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NUST COLLEGE OF ELECTRIAL & MECHANICAL ENGINEERING

DESIGN AND FABRICATION OF A PRECISION FIN ACTUATION CONTROL SYSTEM USING LEAD SCREW

PROJECT REPORT

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Submitted by

NS Muhammad Umair Khalid

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BACHELORS

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Assistant Professor Saheeb Ahmad Kayani

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ACKNOWLEDGEMENTS

First and foremost, we would like to express our heartfelt gratitude to Almighty Allah (SWT), the most gracious and beneficent, for bestowing upon us the strength and determination to undertake and successfully complete this project. We are truly grateful for the blessings and guidance received throughout our academic journey.

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Lastly, we humbly recognize the mercy and blessings of Almighty Allah, who has bestowed upon us the ability to carry out good works on Earth and to whom we all ultimately return.

ABSTRACT

Lead screws are mechanical components that are widely used for linear motion control applications in various fields. They are commonly used in systems such as syringe pumps and pan-and-tilt systems for security cameras. However, one of the most interesting applications of lead screws is in missile technology, where they are used to drive the fin actuation that guides a missile to its target.

In missile applications, precision miniature lead screws are utilized to position the sighting mechanism that identifies and acquires the target while the missile is maneuvering at high speed. The sighting mechanism is crucial for the missile to hit its target accurately. The lead screws also provide the actuation that controls the missile fins, which guide the missile's flight. The fins serve as the missile's wings, and using lead screws to position them enables fine positioning and control, maximizing speed and minimizing drag during transonic and supersonic flight.

Lead screws are also used for raising missile-launching systems and deploying sighting, range-finding, and antenna equipment. This helps to ensure that the missile is launched accurately, and that the necessary equipment is deployed at the right time.

In the past, hydraulic and pneumatic actuators were used for missile actuation purposes. However, precision-engineered miniature lead screws have replaced these actuators due to their high efficiency and reliability. Each lead screw assembly converts torque to thrust as the screw or nut turns to move the other component in a linear direction. The lead screw mechanism eliminates sliding friction and stick-slip, resulting in minimal maintenance requirements beyond initial lubrication. Lead screws automatically minimize the power required for missile-fin actuation due to their high efficiency. The size and weight of the fin drive transmission is also reduced, making lead screws a better option for small missiles and targeted munitions.

In conclusion, lead screws are crucial components in missile technology that enable precise positioning and control of the missile's fins, sighting mechanisms, and other equipment. Their high efficiency, reliability, and low maintenance requirements make them a superior option to traditional hydraulic and pneumatic actuators.

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LIST OF SYMBOLS

MFAC	Missile Fin Actuation System
NASA	National Aeronautics and Space Administration
NACA	National Advisory Committee for Aeronautics
C_g	Center of Gravity
C_P	Center of Pressure
SI	System International
V_f	Flutter-speed
G	Shear-Modulus
a	Speed of Sound
t	Wing-Thickness
c_r	Root-Chord
c_t	Tip-Chord
b	Semi-Span
P	Air-Pressure
AR	Aspect-Ratio
λ	Taper-Ratio
S	Wing-Area
T	Temperature
f	Frictional Force
d_m	Mean Diameter
l	Lead Length
p	Pitch
F	Force
N	Normal Force

CHAPTER NO. 1

INTRODUCTION TO MISSILE

1.1. Introduction

In military applications, a rocket refers to a guided airborne weapon designed for self-propelled flight, typically powered by a jet engine or rocket motor. Rockets are also known as guided rockets or smart rockets when previously unguided rockets are made guided. There are five major components of a rocket, including targeting, guidance, flight, propulsion, and warhead. Rockets come in various types adapted to different purposes, such as surface-to-surface and air-to-surface rockets (including ballistic, cruise, anti-ship, anti-tank, etc.), surface-to-air rockets (including long-range missile interception), aerial rockets, and anti-satellite weapons.

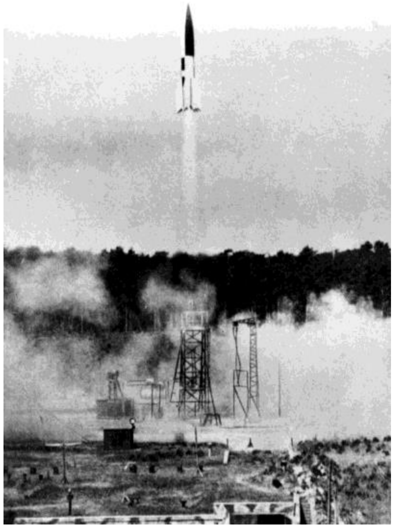

Figure 1-1 Missile Firing

Airborne explosive devices without propulsion are referred to as shells if fired by an artillery piece and bombs if dropped from an aircraft. Unguided missiles or rocket-propelled weapons are often described as rocket launchers. [1]

The term missile is used to refer to anything that is thrown, shot, or propelled towards a target. The first missiles were developed by Nazi Germany and reportedly operated during World War II. Among the famous missiles of that time were the V-1 flying bomb and V-2 rocket, both equipped with mechanical autopilots and pre-selected routes. The German V-II missile is a prominent example of missile technology developed during that period.

A missile typically comprises various system components, including guidance, targeting, and flight control systems, an engine or propulsion system, a warhead or payload, and fins or other control surfaces that enable the missile to steer and maneuver during flight. The guidance and targeting system enable the missile to locate and track a target, while the flight control system manages the missile's trajectory and position during flight. The propulsion system generates the thrust required to propel the missile through the air, while the warhead or payload is the component that delivers the destructive force to the target. The fins or other control surfaces are used to adjust the missile's direction and attitude, providing fine control over the missile's flight path.

Missiles consist of various systems, including the guidance, targeting, and flight control system, the propulsion system, the warhead, and the fins.

- The guidance system is responsible for controlling the missile's flight path and ensuring it reaches its intended target.

- The propulsion system provides the necessary thrust to propel the missile through the air, while the warhead delivers the payload upon impact.

- Fins are used to control the missile's direction and stabilize it during flight.

CHAPTER NO. 2

FIN AND ITS IMPORTANCE

2.1 Importance of Fins in a Missile Actuation System:

The fins can be said to be the wings of missiles. Almost all the missiles are equipped with at least a set of aerodynamic surfaces which are usually referred to as fins as they are essential in providing stability in flight. For enhanced control and additional lift, most of the missiles are also equipped with additional set of fins. Only a few missiles are equipped with fins on all three surfaces.

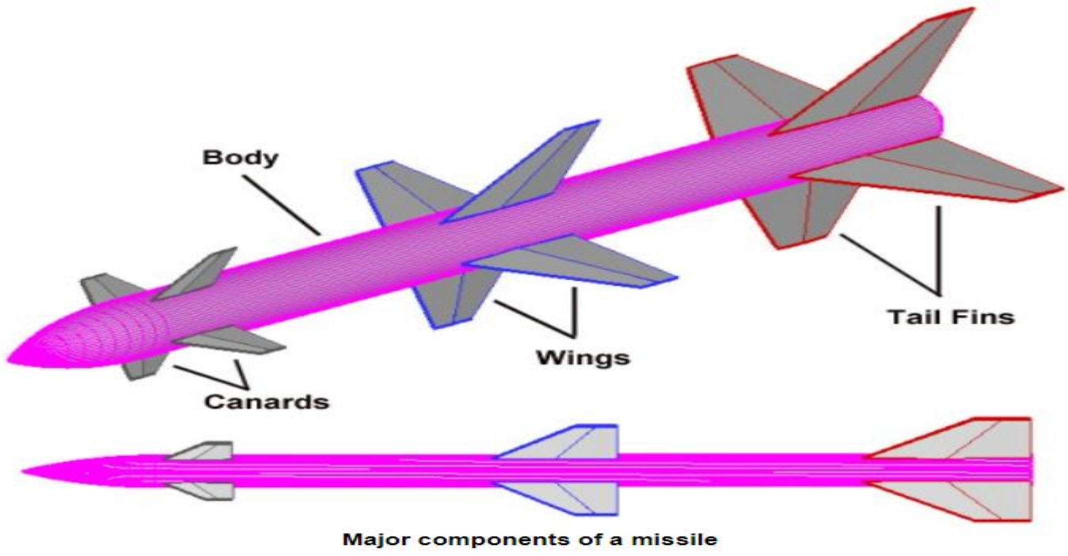

Figure 2-1 Canard, Wing and Fin

We have observed how planes use control surfaces to turn the plane all around in different directions. However, most planes have fixed horizontal and vertical tails with smaller portable rudder and lift surfaces, rockets commonly use each moving surface, like those displayed under, to accomplish a comparative explanation. [2]

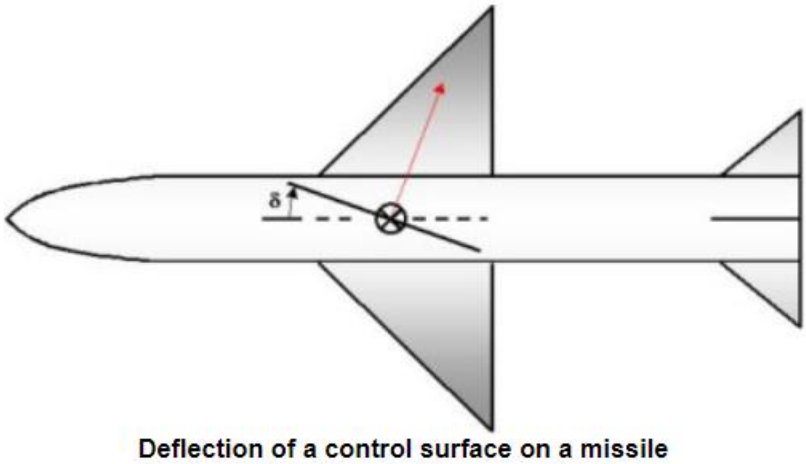

Figure 2-2 Missile Flight

To turn the rocket during flight, something like one bundle of smoothed out surfaces is expected to turn about a center turn point. As such, the angle of attack of the fin is changed with the objective that the lift force circling back to it changes. The changes in the direction and size of the powers circling back to the rocket make it move some place new and grant the vehicle to move along its way and guide itself towards its arranged goal. A delineation of a control surface redirection on an AIM-9M Sidewinder model is addressed below.

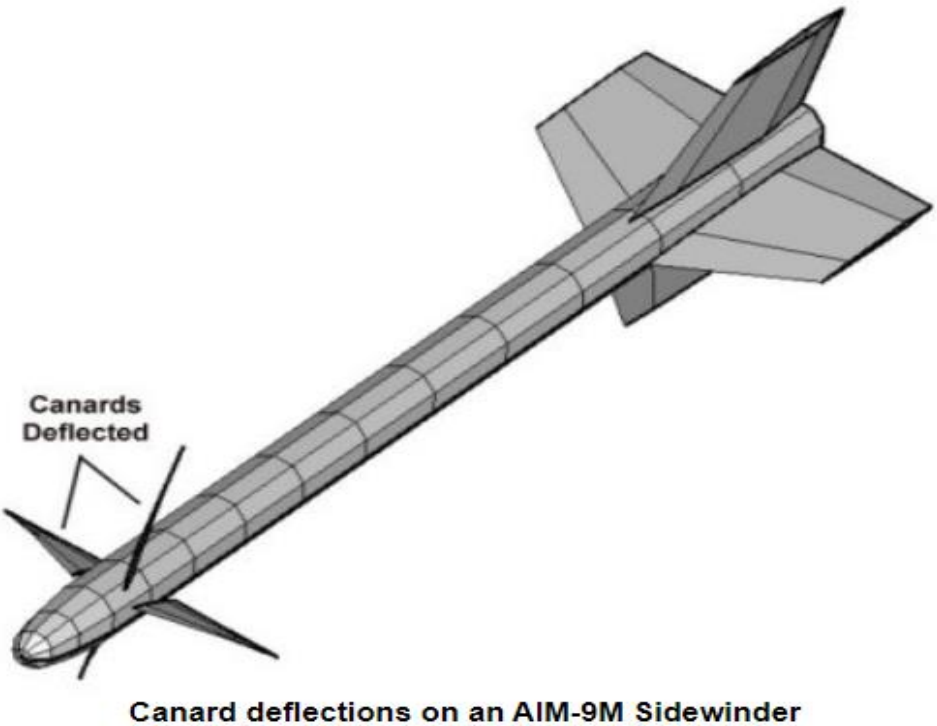

Figure 2-3 Canard Deflection

Canards, wings, and tails are often lumped together and suggested as aerodynamic controls. A later improvement in rocket moving structures is called unconventional control. Most unconventional control systems incorporate some sort of thrust vector control (TVC) or jet interaction (JI). [3]

To date four major categories of missile flight control systems have been introduced which are as follows.

- Tail Control
- Canard Control
- Wing Control
- Unconventional Control

2.1.1 Tail Control:

Tail control is presumably the most normally utilized type of rocket control, especially for longer reach aerial rockets like AMRAAM and surface-to-air rockets like Patriot and Roland. The essential justification for this application is on the grounds that tail control gives fantastic mobility at the high approaches frequently expected to block an exceptionally flexibility airplane. Rockets utilizing tail control are likewise frequently fitted with a non-mobile wing to give extra lift and further develop range. A few genuine instances of such rockets are air-to-ground weapons like Maverick and AS.30 as well as surface-to-surface rockets like Harpoon and Exocet. Tail control rockets seldom have canards, albeit one such model is AIM-9X Sidewinder. A determination of 23 delegate rockets utilizing tail control is presented underneath.

Figure 2-4 Missile Series

In addition to missiles, some bombs also use tail control. An example is the JDAM series of GPS-guided bombs.

2.1.2. Canard Control:

AIM-9M Sidewinder and other short-range air-to-air missiles frequently employ canard control. Better mobility at low angles of attack is the main benefit of canard control, although canards sometimes lose their effectiveness at high angles of attack due to flow separation that causes the surfaces to stall. Canards cause a destabilizing impact because they are ahead of the center of gravity, necessitating massive, fixed tails to maintain the missile's stability. Usually, these two sets of fins offer enough lift to eliminate the need for wings. Twelve examples of canard control missiles are displayed below.

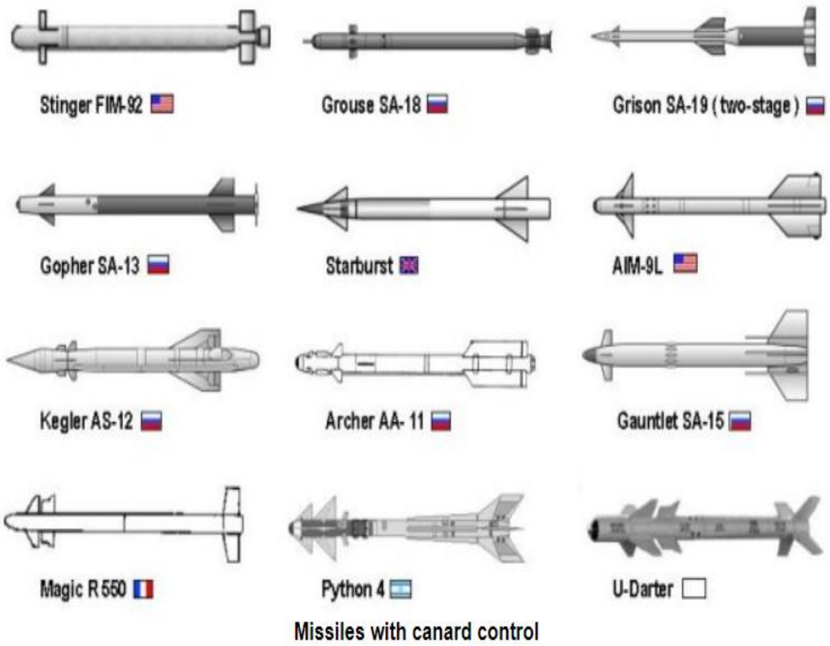

Figure 2-5 Canard Control

The split canard is another subgroup of canard control missiles. Split canards are a relatively recent innovation that have found use on the most recent generation of short-range air-to-air missiles, including the Russian AA-11 and Python 4 missiles. The phrase "split canard" describes the missile's two sets of canards, which are typically placed one after the other and close together. While the second set of canards is adjustable, the first set is fixed. The benefit of this configuration is that the first set of canards produces powerful, energizing vortices that quicken the airflow through the second set of canards, increasing their effectiveness. The vortices also postpone flow separation and enable the canards to attack at greater angles before stalling.

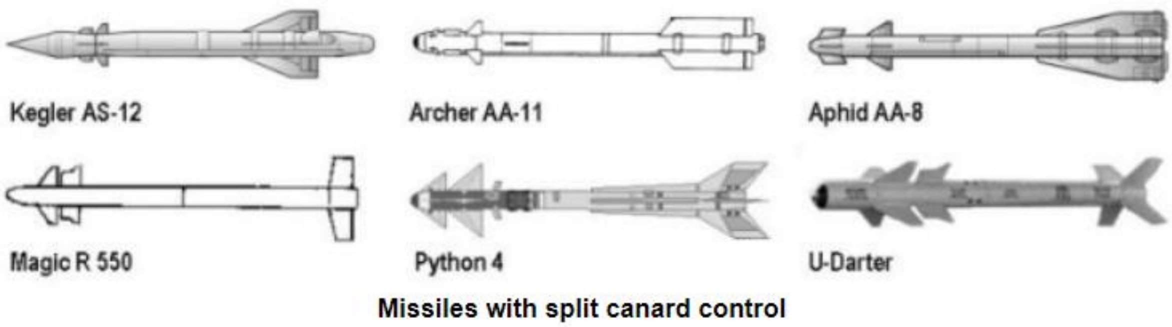

Figure 2-6 Split Canard

Canard control mechanisms are employed by several smart bombs. The most noteworthy of them are the Pave way line of laser-guided bombs.

2.1.3. Wing Control:

One of the oldest types of missile control was wing control, however it is employed less frequently on modern systems. Longer-range missiles like the Sparrow, Sea Skua, and HARM are the ones that need wing control the most. The main benefit of wing control is that it allows for quick responses with little body motion when the wings are deflected. Small seeker tracking error is produced by this feature, which also enables the missile to stay locked on its target even during significant movements.

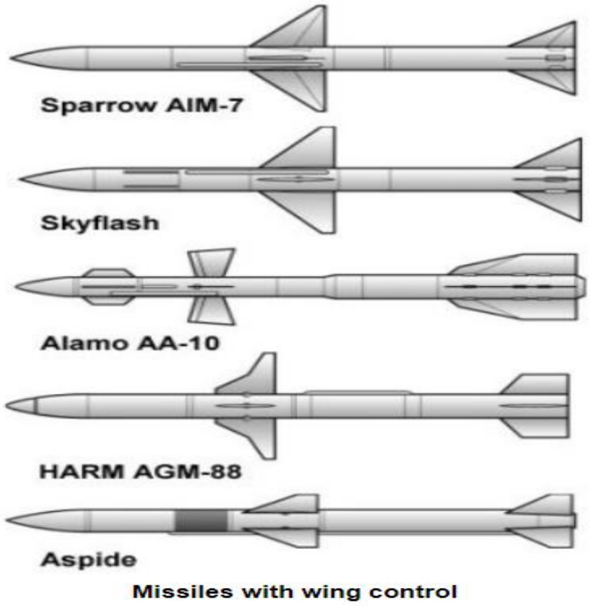

Figure 2-7 Wing Control

The main downside is that the wings must normally be rather broad to provide sufficient lift and control efficacy, resulting in rather large missiles overall. Additionally, the wings produce powerful vortices that might negatively interact with the missile's tails and cause it to roll. Induced roll is the behavior, and if the effect is great enough, the control system might not be able to make up for it. Below are a few illustrations of wing control missiles.

2.1.4. Unconventional Control:

Unconventional control systems are a wide area that encompasses a variety of cutting-edge technology. Thrust vectoring is employed in most approaches. Thrust vectoring is a technique for redirecting missile exhaust to create thrust in a vertical and/or horizontal direction. This increased force causes the missile to turn by pointing the nose in a new direction. Reaction jets are a modern method that is only getting started. Reaction jets are often tiny vents on the surface of a missile that emit jet exhaust perpendicular to the vehicle's surface, producing an effect comparable to thrust vectoring.

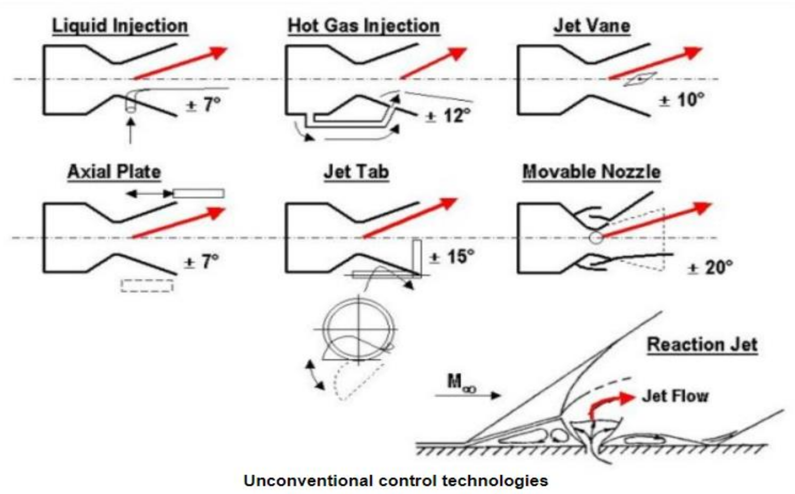

Figure 2-8 Unconventional control

These tactics are most used to offer extraordinary maneuverability to high off-boresight air-to-air missiles such as the AIM-9X Sidewinder and IRIS-T. The most significant advantage of such controls is that they may operate at extremely low speeds or in a vacuum, where there is little or no airflow to act on traditional fins. The main disadvantage is that they will not work once the fuel supply is depleted.

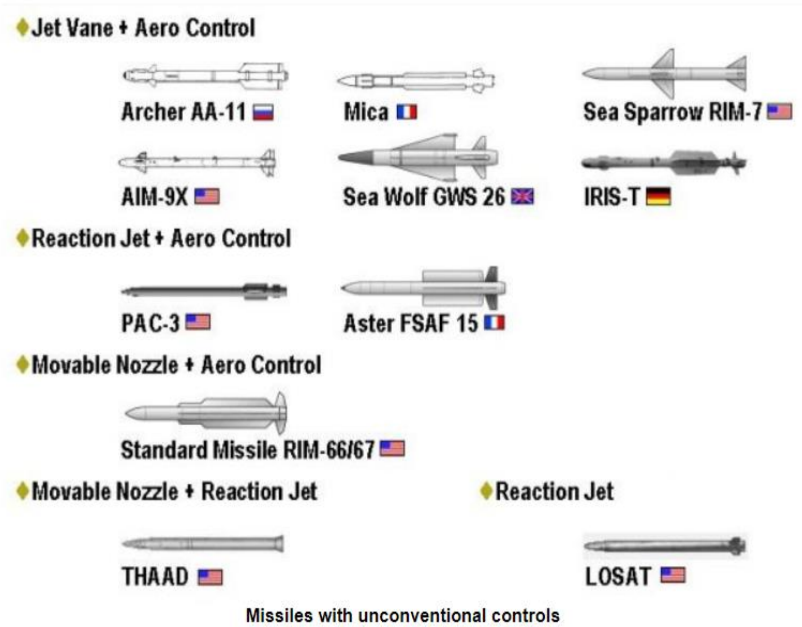

Figure 2-9 Series of Unconventional

CHAPTER NO. 3

ACTUATION OF PRECISION FIN CONTROL SYSTEM

3.1Actuation of Missile System using DC Motors:

Missile systems require precise control to navigate and intercept targets while operating in hostile environments such as high temperature variations and high vibrations. The missile fin actuation system is part of the broader missile system and controls the movement and placement of the missile fins (also known as control fins) in response to steering signals from the flight computer. Because when a missile is fired, these control fins orient the missile's trajectory towards the specified target, miniaturized, lightweight technologies are important to enhancing the mobility of these mission-critical missiles.

Miniaturized, lightweight motors are essential to improving the maneuverability of mission-critical systems. DC motors are especially ideal for controlling missile fin movements to achieve improved aerodynamic stability and trajectory. Missile control applies to the canards, wings, and tail control which is discussed earlier.

The benefits of using a DC motor are discussed below:

- Exceptional dynamic performance (torque over speed range)
- Operating temperature -65° F to 190° F
- Low EMI/EMC
- Power dense designs (compact and lightweight)
- Designed to operate in critical environments (shock, vibration)

3.2 Design Requirements for Missile Fin Actuation Systems:

Missile systems must function and execute with pinpoint accuracy at subsonic, supersonic, and hypersonic speeds and under extreme circumstances. In such conditions, DC motors are intended to provide the best possible performance to fin actuators. These motors' key performance characteristics are as follows:

- **Responsiveness**

  Despite the fact that it depends greatly on the kind of missile, range, and payload capacity, DC and stepper motors often display torque responsiveness and rapid acceleration.

- **Agility**

Optimal motor size reduces weight for increased missile mobility.

- **Ruggedness**

DC motors are built with a strong mechanical enclosure and internal components to withstand mission-critical conditions such as operational and storage temperatures ranging from -40°C to +85°C, relative humidity levels ranging from 40% to 45%, and shocks and vibrations ranging from 100g to 250g @ 15 - 40 msec.

- **Shelf Life**

Motors in storage are expected to endure up to 15 to 20 years.

- **Duty Cycle:**

DC motors typically operate at speeds ranging from 4 to 5 seconds to a maximum of 30 to 40 seconds for fin actuation. [4]

3.2 Motor Used in an Actuation System:

Missile fins are used for maneuvering the missile during flight. The fins can be adjusted to control the direction and altitude of the missile. To move the fins, a motor is used to actuate a mechanism that drives the fins.

The type of motor used for missile fin actuation depends on the size and weight requirements of the missile. For larger missiles, hydraulic or pneumatic motors may be used, while smaller missiles may use electric motors.

Electric motors are preferred for smaller missiles due to their compact size and high efficiency. They can be controlled more precisely than hydraulic or pneumatic motors and require less maintenance. Brushless DC motors and stepper motors are commonly used for missile fin actuation.

The motor is connected to a lead screw mechanism that converts the rotational motion of the motor into linear motion to adjust the position of the fins. This mechanism provides a high degree of accuracy and repeatability, allowing for precise control of the missile's flight path.

Overall, the motor used for missile fin actuation must be reliable, efficient, and able to provide precise control over the movement of the fins to ensure the accuracy of the missile's trajectory. [5]

The most common motor used in a Missile actuation system is **23GST2R82 Brush DC Coreless Motor**. The 23GST2R82 (short version) combines high power density with graphite/copper commutation. This brush DC motor provides excellent acceleration and dynamics in a tiny design. The highlights of the product are as follow:

- Ironless construction
- Neodymium magnet for high performance
- High power density package
- Long brush life
- Compact design
- Winding possibilities
- High acceleration
- Low self-heating

Figure 3-1 DC Motor

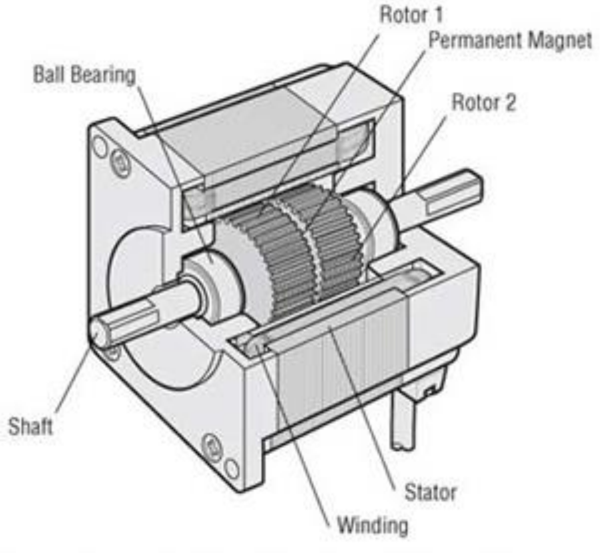

Figure 3-2 Stepper Motor

The motor can be customized as well depending upon the motive required. The customization available for the motor are as follow.

- Cable or terminal outputs
- Coil modifications - resistance and inductance
- Custom shafts - flats, knurling, diameter, length
- Fixation holes
- Sleeve or ball bearings

The specifications of the motor are as follows.

Diameter	23 mm
Shaft Play (Axial)	0.15 mm
Shaft Play (Radial)	<0.03
Continuous Current	0.9 A
Continuous Torque	22 mNm
Mechanical Time Constant	5.2 ms
Motor Regulation	11×10^3 Nms
No-Load Current	60 Ma
No-Load Speed	9010 rpm
Nominal Voltage	24V
Rotor Inertia	4.7 gcm^3
Torque Constant	25 mNm/A
Weight	80g
Efficiency	76%
Output Power	18W
Rotor Inductance	0.3 mH

Table 3- 0-1 Specifications of the 23GST2R82 Brush DC Coreless Motor

3.4 Lead Screw drive Missile Fin Actuation Systems:

Lead and acme screws are employed in a wide range of linear motion control applications, from syringe pumps to security camera pan-and-tilt systems. One of the most intriguing applications of these screws is in driving the fin actuation that directs a missile to its target.

Precision tiny screws are employed in this application to position the sighting mechanism that recognizes and acquires the target while travelling at high speeds. The micro screws also provide actuation for the missile fins, which direct the missile's trajectory. The fins are the wings of the missile. Some missiles have genuine wings and utilizing these screws to position the wings and fins allows for precision placement and control to optimize speed while minimizing drag during transonic and supersonic flight. Screws are used to lift missile-launching systems and deploy sighting, range-finding, and antenna equipment, in addition to guiding the missile. [5]

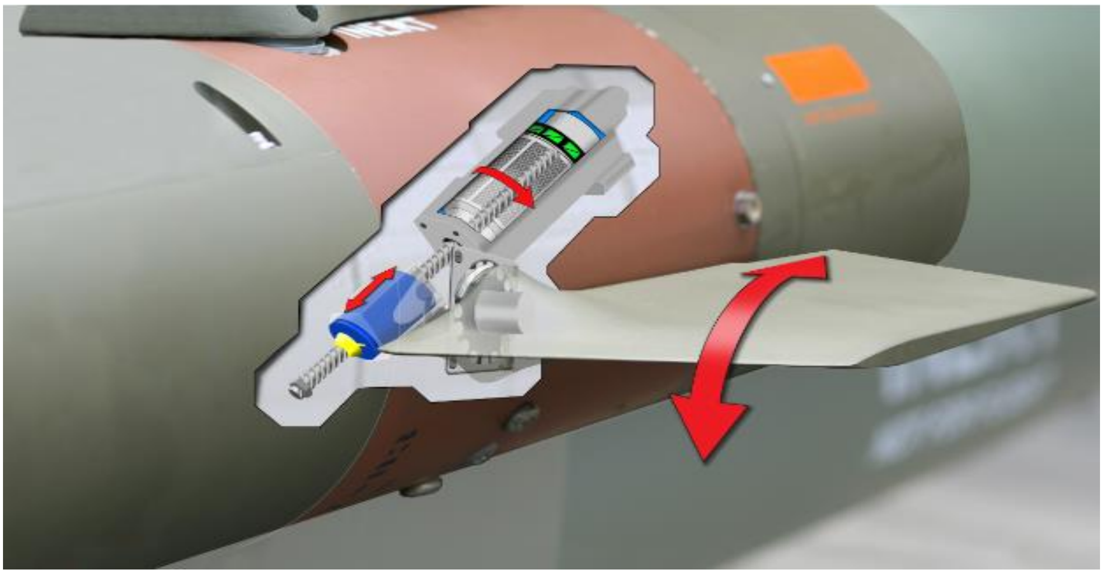

Figure 3-3 Fin Rotation

Precision-engineered micro screws replace the hydraulic and pneumatic actuators that were being used previously. As the screw or nut turns to move the other component in a linear direction, torque is converted to thrust. Because the screw mechanism avoids sliding friction and stick-slip, it requires very little maintenance after the first lubrication.

Because of their excellent efficiency, these screws automatically reduce the power required to drive missile-fin actuation. The fin drive transmission's size and weight are also lowered, making micro screws a better alternative for small missiles and targeted weapons.

CHAPTER NO. 4

NACA PROFILE

4.1 NACA Profiles Background

NACA profiles refer to the series of airfoil shapes developed by the National Advisory Committee for Aeronautics (NACA) in the 1930s and 1940s. These profiles were designed to provide predictable and stable aerodynamic performance for a wide range of aircraft, and they are still used today as the basis for many modern airfoil designs.

NACA profiles are characterized by a series of numerical designations that describe the shape of the airfoil. The first two digits of the designation indicate the maximum camber of the airfoil, as a percentage of the chord length. The second two digits indicate the location of the maximum camber, as a fraction of the chord length. The final digit indicates the thickness of the airfoil, as a percentage of the chord length. [6]

There are several types of NACA profiles, each with its own unique set of design parameters [7]. The most used types include:

1. NACA 4-digit profiles: These are the original NACA profiles, which were developed in the 1930s. They are characterized by a maximum camber of 4% to 12%, and a maximum thickness of 12% to 30%. [8]

2. NACA 5-digit profiles: These profiles were developed in the 1940s and are characterized by a more gradual curvature and a thinner airfoil section than the 4-digit profiles. They are often used in high-speed applications where low drag is important.

3. NACA 6-series profiles: These profiles were developed in the 1950s and 1960s and are characterized by a sharp leading edge and a relatively flat upper surface. They are often used in high-lift applications, such as on the wings of aircraft designed for short takeoff and landing.

Overall, NACA profiles are widely used in the design of aircraft wings, propellers, and other aerodynamic surfaces. Their predictable and stable performance makes them a valuable tool for engineers and designers seeking to optimize the performance of their aircraft.

4.2 NACA Aerodynamic Profiles

The National Advisory Committee for Aeronautics designed the NACA aerodynamic profiles for aircraft wings (NACA). A series of numerals after the term "NACA" describes the form of the NACA airfoils. The numerical code parameters may be inserted into equations to exactly produce the airfoil cross-section and determine its characteristics.

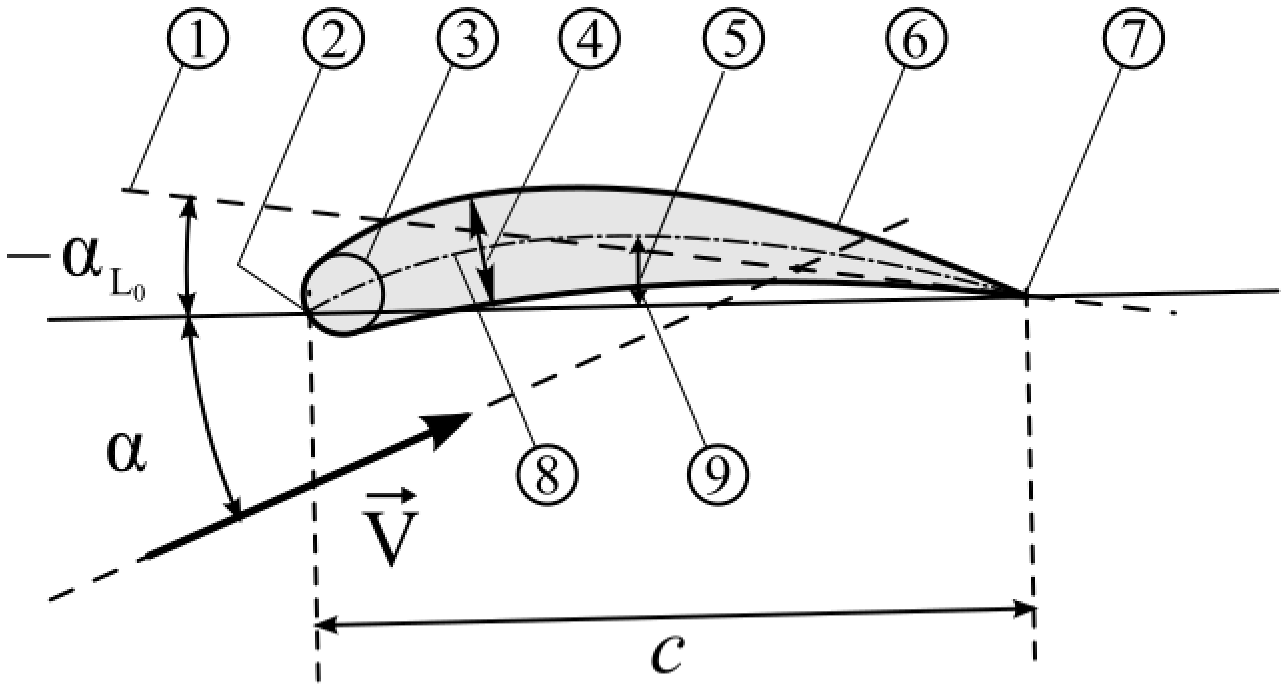

Figure 4-1 NACA Profile

The geometry of profile shown above is as follows:

1: Zero-lift line

2: Leading edge

3: Nose circle

4: Max. thickness

5: Camber

6: Upper surface

7: Trailing edge

8: Camber mean-line

9: Lower surface

NACA profiles describe aerodynamic motion through several numeral series. These series start from 4-digits series and continue till 8-digit series which is for supercritical flow. We will limit ourselves to a 4-digits series and its equation.

4.3 4-Digits Aerodynamic Profile Series

The NACA four-digit wing sections define the profile as:

- First digit describing maximum camber as percentage of the chord.
- The second digit describes the distance of maximum camber from the profile leading edge in tenths of the chord.
- The last two digits describe the maximum thickness of the airfoil as percent of the chord.

For instance, the NACA 4024 profile has a maximum camber of 4% located at the (0 chords) leading edge with a maximum thickness of 24% of the chord.

The terms mentioned above can be understood by the image shown:

A: blue line = chord, green line = camber mean-line.

B: leading-edge radius.

C: ***xy*** coordinates for the profile geometry.

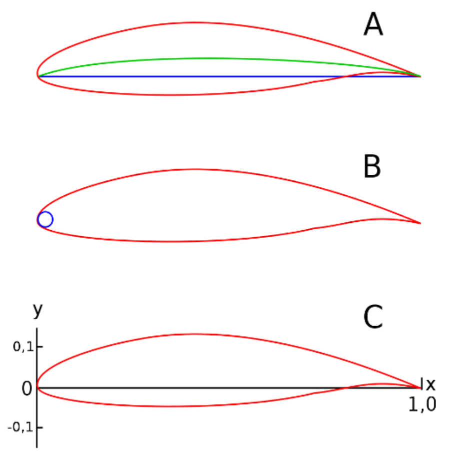

Figure 4-2 Chord, Chamber and Mean Line

4.4 Symmetrical 4-Digits NACA Profile Equation

The equation for the shape of a NACA 00XX profile, with "XX" being replaced by the percentage of thickness to chord, is.

$$y = 5\text{t}[0.2969\sqrt{x} - 0.1260\text{x} - 0.3516x^2 + 0.2843x^3 - 0.1015x^4]$$

Here.

- ***x*** is the position along the chord from 0 to 1.00 (0 to 100%),
- $\boldsymbol{y_t}$ is the half thickness at a given value of *x* (centerline to surface),
- ***t*** is the maximum thickness as a fraction of the chord (so *t* gives the last two digits in the NACA 4-digit denomination divided by 100).

It should be noted that the thickness in this equation is not close to zero when x = 1. (The trailing edge of the airfoil). If a trailing edge with zero thickness is wanted, for example, for computing work, one of the coefficients should be altered such that the sum of the coefficients is zero. The last coefficient (to 0.1036) has the least influence on the overall shape of the airfoil. The leading edge has a cylinder-like form with a chord-normalized radius of

$$r = 1.1019t^2$$

NACA 4024 Profile

As mentioned above NACA 4024 represents that profile has a maximum chamber of 4% located at the (0 chords) leading edge with a maximum thickness of 24% of the chord. The 3D model of the profile is attached below which has been designed keeping in mind the dimensions of the missile.

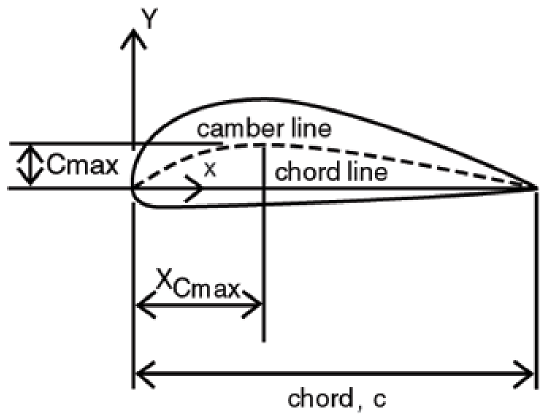

Figure 4-1 NACA 4-Digit

CHAPTER NO. 5

FIN DESIGN

5.1 Introduction

When designing fins for a rocket, it is important to consider various parameters to ensure that they provide the necessary stability without adding excessive weight or drag. The main geometric parameters of fins are the root chord, tip chord, semi-span, aspect ratio, and taper ratio. The root chord is the edge of the fin attached to the body tube, while the tip chord is the edge furthest from the body tube. The semi-span is the distance between the root and tip chord. The aspect ratio is the ratio of the fin's span squared to its area, while the taper ratio is the ratio of the tip to root chord lengths.

The sizing of fins involves determining appropriate dimensions for each of these parameters to achieve the desired stability. Typically, the root chord should be around two diameter lengths, while the tip chord should be around one diameter length. The semi-span can be varied to achieve appropriate stability. Fin tabs, which contact the motor tube and centering rings, should be placed close to the back of the rocket between two centering rings.

5.2Terminology

- Root chord - edge of fin attached to body tube.
- Tip chord - edge of fin parallel and furthest from body tube.
- Leading edge - the edge facing the front.
- Trailing edge - the edge facing the rear.
- Semi-span - distance from the root to tip chord.
- Aspect ratio - ratio of a fin’s span squared to its area.
- Taper ratio - ratio of tip to root chord lengths.

5.3 Material Selection

The choice of material for the fins depends on the durability required and the rocket being made. Plywood, fiberglass, and carbon fiber are some of the common materials used for fins. To ensure that the fins are reinforced and aerodynamic, fillets should be created between the fins and airframe using epoxy. Sanding the leading edge and tip chord of the fins is optional, but highly recommended to decrease air resistance and increase aerodynamics.

5.4 Flutter Speed

Fin flutter is a critical parameter to consider when designing fins. As the rocket flies at high speeds, the fins will vibrate. If the rocket speed exceeds the maximum fin flutter speed, the air will amplify oscillations to the point of destroying the fin. The maximum fin flutter speed can be calculated using parameters such as shear modulus, speed of sound, wing thickness, root chord, tip chord, semi-span, air pressure, aspect ratio, and taper ratio. It is important to ensure that the maximum fin flutter speed lies above the maximum rocket speed. [9]

$$v_f = a\sqrt{\frac{G}{\frac{1.337\,AR^3(P)(\lambda+1)}{2(AR+2)\left(\frac{t}{c_r}\right)^3}}}$$

Where:

Flutter-speed (v_f) - max speed before the fins break

Shear-Modulus (G) - amount of deformation associated with a certain amount of force.

Speed_ of Sound (a)

Wing-Thickness (t)

Root-Chord (c_r)

Tip-Chord (c_t)

Semi-Span (b)

Air-Pressure (P)

Aspect-Ratio (AR) $= \frac{b^2}{s}$

Taper-Ratio $(\lambda) = \frac{c_t}{c_r}$

Wing-Area (S) $= \frac{1}{2} \times (c_r + c_t) \times b$

Speed of Sound $a = \sqrt{\lambda RT}$

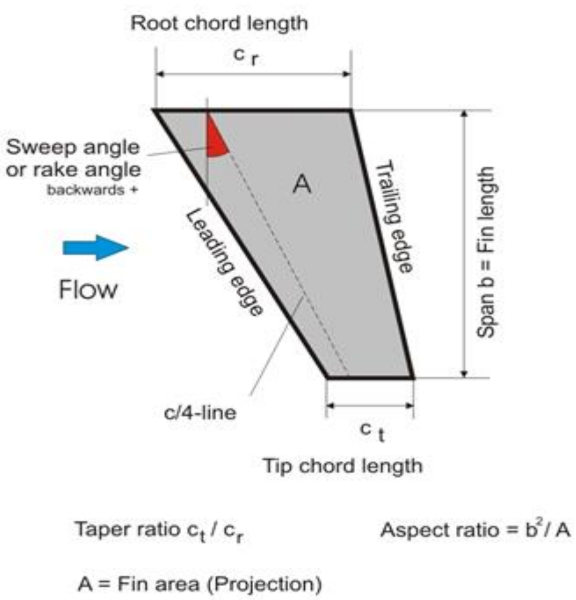

Figure 5-1 Fin Dimensions

5.5 Fin Thickness

Fin thickness is another important parameter to consider when designing fins. Thicker fins are more structurally stable but also increase the weight of the rocket and the drag experienced during flight. The force of drag can be calculated using parameters such as air pressure, velocity, drag coefficient, and area. The drag coefficient can be lowered by improving the cross-sectional area of the fin, with airfoil being the most effective option. Fin thickness should also account for fin flutter as low thickness can risk damaging fins during flight.

5.6 Stability

Stability is the primary purpose of fins, and it is important to ensure that the center of pressure lies below the center of gravity. The center of pressure is the sum of the pressure field on the rocket, which creates a lift force. Stability can be measured in Cals and is calculated using parameters such as the center of pressure from the front of the rocket, center of gravity from the front of the rocket, and rocket diameter. A stability range of 1-2 Cals is recommended, with lower values risking insufficient correction and higher values risking overcorrection. Increasing the surface area of the fins can improve stability by moving the center of pressure towards the aft end of the rocket. [10]

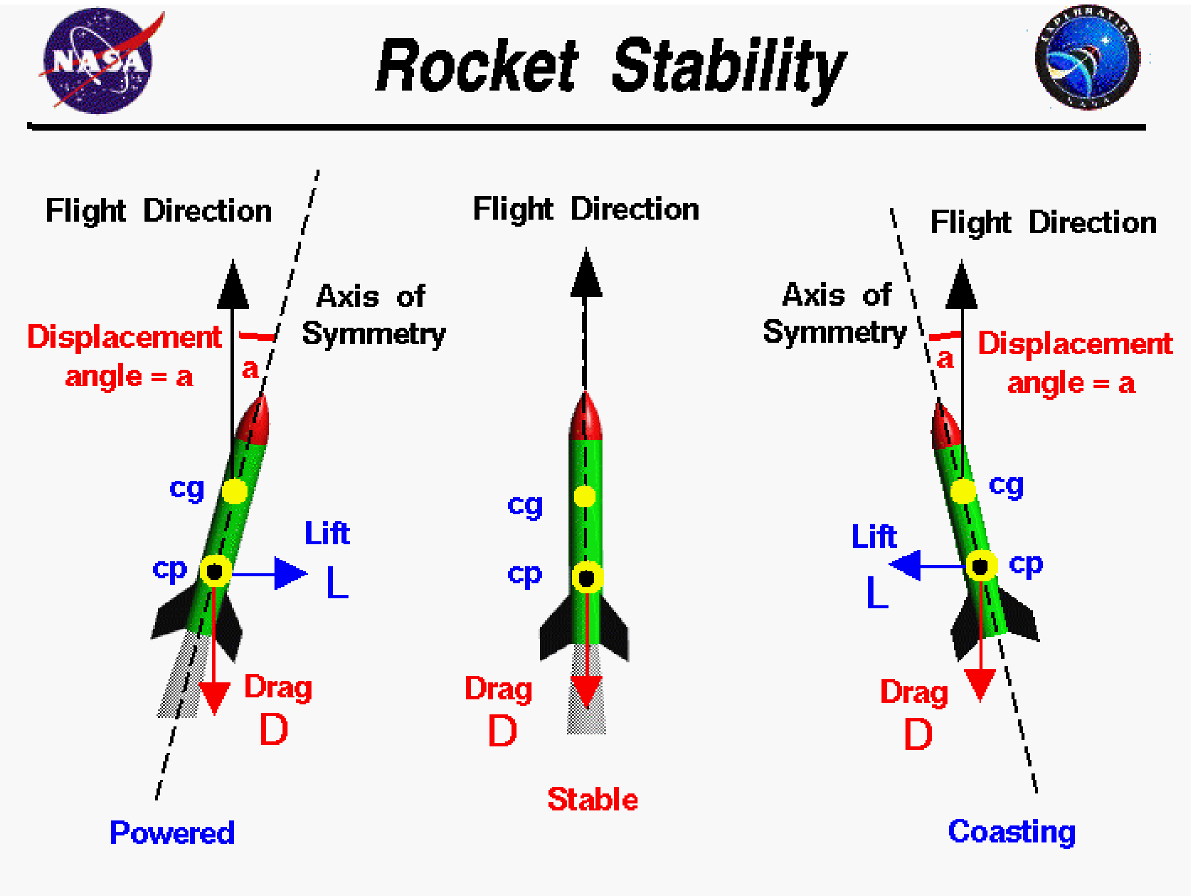

Figure 5-2 Rocket Stability

5.7 Standard Dimensions

The dimensions of the fin are given as:

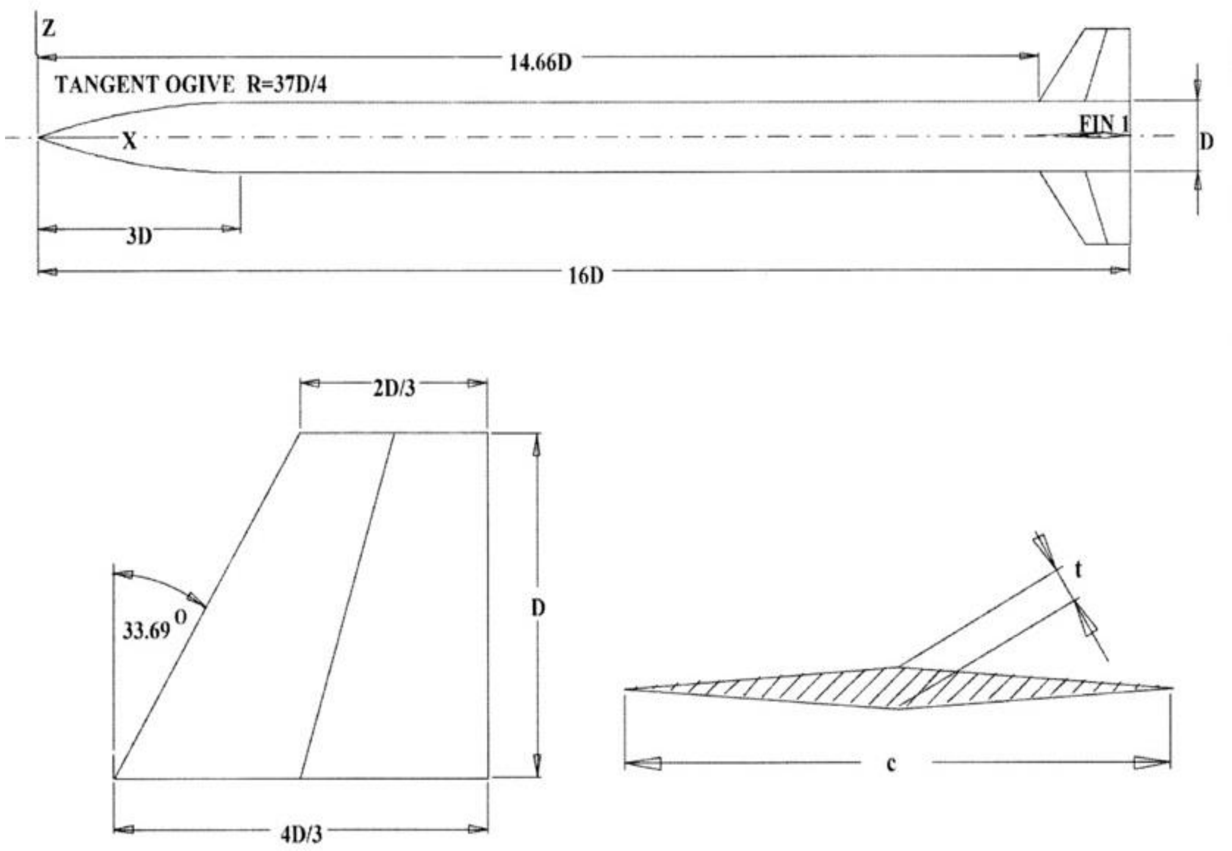

Figure 5-3 Fin Geometry

5.8 Calculations

Taper Ratio

$$\lambda = \frac{c_t}{c_r} = \frac{66.67}{133.33}$$

$$\lambda = 0.5$$

Fin Surface Area

$$S = \frac{1}{2}(c_r + c_t) \times b$$

$$S = \frac{1}{2}(\frac{2}{3} + \frac{4}{3})100 \times 10^{-3}$$

$$S = \ 0.01\, m^{-3}$$

Aspect Ratio

$$AR = \frac{b^2}{S} = \frac{(0.1)^2}{0.01}$$

$$AR = 1$$

Pressure:

$$T(F°) = 59 - 0.00356h$$

Where **h** is in feet.

$$P(lbs/ft^2) = 2116\left(\frac{T + 459.7}{518.6}\right)^{5.256}$$

For **2000 ft** the pressure in 105 kPa and speed of sound ***a*** is **327.6 m/s**.

Fin Thickness

$$v_f = a\sqrt{\frac{G}{\frac{1.337\ AR^3(P)(\lambda + 1)}{2(AR + 2)\left(\frac{t}{c_r}\right)^3}}}$$

Substitute the values:

$$350 = 327.6\sqrt{\frac{4.107 \times 10^9}{\frac{1.337\ (1)^3(105\ \times 10^3)(0.5 + 1)}{2(1 + 2)\left(\frac{t}{0.13333}\right)^3}}}$$

$$t = 20.4\, mm$$

5.9 NACA Profile 0018

1. The first digit denotes the maximum camber as **C_{max}** as percent of cord.

   In our case it is **0**.

2. The second digit represents the chordwise position of maximum camber **X_{cmax}** in tenth of the cord.

   In our case it is **0**.

3. The last two digits represent the maximum thickness **t**, of the airfoil as percent of the cord.

   In our case it is **18** so at the bottom of the fin it is:

$$= \frac{18}{100} \times 133$$

$$= 23.9\ mm$$

At the top of the fin, it is:

$$= \frac{18}{100} \times 83$$

$$= 12.1\ mm$$

Our profile looks like this:

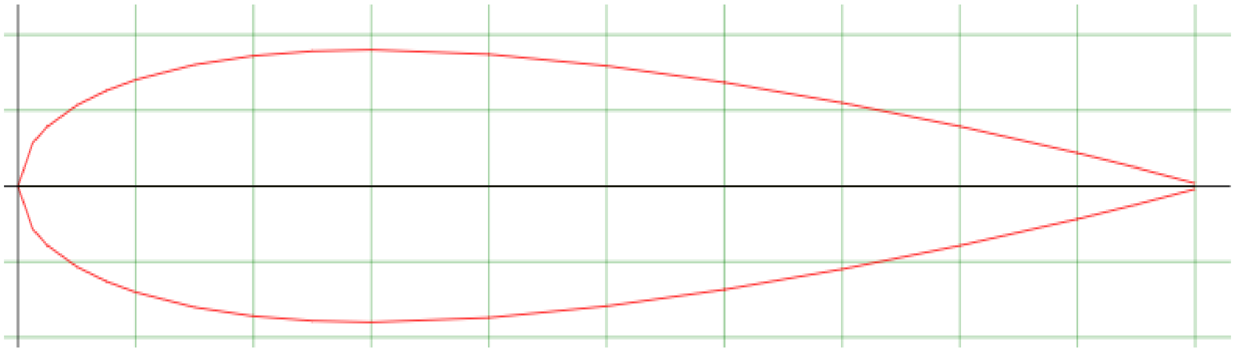

Figure 5-1 NACA Profile 0018

5.10 CAD Model of Fin

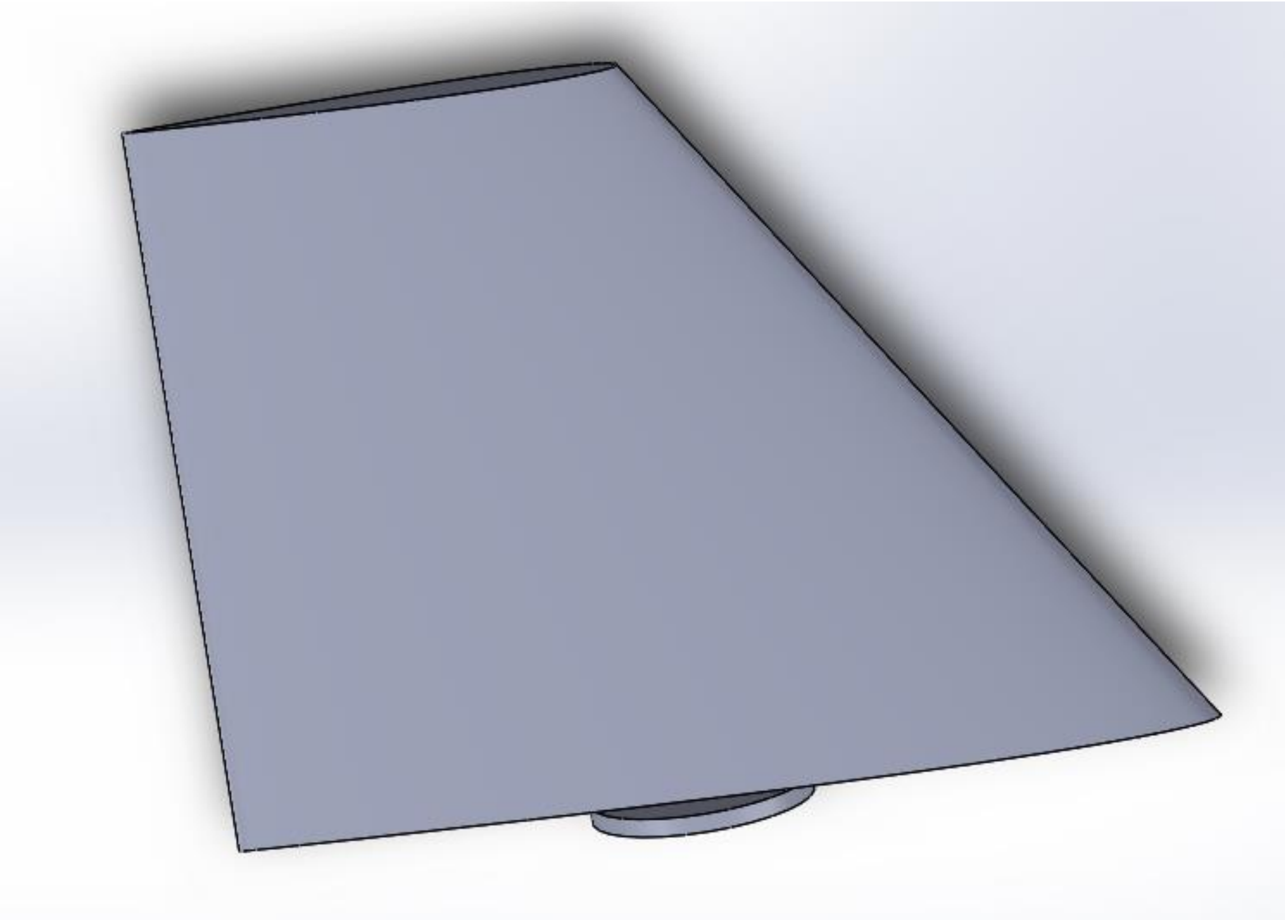

Figure 5-2 One side surface area A = 10264.2 mm²

5.11 2D Dimensions

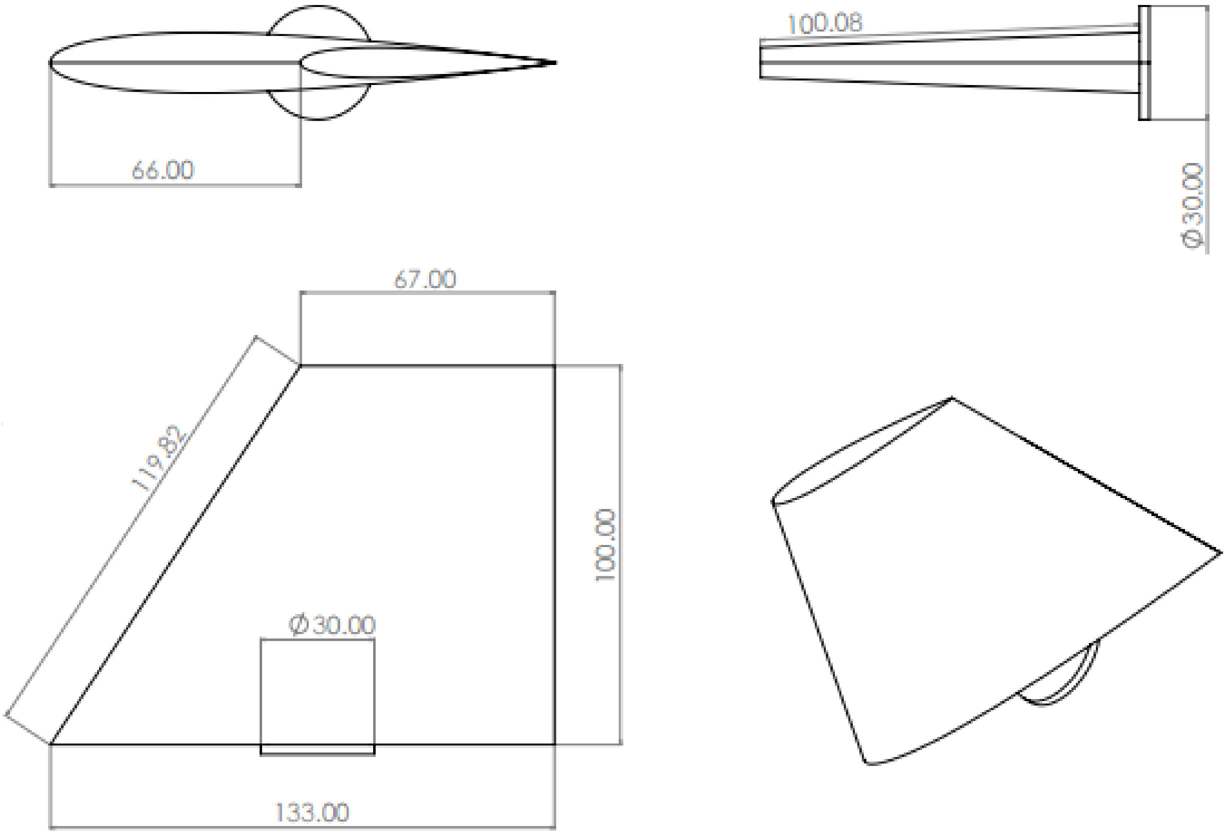

Figure 5-6 Fin 2D Drawing

5.12 FIN Modal Analysis

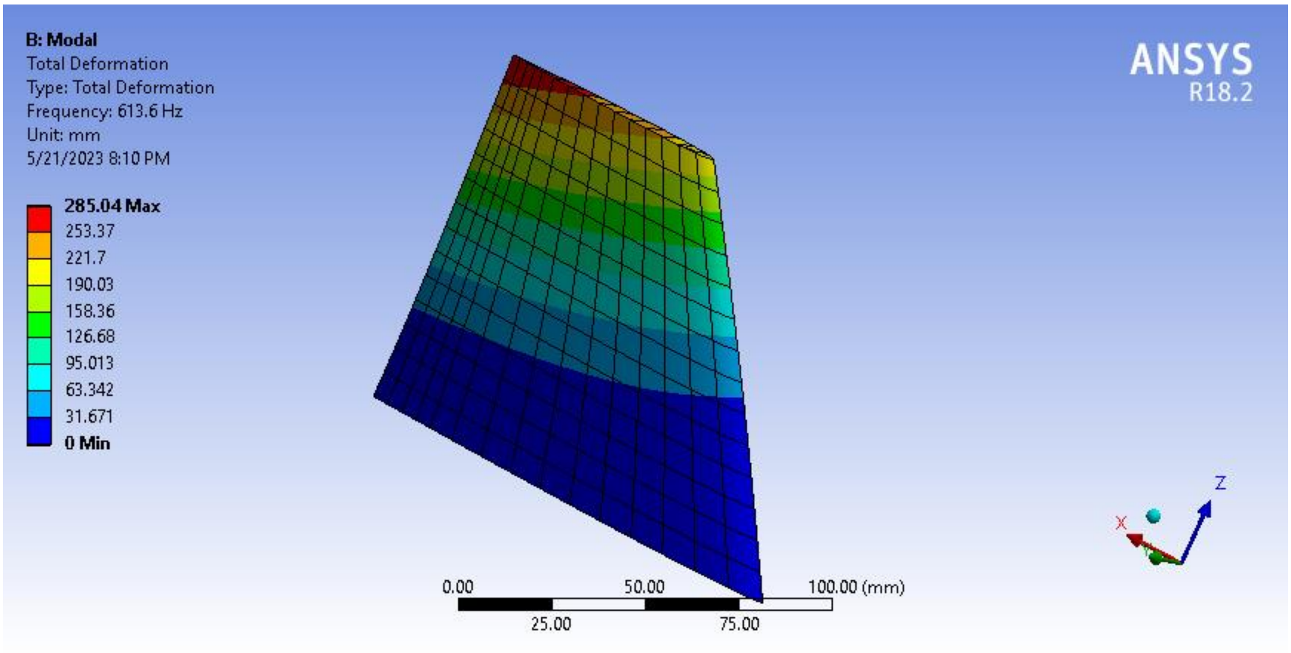

Figure 5-7 Fin Total Deflection Analysis

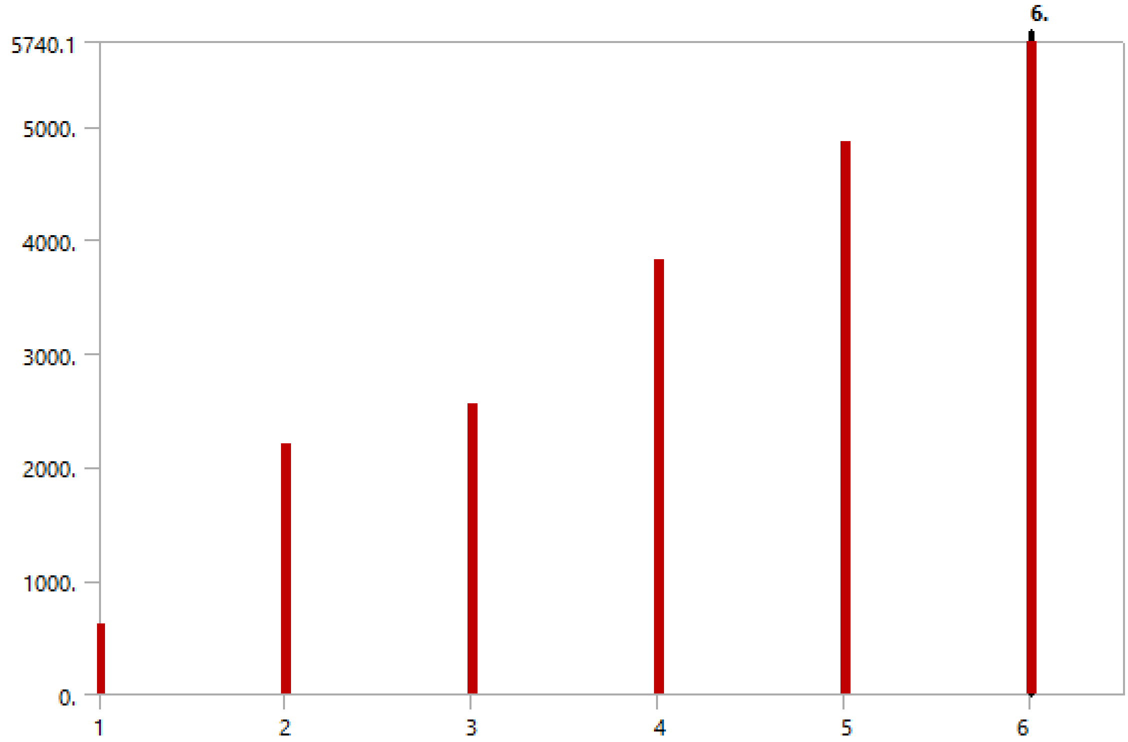

***Figure 5-3** Fin Resonance*

Frequency in Hz

Mode	Frequency [Hz]
1.	613.6
2.	2194.1
3.	2546.7
4.	3821.7
5.	4858.9
6.	5740.1

Table 0-1 Frequency

The modal analysis of the fin reveals that its first resonance occurs at a frequency of 613.6 Hz. Considering that the maximum wind tunnel speed is 50 m/s, it can be concluded that the fin is well within the safe limits. Therefore, the fin can be confidently tested in the laboratory without any concerns of fluttering or the resonance being triggered by the airflow in the wind tunnel.

5.13 FIN Deformation Analysis

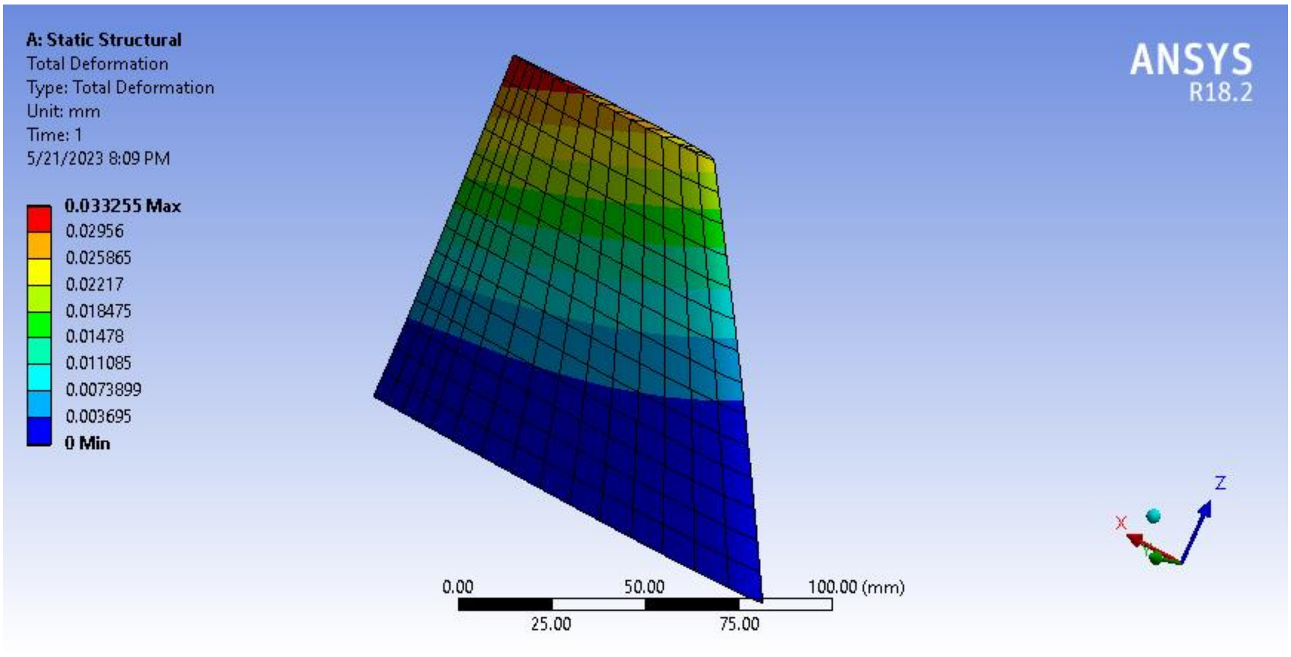

Figure 5-4 Fin Deformation

5.14 FIN Stress Analysis

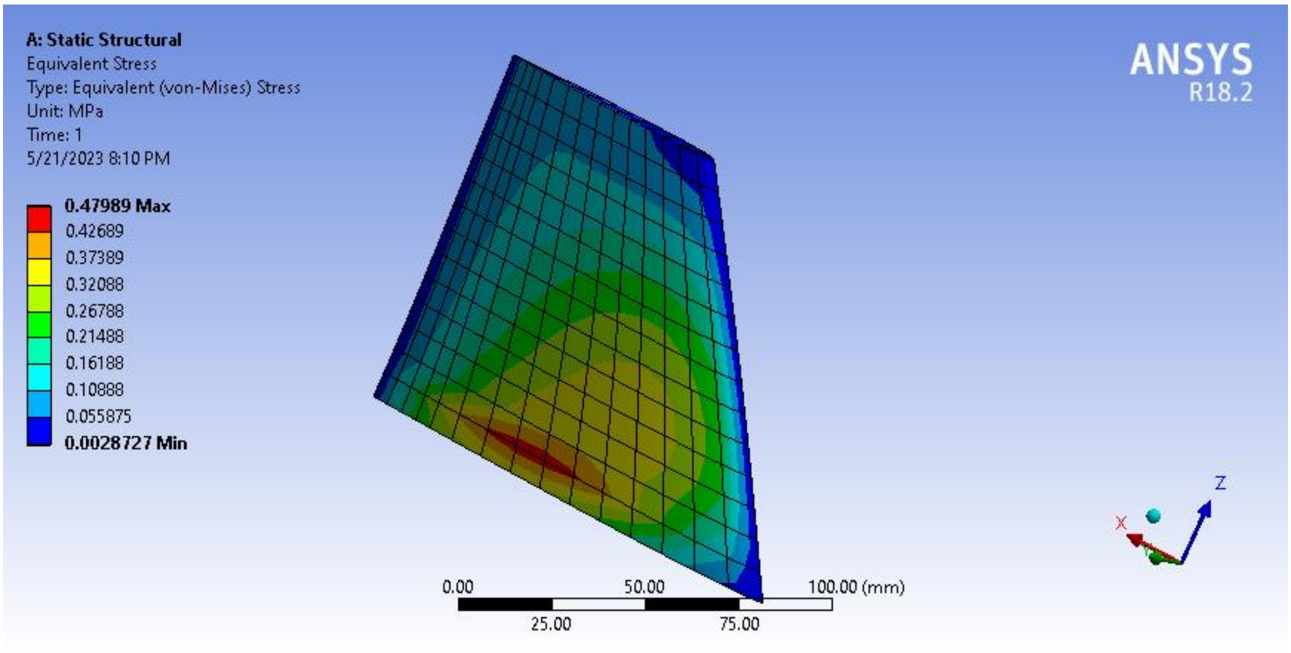

Figure 5-5 Fin Stress Analysis

5.15 Conclusion

In addition to the modal analysis, the structural analysis of the fin further confirms its safety within acceptable limits. The analysis indicates that the total deformation of the fin is measured at 4.7989 mm, while the maximum stress experienced is 0.033 MPa. These results demonstrate that the fin can withstand the expected loads and stresses without experiencing excessive deformation or stress concentrations. [11]

With the fin design validated, the next step is to focus on designing the other parameters and assembly components that will facilitate the motion of the fin. This includes the design of the supporting components and mechanisms, such as the lead screw, which will enable controlled and precise movement of the fin. By designing these complementary elements, the overall system will be engineered to effectively support and facilitate the desired motion and functionality of the fin.

CHAPTER NO. 6

FIN ACTUATION SYSTEM

6.1 Introduction

A missile fin actuation system (MFAS) is a mechanism used to control the motion of a missile's fins or control surfaces. The MFAS is responsible for adjusting the angle of the fins, which in turn affects the missile's direction of flight.

There are two main types of missile fin actuation systems: hydraulic and electromechanical.

1. Hydraulic MFAS: This system uses hydraulic fluid to control the missile's fins. The hydraulic fluid is typically pressurized by a pump, and the pressure is used to move a piston or actuator, which in turn moves the fins. Hydraulic systems are known for their high power-to-weight ratio and their ability to provide precise control, but they can be complex and require regular maintenance.

2. Electromechanical MFAS: This system uses electric motors to control the missile's fins. The motors are typically connected to the fins via a gearbox or other mechanical linkage. Electromechanical systems are simpler than hydraulic systems and require less maintenance, but they may not provide as precise control and may be less powerful.

Both types of MFAS are typically controlled by an onboard computer or guidance system, which calculates the necessary adjustments to the fins based on the missile's trajectory and other factors. The MFAS plays a critical role in the performance of the missile, as even small adjustments to the fins can have a significant impact on its flight characteristics.

6.2 Lead Screw

A lead screw is a type of mechanical screw that is used to convert rotational motion into linear motion. In the context of a missile fin actuation system, a lead screw can be used to control the motion of the missile's fins by translating the rotational motion of a motor or other actuator into the linear motion of the fins. [12]

The lead screw consists of a threaded shaft (the "screw") and a nut with corresponding threads that fits over the screw. As the screw rotates, the nut moves along the length of the screw, causing linear motion in the direction of the screw's axis.

In a missile fin actuation system, a lead screw is typically used in conjunction with a motor or other actuator to control the position of the missile's fins. The motor rotates the lead screw, which in turn moves the nut and the attached fin linkage. By controlling the speed and direction of the motor, the position of the fins can be adjusted to control the missile's flight characteristics.

The lead screw can be designed with various thread pitches and geometries to provide different levels of precision and force output. The thread pitch determines the linear distance traveled by the nut for each revolution of the screw, while the thread geometry can affect factors such as friction, efficiency, and load capacity. [13]

Overall, the lead screw provides a simple and effective mechanism for translating rotational motion into linear motion, making it a common choice for missile fin actuation systems and other applications that require precise control of linear motion.

Figure 6-1 Lead Screw

6.3 Lead Screw Calculation

Now use the formula for torque required to rotate the fin:

$$T = \frac{Fd_m}{2}\left(\frac{l + f\pi d_m}{\pi d_m - fl}\right)$$

With area of one side of the fin **A = 10264.2 mm²** and the pressure is **105 kPa** so the force on the screw is **1.08 kN**. The lead of the screw l is **6 mm**. The mead diameter is **11 mm**. The coefficient of friction is **0.3824**.
So that:

$$T = 3.75\ Nm$$

$$f\pi d_m = 14 > l$$

So, the system is self-locked.

6.4 CAD Model

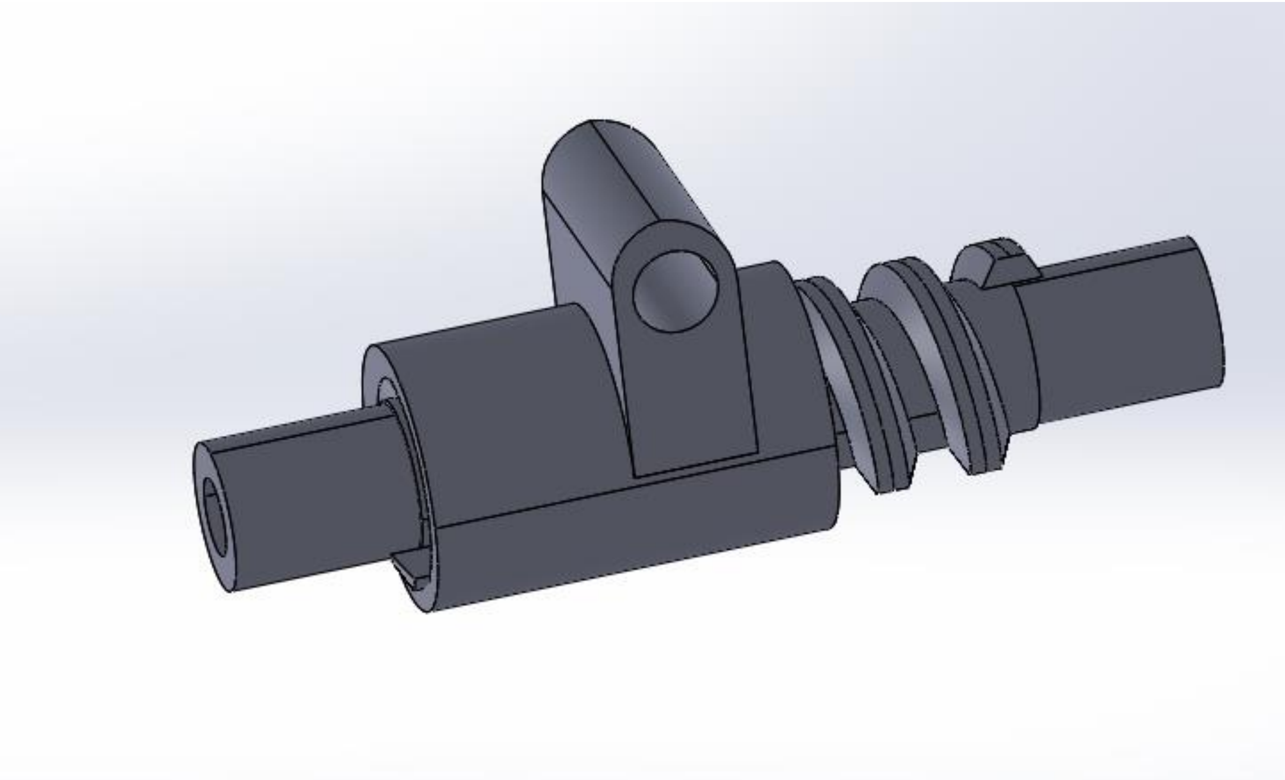

Figure 6-1 Lead Screw CAD Model

6.5 Transient Analysis

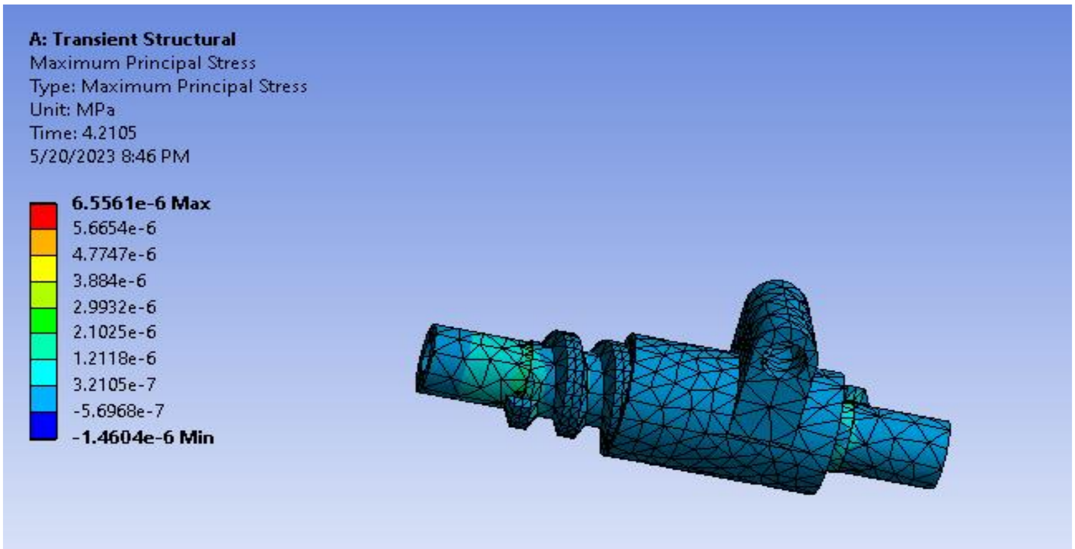

Figure 6-3 Lead Screw Transient Analysis

CHAPTER NO. 7

MCHANICAL COMPONENTS

7.1 Base Component

The lead screw, with a diameter of 10 mm, will be mounted onto a base which will facilitate its rotation. The base will serve as the foundation for the entire system, providing a stable and secure platform for the lead screw to operate on. The support provided by the base will ensure that the lead screw is able to rotate smoothly and without any wobbling or other unwanted motion. This is crucial for the accurate and precise control of the missile's fins, as any vibrations or irregularities in the lead screw's motion could lead to unintended adjustments in the fin position. Overall, the choice of a suitable base for the lead screw is an important consideration in designing an effective missile fin actuation system.

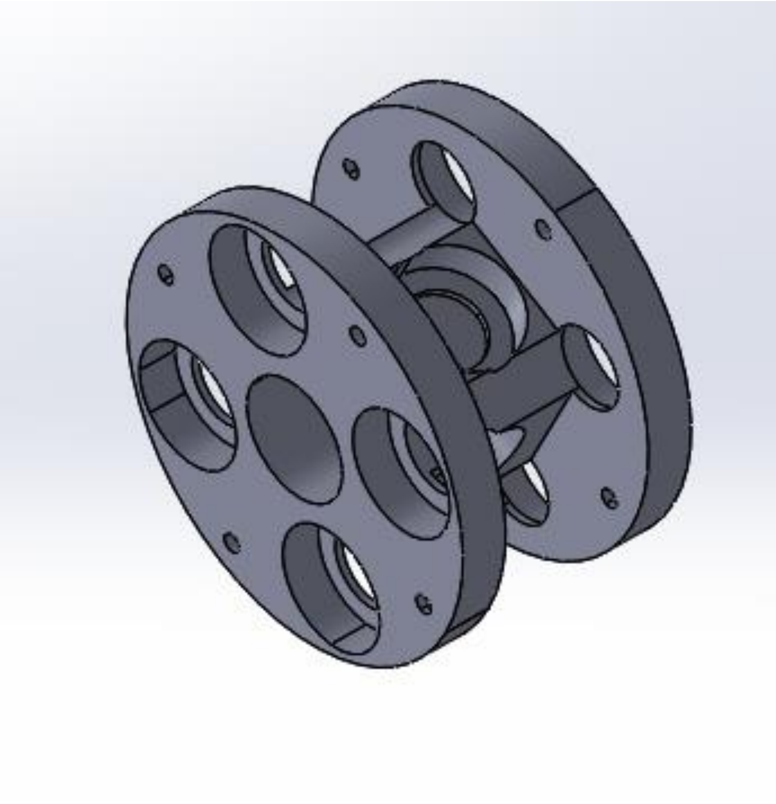

Figure 7-1 Base Part

2D Dimensions

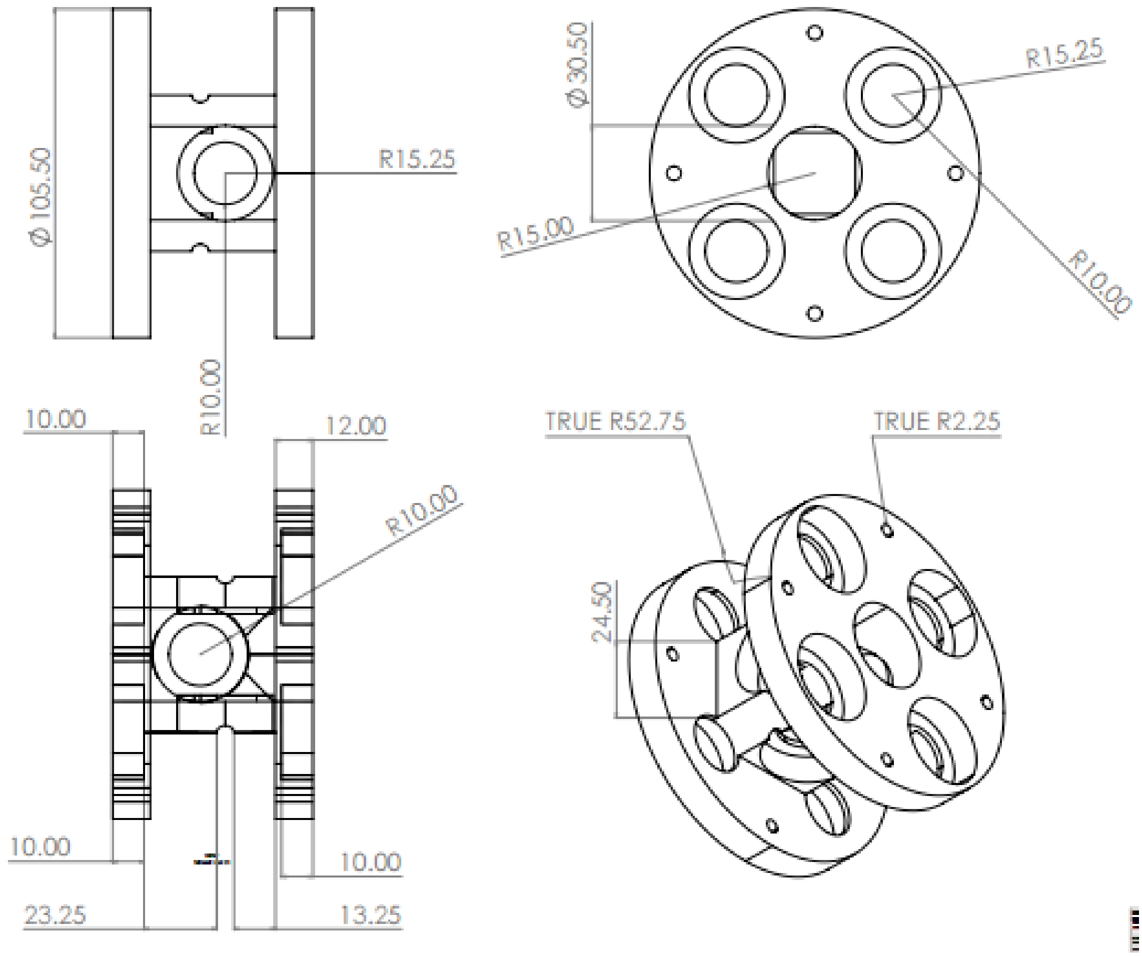

Figure 7-1 2D Drawing of Base Part

7.2 Fin Position Rod

The rod-like component that connects to the fin of a missile serves an important purpose in the missile's fin actuation system. Specifically, this component is responsible for converting rotational motion into linear motion, which in turn controls the position and movement of the missile's fins.

The rod-like component is typically attached to the base of the missile and extends outwards towards the fin. At the end of the component, there is a hinge or pivot point that connects to the fin itself. As the component rotates, it causes the fin to move up or down, or to rotate around its pivot point.

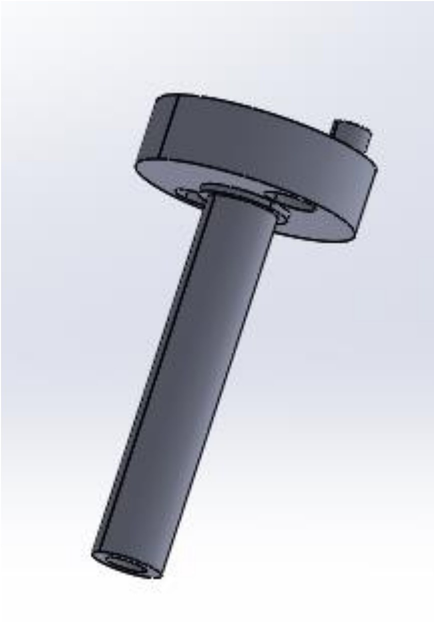

Figure 7-2 Fin Position Rod

The purpose of this mechanism is to provide precise and controlled adjustments to the missile's fins, which can be used to alter the missile's trajectory and improve its accuracy. By adjusting the angle and position of the fins, the missile can be steered towards its intended target or directed away from obstacles or hazards.

The choice of material and design for the rod-like component is also important, as it must be able to withstand the high forces and stresses involved in missile flight. The component must be strong, durable, and lightweight, while also providing smooth and precise motion to the fins.

Overall, the rod-like component that connects to the fin of a missile plays a critical role in the missile's fin actuation system, enabling precise and controlled adjustments to the fins that are necessary for successful missile flight and guidance.

2D Dimensions of Upper Part

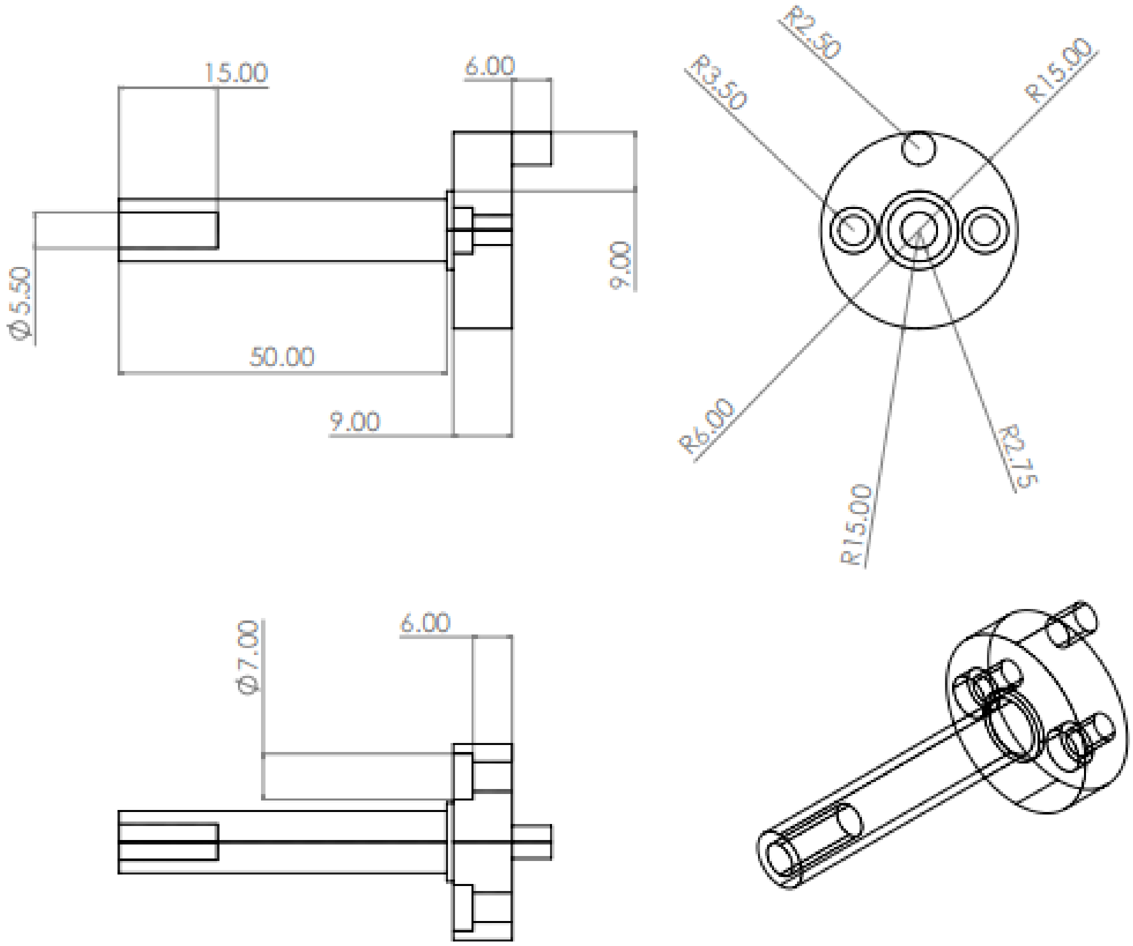

Figure 7-4 2D Drawing of Positioning Rod

7.3 Slider

In a missile fin actuation system, a slider serves an important purpose in providing linear motion to the missile's fins. The slider is a component that moves along a rail or track and is typically attached to the rod-like component that connects to the fin. As the slider moves along the track, it causes the rod-like component to move back and forth, which in turn controls the position and movement of the missile's fins.

The purpose of the slider is to provide precise and controlled adjustments to the missile's fins, which can be used to alter the missile's trajectory and improve its accuracy. By adjusting the position of the slider along the track, the angle and position of the fins can be adjusted, allowing the missile to be steered towards its intended target or directed away from obstacles or hazards.

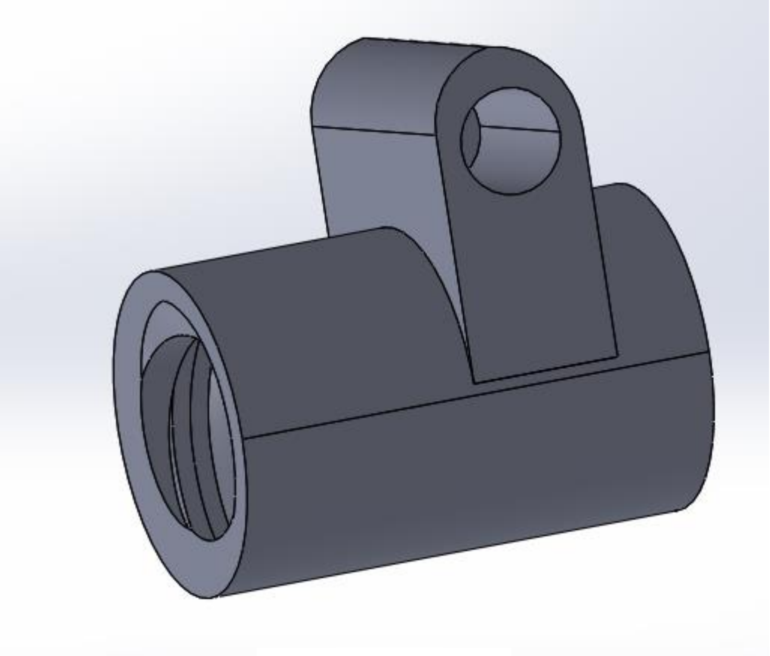

Figure 7-5 Slider

The choice of material and design for the slider is also important, as it must be able to withstand the high forces and stresses involved in missile flight. The slider must be strong, durable, and lightweight, while also providing smooth and precise motion along the track.

Overall, the slider is an essential component of the missile fin actuation system, enabling precise and controlled adjustments to the fins that are necessary for successful missile flight and guidance.

2D Dimensions

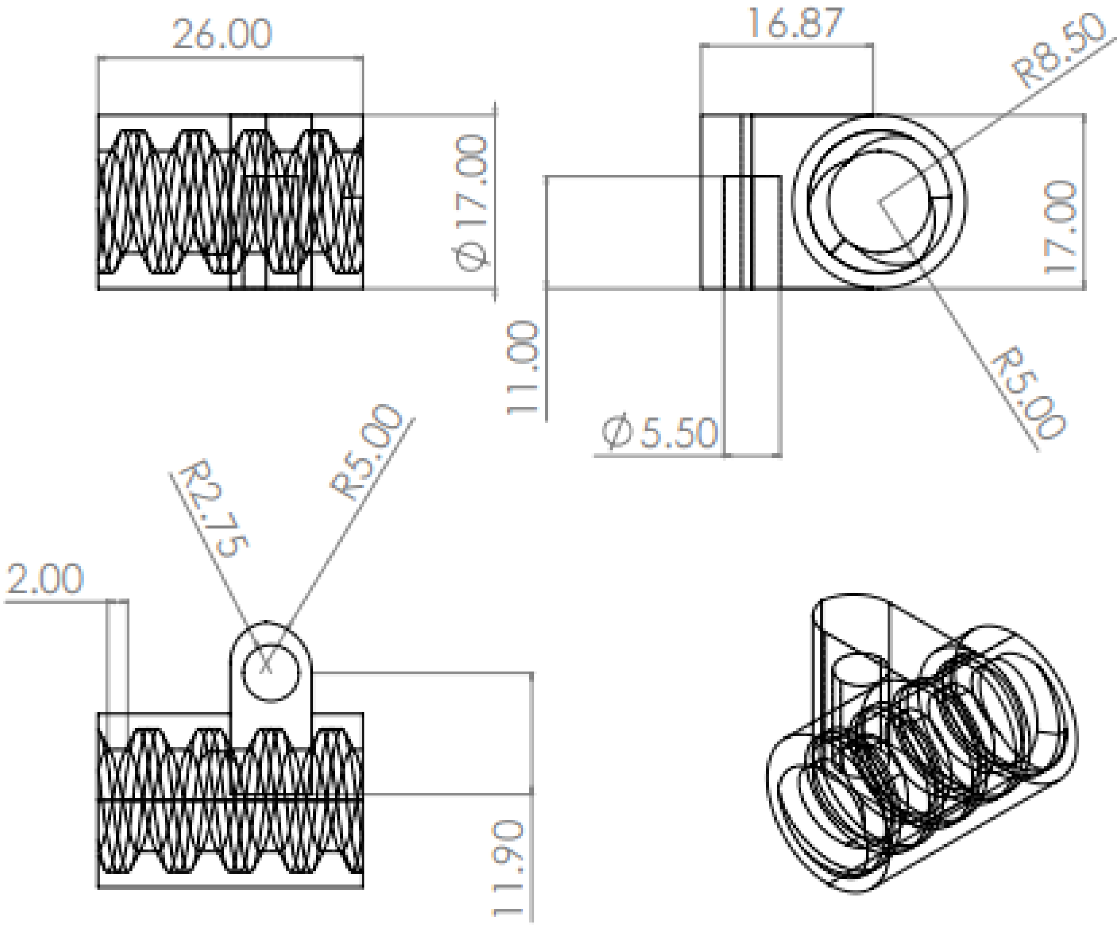

Figure 7-6 2D Drawing of Slider

7.4 Connecting Pin

In a missile fin actuation system, a connecting pin with one pin joint and other sliding point is a component that serves a critical role in connecting the rod-like component that connects to the fin with the slider that provides linear motion to the fins.

The connecting pin typically consists of two parts: a fixed pin joint that attaches to the rod-like component, and a sliding point that moves along a track on the slider. As the slider moves along the track, the sliding point of the connecting pin moves with it, causing the rod-like component to rotate and adjust the position of the missile's fins.

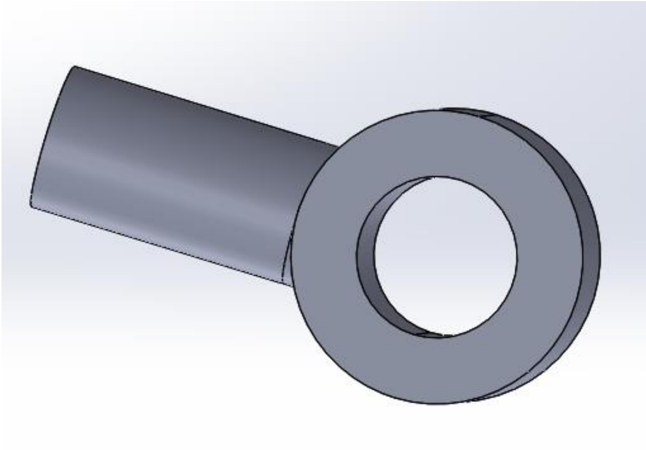

Figure 7-7 Connecting Pin

The purpose of the connecting pin is to provide a flexible and adjustable connection between the rod-like component and the slider, allowing for precise and controlled adjustments to the missile's fins. The pin joint allows the rod-like component to rotate around its axis, while the sliding point allows for linear motion along the track of the slider. Together, these two motions enable the fins to be adjusted in multiple directions, providing greater flexibility and control over the missile's flight.

The choice of material and design for the connecting pin is also important, as it must be able to withstand the high forces and stresses involved in missile flight, while also providing smooth and precise motion between the rod-like component and the slider.

Overall, the connecting pin with one pin joint and other sliding point is a critical component of the missile fin actuation system, enabling precise and flexible adjustments to the fins that are necessary for successful missile flight and guidance.

2D Dimensions

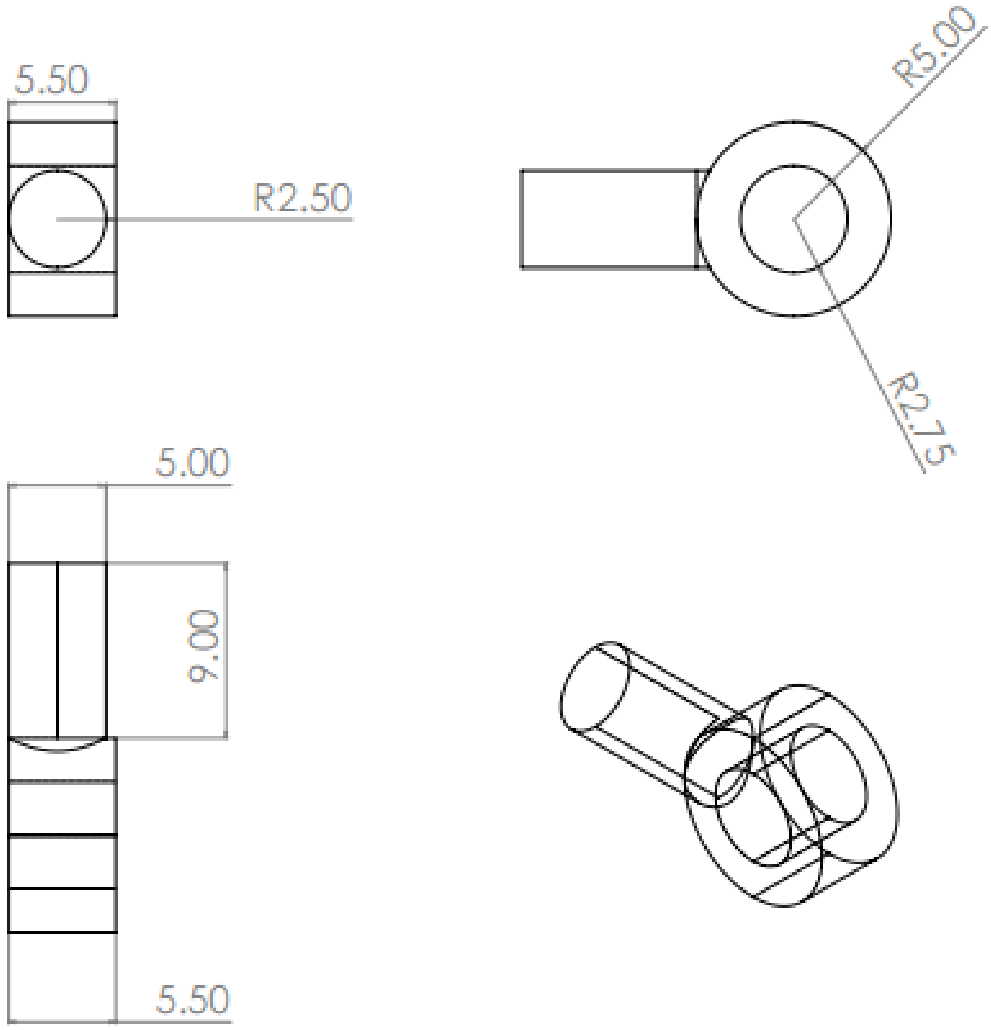

Figure 7-8 2D Drawing of Connecting Pin

7.5 Motor Base Component

The lead screw, with a diameter of 10 mm, will be mounted onto a base which will facilitate its rotation. The base will serve as the foundation for the stepper motor, providing a stable and secure platform for the lead screw to operate on. The support provided by the base will ensure that the lead screw is able to rotate smoothly and without any wobbling or other unwanted motion. This is crucial for the accurate and precise control of the missile's fins, as any vibrations or irregularities in the lead screw's motion could lead to unintended adjustments in the fin position. Overall, the choice of a suitable base for the lead stepper motor is an important consideration in designing an effective missile fin actuation system.

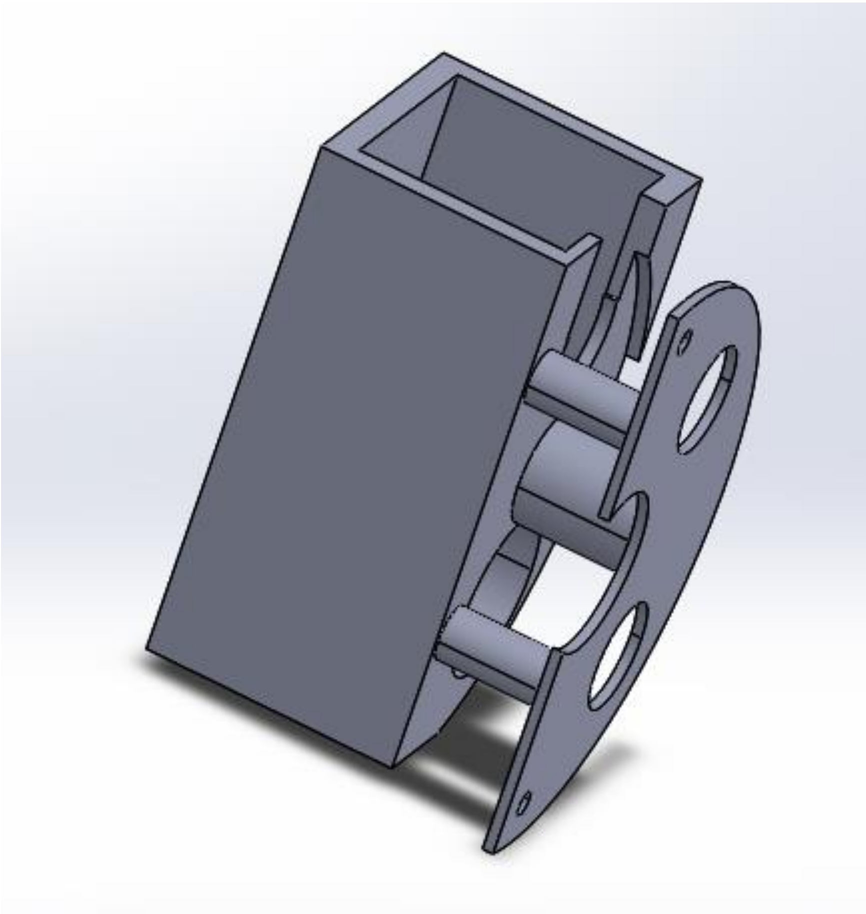

Figure 7-9 Base Motor Component

2D Dimensions

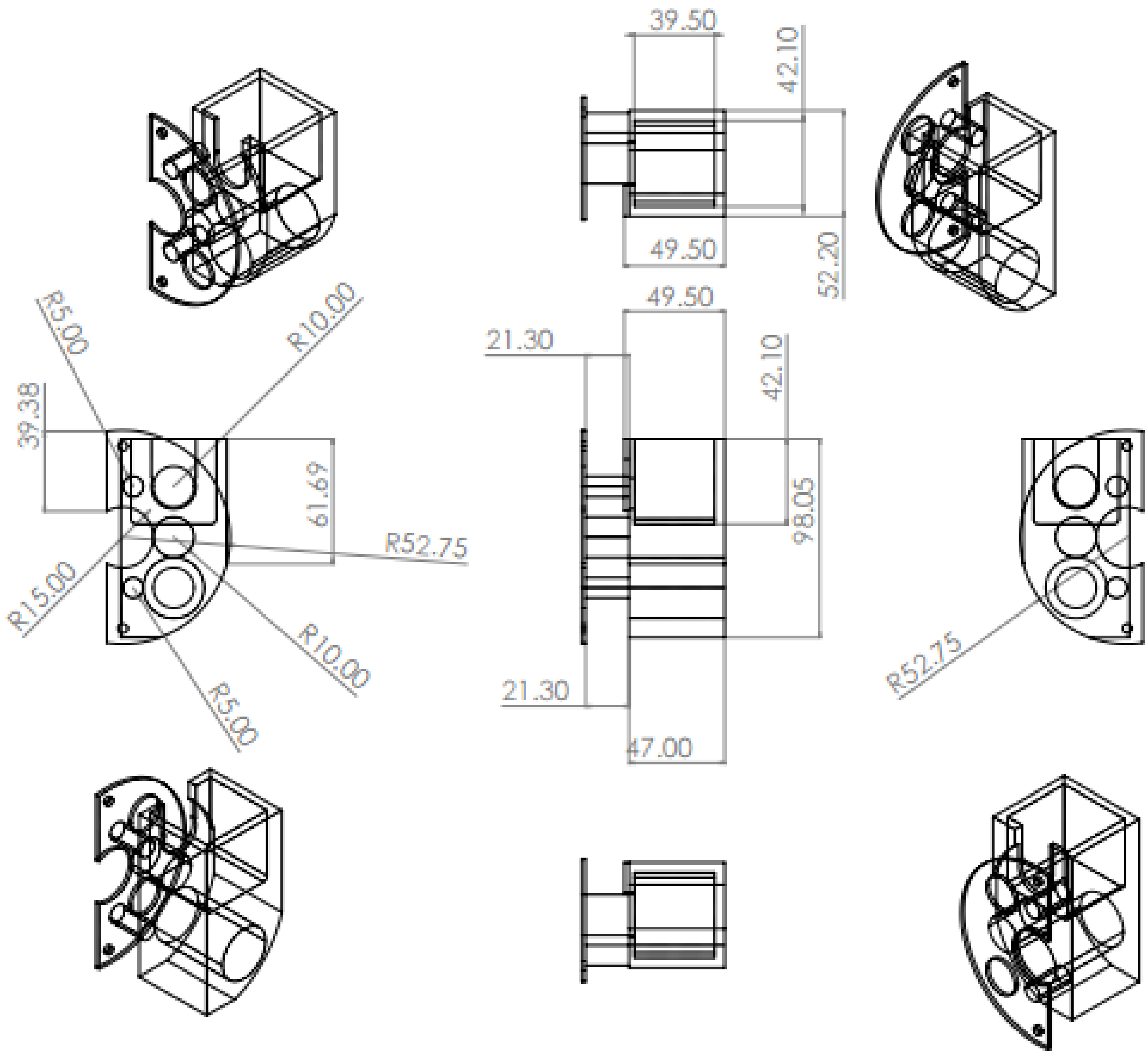

Figure 7-10 2D Drawing of Base Motor

7.7 Screw

Screws serve multiple essential functions in various projects and applications. Their primary purpose is to fasten two or more components together securely. By applying axial force and friction, screws create a strong and reliable connection. Additionally, screws are often used for positioning purposes, allowing for precise alignment and adjustment of components by tightening or loosening the screw. They also help distribute loads evenly across multiple parts, preventing localized stress concentrations. Screws are commonly employed to retain objects in place, such as securing panels or boards in woodworking projects. Furthermore, screws with threaded shafts provide adjustability, allowing for easy depth or tension control in assemblies. In certain mechanical systems, screws can transfer motion, converting rotational motion into linear motion or vice versa. When it comes to dismantling, screws facilitate the disassembly of components without causing damage. Lastly, screws play a crucial role in electrical projects, establishing secure electrical connections in terminals, junction boxes, and grounding applications. The specific function of a screw in a given project depends on the project's context, application, and design requirements.

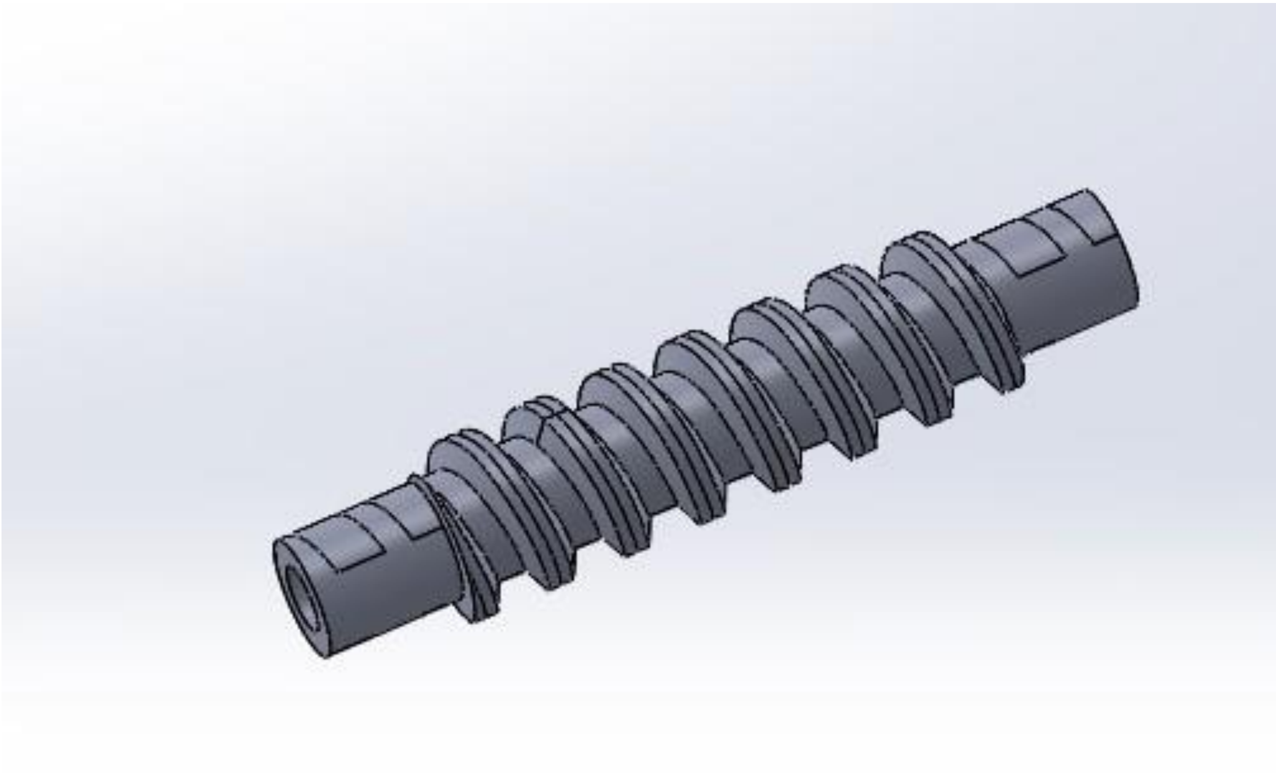

Figure 7-11 Screw

2D Dimensions

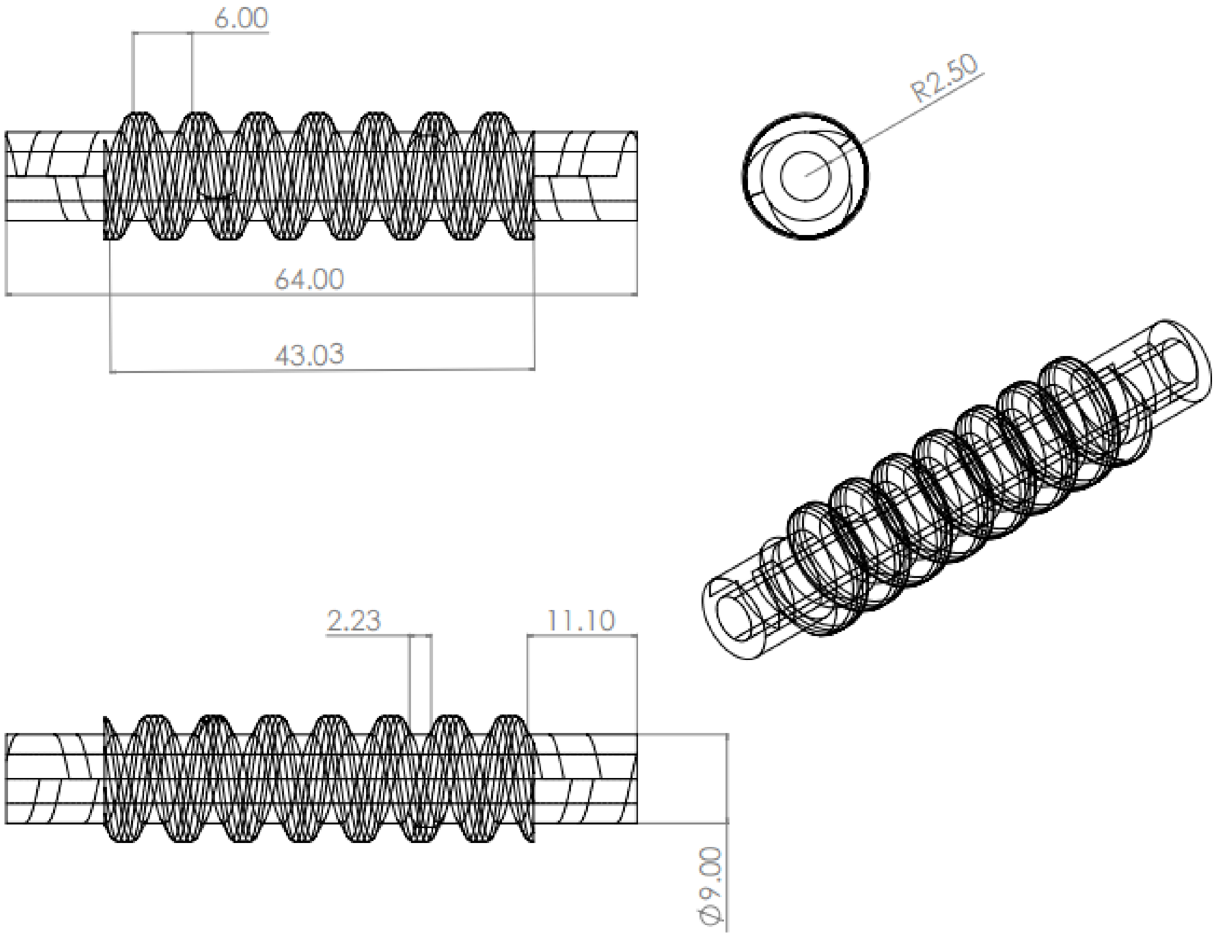

Figure 7-12 2D Drawing of Screw

7.8 Assemble Model

In a missile fin actuation system, a lead screw and connection rod mechanism are commonly used to provide precise and controlled adjustments to the missile's fins.

The lead screw is a component that consists of a threaded rod with a diameter of typically 10 mm. It is mounted onto a base which facilitates its rotation. The connection rod is a rod-like component that connects to the fin of the missile and is responsible for converting rotational motion into linear motion.

The connection rod is attached to the base of the missile and extends towards the fin. At the end of the connection rod, there is a hinge or pivot point that connects to the fin itself.

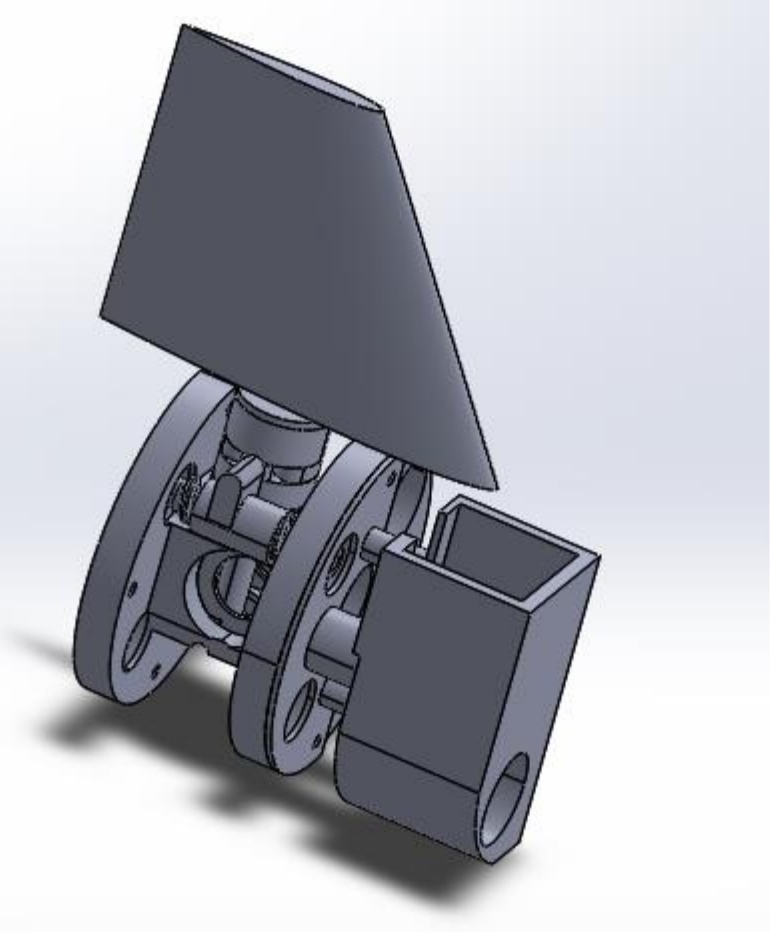

Figure 7-13 Assembly Model

The connection rod is connected to the lead screw via a nut, which moves along the threaded rod as the lead screw rotates. This causes the connection rod to move back and forth, which in turn adjusts the position and movement of the missile's fins.

The lead screw and connection rod mechanism provide precise and controlled adjustments to the missile's fins, which are crucial for successful missile flight and guidance. The angle and position of the fins can be adjusted, allowing the missile to be steered towards its intended target or directed away from obstacles or hazards.

The choice of material and design for the lead screw and connection rod mechanism is important, as it must be able to withstand the high forces and stresses involved in missile flight. The components must be strong, durable, and lightweight, while also providing smooth and precise motion to the fins.

Overall, the lead screw and connection rod mechanism is a reliable and effective method for providing precise and controlled adjustments to the missile's fins, enabling successful missile flight and guidance.

7.6 Mechanical Part along Control System

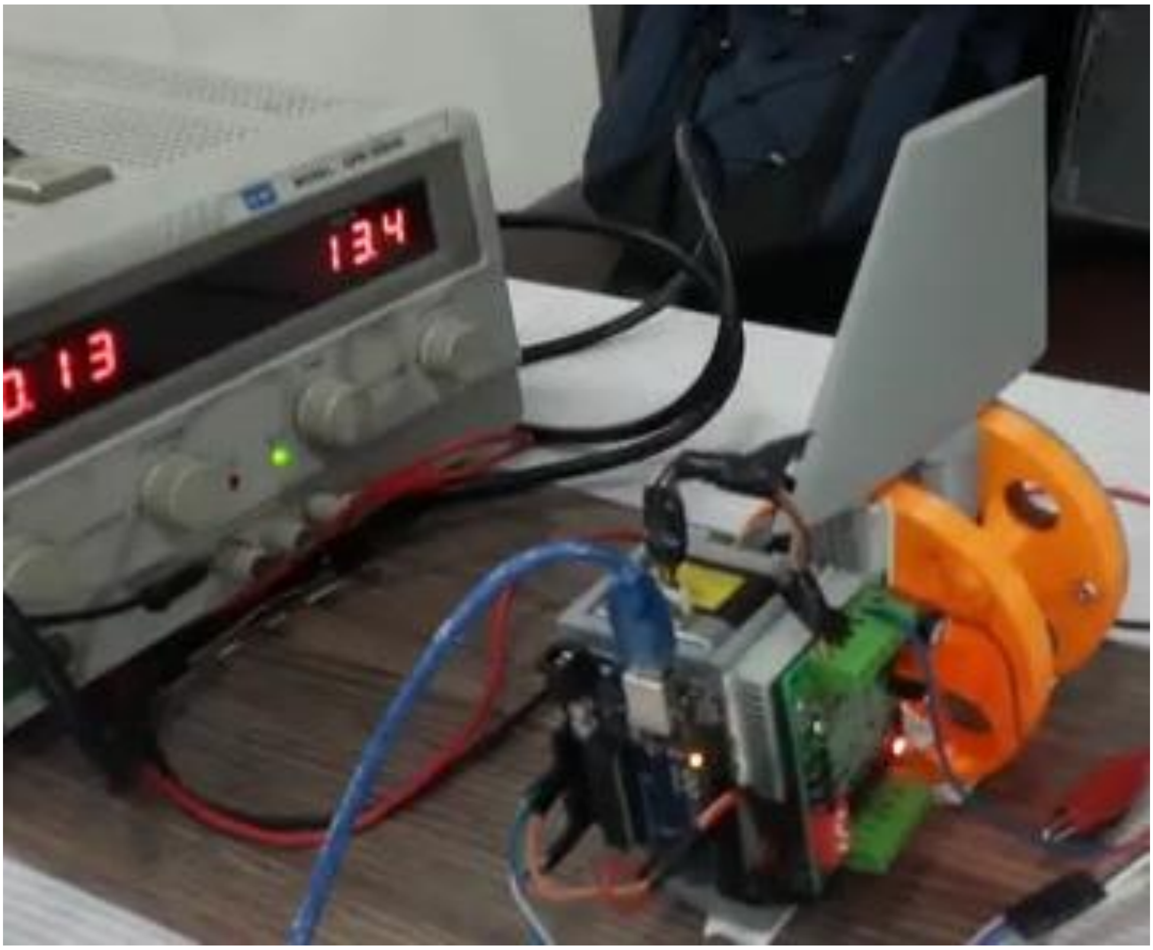

Figure 7-14 Final Model

CHAPTER N0 8

Lead Screw Threads

8.1 Introduction

A screw thread is a helical structure that is commonly used to convert rotational motion into linear movement or force. It consists of a ridge that is wrapped around a cylinder or cone in the form of a helix. Screw threads can be either straight or tapered, depending on the shape of the cylinder or cone. The mechanical advantage of a screw thread is determined by its pitch, which refers to the linear distance that the screw covers in one revolution. This property is crucial for most applications since the pitch must be chosen carefully to prevent the screw from slipping when a linear force is applied.

8.2 The Importance of Screw Threads

Screw threads are the essential feature of a screw as a simple machine and as a threaded fastener. When used as a fastener, tightening the screw thread is comparable to driving a wedge into a gap until it sticks through friction and slight elastic deformation.

8.3 Types of Threads

The Unified Screw Thread System is highly important for fasteners and includes three standard thread series: UNC (coarse), UNF (fine), and 8-UN (8 thread).

8.3.1 UNR Threads

The UNR thread is a modified version of a standard UN thread. The single difference is a mandatory root radius with limits of 0.108 to 0.144 times the thread pitch. Today, all fasteners that are roll-threaded should have a UNR thread because thread-rolling dies with rounded crests are now the standard method for manufacturing most threads.

8.3.2 UNJ Threads

UNJ thread is a thread form having root radius limits of 0.150 to 0.180 times the thread pitch. With these enlarged radii, minor diameters of external thread increase and intrude beyond the basic profile of the UN and UNR thread forms. Consequently, the minor diameters of the UNJ internal threads had to be increased to offset the possibility of interference between mating threads. 3A/3B thread tolerances are the standard for UNJ threads.

UNJ threads are now the standard for aerospace fasteners and have some usage in highly specialized industrial applications. UNJ bolts are like UNR, but the curve of the thread root is gentler, requiring that it be shallower. The thread root is so shallow that the bolt thread cannot mate with a UN nut, so there is a UNJ nut specification as well.

Screw threads are a crucial part of many applications, converting rotational motion into linear force. The Unified Screw Thread System is important for fasteners and includes three standard thread series. UNR and UNJ threads are modified versions of the UN thread that are commonly used in industrial and aerospace applications.

8.4 Types of Thread Used in Fasteners and Machinery

The Unified Screw Thread system comprises three standard thread series that are commonly used for fasteners: UNC (coarse), UNF (fine), and 8-UN (8 threads). In addition to these, there are other types of threads used in fasteners and machinery, such as:

8.4.1 UNR Threads

The UNR thread is a modified version of the UN thread that has a mandatory root radius with limits of 0.108 to 0.144 times the thread pitch. These threads are now standard in roll-threaded fasteners because thread-rolling dies with rounded crests are commonly used to manufacture threads.

8.4.2 UNJ Threads

UNJ threads have root radius limits of 0.150 to 0.180 times the thread pitch. To avoid interference between mating threads due to enlarged radii, the minor diameters of UNJ internal threads are increased. UNJ threads are commonly used in aerospace fasteners and specialized industrial applications.

8.4.3 British Standard Whitworth (B.S.W.)

Thread B.S.W. thread has coarse pitches and an asymmetrical V-thread with an angle between the flanks of 55°. It is commonly used in bolts and screwed fastenings for special purposes. B.S.W. threads with fine pitches (B.S.F.) are used where great strength at the root is required, such as in aero and automobile work.

British Association (B.A.) Thread B.A. thread is a B.S.W. thread with fine pitches used for instruments and precision works.

8.4.4 American National Standard Thread

The U.S. or Seller's thread has flat crests and roots that can withstand rough usage. It is used for general purposes on bolts, nuts, screws, and tapped holes.

8.4.5 Unified Standard Thread

The Unified Standard Thread has rounded crests and roots and an included angle of 60°, agreed upon by Great Britain, Canada, and the United States to facilitate the exchange of machinery.

8.4.6 Square Thread

Square threads are widely used for the transmission of power in either direction on feed mechanisms of machine tools, valves, spindles, screw jacks, etc.

8.4.7 Acme Thread

Acme threads are stronger than square threads and are used on screw-cutting lathes, brass valves, and bench vices. They are used in conjunction with a split nut to facilitate ready engagement and disengagement of the halves of the nut when required.

8.4.8 Knuckle Thread

Knuckle threads have a rounded top and bottom and are used for rough and ready work on railway carriage couplings, hydrants, necks of glass bottles, and large molded insulators used in the electrical trade.

8.4.9 Buttress Thread

Buttress threads are used for the transmission of power in one direction only, with the force transmitted almost parallel to the axis. They have the low frictional resistance characteristic of the square thread and the same strength as that of a V-thread. The spindles of bench vices are usually provided with buttress threads.

8.4.10 Metric Thread

Metric threads are similar to B.S.W. threads but have an included angle of 60° instead of 55°. They are an Indian standard thread.

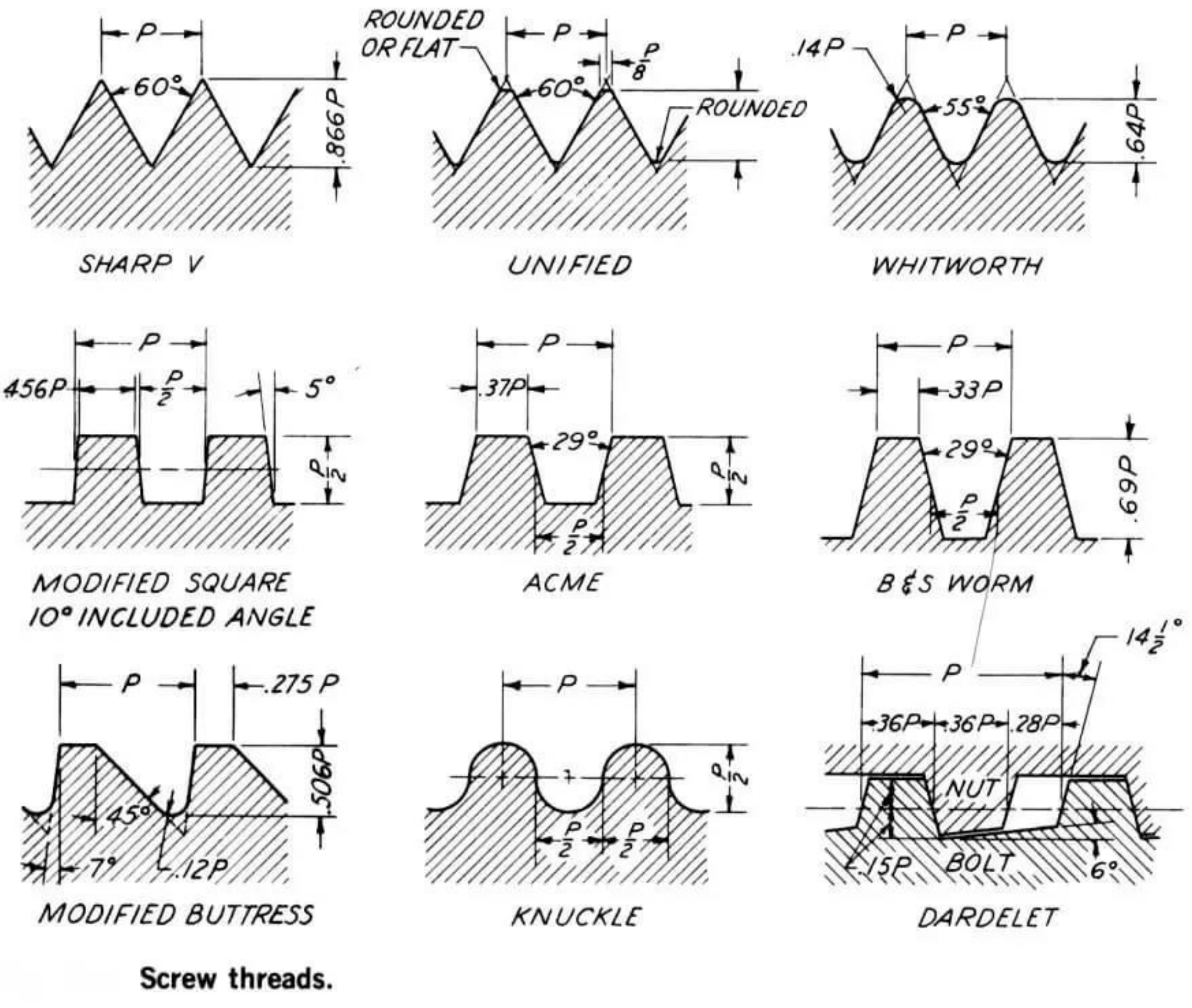

Figure 8-1 Standards of Thread

8.5 Threads Termenologies

To choose the right screw for your project, it's important to understand how screw threads work. Screw threads are designed to meet the needs of specific applications, and there are different types of screw threads to consider. A screw thread chart may be helpful, but it's also important to understand screw thread terminology to accurately select the right screw for your project.

External threads, or male threads, are found on bolts or screws.

Internal threads, or female threads, are found on nuts.

Machine screw threads are designed to mate with threads on nuts or threads present in tapped holes, and they are not self-tapping.

Spaced threads are designed to form their own threads in pre-drilled holes, and they are commonly found on self-tapping, wood, and coach screws.

Lag screws are an example of screws that form their own thread in pre-drilled holes, and they are typically used to fasten metal to wood.

Self-tapping screws are threaded to create their own holes when installed, and they form a matching thread in whatever material they are installed into, making them efficient to use.

Thread-forming screws feature two separate threads, one high and one low, and they are used with plastic materials. This makes the pullout strength higher and ensures the plastic does not crack or break.

Type U screws have an unusual spiral thread that is most often driven with a hammer into materials like plastic and metal casings.

Wood screws have a tapered shank with sharp threading, and they are designed to dig into wood fibers, creating a secure connection between the screw and the wood. They typically have a larger head size than other types of screws, which helps to distribute the load across a larger area of wood.

Understanding screw thread terminology is crucial when selecting the right screw for your project. By considering the different types of screw threads available and their unique features, you can choose the right screw to meet the needs of your project.

8.6 Additional Terms

To fully understand screw and threading terminology, there are a few additional terms that are helpful to know. These terms include major diameter, minor diameter, effective diameter, pitch, crest, thread angles, and coarse and fine threads.

The **major diameter** is the diameter of a screw including the raised helix's height, like an imaginary cylinder around the thread. It is measured using a slot gauge or a caliper rule and can only be measured with an external thread screw.

On the other hand, the **minor diameter** is the screw's diameter measured at the base or root of the thread at the innermost part of the screw. However, measuring the minor diameter accurately requires specialized equipment.

The **effective diameter** is essentially the average of the major and minor diameters and is measured halfway up the raised helix. Again, specialized equipment is needed to accurately measure a screw's effective diameter.

The **pitch** refers to the distance between two threads on the same screw. The crest is the height of an external thread and can be found by subtracting the minor diameter from the major diameter. The crest represents the difference between the two.

Thread angles refer to the actual angle of both flanks of a screw. Symmetrical threads indicate that both sides of the thread are angled to the same degree. Thread angles are commonly referred to as "the flank." [14]

Finally, **coarse,** and fine threads are terms used to describe the distance between the crest of each thread. Smaller gaps create fine threads, while larger ones create coarse threads.

CHAPTER N0 9

Circle Cut Threads

9.1 Introduction

The introduction of circle-based design in lead screws represents a significant advancement in the field. By utilizing circles, the design of lead screw threads can be optimized to offer several benefits. First and foremost, this innovative approach ensures the creation of lead screw threads with minimum backlash. Backlash refers to the undesirable clearance or play between mating components, which can negatively impact precision and accuracy. By employing circle-based design principles, the lead screw threads can be meticulously engineered to minimize or eliminate backlash, resulting in improved performance and reliability.

Furthermore, the circle-based design helps reduce frictional losses during transmission. Frictional losses occur when there is resistance or energy dissipation due to friction between moving parts. By incorporating circular elements into the lead screw design, the contact surfaces can be optimized to minimize friction, thereby enhancing efficiency and reducing energy wastage during power transmission.

In addition to these performance advantages, the circle cut threads also address some inherent limitations of traditional lead screws. One such limitation is the heavy weight of lead screws, which can pose challenges in various applications. However, by adopting circle-based design techniques, the overall weight of the lead screw can be reduced without compromising its strength and functionality. This reduction in weight offers benefits such as improved portability and ease of installation.

Another drawback of traditional lead screws is the slow production process associated with machining and production limits. However, circle cut threads provide a solution to this problem by enabling faster and more efficient manufacturing. The circular design simplifies the machining process, allowing for quicker production of lead screw threads. Additionally, the use of circle cut threads may also lead to cost savings in production, making the manufacturing process more economical.

Overall, the incorporation of circle-based design in lead screws revolutionizes their performance, addressing issues related to backlash, frictional losses, weight, and production speed. This innovation opens up new possibilities for industries relying on lead screw technology, offering enhanced efficiency, improved productivity, and cost-effective solutions.

9.2 Thread Shape

1. Start by drawing a circle with a diameter equal to the desired thread base. The thread base is the distance between corresponding points on adjacent threads.

2. Find the midpoint of the line segment between the center of the circle and the radius of the circle. This point will be used as a reference for further construction.

3. Draw a perpendicular line from the midpoint of the line segment mentioned in step 2. This line should intersect the circle.

4. Repeat step 3 to draw a perpendicular line from the other side of the midpoint. This ensures that the perpendicular lines are symmetrically positioned.

5. Next, draw a tangent line to the circle from the point of intersection of the perpendicular line and the circle. This tangent line will be parallel to the thread profile.

6. Finally, from the point where the tangent line intersects the perpendicular line, draw a line segment that extends to the outer edge of the semicircle. This line segment represents one complete thread profile.

By following these steps, you can design the circle threads with precision and accuracy. This method utilizes the properties of circles and tangents to create a thread profile that meets the desired specifications, ensuring optimal performance in terms of minimizing backlash and frictional losses during transmission.

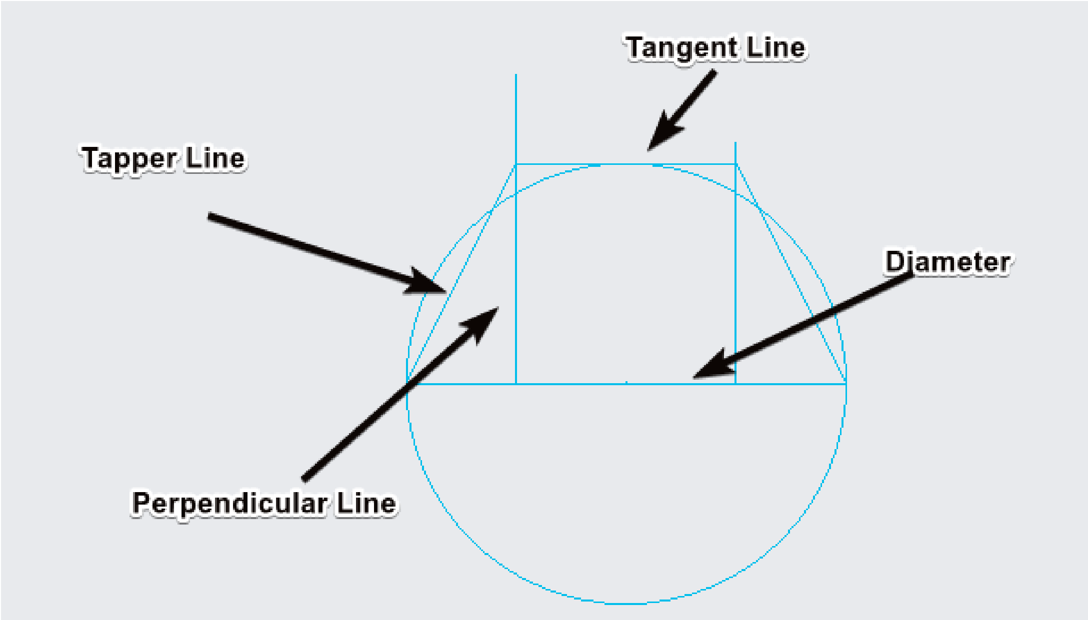

Figure 9-1 Circle Thread Standard

CHAPTER N0 10

Control System

10.1 Intoduction

A control system using Arduino Uno, TB6560, and MPU-6050 sensor for stepper motor control involves integrating various components to enable precise and responsive control of the motor. Here is a detailed explanation of each component's role and the overall system configuration:

10.2 Arduino Uno

The Arduino Uno serves as the central processing unit of the control system. It is a microcontroller board that runs code to execute specific tasks, such as reading sensor data, processing inputs, and generating output signals to control the stepper motor.

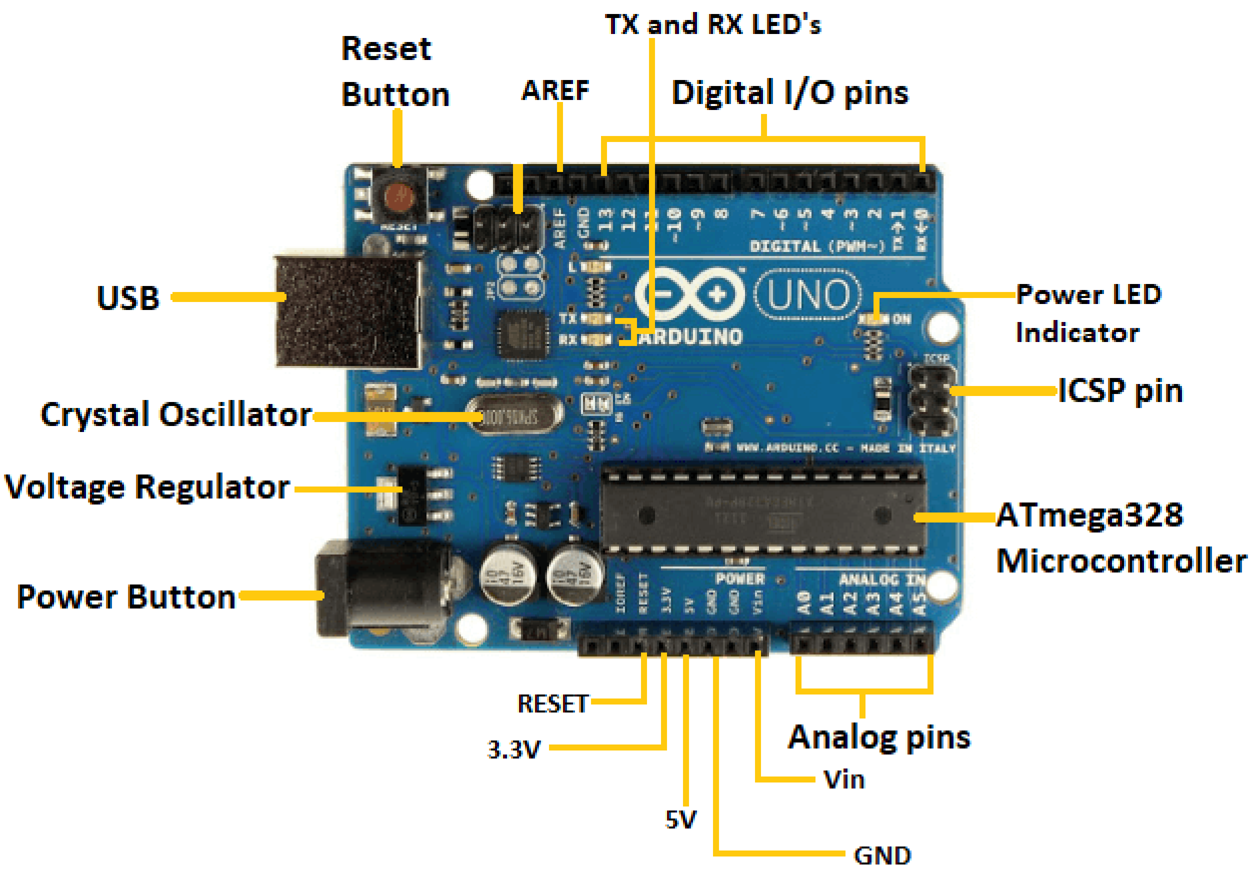

Figure 10-1 Arduino UNO

10.3 TB6560 Stepper Motor Driver

The TB6560 is a motor driver module responsible for driving the stepper motor. It receives control signals from the Arduino Uno and converts them into the appropriate power and current levels to drive the motor coils. The TB6560 typically supports various stepper motor types and provides features like current adjustment and microstepping to fine-tune motor operation.

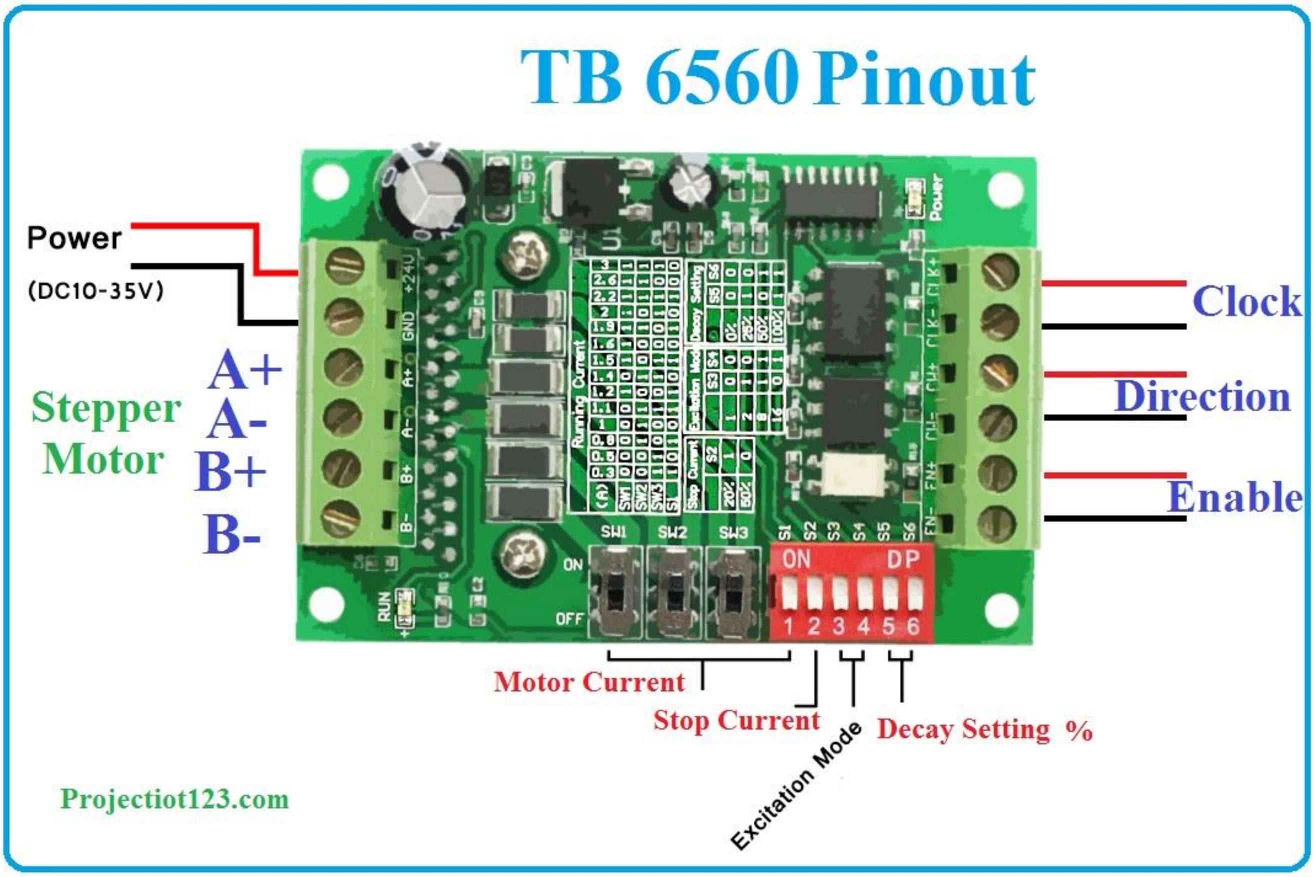

Figure 10-2 TB 6560 Stepper Motor Driver

10.4 MPU-6050 Sensor

The MPU-6050 is an accelerometer and gyroscope sensor module. It measures acceleration and angular velocity in multiple axes. In the control system, the MPU-6050 sensor is used to gather data about the physical orientation and movement of the system. This information can be utilized to implement control algorithms, such as maintaining stability or compensating for external disturbances. [15]

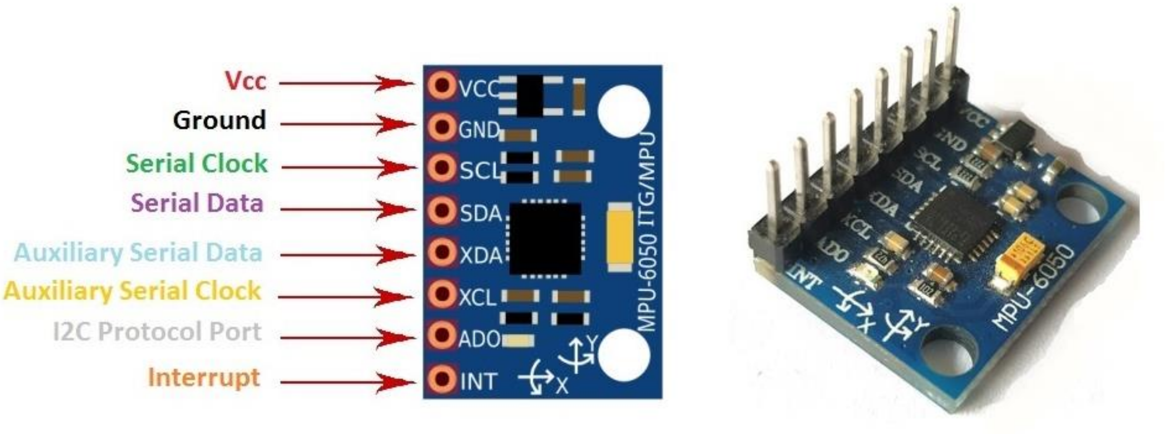

Figure 10-3 MPU 6050 Sensor

10.5 System Configuration and its Operation

Wiring: Connect the Arduino Uno, TB6560 driver, and MPU-6050 sensor as follows:

- Connect the necessary control lines from the Arduino Uno to the TB6560 driver, including step, direction, and enable signals.
- Wire the power and ground connections between the Arduino Uno, TB6560 driver, and stepper motor power supply.
- Connect the MPU-6050 sensor to the Arduino Uno using the appropriate digital or analog pins and ensure the power and ground connections are properly established.

Initialization: Initialize the Arduino Uno by setting up the required libraries and configuring the input/output pins for the TB6560 driver and MPU-6050 sensor. This typically involves importing the necessary libraries and defining pin modes and initial sensor settings.

Sensor Data Acquisition: Utilize the MPU-6050 library and functions to read data from the sensor. Retrieve information such as acceleration and angular velocity in real-time. These sensor readings can be used to monitor the system's position, motion, and orientation.

Control Algorithms: Develop control algorithms or utilize existing ones to process the sensor data and generate appropriate control signals for the stepper motor. For example, you can implement PID control to achieve precise position control or compensate for disturbances using sensor feedback.

Motor Control: Utilize the control signals generated by the control algorithms to drive the stepper motor via the TB6560 driver. Send appropriate step and direction signals to control the motor's rotation and position. Adjust motor parameters like speed, acceleration, and microstepping to achieve the desired motion characteristics.

Feedback and Monitoring: Continuously monitor the system's performance by collecting feedback from the MPU-6050 sensor and comparing it to the desired or reference values. This feedback loop ensures that the motor accurately responds to the control commands and maintains the desired position or motion.

Additional Features: Depending on your specific application, you can add additional features like limit switches or endstops to prevent motor overtravel, emergency stop functionality, or user interfaces for control input and system monitoring.

By integrating the Arduino Uno, TB6560 driver, and MPU-6050 sensor in this manner, you can create a comprehensive control system for precise and responsive stepper motor control. This setup enables you to implement various control strategies and adapt the system to different applications requiring accurate motion control and feedback.

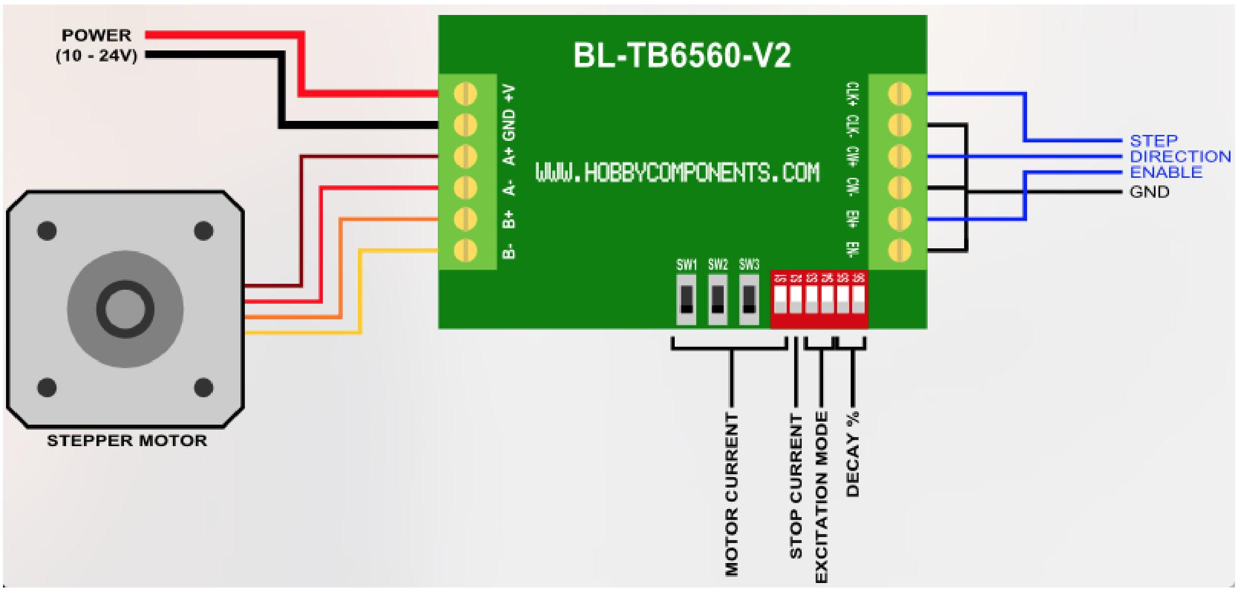

Figure 10-4 Control System

CHAPTER N0 11

Results, Conclusions and Recommendations

11.1 Results

The project on precision fin actuation through a lead screw mechanism yielded significant results. It began with establishing comprehensive design specifications, providing a roadmap for development. Detailed mechanical design documentation, including CAD models, showcased seamless integration of the lead screw mechanism with the fins. Physical prototypes demonstrated functionality and feasibility.

Precise positional accuracy and repeatability of the system were measured and analyzed, ensuring accurate fin positioning. Torque requirements were determined for effective fin movement. Dynamic response evaluation highlighted the system's agility. Backlash analysis minimized sources of error.

Efficiency analysis optimized torque transmission, reducing energy consumption. Successful integration with control electronics and sensors enhanced control and monitoring capabilities. Rigorous testing validated the system's performance under various conditions.

Comparisons between experimental results and theoretical predictions identified successful areas and potential improvements. Comprehensive documentation compiled project reports, specifications, and test results.

Overall, the project's results contribute to advancing precision fin actuation technology for applications in aerospace, robotics, and fluid dynamics.

11.2 Limitations

The precision fin actuation system through a lead screw mechanism has limitations that impact its performance. Mechanical constraints, including backlash and friction, introduce small errors. Sensitivity to external factors such as vibrations and temperature variations affects system accuracy. The system's complexity and size can pose integration challenges in limited spaces. Optimizing power consumption and energy efficiency is crucial. Addressing these limitations will enhance the system's precision and applicability in various domains.

11.3 Future Recommendations

To further enhance the precision fin actuation system through a lead screw mechanism, several recommendations for future work can be considered. Firstly, exploring advanced control algorithms, such as model predictive control or adaptive control, can significantly improve the system's precision and responsiveness. Additionally, integrating additional sensors and feedback mechanisms will enhance the accuracy and reliability of the fin position control. Efforts should also be directed towards minimizing noise and vibrations to improve system stability. Optimizing energy efficiency through techniques like energy recovery and efficient motor control is crucial for sustainability. Continual evaluation of materials and components should be carried out to enhance performance and reduce weight.

Developing a real-time monitoring and diagnostic system will enable proactive maintenance and performance tracking. Investigating scalability and adaptability for different fin sizes and applications will ensure wider applicability. Computational modeling and simulation can be utilized to optimize system performance and prediction. Additionally, exploring advanced actuator technologies, signal processing techniques, and fault-tolerant design strategies will contribute to system improvements. Environmental effects, machine learning, wireless communication, and remote monitoring are other areas that warrant investigation. Collaboration with industry partners, extensive field testing, and the integration with automation and control systems will provide valuable insights for further enhancements.

11.3 Conclusion

In conclusion, the precision fin actuation system through a lead screw mechanism holds great promise for various applications requiring precise control of fin movements. The project has successfully achieved notable results, including comprehensive design specifications, detailed mechanical documentation, and the creation of functional prototypes. The system demonstrated precise positional accuracy, repeatability, and efficient torque transmission. Integration with additional components, such as control electronics and sensors, if applicable, further enhanced its functionality and versatility.

However, it is essential to acknowledge the limitations of the system, such as mechanical constraints, sensitivity to external factors, and the complexity and size of the system. These limitations provide avenues for future work and improvements to enhance the system's performance and applicability.

Recommendations for future work include exploring advanced control algorithms, integrating additional sensors and feedback mechanisms, minimizing noise and vibrations, optimizing energy efficiency, evaluating materials and components, and developing a comprehensive real-time monitoring and diagnostic system. Scalability, adaptability, computational modeling, and fault-tolerant design strategies should also be investigated to further refine the system.

Overall, the results achieved in this project contribute to the advancement of precision fin actuation technology and lay the foundation for future developments in aerospace, robotics, and fluid dynamics. With continued research and implementation of the recommended improvements, the precision fin actuation system through a lead screw mechanism has the potential to revolutionize the field and enable precise and efficient control of fin movements in various industries.

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VENDORS

Sr No	Component Name	Quantity	Vendor
1	Stepper Motor	1	Electrobes
2	ARDUINO UNO	1	Electrobes
3	TB 6560	1	Electrobes
4	MPU 6050	1	Electrobes
5	H- Bridge	1	Electrobes
6	Connecting wires	3	Electrobes
7	Base Motor	1	Sylenzz 3D Printers
8	Base Fin	1	Sylenzz 3D Printers
9	Closing Plate	1	Sylenzz 3D Printers
10	Slider	1	Sylenzz 3D Printers
11	Screw	1	Sylenzz 3D Printers
12	Head Part	1	Sylenzz 3D Printers
13	Connecting Pin	1	Sylenzz 3D Printers
14	Fin	2	Sylenzz 3D Printers
15	Bearing	4	Allied Electronic
16	Nut Bolts	10	Anwar Hardware