Lebanese American University

MEE341 – Kinematics and Dynamics of Linkages

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Project Report: Helicopter Mechanism

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Table of Contents

Table of Figures:

Introduction:

Theory and Background:

A helicopter is a type of aircraft that can fly upwards and downwards, forward and backwards, as well as left and right. A helicopter uses the airfoil principle (i.e. the blades of the main rotor have an airfoil shape) in order to generate lift when the blades rotate relative to air. Controlling the movement of a helicopter is also determined by the airfoil principle. The latter states that the lift force increases when the angle of attack of the main rotor's blades increases. If the angle of attack of each blade were to vary, when the main rotor is rotating, a non-uniform lift force distribution will occur, further creating a torque in the desired direction. As stated previously, the main rotor's blades require rotation, and this is typically achieved through a gas turbine engine. However, this phenomenon has a tendency to spin the helicopter body around itself. This can be avoided through adding a rotor at the tail of the helicopter. The tail rotor will create a thrust force in the sideways direction, which in return counteracts the engine's tendency to spin the body.

Objective of the Project:

The aim of this project is to design a prototype capable of illustrating the mechanism behind driving a helicopter. The project focuses on the main rotor mechanism, as well as that of the tail rotor. Each prototype is designed and animated on *SOLIDWORKS*, in addition to *MATLAB* using simpler 2D animations included in the main design. Finally, the report also includes calculations of design parameters.

SOLIDWORKS Prototype:

Main Rotor Mechanism:

Description:

The main rotor provides lift force allowing the helicopter to fly. In addition to that, the main rotor controls the direction in which the helicopter flies. These controls are communicated to the helicopter through the swash plate assembly. The latter allows the change in the angle of pitch of the helicopter blades, further driving the aircraft in the desired direction.

For the blades to rotate:

- A gear configuration is assembled in a way to allow rotation at the desired speed (a gear parameter analysis is later discussed in this report).
- The gear configuration is then mounted on the main shaft of the rotor, connected to the blade configuration of the helicopter.

For the blades to change angle of pitch:

- A swash plate mechanism is configured in a way to move along a ball-shaped part. This way, when the plate rotates, it will create smooth rotation at an angle. This allows the blades to change pitch angle.
- The swash plate rotation is dictated by the commands of the pilot.

Swash plate mechanism:

- The plate consists of two parts: the upper and lower swash plates.
- The upper plate, which connects to the main rotor shaft, has four equidistant connections/linkages.
- As the gear configuration turns the main rotor shaft, the upper swash plate also turns.

- Each two connections (the ones facing each other) of the plate are interconnected to a series of binary links.
- One pair of the four connections control the pitch angle of the smaller blades, and the other pair controls the pitch angle of the larger blades.
- The lower swash plate is fixed and doesn't rotate, but is connected to the upper plate through ball bearings. This allows the upper plate to spin freely on top of the lower.
- A series of control rods are connected to the lower swash plate. These rods connect to pitch levers, controlled by the pilot.
- As the upper swash plate rotates, the lower swash plate makes the rotation occur at an angle different than 0˚, further pushing and pulling at the links connected to the blades, which allows a change in the pitch angle of the blades.

The above mechanisms can be understood better through the provided videos:

- "Main Rotor 1.mp4" + "Main Rotor 3.mp4": varying the pitch angle of the larger blades.
- "Main Rotor 2.mp4": varying the pitch angle of the smaller blades.

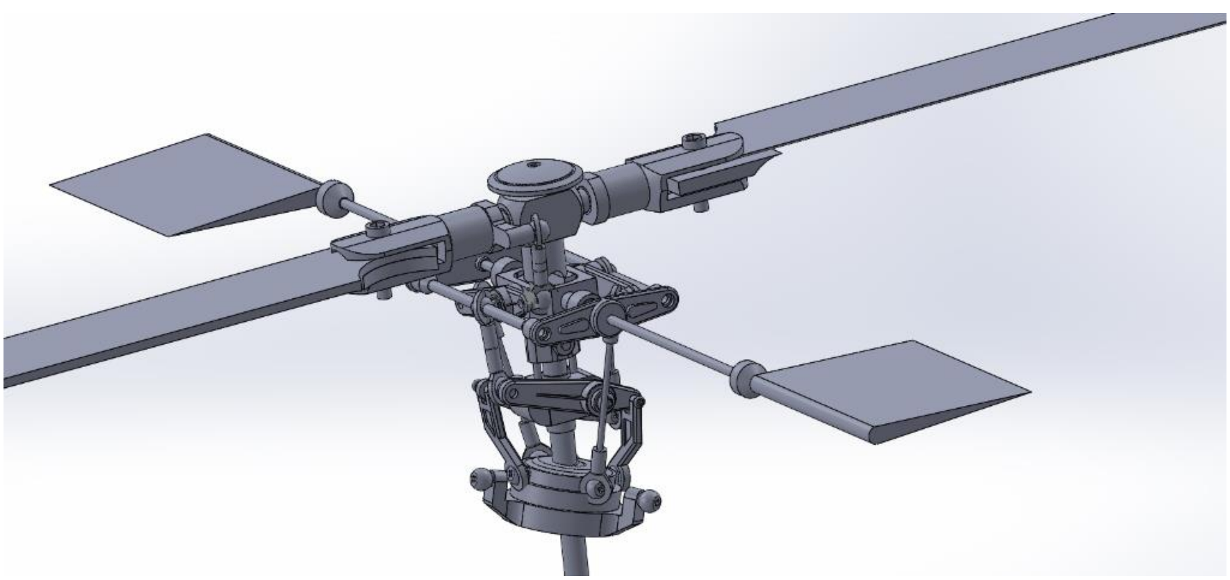

Figure 1: Main Rotor Mechanism (Perspective 1).

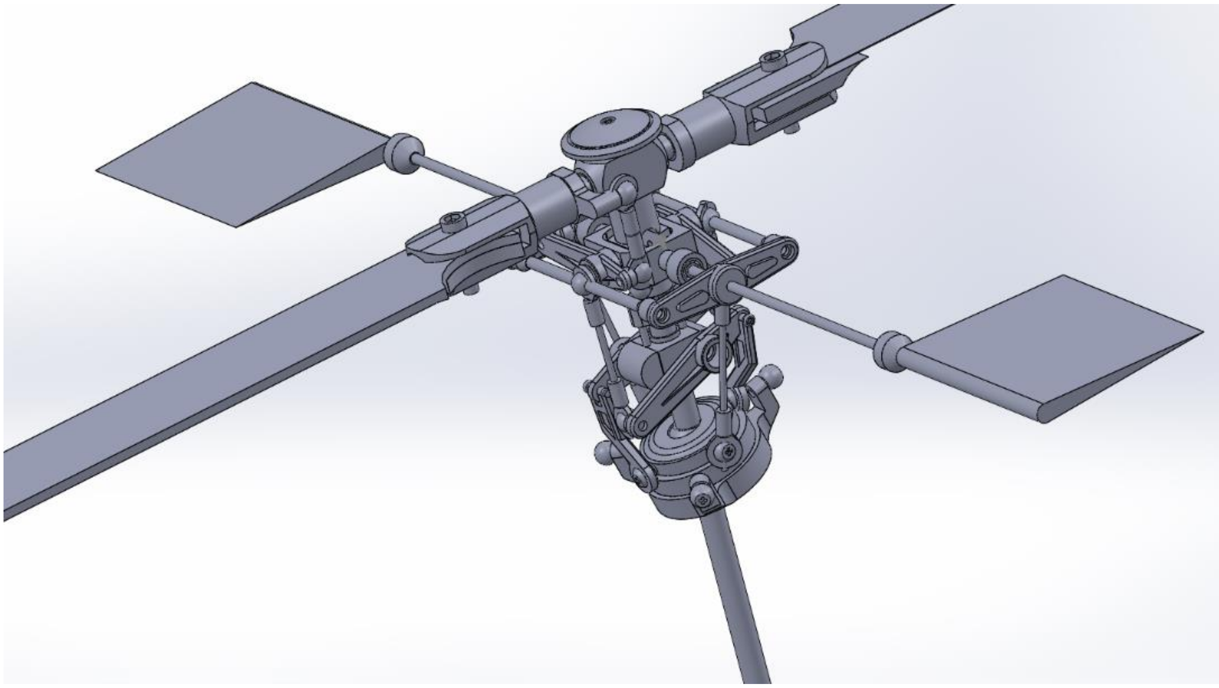

Figure 2: Main Rotor Mechanism (Perspective 2).

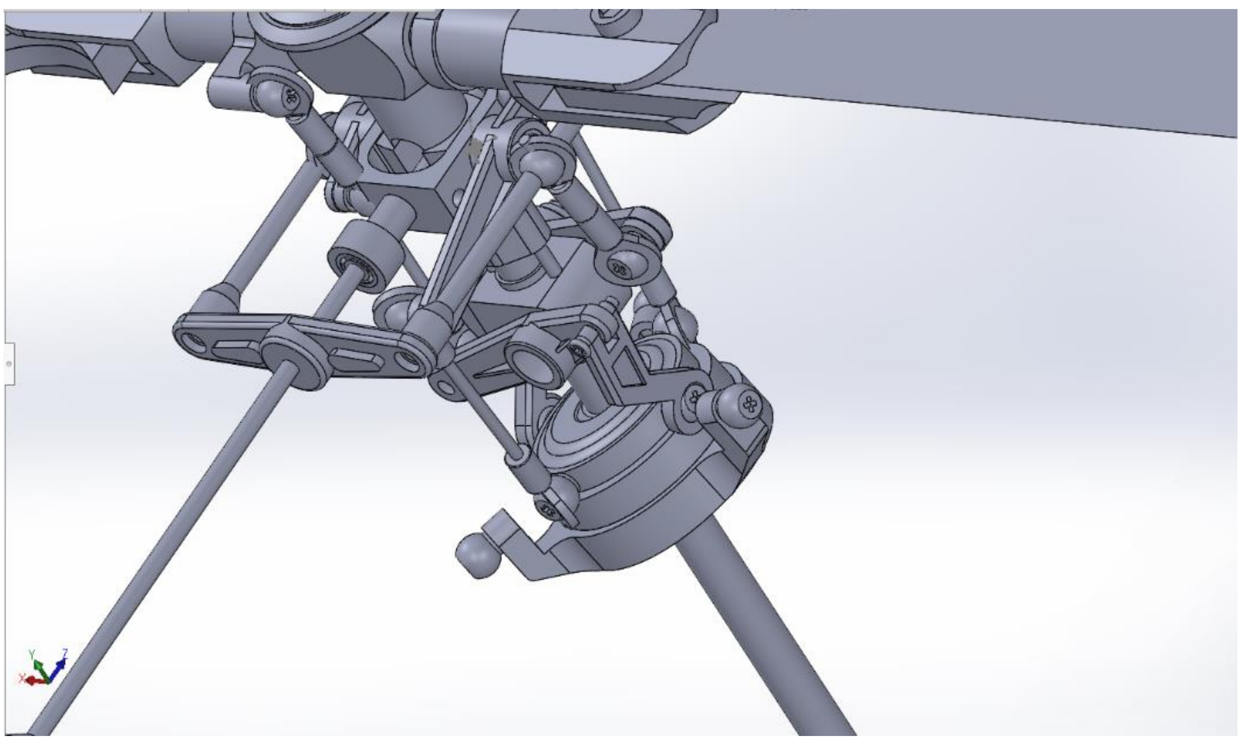

Figure 3: Main Rotor Mechanism (Perspective 3).

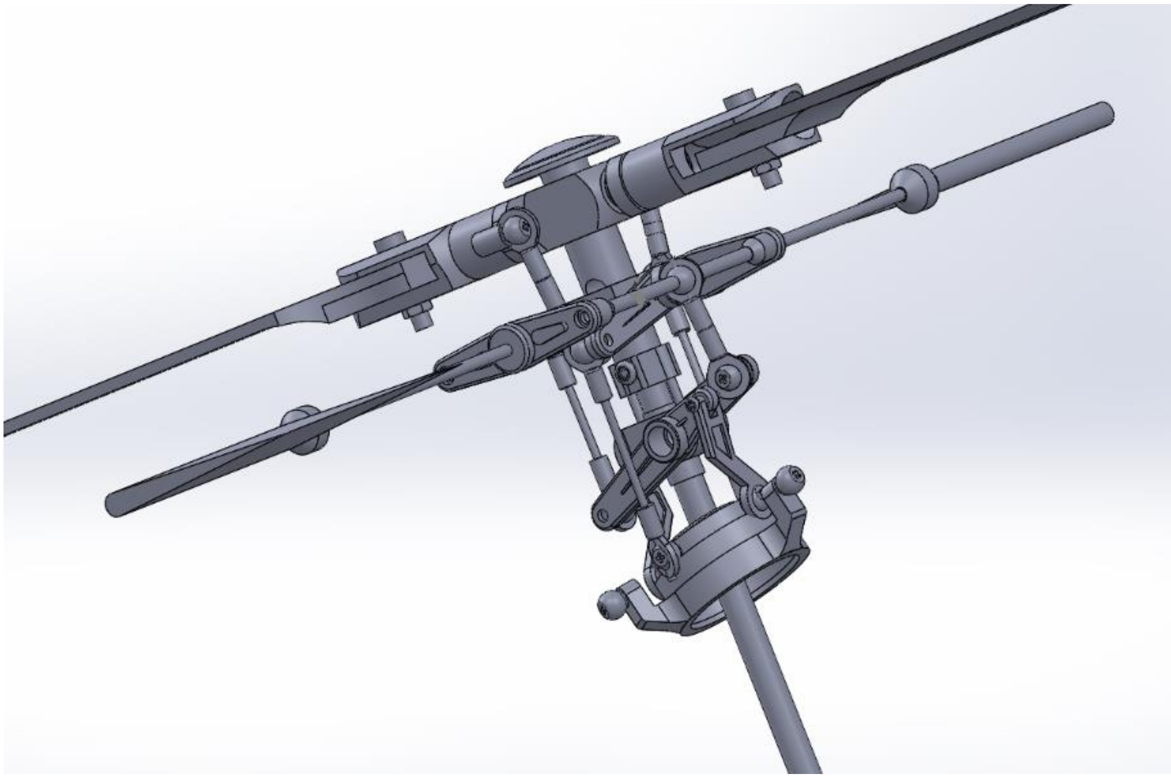

Figure 4: Main Rotor Mechanism (Perspective 4).

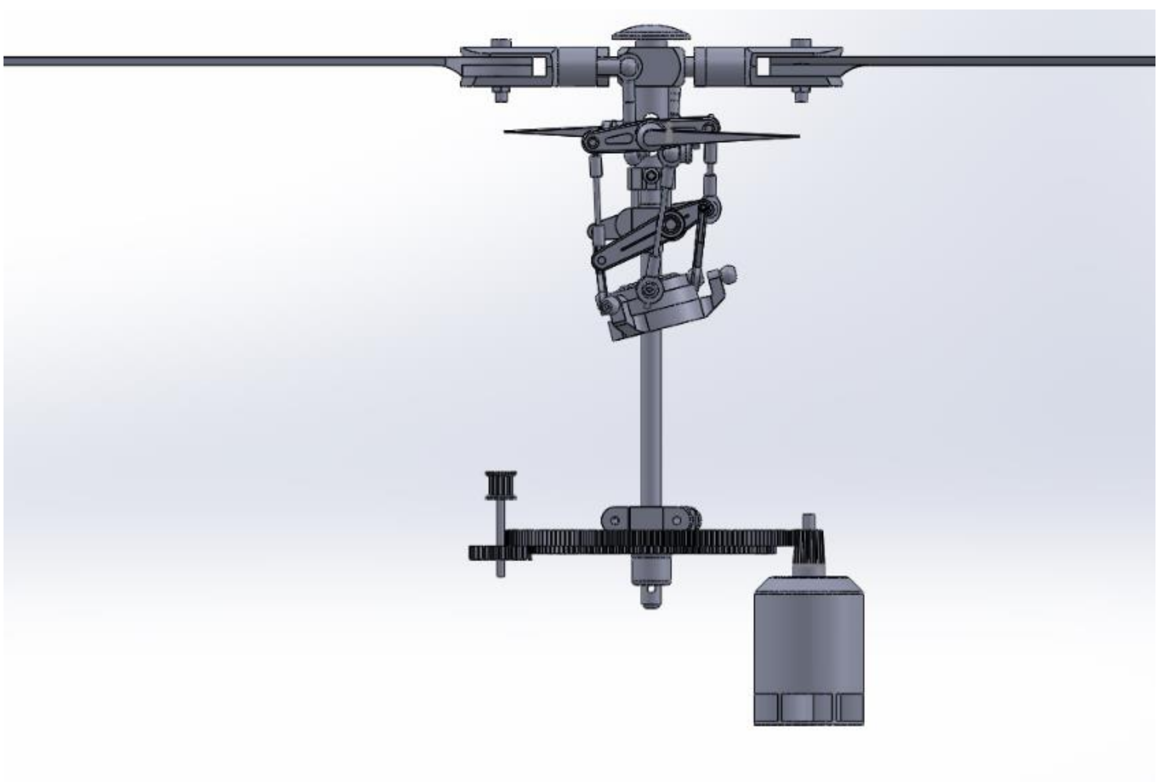

Figure 5: Main Rotor Mechanism and Gear Configuration (Perspective 1).

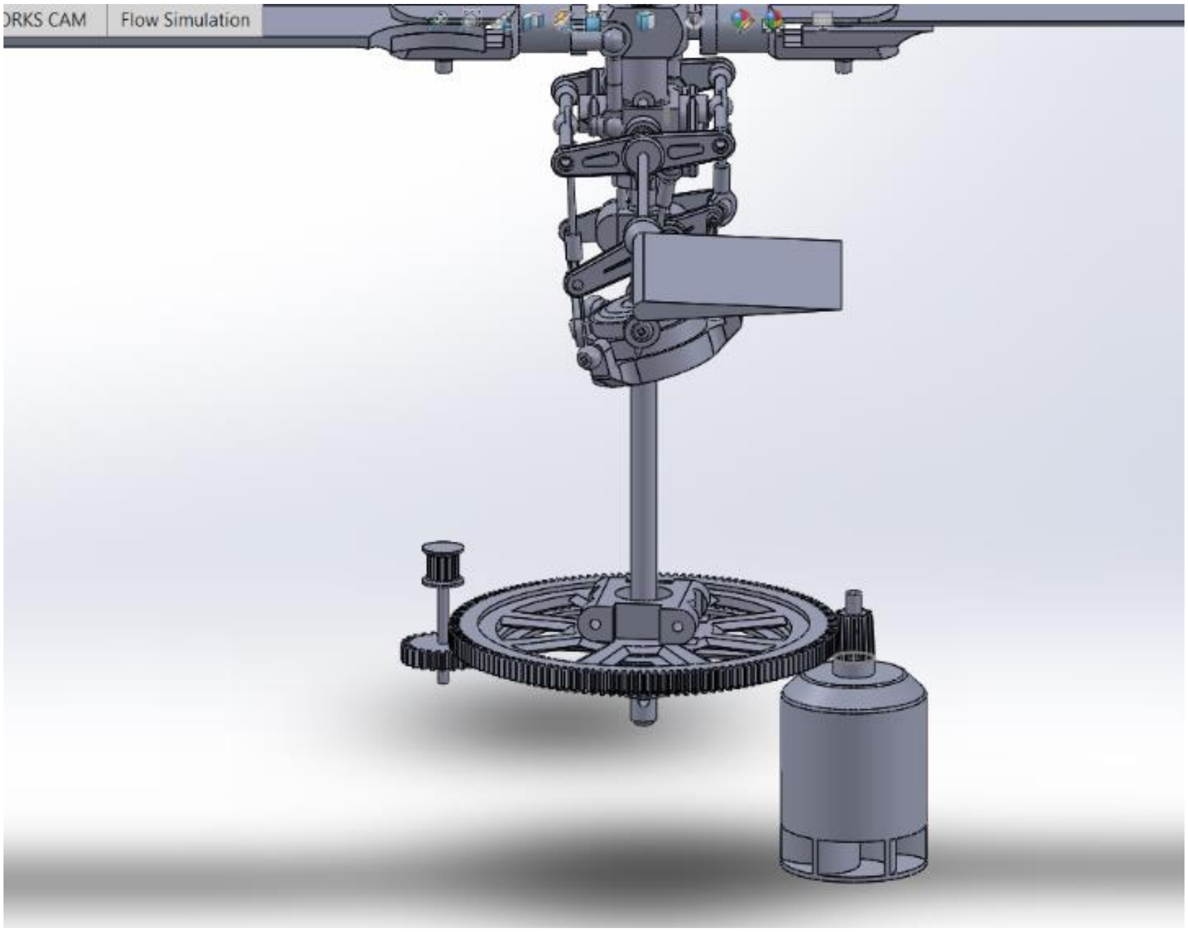

Figure 6: Main Rotor Mechanism and Gear Configuration (Perspective 2).

Tail Rotor Mechanism:

Description:

The main purpose of a tail rotor in a helicopter is to oppose the torque created by the main rotor. This is done by the rotating the blades. Another feature of the tail rotor is to steer the helicopter in a desired direction, by varying the angle of pitch of the blades. These two particular features are illustrated in the prototype below.

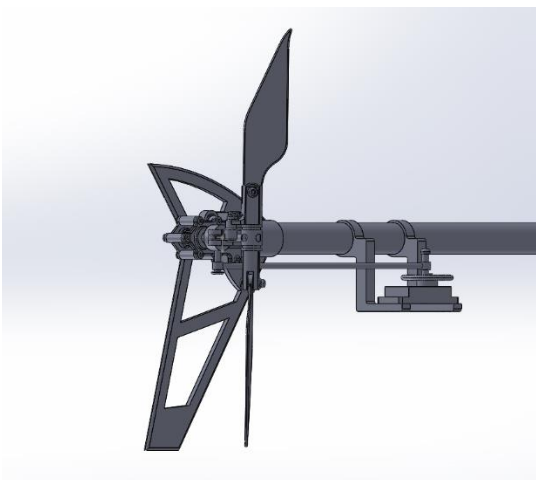

Figure 7: General Overview of the Tail Rotor (Perspective 1).

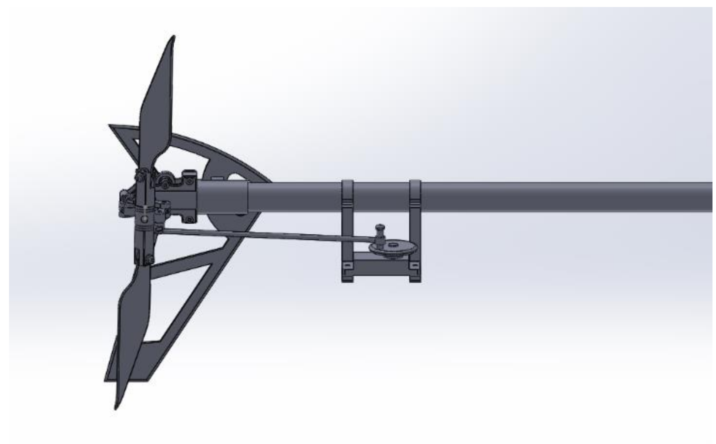

Figure 8: General Overview of the Tail Rotor (Perspective 2).

For the blades to rotate:

- The two rotor blades are mounted on a tail shaft, which rotates (through a motor added to the SOLIDWORKS Motion Analysis).

For the blade pitch angle to change:

- A slider-crank mechanism is used where: a circular disk (made to oscillate clockwise and anti-clockwise at a 3˚angle) is connected to a binary link (1), which in return, is connected to a slider.
- The slider is connected to another binary link, interconnected to other binary links and further connected to the blades (Slider and Rotor Blade Mechanism).

In this mechanism, rotation is changed into linear translation. This translation allows the blades to change their angle of pitch (through the forward and backward motion). This concept is better visualized in the video "*Tail Rotor 2.mp4*", which is found in the given project files.

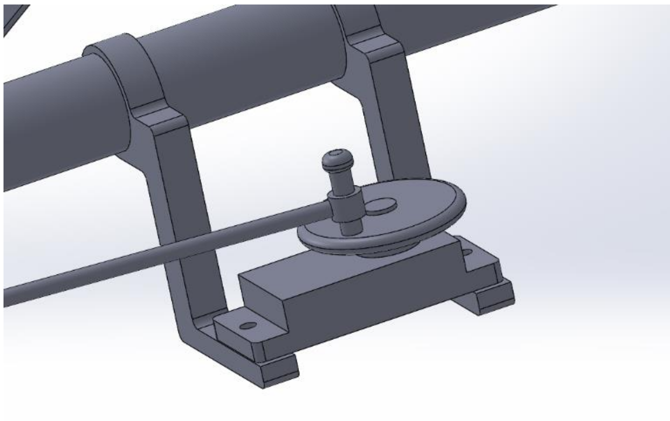

Figure 9: Circular Disk and Binary Link 1.

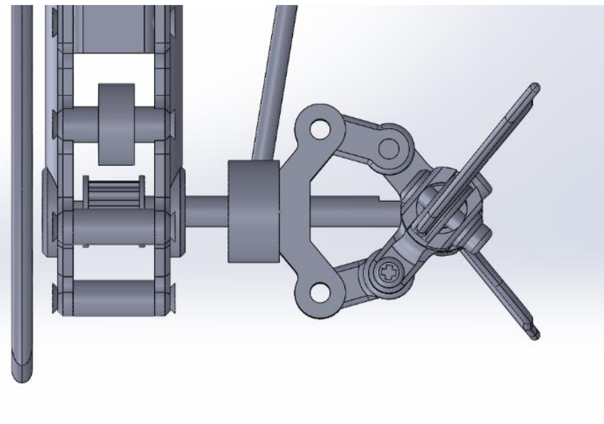

Figure 10: Slider and Rotor Blade Mechanism (Perspective 1).

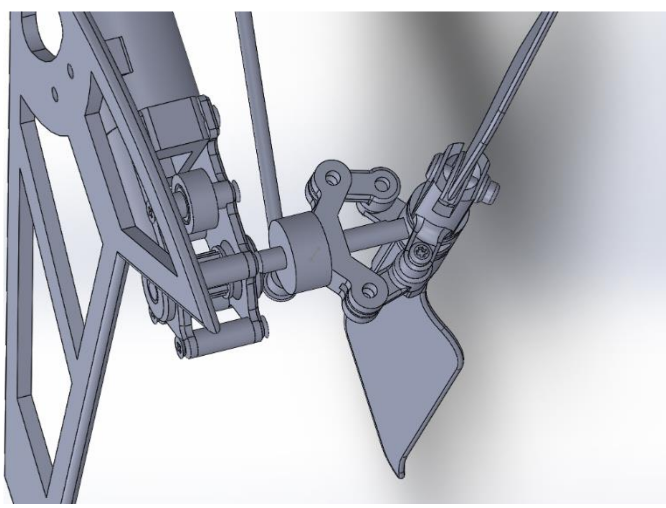

Figure 11: Slider and Rotor Blade Mechanism (Perspective 2).

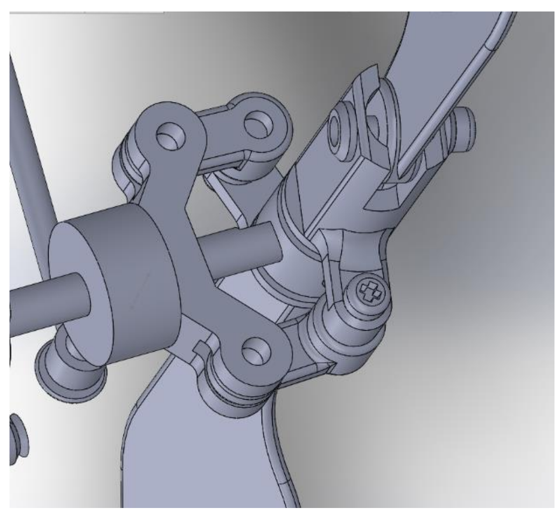

Figure 12: Slider and Rotor Blade Mechanism (Perspective 3).

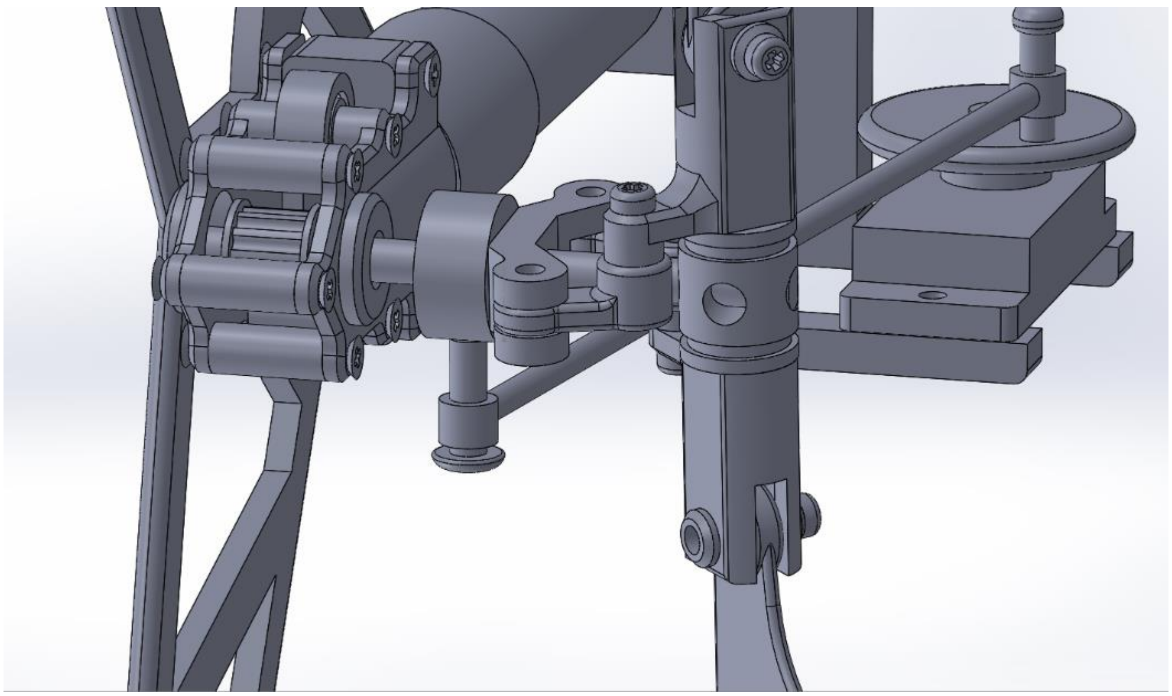

Figure 13: Slider and Rotor Blade Mechanism (Perspective 4).

MATLAB Animations:

Tail Rotor Mechanism:

Description:

The following 2D animation is coded on MATLAB (check “TailMechanism.m”) to simplify how the angle of pitch of the rotor blade can change. The blue rectangle symbolizes the slider, to which we connect four binary links (two on each side), to represent the links responsible for pushing and pulling on the tail blades in order to achieve a change in the angle of pitch. The trajectory of the circular disk as well as the slider is shown below as well (change in rotation to linear translation i.e. slider-crank mechanism).

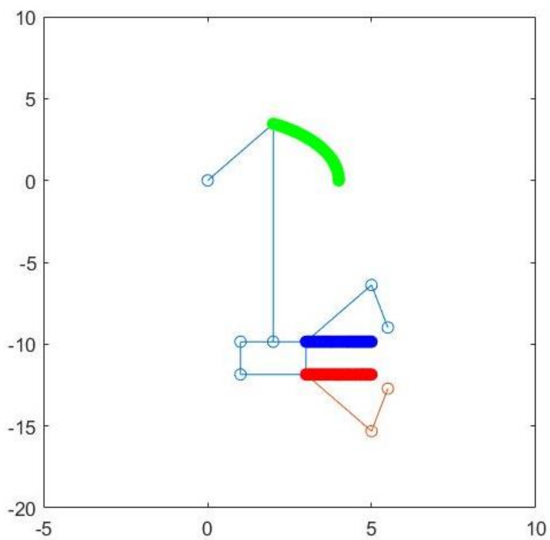

Figure 14: 2D Animation of Slider and Rotor Blade Mechanism.

Calculations:

Main Rotor Mechanism:

A detailed analysis was done on the gears used drive the main rotor. The gears are used in the following configuration:

- A pinion gear mounted on the shaft of a motor (n = 100 rev/min: provided by SOLIDWORKS Motion Analysis).
- The pinion gear drives the upper tail gear.
- The lower tail gear is attached to the same shaft as the upper tail driven gear.
- The lower tail gear drives the tail gear.

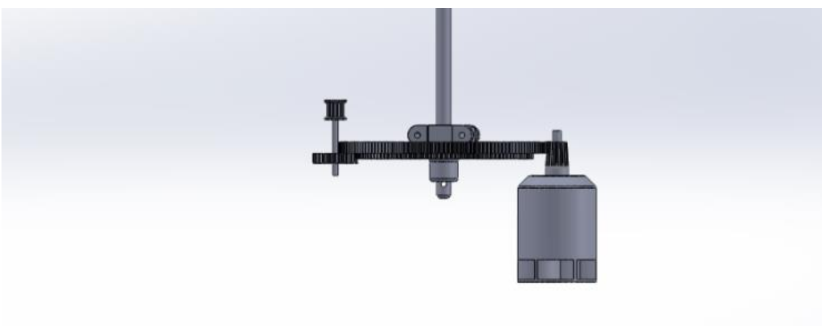

Figure 15: Main Rotor Gear Configuration.

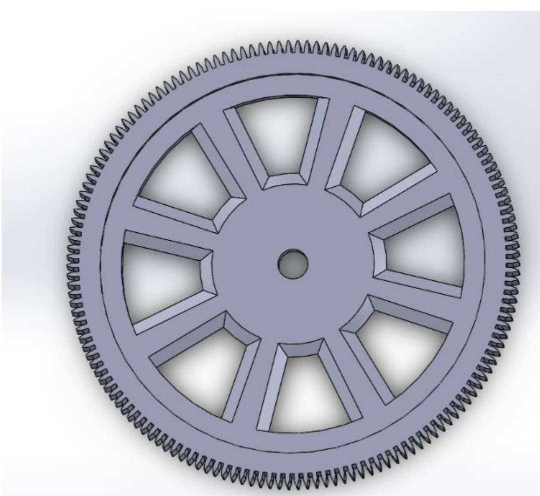

Figure 16: Upper Tail Driven Gear.

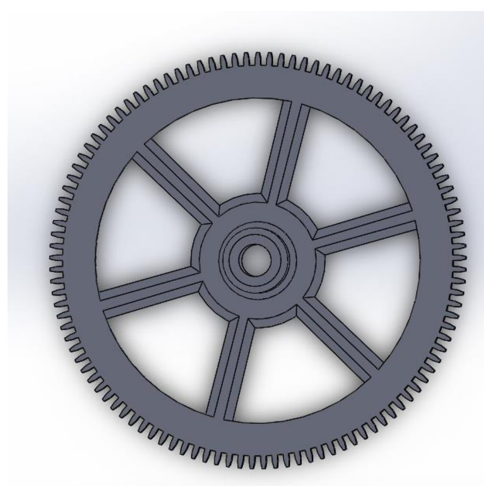

Figure 17: Lower Tail Gear.

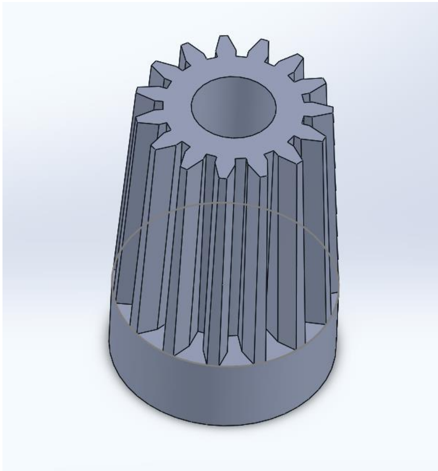

Figure 18: Pinion Gear.

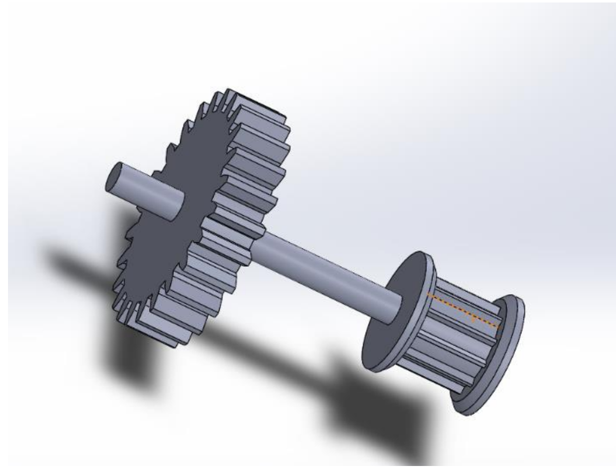

Figure 19: Tail Gear.

	Pinion(driver)	Upper tail driven gear	Lower tail driven gear	Tail gear driven by the lower tail gear
Type of gear	Spur gear	Spur gear	Spur gear	Spur gear
Number of teeth N	15	150	109	24
Pitch diameter d	7.2	72	61	13.431
diametral pitch P d=N/d	15/7.2= 2.08333	150/72= 2.08333	109/61= 1.786	24/13.431= 1.786
Addendum a=1/ p d	7.2/15= 0.48	72/150= 0.48	61/109= 0.5596	13.34/24= 0.5596
Dedendum b=1.25/p d	1.25*7.2/15= 0.6	1.25*72/150= 0.6	1.25*61/109= 0.7	1.25*13.431/24= 0.7
Face width F=12/p d	12*7.2/15= 5.76	12*72/150= 5.76	12*61/109= 6.7155	12*13.431/24= 6.7155
Whole depth a+b	0.48+0.6= 1.08	0.48+0.6= 1.08	0.5596+0.7= 1.2596	0.5596+0.7= 1.2596
Circular pitch P=pi*p d	Pi*2.08333= 6.545	Pi*2.08333= 6.545	Pi*1.786= 5.6108	Pi*1.786= 5.6108
Module m=d/N=a	0.48	0.48	0.5596	0.5596

Length of contact path Z=sqrt((r1+a)^2 – (r1*cos(theta))^2) + sqrt((r2+a)^2 – (r2*cos(theta))^2) -r2*sin(theta) -r1*sin(theta)	Z=sqrt((3.6+0.48)^2 - (3.6*cos(20))^2)+ sqrt((36+0.48)^2 - (36*cos(20))^2) -3.6*sin(20) -36*sin(20)= 2.3895	Z=sqrt((3.6+0.48)^2 - (3.6*cos(20))^2)+ sqrt((36+0.48)^2 - (36*cos(20))^2) -3.6*sin(20) -36*sin(20)= 2.3895	Z=sqrt((30.5+0.5596)^2 -(30.5*cos(20))^2) + sqrt((6.7155+0.5596)^2 - (6.7155*cos(20))^2) -30.5*sin(20) -6.7155*sin(20)= 2.861	Z=sqrt((30.5+0.5596)^2 -(30.5*cos(20))^2) + sqrt((6.7155+0.5596)^2 - (6.7155*cos(20))^2) -30.5*sin(20) -6.7155*sin(20)= 2.861
Base pitch Pb=pi*cos(theta)/ p d	Pi*cos(20)/2.08333= 1.41702	Pi*cos(20)/2.08333= 1.41702	Pi*cos(20)/1.786= 1.653	Pi*cos(20)/1.786= 1.653
Contact ratio Mp=Z/pb	2.3895/1.41702 = 1.686 About 2 teeth in contact		2.861/1.653= 1.73 about 2 teeth in contact	
Base circle db=d*cos(theta)	7.2*cos(20)= 6.765	72*cos(20)= 67.65	61*cos(20)= 57.32	13.431*cos(20)= 12.62
Center distance C=(d1+d2)/2	(7.2+72)/2= 39.6	(7.2+72)/2= 39.6	(61+13.431)/2= 37.21	(61+13.431)/2= 37.21
Input n	100 rev/min			
Angular velocity w(rad/sec)	W1= 2*pi*n =2*pi*100/60 =10.472	W2= w1*d1/d2 =10.472*7.2/72 =1.0472	W3=w2 =1.0472 same shaft	W4 =w3*d3/d4 =1.0472*61/13.431 =4.7561
Velocity of gears V=r*w	V1= 3.6*10.472 =37.7	V2=V1=37.7	V3=30.5*1.0472 =31.94	V4=V3=31.94

The pinion (driver) rotates at n =100 rev/min =1.666 rev/sec.

Pressure angle theta (hand calculation) about 20 degrees.

Values are in mm, velocity in mm/sec.

Tail Rotor Mechanism:

The calculations below (for a slider-crank mechanism) are dependent on the MATLAB code done for the tail rotor mechanism in the previous section:

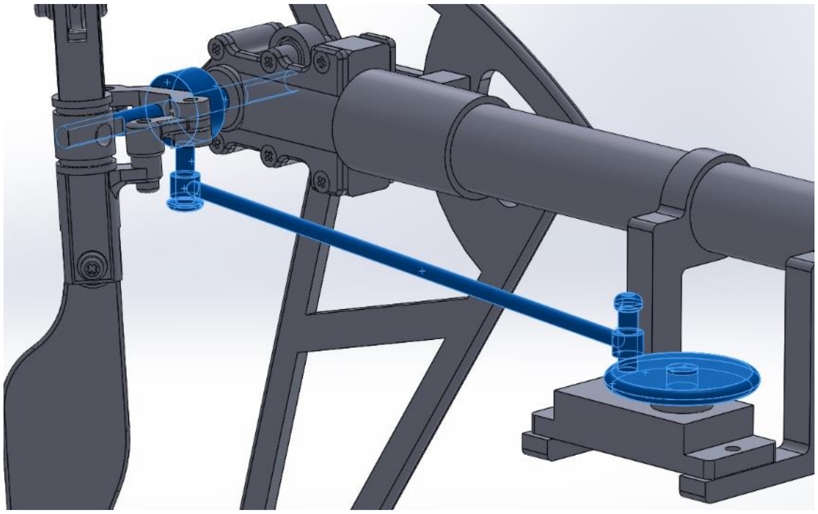

Figure 20: Tail Rotor Slider-Crank Mechanism (in blue).

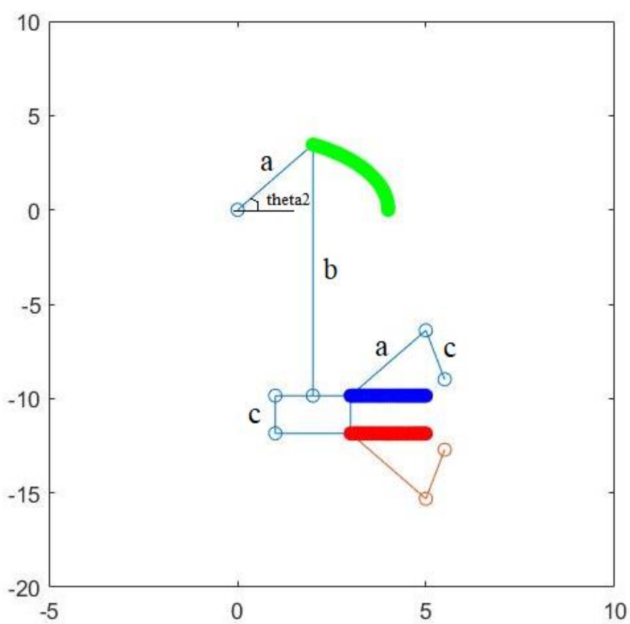

Figure 21: Tail Rotor Slider-Crank Mechanism.

a=4 cm , b=9.85 cm , c=2 cm, theta2=60˚:

Finding theta3 and d (length of link 1)

<u>1st configuration:</u>

Theat31 = asin((a*sin(theta2)-c)/b)

= asin((4*sin(60)-2)/9.85)= 8.55

d=a*cos(theta2) – b*cos(theta31)

d=4*cos(60) – 9.85*cos(8.55)= 7.74

<u>2nd configuration:</u>

Theat32 = asin((-a*sin(theta2)/b) + pi

=asin((-4*sin(60)/9.85)= 20.66˚

d=a*cos(theta2) – b*cos(theta32)

d=4*cos(60) – 9.85*cos(20.66) = 7.216 cm.

Conclusion:

In conclusion, the main and tail rotor mechanism form the basic system for driving a helicopter. Through assembling each mechanism separately and putting each in motion, the complexity of how a helicopter works is further simplified. The use of gear and link combinations for this specific prototype, and the concept of a slider-crank mechanism allowed the whole system to work properly.