation had defined the critical position where the drag condition will created by the power clutch rope when the net had impact from UAV during landing.

Table 11: Rope design specification

TYPE	DIAMETER (Inches)
Auxiliary rope	7.0
Tensor rope	5.0
Net rope	4.0
Elastic tensors rope	8.0

7.2.2 Power Rope Clutch

Figure 38: Spinlock

Typically the clutch is used in front of a winch. The angle from the clutch to the winch should be as close to a straight line as possible. The halyard is tensioned by using the winch, after opening the clutch lever. When the halyard is at its desired tension the clutch lever is closed. There will be a small amount of slip as the cam settles into the line.

It is possible to tension the halyard without opening the clutch, but the clutch will not have as much holding power as if the clutch is opened. The lever type of clutch is opened to release the line, by pushing the lever forward so its handle is almost horizontal. The halyard is then eased from the winch.

Excessive slippage is one of the most common problems for rope clutches. Rope slippage is when the clutch is closed and the line is taken off the winch and now the clutch is taking 100% of the load. The line does have some normal slip due to the cam pushing down and settling on the line. Once it has settled you should not see any more slippage. Slippage is different from the stretch in the line or halyard. The two most common reasons for rope slip above the normal slippage due to line settling are first, the line size author use should be on the upper end for the clutch. With the 4-8mm clutch is best to using 8mm line. It can leave the clutch closed and tension the line, but it will not hold as well as when you open the clutch, tension the line and then close the clutch.

Below are the instructions with this regards how to operate the Spinlock XAS rope clutch;

1. Open the handle fully forward to thread the line through the clutch.
2. With the handle closed, the clutch will hold the rope automatically as the load is eased from the winch. (Allow for a forward rope 'run out' of up to 20mm as the cam engages. Gripping performance on new rope will improve with use).
3. Manual lockdown function. If required, author can achieve increased load holding by lifting the handle until vertical, then locking it down firmly onto the tensioned rope before easing the load from the winch.

Table 12: Spinlock design specification

Brand	Model	Rope Range	Load	Weight	Price	
Spin Lock	XAS0408	4mm - 8mm	180kg - 450kg	0.3kg	£59.90	RM294.91
All Spars	XCS0814	8mm - 14mm	1200kg	0.6kg	£130.67	RM643.33
	XCS0608	6mm - 8mm	700kg	0.6kg	£130.67	RM643.33

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