Boston University

EK301-A1

Professor Farny

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Buckling Lab Report

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Due Date: March 7, 2025

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I. Background

We desire to design, build, and test an acrylic truss structure to meet specified load requirements. The strength of the truss is expected to be limited by the buckling strength of the truss members. The buckling load is expected to depend on the length of the member. The purpose of this lab, therefore, is to measure the buckling strength of acrylic strips as a function of their length.

We wish to determine P_{crit}, which represents the critical buckling load for an acrylic strip, which is loaded in pure axial compression, and simply supported at its ends. P_{crit} depends on the material properties of the strip, its cross sectional dimensions, and its length. We will attempt to keep all those parameters the same from experiment to experiment except the length. "Buckling" is a geometric instability which is characterized by the possibility that the given structure can support the applied load in more than one equilibrium configuration. When this happens, the desired configuration (the desired shape of the structure - in this case a straight strip) is usually unstable, while the undesired configuration (or shape - in this case a bent or wavy strip) is nominally stable. For pure axial loads above P_{crit}, the straight configuration becomes unstable and the structure can suddenly (and catastrophically) change to the collapsed or buckled (wavy) configuration. For pure axial loads below P_{crit}, the straight configuration is the only equilibrium configuration and it is stable.

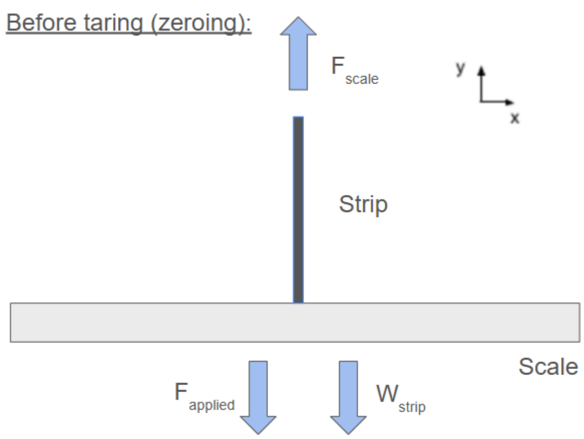
II. Methods & Data

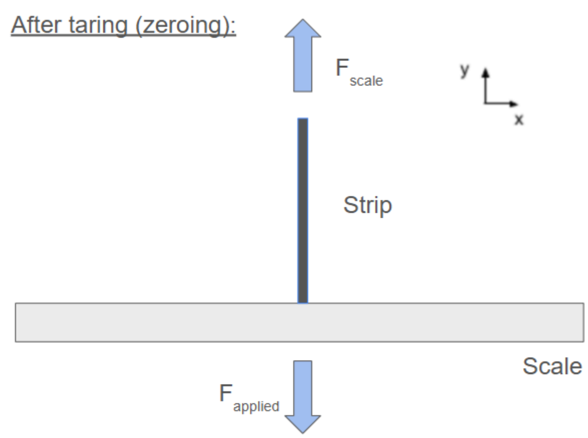
The purpose of this experiment was to determine the critical buckling load, P_{crit}, for acrylic strips under axial compression and to analyze its dependence on length. The following steps were conducted to measure the buckling load for two selected strip lengths. First, two different strip lengths were selected: 10 inches and 12 inches. These lengths were chosen within the bounds of 7 inches and 14 inches. The acrylic bars were placed flat on the workbench with a protective surface underneath to prevent damage on the surface. A scoring knife was used to make deep scratches at the desired length. The strip was then gently bent at the scored line to create a clean break. This process is repeated for each of the two desired lengths.

A digital scale was placed on a level surface and set to measure in ounces (oz). The scale was zeroed by pressing the "tare" button. Each strip was placed horizontally on the scale to measure its weight (W_{strip}), and the scale was re-zeroed with the strip on it. The strip was then positioned vertically with the bottom end resting on the scale, while the top end was lightly supported to prevent it from falling. A downward force was gradually applied by hand to compress the strip. The applied force was increased until the strip buckled. The peak force reading on the scale at the moment of buckling was recorded as P_{crit}.

Each measurement was repeated nine times for each length to ensure accuracy. This process was repeated for all two strip lengths, resulting in 18 buckling load measurements for the group.

III. Analysis





In the free body diagrams above, we can note that F_{scale} is the reaction force from the scale acting on the strip, $F_{applied}$ is the applied force on the strip, and W_{strip} is the weight of the strip.

The first free body diagram shows all forces acting on the strip before the scale is tared. Before tarring the scale, the acrylic strip's weight (W_{strip}) contributes to the total force measured. The scale reads the combined effect of the strip's weight and any applied force ($F_{applied}$). At this stage, the reaction force from the scale (F_{scale}) balances both forces. By applying Newton's Second Law in the vertical direction ($\sum F_y = 0$) at equilibrium: $F_{scale} = F_{applied} + W_{strip}$.

The second free body diagram shows that once the scale is zeroed with the strip on it, the weight of the strip is no longer considered in the measurement. After zeroing the scale, the weight of the strip is no longer included in the measurement, meaning the scale now reads only the applied force. By applying Newton's Second Law in the vertical direction ($\sum F_y = 0$) at equilibrium: $F_{scale} = F_{applied}$, which directly represents the load required to buckle the strip. The reaction force from the scale still counteracts the applied force, ensuring equilibrium until buckling occurs.

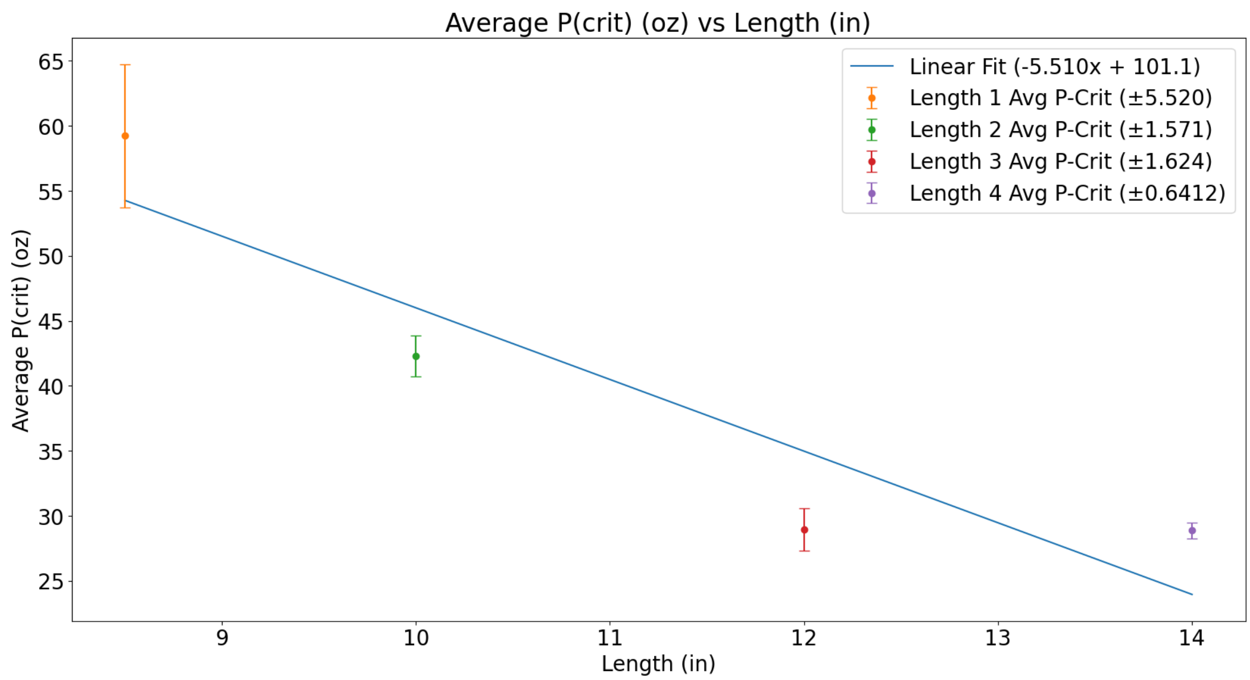
IV. Results

Table 1: Data table Wgt, P_{meas} measurements

	Length 3 (in)		Length 1 (in)		Length 2 (in)		Length 4 (in)	
Nominal length	8.5		10.00		12.00		14	
Trial #	Wgt (oz)	P_{meas}	Wgt (oz)	P_{meas}	Wgt (oz)	P_{meas}	Wgt (oz)	P_{meas}
Trial 1	0.60	53.09	0.9	39.45	1.15	25.8	0.85	29.24
Trial 2	0.60	47.20	0.9	41.48	1.15	27.8	0.85	28.08
Trial 3	0.60	59.97	0.9	43.54	1.15	28.5	0.85	28.08
Trial 4	0.60	62.15	0.9	44.75	1.15	28.7	0.85	28.89
Trial 5	0.60	62.50	0.9	43.70	1.15	28.4	0.85	28.32
Trial 6	0.60	60.00	0.9	41.70	1.15	29.55	0.85	29.14
Trial 7	0.60	64.40	0.9	41.30	1.15	29.77	0.85	28.92
Trial 8	0.60	61.23	0.9	42.30	1.15	30.6	0.85	29.90
Trial 9	0.60	62.43	0.9	42.60	1.15	31.3	0.85	29.31
AVG	0.60	59.22	0.9	42.31	1.15	28.94	0.85	28.88
STDEV	0	5.520	0	1.571	0	1.624	0	0.6142
Range	0	17.2	0	5.3	0	5.5	0	1.82

In Table 1, we recorded nine trials each for four lengths of strip, 10, 12, 8.5, and 14 inches. Each of our measurements included the value of the applied force and the weight of the strip. After taking our measurements, we averaged the nine trials for our final P_{crit} and calculated the P_{meas} standard deviation. To determine the range, we found the difference between our maximum and minimum recorded P_{meas} for each strip.

Figure 2: The relationship between Average P_{crit} and the length of the strip L



This plot displays the variation of the critical buckling load (P_{crit}) as a function of strip length (L), based on experimental measurements. The data points represent the average buckling load for each tested length, with error bars indicating the measurement uncertainty. The figure above shows the relationship between the average P_{crit} and length of the strip in inches is linear and has a best-fit line equation:

$$P_{crit}(L) = -5.510L + 101.1$$

V. Discussion

The range estimate for each length was determined by finding the difference between the maximum and minimum recorded P_{meas} values across the nine trials. For example, at L = 8.50 in, the range was 17.2 oz (from 64.40 oz to 47.20 oz), while at L=14.00 in, the range was much smaller at 1.82 oz (from 29.90 oz to 28.08 oz). The shorter strips exhibited greater variation, likely due to their increased sensitivity to small experimental differences, whereas longer strips had more consistent buckling loads, suggesting a more stable failure behavior.

Comparing the measurements within our group, we observed general consistency in P_{crit} values for each sample length, with some minor variations. These inconsistencies likely arose from small differences in sample preparation, such as slight variations in strip length, grip strength, force distribution, positioning, or small differences in width and thickness. Given the weight per unit length of acrylic strips, small variations in length could influence the measured buckling loads. To add on, there were some factors that could affect the accuracy of the measurements, such as width or thickness variability, which is hard to control as such small differences in length are not noticeable by human eyes.

Data in the Graph		**Analysis:**		
Length (in)	P_{crit}	P_{crit} (calculated from the line of best fit)	Difference	Average Error:
8.50	59.22	54.26	4.96	4.903
10.00	42.31	46	3.69	
12.00	28.94	34.98	6.04	
14.00	28.88	23.96	4.92	

	Standard Deviation	**Average Error**
Length 1 (8.50 in)	5.520	4.903
Length 2 (10.00 in)	1.571	4.903
Length 3 (12.00 in)	1.624	4.903
Length 4 (14.00 in)	0.6142	4.903

The estimated error of the fit is 4.90 oz, which represents the average vertical distance between the measured critical buckling loads (P_{crit}) and the predicted values from the best-fit equation. When compared to the standard deviations of the measured data (ranging from 0.6142 oz to 5.520 oz), the error of the fit is comparable to or larger than the variability in individual measurements. This suggests that while the linear model provides a reasonable approximation, it does not perfectly capture the experimental buckling behavior. When determining the failure load of the truss, it is more appropriate to use the error of the fit (4.90 oz) rather than the range of individual measurements, as it accounts for systematic deviations across all lengths rather than just variability in specific trials. This approach provides a more reliable estimate when applying the model to new truss designs. However, using both the fit error and standard deviations in a safety margin would result in a more reliable failure load estimation.

VI. Conclusion

In this experiment, we measured the critical buckling load of acrylic strips and observed their dependency on the strip length. The results of this experiment demonstrate that the critical buckling load P_{crit} decreases as the length of the acrylic strip increases, confirming the expected inverse relationship between load-bearing capacity and length. The collected data, averaged over multiple trials, provided a reasonably accurate estimate of P_{crit}, with the range serving as an uncertainty measure due to human error and material inconsistencies. Overall, our results provided a reliable estimate of buckling loads, but additional trials with more controlled variables could improve the precision of the data.

VII. Appendix

Minutes of Case Study Discussion

Participants: Jessica (chair), Riasat (recorder), Jinyu
Date: April 19, 2025
Time: 6:00 pm
Location: Photonics 1st Floor

Planned Agenda:

1. Introduction to the case study
2. Discussion of key group dynamics in “It Takes Two to Tango“
3. Identifying strategies to manage freeloaders in group work
4. Conclusions and action items

Discussion:

1. Case study overview:

    - The case study "It Takes Two to Tango" describes a situation where a free-riding group member, Jack, benefits from the hard work of others while contributing little to no effort.
    - Jack not only receives credit undeservedly but also negatively affects the team's performance and morale.
2. Key group dynamics discussed:
    - Free-rider problem:
        - Jessica: Jack's behavior can lead to resentment and decreased motivation among active team members.
        - Riasat: In group settings, social loafing occurs when members feel their contributions are not being valued and recognized.
        - Jinyu: Lack of accountability allows free-riders to continue in group work without consequences.
    - Effects on team performance:
        - Jessica: Jack's actions made the team look bad, which damaged the group's reputation despite their hard work.
        - Riasat: Without proper team structures and expectations, groups often struggle with efficiency and fairness.
        - Jinyu: Jack's behavior aligns with diffusion of responsibility, where individuals assume someone else will take on their workload.
3. Strategies to prevent free-riders:
    - Setting clear expectations: The group agreed that establishing roles and responsibilities at the start of a project prevents ambiguity.
    - Accountability Measures: Implementing weekly check-ins to track progress and ensure each member is contributing.
    - Open Communication: If an issue arises, the first step should be direct communication with the member in question.
    - Escalation Policy: If direct communication fails, escalate concerns to the instructor.
4. Conclusion
    - Accountability is key to successful group work. Members should be assigned specific, trackable responsibilities to prevent free-riding.

- Proactive communication is essential. Concerns should be addressed early to avoid long-term issues.
- If a member consistently fails to contribute, the group should follow a structured escalation process.

5. Action Items & Responsibilities
    - Jessica is responsible for drafting a group contract with expectations, in which the deadline is March 3, 2025.
    - Riasat is responsible for establishing weekly progress reports and meetings, in which the deadline is March 3, 2025.
    - Jinyu is responsible for ensuring check-ins and team communication, in which it is still ongoing till the project ends.
    - All members are responsible for communicating concerns early and addressing issues, which are still ongoing till the project ends.

Group Contract

Group members: Jessica Qiu, Riasat Audhy, Jinyu Fang

Course: EK 301 - Engineering Mechanics I

Lab: Buckling Lab

Date: 3/7/2025

1. Strengths and Weaknesses

Member	**Strengths**	**Weaknesses**
Jessica Qiu	Data Analysis/Visualization, MATLAB	Technical Writing, Documentation
Riasat Audhy	Technical Writing, Python Coding	Data Analysis
Jinyu Fang	Data Analysis	Technical Writing

2. Scheduling and Communication

Our meeting schedule will be held every Friday at 6pm in the Photonics Center. Additional meetings will be held if necessary for near deadlines or assignments. The primary communication will be via text message and email for any updates. Response time should be within 24 hours for routine questions and no more than 4 hours before any agreed-upon deadlines. Shared documents and resources will be shared via Google Drive.

Availability:
Jessica: Mon & Wed 3:00-8:00 pm; Tues & Thurs 1:00-3:30 pm; Friday 6:00-8:00 pm
Riasat: Mon & Wed 3:00-6:30 PM; Tues & Thurs 3:00-8:00 PM; Friday 4:00-8:00 PM
Jinyu: Mon & Wed 1:00-8:00 pm; Friday 5:30-8:00 PM

3. Responsibilities and Expectations

Each group member is expected to contribute equally to all aspects of the lab project or any assignments such as the Preliminary Design Report, Final Design Report, and Truss Testing & Documentation. Specific roles and responsibilities, such as data analysis or coding, will be assigned to individuals who have those strengths and preferences (noted in Strengths and Weaknesses) in those fields, but all members will contribute equally on final edits and submissions for any assignment. Each group member will be responsible for delivering high-quality work. This includes proofreading, checking calculations, and ensuring that the lab report is well-organized and accurate. If any issue occurs when understanding the material, the member should ask help from the group before deadlines.

4. Meeting Deadlines

Members are expected to complete assigned work at least 24 hours before deadlines to allow for group discussion and review. If a group member fails to meet a deadline or is unresponsive to any communication, the first instance will be a reminder sent via group chat. The second instance will be the member will be notified for a one-to-one discussion to resolve the issue. The third instance will be the issue will be reported to the instructor.

5. Decision Making

Group decisions will be made based on the majority vote. Decisions will include calculations or the structure of a specific lab report. If the group is stuck on a decision, they can seek and reach out to the instructor or teaching assistant for advice.

6. Conflict Resolution

Any disagreements will first be discussed within the group to find a mutual resolution. If unresolved, the issue will be escalated to the instructor for mediation.