DESIGN OF ORNITHOPTER FOR AERIAL SEEDING

An Internal Project report submitted in partial fulfilment of the requirement
For the award of the degree of

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IN

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Submitted by

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CERTIFICATE

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ABSTRACT

Broadcast seeding is one of the most widely used post-wildfire emergency response treatments intended to reduce soil erosion, increase vegetative ground cover, and minimize establishment and spread of non-native plant species. Usually for this kind of operation small planes and helicopters are used, however the present method of aerial seeding is not economic, it can be done only by public organizations. Our project is mainly focused on the alternative aerial seeding using ornithopters, which give easy access to the social activist' s to do the task in the economical way.

Traditionally ornithopters are used for military applications like surveillance, these can be used for aerial seeding and land surveying in more natural way like birds without disturbing the ecosystem. This project mainly focuses on the design synthesis and simulation of ornithopters mechanisms suitable for aerial seeding.

The new ornithopter mechanism is designed and is optimized and simulated using the software "Simulation and Analysis of Mechanisms (SAM). The 3D model of the project is designed using the software "AUTODESK Inventor Professional" and various analysis for Velocity, Acceleration, Aerodynamics are performed. And the model is compared with other similar models in the Inventor and optimized. Finally the model with best Aerodynamics is obtained.

1. INTRODUCTION

Today, changes in traditional farming practices motivate robotics researchers to consider ways in which automated devices and intelligent systems can work with farmers to address diverse needs of farming. Because farming tasks can be highly specialized, though often repetitive, a approach is a natural choice. Aerial seeding is a technique of sowing seeds by spraying them through aerial mechanical means such as a drone, plane or helicopter.

Aerial seeding is considered a broadcast method of seeding. It is often used to spread different grasses and legumes to large areas of land that are in need of vegetative cover after fires. Large wildfires can destroy large areas of plant life resulting in erosion hazards. Aerial seeding may quickly and effectively reduce erosion hazards and suppress growth of invasive plant species. Aerial seeding is an alternative to other seeding methods where terrain is extremely rocky or at high elevations or otherwise inaccessible.

The major advantage of aerial seeding is the efficient coverage of a large area in the least amount of time. Aerial seeding facilitates seeding in areas that otherwise would be impossible to seed with traditional methods, such as land that is too hard to reach by non-aircraft or ground conditions being far too wet.

Fig 1.1 Aerial seeding using helicopters

1.1 ORNITHOPTER:

An ornithopter (from Greek ornithos "bird" and pteron "wing") an aircraft that flies by flapping its wings. Designers seek to imitate the flapping-wing flight of birds, bats, and insects. Though machines may differ in for`m, they are usually built on the same scale as these flying

creatures. Manned ornithopters have also been built, and some have been successful. The machines are of two general types: those with engines, and those powered by the muscles of the pilot.

Fig 1.2 ornithopter

1.2 LINK:

A kinematic link or element or link is a resistant body that constitutes part of the machine, connecting other parts which have motion relative to it. piston , piston rod and crosshead of a steam engine constitutes one unit and hence called one link.
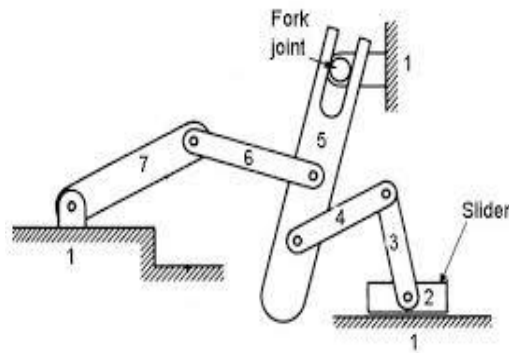
Fig 1.3 Mechanism with links

1.3 MECHANISM:

A mechanism is a device that transforms input forces and movement into a desired set of output forces and movement. Mechanism, in mechanical construction, the means employed to transmit and modify motion in a machine or any assemblage of mechanical parts. The chief characteristic of the mechanism of a machine is that all members have constrained

motion; i.e., the parts can move only in a determinate manner relative to one another. The nature of these relative motions is determined largely by the number of parts and the way in which they are connected.
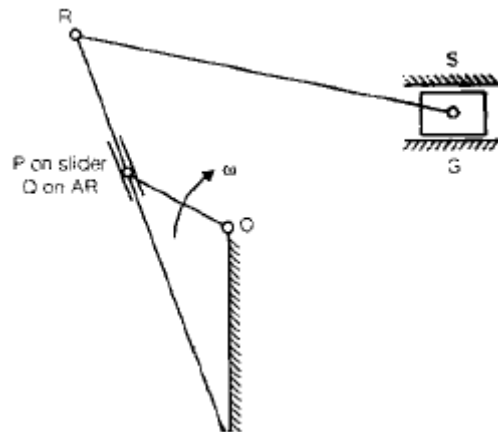
Fig 1.4 Q**uick return Mechanism**

1.4 SIMULATION AND ANALYSIS OF MECHANISMS (SAM) Software:

SAM (Simulation and Analysis of Mechanisms) is an interactive PC-software package for the motion and force analysis of arbitrary planar mechanisms, which can be assembled from basic components including beams, sliders, gears, belts, springs, dampers and friction elements. SAM integrates pre-processing, numerical analysis and postprocessing, such as animation and xy-plots, in an easy to-use environment offering pull-down menus, mouse support and help facilities.
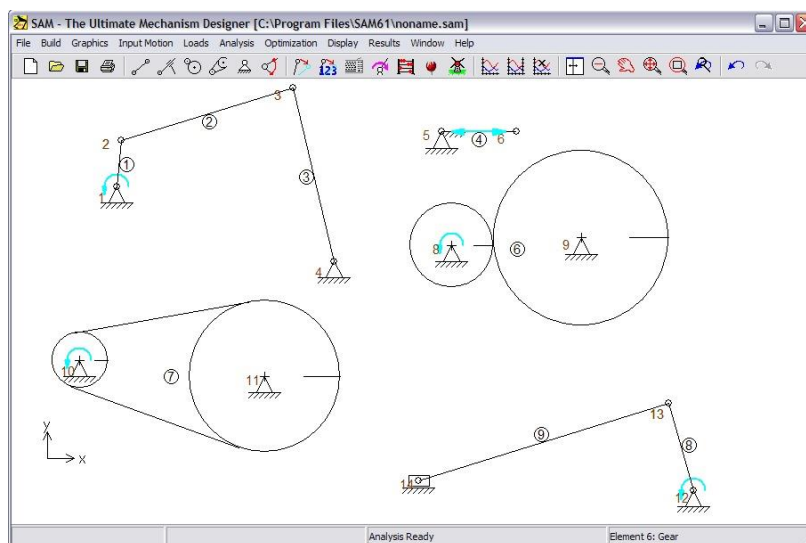
Fig 1.5 SAM user interface

1.5 AUTODESK INVENTOR:

Autodesk Inventor is a Computer – Aided – Design application for 3D mechanical design, simulation, visualization and documentation developed by Autodesk.

Inventor allows 2D and 3D data integration in a single environment, creating a virtual repress- entation of the final product that enables users to validate the form, fit, and function of the product before it is ever built. Autodesk Inventor includes parametric, direct edit and freeform modeling tools as well as multi-CAD translation capabilities and in their standard drawings. Inventoruses Shape Manager, Autodesk's proprietary geometric modeling kernel. Autodesk Inventor competes directly with SolidWorks, Solid Edge, and Creo.

It uses the concept of parametric design, used primarily to create technical drawings for mechanical purposes. It is found in many fields such as automotive, architecture, construction, etc.

Autodesk Inventor is great for any type of machine design. It works very well with creating a combination of custom fabricated parts and purchased pre-designed products

1.6 AERODYNAMICS:

One of the requirements for heavier-than-air flying machines is a structure that combines strength with light weight. This is true for birds as well as planes. Birds have many physical features, besides wings, that work together to enable them to fly. They need lightweight, streamlined, rigid structures for flight. The four forces of flight – weight, lift, drag and thrust – affect the flight of birds.

Godwits – designed to fly

As with other flying birds, godwits have many physical features that work together to enable them to fly. They need lightweight, streamlined, rigid structures for flight.

Physical features Flying birds have:

- lightweight, smooth feathers – this reduces the forces of weight and drag
- a beak, instead of heavy, bony jaws and teeth – this reduces the force of weight

- an enlarged breastbone called a sternum for flight muscle attachment – this helps with the force of thrust
- light bones – a bird's bones are basically hollow with air sacs and thin, tiny cross pieces to make bones stronger – this reduces the force of weight
- a rigid skeleton to provide firm attachments for powerful flight muscles – this helps with the force of thrust
- a streamlined body – this helps reduce the force of drag
- wings – these enable the force of lift.

Wings

The shape of a bird's wing is important for producing lift. The increased speed over a curved, larger wing area creates a longer path of air. This means the air is moving more quickly over the top surface of the wing, reducing air pressure on the top of the wing and creating lift. Also, the angle of the wing (tilted) deflects air downwards, causing a reaction force in the opposite direction and creating lift. Larger wings produce greater lift than smaller wings. So smaller-winged birds (and planes) need to fly faster to maintain the same lift as those with larger wings. Wing loading tells you how fast a bird or plane must fly to be able to maintain lift:

wing loading = weight/wing area (kilograms per square metre).

A smaller wing loading number means the bird/plane can fly more slowly while still maintaining lift and is more manoeuvrable.

Gliding

When a bird is gliding, it doesn't have to do any work. The wings are held out to the side of the body and do not flap. As the wings move through the air, they are held at a slight angle, which deflects the air downwards and causes a reaction in the opposite direction, which is lift. But there is also drag (air resistance) on the bird's body, so every now and then, the bird has to tilt forward and go into a slight dive so that it can maintain forward speed.

Soaring

Soaring flight is a special kind of glide in which the bird flies in a rising air current (called a thermal). Because the air is rising, the bird can maintain its height relative to the ground. The albatross uses this type of soaring to support its multi-year voyages at sea.

Soaring and flapping

Birds can fly in various ways. The albatross demonstrates soaring, while the godwit is on the downbeat, flapping.

Flapping

Birds' wings flap with an up-and-down motion. This propels them forward. The entire wingspan has to be at the right angle of attack, which means the wings have to twist (and do so automatically) with each downward stroke to keep aligned with the direction of travel.

A bird's wing produces lift and thrust during the downstroke. The air is deflected downwards and also to the rear. The bird reduces its angle of attack and partially folds its wings on the upward stroke so that it passes through the air with the least possible resistance. The inner part of the wing has very little movement and can provide lift in a similar way to gliding.

Godwits in flight: Massey University's Dr Phil Battley describes godwits in flight including flapping ability, speed, flying altitudes, streamlining, time taken for non-stop flight and V-formation flight.

Obtaining thrust

Birds obtain thrust by using their strong muscles and flapping their wings. Some birds may use gravity (for example, jumping from a tree) to give them forward thrust for flight. Others may use a running take-off from the ground.

Different flight abilities

Different birds have different adaptive features to meet their flight needs:

Some birds are small and can manipulate their wings and tail to manoeuvre easily, such as the fantail (pīwakawaka). The hawk, with its large wingspan, is capable of speed and soaring. Gannets and seabirds are streamlined to dive at high speeds into the ocean for fish. Godwits, although small, are equipped to fly long distances.

As demonstrated by birds, flapping wings offer potential advantages in maneuverability and energy savings compared with fixed-wing aircraft, as well as potentially vertical take-off and landing. It has been suggested that these advantages are greatest at small sizes and low flying speeds, but the development of comprehensive aerodynamic theory for flapping remains an outstanding problem due to the complex non-linear nature of such unsteady separating flows.

Unlike airplanes and helicopters, the driving airfoils of the ornithopter have a flapping or oscillating motion, instead of rotary. As with helicopters, the wings usually have a combined function of providing both lift and thrust. Theoretically, the flapping wing can be set to zero angle of attack on the upstroke, so it passes easily through the air. Since typically the flapping airfoils produce both lift and thrust, drag-inducing structures are minimized. These two advantages potentially allow a high degree of efficiency.

Fig 1.6 Aerodynamics of flying

Wing design

If future manned motorized ornithopters cease to be "exotic", imaginary, unreal aircraft and start to serve humans as junior members of the aircraft family, designers and engineers will need to solve not only wing design problems but many other problems involved in making

them safe and reliable aircraft. Some of these problems, such as stability, controllability, and durability, are necessary for all aircraft. Other problems specific to ornithopters will appear; optimizing flapping-wing design is only one of them.

An effective ornithopter must have wings capable of generating both thrust, the force that propels the craft forward, and lift, the force (perpendicular to the direction of flight) that keeps the craft airborne. These forces must be strong enough to counter the effects of drag and the weight of the craft.

Leonardo's ornithopter designs were inspired by his study of birds, and conceived the use of flapping motion to generate thrust and provide the forward motion necessary for aerodynamic lift. However, using materials available at that time the craft would be too heavy and require too much energy to produce sufficient lift or thrust for flight. Alphonse Pénaud introduced the idea of a powered ornithopter in 1874. His design had limited power and was uncontrollable, causing it to be transformed into a toy for children. More recent vehicles, such as the human-powered ornithopters of Lippisch (1929) and Emil Hartman (1959), were capable powered gliders but required a towing vehicle in order to take off and may not have been capable of generating sufficient lift for sustained flight. Hartman's ornithopter lacked the theoretical background of others based on the study of winged flight, but exemplified the idea of an ornithopter as a birdlike machine rather than a machine that directly copies birds' method of flight. The 1960s saw powered unmanned ornithopters of various sizes capable of achieving and sustaining flight, providing valuable real-world examples of mechanical winged flight. In 1991, Harris and DeLaurier flew the first successful engine-powered remotely piloted ornithopter in Toronto, Canada. In 1999, a piloted ornithopter based on this design flew, capable of taking off from level pavement and executing sustained flight.

An ornithopter's flapping wings and their motion through the air are designed to maximize the amount of lift generated within limits of weight, material strength and mechanical complexity. A flexible wing material can increase efficiency while keeping the driving mechanism simple. In wing designs with the spar sufficiently forward of the airfoil that the aerodynamic center is aft of the elastic axis of the wing, aeroelastic deformation causes the wing to move in a manner close to its ideal efficiency (in which pitching angles lag plunging displacements by approximately 90 degrees.) Flapping wings increase drag and are not as efficient as propeller-powered aircraft. Some designs achieve increased efficiency by applying more power on the down stroke than on the upstroke, as do most birds.

In order to achieve the desired flexibility and minimum weight, engineers and researchers have experimented with wings that require carbon fiber, plywood, fabric, and ribs, with a stiff, strong trailing edge. Any mass located aft of the empennage reduces the wing's performance, so lightweight materials and empty space are used where possible. To minimize drag and maintain the desired shape, choice of a material for the wing surface is also important. In DeLaurier's experiments, a smooth aerodynamic surface with a double-surface airfoil is more efficient at producing lift than a single-surface airfoil.

Other ornithopters do not necessarily act like birds or bats in flight. Typically birds and bats have thin and cambered wings to produce lift and thrust. Ornithopters with thinner wings have a limited angle of attack but provide optimum minimum-drag performance for a single lift coefficient.

Although hummingbird fly with fully extended wings, such flight is not feasible for an ornithopter. If an ornithopter wing were to fully extend and twist and flap in small movements it would cause a stall, and if it were to twist and flap in very large motions, it would act like a windmill causing an inefficient flying situation.

A team of engineers and researchers called "Fullwing" has created an ornithopter that has an average lift of over 8 pounds, an average thrust of 0.88 pounds, and a propulsive efficiency of 54%. The wings were tested in a low-speed wind tunnel measuring the aerodynamic performance, showing that the higher the frequency of the wing beat, the higher the average thrust of the ornithopter.
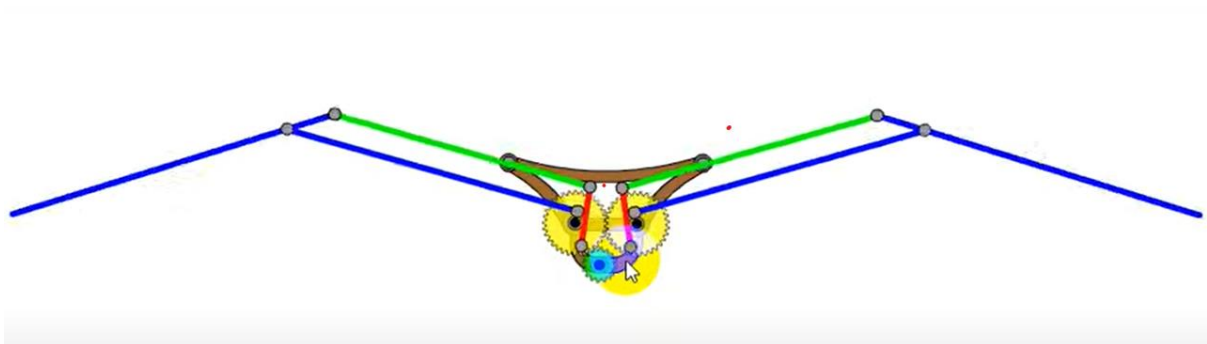

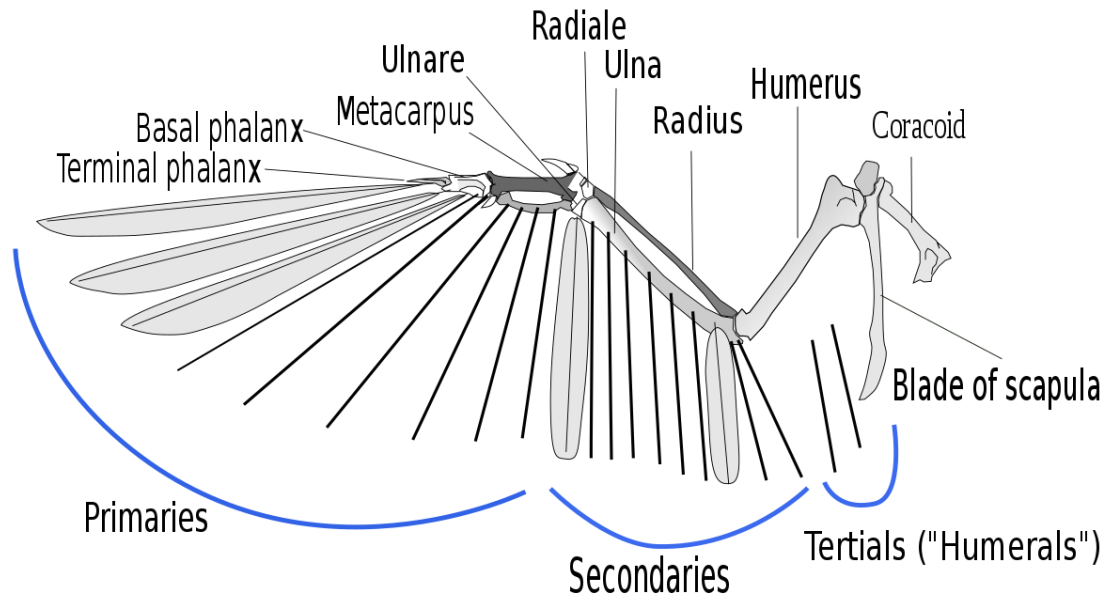**Fig 1.7 Basic Mechanism of ornithopter**

Fig 1.8 Bird Wing Terminology

1.7 APPLICATIONS OF ORNITHOPTERS:

Practical applications capitalize on the resemblance to birds or insects. Colorado Parks and wildlife has used these machines to help save the endangered Gunnison sage grouse. An artificial hawk under the control of an operator causes the grouse to remain on the ground so they can be captured for study.

Because ornithopters can be made to resemble birds or insects, they could be used for military applications such as aerial reconnaissance without alerting the enemies that they are under surveillance. Several ornithopters have been flown with video cameras on board, some of which can hover and maneuver in small spaces. In 2011,demonstrated a remotely piloted ornithopter resembling a large hummingbird for possible spy missions.

Since 2002, Prof. Theo van Holten has been working on an ornithopter that is constructed like a helicopter. The device is called the "ornicopter" and was made by constructing the main rotor so that it would have no reaction torque.

In 2008, Amsterdam airport Schipol started using a realistic-looking mechanical hawk designed by falconer Robert Musters. The radio-controlled robot bird is used to scare away birds that could damage the engines of airplanes.

In 2012, RoBird (formerly Clear Flight Solutions), a spin-off of the University of Twente, started making artificial birds of prey (called RoBird) for airports and agricultural and waste-management industries.

Adrian Thomas(zoologist) and Alex Caccia founded Animal Dynamics Ltd in 2015, to develop a mechanical analogue of dragonflies to be used as a drone that will outperform quadcopters. The work is funded by the Defence Science and Technology Laboratory, the research arm of the British Ministry of Defence, and the United States Air Force.

1.8 PROBLEM DEFINITION:

Broadcast seeding is one of the most widely used post-wildfire emergency response treatments intended to reduce soil erosion, increase vegetative ground cover, and minimize establishment and spread of non-native plant species. Usually for this kind of operation small planes and helicopters are used, however the present method of aerial seeding is not economic, it can be done only by public organizations. Our project is mainly focused on the alternative aerial seeding using ornithopters, which give easy access to the social activist's to do the task in the economical way.

1.9 SCOPE OF PROJECT:

The main scope of the project is to design and fabricate the new ornithopter mechanism suitable for aerial seeding. At first we will be designing the mechanism which is further optimized and simulated using the software "Simulation and Analysis of Mechanisms (SAM). The 3D model of the ornithopter will be designed using the software "AUTODESK Inventor Professional" and various analysis for Stresses, aerodynamics will be performed by using software "ANSYS Workbench". Finally with help of 3D printing the prototype will be prepared and tested.

2. LITERATURE SURVEY

The ornithopter is a complex mechanism as it should mimic with bionics of the bird. The following journals, articles and patents were referred for better understanding of the mechanism which will be helpful for the design of ornithopter for Aerial seeding.

2.1 LITERATURE REVIEW:

Nathan Chronister et al [1]: The invention described here offers a more effective method of ornithopter flight control. To accomplish this, the ornithopter has dual microprocessor-controlled drive systems for flapping the wings independently of each other. Various wing movements can cause the ornithopter to turn, roll, or pitch up or down. Weight and complexity are reduced by eliminating the need for servo-controlled tail surfaces.

Micael S. Couceiro, Ingeniarius et al [2]: This paper presents the development of computational simulation and a robotic prototype based on the dynamic modelling of a robotic bird. The study analyse the bird flight with different strategies and algorithms of control. The results are positive for the construction of flying robots and a new generation of airplanes developed to the similarity of flying animals. A bird robot prototype was implemented based on mate- rials used to construct model planes. It consists on a body, wings and tail with servo actuators independently controlled though a microcontroller; a radio transmission system and batteries were also used in order to avoid wired connections between the computer and the robot.

Rose et al [3]: We develop a cooperative launching system for a 13.2 gram ornithopter micro-aerial vehicle (MAV), the H2Bird, by carrying it on the VelociRoACH. We determine the necessary initial velocity and pitch angle for take off using force data collected in a wind tunnel and use the VelociRoACH to reach these initial conditions for successful launch.

Sutthiphong Srigrarom and Woei-Leong Chan[4]: In this paper, an ornithopter prototype that mimics the flapping motion of bird flight is developed, and the lift and thrust generation characteristics of different wing designs are evaluated. This project focused on the spar arrangement and material used for the wings that could achieves improved performance. Various lift and thrust measurement techniques are explored and evaluated. Various wings of

insects and birds were evaluated to understand how these natural flyers with flapping wings are able to produce sufficient lift to fly. The differences in the flapping aerodynamics were also detailed. Experiments on different wing designs and materials were conducted and a paramount wing was built for a test flight. The first prototype has a length of 46.5 cm, wing span of 88 cm, and weighs 161 g. A mechanism which produced a flapping motion was fabricated and designed to create flapping flight. The flapping flight was produced by using a single motor and a flexible and light wing structure. A force balance made of load cell was then designed to measure the thrust and lift force of the ornithopter. Three sets of wings varying flexibility were fabricated, therefore lift and thrust measurements were acquired from each different set of wings. The lift will be measured in ten cycles computing the average lift and frequency in three different speeds or frequencies (slow, medium and fast). The thrust measurement was measure likewise but in two cycles only. Several observations were made regarding the behaviour of flexible flapping wings that should aid in the design of future flexible flapping wing vehicles. The wings angle or phase characteristic were analyze too and studied. OPEN ACCESS Aerospace 2015, 2 236 The final ornithopter prototype weighs only 160 g, has a wing span of 88.5 cm, that could flap at a maximum flapping frequency of 3.869 Hz, and produce a maximum thrust and lift of about 0.719 and 0.264 N respectively. Next, we proposed resonance type flapping wing utilizes the near resonance phenomenon of a two-degree of freedom elastic system, that is, the wing is supported by the springs for flapping and feathering motions. Being oscillated close to the resonance frequency of the system, only by the torque in flapping motion, the amplitude gained is a few times higher than that of normal case. The first prototype was made from acrylic using a laser cutting machine. The wings were made up of carbon rods and kite material Ripstop. First test showed that the wings were too heavy for the mechanism to work. The third prototype was a smaller single gear crank design which was fabricated using a 3D printer. Initial test proved that the second prototype could withstand the high frequency flapping and near resonance amplitude as designed. With remote control, the third prototype was able to take off, climb, cruise and land in flapping mode successfully.

K. Peterson and R. Fearing [5]: BOLT is a lightweight bipedal ornithopter capable of high-speed dynamic running and effecting transitions between aerial and terrestrial locomotion modes. The gait dynamics of both quasi-static and dynamic locomotion are examined through the use of an on-board accelerometer, part of a one gram electronics package also containing a

processor and radio. We discuss the accelerations in the context of the traditional spring-loaded inverted pendulum model seen in nearly all legged locomotion in organisms. Flapping wings are shown to provide damping along with propulsive force. The aerodynamic forces of the flapping wings also impart passive stability to the robot, enabling it to run bipedally with only a single actuator. BOLT transitions from ground running to aerial hovering in as little as one meter of runway. Overall, the advantages provided by wings in terrestrial locomotion, coupled with aerial capabilities, allow BOLT to navigate complex three dimensional environments, switching between locomotion modes when necessary.

Groen, M.A. [6]: Recent years have seen an increasing interest in Micro Air Vehicles (MAVs). MAVs are small (micro sized) aircraft and find their application in a multitude of commercial, industrial and military purposes. To perform their missions MAVs should be small sized, have good manoeuvrability, be well controllable and have a broad flight envelope. When flying in small confinements, the ability to fly at low airspeed and to have good manoeuvrability is critical. One type of MAVs, the flapping-wing MAV, particularly has attractive characteristics for flight in confined spaces. DelFly is a biplane flapping-wing MAV designed and built at Delft University of Technology. DelFly is able to hover and has an onboard camera for observation and vision-based control. For the DelFly project a top-down approach is followed, where from the study of a relative large model experience and theoretical insights can be gained, that can assist to create smaller, functional versions of the DelFly. The ultimate aim of the DelFly project is to improve the design to a very small full autonomous aircraft.

MR.SREEDHAR [7]: The present world has reached to a stage where most of the sophisticated and sensitive tasks are mostly done by artificial hands. This paper discuss about the details of artificial birds are also called as ornithopters which belongs to Micro Arial vehicle (MAV) category. Bio-mimicking robots have been replaced the place of human with their uncompromised accuracy and efficiencies. However the real challenges in developing MAVs is still unsolved and not interpreted as it flies in the transient and low Reynolds number flow. This paper investigated the aerodynamic factors of fly's which influence their flight, different kinematic mechanisms which drives the vehicle and different types of designs for wings and their performance. In line with this, both past and future of this innovative area were discussed. One other hand selection of material is also plays vital role in case of MAVs weight

consideration . So this paper explain the different material which suited for this kind of flying machine.

2.2 SUMMARY:

Hence by considering and studying the above journals we got an idea of different mechanisms and gathered all the required information from them. In this chapter, our detailed research on various journals has been described. The inputs we took from these journals help us in designing a mechanism according to our requirements.

3. MECHANISMS

3.1 INTRODUCTION:

A mechanism is a device which consists of various rigid bodies(links) connected together that transforms input forces and movement into a desired set of output forces and movement.
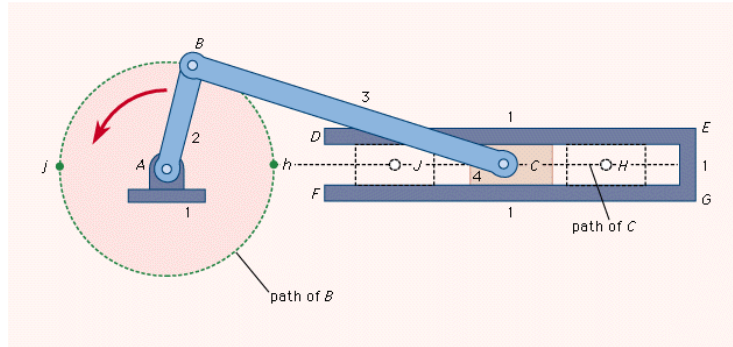

Fig 3.1 Simple Mechanism

Mechanism comsists of various links, some are fixed and some are movable with limited degrees of freedom to achieve various output from the mechanism.

3.2 WORKING WITH VARIOUS MECHANISMS:

We have studied various mechanisms presented in different papers for our reference and took few of them into consideration.
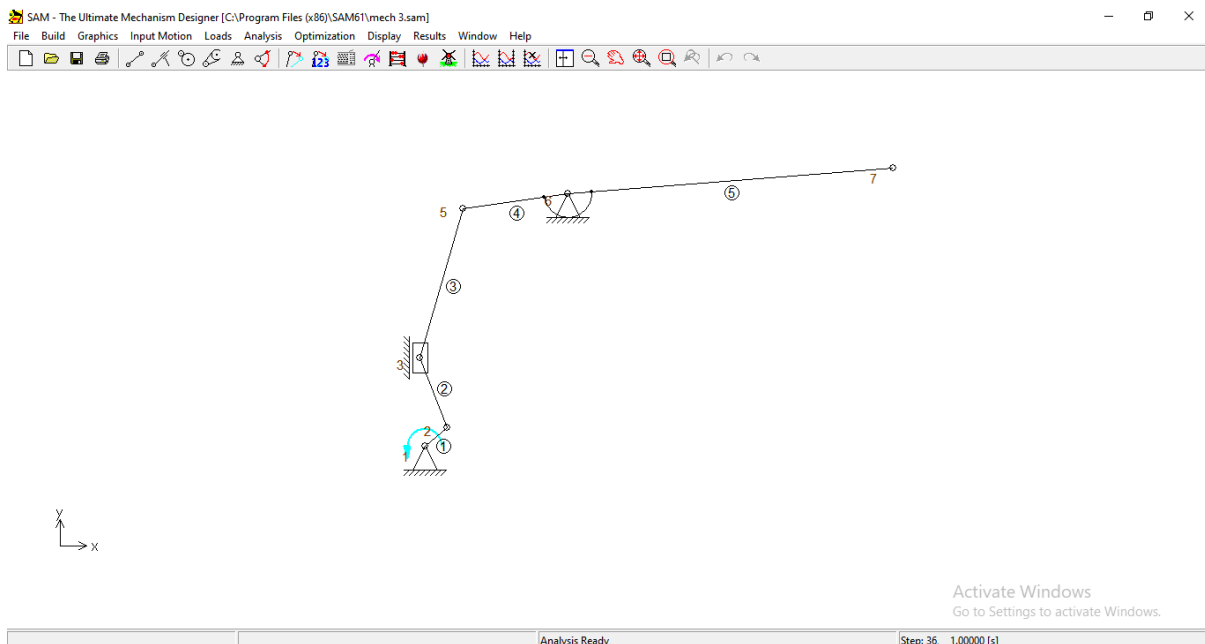

Fig 3.2 Basic Mechanism

We used SAM software to analyse the mechanisms that we selected and determine the best mechanism of them all. The above image is taken from SAM software which shows the flapping mechanism of a wing. Here we employed a slider for the flapping and a crank being used, where as a proper gearing is to be employed in actual fabrication process.
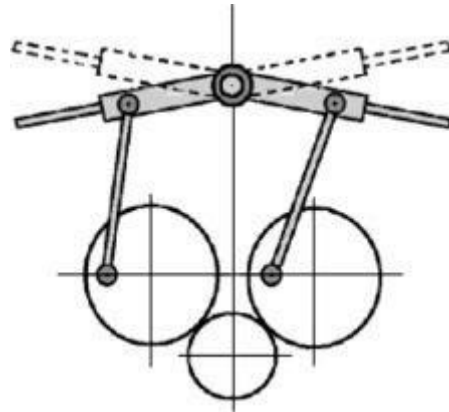

Fig 3.3 Detailed observation of wing mechanism-I

But on a detailed observation and comparison with the actual bird we thought that this mechanism would be inappropriate. Hence moved for searching other mechanisms.
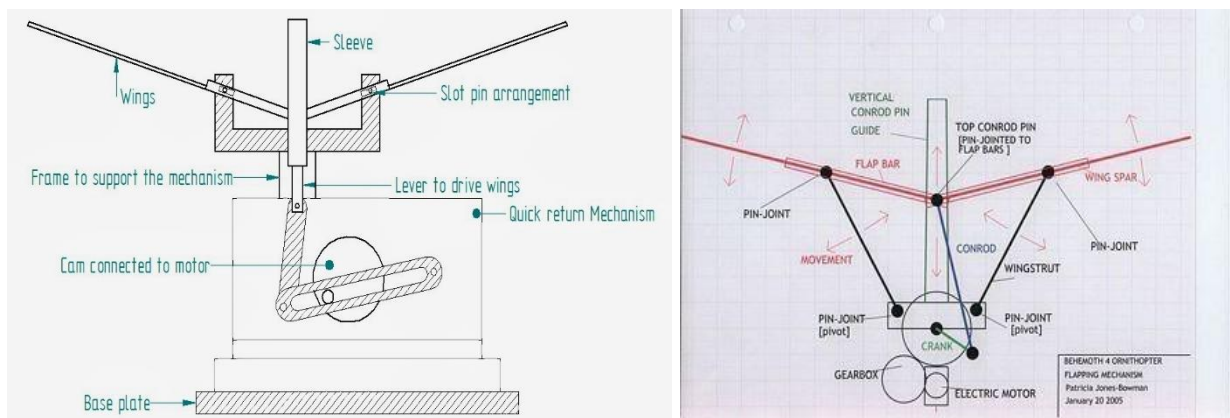

Fig 3.4 Various mechanism considered

Some of the above mechanisms were not suitable to us to develop in SAM software, eventhough we tried it, the analysis could not be done. The mechanisms whose analysis was completed were put here. And some of the mechanisms doesn't support our design criteria and were ignored. We chose the best mechanism by doing various analysis which is also accepted by the design criteria.

3.3 PROBLEMS OCCURRED IN SAM:

During this phase of analysis of mechanisms we have come across various analysis problems in SAM which were being listed below.

Mechanism underdetermined:

Some sort of constraint is missing, the reason maybe one of the following:

- Forgot to define a support.
- Did not connect the anle between two beams.
- Intended to connect a beam to a belt/gear but forgot to connect the angles.
- Missing input motion.
- Two nodes were intended to coincide but were created as separate nodes.

Mechanism overdetermined:

Too many constraints might be specified such that mechanism cannot work. The reason might be:

- Fixing an angle or position somewhere which is supposed to move instead.

Convergence problem:

Mechanism cannot reach the desired position and analysis is stopped. The reason might be:

- Defining a motion profile leading to a position that the mechanism cannot reach. The results prior to that situation are valid and can be used for animation of the mechanism and postprocessing of the results.

No input defined:

This occurs if we forget or does not define any input motion to the drawn mechanism. Thorough checking of the mechanism and cross checking the input motion will help in avoiding such errors while doing a project.
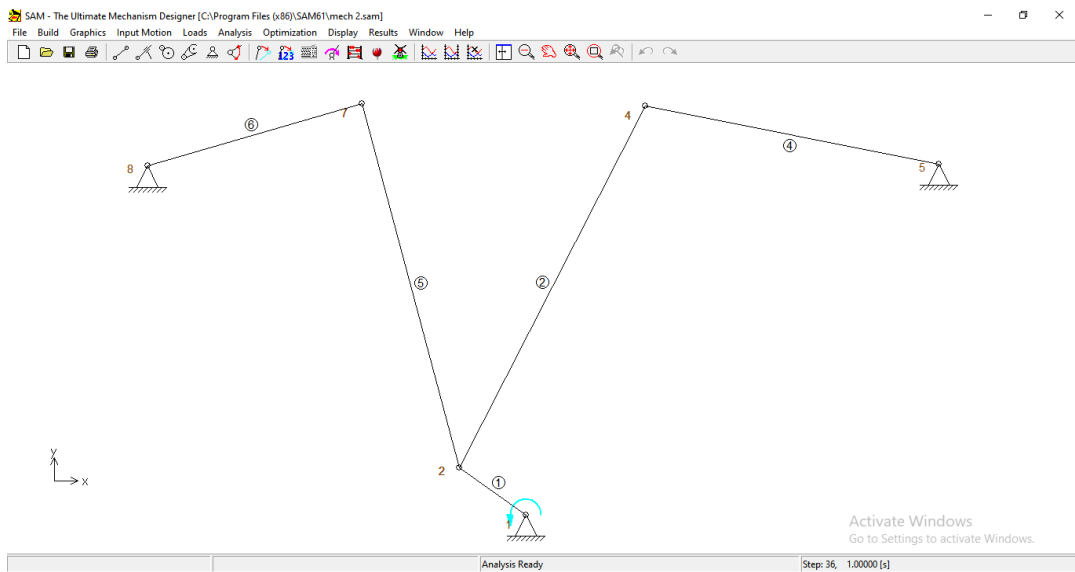
3.4 OUR MECHANISM:

Fig 3.5 Refined Mechanism

The above is a mechanism which is successfully analyzed with no analysis problems. But we encountered another major issue with this mechanism that the flapping of the two wings did not happen evenly. In the actual bird both would happen evenly at the same time, so due to this we could not move forward with this mechanism.
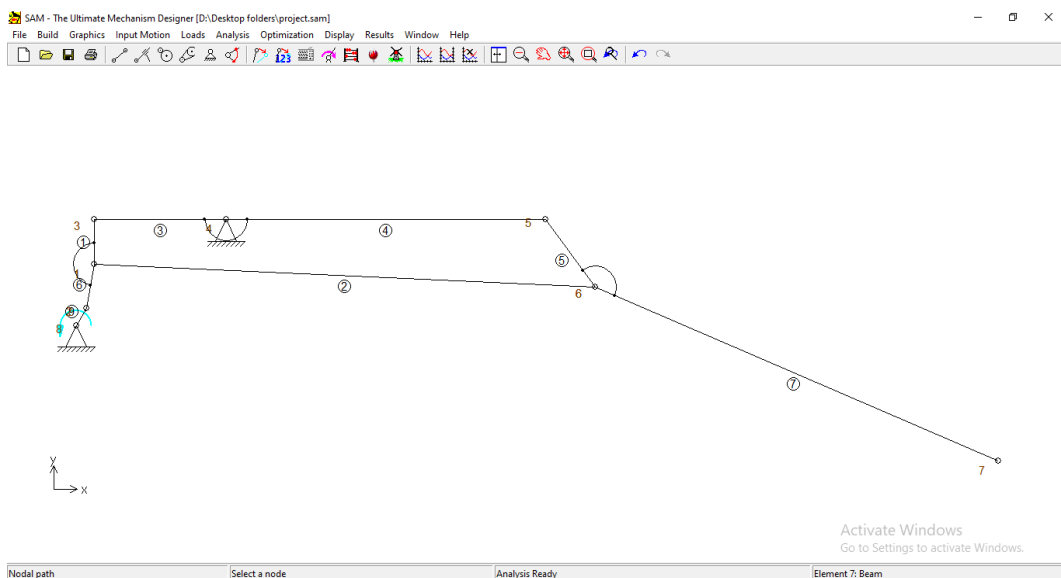

Fig 3.6 Final Mechanism

And after few more changes to the above mechanism we were able to achieve all design aspects and the mechanism works properly. The above mechanism is designed in SAM.

3.5 DEGREES OF FREEDOM CALCULATION:

Degrees of Freedom also known as Mobility of a Mechanism, indicates the minimum number of inputs required to have a constrained or definite motions of all other links of the mechanism. The Kutzbach criterion is also called the mobility formula, because it computes the number of parameters that define the configuration of a linkage from the number of links and joints and the degree of freedom at each joint.

Eg: DOF=2

    Two inputs may be necessary to get constrained motions of other links.

According to **Kutzbach Criteria** we find degree of freedom for a mechanism using the formula:

$$DOF = [3(L-1)] - 2J - H$$

Where,

      L is the number of links,

      J is the number of joints,

      $J = (1.5L) - 2$

For our mechanism:

$L = 6$

$J = (1.5*6)-2=7$

$H=0$

On applying the Kutzbach criterion to our mechanism we get,

$$DOF = 3(6-1)-2(7)-0 =1$$

It means our mechanism has one degree of freedom, i.e we just need one input motion to completely constrain the mechanism.

4. SAM ANALYSIS

4.1 INTRODUCTION:

   SAM (**S**ynthesis and **A**nalysis of **M**echanisms) is an interactive PC-software package from the Dutch company *ARTAS-Engineering Software* for the design, analysis (motion and force) and optimization of arbitrary planar mechanisms. Mechanisms can either be generated via the design wizards or they can be assembled from basic components including beams, sliders, gears, belts, springs, dampers and friction elements. SAM integrates pre-processing, numerical analysis and post processing, such as animation and xy-plots, in an easy to-use environment offering pull-down menus, mouse support and help facilities.

   The mathematical foundation of the analysis kernel, which is inspired by the well-known finite element approach, offers a large number of features and overcomes many of the problems of traditional mechanism programs. Open loop, closed loop, multiple loop and even complex planetary mechanisms can equally well be analyzed due to the finite element formulation. Even the most complex mechanisms, including planetary gear trains, can be modeled within minutes.

   SAM is a popular tool for everybody involved in the conceptual design, motion/force analysis and optimization of mechanisms as applied in equipment, automotive industries (roof mechanisms of convertibles) but also in medical, lifestyle or domestic products. It has been using in many educational institutes and professional companies in Europe and around the world.

4.2 FEATURES:

   SAM offers a set of design wizards which will help you to synthesize mechanisms for specific tasks, such as:

- Angle function generation
- 3-Position/angle synthesis of the coupler plane.
- Approximated straight line motion
- Exact straight line motion

4.3 TOOL BARS:

We used the following tool bars in our project:

- File menu

- Build

- Input motion

- Analysis

- Display

- Window

- Help

4.3.1 File Menu:

From the file menu we can open or create a new project. File menu consists of various functions:
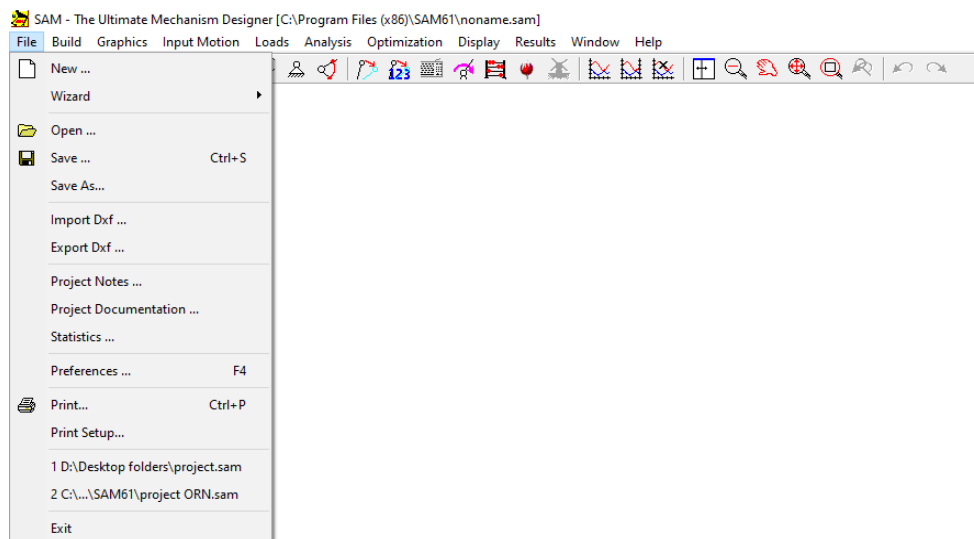

Fig 4.1 File Menu

The following options are available in file menu:

- **New** - Opens a new mechanism project. When you choose New, you can save changes to the project you have been working on.

- **Wizard -** Lets you choose from a number of mechanism design wizards.

- **Open** - Opens an existing mechanism project.

- **Save** - Saves changes to the document you have been working on. When you choose Save, the project remains open so you can continue working on it.

- **Save As** - Saves a new or existing project. You can name a new project or save an existing project under a new name. The original project file remains unchanged. When you choose Save As, the project remains open so you can continue working on it.

- **Import DXF** - Imports a DXF-file and automatically groups graphical data (see menu Graphics).

- **Export DXF** - Exports the current mechanism to DXF-file which can be imported in any CAD-software for adding details. Note that only the nodes and elements are exported.

- **Print** - Prints the current mechanism/graph. Prior to printing the user can select whether the graph, the mechanism or both will be printed.

4.3.2 Build Menu:

The Build Menu contains all items that are required to create or modify elements and the commands which define the support node of an element.
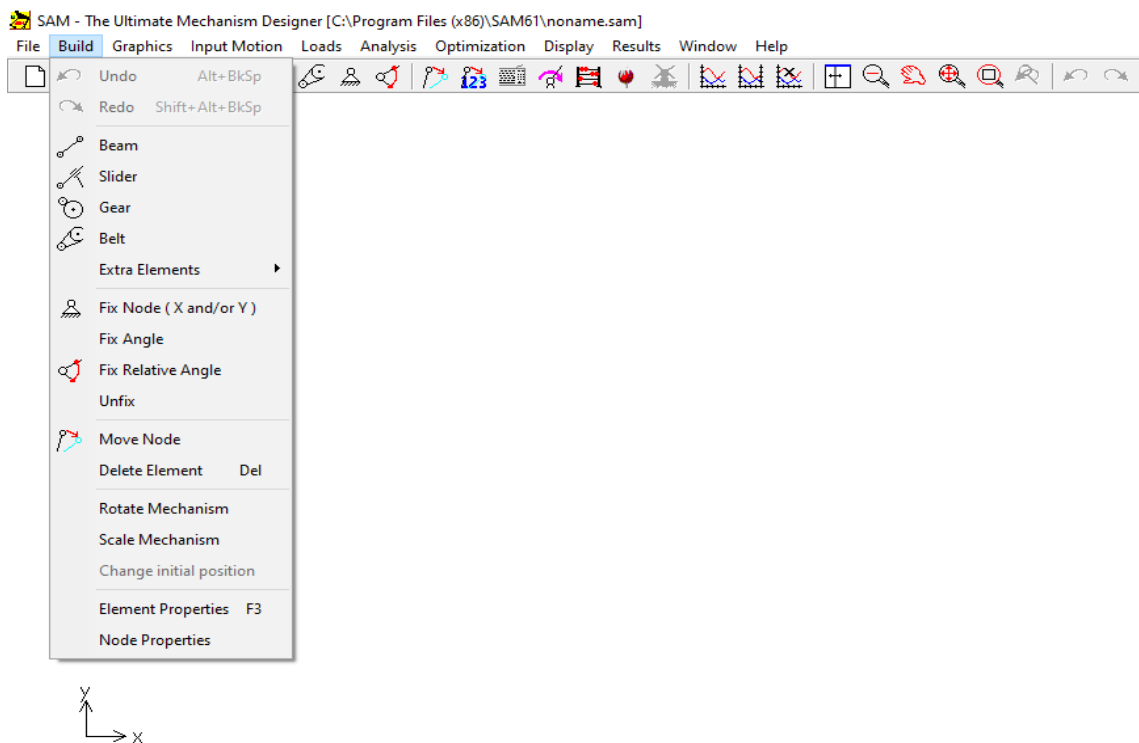

Fig 4.2 Build Menu

The following options are available in Build Menu:

- **Elements available in SAM** -
  - ➤ Beam
  - ➤ Slider
  - ➤ Gear
  - ➤ Belt
  - ➤ Sensor
  - ➤ Spring
  - ➤ Damper
  - ➤ Friction
- **Fix Node (X or Y)** - After selection of this item you are requested to click a node. Now, move the mouse around the selected node in order to choose between a x-, y- or xy-support. If the desired support condition is shown, press the left button to activate it.
- **Fix Angle** - Fix an angle of an element relative to the world.
- **Fix Relative Angle** - Create a rigid fixation between the angles of two elements.
- **Unfix** - Remove fixation of any kind.
- **Move Node** - This command lets you to click on a node and drag it to a new position.
- **Delete Element** - After selection of this menu item, you are prompted to click the element, that you want to delete.
- **Undo Delete/Move** - This command restores the situation just before a delete or a move action. Only the situation just before your last action can be recovered.
- **Element Properties** - If you want to specify certain element properties, such as inertia or center of gravity, select this menu item first, then click an element. Depending on the selected element type an element property dialog will be opened.
- **Nodal Coordinates** - If you want to specify exact nodal coordinates select this menu item first, then click a node. A dialog will be opened which lets you specify exact nodal coordinates in various manners.

4.3.3 Input Motion Menu:

The input menu lets you define various kinds of input type, such as x-displacement, y-displacement, angle, relative angle and elongation (elongation is used to model a linear

actuator, such as a hydraulic or pneumatic cylinder). You will then be prompted to select the appropriate node or element. Next, a dialog box is opened, which lets you define the input motion by combining basic motion laws. Furthermore, an arbitrary motion profile can be imported from a motion file (ASCII-format).

In order to use SAM in a proper way it is essential to remember that :

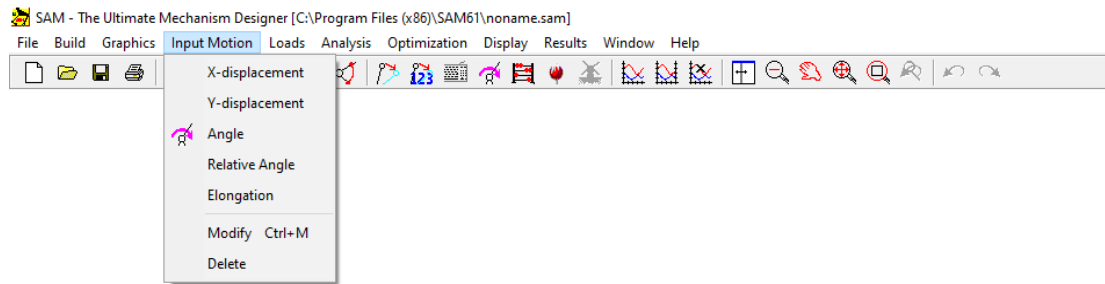➢ All input data is relative to the initial position of the mechanism.

Fig 4.3 Input Motion Menu

The following options are available in the Input Motion Menu:

- **Angle** - Lets you define any angle as input motion. After selection of this menu item you are prompted to select an angle by first clicking a node and - if necessary - by choosing between elements that are attached to that node.

- **Relative Angle** - Lets you define the relative angle between two elements. You will be prompted to select the two elements.

- **Delete** - Lets you delete an existing input motion.

4.3.4 Analysis Menu:

This menu command starts the analysis process. However, first a dialog will be shown , from which you can select the output results, that you need for post processing. You can either select individual items or select entire groups of variables or even select all data. This selection procedure has been introduced in order to speed up analysis and because one is normally only interested in a limited number of variables.

You can use <F9> to start an analysis without invoking the options dialog. This is especially useful when doing identical analyses of the same mechanism with only slight parameter changes.

4.3.5 Display Menu:

Display menu consists various options such as path which helps in visualising the motions and working simulation of the project.
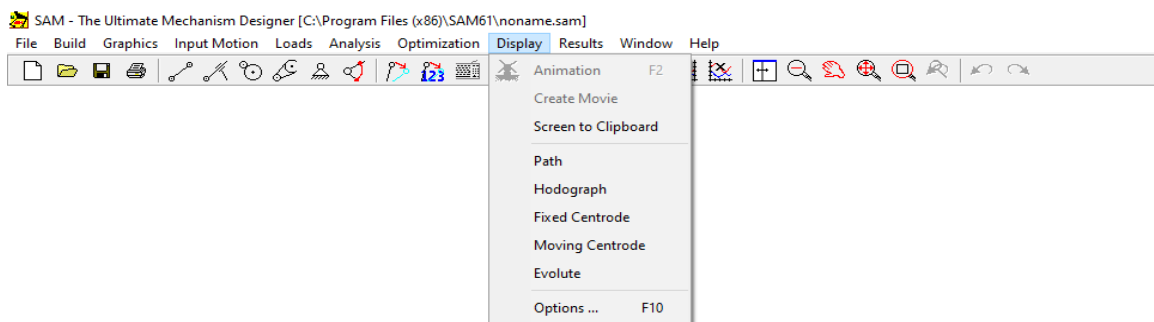

Fig 4.4 Display Menu

The following options are available in the Display Menu:

- **Animation** - Starts animation of the mechanism. It is stopped by pressing <ESC> or the right mouse button. The Build/Set_Initial_Position menu lets you perform a "manual" animation by dragging the mechanism.
- **Create movie (AVI)** - Starts an animation which is recorded as AVI-file.

- **Path** - Lets you (de)select nodes for the display of the motion path.

- **Hodograph** - Lets you (de)select nodes for the display of the velocity hodograph.

- **Options** - Opens a dialog box, which lets you modify the display and various line settings.

4.3.6 Window Menu;

The Window Menu has various options through which various mechanism , graph windows can be opened.
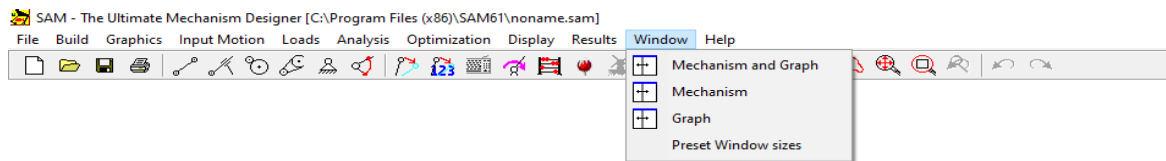

Fig 4.5 Window Menu

The following options are available in the Window Menu:

- **Title** - If a graph window exists, it will be displayed next to the mechanism window.

- **Cascade** - Displays the mechanism and graph window (if present) in cascade type.

- **Arrange Icons** - In case the graph or mechanism window has been minimized and the icon has been moved around, this command will position the icon at the default location.

- **Close all** - Closes the mechanism and - if present - the graph window.

4.3.7 Help Menu:

Help menu helps in giving the information regarding a particular topic and and helps in many other aspects.
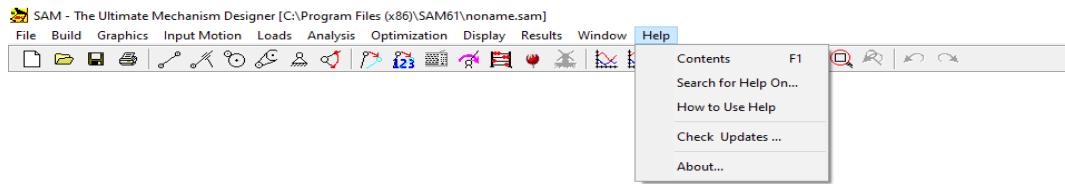
4.6 Help Menu

The following options are available in the Help Menu:

- **Contents** – Start the SAM help system.
- **Search for Help on** - Find help on a specific SAM topic.
- **How to use Help** - Opens the Windows help file, that explains the standard help functionality.
- **Check updates** - Lets you check whether updates (minor changes/fixes) or even upgrades (new functionality) are available.
- **About Sam** - Displays information about SAM.

4.4 WORKING ON SAM:

We used SAM for various analysis of the mechanism we chose after the research we did and combining the research with the design specifications.

First we sorted various link lengths for our mechanism, this analysis was done by taking reference from various sources which include previous ornithopter models, papers and finally modified them according to our application.

Once we finalized link lengths we started to draw a two dimensional mechanism using SAM software. For drawing a 2d mechanism in SAM the toolbar provided is very user friendly and is shown below.

Fig 4.7 Tool bar

We used the following shortcut tools for our work:

- New
- Open
- Save
- Print
- Beam
- Support (For applying support in X or Y direction)
- Fix Relative Angle
- Input
- Move
- Exact coordinates
- Keyboard entry
- Anakysis
- Animation
- Graph
- Zoom
- Pan
- Undo

The DXF import/export facility lets you export your conceptual mechanism design to any CAD program to work out the details and it lets you import CAD data to easily set-up the mechanism in SAM or to perform animation of the final mechanism.

Procedure to draw two dimensional mechanism:

1. Create a beam element (Link-1) of length 10 mm. Beam element has two nodes and first node of link-1 has to be fixed and it acts like a crank.

2. Draw Link-2 of length 57 mm from node 2 and similarly draw Link-3 of length 12mm from Node 3.

3. From node 4 draw a horizontal beam element of length 48mm (Link-4) and fix the node 5. From node 5 draw a beam element of length 20mm and 16mm (Link-5,Link-6).

4. Join a link between node 3 and node 7 this link7 of length 85mm and from node 7 draw a free link.

After drawing the 2D mechanism the mechanism was ready for ready for analysis which is shown in below figure.
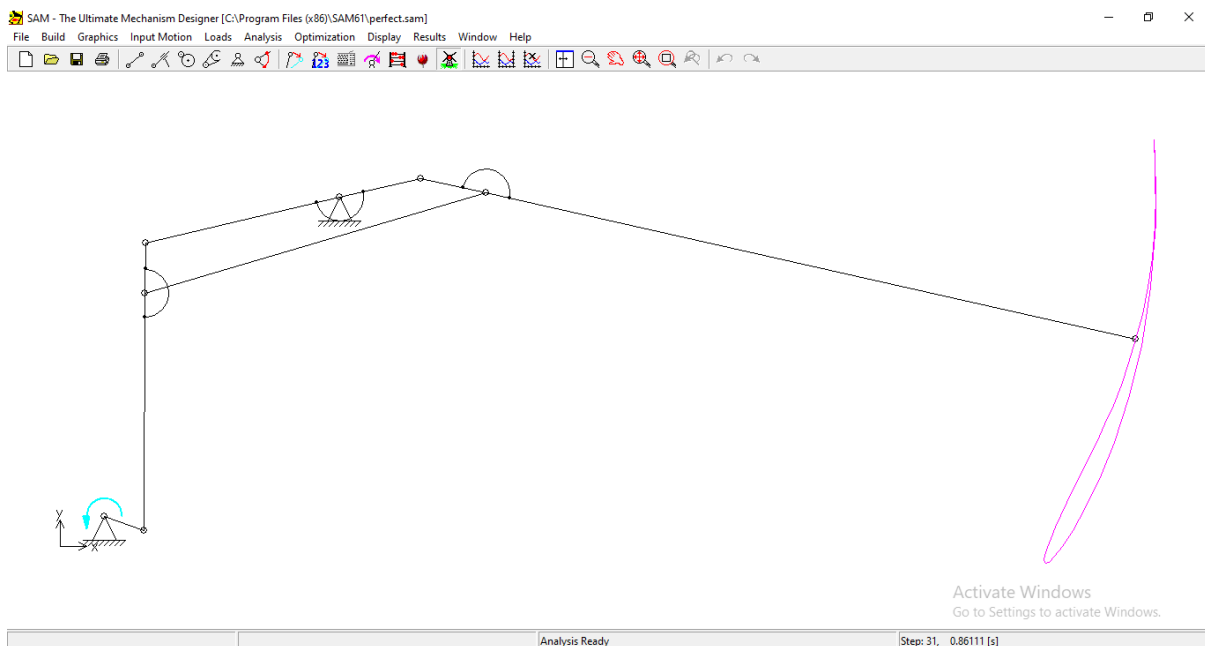

Fig 4.8 2D Mechanism

5. DESIGNING & MODELLING IN AUTODESK INVENTOR

5.1 INTRODUCTION:

Autodesk Inventor is a computer-aided-design application for 3D mechanical design, simulation, visualization, and documentation developed by Autodesk.

Inventor allows 2D and 3D data integration in a single environment, creating a virtual repress- entation of the final product that enables users to validate the form, fit, and function of the product before it is ever built. Autodesk Inventor includes parametric, direct edit and freeform modeling tools as well as multi-CAD translation capabilities and in their standard drawings. Inventoruses Shape Manager, Autodesk's proprietary geometric modeling kernel. Autodesk Inventor competes directly with SolidWorks, Solid Edge, and Creo.

It uses the concept of parametric design, used primarily to create technical drawings for mechanical purposes. It is found in many fields such as automotive, architecture, construction, etc.

Autodesk Inventor is great for any type of machine design. It works very well with creating a combination of custom fabricated parts and purchased pre-designed products.

It is robust engineering documentation software that is purpose built to allow designer to:

- ➢ Create
- ➢ Visualise
- ➢ Simulate designs
- ➢ To create a digital prototype

5.2 ADVANTAGES OF INVENTOR:

- • Easy-to-Use Simulation
- • 3D Mechanical Design
- • Automatic drawing update and view
- • Design Automation
- • State of the Art Visualization

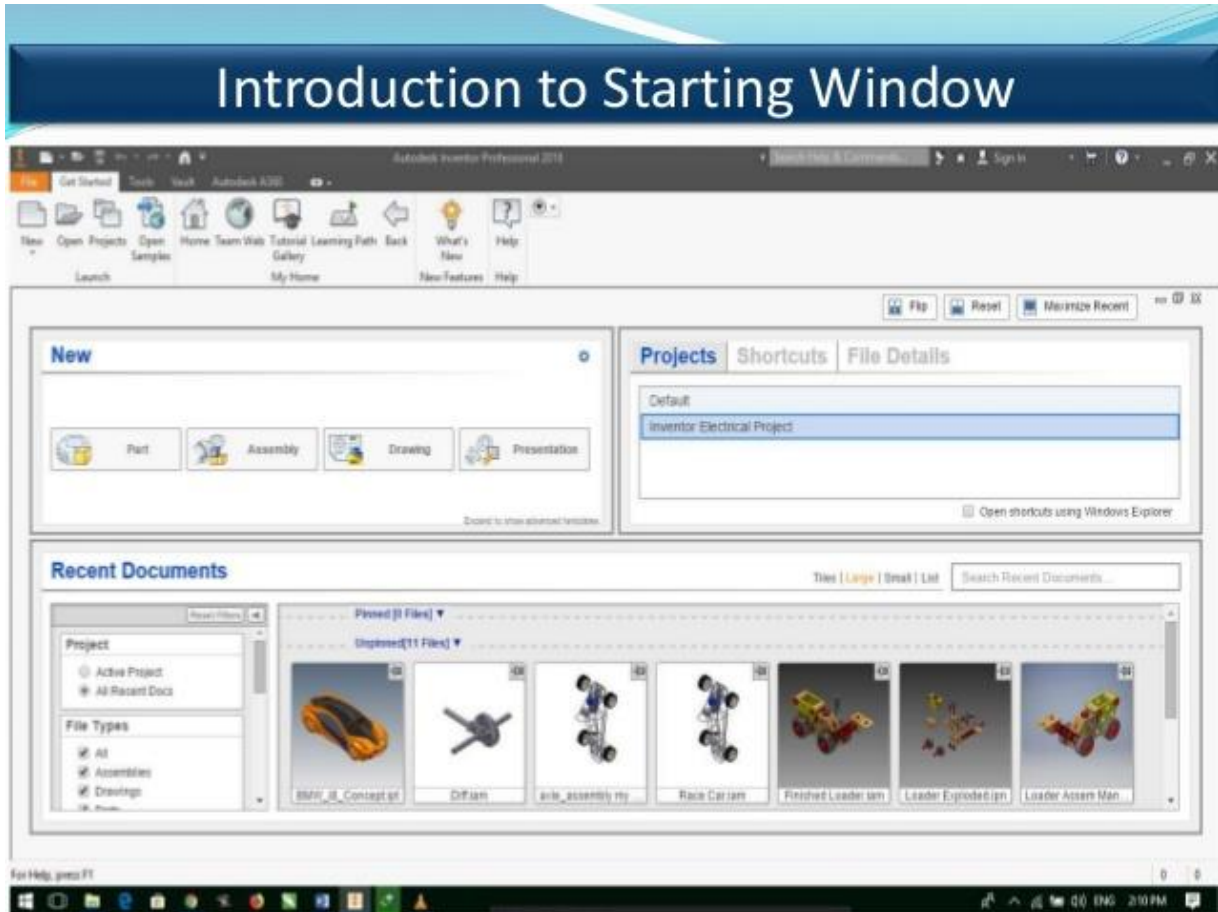## 5.3 GETTING STARTED WITH INVENTOR:

5.3.1 Introduction:

Fig 5.1 Starting Window of Inventor

As soon as we open the inventor a window like the above figure pops up. From the window we can choose what we want to draw form the list. In the new window tab there will be four options from which we can select what we want to draw or what we want to draw. There are four options namely Part, Assembly, Drawing, Presentation. We can select any one of the following and do our work accordingly. And we can name our project in the same window itself.

In the starting page it also shows the recent drawings and documents you made and we can open and modify them quickly from the easy access. The starting window also has some sample projects from which wen can get some information and help on how to draw and process our projects. From the help button we can know about all the commands and features of the software which helps us in making our project.
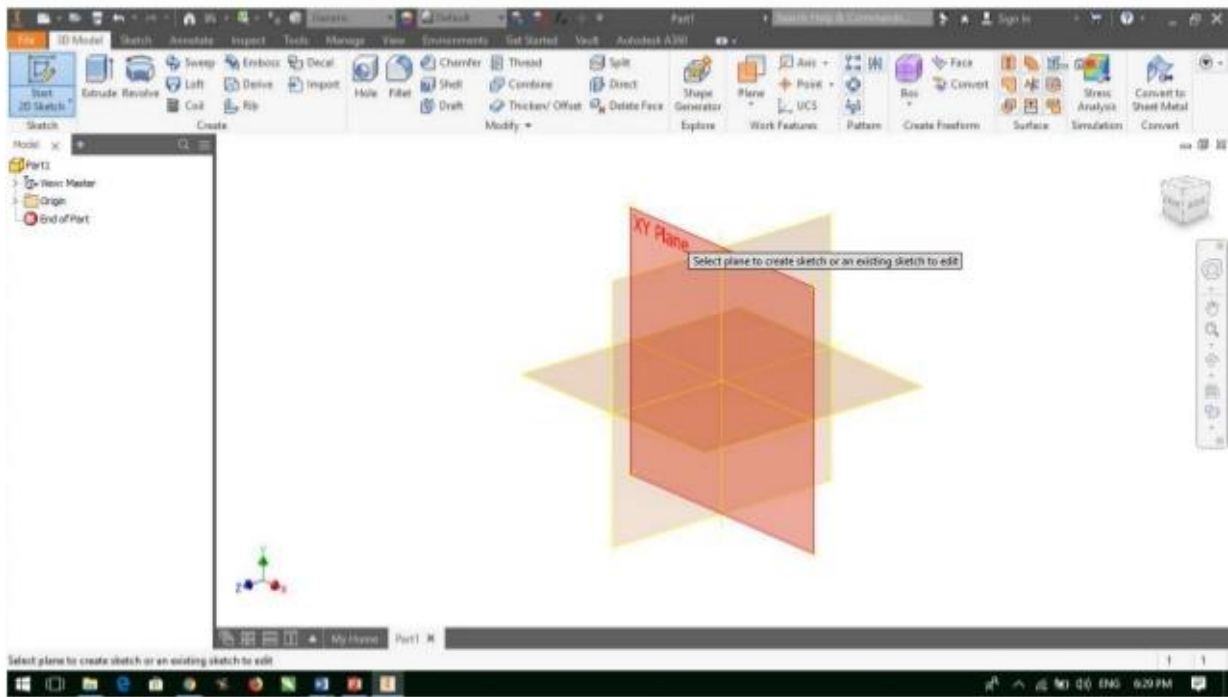
5.3.2 User Interface:

Fig 5.2 User Interface

The user interface has the following options:

- File menu
- Quick access tool bar
- Ribbon
- Tabs
- Panels
- Tools
- Browser
- Navigation bar
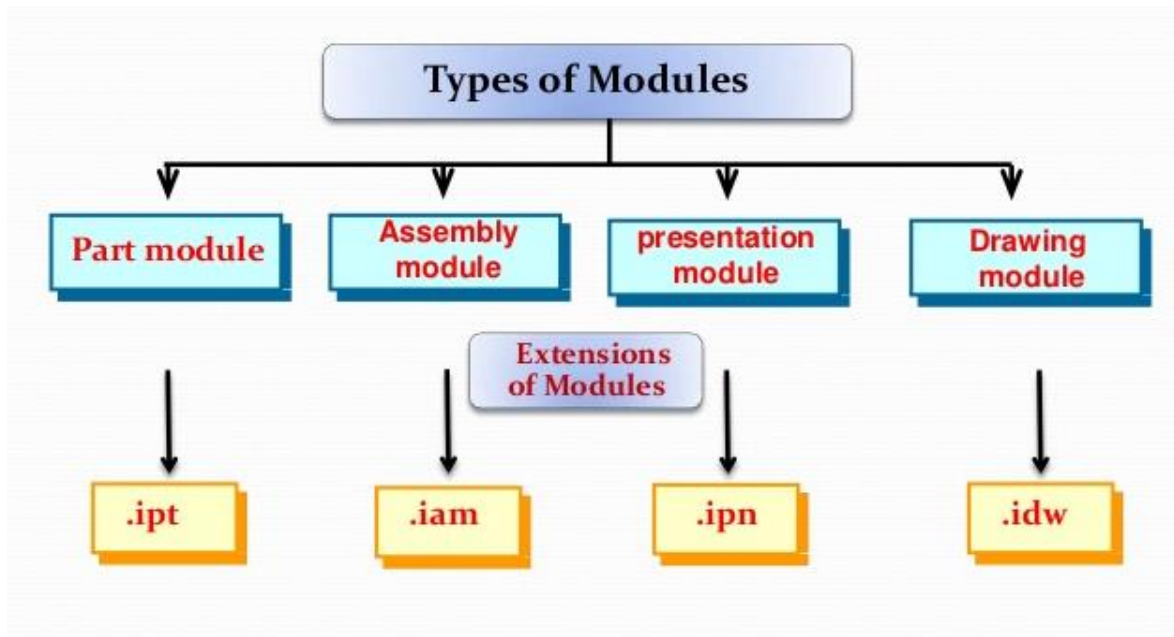- Navigation cube
- Status bar

5.3.3 Modules:

Fig 5.3 Modules

There are four types of environments in Autodesk Inventor. In which according to requirement different types of tools are available to fulfill the need of design. These equipped environments are called modules.

1. **Part Module:**

We can create 2D drawing and 3D models in this environment. Entire work related to designing and ceating is done here in this module.
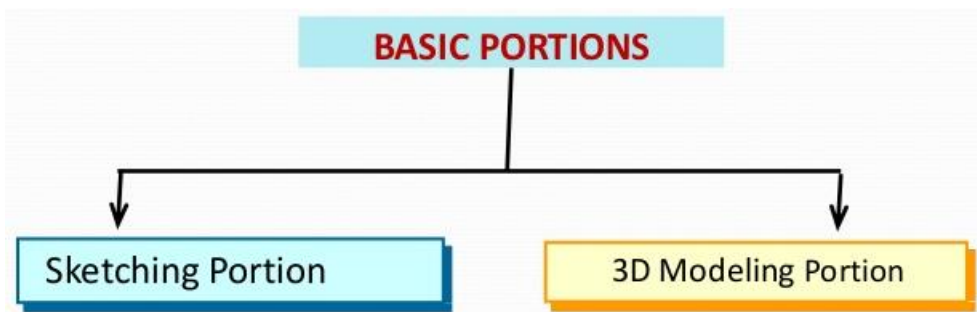

Fig 5.4 Basic portions of part module
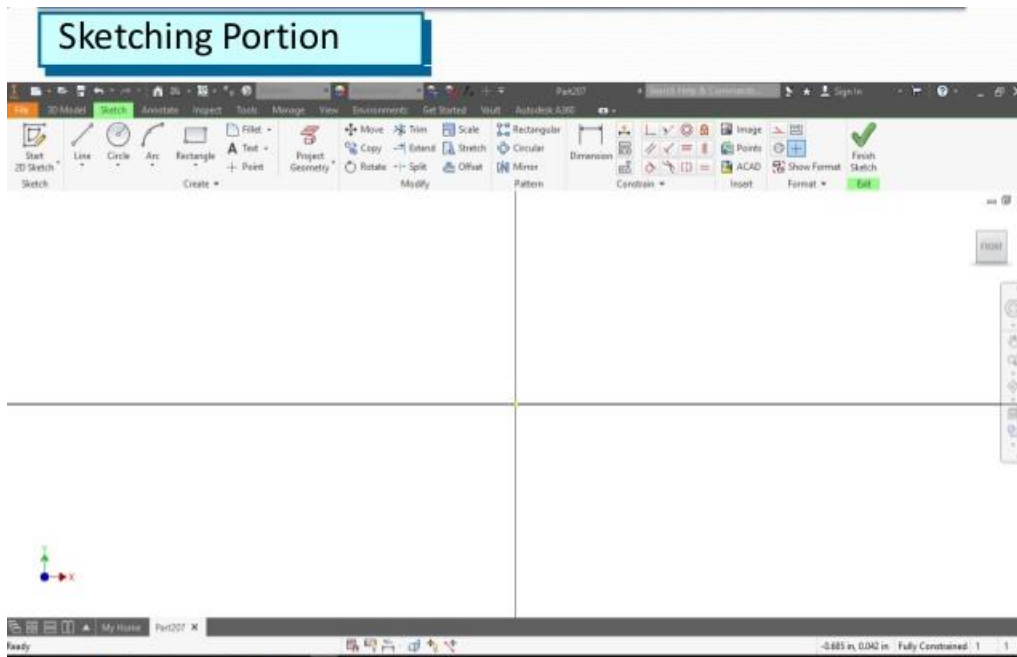
Sketching portion:

Fig 5.5 Sketching portion

This portion has all the tools to draw , create new sketches and refine them into new projects. This portion also has various panels essential to draw basic sketches.
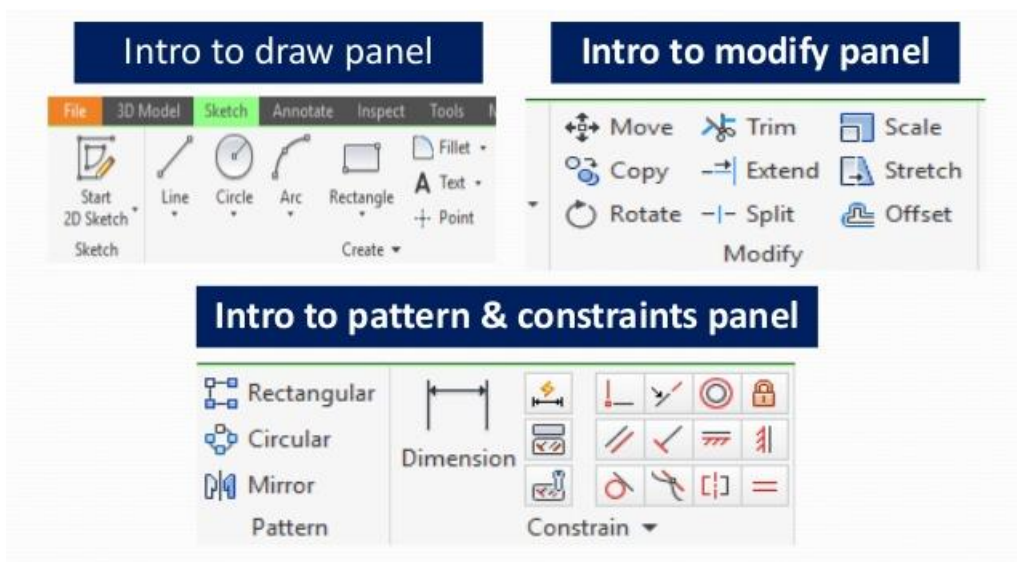

Fig 5.6 Panels for sketching

3D Modelling portion:

Fig 5.7 3D Modelling portion

Here in 3D modelling portion all sorts of 3d modelling are done by using various tools present on the tool bar and different working panels.
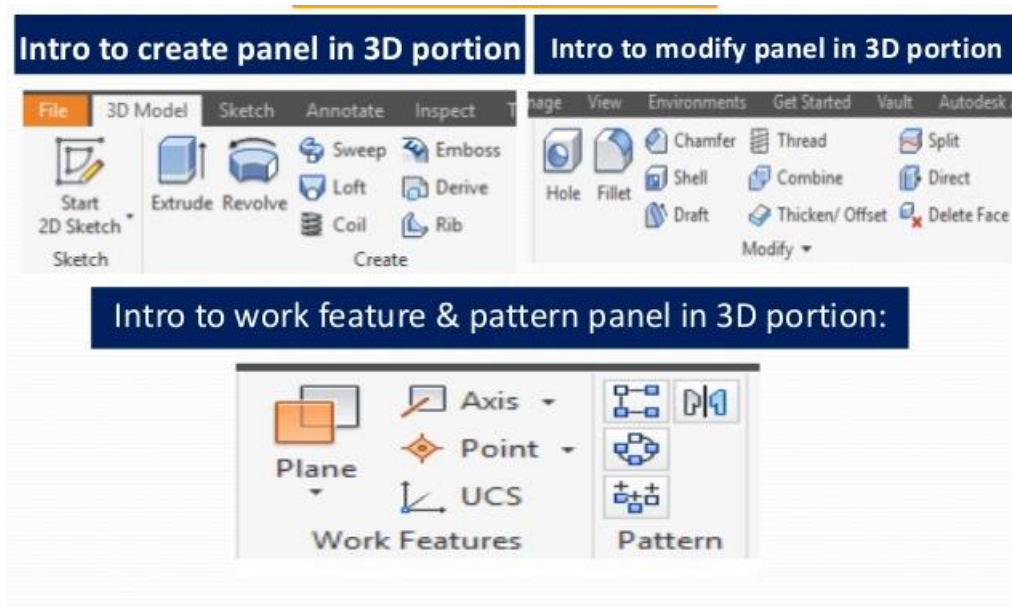

Fig 5.8 Panels for 3D modelling
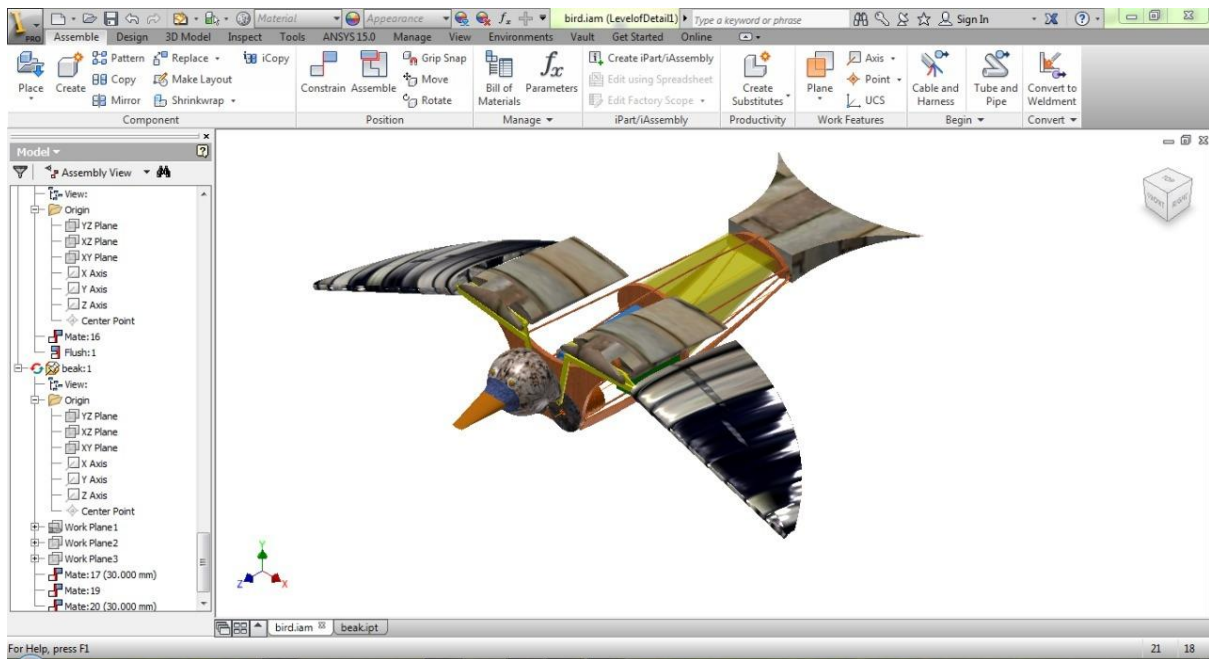
2. Assembly Module:

Fig 5.9 Assemble Module

In assembly module different part drawings are assembled with the help of various tools and panels. The part drawings previously drawn are used to create assembly drawing by the help of tools and constraints from various panels.
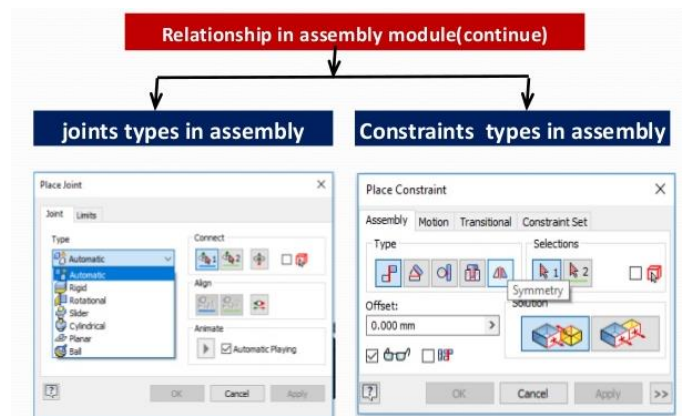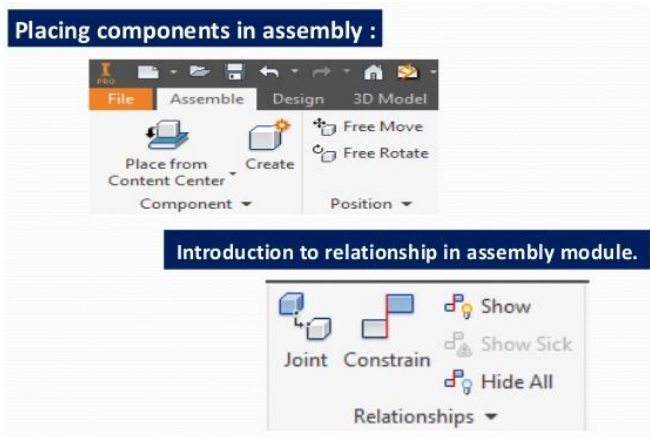

Fig 5.10 Panels in Assemble Module

3. Presentation Module:

A presentation file lets you tell a story of how an assembly is put together or taken apart. A presentation file includes one or more scenes. Scenes are independent and can use different source models and different sets of model representations. Using the default template or a custom template we can create a presentation file (.ipn). We can insert an assembly model and create tweaks, trails, and snapshot views. We can use snapshot views to create exploded drawing views or raster images of the model. Or, create animations, and output them as video files.

Fig 5.11 Panels in presentation module.

4. Drawing Module:

Autodesk inventor provides a unique platform where we can project multiple views of a drawing. This can be done in the Drawing module. Create a new .idw file. and click the leftmost button "Base. Click ok or click on the place where you want the part to be. Then we can place the 2D and 3D views in different positions of the parts.
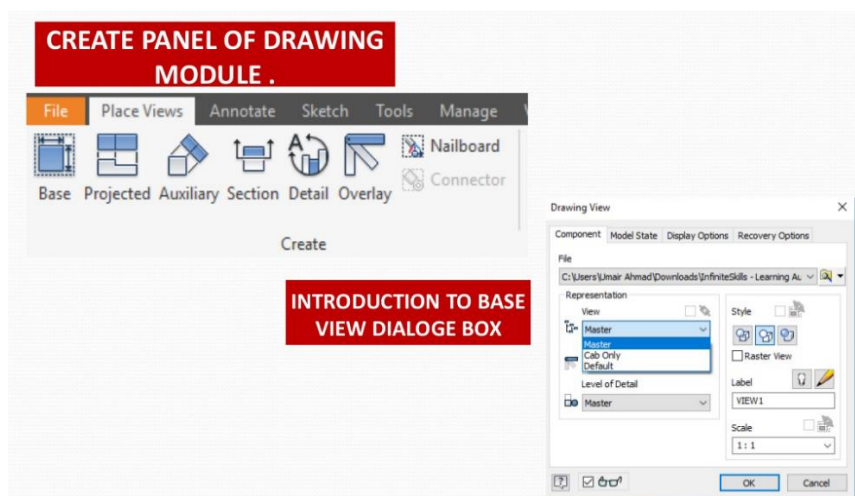
Fig 5.12 Panels in drawing module.

5.4 DESIGNING USING INVENTOR:

5.4.1 Wing:

Wing design is divided into two major parts:

1. **Middle flank**

Fig 5.13 Middle Flank

The middle flank is a bulk model designed to accomplish the mechanism so not to restrict the motion of the wing.

2. **Edge Aerofoil**

Fig 5.14 Aerofoil

This part does most of the worl of the wing. This portion is made in the form of an aerofoil so as to increase thrust and lift of the MAV. The both wing parts have a small channel in them so as to accomplish the mechanism links into them which makes the MAV work.

5.4.2 Tail:
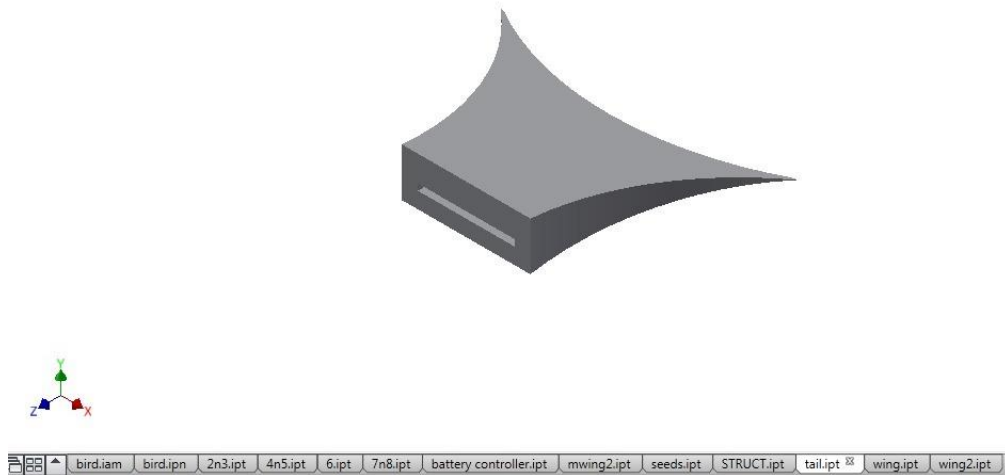
Fig 5.15 Tail

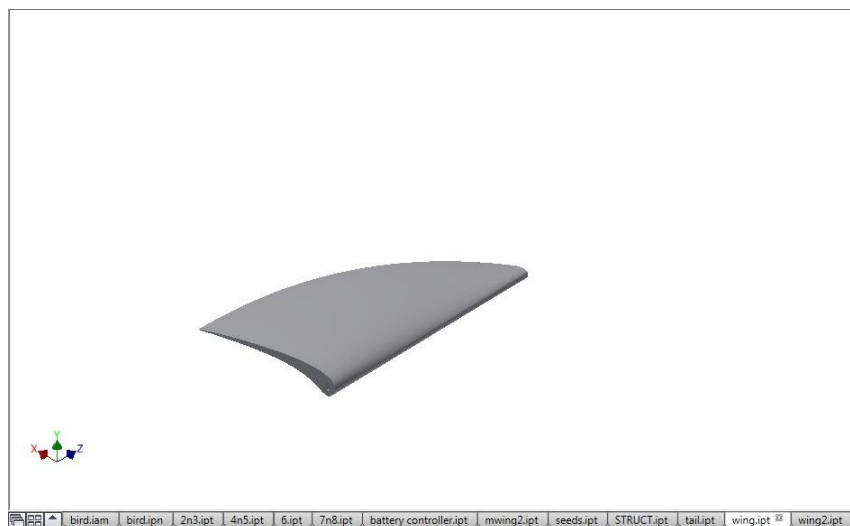The tail is also designed in the form of an aerofoil. Such that the tail part does not increase drag on the Miniature Air Vehicle and does not increase power consumption.

By controlling tail movement we can control the direction in which the Ornithopter will be flying. This can be achieved by installing servo motors to control the movement of the tail.

The tail movement also helps while landing and taking off. When the tail push downwards the MAV lifts up and when the tail lifts up the MAV tends to go down or to land.

5.4.3 Head:

The head part is designed in such a way that it looks more realistic like a real bird. By designing in such a manner the animals and birds in the ecosystem does not get concerned by our Miniature Air Vehicle and it blends more into the surroundings.

Fig 5.16 Head

5.4.4 Body:
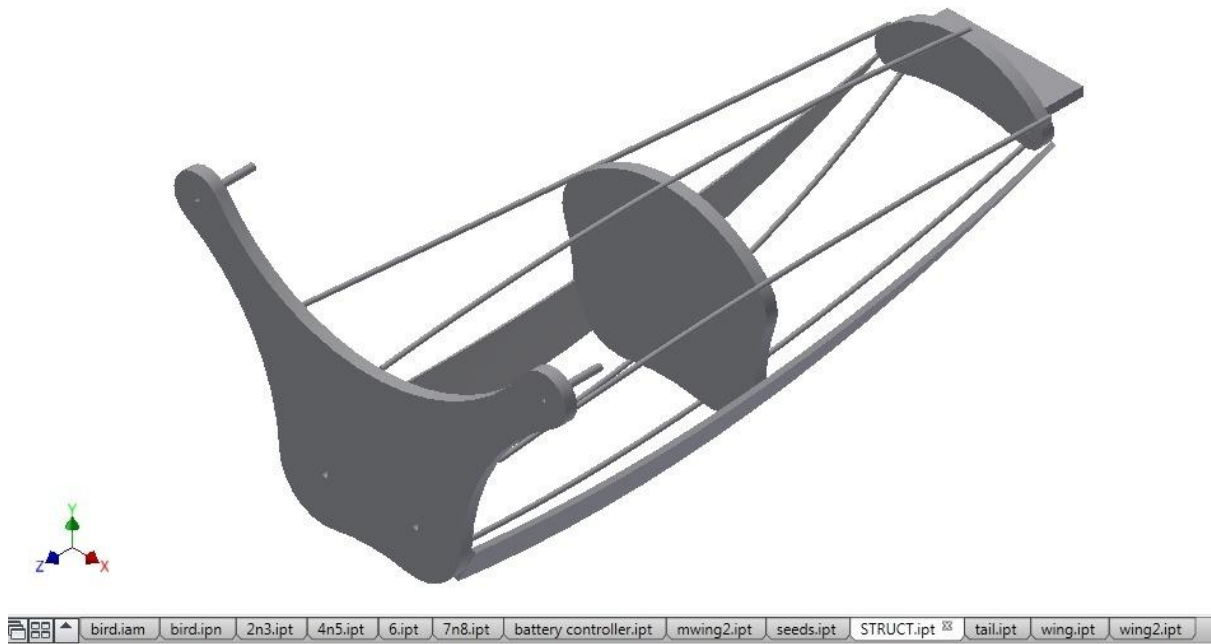
Fig 5.17 Body

The body acts as the main skeletal frame for the whole MAV and it is the sturdiest part in the whole project.

- The body holds different parts required for the flight of the MAV.
- The front part of the Ornithopter body holds the head
- The immidiate housing holds the gear box and main mechanism required for the flight of the Ornithopter.
- The centre body housing holds the battery, rc control module and wiring of the Miniature Air Vehicle.
- The third housing consists of the pocket to hold grains to be dropped through bottom of the Bird model for aerial seeding purpose.
- The house space is designed in such a way that there is enough space for all the parts of the Miniature Air Vehicle.
- The end of the body holds the tail of the Ornithopter
- The servos required for the movement of the tail are also located in the middle housing.

5.4.5 Link:

Fig 5.18 Link

The link is the most important part of the whole model. This link goes into the wing compartment so that when the link is given motion it tranfers it to the wing parts and the flapping motion is achieved through this.

The link is attached to the main body frame and plays a major role in the mechanism of the flapping motion of the Ornithopter.

- The link ensures proper flapping motion is achieved
- Link helps in the gliding of the Ornithopter
- It plays major role in lifting the Ornithopter up in the air
- It also regulates the speed at which the Ornithopter moves in the air.
- The following speed is achieved by controlling the thrust which can be controlled by the flapping speed of the link.
- One end of the link is connected to the Oscillating link whilwe the other is connected to the wing profile
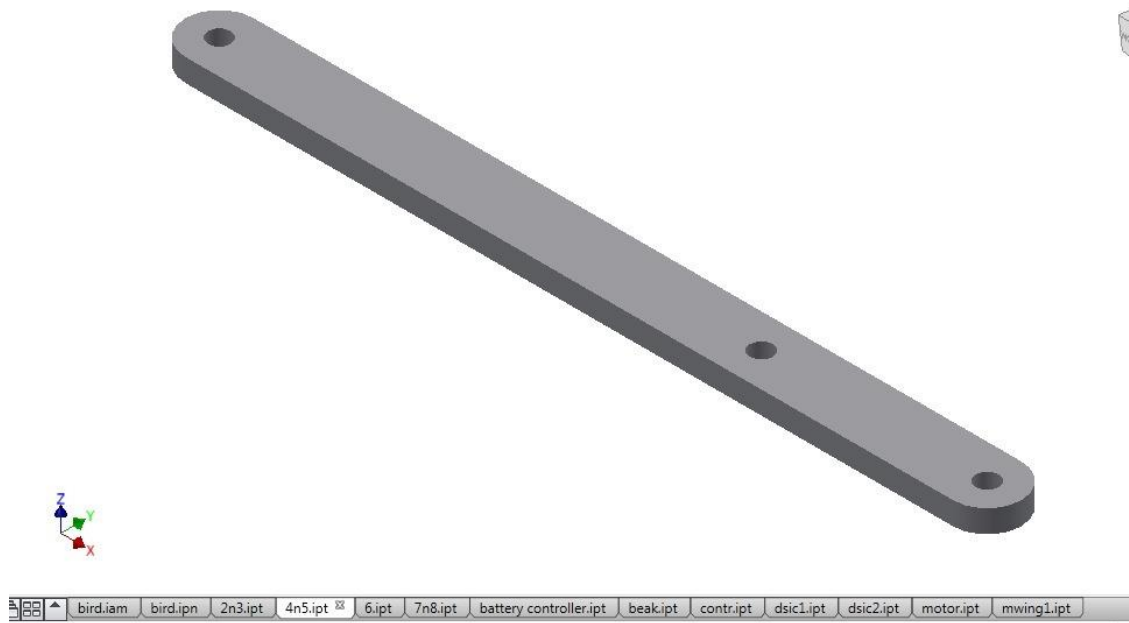
5.4.6 Mediatory link:

Fig 5.19 Mediatory link

The mediatory link connects the main link and motor drive or the gear box of the Miniature Air Vehicle.

The one end of this link is connected to the motor drive. As the motor rotates this link transforms the rotating motion of the link to oscillating motion.

The oscillating motion is then transferred to the main link which is connected at the other end of this link.

The main link connected to this mediatory link is connected to the wing profile as already mentioned before, this main link tranfers this oscillataing from the mediatory link to the wing profile which helps in achieving the flapping motion of the Ornithopter.

The end hole of this link is connected to the motor. The other end hole is connected to the main link. The intermidiate hole is connected to an another link which helps in achieving the original bird flapping motion.

5.4.7 Intermidiate link:
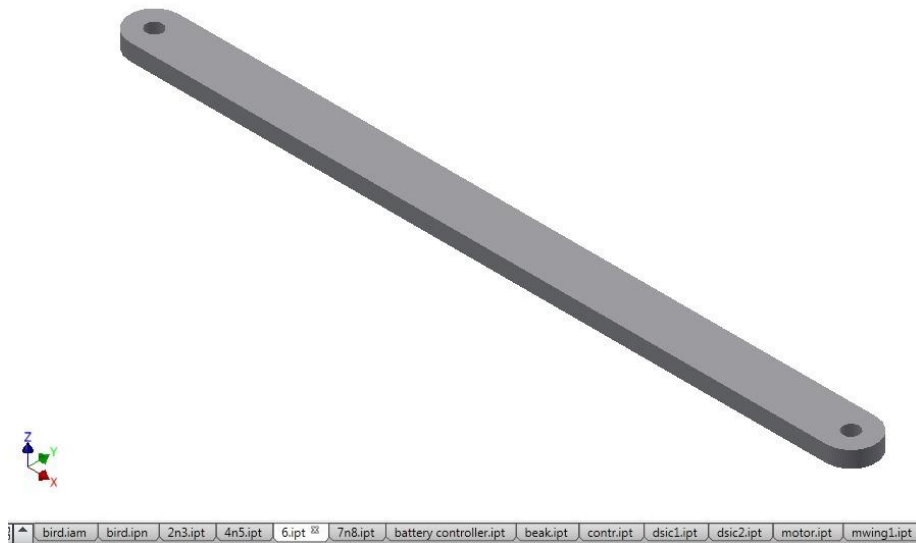
Fig 5.20 Intermidiate link

This intermidiate link connects the mediatory link and the link which achieves the flapping motion.

5.4.8 Semi fixed link:
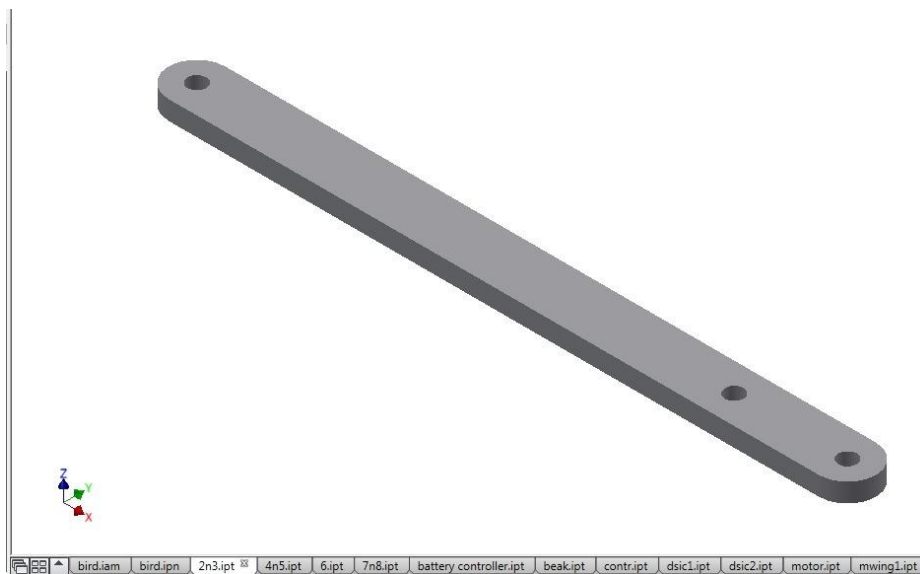
Fig 5.21 Semi fixed link

One end of this link is attached to the mediatory link to transmit oscillatory motion and the other end is attached to the flapping link. This link is semi fixed to the body of the MAV which ensures there is only single degree of freedom in the motion of the wing.

5.4.9 Assembled model:
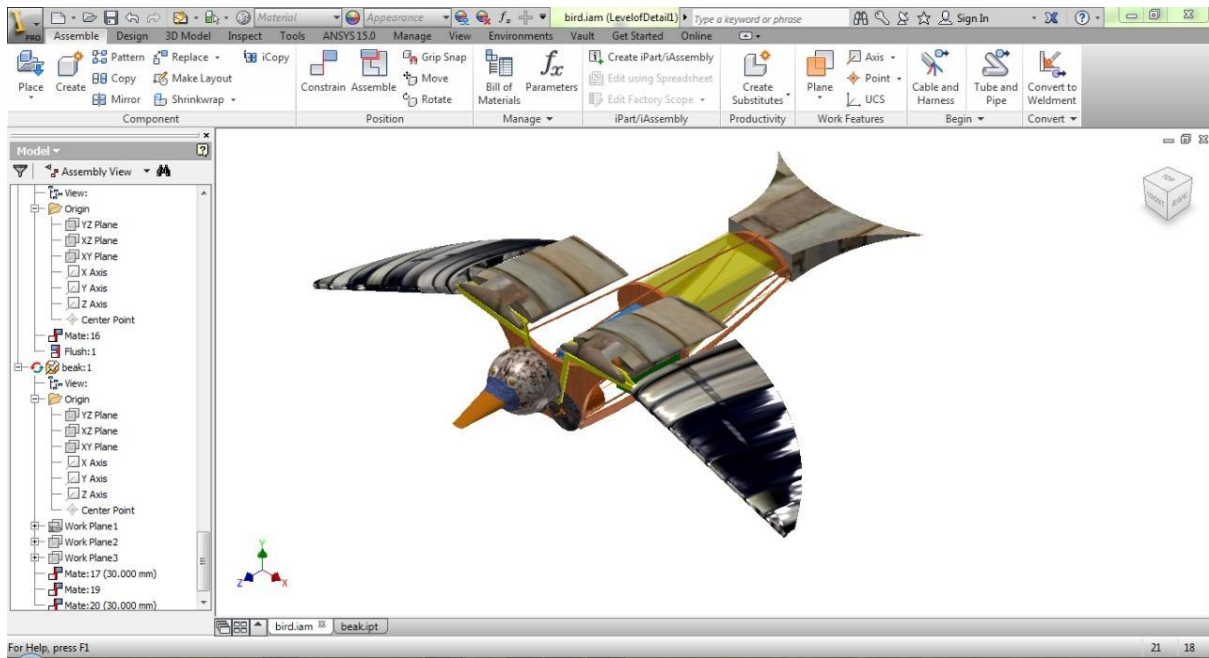
Fig 5.22 Assembled model

The part drawings are all collected in a single folder and using the assembly module of the inventor the Ornithopter model is assembled. By applying various constraints and resulting a single degree of freedom for the whole wing structure.

Fig 5.23 Degree of mobility

Fig 5.24 Front view

Fig 5.25 Top view

Fig 5.26 Side view

6. RESULTS AND DISCUSSIONS

In this chapter, a summary of our analysis and results are studied and analysis of the design and mechanism of Ornithopter is discussed.

6.1 SAM ANALYSIS RESULTS:

6.1.1 Introduction:

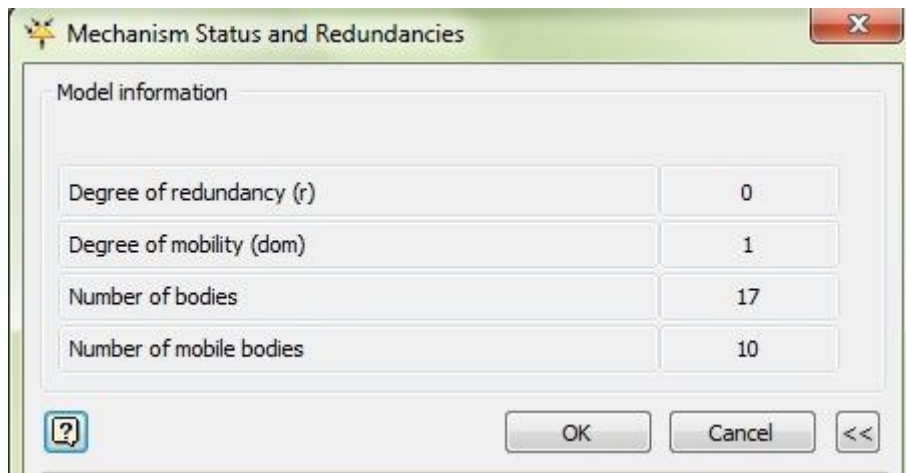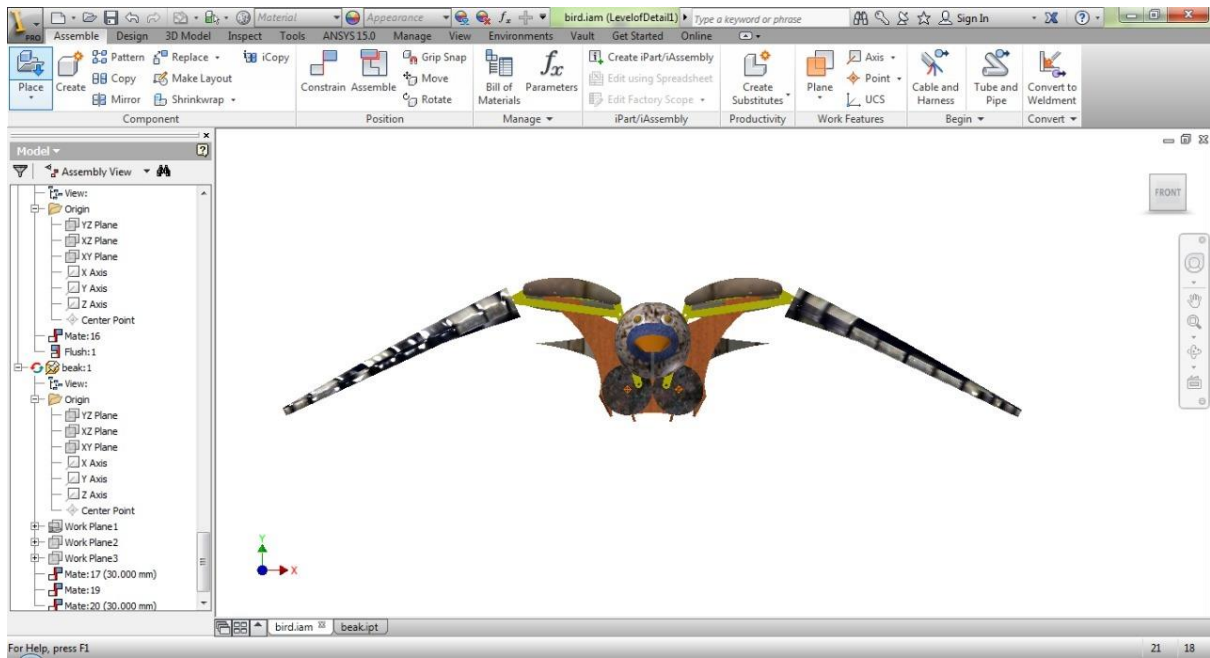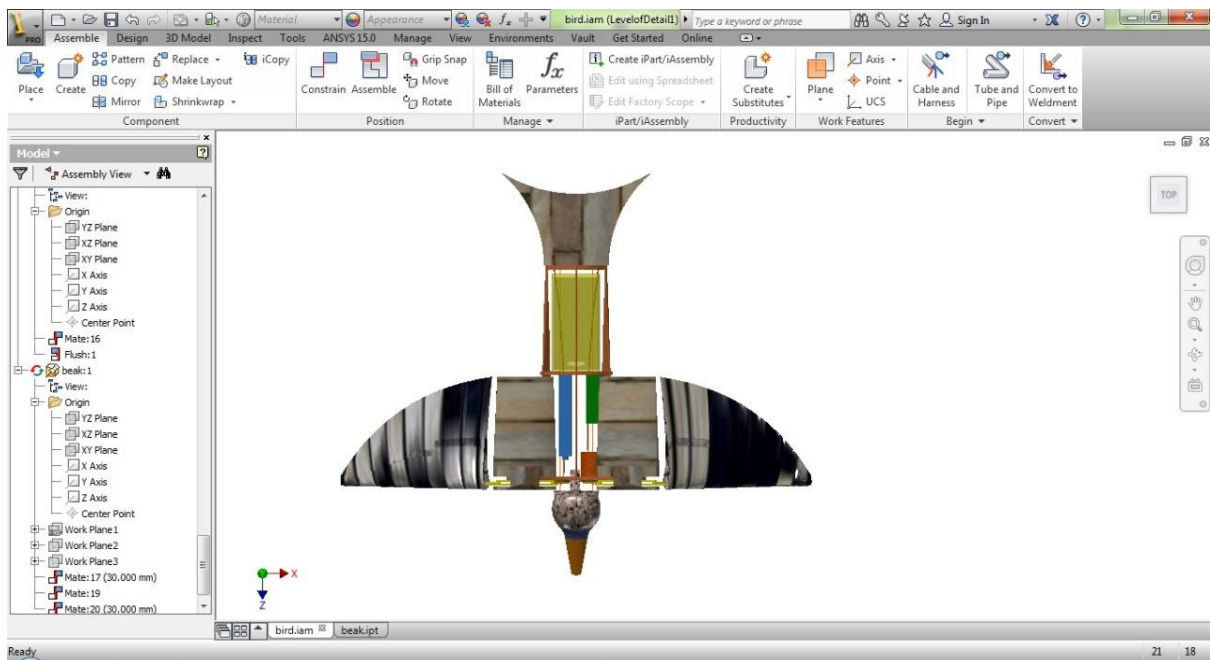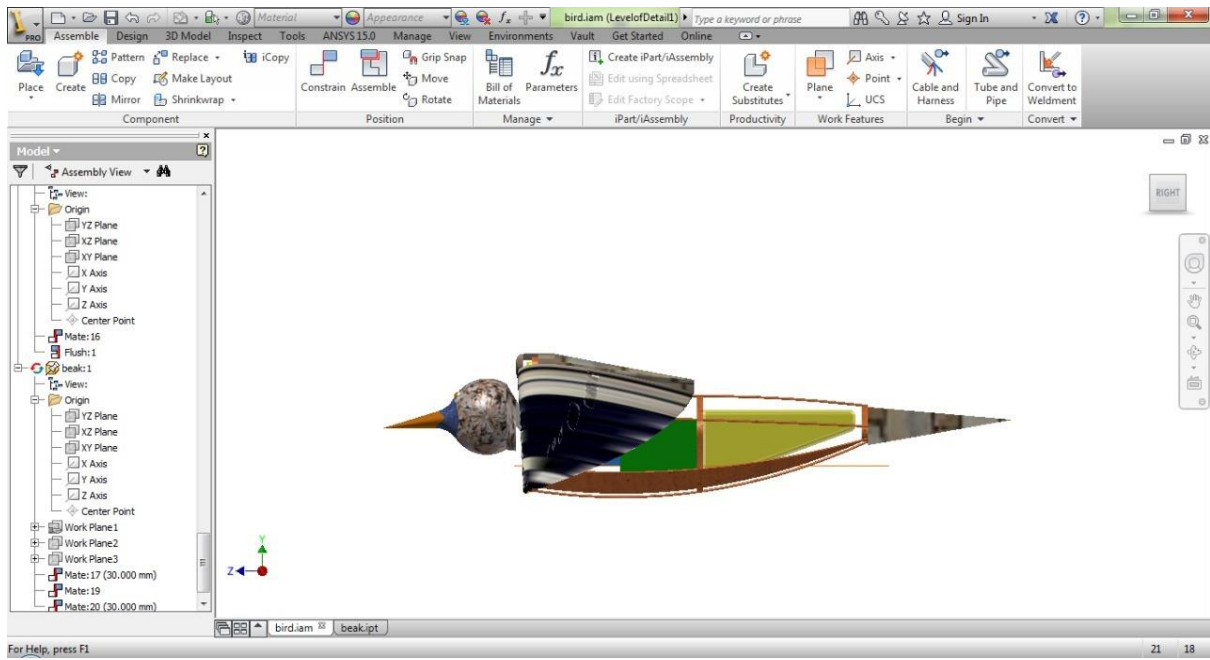Once the mechanism has been constructed and the inputs have been defined any of the following kinematic quantities can be calculated (all relative or absolute):

- Nodal position, displacement, velocity, acceleration
- Angles, angular velocity and acceleration

Furthermore SAM can perform force-analysis, thus enabling the calculation of:

- Driving torque (force)
- Reaction forces in bearings
- Internal forces in elements
- Required or transmitted power

A detailed study of position (y direction), velocity and acceleration with respect to time is carried out on our mechanism in SAM software by varying the free link length of our mechanism. These are studied to identify the optimum free link length.

For mechanism of wing length 160 mm the velocity vs time, acceleration vs time and postion vs time graphs are plotted in graphs 7.1, 7.2 and 7.3 respectively. The optimum free link length for our mechanism was taken as 200 mm on comparing all results from the graphs and tables. And hence while doing 3D modeling in AUTODESK INVENTOR we used the free link length of 200mm as shown in our 5th chapter.

An image for every mechanism after varying link lengths were being shown below which were taken from SAM software. Also the path traversed by the end node 8 was clearly shown in each image, which almost looked like an aerofoil.

6.1.2 Procedure for drawing graphs:

1. First select the node and right click the mouse, in the tab we find 'select curves' as an option.

2. After selecting 'select curves' option an other dialog box will appear and in that there will be different options shown.

3. Select the 'graph selection' option and there we can get all the required graphs either individually or combined.

4. In our project we plotted graphs for velocity, acceleration, position in y- direction for the last node 8 of the free link which is shown in figures below.

5. For the path appearance of the node we have to click 'display' option in the dialog box appeared and select path option there.

6. This dialog box can also be obtained by a simple double click on the particular node at which we want the desired graphs and tables.

6.1.3 Mechanism of Wing length : 160mm
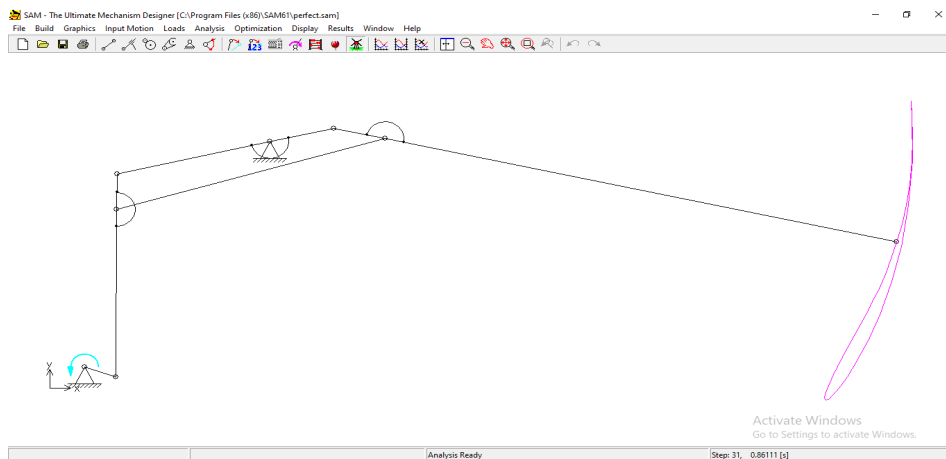
Fig 6.1 Mechanism(160mm)

<u>**Graphs**</u>**:**

1. Velocity vs Time

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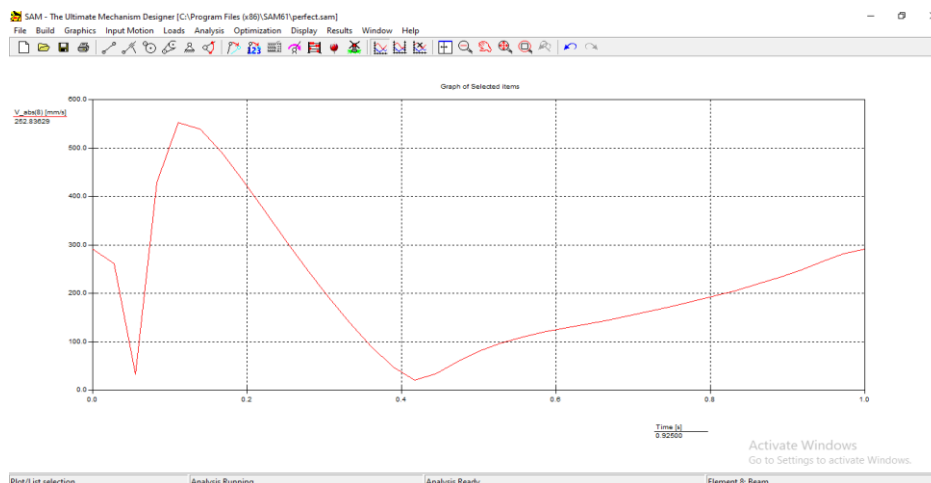
2. Acceleration vs Time
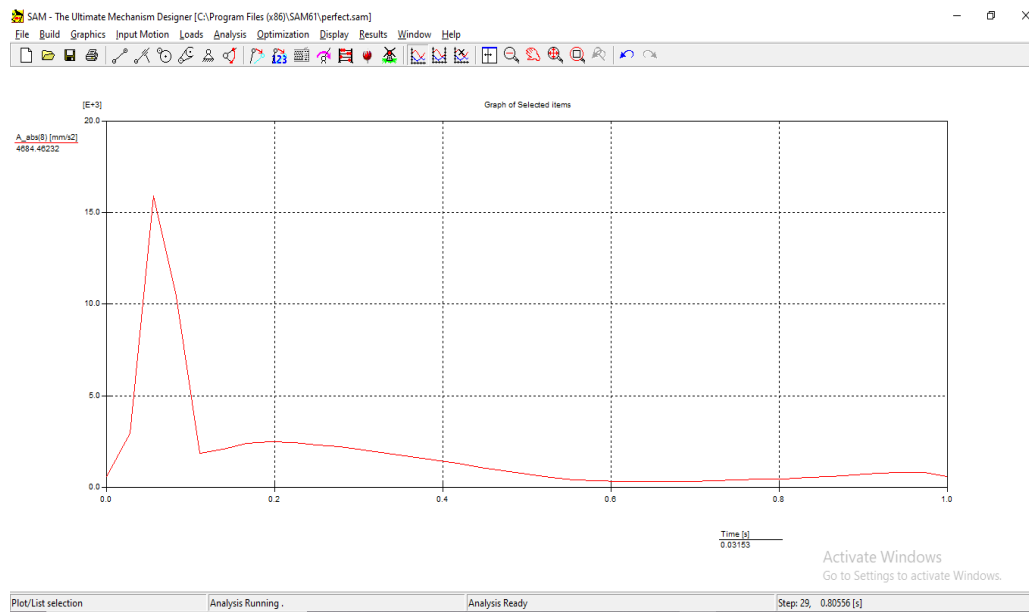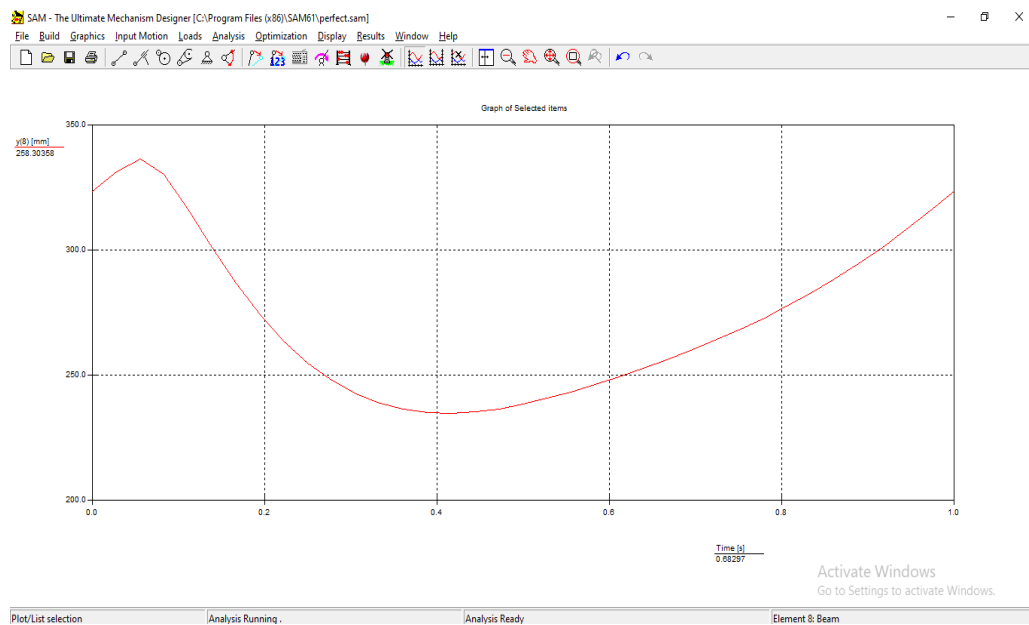
3. Position vs Time

Also the exact numerical values are being extracted from the SAM software in the form of tables. The velocity vs time, acceleration vs time and position vs time in tabular format are being presented below for better understanding.

Tables:

1. **Velocity vs Time**

Nr: [-]	Time [s]	V abs(8) [mm/s]
0	0.000	290.935
1	0.028	261.214
2	0.056	32.268
3	0.083	428.730
4	0.111	551.835
5	0.139	538.229
6	0.167	491.329
7	0.194	433.279
8	0.222	371.380
9	0.250	309.162
10	0.278	248.723
11	0.306	191.440
12	0.333	138.283
13	0.361	90.094
14	0.389	48.233
15	0.417	20.703
16	0.444	34.213
17	0.472	58.661
18	0.500	79.667
19	0.528	96.314
20	0.556	109.208
21	0.583	119.426
22	0.611	128.154
23	0.639	136.410
24	0.667	144.874
25	0.694	153.858
26	0.722	163.402
27	0.750	173.415
28	0.778	183.818
29	0.806	194.639
30	0.833	206.068
31	0.861	218.451
32	0.889	232.224
33	0.917	247.722
34	0.944	264.769
35	0.972	281.579
36	1.000	290.935

2. Acceleration vs Time

Nr: [-]	Time [s]	A_abs(8) [mm/s2]
0	0.000	589.370
1	0.028	2928.581
2	0.056	15922.100
3	0.083	10412.933
4	0.111	1868.642
5	0.139	2108.832
6	0.167	2416.226
7	0.194	2477.383
8	0.222	2432.167
9	0.250	2332.599
10	0.278	2200.490
11	0.306	2046.704
12	0.333	1877.164
13	0.361	1695.135
14	0.389	1502.656
15	0.417	1301.959
16	0.444	1097.051
17	0.472	895.139
18	0.500	707.104
19	0.528	546.015
20	0.556	423.263
21	0.583	343.964
22	0.611	305.251
23	0.639	298.757
24	0.667	313.721
25	0.694	339.680
26	0.722	369.439
27	0.750	400.578
28	0.778	434.738
29	0.806	475.773
30	0.833	527.825
31	0.861	593.722
32	0.889	673.061
33	0.917	758.085
34	0.944	822.969
35	0.972	794.171
36	1.000	589.370

3. Position vs Time

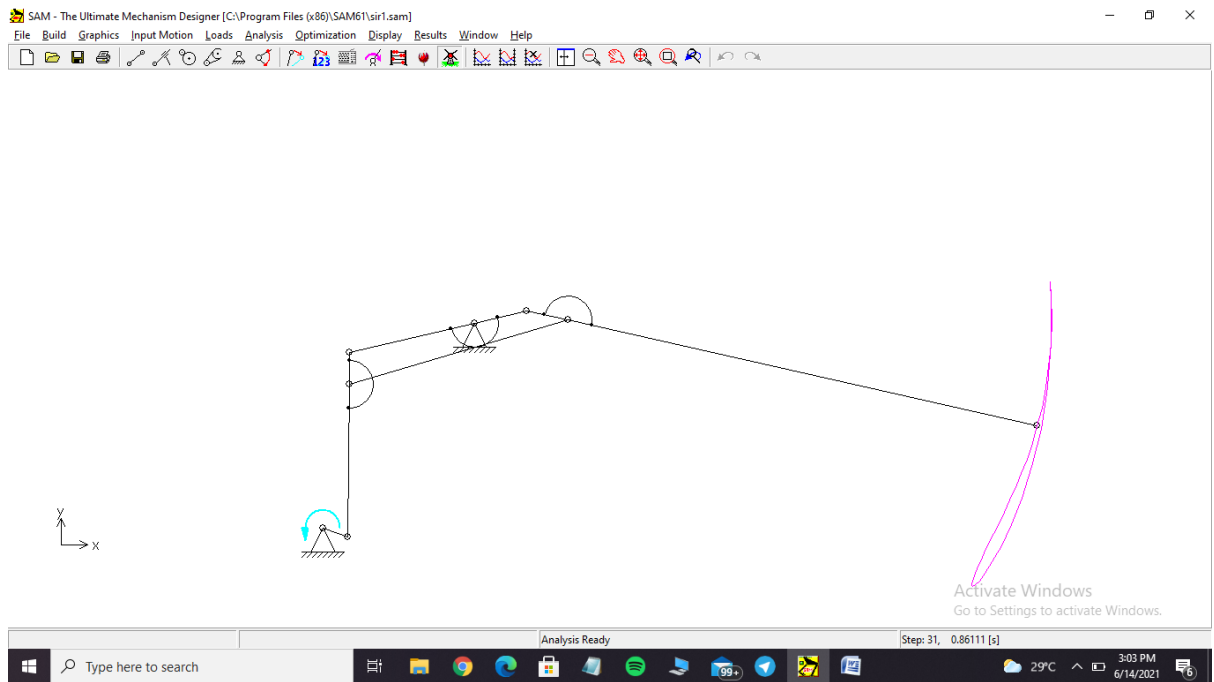| Nr:	Time	y(8)
[-]	[s]	[mm]
0	0.000	323.577
1	0.028	331.419
2	0.056	336.336
3	0.083	330.398
4	0.111	316.184
5	0.139	300.960
6	0.167	286.806
7	0.194	274.318
8	0.222	263.687
9	0.250	254.923
10	0.278	247.945
11	0.306	242.623
12	0.333	238.801
13	0.361	236.317
14	0.389	235.007
15	0.417	234.713
16	0.444	235.280
17	0.472	236.561
18	0.500	238.414
19	0.528	240.711
20	0.556	243.346
21	0.583	246.237
22	0.611	249.338
23	0.639	252.630
24	0.667	256.123
25	0.694	259.839
26	0.722	263.807
27	0.750	268.057
28	0.778	272.616
29	0.806	277.509
30	0.833	282.760
31	0.861	288.399
32	0.889	294.462
33	0.917	300.993
34	0.944	308.034
35	0.972	315.596
36	1.000	323.577

6.1.4 Mechanism of Wing length : 180mm

Fig 6.2 Mechanism(180mm)

<u>Graphs</u>:

1. **Velocity vs Time**
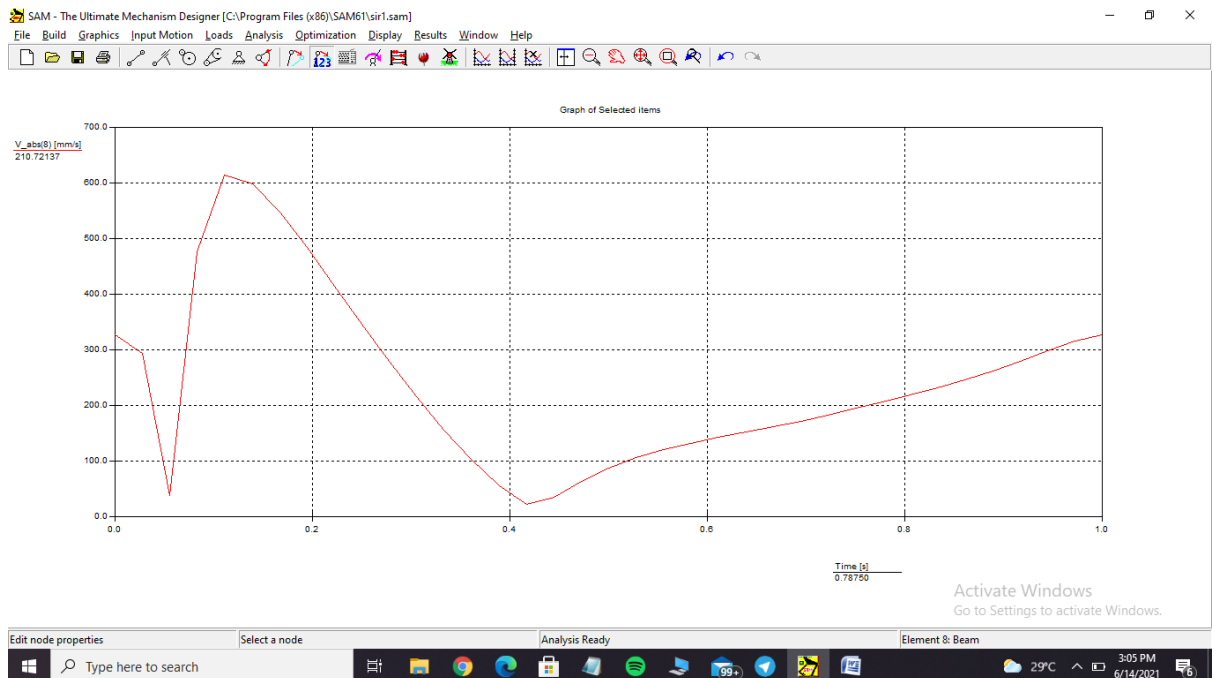
2. Acceleration vs Time
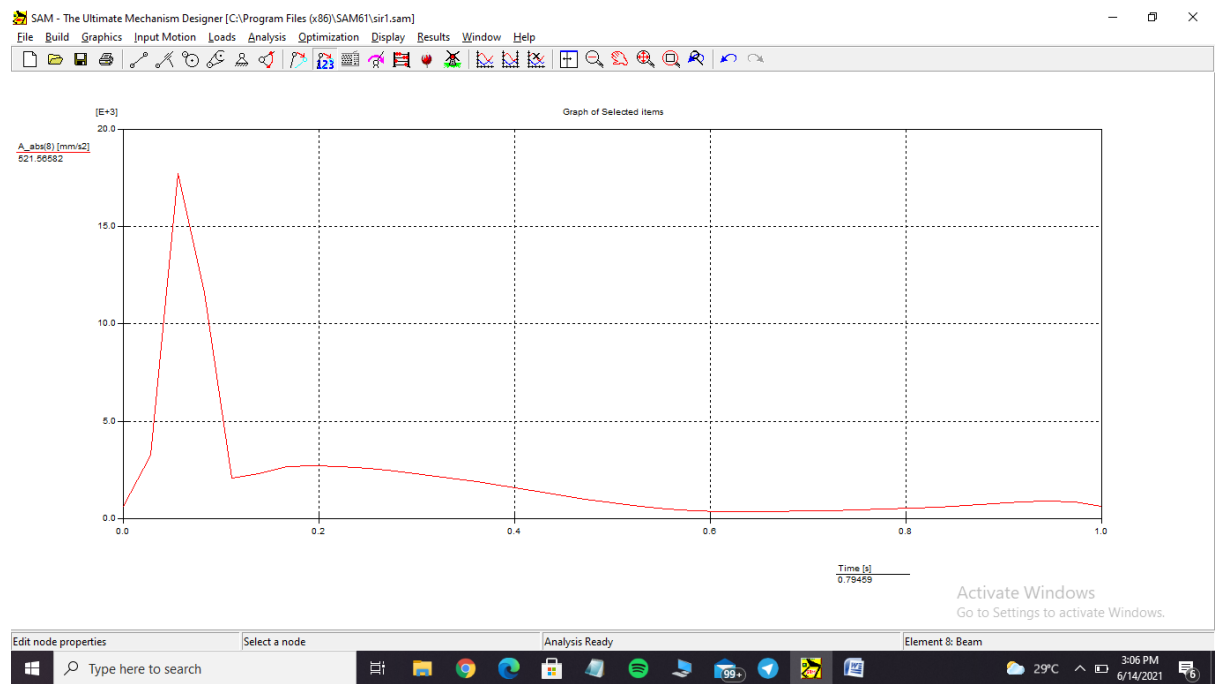
3. Position vs Time
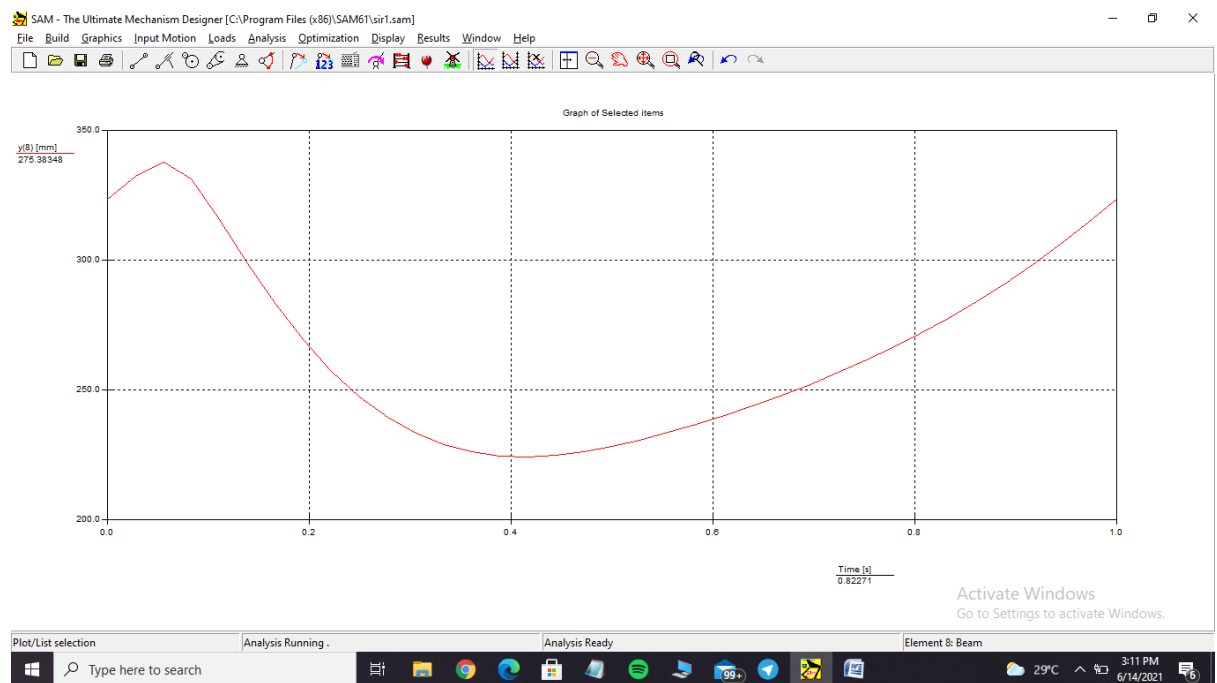
Tables:

1. Velocity vs Time

Nr:	Time	V_abs(8)
[-]	[s]	[mm/s]
0	0.000	326.571
1	0.028	293.151
2	0.056	37.762
3	0.083	476.101
4	0.111	613.740
5	0.139	599.170
6	0.167	547.531
7	0.194	483.444
8	0.222	415.008
9	0.250	346.127
10	0.278	279.117
11	0.306	215.492
12	0.333	156.312
13	0.361	102.459
14	0.389	55.199
15	0.417	21.670
16	0.444	35.045
17	0.472	62.855
18	0.500	86.747
19	0.528	105.743
20	0.556	120.538
21	0.583	132.328
22	0.611	142.433
23	0.639	151.988
24	0.667	161.752
25	0.694	172.083
26	0.722	183.030
27	0.750	194.498
28	0.778	206.397
29	0.806	218.752
30	0.833	231.765
31	0.861	245.806
32	0.889	261.339
33	0.917	278.719
34	0.944	297.728
35	0.972	316.360
36	1.000	326.571

2. Acceleration vs Time

Nr: [-]	Time [s]	A_abs(8) [mm/s2]
0	0.000	653.226
1	0.028	3274.318
2	0.056	17747.834
3	0.083	11614.967
4	0.111	2089.655
5	0.139	2333.958
6	0.167	2671.742
7	0.194	2738.880
8	0.222	2689.526
9	0.250	2581.094
10	0.278	2437.413
11	0.306	2270.139
12	0.333	2085.472
13	0.361	1886.740
14	0.389	1675.984
15	0.417	1455.542
16	0.444	1229.777
17	0.472	1006.645
18	0.500	798.214
19	0.528	619.053
20	0.556	482.066
21	0.583	393.502
22	0.611	350.779
23	0.639	344.543
24	0.667	362.181
25	0.694	391.557
26	0.722	424.525
27	0.750	458.402
28	0.778	495.056
29	0.806	538.845
30	0.833	594.489
31	0.861	665.253
32	0.889	750.775
33	0.917	842.471
34	0.944	911.693
35	0.972	876.998
36	1.000	653.227

3. Position vs Time

Nr:	Time	y(8)
[-]	[s]	[mm]
0	0.000	323.577
1	0.028	332.377
2	0.056	337.910
3	0.083	331.342
4	0.111	315.543
5	0.139	298.603
6	0.167	282.838
7	0.194	268.913
8	0.222	257.039
9	0.250	247.230
10	0.278	239.398
11	0.306	233.398
12	0.333	229.061
13	0.361	226.207
14	0.389	224.658
15	0.417	224.241
16	0.444	224.787
17	0.472	226.133
18	0.500	228.125
19	0.528	230.624
20	0.556	233.511
21	0.583	236.698
22	0.611	240.132
23	0.639	243.795
24	0.667	247.695
25	0.694	251.855
26	0.722	256.308
27	0.750	261.087
28	0.778	266.218
29	0.806	271.729
30	0.833	277.647
31	0.861	284.003
32	0.889	290.835
33	0.917	298.190
34	0.944	306.113
35	0.972	314.614
36	1.000	323.577

6.1.5 Mechanism of Wing length: 200mm
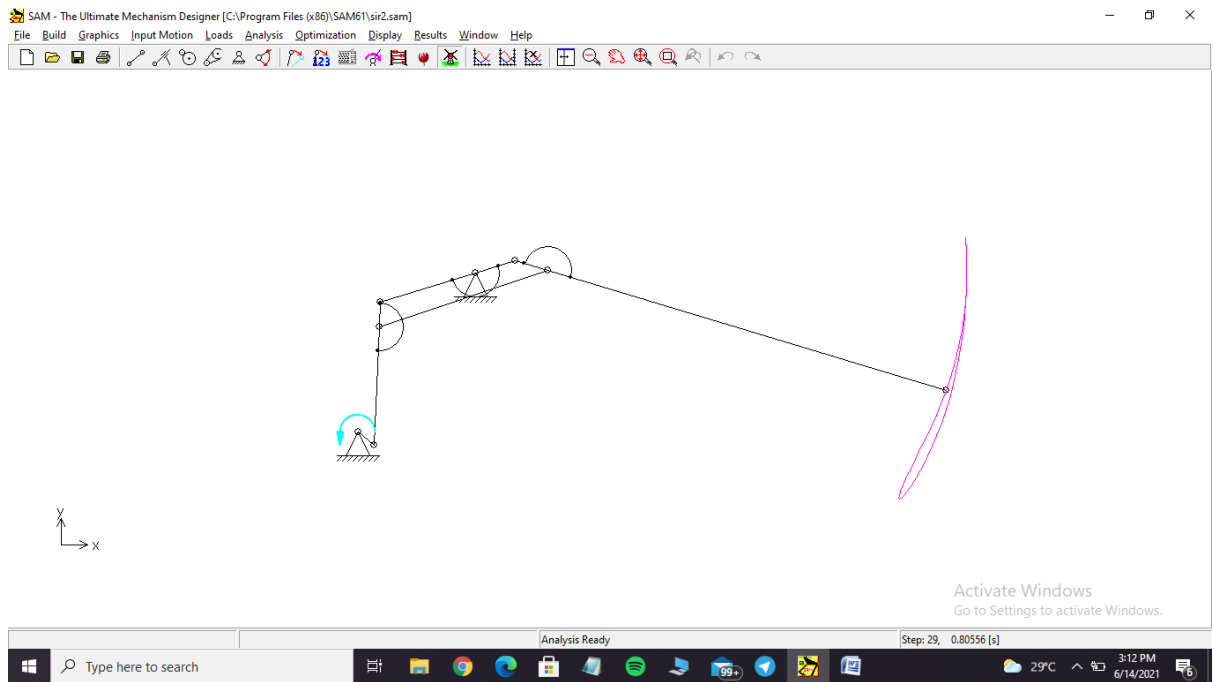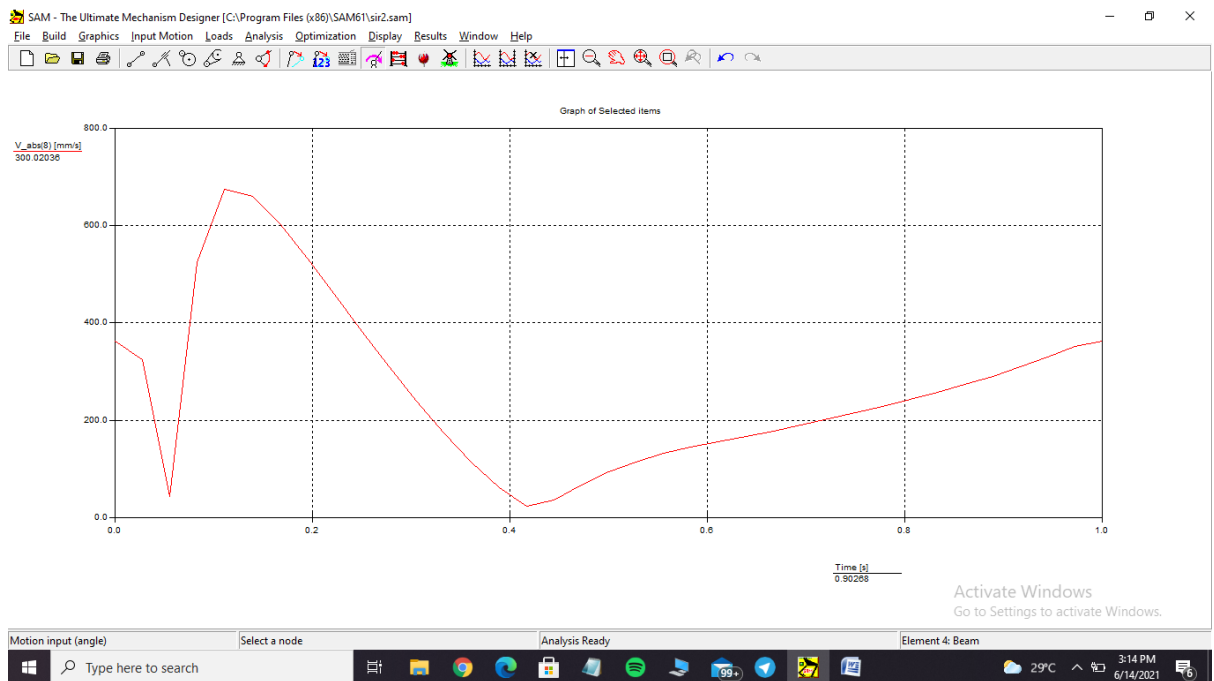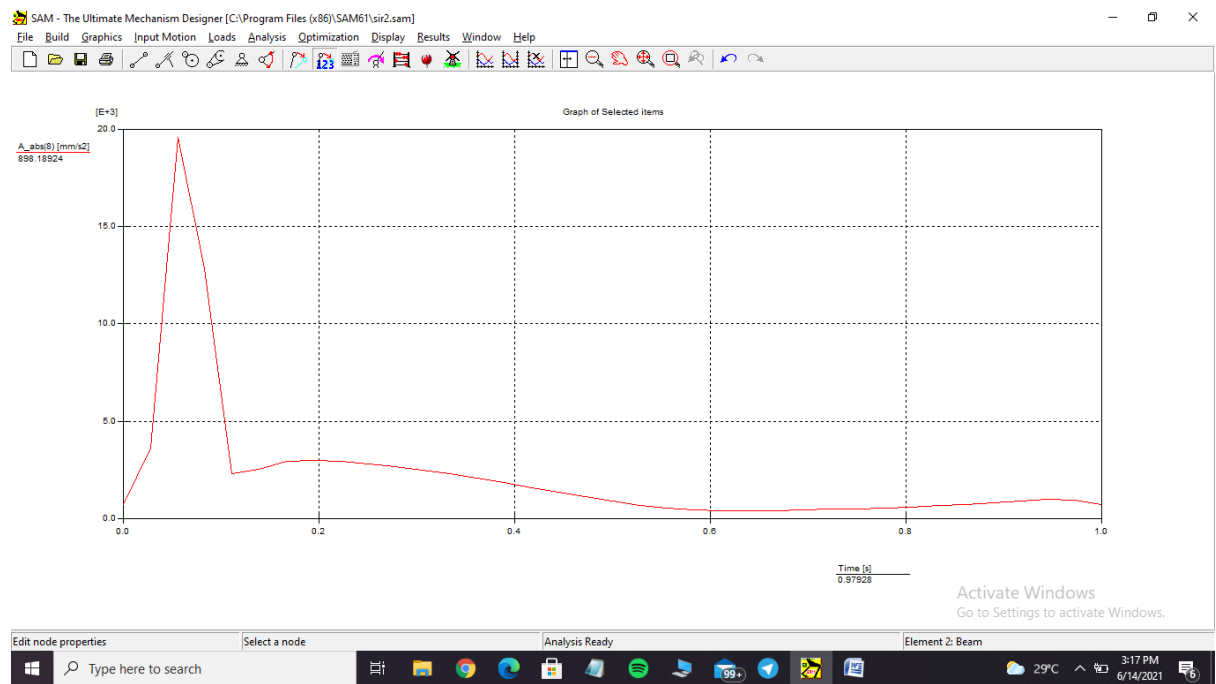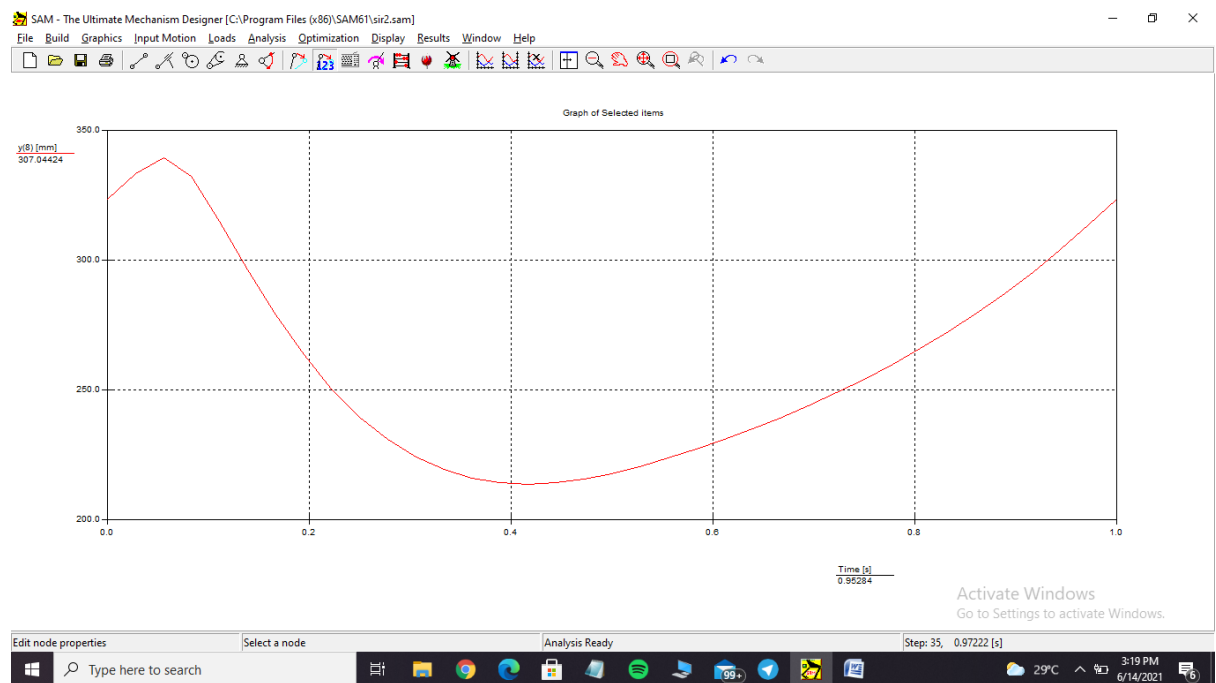

Fig 6.3 Mechanism(200mm)

<u>**Graphs:**</u>

1. Velocity vs Time

2. Acceleration vs Time

3. Position(Y direction) vs Time

Tables:

1. Velocity vs Time

Nr:	Time	V_abs(8)
[-]	[s]	[mm/s]
0	0.000	362.208
1	0.028	325.087
2	0.056	43.258
3	0.083	523.472
4	0.111	675.644
5	0.139	660.112
6	0.167	603.733
7	0.194	533.609
8	0.222	458.636
9	0.250	383.093
10	0.278	309.514
11	0.306	239.553
12	0.333	174.362
13	0.361	114.869
14	0.389	62.292
15	0.417	22.980
16	0.444	35.888
17	0.472	67.077
18	0.500	93.850
19	0.528	115.188
20	0.556	131.876
21	0.583	145.234
22	0.611	156.714
23	0.639	167.565
24	0.667	178.631
25	0.694	190.310
26	0.722	202.663
27	0.750	215.588
28	0.778	228.984
29	0.806	242.874
30	0.833	257.470
31	0.861	273.167
32	0.889	290.460
33	0.917	309.719
34	0.944	330.687
35	0.972	351.141
36	1.000	362.208

2. Acceleration vs Time

Nr: [-]	Time [s]	A_abs(8) [mm/s2]
0	0.000	717.208
1	0.028	3620.059
2	0.056	19573.568
3	0.083	12817.001
4	0.111	2310.801
5	0.139	2559.169
6	0.167	2927.286
7	0.194	3000.383
8	0.222	2946.885
9	0.250	2829.593
10	0.278	2674.349
11	0.306	2493.593
12	0.333	2293.802
13	0.361	2078.361
14	0.389	1849.320
15	0.417	1609.125
16	0.444	1362.507
17	0.472	1118.182
18	0.500	889.428
19	0.528	692.330
20	0.556	541.299
21	0.583	443.649
22	0.611	396.964
23	0.639	390.866
24	0.667	410.985
25	0.694	443.609
26	0.722	479.678
27	0.750	516.240
28	0.778	555.373
29	0.806	601.923
30	0.833	661.170
31	0.861	736.808
32	0.889	828.508
33	0.917	926.870
34	0.944	1000.421
35	0.972	959.828
36	1.000	717.209

3. Position vs Time

Nr:	Time	y(8)
[-]	[s]	[mm]
0	0.000	323.577
1	0.028	333.336
2	0.056	339.484
3	0.083	332.286
4	0.111	314.901
5	0.139	296.246
6	0.167	278.871
7	0.194	263.508
8	0.222	250.392
9	0.250	239.538
10	0.278	230.851
11	0.306	224.173
12	0.333	219.320
13	0.361	216.097
14	0.389	214.310
15	0.417	213.770
16	0.444	214.293
17	0.472	215.705
18	0.500	217.836
19	0.528	220.536
20	0.556	223.676
21	0.583	227.159
22	0.611	230.927
23	0.639	234.960
24	0.667	239.266
25	0.694	243.871
26	0.722	248.810
27	0.750	254.116
28	0.778	259.820
29	0.806	265.950
30	0.833	272.535
31	0.861	279.606
32	0.889	287.207
33	0.917	295.387
34	0.944	304.191
35	0.972	313.632
36	1.000	323.577

From tables we observed that:

	Free link - 160 mm	Free link – 180 mm	Free link – 200mm
Maximum Velocity	551.835 mm/sec	613.740 mm/sec	675.644 mm/sec
Maximum Acceleration	15922.1 mm/sec^2	17747.834 mm/sec^2	19573.568 mm/sec^2
Maximum Position (y-direction)	336.336 mm	337.910 mm	339.484 mm

Finally we observed that the path at the tip of the wing is in air foil shape.

REASON: The path looks like airfoil because the cross section of the wing is in air foil shape. Purpose of air foil is to increase the velocity of air and decrease the pressure so that there will be lift generated in order to move the bird vertically upwards.

6.2 INVENTOR RESULTS:

The below figure shows the path traced by the free end of the wing and is taken from AUTODESK INVENTOR software.
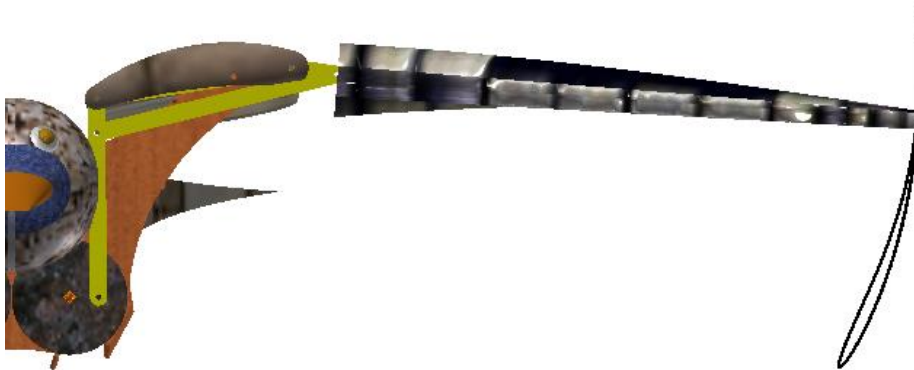

Fig 6.4 Path traced by the wing

A detailed study of position (y direction), velocity and acceleration with respect to time is carried out on the 3D model in AUTODESK INVENTOR software. These are studied on the optimum free link length obtained from SAM software.

For the 3D MODEL we obtained the velocity vs time, acceleration vs time and postion vs time graphs are shown in images below which are directly obtained from the software.
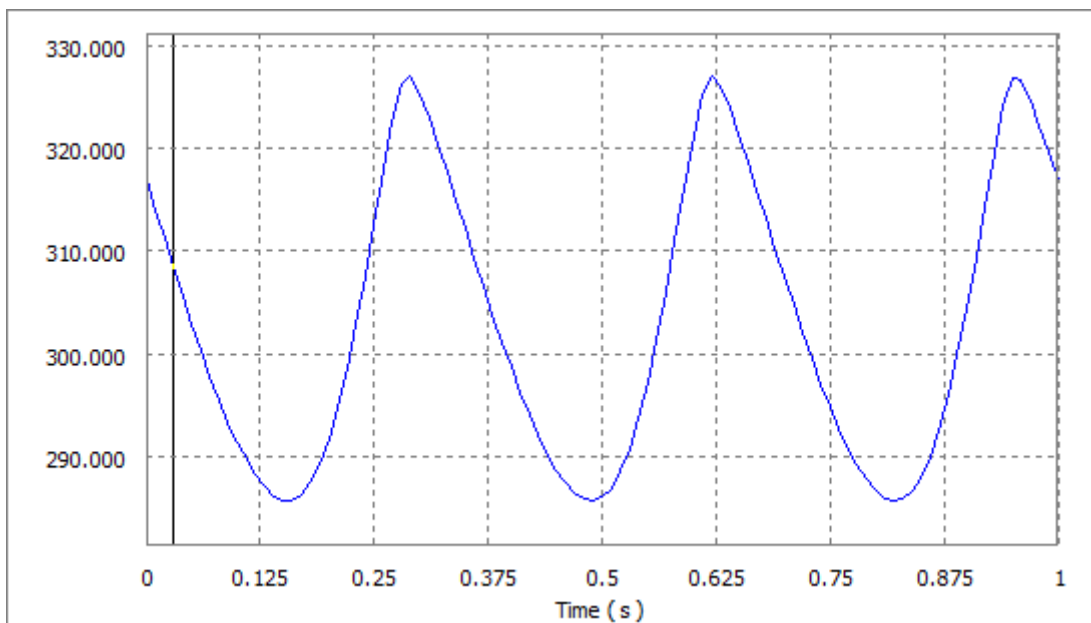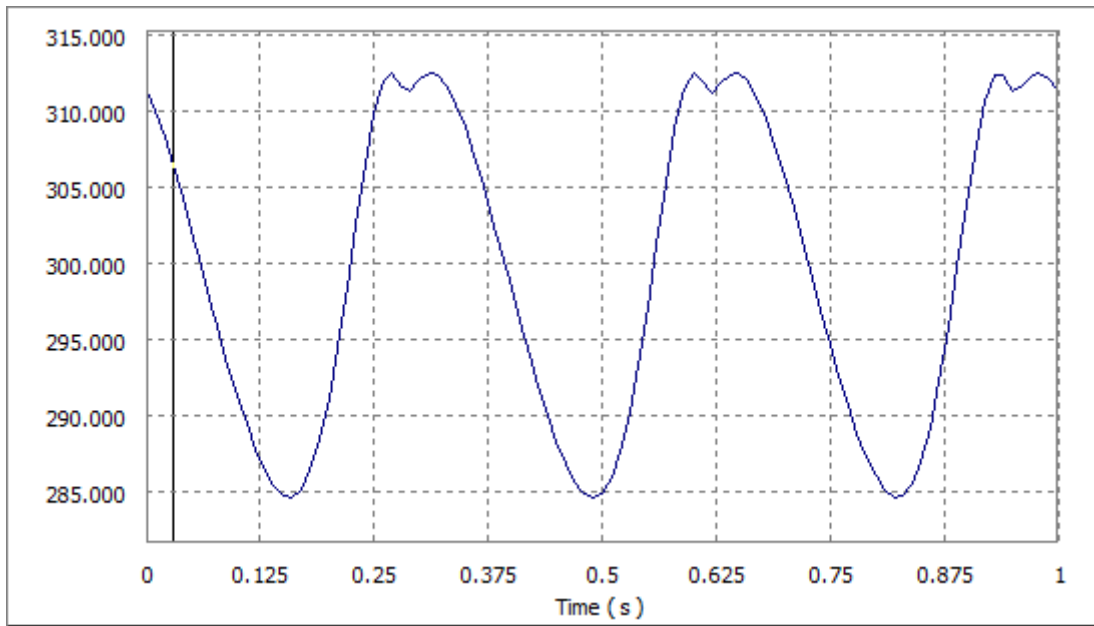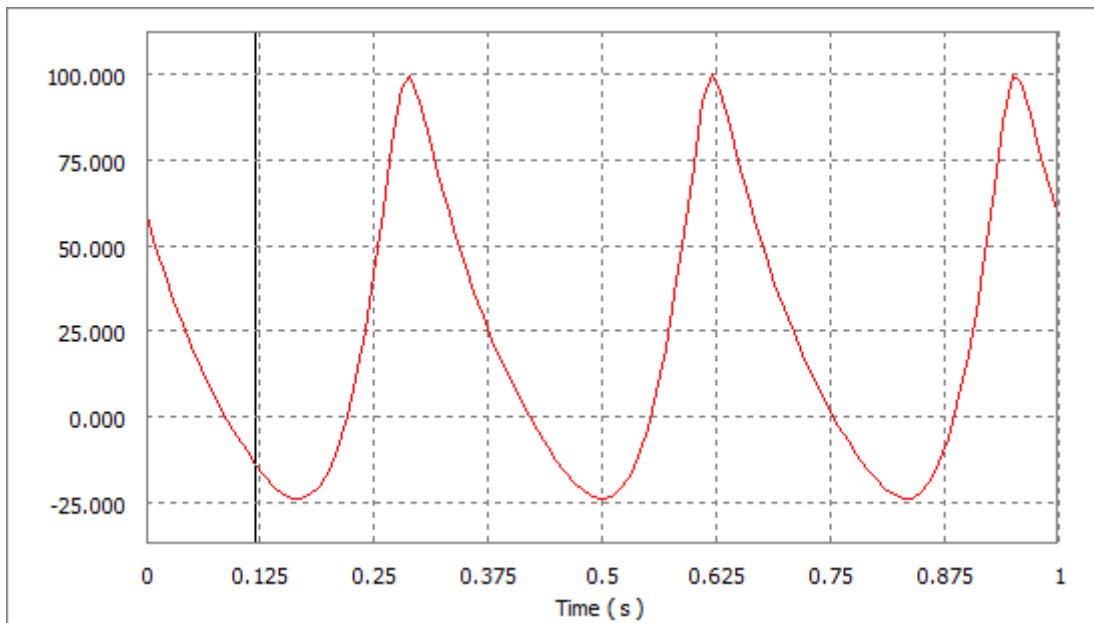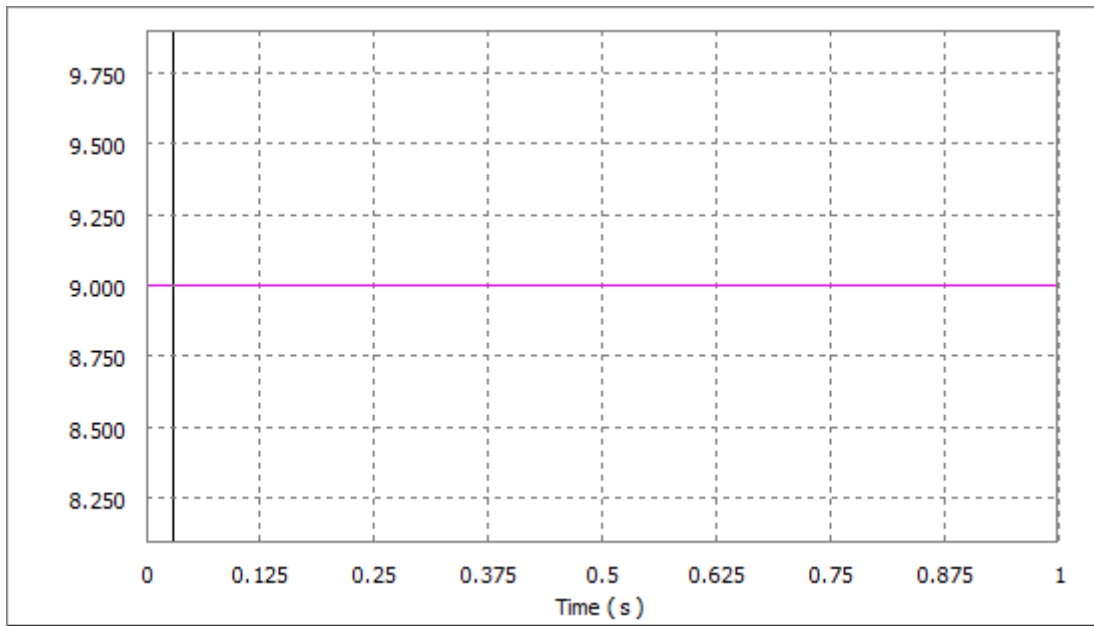
Graphs:

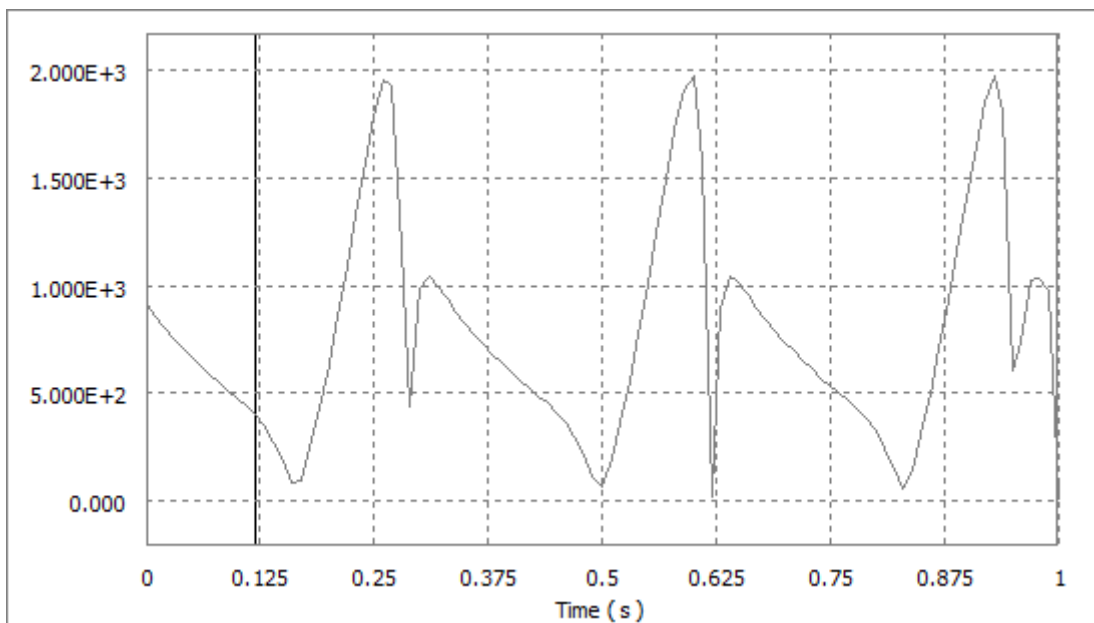**Input data**
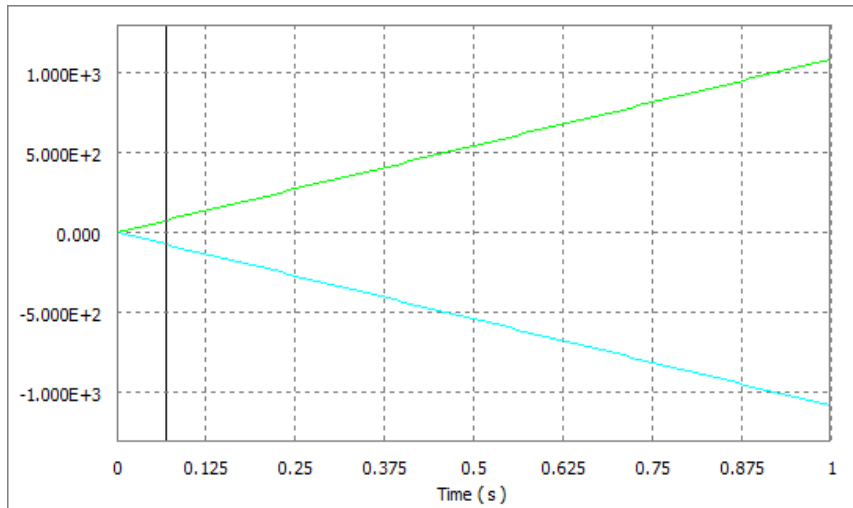
1. **Position vs Time**
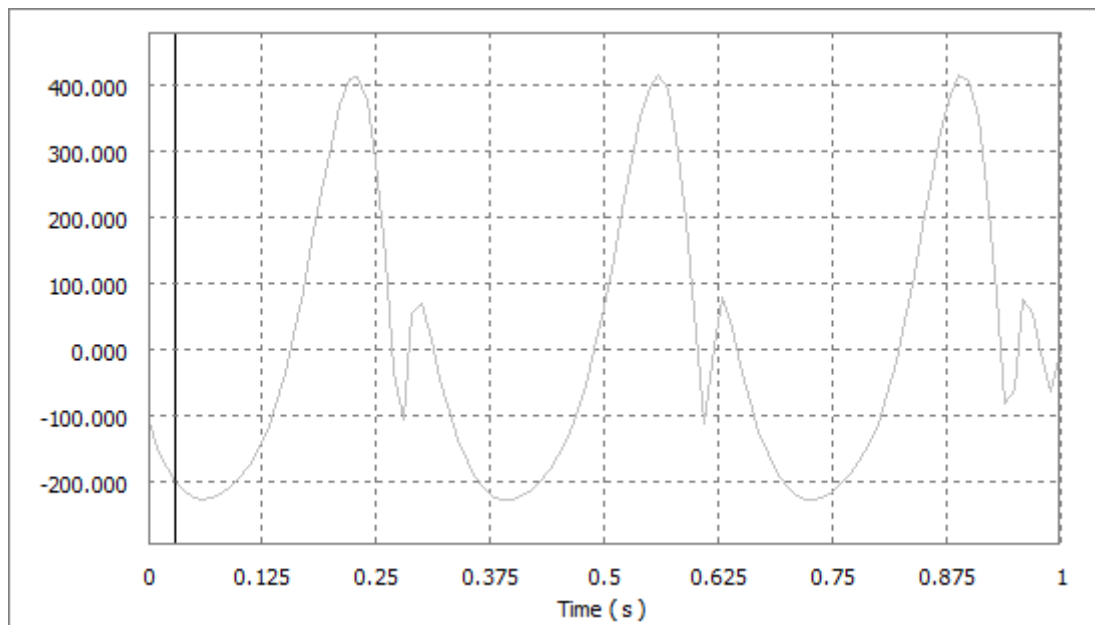
P VS TIME

P(X) VS TIME

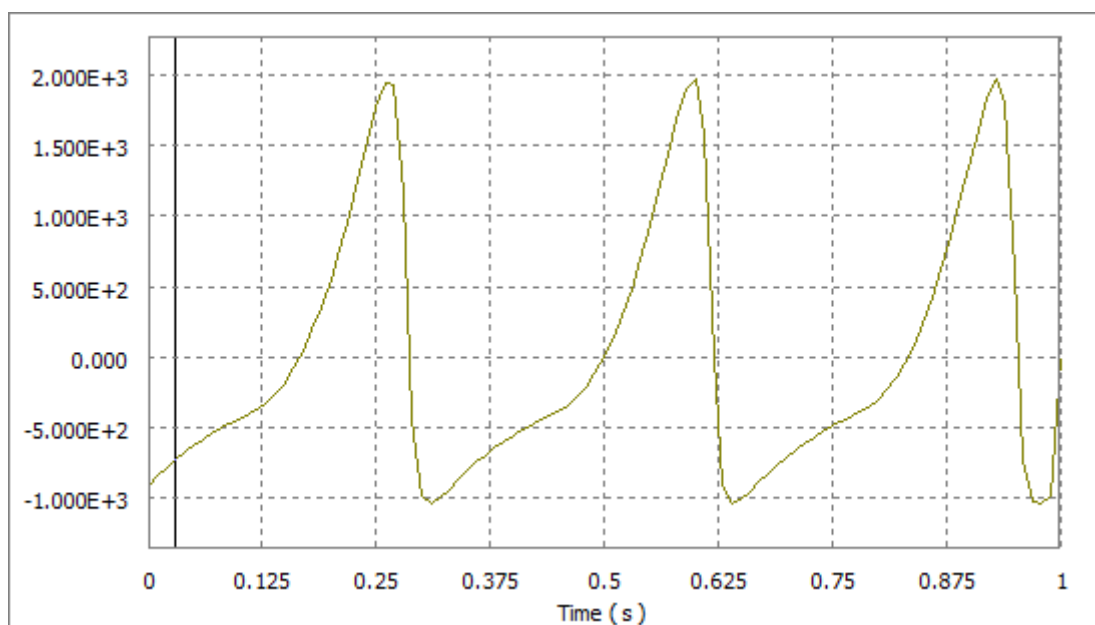P(Y) VS TIME

P(Z) VS TIME

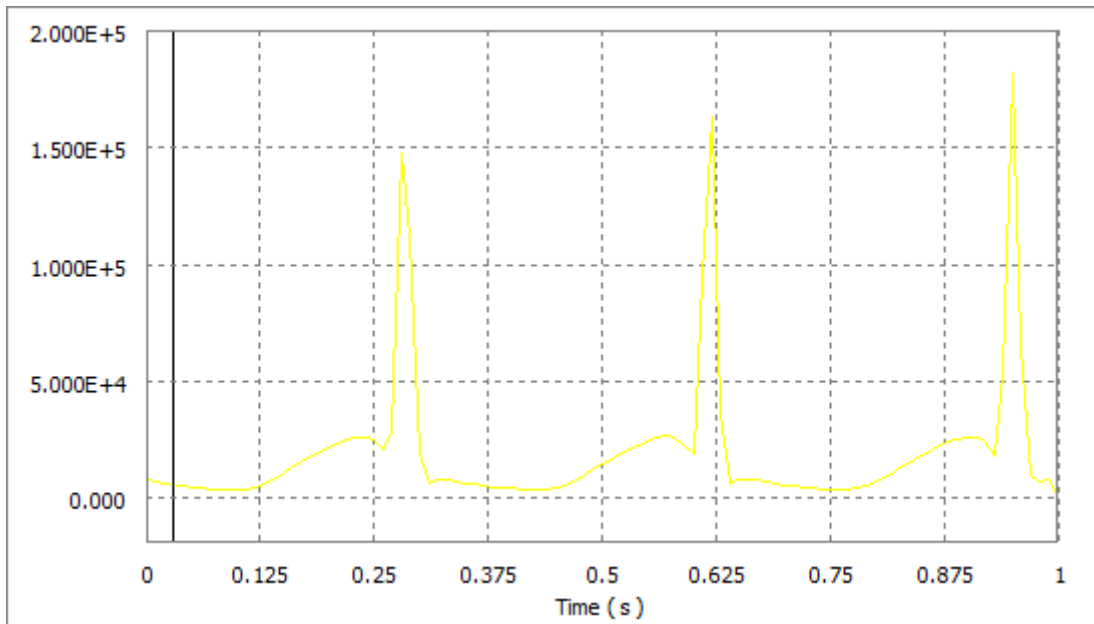2. **Velocity vs Time**

V VS TIME
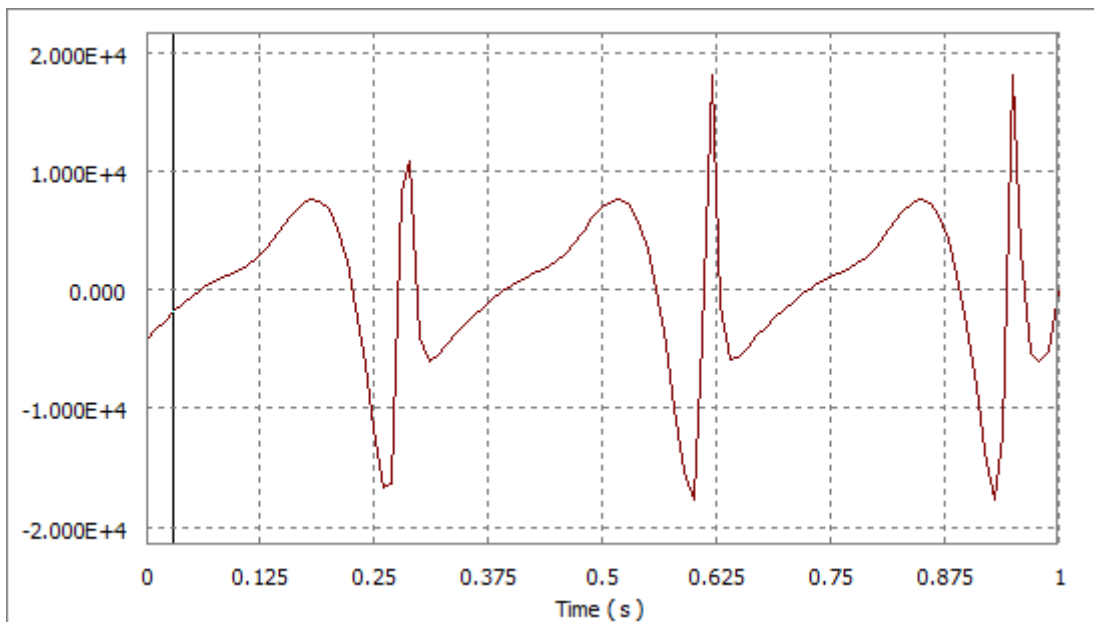
V(X) VS TIME

V(Y) VS TIME
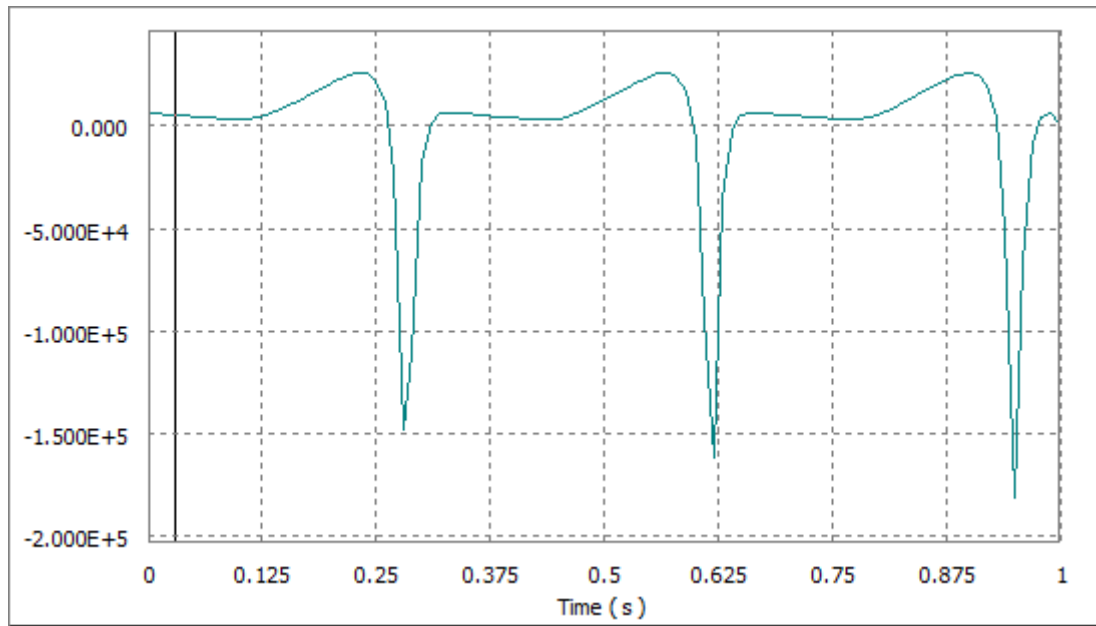
3. Acceleration vs Time

A VS TIME

A(X) VS TIME

A(Y) VS TIME

Also the exact numerical values are being extracted from the INVENTOR software in the form of tables. The velocity vs time, acceleration vs time and position vs time in tabular format are being presented below for better understanding.

Tables:

1. Position vs Time

Time(s)	P(mm)	P[x] mm	P[y] mm	P[Z] mm
0	316.823	311.267	58.3835	9
0.1	291.44812	291.249	-5.91637	9
0.2	291.658	291.092	-15.7671	9
0.3	325.357	312.046	91.67	9
0.4	298.684	298.364	10.4833	9
0.5	286.027	284.857	-24.2254	9
0.6	321.123	312.521	73.2772	9
0.7	307.51178	305.763	31.4833	9
0.8	286.703	285.96344	-18.501	9
0.9	304.401	303.877	15.4295	9
1	316.823	311.267	58.3835	9

2. Velocity vs Time

Time(s)	V(mm/sec)	V[X]	V[Y]
0	917.45	-109.74437	-910.863
0.1	477.288	-193.486	-436.31076
0.2	633.188	308.964	552.692
0.3	986.699	68.7505	-984.30072
0.4	598.671	-226.644	-554.111
0.5	64.61	64.5999	-1.1394
0.6	1973.65	22.4437	1973.52
0.7	741.009	-206.183	-711.746
0.8	323.836	-112.349	-303.722
0.9	1410.56	404.767	1351.24
1	0	0	0

3. Acceleration vs Time

Time(s)	A(mm/sec^2)	A[X]	A[Y]
0	7948.53	-4249.97	6716.91
0.1	3475.14	1577.35	3096.54
0.2	21658.9	6694.5	20598.4
0.3	18880	-4035.54	-18443.6
0.4	4183.05	329.487	4170.05
0.5	14442.4	6892.32	12691.7
0.6	18766.7	-17744.5	-6109.16
0.7	5511.27	-1665.51	5253.59
0.8	6850.88	3631.89	5808.96
0.9	26248.4	-2950.63	26082
1	0	0	0

7. CONCLUSIONS

The new ornithopter mechanism is designed and optimized. The simulation is done using SAM software. The 3D model of the project is designed by using Autodesk Inventor. The analysis of mechanism for velocity, acceleration, position are done and the best mechanism has been chosen. The model is also tested for aerodynamics and degrees of freedom and best model is obtained after comparing with other models in Autodesk Inventor.

- The Mechanism of flapping for ornithopter is succefully simulated in SAM software
- The replica of actual bird flapping motion is obtained and tested for different wing lengths
- The path of the trace extreme point of the wing was generated and it is observed that mimic with actual path.
- 3D model of all parts of the ornithopter model is created and assembled.
- Kinematic analysis of mechanism is performed 3D CAD Model and similar results were obtained compared to 2D mechanism of the SAM

Future scope:

- Ornithopter can be fabricated using 3D printing and that can be tested in real time.
- Seed dropping Mechanism can be designed.
- FEA analysis can be performed to identify the week joints.
- CFD analysis can be performed on the 3D model.

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