Labs 08 and 09: Rotational Motion

Learning Objective:

- Design and conduct controlled experiments to develop mathematical models from experimental data

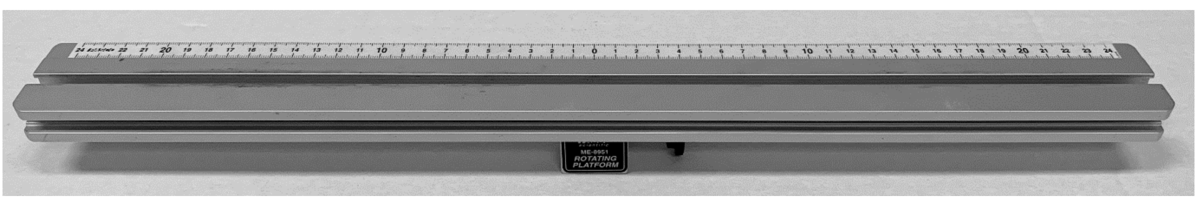
This is a double week lab with nothing due for two weeks! For both Labs 08 and 09 you will compile **Lab Records** *during class as you normally do, however, these will submitted as part of a* ***group Lab Report*** *after Lab 09. All requirements and instructions are included in this document, including portions of the scoring rubric, which details expectations, scattered throughout.*

Group Lab Records/Report Scoring Rubric (100 pts total)

	Excellent (2)	Limited (1)	Missing (0)
General Clarity	1. Names of all students. 2. Experiment name & date. 3. Course and section #. 4. Organization and neatness.	A couple of the parameters are missing or submissions are disorganized, difficult to read.	Multiple parameters are missing or submissions are highly disorganized or difficult to read.

I. Determine the Moment of Inertia of an Aluminum Beam

a. **Calculate moment of inertia.** Consider the aluminum beam shown in the photo below. It has a length of 0.506 ± 0.0005 m, a width of 0.055 m ± 0.0005 m, a height of 0.018 m ± 0.0005 m, and a mass of 0.574 kg ± 0.0001 kg. Determine the moment of inertia of the beam using an equation selected from the figure in this week's pre-lab notes. Include your calculation and final value for the moment of inertia in your **lab records**.



b. **Accuracy of computed value.** Look carefully at the photo above. Do you think the calculated value is accurate? Discuss in your **lab records** the reasoning for your response.

c. **Experimentally determine the moment of inertia.** Look at the set-up in Fig. 1. The beam has been attached to a vertical rod that can freely rotate. The shaft has three stacked and fixed axial pulleys. A string is wound around the middle pulley and the string then passes over another pulley to a hanging mass, *m*. The weight of the hanging mass applies a torque (τ) to the middle pulley, causing the entire beam on top to undergo angular acceleration when the mass is allowed to accelerate downward. A video of this motion is posted in this week's lab module.

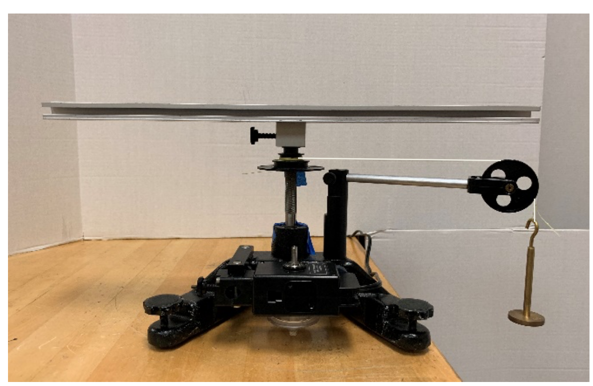


Fig. 1. Apparatus for measuring moment of inertia.

A student videotaped one run of the experiment in which the video shows the hanging mass starting at rest and then accelerating downward, while the beam also starts at rest and then undergoes angular acceleration. The student used Tracker to determine the acceleration of the falling mass, *m*. The values the student collected are in the box below Figure 2.

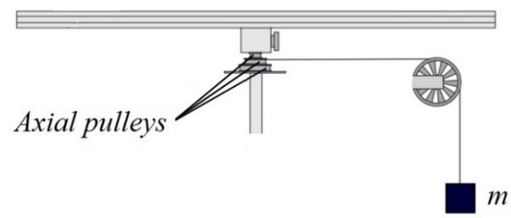


Fig. 2 Diagram of the apparatus.

Measurements:

Length (beam) = 0.506 m ± 0.0005 m
Width (beam) = 0.055 m ± 0.0005 m
Height (beam) = 0.018 m ± 0.0005 m
M_{beam} = 0.574 kg ± 0.0001 kg
$d_{middle\ pulley}$ = 0.0253 m ± 0.00004 m
$m_{hanging\ mass}$ = 0.150 kg ± 0.0001 kg
$a_{falling\ mass}$ = 0.0183 m/s^2 (from Tracker)

As a group, calculate the moment of inertia of the beam using the data collected experimentally by the student. Be sure to include your calculation and final answer in your **lab records**. You may do the calculation on paper and include a screenshot rather than use an equation editor.

d. **Compare values.** Compare the experimental and theoretical moments of inertia for the beam. In your **lab records**, comment on whether you expected them to be the same. Also, comment on which one you expected to be lower in value than the true value. Explain why.

	Excellent (4)	Limited (2-3)	Missing (0-1)
Calculation for theoretical value for I_{beam}	1. Equation selected from Table 1 in pre-lab is appropriate. 2. Shows enough **detail** for calculation so it could be repeated. Includes **units**.	A couple parameters are missing.	A significant amount of detail is missing.
	Excellent (6)	**Limited (3-5)**	**Missing (0-2)**
Calculation for experimentally determining I_{beam}	Clearly shows **calculations** for finding experimental value so it could be easily repeated by others. Includes units.	A couple parameters are missing.	A significant amount of detail is missing.
	Excellent (2)	**Limited (1)**	**Missing (0)**
Comparison of experimental and theoretical values	Appropriate comments are provided regarding the rationale behind why the two may differ.	Rationale behind differences is not provided.	A significant amount of detail is missing.

II. Further Exploration of the Moment of Inertia

a. **Consider a new scenario.** As shown in Fig. 3, the system now includes a mass ***M*** attached to the top of the beam at a location R distance from the center of the beam's rotation. Explain in your **lab records** how the moment of inertia ***I*** of the new beam-and-mass system might differ from that of the beam alone. Will it be less, roughly the same, or greater?

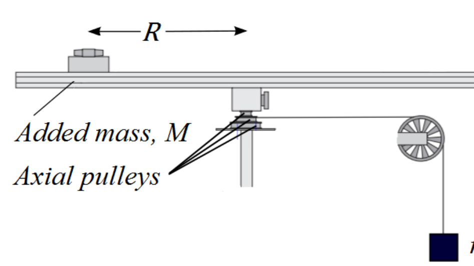


Fig. 3. Rotating beam with added mass *M*.

b. **Brainstorm.** Given this new scenario, what factors might impact the moment of inertia of the system, I_{system}. Record at least two factors in your **lab records**.

c. **Design the experiments to investigate two of these factors.** Decide on the design of your experiment by filling out two templates, such as that provided below, in your **lab records**. You will not conduct the experiment until after completing Checkpoint 1 with your instructor.

Experimental Design Template	
Research Question:	*What factors impact the moment of inertia of a rotating system?*
Dependent variable (DV):	
Independent variable (IV):	
Control Variables (CV): (*include <u>actual</u> values*)	
Testable Hypothesis: *(should contain IV and DV)*	
Prediction:	

Checkpoint 1! *Discuss with your instructor the outcomes from Section I as well as your two experimental design templates before continuing.*

If waiting for this checkpoint, check your lab records for completeness using the rubric below.

	Excellent (2)	**Limited (1)**	**Missing (0)**
Brainstorm Factors	Complete list of factors is included.	List is limited.	List is missing.
Experimental Set-up	Includes a **screenshot** of the experimental set-up; *essential* features are included and **labeled**.	Some features and/or labels are missing.	Screenshot is missing.
Experimental Design Templates (2 pts each)	Two completed **design templates** are included (contains research question, IV, DV, CV with values, hypothesis, and prediction).	A couple parameters are missing or provided detail is limited.	Significant number of parameters missing or too little detail provided.

d. **Graph the data.** The data will be provided to you for this lab given that you have already used Tracker to analyze videos for falling masses. Use Excel to graph the data provided for both experiments. Put the IV on the x-axis and the DV on the y-axis. Include error bars.

e. **Add a trendline to each graph.** Determine the mathematical relationship between the two variables by adding a trendline and displaying the equation and R^2 value on both graphs. Include the graphs in your **lab records**. Also, rewrite the equation provided by Excel in your lab records in terms of the variables under study. Include units on any numerical values.

f. **Conclusion.** Write a general claim for how each IV impacts, or does not impact, the moment of inertia of the system. Be sure to include any assumptions made in regards to your claim and well as state the conditions under which the claim holds.

Checkpoint 2! *Have your graphs and resulting mathematical models checked by your instructor. While waiting, be sure your lab records are complete using the rubric on the next page.*

	Excellent (3)	Limited (1-2)	Missing (0)
Data Tables (3 pts each)	Organizes **measurements** into a neat table, **labels** values, **units** included.	Some measurements are missing; labels/units missing.	Data table is missing.
Estimation of Uncertainties	1. Gives **uncertainty estimates** for each type of measurement. 2. **Describes** *how* uncertainties were determined.	Several uncertainty values or the description of how uncertainties were determined are missing.	A significant number of uncertainty values or description is missing.
Graphs with Error Bars (3 pts each)	1. Includes **graph**; labels axes (units) 2. Includes **x and y error bars** (indicates if too small to be seen).	Labels with units are missing; some error bars are missing or are incorrect.	Graph is missing.
Trendline Equation(s)	Trendline **equation** and **R^2 value** are included on all graphs, as warranted.	Trendline equation or R^2 is missing for some graphs.	Trendline equation and R^2 are missing on graphs.
Experimental Mathematical Models (3 pts each)	Writes the **experimental mathematical models** in terms of the IV and DV and includes a description about the relationship.	The model is written in terms of x and y, or a description of the relationship is missing.	A significant amount of the requested information is missing.
Claims	A **claim** about the **relationship** between the IV and DV is included next to the graph.	Claim does not include reference to supporting evidence.	A significant amount of evidence is missing or claim incorrect.
Conditions of Claims	**Conditions** under which the claims hold are clearly stated with the claims.	Essential details about the conditions are missing.	Conditions are not included with the claim.
Assumptions	**Assumptions** in regards to the claim are included with the claim.	Essential details about any assumptions are missing.	Assumptions are not included.
Tables and Figures are Labelled	All templates, tables, graphs, etc. are labelled using standard headers w/numbers, such as, "Fig 1. Graph of T vs Mass".	Several labels on data tables, graphs, or other figures are missing.	A significant number are missing.

III. Scientific Research Community

Scientists often compare their own findings with those of other researchers. This helps in understanding their own data, identify possible errors, and builds confidence in outcomes. The tables below contain the models developed by students in previous lab courses. Copy both tables into your **lab records** and enter your own models as Group A in each.

Group	Model 1: IV is added mass	CV for Model 1	R^2 Value
A			
B	I_{sys}= (0.0527 m^2)M + 0.0124 kg m^2	R=0.225 m I_{beam}=0.0122 kg m^2	0.9952
C	I_{sys}= (0.0506 m^2)M + 0.0152 kg m^2	R=0.220 m I_{beam}=0.0126 kg m^2	0.9994
D	I_{sys}= (0.0675 m^2)M + 0.0106 kg m^2	R=0.257 m I_{beam}=0.0129 kg m^2	0.9963

Group	Model 2: IV is R distance	CV for Model 2	R^2 Value
A			
E	I_{sys}= (0.6349 kg) R^2 – 0.0006 R + 0.0118 kg m^2	M=0.604 kg I_{beam}=0.0122 kg m^2	0.9998
F	I_{sys}= (0.5319 kg) R^2 – 0.0013 R + 0.0271 kg m^2	M=0.511 kg I_{beam}=0.0268 kg m^2	0.9999
G	I_{sys}= (0.0253 kg) R^2 + 0.0098 R + 0.012 kg m^2	M=0.204 kg I_{beam}=0.0118 kg m^2	0.9884

a. **Theoretical model**. The mathematical models describe the moment of inertia of a system, where the system in this case includes a beam and a mass (you can consider it a point mass). Using the pre-lab notes or your textbook, write out in your **lab records** the theoretical (scientifically accepted) equation for the moment of inertia of these two objects. Use the models provided by other students in the tables above to guide your thoughts here.

b. **Compare Model 1 with theory**. Carefully compare your Model 1 to the theoretical model. Discuss what each coefficient and constant in Model 1 physically represents in regards to this experiment. For example, if you believe the units on a constant in your model and the process of comparing your model to theory indicates that the constant represents the mass of the system, then compare the value of the constant in Model 1 with the actual mass of the system used in the experiment. Also, as you make the comparison, discuss what might account for any differences in values. Again, use the models provided by other students in the tables above to guide your thoughts here.

c. **Compare Model 2 with theory**. Repeat the above for Model 2.

Checkpoint 3! *Have your understanding checked for how your two mathematical models compare to the scientifically accepted theory. While waiting, be sure your lab records are complete using the rubric on the next page.*

	Excellent (3)	Limited (1-2)	Missing (0)
Theoretical Model	Identifies the correct **theoretical model** for this investigation.	The theoretical model is not entirely correct.	The theoretical model is missing.
	Excellent (5)	**Limited (1-4)**	**Missing (0)**
Compares Experimental and Theoretical Models (5 pts each)	1. Discusses what each coefficient and constant **physically represents** for this experiment. 2. Discusses what may account for differences in values in models and actual measured values in lab.	The model is written in terms of x and y, or a description of the relationship or possible physical meaning of the constants is missing.	A significant amount of the requested information is missing.

IV. Final Wrap-Up

Rather than turn in group lab records and then an individual lab report for this two week investigation, you will submit ONE document which will be a **group lab report**. Note that the group lab report will be essentially the lab records up to this point (in the same order as in this document), followed by answers to the wrap-up questions below. Be sure to thoughtfully and completely answer the wrap-up questions in this combined **lab records/group lab report** document. In your responses, be sure to refer back to the data tables, graphs, and figures already included in your document. If your tables and graphs are not numbered and contain labels, please do so now before continuing.

a. **Research question.** Remind the reader what research question was investigated in this lab. Tell the reader which variables (IVs) were tested to address the research question.

b. **Summarize findings into a general claim.** Describe how each of the experiments led to a separate claim about a given IV. As part of this discussion, be sure to state the resulting mathematical models (with units), explain how the models were determined, and then discuss how the models led to a general claim. You can cut and paste from an earlier section of your lab records if you have previously described this. Just be sure what you cut and paste is integrated into this section.

Many factors impact how much confidence your group might have in their experimental outcomes. Figure 4 portrays some of the factors discussed this term. Use the figure to help in addressing the two questions below. Refer back to your data tables and graphs, as needed, in your discussion and be sure your responses are complete.

c. **Lack of confidence.** Write a paragraph or two about what makes your claims credible. That is, discuss what gives you confidence that your models and claims are trustworthy.

d. **Lack of confidence.** Write a paragraph or two about what makes your claims less credible. That is, discuss what might cause you to question whether your models and claims are trustworthy.

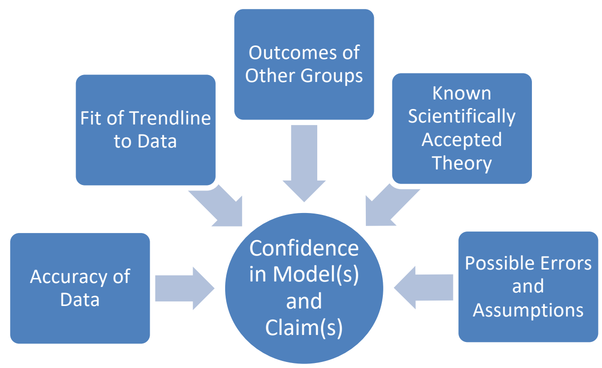


Fig. 4. Diagram of the possible factors that might impact confidence in claims.

Check your group lab records/report for completeness using the rubric below:

	Excellent (3)	**Limited (1-2)**	**Missing (0)**
Research Question	Research Question is restated and both variables that were tested are mentioned.	Not all variables included.	Missing entirely.
General Claim (3 pts each experiment)	Describes how each of 2 experiments led to separate claim about a given IV. Mathematical models are included in the discussion.	One of the IVs is not discussed; models not part of discussion.	Missing entirely.
	Excellent (10)	**Limited (1-9)**	**Missing (0)**
Confidence in Claims and Models	Thorough discussion of why a reader should feel confident about the group's reported claims and models. Includes as many of the factors from Figure 4 as make sense for this discussion.	Some essential components from Fig. 4 are missing in the discussion.	Missing entirely.
Lack of Confidence in Claims and Models	Thorough discussion of why a reader might question the group's reported claims and models. Includes as many of the factors from Figure 4 as make sense for this discussion.	Some essential components from Fig. 4 are missing in the discussion.	Missing entirely.

This ends the lab. Submit your **group Lab Report** on Canvas before your next lab class. There is nothing else to submit for this two week lab.