Fan Flyer 3

Preliminary Report

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DISCLAIMER

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1 BACKGROUND

1.1 Introduction

In this project the client requires the team to design and prototype a pitch control actuator for the fan blades of a Fan Flyer. The ducted fans will be operating at 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 rotor blades angle. These blades are responsible for ensuring that the rotational speed of the blades in the flyer. However, the pitch actuator system adjusts the blades through their rotation so that they are able to capture the optimum amount of wind energy hence facilitating efficient power output. The DC motors which have a high rotational speed will provide the rotational power for the fans. 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 the customer has detailed. These 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. Successful completion of this device is crucial since it will help the client and the users in 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”x12” so that it is small ad light in weight.

1.3 Original System

In this project the team is going to make an original new system and the team is focus on developing a pitch control actuator for the fan blades of a Fan Flyer.

“This project involved the design of a completely new pitch control actuator for the fan blades of a Fan Flyer disability aid product. There was no original system when this project began.”

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. To start with is the customer requirements as explained below.

2.1 Customer Requirements (CRs)

Customer requirements are the various forms of requests which the clients 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 due to a lot of experience regarding the operation of the device. They have a lot of ideas on the strengths and weaknesses of the device. This is very crucial since clients and users contribute feasible views regarding how the device is to made, and how it relates to the customer requirements. The customer requirements for each portion is a list in the table 1 below.

Customer requirement	**Weight**
Reliability of Actuator	6
Durability of Materials	6
Actuator Size	9
Safe to Operate	9
Actuator Weight	6
Efficiency of Device	3
Steer Rod Travel Rate	9
Actuator Force	6
Motor power	6

Table 1: Customer Requirements for pitch control actuator

Discussion

1. Reliability of Actuator

The device should at any one moment fail 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 last for a long period of time. Also, such materials will enable the device to withstand extreme weather conditions.

3. Actuator Size

This is very crucial in this case as it is going to determine the efficiency of the device in relation to weight. In this regard, 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 therefor 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. The actuator should be within the proposed weight requirements. This is crucial since it will make the device light hence facilitating its movement during operation.in this case the weight must not exceed 2 lbs.

6. Efficiency of Device

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

7. Steer Rod Travel Rate

The travel rate should be applied as determined by the team and in this case is 1.5” per second.

8. Actuator Force

The force should be effective in facilitating linear motion and this should be determined ground rig testing of the spring.

9. 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 which 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 so that during later stages of analysis and interpretation they can make work easier. Table 2 below shows the list of engineering requirements.

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

Table 2: 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.

2. Height

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

3. Length

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

4. Width

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

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

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

7. Mass

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

8. Duty Cycle

The system should have a duty cycle of 100% and this means that there is maximum efficiency during operation.

9. Actuation Speed

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

10. Force to move Rod

A force of 25 lb. will push the rod and hence ensure appropriate power output.

11. Motor

The device will make use of a motor which has 12 Volts to facilitate rotation of the shaft and hence provide efficient power output.

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.

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 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 facilitate 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 list on the left and weighted in respect to their importance on a scale of 3 to 9. 3 is the lowest on importance whereas 9 is the highest on significance. Weak, medium and strong correlation between the customer requirements and the engineering requirements is represented by use of symbols +, -, and no correlation are empty respectively. The factor of weight is multiplied by the correlation value. The value obtained is summed up at the bottom to get the absolute technical importance (ATI). The engineering requirement with the highest ATI number will be placed first in Relative Technical Importance (RTI) and this continues until the lowest ATI is obtained at last. The House of Quality is as show in the Appendix A.

3 DESIGN SPACE RESEARCH

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

3.1 Literature Review

This part shows a discussion of the various activities which the various team members conducted to accomplish the project. Every member was to use at least five sources and a summary of the source in each section. The sections are below and provide a good overview of the resources each student used.

3.1.1 Student 1 (Faisal)

a) Mechanical Actuators [6]

Mechanical actuation is the most commonly used method for producing linear motion and is extensively used in industrial plants, workshops etc. There is however a limitation in terms of losses due to friction between mechanical parts and sufficient arrangement for lubrication is to be made.

b) Principles of engineering design [1]

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.

c) Operating systems: internals and design principles. Pearson [2]

The book focuses on the design principles which are incorporated in engineering projects.

d) The Vital Roles of a Pitch Control System [3]

The source is focusing on how the working of a pitch control system. in this case, the pitch angle gets transferred to the hydraulic cylinder or motor thus enabling the actuator to position the blade to the proper angle.

e) Wind turbine load mitigation [4]

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 automatic blade pitch control system for wind turbines used as electrical generators connected to the electrical grid.

3.1.2 Student 2 (Khaled)

Khaled conducted a research on the already existing designs of pitch actuator systems. Some of the resources he used are as follows:

a) Professional journal [5]

This source is focusing on hinge control actuator system. 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.

b) Valves and Actuators [19]

This book focusing in gears, springs, valves and dc motor of the actuator and how to calculate the force and torque of the device.

c) Shigley's mechanical engineering design [20]

This book is the official source for ME365 machine design class in NAU. 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.

d) professional article [21]

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

e) control of a system with the switched actuator rate limitation [22]

This article is a study to control the duty cycle of actuator and the over current limitation for safety purposes.

f) Engineering book [2]

The book focuses on the principles of design which are incorporated in any form of an engineering project.

g) Website [6]

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.

h) Discussion with a lab assistant

In this case Khaled made consultations with the lab assistant so that he can derive significant details related to the design of the device.

i) Academic journal

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.

3.1.3 Student 3 (Ali)

The major focus of Ali is on the most appropriate bearings which could be used on the moving parts of the pitch actuator system. some of the sources he used are as follows.

a) Engineering book [2]

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.

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.

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, ad comprising of a sliding bearing and a shaft, without re-lubrication.

d) Website [10]

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.

e) Interviews

The interviews with clients enabled the team to know the appropriate customer requirements which should be incorporated in the project.

3.1.4 Student 4 (Chris)

Chris focused on the motors which was to be incorporated in the system in reference to the engineering requirement. In this case the team require a motor which is able to supply a voltage of 12V. the following sources were used.

a) Conducting interviews to the client

Chris conducted an interview to the client so that he can get exact details regarding the most appropriate mortar that was to be used in the system.

b) Holding discussion with the lab assistant

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

c) Engineering book [1]

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.

d) Website [11]

The source is focusing on a continuous DC motor and how it is used to provide power to facilitate continuous movement of the shaft.

e) Website [12]

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.

3.2 Benchmarking

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

3.2.1 System Level Benchmarking

The following section gives a description of the already existing designs which have requirements related to 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 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 linear actuator connects to the linear part and operates the whole pitch control system. The major challenge with this design is that it is heavy [13].

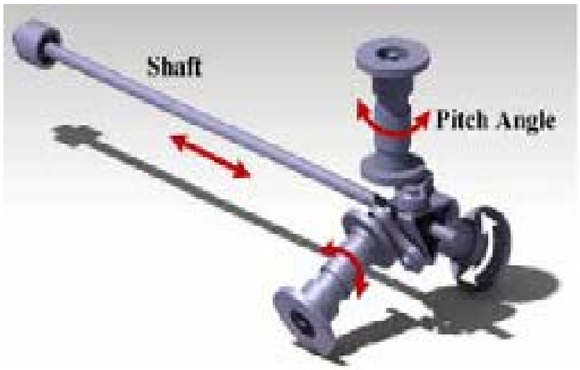


Figure 1: Hinge control actuator system [13]

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 hold strong against mechanical stresses such as wind hence facilitating electromechanical actuation system. the major con is that it is quite expensive.

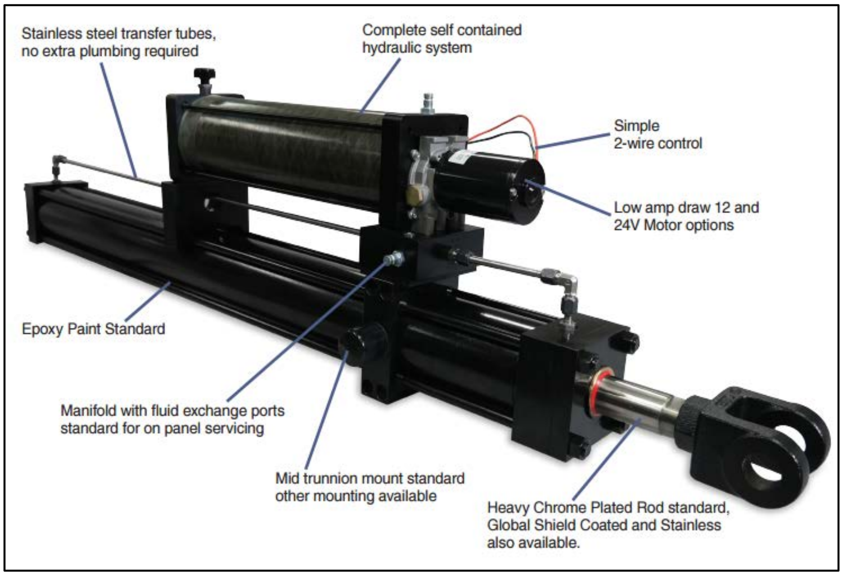


Figure 2: Hybrid Actuation System (HAS) [14]

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 one 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 to manufacture.

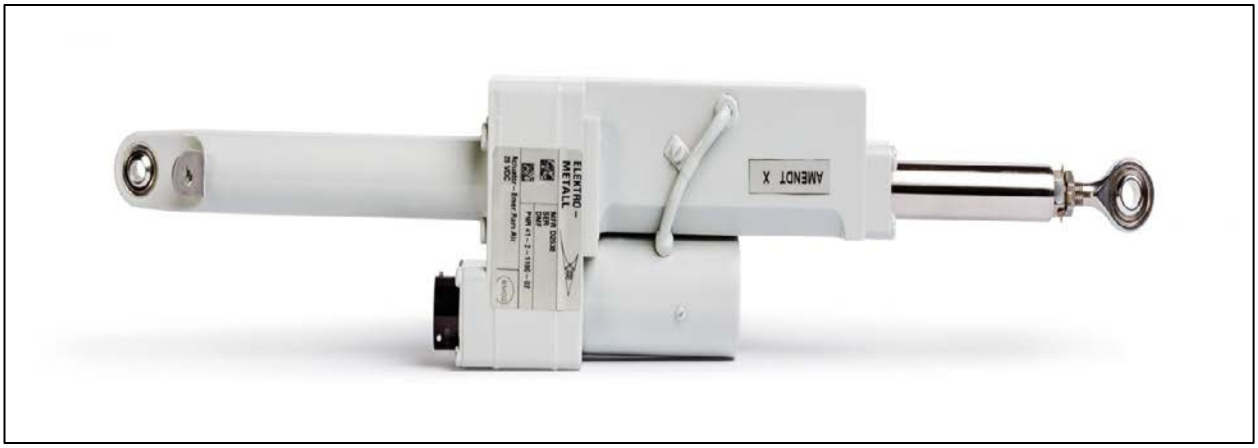


Figure 3: Linear Actuator - ERAIA 41-2 [14]

3.2.2 Subsystem Level Benchmarking

This section will discuss the different subsystems used to make pitch control actuator. 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 components of the pitch actuator system to facilitate efficiency bearings.

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 radial loads third the amount of side or axial load. 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.

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.

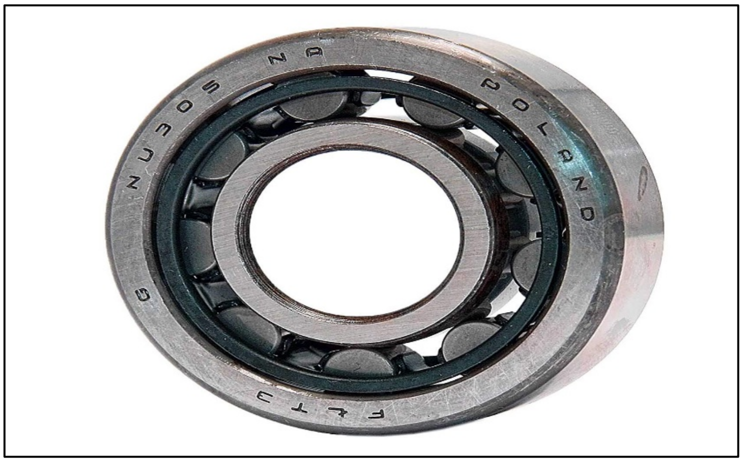


Figure 5: NU305 Cylindrical Roller Bearing [15]

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.

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.

3.2.2.2.1 Existing Design #1: Continuous DC motor

DC motor will provide power to facilitate continuous movement of the **shaft.**

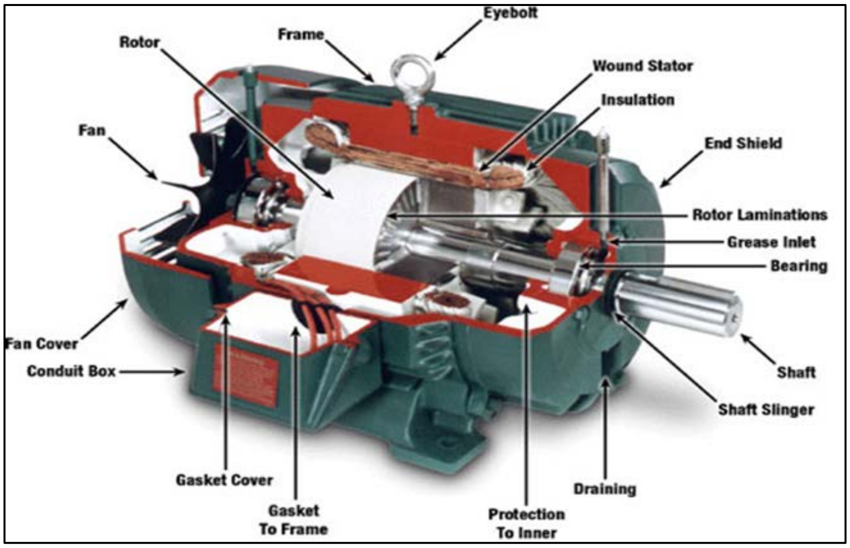


Figure 7: Continuous DC Motor [11]

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.

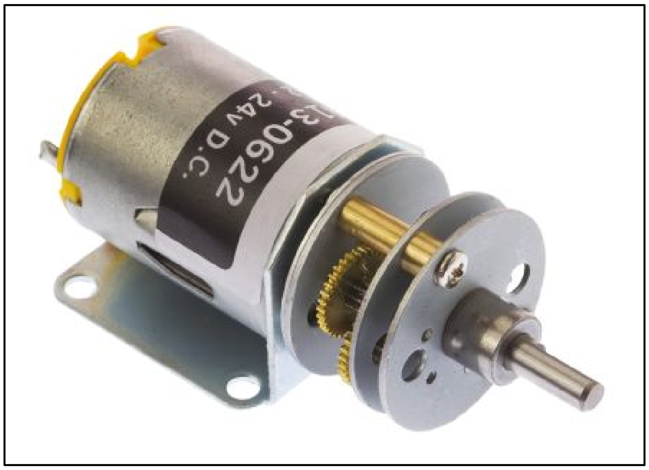


Figure 8: RS PRO, 12 V Brushed DC Geared Motor [12]

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 very applicable to high demanding applications. It has an efficiency of over 90% ad has an output Speed of 221 rpm.

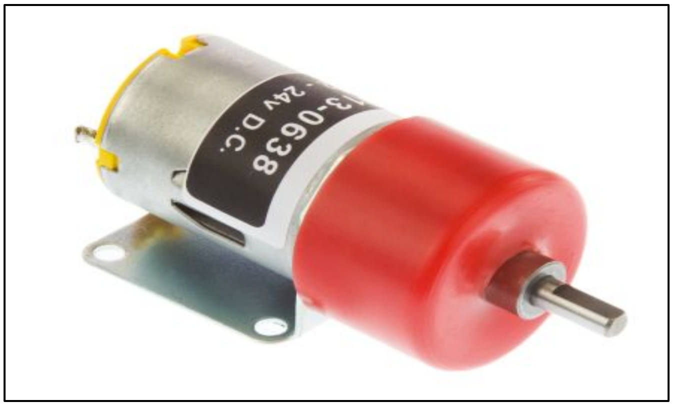


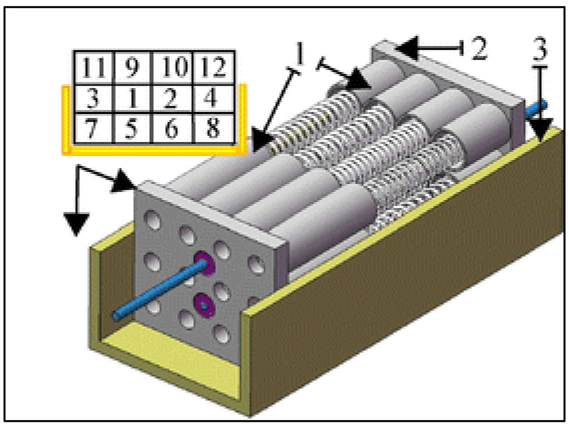
Figure 9: RS PRO, 12 V Brushed DC Geared Motor [12]

3.2.2.3 Subsystem #3: Spring design

The Heat sink will be to dissipate the great heat emitted by the system during operation.

3.2.2.3.1 Existing Design #1: Quadratic compression spring

This design is comprised of compression springs which are set in parallel manner. 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 sprig set pedestal in such a manner that they do not touch each other to reduce friction as shown in the figure below.

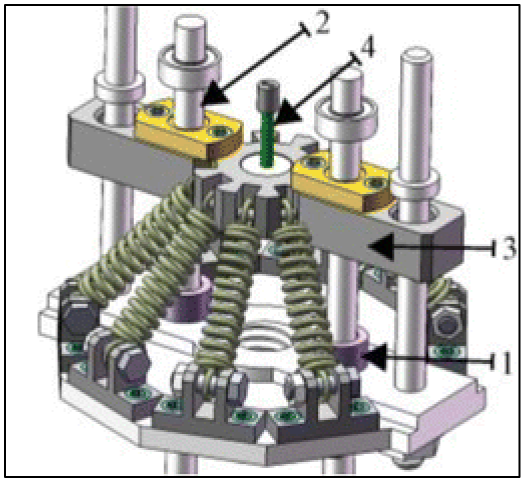


Key: 1-spring pedestal guide sleeves; 2-spring set pedestal; 3-guide grove.

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. The arrangement s as shown in the figure below.

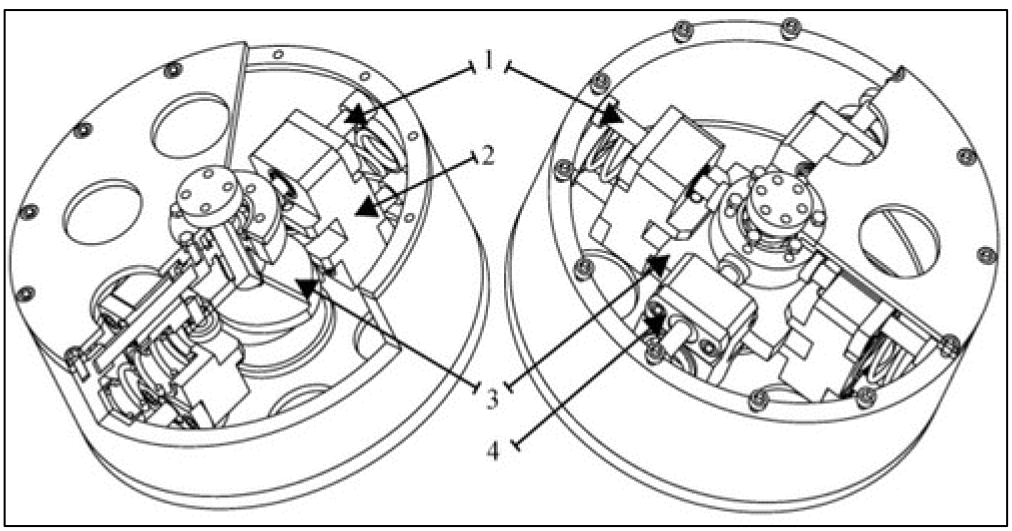


Key: 1- bulge; 2-guide rod; 3- pedestal; 4- cable

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. The arrangement is as shown in the figure below.



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.

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. 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.

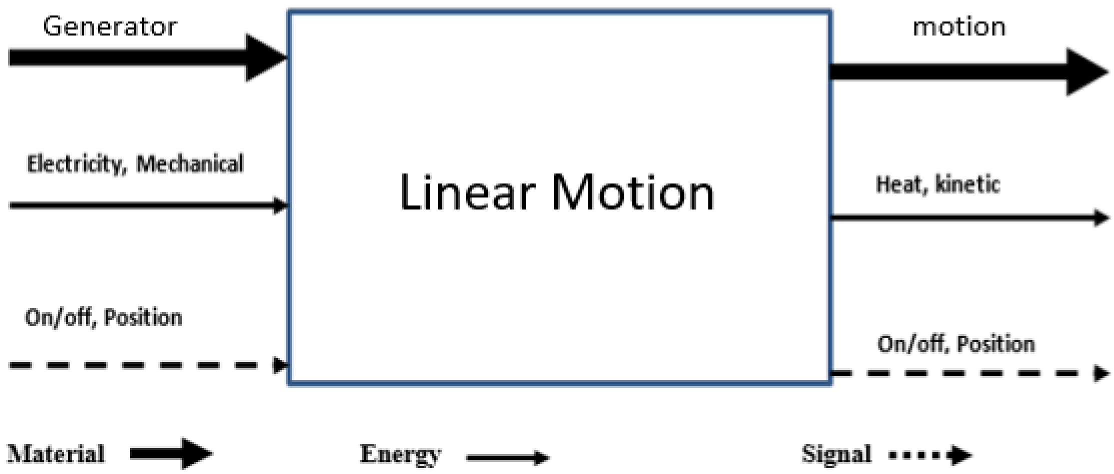


Figure 13: A black box Model

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

In this section there is a description 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. However, 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 subsystem. 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 facilitating 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 capture the optimum amount of wind energy hence resulting in the efficient power output. The DC motors which have a high rotational speed will give the rotational power in the application. By use of the functional model, it is evident that the functionality of the pitch actuator system device is crucial for being able to meet requirements for power usage as described in the engineering requirements, in order to facilitate operations.

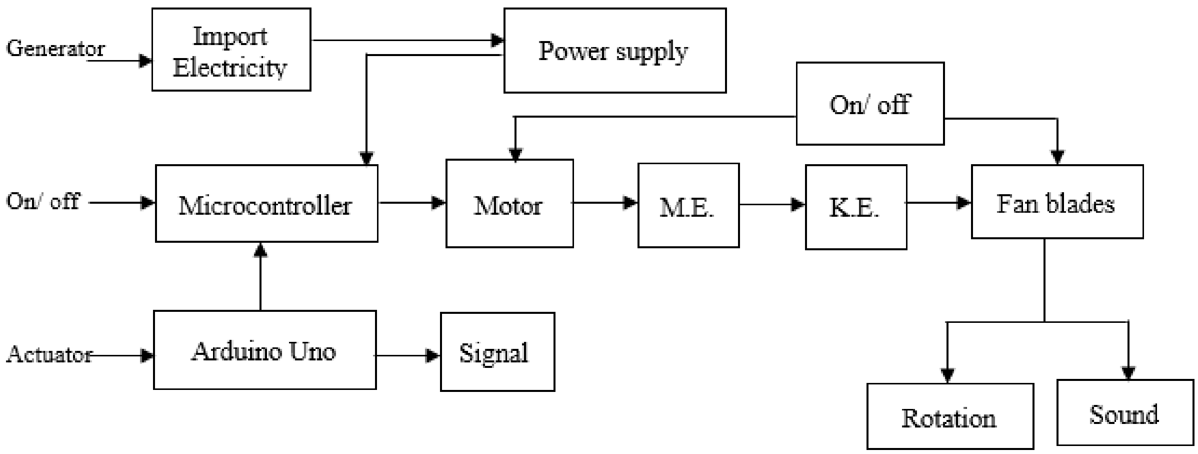


Figure 14: Functional Model

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 a lot of force and there is no need of gears. The major challenge is increased incidences of leakage.

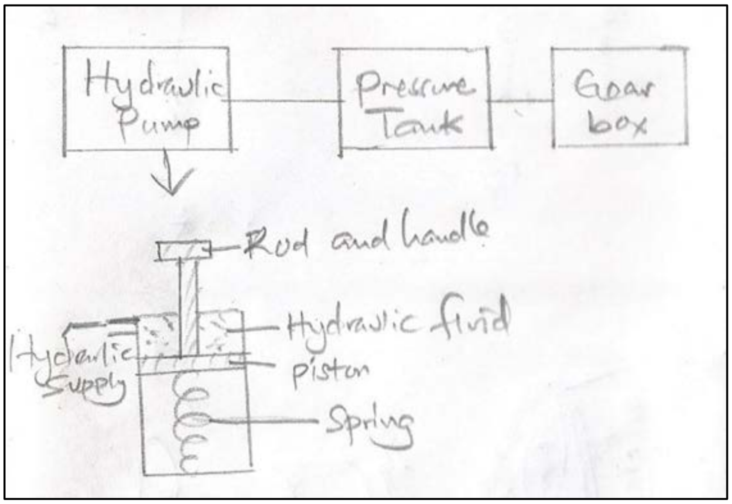


Figure 15: Hydraulic Pitch System

4.1.2 Full System Design #2: Electric pitch system

This design is of a power source of a battery. The battery is to charge from an external source or from an on-board solar panel. The battery is to connect to a rectifier and a converter which are responsible for converting the DC current into an alternating current. The major benefit of this design is that it is efficient in operating and require minimal maintenance. The major challenge is hat at low temperatures batteries have low power and servicing might be cumbersome.

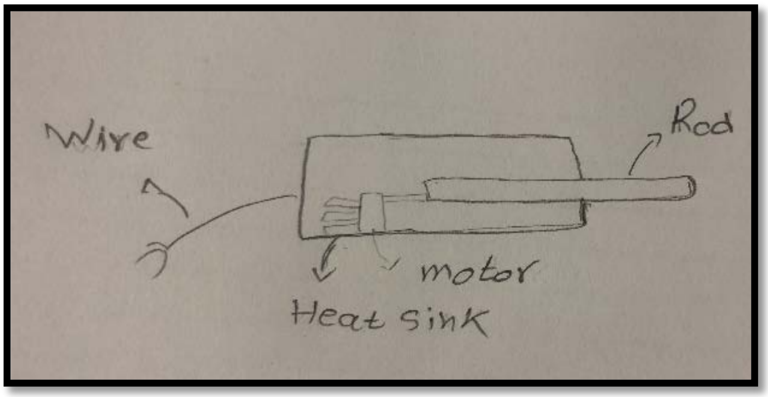


Figure 16: Electric pitch system

4.1.3 Full System Design #3: 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 sense of equilibrium

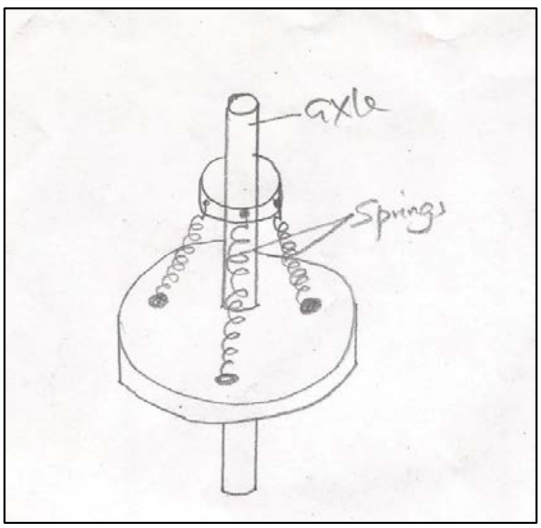


Figure 17: Aluminum rotor blade

4.1.4 Full System Design #3: Quadratic springs design

This design is comprised of four springs which are to arrange in a vertical manner as presented in the diagram below. 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.

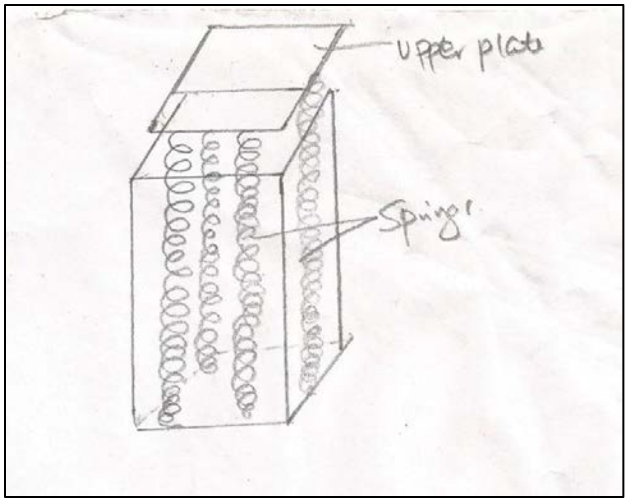


Figure 18: Composite rotor blade

4.2 Subsystem Concepts

The subsystem concepts that were developed by the team include:

4.2.1 Subsystem #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.

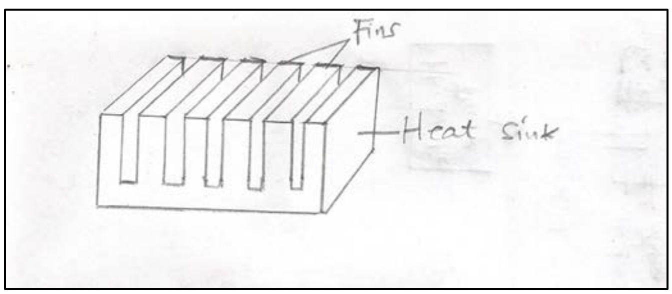


Figure 19: Fin design heat sink

4.2.2 Subsystem #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

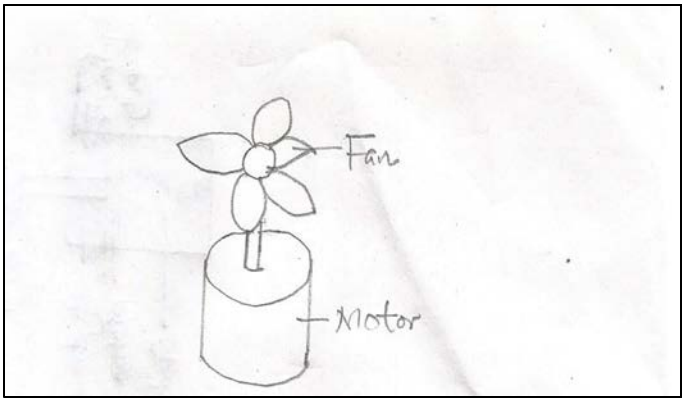


Figure 20: Fan design heat sink

4.2.3 Subsystem #3: 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.

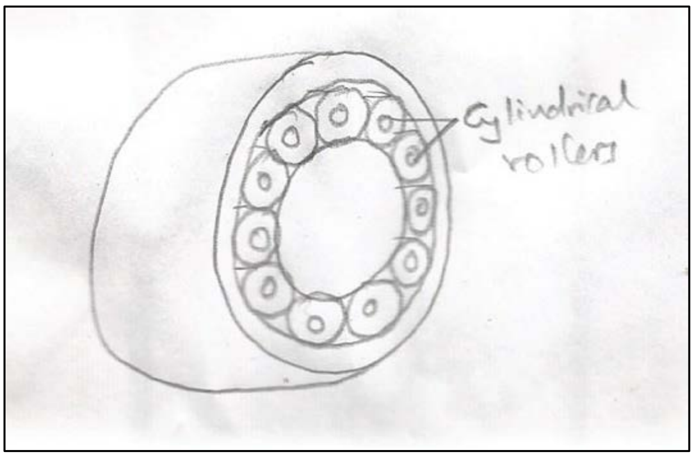


Figure 21: Cylindrical Roller Bearings

4.2.4 Subsystem #4: 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.

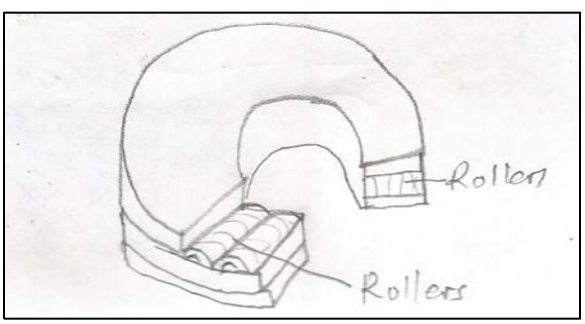


Figure 22: Thrust Roller Bearings

4.2.5 Subsystem #5: 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.

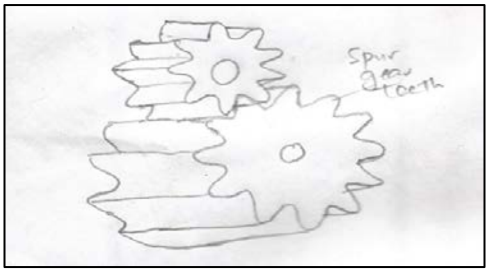


Figure 23: Spur Gears

4.2.6 Subsystem #6: 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 fun flyer since it has a better tooth meshing compared to other gear types. This design also is very 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.

Figure 24: Helical gears

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 all the analysis, 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 sleeted the most appropriate design they concentrated on the one which concept met 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 120v.

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.

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 whereby customer requirements are on the list on the left and were varying weights depending on their significance. 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.

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**

Table 3: Decision Matrix

6 REFERENCES

[1] Hubka, V. (2015). Principles of engineering design. Elsevier.

[2] Stallings, William, and Moumita Mitra Manna. Operating systems: internals and design principles. Pearson, 2015.

[3] Windurance (2018). “The Vital Roles of a Pitch Control System.” Matric. Retrieved from: https://blog.matric.com/pitch-control-system-basics

[4] Clint Coleman. "Wind turbine load mitigation." EP Patent No. EP0266715A2.

[5] Sung, Chang-Min, and Myung-Chul Han. "Design and performance evaluation of hinge type pitch control system in small-size wind turbine." International Journal of Precision Engineering and Manufacturing-Green Technology 3.4 (2016): 335-341.

[6] https://www.hydraulicspneumatics.com/blog/compact-hybrid-actuation-system-targets-renewable-energy-designs

[7] Cho, Seongpil, Zhen Gao, and Torgeir Moan. "Model-based fault detection of blade pitch system in floating wind turbines." Journal of Physics: Conference Series. Vol. 753. No. 9. IOP Publishing, 2016.

[8] Andersen, Jesper Lykkegaard, and Anton Bech. "Pitch gear." U.S. Patent Application No. 10/047,721.

[9] Beno, Pavel, et al. "The friction factor dependence on the load and revolutions in sliding bearings without relubrication." Tehnički vjesnik 23.4 (2016): 997-1001.

[10] https://www.nskamericas.com/types-2245.htm

[11] https://www.elprocus.com/difference-dc-motor-servo-motor-stepper-motor/

[12] https://ph.rs-online.com/web/c/automation-control-gear/electric-motors-motor-controllers-peripherals/dc-geared-motors/

[13] Sung, Chang-Min, and Myung-Chul Han. "Design and performance evaluation of hinge type pitch control system in small-size wind turbine." International Journal of Precision Engineering and Manufacturing-Green Technology 3.4 (2016): 335-341.

[14] Leah Scully (May 03, 2016). “Compact Hybrid Actuation System Targets Renewable-Energy Designs.” Hydraulics and Pneumatics. Retrieved from: https://www.hydraulicspneumatics.com/blog/compact-hybrid-actuation-system-targets-renewable-energy-designs

[15] https://www.rainbowprecisionproducts.com/single-row-ball-bearings-ss6000-stainless-series-c:-1_2_504.html#1

[16] https://www.amazon.com/Cylindrical-Roller-Bearing-25x62x17-Bearings/dp/B002BBGPXC?ref_=Oct_BSellerC_16411271_4&pf_rd_p=5a02f1dc-64d0-5bf8-a947-2808e9cc7b6d&pf_rd_s=merchandised-search-6&pf_rd_t=101&pf_rd_i=16411271&pf_rd_m=ATVPDKIKX0DER&pf_rd_r=NPZ7AZRFWJW8YDWFSJH5&pf_rd_r=NPZ7AZRFWJW8YDWFSJH5&pf_rd_p=5a02f1dc-64d0-5bf8-a947-2808e9cc7b6d

[17] https://www.rainbowprecisionproducts.com/87000_88000_wc88000_series_ball_bearings#1

[18] Guo, Jishu, and Guohui Tian. "Conceptual design and analysis of four types of variable stiffness actuators based on spring pretension." International Journal of Advanced Robotic Systems 12.5 (2015): 62.

[19] Thomas Howard Blair, "Valves and Actuators," in *Energy Production Systems Engineering* , , IEEE, 2017, pp.

doi: 10.1002/9781119238041.ch25
[20] Budynas, R. and Nisbett, J. (2015). *Shigley's mechanical engineering design*. New York, NY: McGraw-Hill Education.
[21] J. Gebauer and P. Kočí, "Measurements of features of the ducted fan as a possible actuator of a multi-copter vehicle," *2011 12th International Carpathian Control Conference (ICCC)*, Velke Karlovice, 2011, pp. 127-130.
doi: 10.1109/CarpathianCC.2011.5945831
[22] A. Baskys and V. Zlosnikas, "Control of system with the switched actuator rate limitation," *2009 13th European Conference on Power Electronics and Applications*, Barcelona, 2009, pp. 1-8.

7 APPENDICES

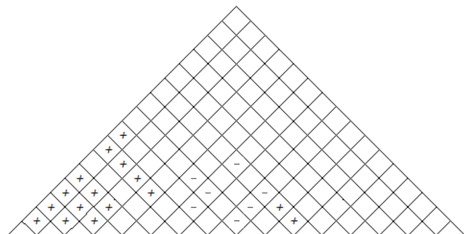
7.1 Appendix A: House of Quality

QFD: House of Quality
Project: FanFlyer Project 3
Revision: 2
Date: 02-13-2019

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

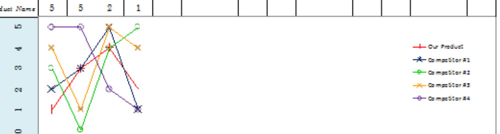


Row #	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements \ Engineering Requirements	1 Material Toughness (in-lbf/in3)	2 Actuator Height (in)	3 Actuator Length (in)	4 Actuator Width (in)	5 Stroke Length (in)	6 Over Current Protection (A)	7 Device Mass (lb)	8 Duty Cycle (100%)	9 Actuation Speed (>1 in per sec)	10 Force to move Rod (>95 lb)	11 Motor Voltage (V)	12	13	14	15	16	Our Product	Competitor #1 : *Product Name*	Competitor #2 : *Product Name*	Competitor #3 : *Product Name*	Competitor #4 : *Product Name*	Row #
				Direction of Improvement	▲	◇	◇	◇	▲	▼	▼	◇	▼	◇	◇											
1	10%	■	■	Reliability	○	○	○	○	○	●		●	○	○	○						3	3	4	1	5	1
2	10%	■	■	Durability of Materials	●				○		○	○									5	4	1	2	4	2
3	15%	■	■	Actuator Size	○	●	●	●	○		○										1	2	4	0	2	3
4	15%	■	■	Safety to Operate					○	●		●			○											4
5	10%	■	■	Actuator Weight		○	○	○			●															5
6	5%	3	■	Efficiency of Device						○		●			○											6
7	15%	■	■	Speed and Travel Rate					●			○	●													7
8	10%	■	■	Actuator Force	○							○	○	●	●											8
9	10%	■	■	Motor Power	○						○	○	○	○	●											9
10																										10
11																										11
12																										12
13																										13
14																										14
15																										15
16																										16

Customer Competitive Assessment

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Target	50	4	14	4	1.5		8	100%	1	95	12					
Max Relationship	■	■	■	■	■	■	■	■	■	■	■					
Technical Importance Rating	225	195	195	195	285	240	195	405	225	150	270					
Relative Weight	9%	8%	8%	8%	11%	9%	8%	16%	9%	6%	10%					
Weight Chart																
Our Product	1	3	4	2												
Competitor #1: *Product Name*	2	3	5	1												
Competitor #2: *Product Name*	3	0	4	5												
Competitor #3: *Product Name*	4	1	5	4												
Competitor #4: *Product Name*	5	5	2	1												

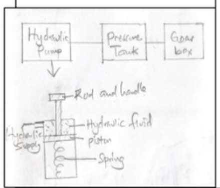
Technical Competitive Assessment

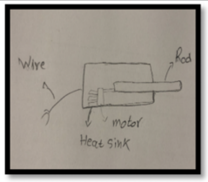


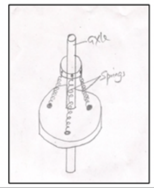
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

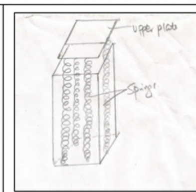
Template Revision: 0.9 Date: 4/22/2010
Christopher Battles

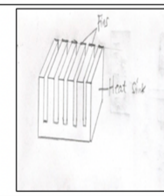
7.2 Appendix B: Pugh chart



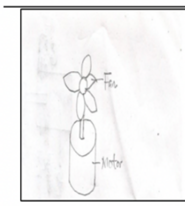


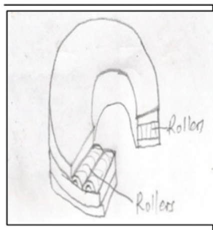


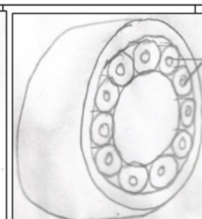


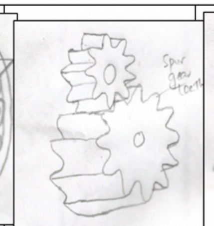


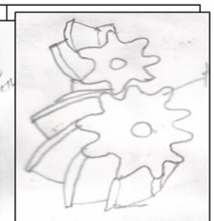
Requirements	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Reliability	+	S	S	-	-
Durability	+	-	+	S	+
Actuator Size	S	S	-	S	S
Safety	S	S	S	+	+
Weight	-	-	+	S	-
Efficiency	+	+	+	S	S
Steer Rod Travel Rate	S	+	S	-	+
Actuator Force	S	-	-	S	S
No. of '+'	**3**	**2**	**3**	**1**	**3**
No. of '-'	**1**	**3**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