Fan Flyer 3

Final Report

Faisal Almutairi

Khaled Alazemi

Ali Almari

Christian Riggs

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Project Sponsor: Jim Corning, Nova Kinetics

Instructor: David Willy

DISCLAIMER

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EXECUTIVE SUMMARY

A fan flyer is a personal flying device that is used for flying in the air for exploration or competition purposes. In this project, the client, the Northern Arizona University and Jim Corning of Nova Kinetics who are the major sponsors of the project Sponsor, requires the team to design and prototype a pitch control actuator for the fan blades of a Fan Flyer. By designing and constructing the fan flyer in a successful manner by following the requirements will be of great benefit to Nova Kinetics since the device will have a higher competitive edge in the market hence lead to the generation of a lot of profit. Since all the other parts of the fan flyer had been designed by Nova Kinetics the sponsor required the team to only design the pitch control actuator for the fan blades of a Fan Flyer so that it is able to carry out its functions effectively.

Before embarking on the project, the team met with the clients so that they could get the requirements which were supposed to be incorporated in the device. Some of the requirements that the team is required to fulfill are as follows. The actuator should be reliable hence should be made from efficient and high-quality components; the materials used should be durable; a small and light in weight which is not larger than 4”x4”x14”. The device should also be safe to operate, and the actuator weight should not exceed 2 lbs. The motor used should be powerful enough to ensure that there is a proper rotation of components in an effective manner. Specifically, a 12-volt DC motor will be used. However, more details on the requirements of the pitch control actuator have been discussed in the requirements section.

In order to ensure that the team constructed an appropriate device, the team conducted detailed and intensive research online. In this case, the team consulted engineering books and journals so as to get the most efficient components to incorporate. The team conducted benchmarking by use of other models which had been already designed previously so that they can end up with a device that will be competitive in the market. In order to determine the functioning of the device, the team used a black box model and a functional model. There were also calculations regarding stresses and pressure exerted to springs and screws so as to determine the most appropriate value. In the prototyping phase, the team determined areas which required improvements so that the final design could be perfect.

In the end, the team used the Pugh chart and a decision matrix to select the design concept which met the client’s requirements. Specifically, the Pugh chart narrowed down the 10 concepts into 4 concepts. The decision matrix was used to select the design which will be used as the alpha prototype. Eventually, in the end, the team selected the electrical actuator over the hydraulic one and this was arrived at after considering the client’s requirements.

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1 BACKGROUND

1.1 Introduction

A fan flyer is a personal flying device that is used for flying in the air. However, the device is normally used for exploration or competition purposes. In this project, the client, who is the Northern Arizona University and Project Sponsor, Jim Corning of Nova Kinetics requires the team to design and prototype a pitch control actuator for the fan blades of a Fan Flyer. This is of great significance to the client since he will have a device which has been made using the specifications provided by them. The ducted fans will be operating at a constant speed of approximately 5500 RPM. This pitch control actuator or servo needs to provide linear motion. The major role of the pitch control system in the Fan Flyer is monitoring and adjusting the rotor blades angle. These blades are responsible for ensuring that the rotational speed of the blades is regulating so that the device can fly in the intended direction and with appropriate speed. However, the pitch actuator system adjusts the blades through their rotation so that they are able to produce the optimum amount of energy hence facilitating efficient power output. The DC motors which have a high rotational speed will provide the rotational power for the fans. The major function of electric linear actuators is to convert the rotary motion into linear motion. This conversion of motion is done with the help of a gearbox and a lead screw. These are the two basic components of an electric linear actuator. The connection of the actuator to the fan flyer which in turn reveals its working starts with the stator and the rotor assemblies which facilitate both the primary and secondary workings of the motor. The primary workings entail the stator assembly whereby voltage is applied. The voltage is then converted into a current that is propelled into the rotor assembly, which operates as the secondary operations. The rotor and stator assemblies working leads to the creation of a field which enables motion. The motion as a result of the motor is then passed to the cylinder whereby the interaction with the limit switch converts this motion into a linear one. The gears are used to turn the cylinder hence promoting linear motion. In this regard, the major objective of the project is to design a prototype pitch control actuator for the fan blades of a Fan Flyer. In order for the device to be effective, it must meet customer requirements that are listed in the requirements section. Successful completion of this device is crucial since it will help the client and the users in the operation of the Fan Flyer.

1.2 Project Description

In this project, the team is to design and prototype a pitch control actuator for the fan blades of a Fan Flyer. The ducted fans in the Fan Flyer will be operating at constant speed, approximately 5500 RPM, and the fan blade pitch in each fan will be variable to vary the fan thrust and create control forces for maneuvering. This pitch control actuator or servo needs to provide linear motion, and meet the following specifications: a travel rate of 1” per second; overall travel of 1.5”; maximum actuator force of 25 lbs.; duty cycle of 100%; power should be electric or 12 volts DC or 120 volts DC (the team will make their choice); a maximum weight of 2 lbs.; a size which is not larger than 4”x4”x14” so that it is small and light in weight.

2 REQUIREMENTS

This chapter will discuss the requirements of the project which entail customer and engineering requirements. The team is going to implement these requirements in the final design system to make sure that the device operates in an efficient manner. The requirements are base off weights against each other in the House of Quality to determine their significance. This section will start with the customer requirements as explained below.

2.1 Customer Requirements (CRs)

Customer requirements are the various forms of requests which the client and the users have regarding how the system needs to be designed so that it can suit their needs. Since they are the major users of the device, they are the best suited in giving the customer requirements since they are experienced regarding the operation of the device. They have significant ideas on the strengths and weaknesses of the device. This is crucial since clients and users contribute feasible views regarding how the device is made, and how it relates to the customer requirements. The customer requirements for each portion is a list in the table 1 below. And scaled from 1 to 5 where 1 is the less important and 5 is the most important.

Customer requirement	Weight
Reliability of Actuator	3
Durability of Materials	3
Actuator Size	5
Safe to Operate	5
Actuator Weight	3
Efficiency of Device	2
Steer Rod Travel Rate	4
Actuator Force	3
Motor power	3

Table 1: Customer Requirements for pitch control actuator

Discussion

1. Reliability of Actuator

The device should not fail at any one moment during operation and as a result it needs components that are efficient and of high quality.

2. Durability of Materials

The materials to make the pitch control actuator should be of high quality to ensure that it lasts for a long period of time. Also, such materials will enable the device to withstand extreme weather conditions.

3. Actuator Size

This is crucial in this case as it is going to determine the efficiency of the device in relation to weight hence the design should be small and light in weight and not larger than 4”x4”x14”.

4. Safety to Operate

The device should not pose any risk to the user and therefore it should not have any protruding parts or movable parts which are hazardous.

5. Actuator Weight

Weight is a crucial requirement that must be applicable in the design hence its weight must not exceed 2 lbs., and this is crucial since it will facilitate its movement during operation.

6. Efficiency of Device

The pitch control actuator should be able to perform its intended function, that is provision of linear motion in the appropriate way possible and within the shortest time possible.

7. Motor power

The motors used in this case should have enough power to ensure that there is proper rotation of components in an effective manner.

2.2 Engineering Requirements (ERs)

From the customer requirements, the team formulated engineering requirements. These were to be applied in designing and making of the pitch actuator so that it is effective in its operations. The engineering requirements are specific and measurable. This ensures that during later stages of analysis and interpretation they can make work easier. Table 2 below shows the list of engineering requirements.

Table 2:

Engineering Requirements	Target
Material Toughness (in.lbf.in-3)	50
Height (in)	4
Length(in)	14
Width (in)	4
Stroke Length (in)	1.5
Over Current Protection (A)	10
Mass (lb.)	2
Duty Cycle (100%)	100%
Actuation Speed (>1 in per sec)	1
Force to move Rod (>25 lb.)	25
Motor Volt (V)	12

Engineering Requirements for pitch control actuator

Discussion

1. Material Toughness

The materials used in making the pitch actuator should be tough and strong so that the device is able to withstand harsh conditions and last long. Specifically the material used should have a maximum toughness of 50 in.lbf.in-3 as steel.

2. Height

The device should have a maximum height of 4 inches to facilitate ease of operation and storage.

3. Length

The device should have a maximum length of 14 inches to facilitate ease of operation and storage.

4. Width

The device should have a maximum width of 4 inches to facilitates ease of operation and storage.

5. Stroke Length

The stroke length is the extent to which the piston travels in the cylinder and is determined by the cranks on the crankshaft. The larger the stroke length the greater the rotation hence high speed. s in this regard, the device should have appropriate stroke length of 1.5 inches which will in turn facilitate efficient blade rotating and at the right speed.

6. Over Current Protection

The device should not exceed a maximum current of 10 A to avoid damage of some other electrical components and for safety purposes.

7. Mass

The device should have a maximum weight of 2lb so as to lower the load and to facilitate efficiency of operation.

8. Duty Cycle

A duty cycle also known as power cycle is the fraction of one period whereby a signal or system is active. It is commonly expressed as a percentage or a ratio. The system should have a duty cycle of 100% and this means that the device should operate all the time.

9. Actuation Speed

The device should have a linear actuation speed of 1 inch per second so as to ensure that rotation of the blades is constant.

10. Motor

The device must operate at a voltage of 12 Volts to after all necessary flight component power consumptions are considered. A motor of 12 volts will provide sufficient power output that will be able to rotate the shaft effectively.

11. Control circuitry needed in a linear actuator

When power is removed, the linear actuator will still hold its position. However, when a force that is great enough s applied such that it is able to overcome the internal friction, chances are high that the actuator will back drive. As a result, a control circuit is required to make sure that the motor is started and stopped safely for both the equipment and the operator. In this case, a DC voltage of 12V is being used and therefore the best circuitry is the one that is built around a CD4017 IC to clip an electromagnetic relay with switch contacts. A schematic diagram of such a circuit is as presented in the appendix.

2.3 Testing Procedures (TPs)

This section discusses the testing procedures used to verify the engineering requirements. The subsections below show the results.

1. Material Toughness

The toughness of materials will calculate the stress generated within various elements which make up the device.

2. Height

A ruler calibrated in inches will be used to measure the height of the device and it should be 4 inches.

3. Length

A ruler calibrated in inches will be used to measure the length of the device and it should be 14 inches.

4. Width

A ruler calibrated in inches will be used to measure the width of the device and it should be 4 inches.

5. Stroke Length

The device should have appropriate stoke length of 1.5 inches which will in turn facilitate efficient blade rotating and at the right speed.

6. Over Current Protection

An ammeter will be used to determine the current flowing through the system and determined that it will be within the required range allowed.

7. Mass

A spring balance calibrated in lb. will be used to measure the weight and revealed that it did not exceed 2lb.

8. Duty Cycle

The system will be operating in a mock test to determine whether it was able to meet the duty cycle of 100%.

9. Actuation Speed

A rotameter will be used to measure actuation speed and evidenced that it was within the required range of 1 inch per second.

10. Force to move Rod

A mock operation of the device will conduct after be subjecting to a load of 25 lb.

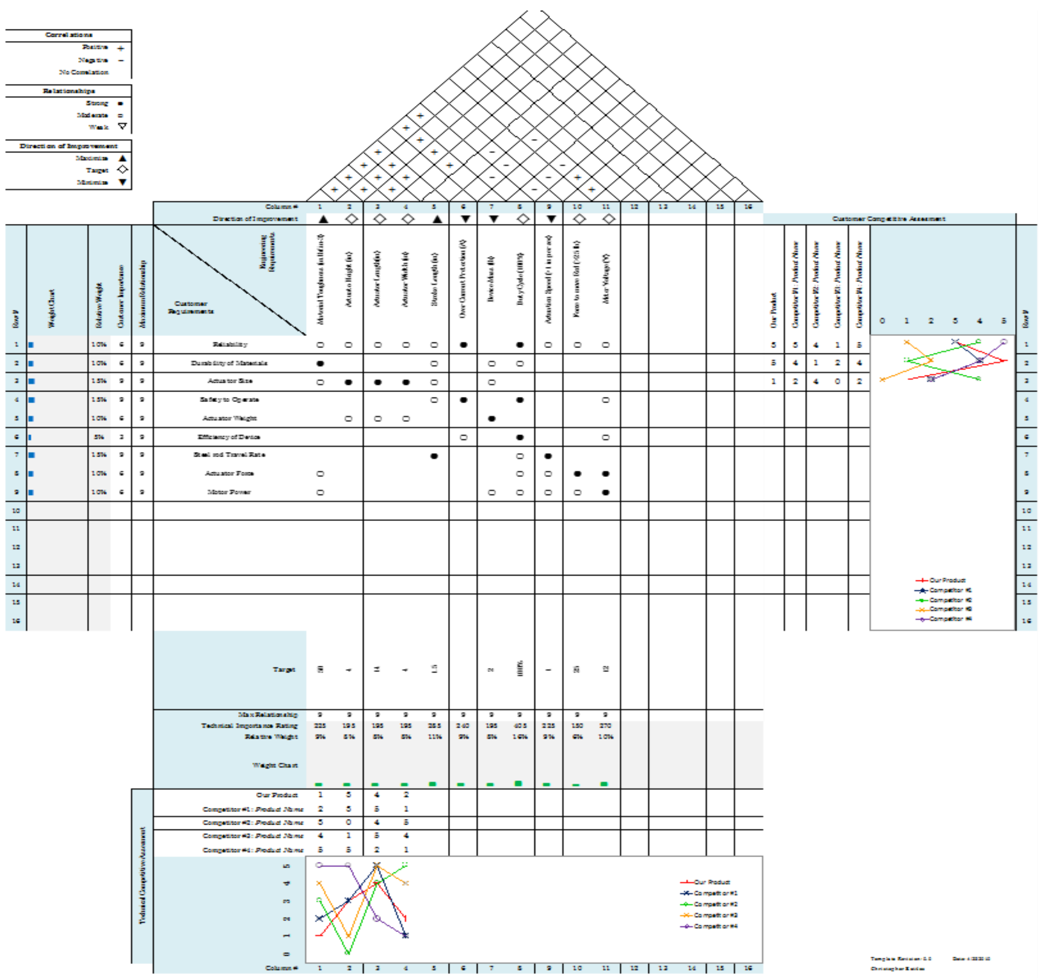
11. Motor

Power input test will conduct using digital multimeter (DMM) to measure voltage supplied by the motor to the system to make sure the correct voltage of 12V.

2.4 House of Quality (HoQ)

The major aim of the \House of Quality is to determine the most significant engineering requirements for this project. It will help the team in analyzing various components by using the various laid down parameters. Also, the team will use it to come up with the most appropriate plan which will ensure that there is success of the project. As a result, the team members will remember all the requirements in the sections 2.1 and 2.2. The customer requirements are a listed on the left-hand side and are weighted depending on their importance on a scale of 3 to 9. In this case, 3 and 9 are the lowest and highest on importance respectively. These weights are applied depending on the score that was given by the customer. Weak, medium and strong correlation between the customer and the engineering requirements is represented by use of symbols '+', '-', and no correlation are empty respectively. Weight factor is then multiplied by the value of correlation. Then the value obtained is summed up at the bottom to get the absolute technical importance (ATI). However, the engineering requirement with the highest ATI number is placed first in Relative Technical Importance (RTI) and this moves on until the lowest ATI is obtained at last. The House of Quality used is presented in the figure below.

Table 3: House of Quality



3 DESIGN SPACE RESEARCH

This chapter discusses the research implemented to help in designing the pitch control actuator. A variety of resources to conduct research include article databases and websites. In addition, the chapter includes the functional decomposition and the subsystems developed for the project and research on the already existing designs at each subsystem level.

3.1 Literature Review

This section discusses the various research which the various team members conducted to accomplish the project. The sections are below and provide an overview of the resources each student used.

3.1.1 Student 1 (Faisal)

a) Mechanical Actuators [1]

This article is focusing on the significance of using compact hybrid mechanical actuators. For instance, it enables a variety of stroke lengths hence controlling motion and resilience against mechanical stresses. Also, it has transfer tubes and rods are made of stainless steel for protection against corrosion.

b) Principles of engineering design [2]

This source is focusing on the principles which need to be applied in designing so that the device at hand can operate efficiently as per the customer and engineering requirements given. The book analyzes the design process that will be applied in this project in terms of modelling, case problems, structure, tactics, strategies, representation, and working means.

c) Operating systems: internals and design principles. Pearson [3]

The book focuses on the design principles which are incorporated in engineering projects. The design principles discussed that will be incorporated in the project include: determining structural elements in the process of design; determining a general sequence for the design process; modifications that affect the design process; and selection of various designs.

d) The Vital Roles of a Pitch Control System [4]

The source focuses on how the pitch control system works. The source reveals how the pitch angle gets transferred to the hydraulic cylinder or motor hence allowing the actuator to position the blade in the proper angle.

e) Wind turbine load mitigation [5]

The source is a patent entitled “Wind Turbine Pitch Control Hub.” The invention is related to a wind turbine rotor control system, and specifically to automate the blade pitch control system for wind turbines used as electrical generators connected to the electrical grid. The team will use the source for benchmarking purposes.

3.1.2 Student 2 (Khaled)

Khaled conducted a research on the already existing designs of pitch actuator systems to determine how the major components such as motors, gears, and blades operate. Some of the resources he used are as follows:

a) Professional journal [6]

The source focuses on hinge control actuator systems. The source has revealed how the actuator operates. When the rotational part of the hinge moves, there is control of pitch angle. The linear actuator connects to the linear part and operates the entire pitch control system. in this manner, the actuator enables that the entire system operates in a manner which ensures there is maximum energy output.

b) Valves and Actuators [7]

This book focusing on gears, springs, and DC motors of the actuator and how to calculate the force and torque of the device. The gears will be useful in the project since they will facilitate movement. the springs will ensure that the appropriate amount of torque is acquired while DC motors will facilitate the rotational movement of the actuator system.

c) Shigley's mechanical engineering design [8]

Only chapter 12 to 15 needed to support our design and the tables. These chapters focus on the difference kind of gears such as helical and spur gear. This will help in designing of the device as it will help to determine the most appropriate gear that will support huge axial loads.

d) Professional article [9]

This article is measurements for ducted fan for actuator and how to maintain its speed and how the actuator will control the fan with its speed. This is crucial since it will ensure that the fan rotates with the optimal speed to avoid unnecessary pressure on components or even damage.

e) Control of a system with the switched actuator rate limitation [10]

This article is a study to control the duty cycle of actuator and the over current limitation for safety purposes. In this case the team will adopt the mechanism presented to design controller to regulate differential air pressure of the fan based on the AC induction motor that is supplied by the frequency converter.

f) Engineering book [11]

The book focuses on the principles of design which are incorporated in any form of an engineering project. The design principles that will be incorporated in the project include modelling, structural analysis, tactics, strategies, representation, and working means.

g) Website [12]

This source is focusing on the Hybrid Actuation System (HAS) which is used as a benchmark by the team. A description of HAS, has been given in the source. The source will help the design since the team will be able to incorporate various stroke lengths for resilience against mechanical stresses and controlled motion.

h) Academic journal [13]

The source is focusing on a model-based scheme for fault detection of a blade pitch system in floating wind turbines so as to enhance operational safety. This will be incorporate in the fan flyer design whereby the factor of safety will be enhanced by use of a fault detection system.

3.1.3 Student 3 (Ali)

The major focus of Ali is on the bearings which could be used in designing the pitch actuator system. Some of the sources he used are as follows.

a) Engineering book [14]

Stallings, William, and Moumita Mitra Manna. Operating systems: internals and design principles.

The source is focusing on the most appropriate principles that every engineer should incorporate in their design so that it is effective in its intended purpose. The source will be helpful in the project as it will help the team to incorporate design principles such as problem identification, concept selection, and modelling.

b) Patent

The source is a patent of a pitch gear with the patent number US 10,047,721 B2. The patent gives a description of a pitch system that has a pitch bearing and a wind turbine hub including a pitch gear coupled to the pitch system. the source will be useful since it will help in benchmarking.

c) Academic journal

The source is focusing on friction factor values and how they compare in respect to load and revolutions measured on sliding pairs, and comprising of a sliding bearing and a shaft, without re-lubrication. The source will be used in this project since the team will buy the idea of avoiding the need of lubrication by use of a sliding shaft that is lubrication free.

d) Website [15]

The source is focusing on the various types of bearings which can be incorporated in the design of the pitch actuator system. Some of the bearings focused on include: deep grove ball bearings, thrust ball bearings, needle roller bearings, spherical roller bearings and self-aligning roller bearings. The source will be useful in the project as the team will be able to determine the appropriate bearing that will be able to support huge axial load.

e) Interviews

The interviews with clients enabled the team to know the appropriate customer requirements which should be incorporated in the project. This was crucial to the project since the team was able to incorporate the design specifications given in making of the device.

3.1.4 Student 4 (Chris)

Chris focused on the motors that will be incorporated in the system in reference to the engineering requirement. In this case, the team required a motor which is able to supply a voltage of 12V. The sources used include: conducting interviews to the client, holding discussion with the lab assistant, engineering book, and website.

a) Conducting interviews to the client

Chris conducted an interview to the client so that he can get exact details regarding the most appropriate motor that was to be used in the system. this was crucial for the project since it ensured that the team met the design specifications provided.

b) Holding discussion with the lab assistant

This was crucial since it helped Chris to get finer details on the appropriate specifications of the motor and how it should be fixed to achieve maximum output. This will be shared with the rest of the team members.

c) Engineering book [16]

This source is focusing on the principles which need to be applied in designing so that the device at hand can operate efficiently as per the customer and engineering requirements given. Some of the design principles learnt which will be incorporated in the design include: brainstorming, concept selection depending on the customer and engineering requirements, prototyping, and physical modelling.

d) Website [17]

The source is focusing on a continuous DC motor and how it is used to provide power to facilitate continuous movement of the shaft. I this case the source is useful as it has given details regarding the motor that has greatest number of revolutions that will facilitates maximum efficiency.

e) Website [18]

The source is focusing on the specifications of RS PRO, 12 V Brushed DC Geared Motor such as over 90%. Efficiency, small size, low weight and co-axial configuration of input and output shafts. In this manner, the source is useful since it will make the team to test this moor to determine its effectiveness.

3.2 Benchmarking

In order to conduct benchmarking, the team searched for pitch control actuator systems which have been manufactured by other engineers. In order to understand how the pitch control actuator operated the team watched pitch control actuator videos.

3.2.1 System Level Benchmarking

The following section gives a description of the already existing designs which have requirements of the pitch control actuator. The pro and cons of each of the three designs are as follows.

3.2.1.1 Existing Design #1: Hinge control actuator system

The hinge control actuator system is an appropriate benchmarking design in relation to the project since it has some specifications that can be incorporated into our design. In this device, a rotating shaft force will push the shaft making the pitch angles of all blades through a hinge structure. A linear actuator is rotating at the back of the generator and it moves the shaft back and forth. When the rotational part of the hinge moves the pitch, the angle is controlled. The major challenge with this design is that it is heavy [19]. Hinge control actuator is as presented in the figure below.

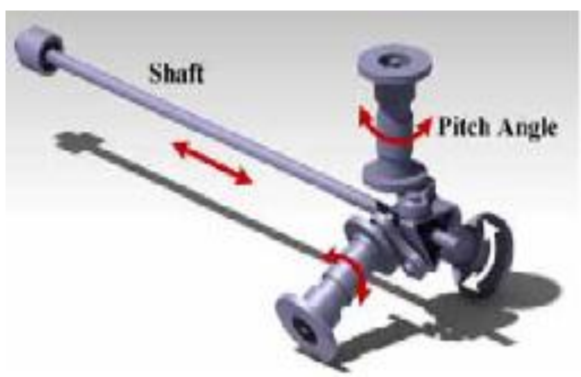


Figure 1: Hinge control actuator system [13]

3.2.1.2 Existing Design #2: Hybrid Actuation System (HAS)

This design is comprised of hydraulic and electromechanical actuators for specific control and holding power. It has a pump, double-acting cylinder, and manifold with fluid-exchange ports. Tubes and rods compose of stainless steel hence protecting it from corrosion. Due to permanent lubrication to the internal wear items by the hydraulic fluid, the system has a longer service life. It has a locking mechanism which is achieved through static hydraulic fluid and this makes it to withstand against mechanical stresses such as strong wind hence making it to be effective. The major con is that it is quite expensive [20].

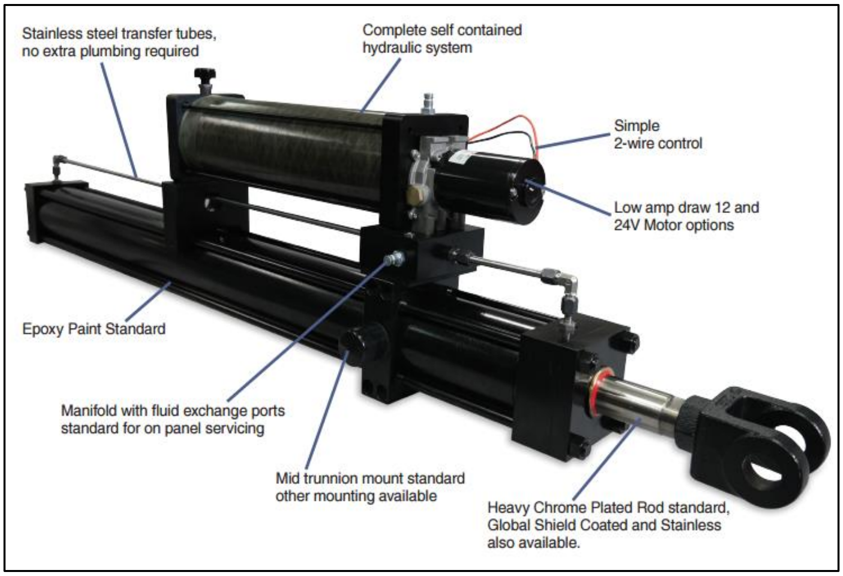


Figure 2: Hybrid Actuation System (HAS) [14]

3.2.1.3 Existing Design #3: Linear Actuator - ERAIA 41-2

This actuator's primary use is in aircrafts to control the emergency ram air intake by use of a permanent magnet DC motor. It operates through a two-step reduction gear train and an acme jack screw with high static load capacity. Its design makes it able to withstand harsh environmental operation purposes. The major challenge of this actuator is the high cost of manufacturing.

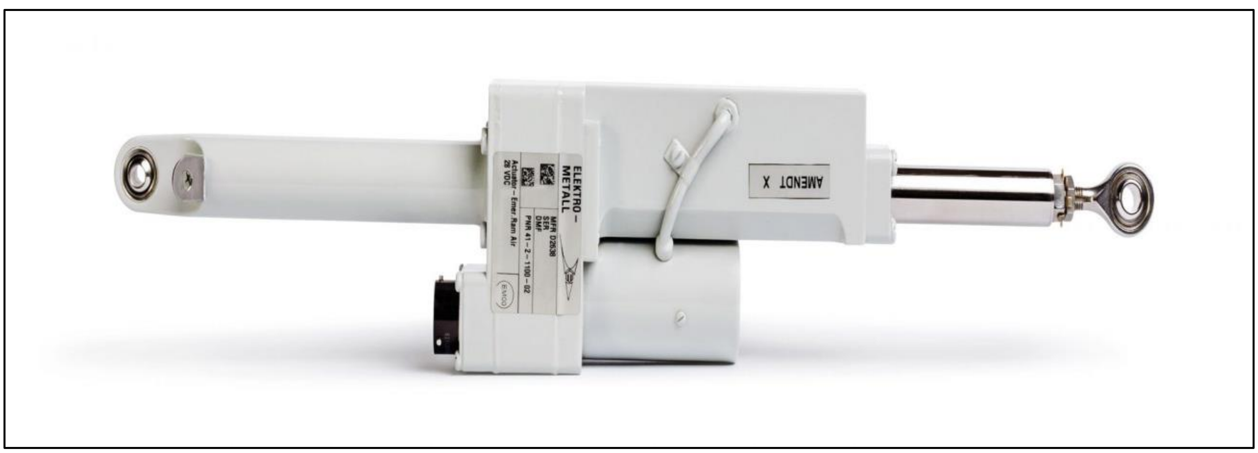


Figure 3: Linear Actuator - ERAIA 41-2 [14]

3.2.2 Subsystem Level Benchmarking

This section will discuss the different subsystems of pitch control actuators. The pitch control actuator system is placed into three subsystem categories including the bearing, motor, and springs. These subsystems are in the following subsections plus with their existing designs.

3.2.2.1 Subsystem #1: Bearings

To facilitate movement of movable parts of the pitch actuator system to facilitate efficiency.

3.2.2.1.1 Existing Design #1: Single Row Ball Bearings SS6000 Stainless Series

It is characterized by high tolerance standards and is able to handle heavy radial loads. It is able to withstand a temperature range of –22° to 240° F. It is corrosion resistant hence can last for a long period of time. The major challenge is that it requires constant lubrication which is quite cumbersome. This bearing will be useful in the project since it will be used in enhancing efficient movement in all moving parts[21].

Figure 4: Single Row Ball Bearings SS6000 Stainless Series [15]

3.2.2.1.2 Existing Design #2: NU305 Cylindrical Roller Bearing

Bearings have a wide variety of applications since its size is 25mm x 62mm x 17mm. It is composed of Chrome Steel and hence is able to last for a long period of time. It is 8.5 ounces in weight. It has an efficiency of over 80%. The major challenge is that it requires a lot of lubrication to facilitate efficiency [21]. However, the bearing will be useful in the project since it will ensure that there is highly precise rotary motion of the actuator system.

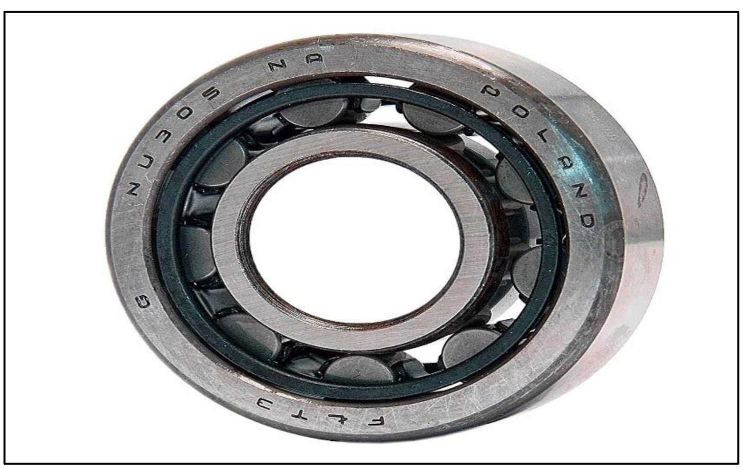


Figure 5: NU305 Cylindrical Roller Bearing [15]

3.2.2.1.3 Existing Design #3: 87000 88000 WC88000 Series bearing

This series is normally applicable in high speed air tools hence highly effective. It has double contact seals and shields. It is composed of stainless steel hence free from corrosion. The major challenge is large axial loads will be present [21]. The bearing will be useful in the project since it will ensure that the final design will remain effective for a long period of time since it requires minimal maintenance.

Figure 6: 87000 88000 WC88000 Series bearing [15]

3.2.2.2 Subsystem #2: Motor

Motors are crucial in pitch control actuator as since they facilitate effective movement of various components in the device. Motors converts energy into torque which in turn controls the pitch control actuator mechanism. In case the AC motor is an induction motor, the rotor rotates at a slower rate than the stator's field. In case a synchronous motor is used, the rotor and the stator move in synchronization.

3.2.2.2.1 Existing Design #1: DC Servo Motor SANMOTION T T850T-012

The motor has an output of 0.5Kw, a maximum speed of 3000 min-1, continuous stall torque of 2.16 Nm., rotor inertia of 0.0006 kg.m2, and has a mass of 4.45 kg. The motor will provide power to facilitate continuous movement of the pitch control actuator [11]. It will be of great help in this project since it will a way of controlling speed and positioning.

Figure 7: Continuous DC Motor [11]

3.2.2.2.2 Existing Design #2: RS PRO, 12 V Brushed DC Geared Motor

It has a higher efficiency of over 90%. It has a small size low in weight and is quite efficient in either direction. Its co-axial configuration of input and output shafts facilitates inline installation with motor and the device [23]. This motor will be useful in the project since it can be used for varying loads and is energy efficient.

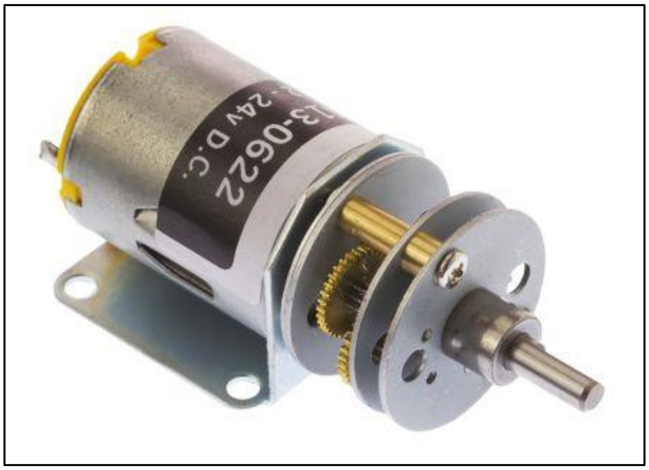


Figure 8: RS PRO, 12 V Brushed DC Geared Motor [12]

3.2.2.2.3 Existing Design #3: RS PRO, 12 V Brushed DC Geared Motor

It has a high quality three pole motor with sleeved bearings. It is durable and is applicable to high speed situations. It has an efficiency of over 90% ad has an output Speed of 221 rpm. The motor will be of great benefit to the project since it will help the actuator to handle constant loads and facilitate positional accuracy [23].

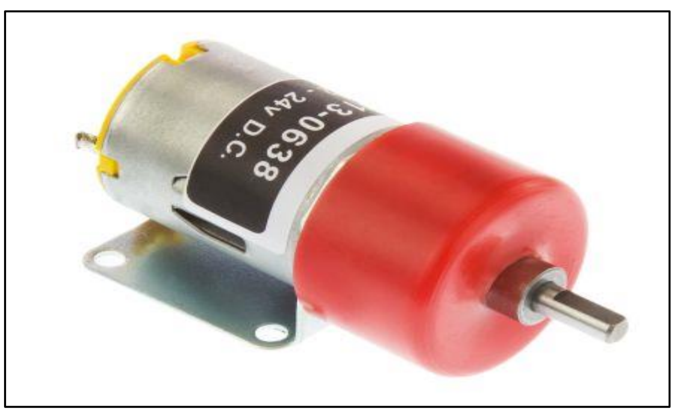


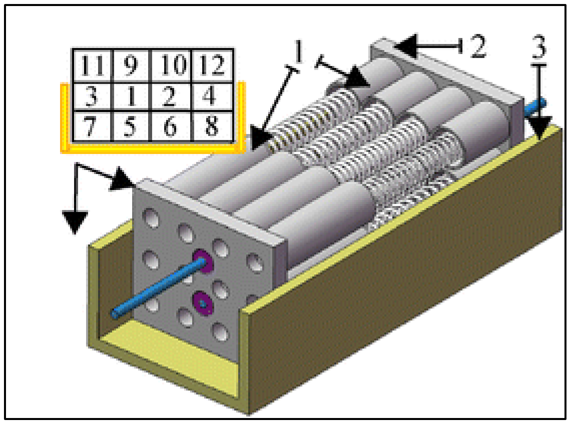
Figure 9: RS PRO, 12 V Brushed DC Geared Motor [12]

3.2.2.3 Subsystem #3: Spring design

The spring is crucial in this design since it ensures that there is convenience control of stiffness and the torque of the actuator. The torque and stiffness are a linear function of the kinematic parameters of the variable stiffness actuators (VSA).

3.2.2.3.1 Existing Design #1: Quadratic compression spring

This design is comprised of compression springs which are set in parallel. The end of the spring is flat, and the material used is piano wire of D grade. The total number of springs used is 12. The springs are set in the spring set pedestal in such a manner that they do not touch each other to reduce friction as shown in the figure below [24]. In terms of mechanical solutions for the first VSA, the relationship between the output stiffness and angular deflection is linear; for the third VSA, the linear relationship between the torque and angular deflection is achieved for quadratic torsion spring configuration. However, in the fourth VSA, the relationship between output stiffness and angular deflection is linear.

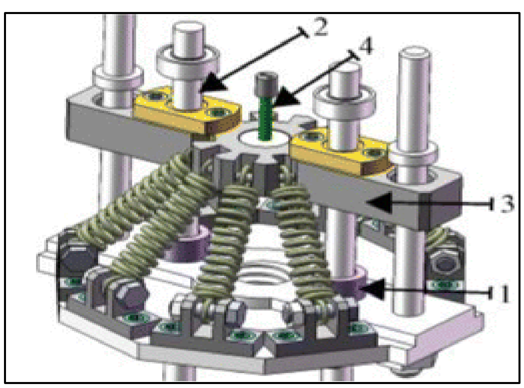


Key: 1-spring pedestal guide sleeves; 2-spring set pedestal; 3-guide grove.

Figure 10: Quadratic compression spring [18]

3.2.2.3.2 Existing Design #2: Quadratic Tension Spring

The design is comprised of a tension spring that is set with a triangular structure. It is comprised of eight tension springs. The bulge (1) is for initial pretension of the spring. The guide rod (2) and the pedestal (3) are to connect using linear bearing [24]. The arrangement s as shown in the figure below. When compared with the other springs, based on a curved surface and varying-radius shaft, the design is compact and easy to use.

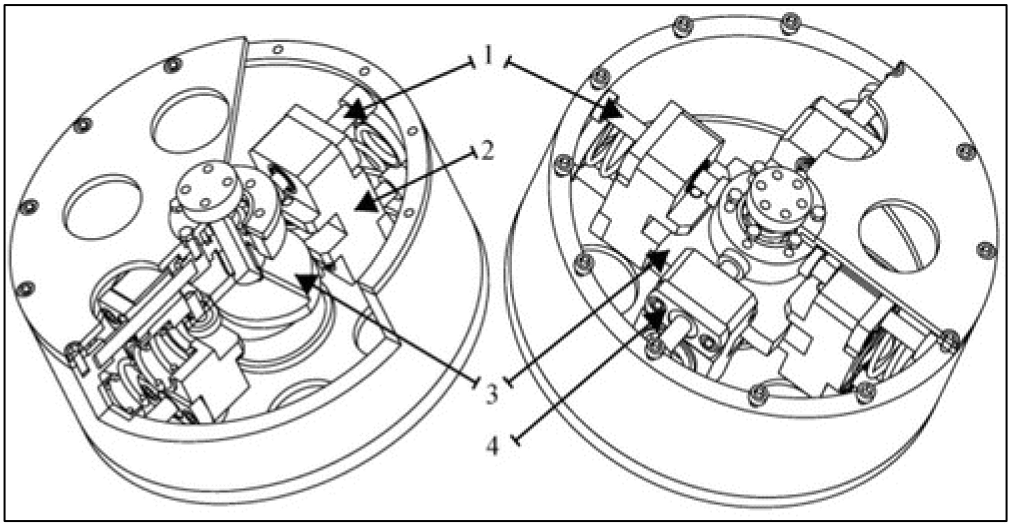


Key: 1- bulge; 2-guide rod; 3- pedestal; 4- cable

Figure 11: Quadratic Tension Spring [18]

3.2.2.3.3 Existing Design #3: Quadratic torsion spring

The design is comprised of compression springs which have two linear bearings and 2 guide shafts. The spring is in position in the pedestal and the roller is driven by the cam [24]. The arrangement is as shown in the figure below. The major benefit of this kind of spring is that it exhibits a high level of accuracy hence there is minimal errors between the prescribed and achieved load-displacement function. The major problem is that it requires regular maintenance which can be tedious and expensive.



Key: 1-gude shaft; 2-pedestal; 3-cam; 4-linear bearing

Figure 12: Quadratic Torsion Spring [18]

3.3 Functional Decomposition

The main function of the pitch actuator system is to control rotation of the ducted fans in the Fan Flyer at constant speed of approximately 5500 RPM. However, there will be a variation in the fan blade pitch in each fan so as to vary the fan thrust and create forces for maneuvering. The action of the system will be broken down further in the functional model by each step that is carried out including the individual input and output. However, the functional decomposition is of great significance in the design process since it will help in the analysis of various tasks and design subsystems that will be integrated to ensure that the device operates in an effective manner.

3.3.1 Black Box Model

The use of a Black Box model is very crucial since it allows for a full scale understanding of what the system requires to accomplish. In this case, the system is simplified to the basic inputs and outputs, such as materials, energy, and signal. This enabled the team to focus on the basic elements and make sure that the device addresses the needs of the client in a successful manner. I respect to this project; the black box model will show how electrical and mechanical energy will be converted to kinetic energy to facilitate motion of the linear actuator. The Black Box model presented in the figure below shows all materials that enter and exit the system. This means that no material stays in the system. The input for the Black Box is DC energy and wind energy whereas outputs are heat and sound. Lastly, a signal to control rotation of the ducted fans and variation in the pitch of the blade.

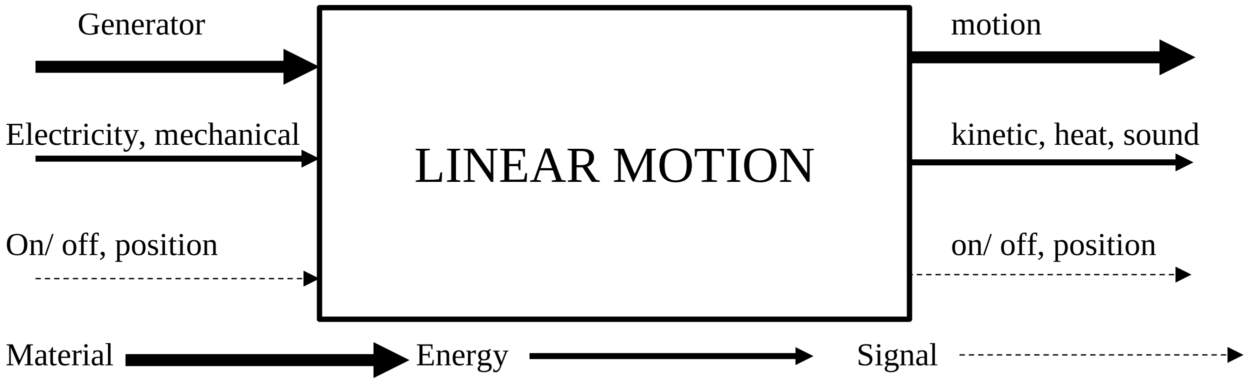


Figure 13: A black box Model

3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

This section is a description of the functional model for the pitch actuator system. The functional model is a breakdown of how the team theorized the working of pitch actuator system. the functional model is of great significance since it helps one to understand the sub functions and subsystems of the design. As a result, the team is able to conduct detailed research on the various systems and sub-systems which will be incorporated. The data is derived from the black box model whereby the material, energy, and signals were analyzed. The pitch actuator system creates pitch angle demands through the actuator subsystems. The major role of the pitch control system in the Fan Flyer is to monitor and adjust rotor blades angle. These blades are responsible for the rotational speed of the blades in the flyer. In this regard, the pitch actuator system adjusts the blades by rotating them, so they are able to produce optimum amount of energy hence resulting in the efficient power output. The DC motors which have a high rotational speed will give the rotational power. By use of the functional model, it is evident that the various sub-systems of the pitch actuator system are highly interrelated to ensure that there is efficient operation.

engineering requirements, in order to facilitate operations.

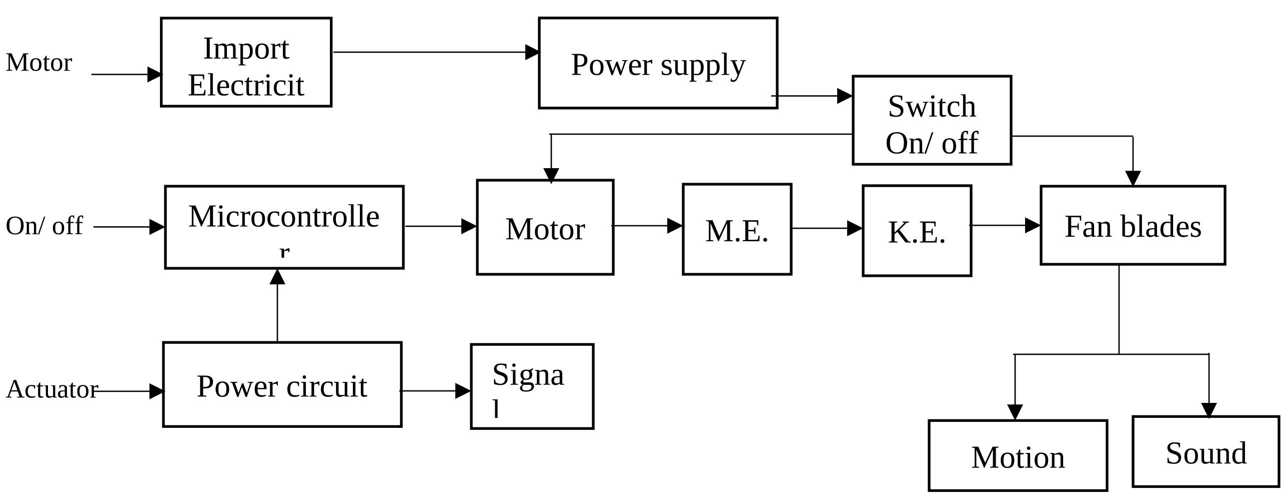


Figure 14: Functional Model

4 CONCEPT GENERATION

During the brainstorming process, the team generated a total of 10 different concepts based on the proposed customer and engineering requirements. The descriptions of these designs including their figures are below.

4.1 Full System Concepts

The team generated the full systems that include: Hydraulic pitch system; and electric pitch system.

4.1.1 Full System Design #1: Hydraulic pitch system

This design is of a hydraulic pump comprising of specialized control valves and distribution blocks of pressure. The major casing of the piston is to attach to the hub whereas the extendable part is attached to a pivot. In order to maintain the required fluid pressure, the hydraulic pumps must be operating frequently thus facilitating effective control. The design is crucial since it generates great force and there is no need for gears. The major challenge is increased incidences of leakage.

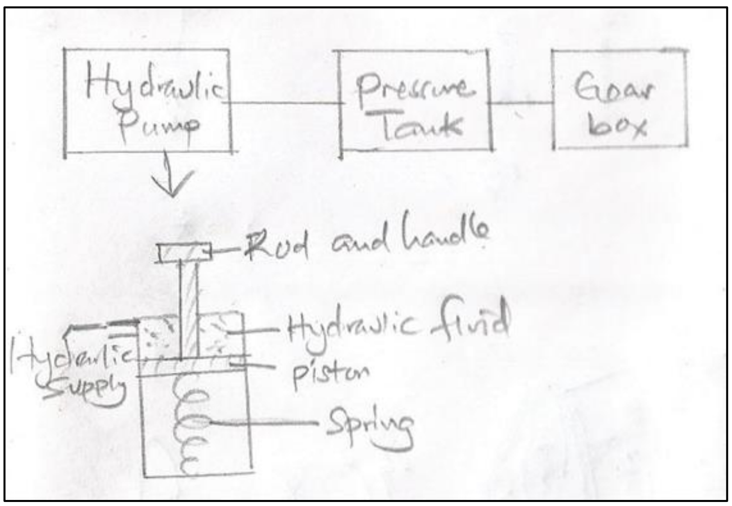


Figure 15: Hydraulic Pitch System

4.1.2 Full System Design #2: Electric pitch system

This design system starts with a specialized electronic programmable logic controller (PLC). The PLC has a task of controlling the servo motor drives which in turn operate the stepper motors. The major benefit of this design is that it is efficient in operating and require minimal maintenance. The major challenge is that the design is dependent on electricity and its components are quite expensive.

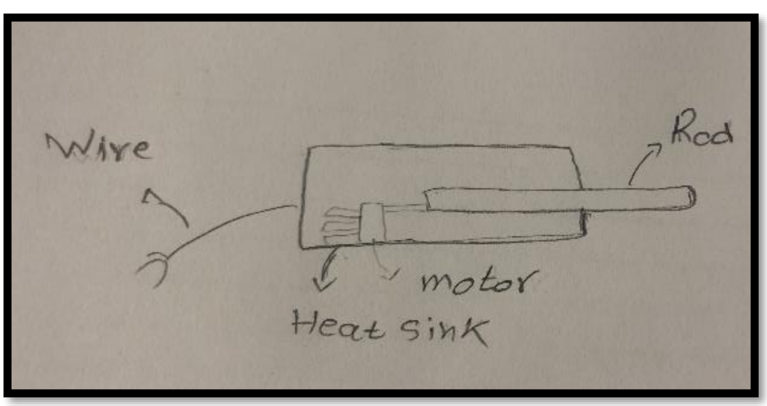


Figure 16: Electric pitch system

4.2 Subsystem Concepts

The subsystem concepts are the ones which assist the major systems in their operations so that a device can perform in an effective manner. In this project some of the concepts which the team came up with include: Heat sink, Bearing, Gears, Springs

4.2.1 Subsystem #1: Heat sink

The team developed two design to reduce the heat transfer to increase the duty cycle of the device.

4.2.1.1 Design #1: Fin design heat sink

Fins which are arranged in a vertical manner and at the same time compacted in a small area characterize the design presented in Figure 18. The material used to make this design of heat sink is copper since it has outstanding heat sink properties in regard to thermal conductivity and resistance to corrosion and biofouling. The major challenge with this design is that copper is quite expensive. In this project, a heat sink will be very effective since it will help to dissipate the amount of heat that is generated by the coils in the motor due to force and ambient conditions. This will in turn ensure that the linear actuator operates in an efficient manner. Fins are effective for a heat sink since they have a large surface area which ensure great interaction with the surrounding air.

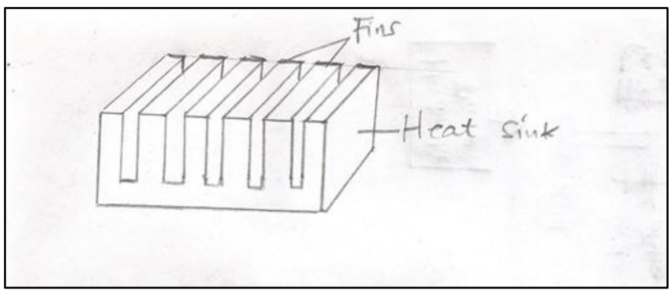


Figure 17: Fin design heat sink

4.2.1.2 Design #2: Fan design heat sink

This design is comprised of a fan which is attached to a motor. When the motor is powered, it rotates and consequently makes the fan to rotate at a very high speed. The rotating motion of the fan leads to transfer of heat from where it is highly accumulated to the areas where there is less accumulated. The design is appropriate since it is easy to assemble. The major challenge is that it is not durable. Schematic diagram of the fan-based heat sink is shown in Figure 27. The fan design heat sink will be crucial to the project since it will help to lower the amount of heat generated by the motors. The fan design is effective since the wind generated by the rotating action of the blades makes constant flow of air resulting to instant cooling.

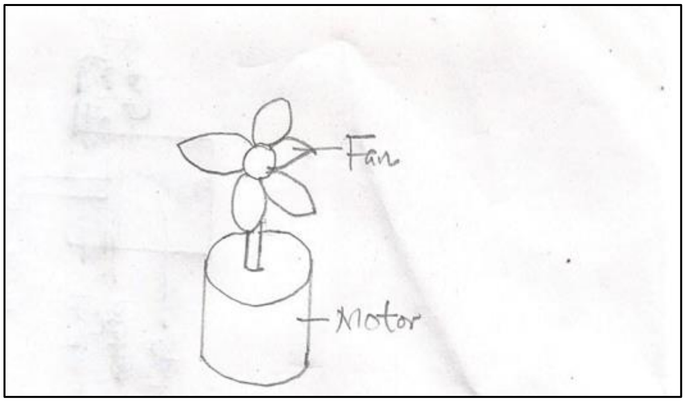


Figure 18: Fan design heat sink

4.2.2 Subsystem #2: Bearing

Two design have developed for hydraulic and electric actuator that can fit and will help for reducing the fraction of the rotation.

4.2.2.1 Design #1: Cylindrical Roller Bearings

In this design the cylindrical rollers which are used contact in a linear manner with the raceways. The major strength of this design is that it has a high radial load capacity and is very appropriate for high speeds. Cylindrical roller bearings are effective in this project since they have a higher radial load capacity, have a high mechanical efficiency, and is easy to maintain.

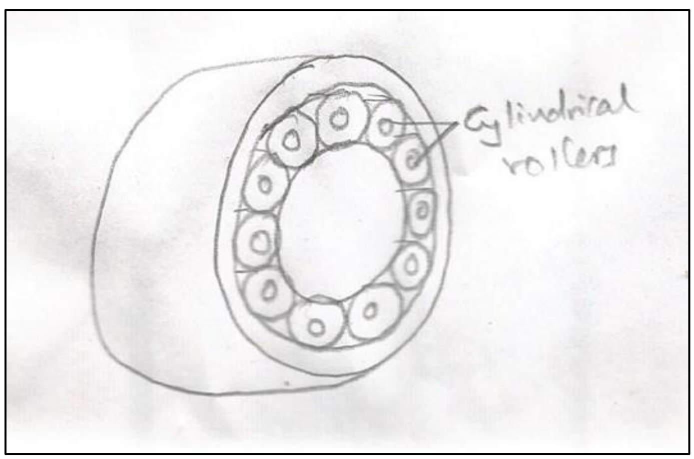


Figure 19: Cylindrical Roller Bearings

4.2.2.2 Design #2: Thrust Roller Bearings

This design is comprised of convex rollers which are contacted to the raceways in a linear manner. they are made from brass hence making them to be strong and durable. The fact that this kid of roller bearing has as a high axial rigidity makes it suitable for supporting extremely heavy loads. Their convex nature makes them to be self-aligning and are not prone to errors as a result of shaft deflection. They will be applicable in the project since they ensure that the shaft leading to the blades is able to rotate under heavy load conditions with less deflection hence high level of accuracy.

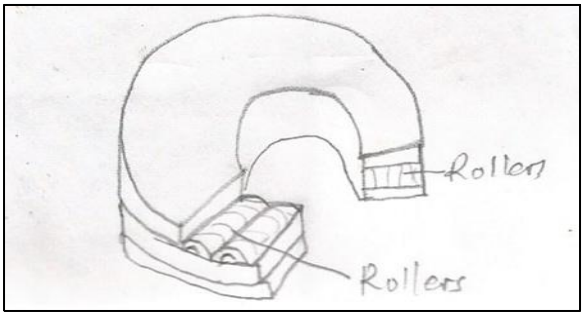


Figure 20: Thrust Roller Bearings

4.2.3 Subsystem #3: Gears

The gear consisted for electric system and it will fit in the motor and drives the screw.

4.2.3.1 Design #1: Spur Gears

Cylindrical gears with a straight tooth line which is parallel to the shaft characterize this type of gear design. These gear designs are of great significance since the exhibit a high degree of accuracy hence minimizing incidences of errors. The major setback of this design is the fact that it cannot be used in instances where the load is big. This will be used in the project, I the moving parts of the device such as the shaft leading to the blades to ensure that there is less mechanical energy that is required.

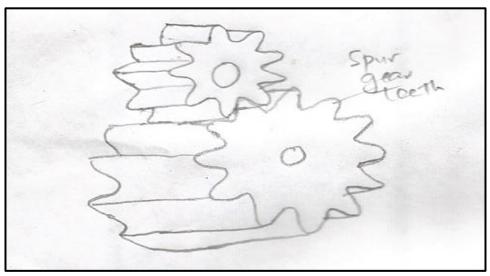


Figure 21: Spur Gears

4.2.3.2 Design #2: Helical gears

Helical gears are a certain category of gears which have winding tooth lines. The design is appropriate for the pitch actuator control for fan flyer since it has a better tooth meshing compared to other gear types. This design also suitable since it is able to withstand high speeds. The major challenge is that it can be prone to errors due to creation of a thrust force in the axial direction. In this project, it is effective since it will ensure there is a firm grip even in situations where there are heavy loads.

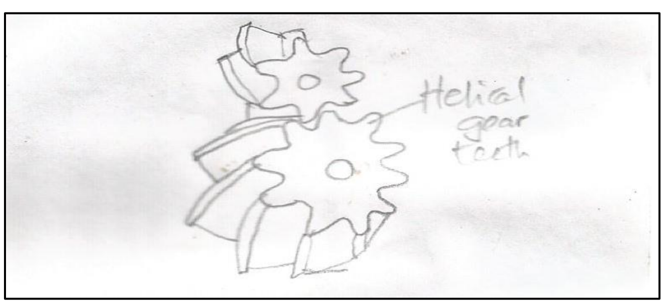


Figure 22: Helical gears

4.2.4 Subsystem #3: Springs

The springs will be consisted for a hydraulic actuator.

4.2.4.1 Design #2: Three springs design

In this design the three springs are to be arrange in a diagonal manner starting from the axle to the bottom plate as indicated in the figure below. The springs are arranging in such a manner that they are balancing the plate during rotation hence creating a state of balance. As a result, the blades are adjusted as they rotate such that they are able to produce optimum amount of energy hence efficient power output.

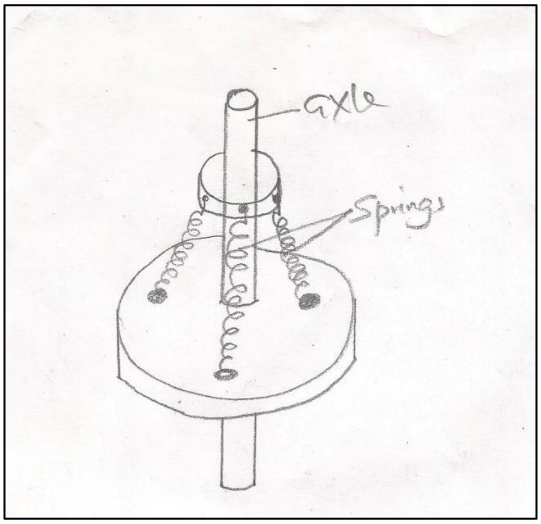


Figure 23: Aluminum rotor blade

4.2.4.2 Design #2: Quadratic springs design

This design is comprised of four springs which are to arrange in a vertical manner as presented in the diagram below. When there are four springs there is less linear angular deflection and more torque.

torque and angular deflection are achieved for quadratic torsion spring configuration. However, in the fourth VSA, the relationship between output stiffness and is linear. This ensures that there is equal pressure distribution hence making the actuator to operate in an efficient smooth flow. The hydraulic pitch actuator system can comfortably integrate this design into the system.

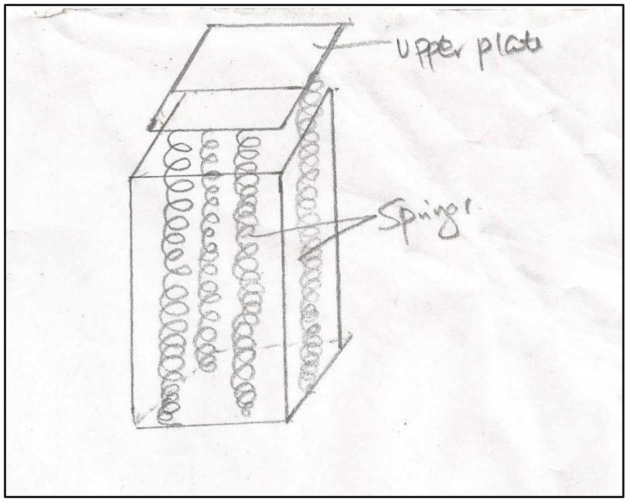


Figure 24: Composite rotor blade

5 DESIGN SELECTED – First Semester

All the concepts presented in Section 4 will be evaluated to develop the final design. A detailed method by which the team arrived in the final design concept are in the following subsection which includes the parameters based on which these concepts has been evaluated. After conducting the analysis, the concept of Hydraulic pitch system turns out to be the best possible solution which is presented in the Figure 22. The team will further develop the 3D cad model as well as the prototype of this concept.

This section discusses the concept chosen and the process used in the selection process. In this case, the processes used to select the design are the Pugh Chart and Decision Matrix.

5.1 Technical Selection Criteria

In order to ensure that the team selected the most appropriate design, they concentrated on the concept which met most of the customer requirements. The customer requirements include: reliability of actuator, durability of materials, actuator size, safe to operate, actuator weight, efficiency of device, steer rod travel rate, actuator force, and motor power. The engineering requirements include: tough material; 4in height, 14in length, 4 in width, stroke length, over current protection (a), a mass of 2 lb., 100% duty cycle, actuation speed of 1 in per sec, force to move rod of 25 lb., a motor of 12V.

5.2 Rationale for Design Selection

Two methods in selecting the most appropriate design and they are Pugh Chart and Decision Matrix.

5.2.1 Pugh Chart

In order to analyze the 10 concepts, a Pugh Chart as presented in Appendix B below gave the team an idea of what to choose. The client gave an existing concept and is the DATUM since it had fulfilled most of the customer and engineering requirements. In instances whereby, a certain concept surpassed the datum in regard to customer requirements, it was awarded a plus (+), whereas the one which failed to exceed was awarded a minus (–). An “S” was awarded to the concepts which showed a similarity in customer requirement. In each design a total of the symbols awarded the meaning was given below each concept. After using the Pugh chart, four designs were selected to have met the customer and engineering requirements and were to be analyzed by use of a decision matrix. These concepts include: concepts 1, 3, 5, and 8 which are hydraulic pitch system, three springs design, fin design heat sink, and cylindrical roller bearings.

5.2.2 Decision Matrix

After narrowing down the 10 concepts using a Pugh Chart, a decision matrix helped to determine the most appropriate design. The decision matrix entailed a table (Table 3) whereby customer requirements are on the list on the left and were varying weights based on their importance to the design. A scale of 1-5 was adopted whereby 1 had low importance 3 medium importance and 5 high importance. The various concepts rate is chosen by referencing the customer requirements on the same scale of 1-5. Then the rate is the product of the weight awarded in each case and the total score determined as presented in the table 5 below. After this analysis the 1st concept that is the hydraulic pitch system emerged the best since it has the highest score of 75. The team determined the back-of-the-envelope calculation for the angle of attack. The equation used for

$$\alpha = \left(\left(\frac{2W}{\rho V^2 S_{ref}}\right) - C_{L_0}\right)\left(\frac{1}{C_{L_\alpha}}\right)$$

elow.

Where,

α is the angle of attack.

ρ is the density of the wind.

W is the weight of object.

V is the true air speed.

S_{ref} is the reference area.

C_{L0} is the coefficient of lift at 0 degrees angle of attack

$C_{L\alpha}$ is the change in lift due to angle of attack

Table 4: Decision Matrix

Criteria	Weight	Concept 1		Concept 3		Concept 5		Concept 8	
		Score	WS	Score	WS	Score	WS	Score	WS
Efficient	5	5	**25**	4	**20**	3	**15**	4	**20**
Travel rate of 1" per second	5	4	**20**	3	**15**	4	**20**	3	**15**
Overall travel of 1.5"	4	3	**12**	3	**12**	4	**16**	3	**12**
Maximum force of 25lbs	3	4	**12**	4	**12**	3	**9**	4	**12**
Weight of 2lbs	2	2	**4**	3	**6**	2	**4**	2	**4**
Lightweight	1	2	**2**	3	**3**	2	**2**	2	**2**
Total			**75**		**68**		**66**		**65**

5.3 *Analytical Summaries*

In the Analytical report, team three analyzed four different aspects of the linear actuator. The aspects are motion study, motor analysis, power analysis and thermal analysis.

5.3.1 Motion Study: Khaled Alazemi

The motion analysis of the mechanism is carried out in solid works software. The appropriate mate (constraints) were made between components, blades hinged, linkages hinged, Frame grounded (fixed). Piston constrained to move linearly. As the piston moves the guide moves linearly which in turn moves the linkages, the linkage is connected to blades which causes the blade to rotate. The amount of rotation is controlled by the linkage length connected the guide and blade and the arm length provided on the blade. The zero position and the deployed position of the blades is shown in figure 8 and 9 respectively. The configuration with 1.5-inch stroke to achieve 60 degree of blade rotation is done by varying linkage length manually in solid works software.

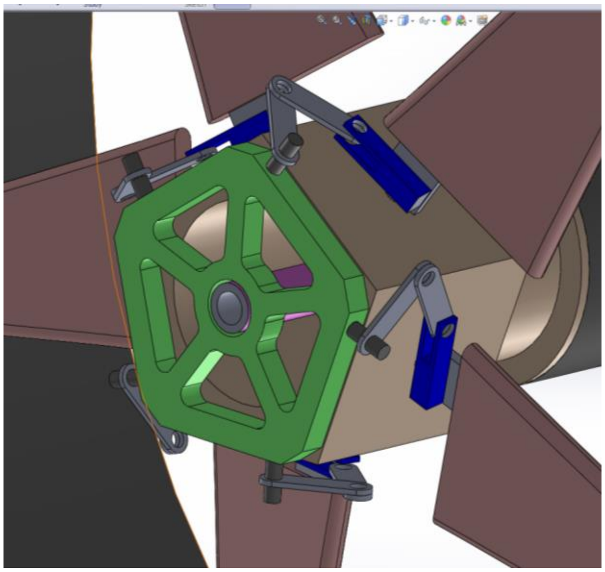


Figure 25 Mechanism in stowed condition.

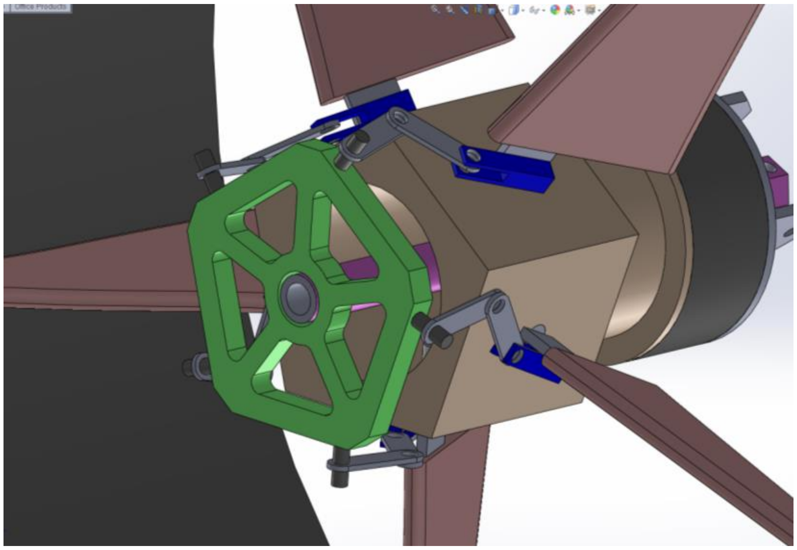


Figure 26 Mechanism in fully deployed condition

5.3.2 Motor Analysis: Faisal

In this analysis Faisal found the power needed in our motor to hold and lift the weight.

$$w = \int_0^{1.5} f dx$$

Where w is the work needed, f is the force applied and dx is the distance. Dave Willie gave Faisal this equation.

$$w = \int_0^{1.5} 25dx$$
$$w = 25(1.5) = 37.5\ lb - in$$

To convert lb-in to kwh. 1 lb-in is 3.1385E-8 kWh. So, 37.5 ln-in is **1.176925E-6** kWh [#]
So, from that Faisal get the power in kw using the time needed to travel 1.5 in. the time is 1 sec.
$P(\text{kW}) = E(\text{kWh}) / t(\text{h})$ [#]
Where power P in kilowatts (kW). energy E in kilowatt-hours (kWh), and t is the time in hour.

$$P(\text{kW}) = 1.1769\text{E} - 6 / 0.000277778$$
$$P = 0.004Kw$$

With safety factor of 10 the power needed is 0.04 Kw

5.3.3 Power Analysis: Ali

A design has been completely specified for a fractional horsepower motor that will be able effortlessly to comply with the specified terminal and performance characteristics governing fan blade mass and range of motion and applicable onboard power supply considerations.

As per the specified conditions for the Linear Actuator as specified below:

- Travel rate: 0.0254 m/s
- Overall travel: 0.0381 m
- Max actuator force: 111.2 N.
- Duty cycle: 100%, or continuous duty cycle
- Power: Electric, 120 volts DC

5.3.4 Thermal Analysis: chris

The actuator is design with a motor inside the device, aluminum casing and steel used for the rod that will be actuating the device. The thermal heat is generated from the motor and has a duty cycle of only 10 percent, meaning, as the motor is on for 2 minutes, it will need to rest for 18 mins. The motor will generate a lot heat and this will cause the motor to burn out if it’s not shut off for the allotted time.

The convection heat transfer equation of the motor and the casing. The Actuator has a gap before it contacts the outside edge of the aluminum, there is convection occurring in the actuator. The heat transfer coefficient is dependent on the materials between convection.

From this analysis we found that heat transfer depends on materials that will be used and also ways to increase the heat transfer rate so the motor does not burn out. Thermal analysis experimenting will take place in a few weeks and hope to conclude the findings that founded in this documentation.

5.4 Design Description

After a meeting with the client, there were a variety of concerns that were exposed to the original design that was developed by the team. In order to resolve these problems as evidenced in the original design, they had to adhere to the request of the client. However, the hydraulic linear actuator has the ability to deliver high force due to high pressures associated with it. instance, 3-inch, and 5-inch bore cylinders at 2200 psi are able to gain about 15,000 lbf and 43,000 lbf respectively. Hydraulic actuators are also tough and are able to withstand harsh conditions. For instance, they can handle shock loads. Despite all these benefits, the team selected the electrical actuator since it is the choice that was made by the client.

Since the electric linear actuators are supposed to convert the rotary motion into a linear motion the design has a gearbox and a lead screw which are the major components of an electric linear actuator. The voltage is applied at the stator assembly. The voltage is then converted into a current that is propelled into the rotor assembly, which operates as the secondary operations. There is also the DC Servo Motor which is responsible for linear motion. There are also gears that are used to turn the cylinder hence promoting linear motion.

Team three went to Dr. Trevas to get his help on what is the best gear ratio for the project. He advises the team to choose a gear ratio of 40:1. After that, the team search for gear with that ratio and found a worm gear that fits the design and has a ratio of 40:1 as shown in figure 25. In addition, fun flyer team chose a motor with 0.04 kW output in figure 26. The team chose this motor based on motor analysis. The power screw will be manufactured in the machine shop at NAU but for now, will use that screw which provided from the client in figure 27. A limiting switched should be considered for testing. A limit switch will prevent the stork from going over 1.5 in. Also, the actuator is connected to the switchblade by a screw in the piston as shown in figure 28 where the arrow shows that. The bottom side is connecting by a shoulder bolt as given from the client. The team developed full CAD design in figure 29 and its dimensions as shown in Appendix B

Figure 25 Gearbox [25]

Figure 26 Motor [26]

Figure 27 acme screw

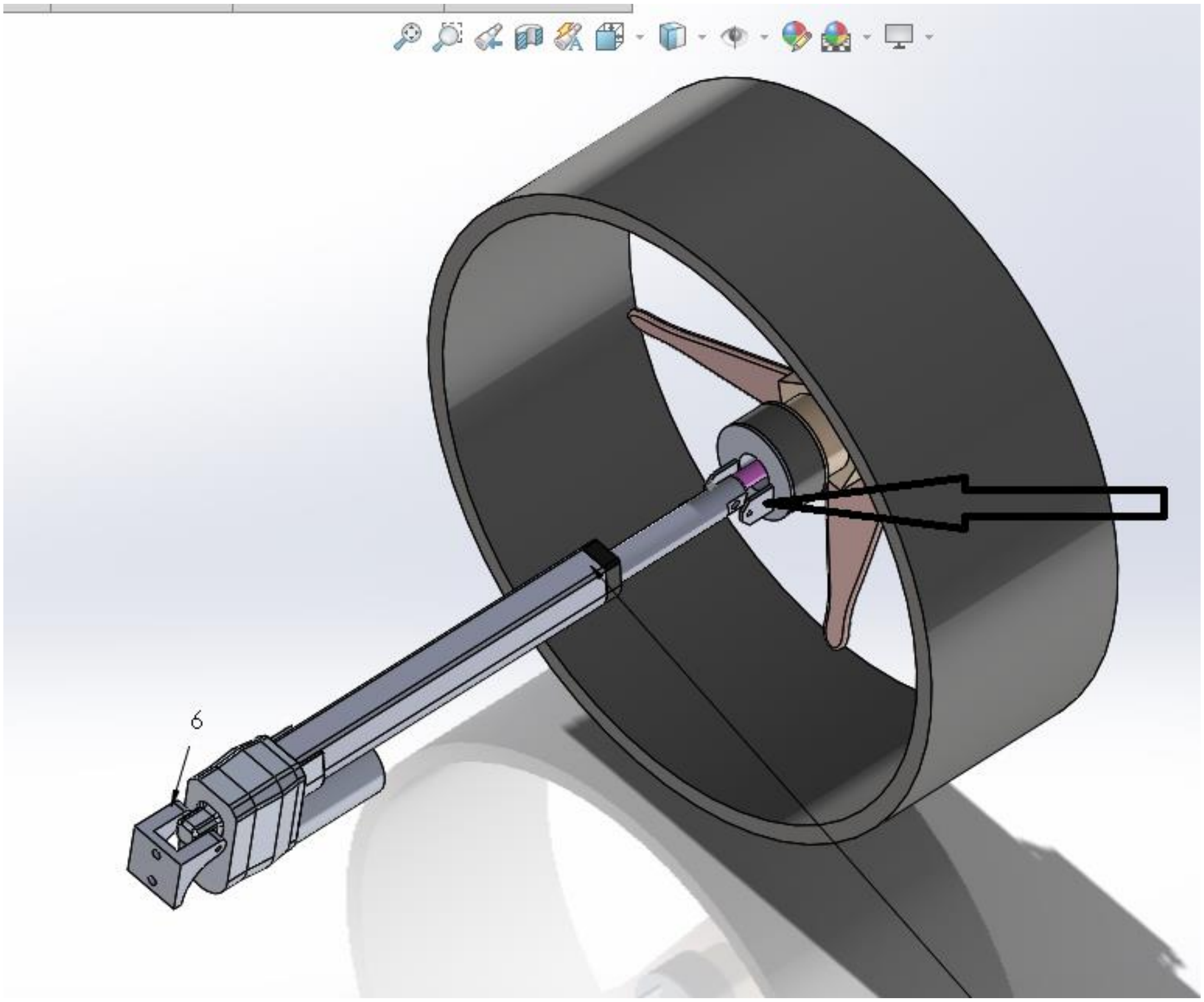
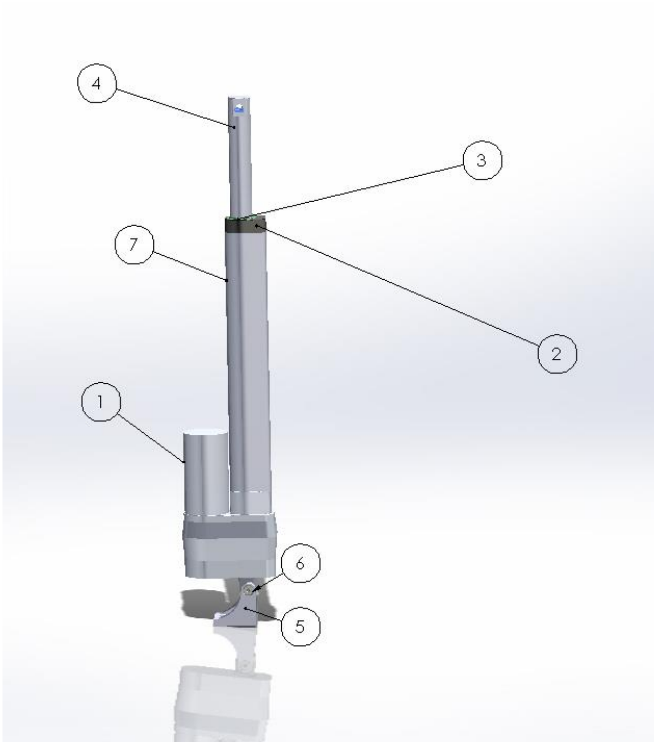


Figure 28: How the actuator connecting to FanFlyer



ITEM NO.	PART NUMBER	QTY.
1	HDA-BASE	1
2	HDA-SHROUD-CAP	1
3	HDA-CAP-SEAL	1
4	HDA-STROKE_8IN	1
5	HDA Clevis Mount	1
6	Shoulder Bolt .25 x 1 - 10-24	1
7	HDA-SHROUD-8INCH	1

Figure 29: Final Design

6 IMPLEMENTATION PLAN – First Semester

This section describes the processes that were used in the manufacturing and assembly of the linear actuator system.

6.1 Manufacturing

The team used the 3D printing method so that they make sure that the electric linear actuator and all parts will fits together also will use to manufacturing all the components for prototyping in machine shop Lab at NAU. The design specification was based on the strength and durability of the material. The linear actuator was supposed to be able to handle the weight of the DC Servo Motor in figure 26. In order to ensure that the size of the actuator was able to fit in the fan flyer, the team ensured that the design adopted was small and light in weight and not larger than 4”x4”x14”. The team also ensured that the design weight did not exceed 2 lbs. It was crucial to use gears to facilitate movement and as a result, the efficient gearbox ratio is 40:1.

6.2 Purchasing components

The team selected the DC Servo Motor in figure 26 to be used in the Fan flyer. However, the motor and the gearbox will be purchased online and this was arrived at after being advised by Dr. David Trevas. In the case of the lead screw, the team will build a acme screw and test it for future analysis. The team followed a strict schedule for their manufacturing and this enabled them to stay on track in the course of the project. The team ensured that all deadlines were met regarding manufacturing.

7 REFERENCES

[Include here all references cited, following the reference style described in the syllabus. There should only be one Reference list in this report, so all individual section or subsection reference lists must be compiled here with the main report references. If you wish to include a bibliography, which lists not only references cited but other relevant literature, include it as an Appendix.]

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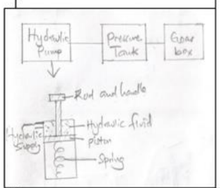
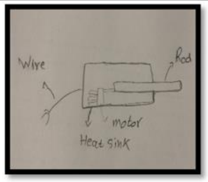
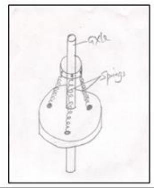
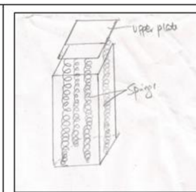
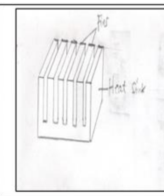
8 APPENDICES

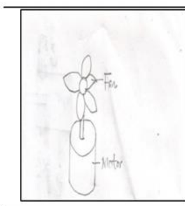
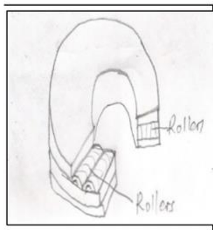
8.1 Appendix A: Pugh chart

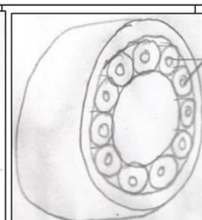
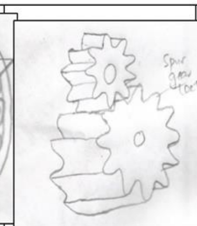
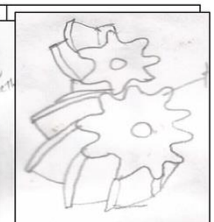




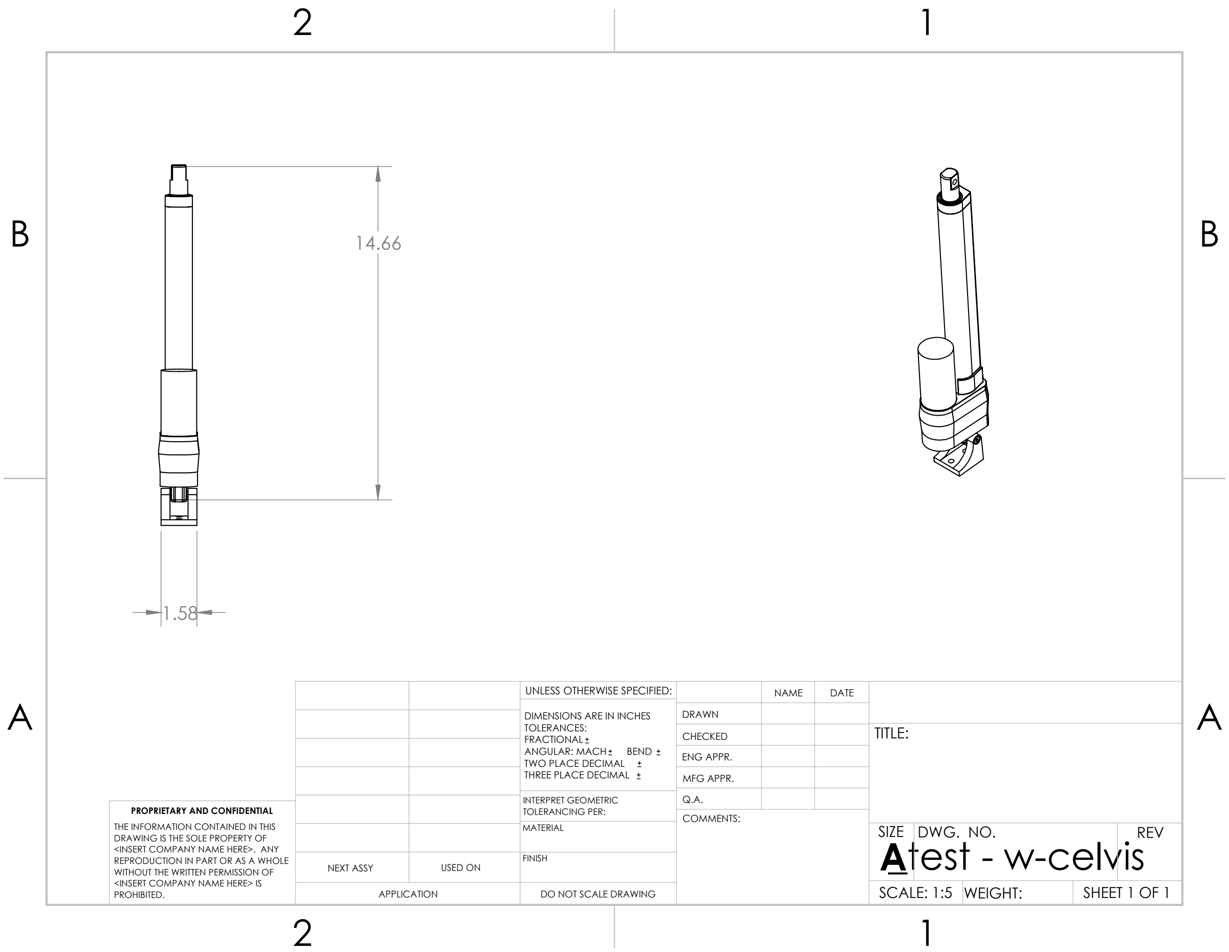
Requirements	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Reliability	+	S	S	-	-
Durability	+	-	+	S	+
Actuator Size	S	S	-	S	S
Safety	S	S	S	+	+
Weight	-	-	+	S	-
Efficiency	+	+	+	S	S
Steer Rod Travel Rate	S	+	S	-	+
Actuator Force	S	-	-	S	S
No. of '+'	**3**	**2**	**3**	**1**	**3**
No. of '-'	**1**	**3**	**2**	**2**	**2**
No. of 'S'	**4**	**3**	**3**	**5**	**3**
Score	**2**	**-1**	**1**	**-1**	**1**

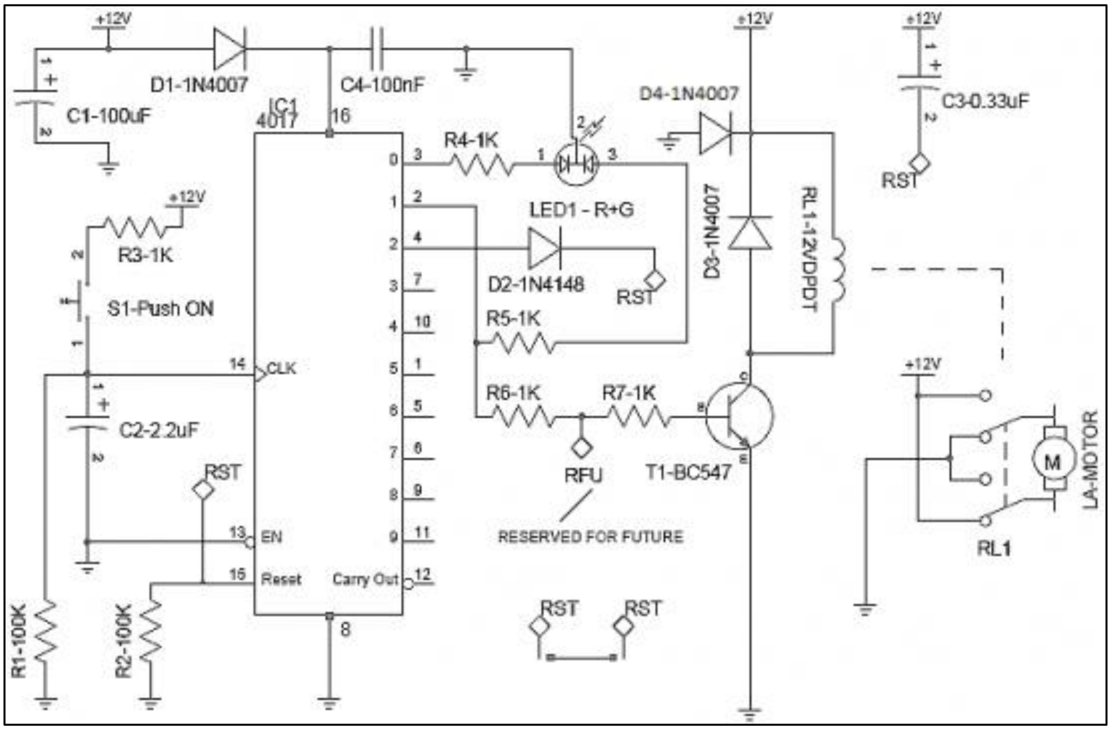




Requirements	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10
Reliability	-	S	S	S	+
Durability	S	+	+	S	S
Actuator Size	-	-	S	-	S
Safety	S	S	+	S	S
Weight	S	+	-	-	S
Efficiency	S	+	S	S	S
Cost	S	-	+	+	-
Actuator Force	S	-	S	S	S
No. of '+'	**0**	**3**	**3**	**1**	**1**
No. of '-'	**2**	**3**	**1**	**2**	**1**
No. of 'S'	**6**	**2**	**4**	**5**	**6**
Score	**-2**	**0**	**2**	**-1**	**0**

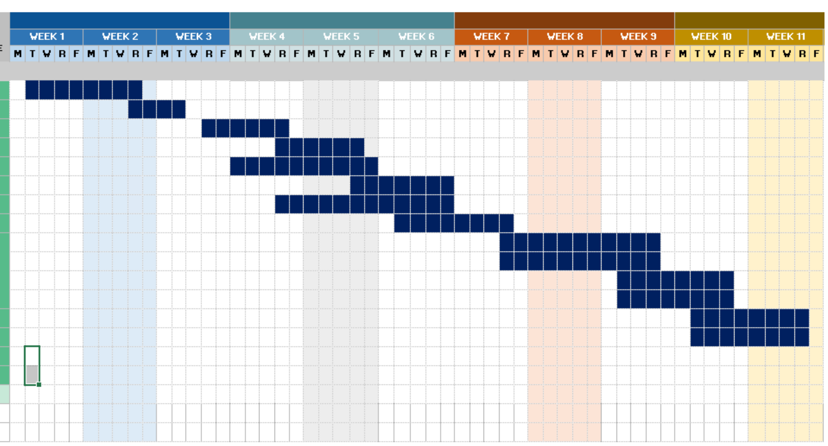
8.2 Appendix B: CAD dimension


2
1
B
A
14.66
1.58
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
A
test - w-celvis
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

8.3 Appendix C: Control circuitry of a linear actuator



8.4 Appendix D: Gantt Chart



PROJECT TITLE	Fan Flyer	COMPANY NAME	Jim Corning
PROJECT TEAM LEAD	Faisal	DATE	4/16/19

VBS NUMBER	TASK TITLE	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
1	**Project Steps**				
1.1	Meet The TA	1/22/19	1/31/19	9	100%
1.2	**Presentation 1**	1/31/19	2/5/19	5	100%
1.3	Team Staff meeting 2	2/14/19	2/21/19	7	100%
1.4	Team/ Staff meeting 3	2/21/19	2/28/19	7	100%
1.5	**Preliminary Design Report**	2/17/19	3/3/19	16	100%
1.6	**Website Check 1**	2/28/19	3/8/19	8	100%
1.7	**Presentaion 2**	2/21/19	3/8/19	17	100%
1.8	**Analysis Memo**	3/5/19	3/14/19	9	100%
1.9	Staff Meeting 4	3/14/19	3/28/19	14	100%
2	**Website Check 2**	3/14/19	3/28/19	14	100%
2.1	**Analytical Reports**	3/26/19	4/4/19	8	100%
2.2	Staff Meeting 5	3/26/19	4/4/19	4	100%
2.3	Peer Eval 2	4/2/19	4/11/19	3	100%
2.4	Team/ Staff meeting 6	4/2/19	4/11/19	0	100%
2.5	Team/Staff Meeting 7	4/16/19	4/25/19	0	100%
2.6	**Final Report**	4/17/19	4/26/19	0	100%
2.7	**Website 3 Check**	5/1/19	5/2/19	0	80%
2.8	**Bill of Materials**	5/1/19	5/2/19	0	70%
2.9	**CAD Model**	5/1/19	5/2/19	0	70%

8.5 Appendix E: Summer Schedule (Notional)

PROJECT TITLE	Fan Flyer	COMPANY NAME	Jim Corning
PROJECT TEAM LEAD	Faisal	DATE	4/16/19

WBS NUMBER	TASK TITLE	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE	WEEK 1					WEEK 2		
						M	T	W	R	F	M	T	W
1	Staff meeting 1												
1.1	Staff meeting 2				100%								
1.2	Staff meeting 3				100%								
1.3	Staff meeting 4				100%								
1.4	Staff meeting 5				100%								
1.5	Hardware Review 1				100%								
1.6	Staff meeting 6				100%								
1.7	Staff meeitng 7				100%								
1.8	Midpoint Presentations				100%								
1.9	Hardware Review 2				100%								
2	Staff Meeting 8				100%								
2.1	Final Product Testing				100%								
2.2	Ugrad Practice				100%								
2.3	Ugrad Practice				100%								
2.4	Team Meeting				100%								

8.6 Appendix F: Bill of Materials

Bill of Materials

Materials	Part No.	Manufactor	Description	Number of part:	Cost per Part	Total Cost
Servo Motor	T404-012	Sanmotion	Servo Motor	1	$ 132.25	$ 132.25
GearBox	T404-012	IronHorse	IronHorse heavy-duty worm gearbox, 40:1 ratio	1	$ 208.00	$ 208.00
Steel Rod	ASTM A36	Discount Steel	12L14 Cold Rolled Steel Rou	1	$ 10.61	$ 10.61
Aluminum Rod	ASTM B221-08 6061-T6	Discount Steel	Aluminum Rod	1	$ 24.67	$ 24.67
Power Screw	-	-	-	1	$ -	$ -

8.7 Appendix G: Budget

Project Budget Reporting

PROJECT TITLE	Fan Flyer	**CLIENT**	Jim Corning
PROJECT TEAM LEAD	Faisal	**DATE**	4/17/19

Total Budget : $ 500.00

***NOTE THIS BUDGET PLAN IS A ROUGH ESTIMATE**

Expenses	Plan ($)	Actual ($)	Date Recorded	Purchaser
Manufactured parts	$ 100.00	$ 6.76		
3D Part	$ 10.00	$ 6.76	4/15/2019	Khaled
	$ -	$ -		
	$ -	$ -		
	$ -	$ -		
	$ -	$ -		
Aluminum Bar	$ 75.00	$ -		
Steel Bar	$ 150.00	$ -		
Materials used	$ 50.00	$ -		
Motor	$ 100.00	$ -		
Unused	$ 25.00	$ -		
Total For parts	**$ 500.00**	**$ 6.76**		
Total Budget Remaining	**$ 493.24**			