INDIAN INSTITUTE OF TECHNOLOGY GANDHINAGAR

ME 206

STATICS & DYNAMICS

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Experiment-4

Group Number: 3

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MSC Adams Setup

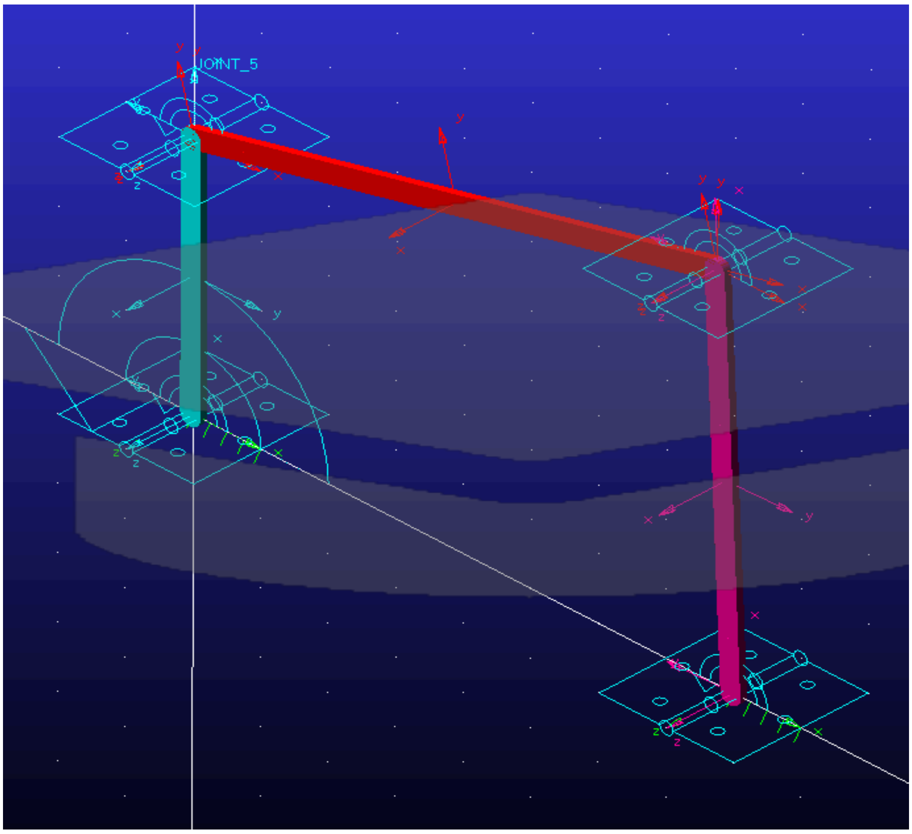


Fig 1 : MSC Adams Setup (Isometric View)

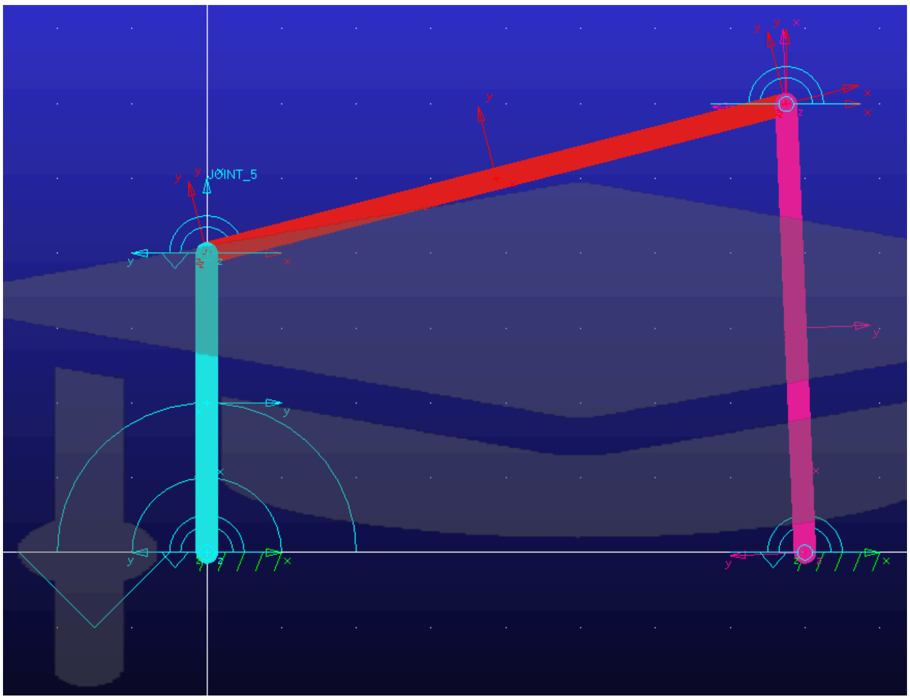


Fig 2 MSC Adams Setup (Front View)

Abstract:

This report details the experiment's outcomes, wherein we designed and analyzed a planar four-bar linkage mechanism. The experiment focused on a uniquely configured system where one crank could complete a full 360-degree rotation at a constant angular velocity while the opposite link, the rocker, executed only partial rotations. Central to our study was the coupler link, connecting the crank and the rocker, where we meticulously measured the velocity of its center of mass and its angular velocity. To understand the system's kinematic behavior, these parameters were evaluated under various crank angles, precisely at 90 degrees, 150 degrees, 210 degrees, and others. Our approach encompassed analytical calculations, hands-on experimental observations, and ADAMS software simulations, offering a holistic view of the mechanism's dynamics. The integration of theoretical analysis, practical experimentation, and digital simulation solidified our understanding of the fundamental principles of mechanics. It provided valuable insights into the practical challenges and complexities inherent in mechanical system design and analysis.

Objective:

To design a planar four-bar mechanism with one link (crank) that can rotate (at a constant angular velocity) entirely and the opposite link (rocker) rotates partially, and also find the velocity (analytically, experimentally and in ADAMS) of the center of mass of the coupler link (that connects crank and the rocker) and the angular velocity of the coupler for at least six different angles $(0, \pi/3, 2\pi/3, ...)$ of the crank.

Educational Alignment and Practical Engagement:

1. Alignment with Learning Objectives-

Objective Correlation: This experiment directly aligns with the experiment objectives, particularly in understanding and applying dynamics principles to mechanical systems. The construction and analysis of a four-bar linkage offer practical insight into the fundamental concepts of kinematic motion.

Skills Development: The experiment fosters analytical thinking skills, measurement precision, and practical application of theoretical concepts. It also enhances our understanding of mechanical advantage and efficiency in simple machines, which is crucial for future mechanical engineering endeavors. In addition, introducing a simulation tool (MSC Adams) develops computational skills critical for modern engineering practices.

2. Bridging Theoretical and Practical-

Theoretical Foundations:

Practical Implementation:

3. Preparation for Complexities-

Anticipating Real-World Challenges: The experiment simulates real-world engineering challenges, such as material imperfections and mechanical constraints. It prepares us to anticipate and solve practical problems, an essential skill in engineering.

Adaptability and Problem-Solving: We learned to adapt our theoretical knowledge to practical situations, developing problem-solving skills through the experiment. For instance, ensuring the smooth operation of the revolute joints and aligning the linkage accurately were significant challenges that required innovative solutions.

Application of Fundamental Principles:

1- Kinematic Analysis: The experiment allowed us to apply kinematic principles to analyze the movement of the crank, coupler, and rocker. By giving constant the angular velocity to the crank and observing the resulting motion of the coupler (velocity and angular velocity about COM) and rocker, we could practically apply and validate theoretical models and equations.

2- Integration of Technology: Utilizing the Arduino Uno R3 to control the crank's motion exemplifies the integration of modern technology in applying fundamental principles. This approach made the experiment more engaging and demonstrated how technology can aid in better understanding and implementing mechanical concepts.

3- Linkage Design Principles: The experiment also involved applying mechanical design principles, especially in selecting and using materials like MDF board and chopsticks for constructing the linkage. The design process highlighted the importance of choosing appropriate materials and designing joints that can withstand operational stresses while maintaining the accuracy and efficiency of the mechanism.

Fabrication Details:

Materials Used: Chopstick and MDF Board.

- Usage: Utilized for creating revolute joints in the linkage. The chopstick serves as the pivot, and the MDF board is the structural material for the crank, coupler, and rocker.
- Joint Construction: Revolute joints were made to connect the crank to the coupler and the coupler to the rocker. Precision in creating these joints is essential for the accurate movement of the linkage.

Integration of Technologies:

1- Arduino Uno R3 in Mechanism Control:

The Arduino Uno R3 was crucial for imparting consistent motion to the crank, programmed to rotate it at a constant angular velocity. This precise control allowed for accurate data collection, which is critical for comparing experimental results with theoretical predictions. The Arduino's integration exemplifies the practical application of electronic control in mechanical systems, enhancing the experiment's relevance to modern engineering practices.

2- Utilization of Laser Cutting Machine:

The laser cutting machine was used to fabricate the linkage components from MDF board. Its high accuracy ensured uniformity in the parts, which was essential for the experiment's success.

3- MATLAB for Image Processing:

MATLAB was utilized for image processing tasks, crucial for analyzing the motion of the linkage. By processing the visual data captured during the experiment, we could extract detailed kinematic information like displacement, velocity, and angular velocity profiles of the linkage.

4- MSC ADAMS for Simulation:

The MSC ADAMS simulation software was instrumental in virtually modeling the four-bar linkage mechanism. It allowed us to simulate the kinematic and dynamic behavior of the system under various conditions, providing a comparative platform against our physical experiment.

What is a Four Bar Linkage ?

A four-bar linkage is a fundamental mechanical assembly used to convert motion. It consists of four rigid links which are connected in a loop by four rotating joints. Here's a breakdown:

Links: These are the rigid bars or rods. The four links include one fixed link (ground link), two moving links (input and output links), and one connecting link (coupler or floating link).

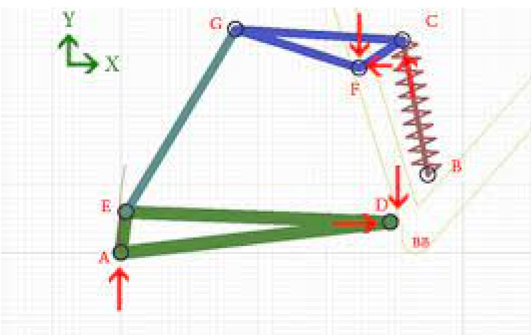
Joints: The links are connected by joints, usually pivot joints, allowing rotational motion.

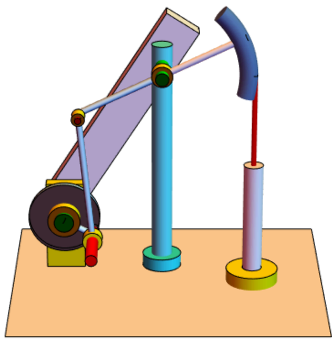
Where can we find Four Bar Linkages ?

1. **Bicycle Suspension Systems**: To provide shock absorption and maintain wheel alignment.
2. **Engine Connecting Rods**: Connecting the piston to the crankshaft in an internal combustion engine.
3. **Pumping Mechanisms**: In old-fashioned water pumps.
4. **Door Hinge Mechanisms**: Particularly in some car doors and machinery covers.

Bicycle Suspension System

Pumping Mechanism





What is the physics / mechanics behind four bar linkages ?

The mechanics of four-bar linkages are governed by principles of kinematics and dynamics of rigid bodies. Key points include:

Degrees of Freedom (DOF): For planar mechanisms, DOF is given by the formula:

$$DOF = 3\,(N-1) - 2J$$

Where N is the number of links and

J is the number of joints. For a standard four-bar linkage, DOF = 1, meaning it has a single, independent motion.

Angular Velocity and Acceleration: The angular velocities and accelerations of the links are related through the geometry of the linkage. For example, if w_1 and w_2 are the angular velocities of two links, then their relationship can be expressed as:

$w_2 = w_1\ (l_2/l_1)$

Where l_1 and l_2 are the lengths of the respective links.

Transmission Angle: This is the angle between the coupler and the output link, which affects the efficiency of force transfer. The transmission angle is a critical factor in determining the mechanical advantage and efficiency of the linkage.

Four bar linkage working principle

A four-bar linkage works primarily on the principles of angular motion. When the input link (often called the driver or crank) is rotated, this motion is transmitted through the coupler link to the output link (follower or rocker). The angular velocity of each moving link is interconnected, and the relationship can be described by the lengths of these links and their respective angular velocities. The input link's rotation causes the coupler to pivot about its joints, leading to a corresponding movement in the output link. The specific path and range of motion of the output link depend on the lengths of the links and their arrangement. This simple yet effective mechanism allows for a wide range of motions, from full circular rotations to back-and-forth oscillations, making the four-bar linkage a versatile component in mechanical systems.

Four Bar Linkage Parts

1. **Ground Link or Frame** : This is the fixed link of the mechanism.

2. **Input Link (Driver or Crank)**: This is where the input force or motion is applied.

3. **Output Link (Follower or Rocker)**: This link provides the desired output motion.

4. **Coupler (Floating Link):** Connects the input and output links.

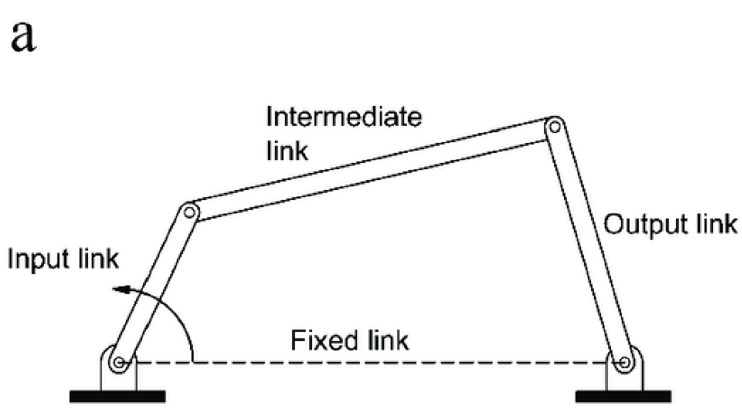


Fig 7 : Parts of 4 Bar Linkage

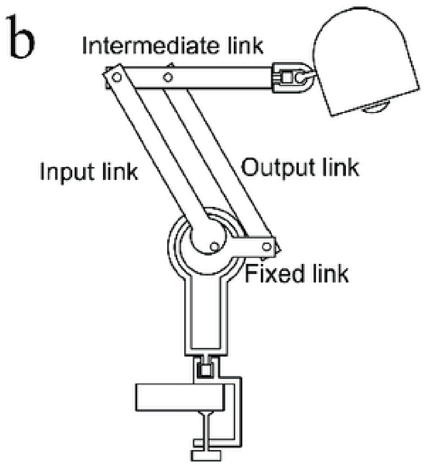


Fig 8 : 4 Bar linkage use in a desk lamp

Procedure:

1- Assembling the Linkage:

Revolute Joints: We constructed the Revolute joints using chopsticks and MDF board. These joints connected the crank to the coupler and the coupler to the rocker, ensuring smooth and accurate motion within the linkage.

Ground Fixation: The rocker's end was securely fixed to a stable platform, creating a precise pivot point. This setup was crucial for the consistent oscillatory movement of the rocker.

Integration of Arduino Uno R3: At one end of the crank, we integrated the Arduino Uno R3 to control its motion. The Arduino was programmed to rotate the crank at a constant angular velocity. This controlled movement was essential for generating repeatable and accurate experimental data.

2- Alignment and Measurements:

Horizontal Alignment: We meticulously checked and adjusted the alignment to ensure that the fixed end of the rocker and the rotating end of the crank were on the same horizontal level. Accurate alignment is key to the proper functioning of the linkage mechanism.

Distance Measurement: The distance between the fixed point of the rocker and the crank's rotating end was measured to be exactly 40 cm. This precise measurement was critical for the kinematic analysis of the linkage, and it works as the fourth bar, which is fixed.

3- Integration of MSC ADAMS Simulation:

Simulation Setup: We used MSC ADAMS to simulate the four-bar linkage mechanism before conducting the physical experiment. This step allowed us to predict the system's behavior under various conditions and prepare for potential challenges in the physical setup.

Modeling the Linkage: In MSC ADAMS, the dimensions and constraints of the linkage were inputted precisely, mirroring our physical model. This virtual representation helped us understand the expected motion patterns and identify any areas of concern.

4- Image Processing with MATLAB:

Capturing Motion Data: During the physical experiment, we recorded the movement of the linkage using a camera (60 fps). This visual data was crucial for analyzing the motion characteristics of the linkage.

Processing in MATLAB: The recorded video was imported into MATLAB for image processing. Here, we extracted vital motion parameters, such as the displacement and velocity of different linkage parts at various crank angles. This processing provided us with quantitative data to compare against our theoretical calculations and MSC ADAMS simulation results.

Observations and Results:

ADAMS Simulation

(Crank angle with horizontal)	(Coupler)	
Angles (degrees)	**V com (m/s)**	**W coupler (degrees/s)**
90 (initial stage)	0.6189	3.8267
150.5938	0.5528	32.6604
209.4054	0.3403	82.5422
269.9992	0.3927	75.1143
330.593	0.7597	94.6703
389.4046	0.3446	79.9

Analytical Derived

(Crank angle with horizontal)	(Coupler)	
Angles (degrees)	**V com (m/s)**	**W coupler (degrees/s)**
90 (initial stage)	0.618896756453751	3.8365899470288
150.5938	0.5527802796705288	32.655021065817
209.4054	0.34027854683547315	82.548549681726
269.9992	0.39266960561758435	75.124753446512
330.593	0.7104231819850962	69.229684782911
389.4046	0.3375707397381995	81.968416042373

Experimentally Calculated

(Crank angle with horizontal)	(Coupler)	
Angles (degrees)	**V com (m/s)**	**W coupler (degrees/s)**
90 (initial stage)	0.37	105
150.5938	0.39	26.76
209.4054	0.35	60.47
269.9992	0.33	74.48
330.593	0.7	129.61
389.4046	0.45	67.32

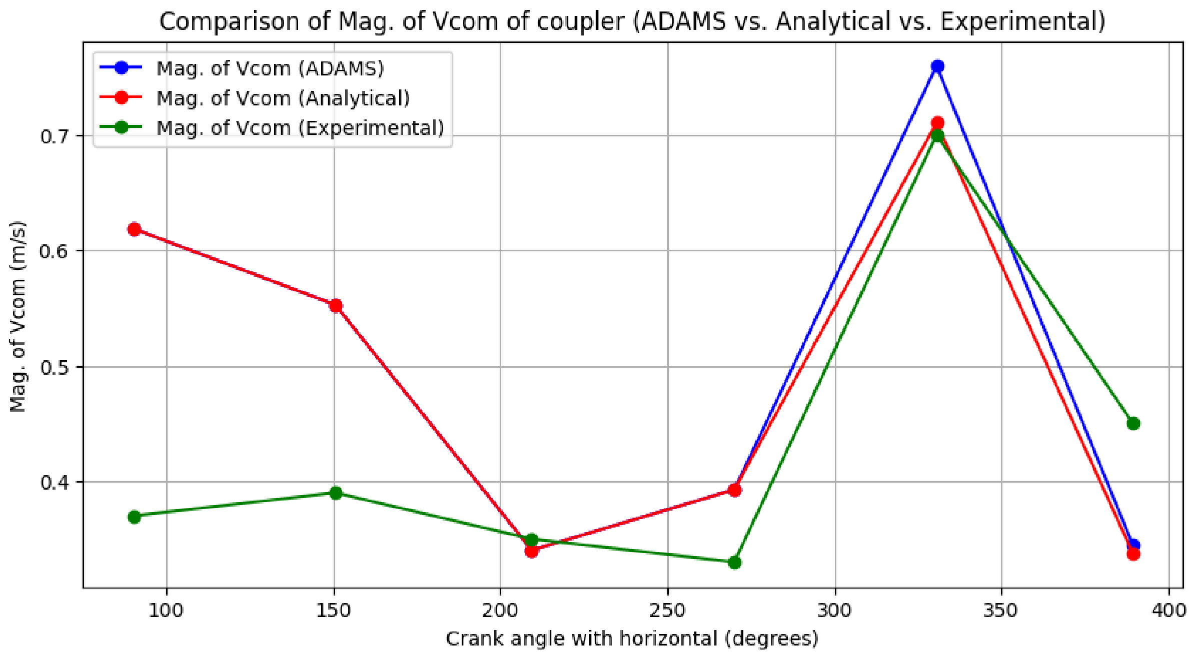


Fig 9 : Comparison of Magnitude of Vom of Coupler (ADAMS vs. Analytical vs. Experimental

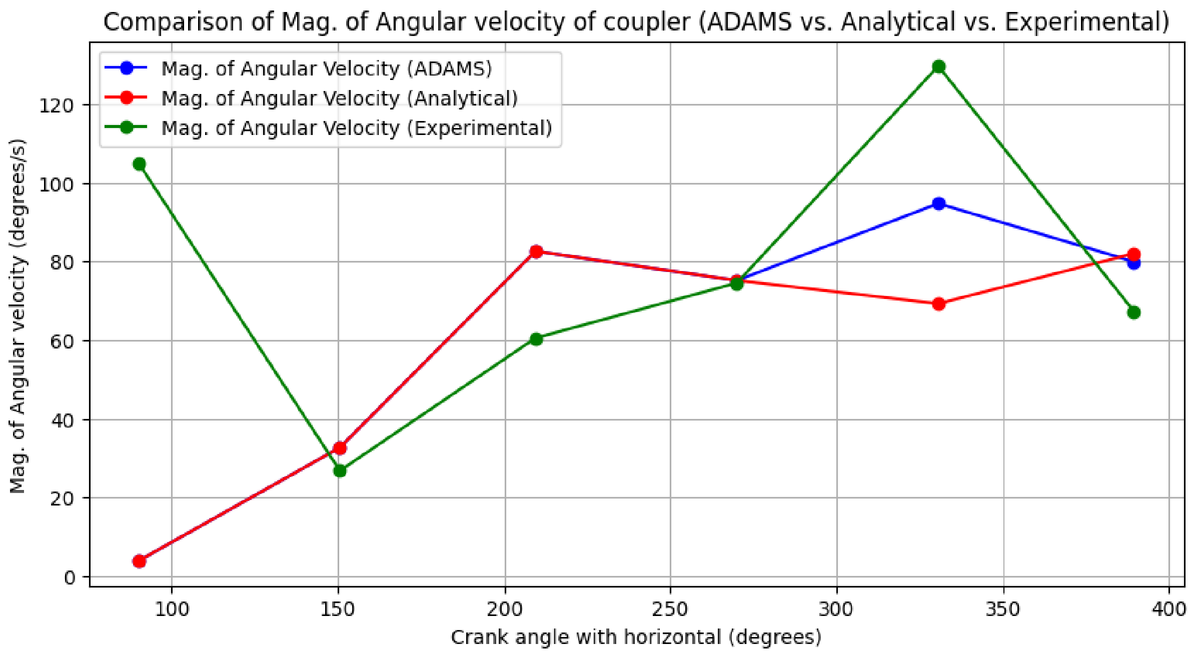


Fig 10 : Comparison of Magnitude of Angular Velocity of Coupler (ADAMS vs. Analytical vs. Experimental

ADAMS Simulation

Angular Velocity vs Angle

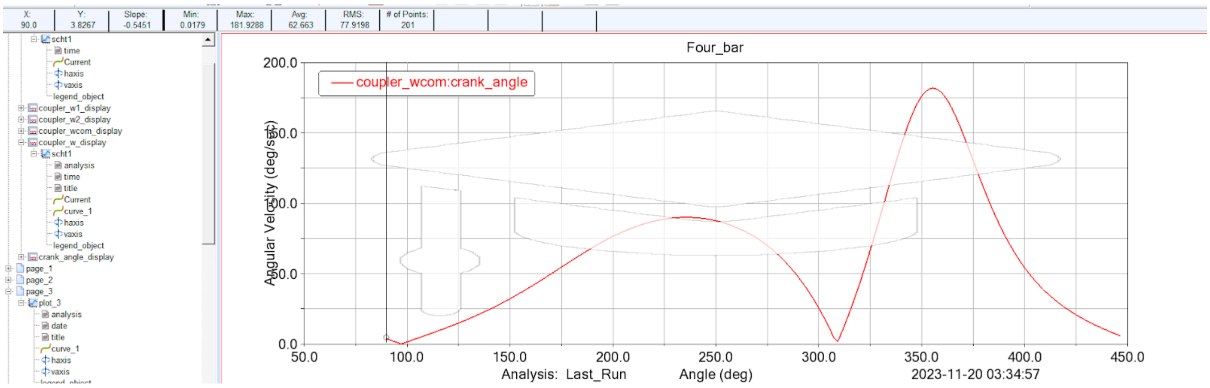


Fig 11 (90 degree)

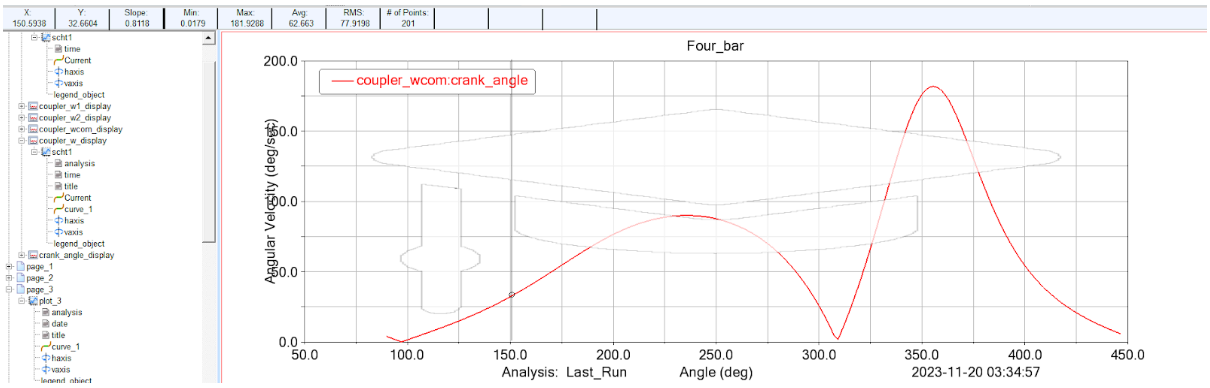


Fig 12 (150.5938 degree)

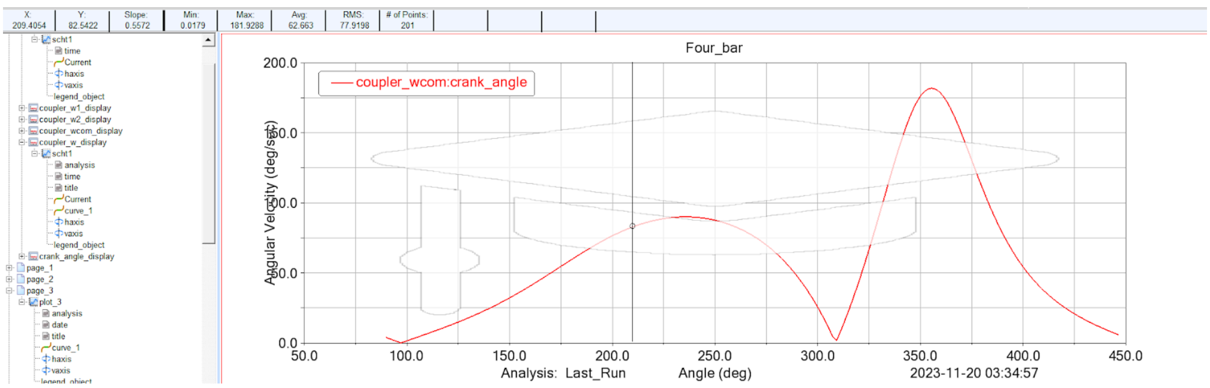


Fig 13 (209.4054 degree)

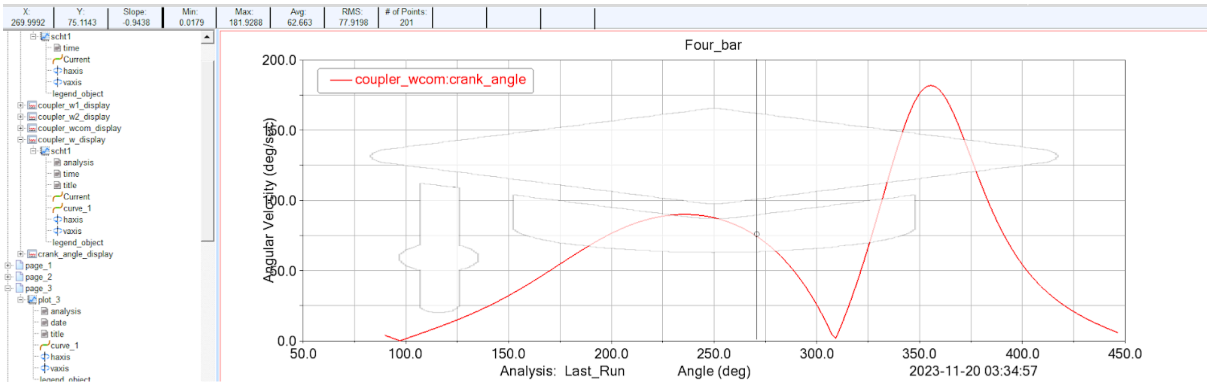


Fig 14 (269.9992 degree)

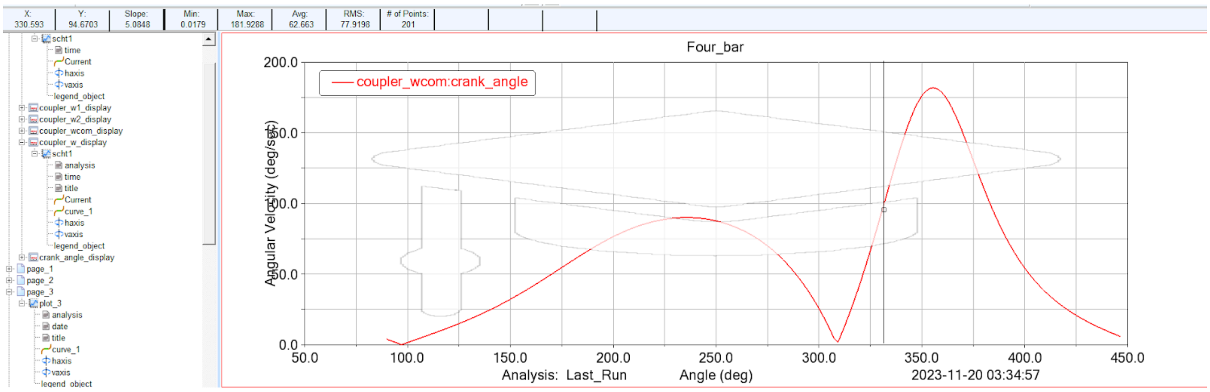


Fig 15 (330.593 degree)

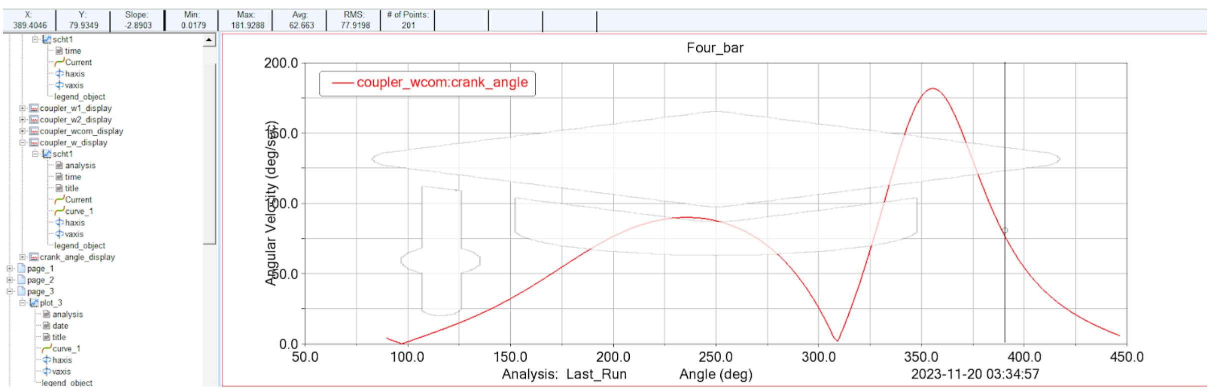


Fig 16 (389.4046 degree)

Velocity (COM) vs Angle

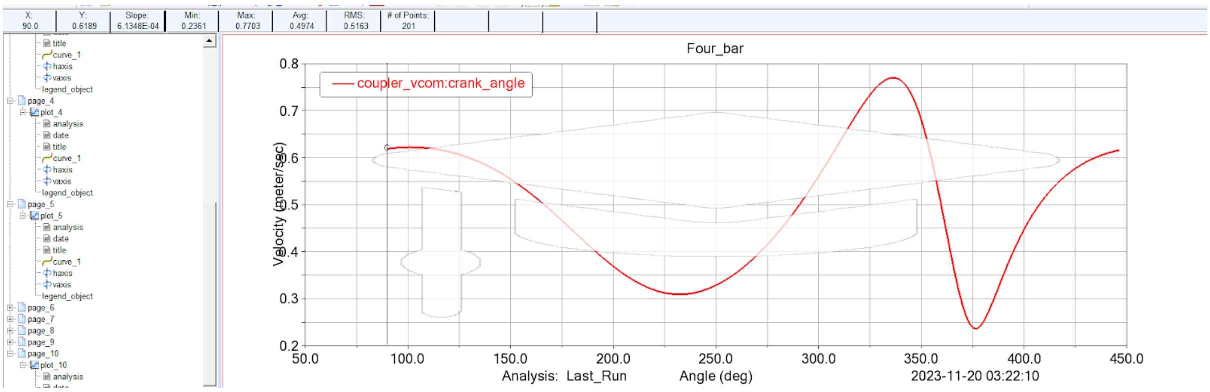


Fig 17 (90 degree)

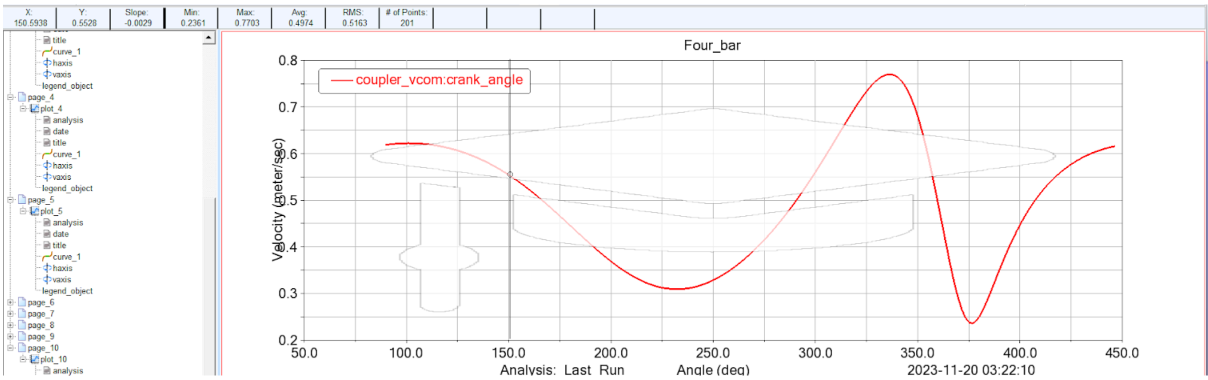


Fig 18 (150.5938 degree)

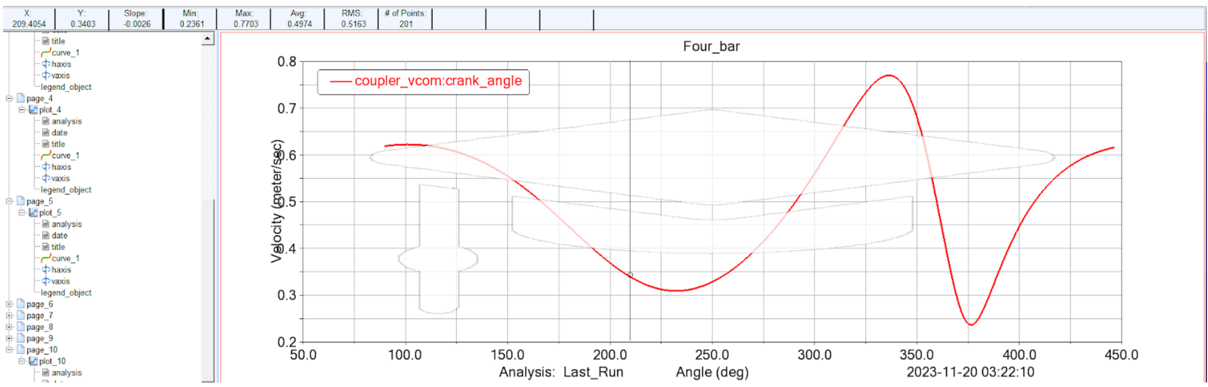


Fig 19 (209.4054 degree)

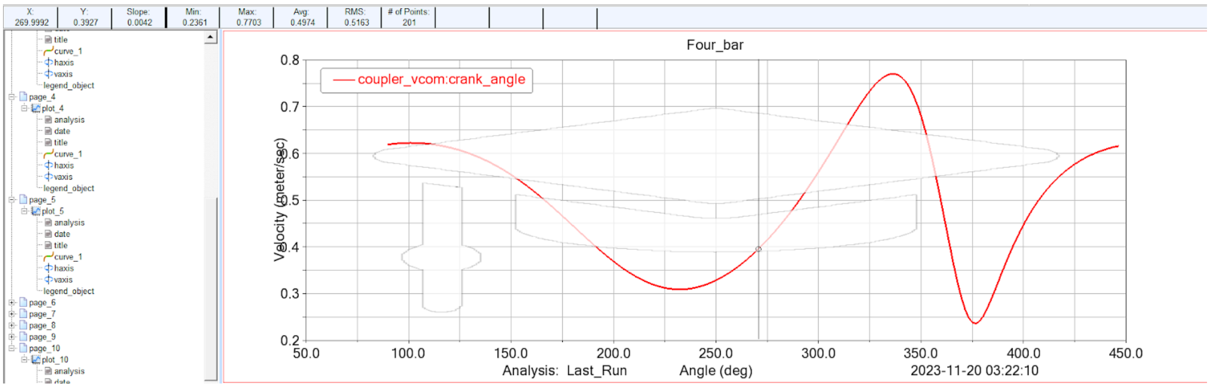


Fig 20 (269.9992 degree)

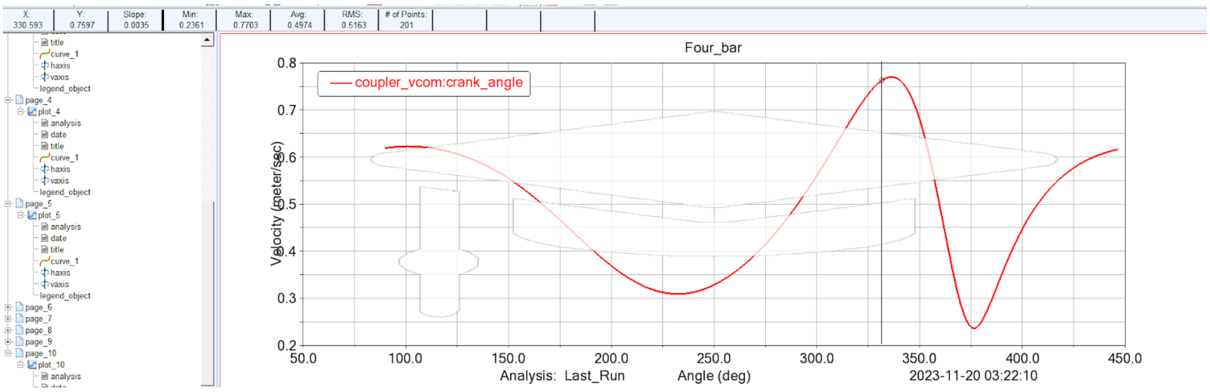


Fig 21 (330.593 degree)

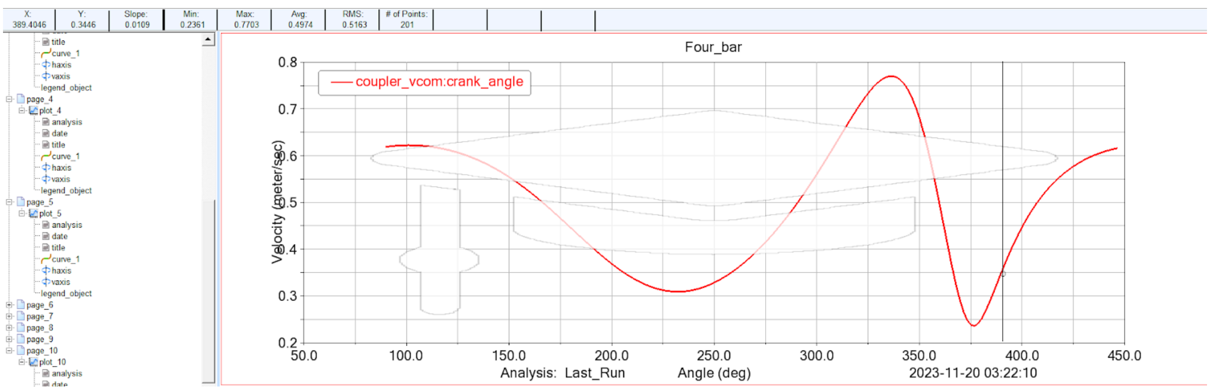


Fig 22 (389.4046 degree)

Values obtained from python

Theta 2 (rad)	l (m)	Alpha (rad)	Beta (rad)	Theta 3 (rad)	Lambd (rad)	Theta 4 (rad)	v4 (m/s)	omega3 (rad/s)	vcom (m/s)
1.57	0.45	0.72	0.46	0.25	1.07	1.61	0.62	-0.06	0.62
2.63	0.58	0.5	0.17	0.33	0.69	2.28	0.5	0.57	0.55
3.66	0.58	0.5	-0.17	0.67	0.69	2.62	0.1	1.44	0.34
4.71	0.45	0.72	-0.46	1.18	1.07	2.54	-0.24	1.31	0.39
5.77	0.25	0.85	-0.41	1.26	1.51	2.04	-0.85	-1.2	0.71
6.8	0.25	0.85	0.41	0.44	1.51	1.22	0.06	-1.43	0.34

Python code

```python
import math

def calculate_values(theta2):
    v2=0.6221
    l=(0.2-0.16*math.cos(theta2))**0.5
    alpha=math.acos(((l**2)+0.07)/(0.8*l))
    beta=math.asin((0.2/l)*math.sin(theta2))
    theta3=alpha-beta
    lambd=math.asin((4/3)*math.sin(alpha))
    theta4=(math.pi)-(lambd+beta)
    v4=v2*((math.cos((math.pi/2)+theta3-theta2))/(math.cos(lambd+alpha-(math.pi/2))))
    omega3=-1*(0.6221*math.sin(theta4-theta2))/(0.4*math.sin(theta4-theta3))
    vcom=(((-1*(0.6221*math.sin(theta2)+0.2*omega3*math.sin(theta3)))**2)+((0.6221*math.cos(theta2)+0.2*omega3*math.cos(theta3)))**2)**0.5
    return l, alpha, beta, theta3, lambd, theta4, v4, omega3, vcom

theta2 = float(input())
result = calculate_values(theta2)

print("l:", result[0])
print("alpha:", result[1])
print("beta:", result[2])
print("theta3:", result[3])
print("lambd:", result[4])
print("theta4:", result[5])
print("v4:", result[6])
print("omega3:", result[7])
print("vcom:", result[8])
```

Fig 23 Python Code for calculating Vcom and angular velocity of coupler (analytically)

```python
import matplotlib.pyplot as plt

theta2_values_degrees = [90, 150.5938, 209.4054, 269.9992, 330.593, 389.4046]

# Analytical data
omega3_values_a = [3.8365899470288, 32.655021065817, 82.548549681726, 75.124753446512, 69.229684782911, 81.968416042373]
vcom_values_a = [0.618896756453751, 0.5527802796705288, 0.34027854683547315, 0.39266960561758435, 0.7104231819850962, 0.3375707397381995]

# ADAMS data
omega3_values = [3.8267, 32.6604, 82.5422, 75.1143, 94.6703, 79.9]
vcom_values = [0.6189, 0.5528, 0.3403, 0.3927, 0.7597, 0.3446]

# Experimental data
omega3_values_e = [105, 26.76, 60.47, 74.48, 129.61, 67.32]
vcom_values_e = [0.37, 0.39, 0.35, 0.33, 0.7, 0.45]


plt.figure(figsize=(10, 5))
plt.plot(theta2_values_degrees, omega3_values, marker='o', linestyle='-', color='b', label='Mag. of Angular Velocity (ADAMS)')
plt.plot(theta2_values_degrees, omega3_values_a, marker='o', linestyle='-', color='r', label='Mag. of Angular Velocity (Analytical)')
plt.plot(theta2_values_degrees, omega3_values_e, marker='o', linestyle='-', color='g', label='Mag. of Angular Velocity (Experimental)')
plt.title('Comparison of Mag. of Angular velocity of coupler (ADAMS vs. Analytical vs. Experimental)')
plt.xlabel('Crank angle with horizontal (degrees)')
plt.ylabel('Mag. of Angular velocity (degrees/s)')
plt.legend()
plt.grid(True)
plt.show()

plt.figure(figsize=(10, 5))
plt.plot(theta2_values_degrees, vcom_values, marker='o', linestyle='-', color='b', label='Mag. of Vcom (ADAMS)')
plt.plot(theta2_values_degrees, vcom_values_a, marker='o', linestyle='-', color='r', label='Mag. of Vcom (Analytical)')
plt.plot(theta2_values_degrees, vcom_values_e, marker='o', linestyle='-', color='g', label='Mag. of Vcom (Experimental)')
plt.title('Comparison of Mag. of Vcom of coupler (ADAMS vs. Analytical vs. Experimental)')
plt.xlabel('Crank angle with horizontal (degrees)')
plt.ylabel('Mag. of Vcom (m/s)')
plt.legend()
plt.grid(True)
plt.show()
```

Fig 24 Python code for plotting graphs of Angular Velocity vs Angle and Velocity (COM) vs Angle for ADAMS, Analytical and Experimental

MATLAB Code

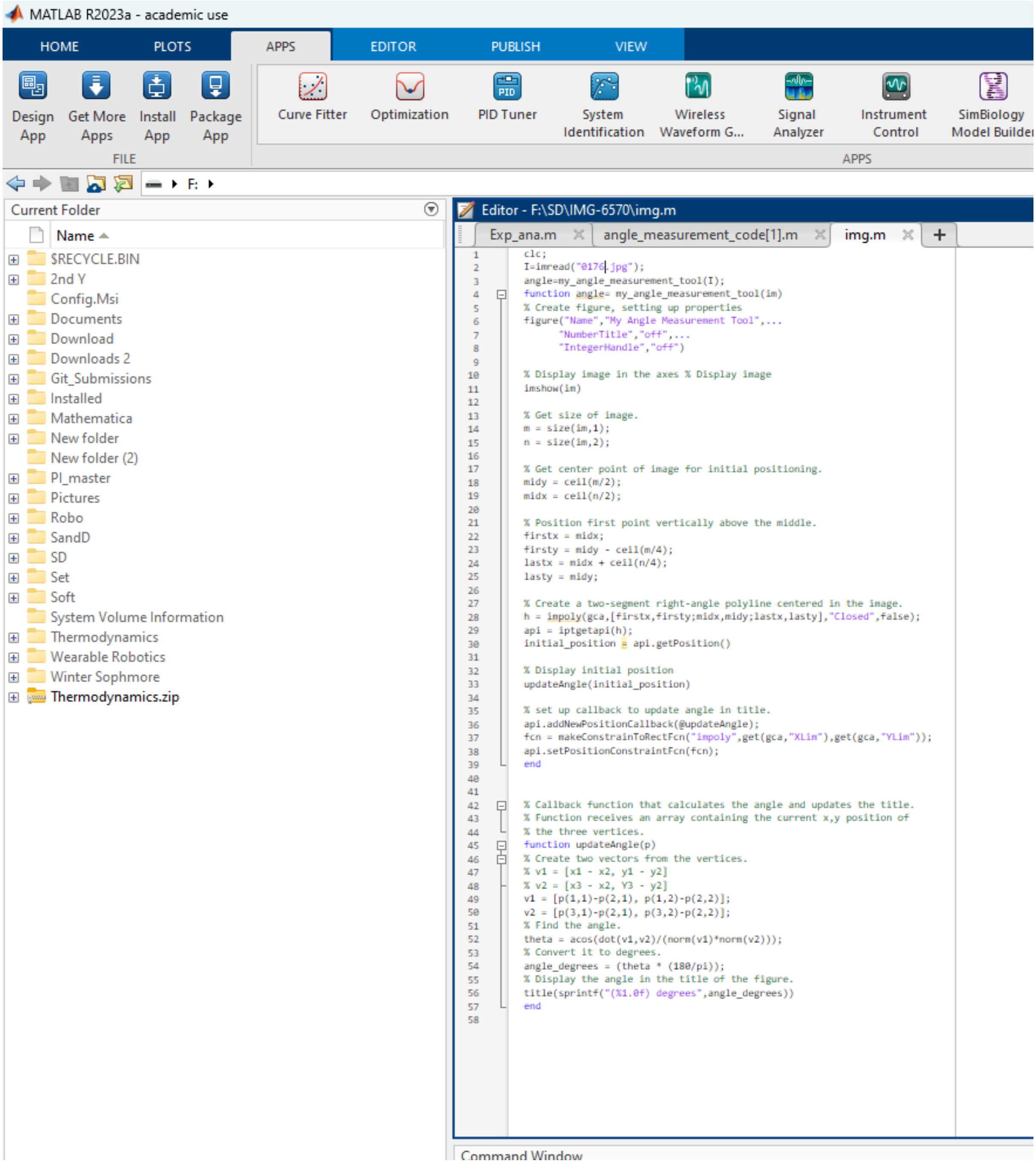


Fig 25 : MATLAB code for angle calculation of Images

Conclusion & Discussion :

Experimental vs. Theoretical Results: The experiment aimed to analyze a planar four-bar linkage mechanism, comparing experimental data with MSC Adams simulations and analytical calculations. While the results from MSC Adams and analytical methods closely aligned, the experimental results showed a variance of 25% to 40%. This discrepancy highlights the challenges in precisely replicating theoretical models in practical scenarios.

Source of Errors: Several factors could contribute to this variance:

> **Measurement Errors:** Inaccuracies in measuring lengths and angles of the l inkage could lead to significant deviations in experimental results.
>
> **Manufacturing Tolerances:** Slight differences in the construction of the linkage components, such as uneven lengths or misaligned joints, can affect the mechanism's motion.
>
> **Friction and Wear:** Friction at the joints and possible wear of components during the experiment can alter the motion characteristics of the linkage.
>
> **Data Collection Methodology:** The methods used to collect experimental data, such as the placement of sensors or the precision of timing devices, can introduce errors.

Interpretation of Results: Despite these discrepancies, the experimental data were of the same order of magnitude as the simulated and calculated results. This consistency underscores the validity of the theoretical models used and provides a realistic understanding of the system's behavior.

Implications for Mechanical Design: The experiment emphasizes the importance of considering practical constraints and real-world variables in mechanical design and analysis. It also highlights the role of simulation tools like MSC Adams in predicting system behavior and aiding in the design process.

Overall we can see the experimental, analytical and values generated from simulation follow the same trend with some deviation. These deviations could be due to the errors mentioned above.

Learnings:

Theoretical vs. Practical Knowledge: The experiment reinforced the importance of bridging the gap between theoretical knowledge and practical application. Understanding the nuances of real-world conditions is crucial for effective mechanical design.

Precision in Construction: The necessity for precise manufacturing and alignment in mechanical systems was evident. Even minor deviations can significantly impact the system's performance.

Importance of Simulation Tools: The experiment underscored the utility of simulation tools in predicting and analyzing the behavior of mechanical systems, serving as a valuable complement to physical experiments.

Data Analysis Skills: Analyzing the discrepancies between theoretical and experimental results honed our data interpretation skills, an essential aspect of engineering research.

What could have been done better?

Enhanced Measurement Techniques: More precise measurement tools and methods could reduce errors in the experimental setup. Implementing digital measuring devices and ensuring meticulous alignment and calibration could improve accuracy. More FPS cameras could be used for experimental analysis.

Improved Experimental Setup: Redesigning the experiment to minimize friction and wear, perhaps by using higher quality materials or better lubrication at joints, could yield results more consistent with theoretical predictions.

Data Collection and Processing: Refining the data collection methodology, such as using high-precision sensors or advanced image processing techniques, could enhance the reliability of the experimental data.

Iterative Testing and Analysis: Conducting multiple iterations of the experiment with adjustments based on initial findings could help in identifying and minimizing sources of error.

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