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Teaching Factorial Design of Experiments (DOE) by Optimizing Glider Flight Range and Cargo Distribution in a Freshman Engineering Lab

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Abstract

In an introductory mechanical engineering course, students are often eager for hands-on projects that connect fundamental concepts to tangible design challenges. This paper presents a two-lab sequence developed to integrate design of experiments (DOE), optimization, and aerodynamics using balsa wood glider wings fabricated in the campus maker space.

The sequence begins with students completing maker space safety certification, enabling them to laser-cut trapezoidal wings. In the first lab, students conduct a three-factor full factorial design of experiment, systematically varying geometric parameters of the wing to investigate their impact on flight range. Using the data collected, students analyze the results and identify an optimized wing design.

In the second lab, students extend their optimized design to explore the relationship between aerodynamic forces, stability, and weight distribution of stored cargo. Using a graphical method, they determine the center of lift of their wing, then experimentally adjust the cargo's weight distribution/location to align the center of mass beneath the center of lift, thus eliminating destabilizing moments. This exercise reinforces concepts of lift, balance, and moment arms, demonstrating how stable flight is achieved and how poor alignment can lead to stalling or crashes. The sequence culminates in a small competition where students test the range and stability of their gliders, adding a motivating and playful dimension to the experience.

Overall, the lab sequence provides first-year students with an engaging introduction to experimentation, optimization, and aerodynamics while building teamwork, problem-solving, and prototyping skills. It highlights the value of integrating fabrication tools into engineering education to foster creativity and experiential learning. The paper provides packaged lab assignments.

1. Introduction and Educational Motivation

Introductory mechanical engineering courses play a critical role in shaping how students perceive the discipline and their place within it. Early curricular experiences strongly influence student confidence, engagement, and persistence, particularly as students begin understanding what engineers do in practice. Yet many foundational topics introduced in the first year—such as experimentation, optimization, and system performance—are commonly presented in abstract or procedural forms that limit students' ability to bridge idealized theory into real-world practices. Engineering education literature has demonstrated the instructional value of design–build–test activities in developing problem-solving ability, technical intuition, and professional skills [1]–[3]. These experiences provide students with opportunities to apply theoretical concepts in tangible contexts, reinforcing the iterative nature of engineering design. Prior studies have also shown that students consistently report higher perceived learning and engagement when coursework includes hands-on construction, performance evaluation, and iterative refinement [4]–[9]. As a result, design-and-build projects have become a well-established component of undergraduate engineering education.

Despite this broad recognition, such experiences are sometimes concentrated in the later stages of the curriculum, most notably in junior-level design courses and senior capstone projects. When early exposure is limited, students often encounter fabrication, experimental uncertainty, and design tradeoffs for the first time in high-stakes, outward-facing projects. This timing reduces opportunities for productive failure and limits students' ability to leverage prior experience when tackling complex, open-ended problems [10]–[12]. Introducing structured design-and-build activities earlier allows students to develop foundational skills incrementally, improving both technical performance and confidence in subsequent coursework.

This paper presents a novel two-laboratory instructional sequence that integrates design of experiments (DOE), optimization, aerodynamic stability, and maker space fabrication within a first-year mechanical engineering course. While DOE topics have been taught through aerodynamic labs before [13], tying the activity to design, advanced fabrication, and optimization is reasonably unique as a multi-session design-test-build series. The sequence emphasizes predictive reasoning and planned experimentation, positioning fabrication as a mechanism for validating design intent rather than correcting unforeseen shortcomings. The structured learning activities seek to strengthen early engineering judgment while reinforcing the connection between analysis, experimentation, and physical performance. The contribution of this publication is a unique and useful design-and-build lab that may be implemented by educators.

2. Course Context and Pedagogical Framework

The unique laboratory sequence described in this paper was implemented within a required introductory mechanical engineering course serving first-year undergraduate students. Enrollment commonly includes students with minimal experience with formal experimental design, aerodynamic principles, or fabrication equipment. As a result, students may approach early design tasks with an expectation that analytical or simulated results should directly translate to physical performance, without fully appreciating the role of variability, uncertainty, or implementation constraints.

There are several practical constraints that informed the development of the laboratory sequence. Laboratory contact time is limited to weekly 1-2 hour sessions, requiring activities to be completed within a narrow window while remaining repeatable across multiple sections. All fabrication activities must comply with institutional safety requirements, and access to maker space equipment is shared among multiple courses and student organizations. Students must complete the activities in teams to manage the high enrollment of early-curriculum classes.

These factors necessitate laboratory exercises that are robust, time-efficient, and scalable, while still providing meaningful hands-on engagement.

The pedagogical structure of the sequence is grounded in experiential and active learning principles, and students are encouraged to treat experimental results as a primary source of information guiding design decisions. Learning occurs through comparison of predicted behavior and observed performance. Unstable flight, inconsistent results, and unexpected interactions are intentionally preserved as instructional opportunities. These outcomes prompt discussion of model limitations, idealizing assumptions, and the role of engineering judgment when data does not align perfectly with real-world expectations.

Failure within the laboratory is explicitly framed as informative rather than punitive. By decoupling unsuccessful performance from grading penalties, students are encouraged to engage more fully in experimentation and iteration. This approach supports risk-taking, curiosity, and reflective analysis.

The laboratory sequence aligns with ABET student outcomes 1 (solve complex engineering problems), 5 (ability to function on a team), 6 (develop and conduct appropriate experimentation), and 7 (ability to acquire and apply new knowledge). By integrating fabrication, experimentation, and performance evaluation within a controlled instructional setting, the sequence provides first-year students with an early and authentic introduction to the realities of mechanical engineering practice.

3. Overview of the Two-Laboratory Sequence

The instructional sequence consists of two linked laboratory experiences designed to introduce first-year mechanical engineering students to experimentation, optimization, and aerodynamic stability through a unified design context. The laboratories are intentionally structured to build upon one another, allowing concepts introduced in the first activity to directly inform analysis and decision-making in the second. Detailed instructional handouts may be viewed and utilized in Appendix A and B.

The first laboratory focuses on design of experiments and data-driven optimization using provided wind tunnel data for a small set of swept wing configurations. Three geometric variables are systematically varied in a three-factor, full factorial experimental design. Using the provided dataset, students analyze main effects and interaction terms, develop simple empirical models relating geometry to aerodynamic performance, and evaluate the relative influence of each design variable. Students use the results to predict an optimized combination of geometric parameters.

The second laboratory transitions from analytical optimization to physical implementation and testing. Students fabricate a trapezoidal balsa wood glider wing based on their data-informed optimized design and investigate the aerodynamic stability of the system under payloads. Using a simplified graphical method [14], students determine the approximate center of lift of the wing and experimentally adjust payload mass and location to align the center of mass beneath it. Through systematic testing, students directly observe the effects of stable and unstable configurations, including stall behavior and pitch instability.

Across both laboratories, students are required to document analytical reasoning, experimental interpretation, and observed performance. Deliverables include DOE analysis and modeling results, predicted optimal configurations, stability testing observations, and written reflection addressing design tradeoffs and limitations. Together, the sequence emphasizes predictive design, informed experimentation, and the critical connection between analytical expectations and real-world physical behavior.

4. Laboratory Implementation

The laboratory sequence was structured to separate experimental reasoning from physical fabrication. This approach allows first-year students to develop conceptual understanding of design of experiments and optimization prior to confronting the additional variability introduced by manufacturing, launch technique, and environmental conditions. By decoupling these learning objectives, the sequence reinforces predictive reasoning and mirrors professional engineering workflows in which experimental data often precede prototype construction.

4.1 Laboratory 1: Analytical Design of Experiments and Optimization

The first laboratory introduces students to design of experiments through analysis of a provided wind tunnel dataset for a family of swept wing configurations. The dataset was generated by the teaching faculty using controlled wind tunnel testing conducted under consistent flow conditions, with geometry selected to produce measurable and interpretable aerodynamic trends appropriate for novice learners.

Three geometric variables were systematically varied according to a three-factor full factorial experimental design: Root Chord Length, Tip Chord Length, and Angle of Attack. Figure 1 demonstrates the physical representation of the Root Chord and Tip Chord variables in a bounding box for swept glider wings. The Angle of Attack references the angle at which the wing sits with respect to the fuselage. All other parameters, including material, surface finish, and test conditions, were held constant. This structure enables students to isolate the influence of individual variables while also identifying interaction effects between them.

Rather than tasking students with collecting the aerodynamic data themselves, the dataset is intentionally provided, which ensures that all students begin under the same circumstances. This decision serves several instructional purposes. First, it eliminates variability associated with measurement technique, equipment calibration, and experimental setup, which are difficult for first-year students to work with. Second, it allows students to focus on the structure and purpose of experimental design, rather than on procedural execution. Finally, it reflects common engineering practice, where designers frequently rely on previously generated experimental or archival datasets during early-stage analysis.

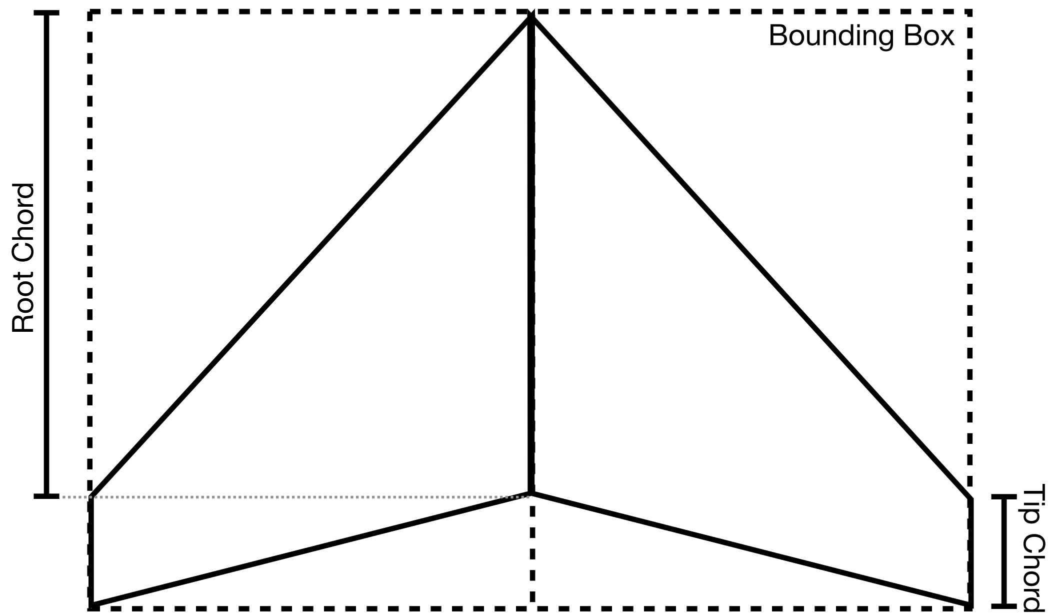

Figure 1: Swept wing style identifying Root Chord and Tip Chord geometry.

Students begin the laboratory by interpreting the wind tunnel data and organizing it into a standard factorial design matrix, an example of which can be seen in Table 1. Using Microsoft Excel, they calculate main effects and interaction terms and examine trends in aerodynamic performance as a function of each variable. Visualization tools are used to support interpretation and to emphasize that interaction effects cannot be inferred from one-factor-at-a-time reasoning.

Table 1: Three-Variable Full Factorial Design of Experiment (Wind Tunnel Data)

Root Chord		**Tip Chord**		**Angle of Attack**		**Wind Tunnel Lift**
L_{root} [mm]	+/- 10%	L_{tip} [mm]	+/- 10%	θ [º]	+/- 10%	[N]
66	+1	22	+1	5.5	+1	0.06
66	+1	20	-1	5.5	+1	0.065
60	-1	22	+1	5.5	+1	0.06
60	-1	20	-1	5.5	+1	0.07
66	+1	22	+1	5.0	-1	0.08
66	+1	20	-1	5.0	-1	0.06
60	-1	22	+1	5.0	-1	0.05
60	-1	20	-1	5.0	-1	0.075

Following analysis, students develop simple empirical models describing the relationship between wing geometry and aerodynamic performance. These models are not intended to provide high-fidelity aerodynamic prediction, but rather to reinforce the concept that different variables will have different impacts on the overall performance. Students learn first-hand that time and attention should be more heavily allocated to high-impact variables during the design phase.

Using these models, students identify a predicted optimal combination of geometric variables. Optimization is presented not as a purely mathematical process, but as an engineering decision informed by data trends, assumptions, and model limitations. Students are required to justify their selected design, explicitly acknowledging sources of uncertainty and the bounds of the experimental dataset.

By the conclusion of the first laboratory, students have developed an analytically informed design recommendation that serves as the basis for the subsequent lab centered around physical implementation.

4.2 Laboratory 2: Fabrication and Aerodynamic Stability

The second laboratory transitions from analytical prediction to prototyping and testing. Students fabricate a trapezoidal balsa wood glider wing based on the optimized geometry identified during the first laboratory. Fabrication is completed using laser-cut components following completion of required maker space safety certification.

Constraining the fabrication process to a standardized general geometry of a swept wing ensures consistency across student groups while still allowing meaningful design variation based on DOE-informed decisions. Students must model their assembled glider design in CAD, and utilize the technology to determine the location of the center of mass. An example of this is shown in Figure 2.

From the CAD model, the glider parts are laser cut and then assembled. Students learn about the specific quirks of the utilized fabrication methods that would not be readily evident in a basic CAD model. First and foremost, typical laser cut parts are produced with either a vertical (gantry style laser) or an angled cut edge (galvo style laser), which becomes more prominent with thicker material. As such, orthogonal planes might not be reliably aligned during assembly. Additionally, joining methods, particularly adhesives, add weight to the glider typically unaccounted for in the Freshman level CAD rendering. This may throw off the approximated center of mass of the assembled glider.

Once constructed, the glider is modified to accommodate a stored payload with adjustable mass locations. This configuration introduces students to aerodynamic stability and the influence of weight distribution on flight behavior.

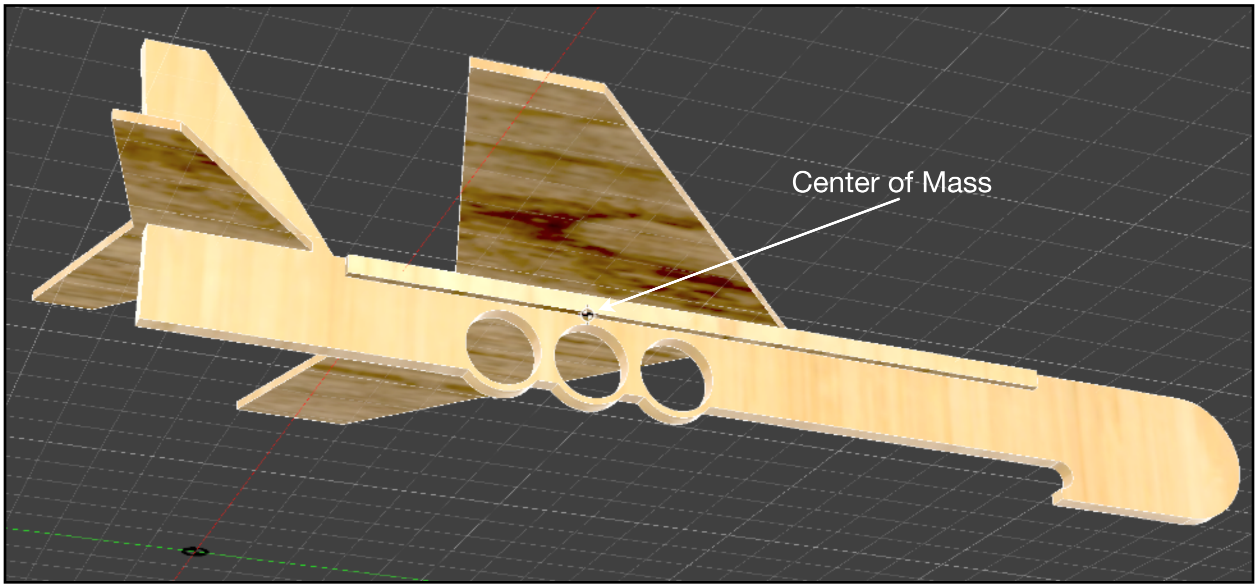

Figure 2: Sample CAD model of basswood glider identifying approximate center of mass.

Instruction focuses on foundational aerodynamic concepts, including lift force, center of pressure, center of mass, and pitching moments. These topics are introduced qualitatively, with emphasis placed on physical reasoning rather than more advanced formal aerodynamic derivation.

Students determine the approximate center of lift for their wing using a simplified graphical method appropriate for first-year instruction (Figure 3). This approach preserves conceptual understanding while avoiding dependence on advanced aerodynamic theory. Students then systematically adjust payload mass and location to align the center of mass beneath it. Through iterative testing, students directly observe the effects of stable and unstable configurations. Stable flights, stalls, and nose-heavy or tail-heavy failures provide immediate visual feedback, reinforcing the relationship between moment balance and flight behavior. These observations allow students to connect abstract concepts of force and moment to tangible outcomes.

Throughout the laboratory, students document observed behavior and compare actual performance to expectations developed during the analytical phase. Discrepancies between prediction and observation are discussed explicitly, reinforcing the role of uncertainty, simplification, and real-world variability in engineering systems.

Together, the two laboratories establish a coherent design narrative:

1. Experimental data informs the design process
2. The design guides and/or is adjusted for fabrication choices
3. Prototype testing validates or challenges analytical assumptions
4. Optimization through iterative adjustments produces a functional final product

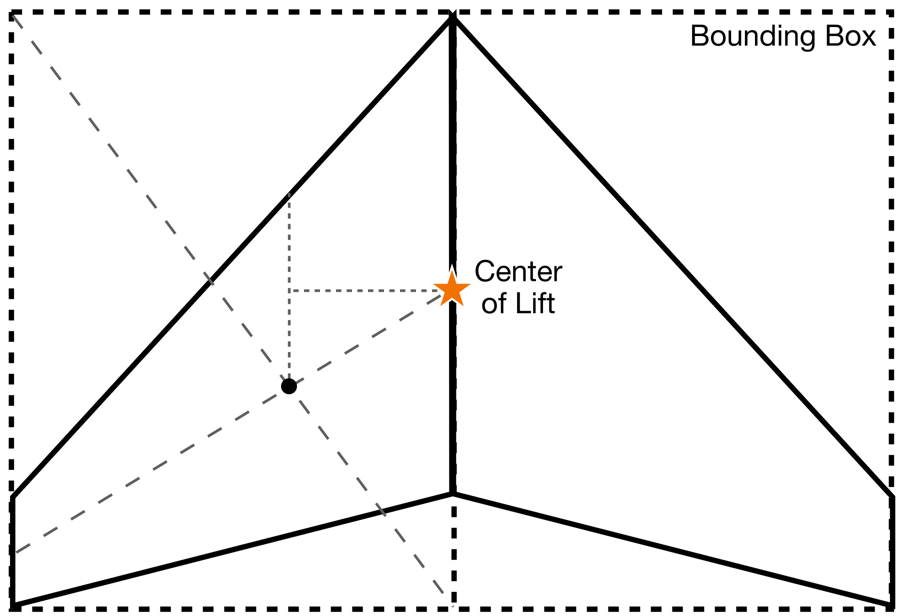

Figure 3: Demonstration of graphical method used to identify the approximate center of lift. First, find the intersection of the half-wing bounding box diagonal line and the wing centerline. From that intersection point, extend a vertical line up to the wing's edge. The midpoint of the vertical line extends to the wing fold, *approximating* the center of lift.

This progression reinforces the iterative nature of engineering design and strengthens students' understanding of how experimentation, modeling, and physical behavior interact within real systems.

At the end of the activity, a low-stakes flight competition is held. This is a useful addition to encourage students to truly engage in the iterative optimization process to produce a better glider. The competition leaderboard is primarily driven by radial flight distance, favoring longer and more direct fight paths as measured linearly from the launch point to the landing point. The Score is calculated by subtracting the lateral deviation from the intended linear path from the radial flight path. Ties are broken in favor of the glider carrying the most cargo. Secondary ties are broken in favor of the lighter aircraft.

Students enjoy the competition aspect and it appears to successfully engage them in the design and refinement process. It is key that the student grades are not diminished by a low ranking on the leaderboard, to keep the competition friendly and low-stakes. However, a small bonus for the winner has proven an effective motivator.

5. Assessment and Results

Student understanding of Design of Experiment topics was assessed using multiple-choice and calculation questions standard to the course final exam. Assessment focused on conceptual understanding of design of experiments, optimization reasoning, the ability to interpret experimental results, predict system behavior, and identify the implications of design decisions. No questions required prior exposure to advanced aerodynamic theory or fluid mechanics coursework. Student learning was evaluated using course-level assessment data collected as part of normal instructional practice. All data were analyzed in aggregate and used solely for instructional evaluation.

5.1 Analysis Method & Results

To evaluate the instructional impact of the laboratory sequence, student performance on selected final exam questions was compared across course offerings before and after implementation of the flight-based laboratories. The same or equivalent conceptual questions were used to ensure consistency in content coverage. Performance was evaluated using percentage-correct responses aggregated across the student population. This approach was selected to provide a measure of conceptual understanding appropriate for large enrollment introductory courses.

There were four questions on the final exam related to DOE topics, three of which were calculations, and one of which was multiple choice. The specific topics assessed were:

1. Calculating the effect of a variable given a full factorial DOE data set
2. Calculating the effect of variable interaction given a full factorial DOE data set
3. Identifying the most impactful variable given a full factorial DOE data set
4. Calculating the number of experiments needed for a full factorial DOE setup

The aggregate population of student exam results pre-flight lab was N=661 across nine sequential semesters spanning years 2023-2025. After the flight lab was integrated in to the curriculum, the aggregate population of student exam results was N=171 from one semester in 2026. While there were no significant changes seen in the exam performances for Topics 1-3, there was great improvement seen in Topic 4.

Results indicate that calculation-based DOE topics 1 and 2 are found to be challenging, as roughly half the class is able to correctly answer those questions in a typical semester. The common mistake typically seen in calculating the impact of a single variable or interaction is skipping the division end-step. Topic 3, which is centered on identifying the variable with the most impact, was much higher than the calculation questions, with most students taking the exam answering correctly. This suggests that students generally grasp the purpose and interpretation of DOE, but that procedural execution remains inconsistent. This trend persisted following implementation of the flight lab series, and showed no significant change..

Student feedback suggests that this difficulty is likely tied to uneven participation during team-based calculations. In practice, one student often performs the majority of the computation while others take physical measurements needed for those calculations. As a result, many students develop conceptual understanding without sufficient reinforcement of the analytical procedure.

Performance on Topic 4 (determining the number of required experiments) showed great improvement. Historically, roughly 62% of students would answer correctly, but that increased to nearly 84% after the implementation of the lab series. This aligns with the theory developed off of student feedback, where all team members participate in setting up the DOE lab data tables before dividing up the remaining activity tasks.

The most substantial gains were observed in student understanding of experimental structure and variable interaction. While these improvements are more difficult to isolate through exam performance alone, they were consistently reflected in student reasoning and interpretation during laboratory activities.

5.2 Observed Instructional Outcomes

In addition to quantitative assessment results, several qualitative instructional outcomes were consistently observed. Students exhibited greater confidence when interpreting experimental data and were more willing to discuss uncertainty and limitations in their analyses for the flight lab as compared to prior design-build-test labs earlier in the semester. This shift was particularly evident in how students connected analytical predictions to design decisions. Some sample quotes showcase this:

> *"In an earlier lab, an equation for drag was developed…and our group settled on the listed dimensions as the most optimal wing design."*
>
> *"The larger tapered wing was still the right choice aerodynamically since the greater surface area generates more lift and the taper reduces drag toward the wingtips."*
>
> *"This [CAD] model successfully demonstrated that the Center of Mass, including the metal washers in the test flights, accurately coincided with the aerodynamic center of the wing. Overall, the swept wing model developed by our group was far and away a successful design. Each of the flight tests more than doubled the distance of the next closest group."*

Students also began to articulate how design modifications influenced performance:

> *"The cutouts of the lightweight fuselage of the glider improved the lift-to- weight ratio and allowed the glider to carry the washer without reducing the overall performance."*

During laboratory activities, students engaged more readily in iterative testing and refinement, particularly when physical behavior deviated from analytical prediction. Rather than viewing discrepancies as errors, students increasingly framed them as opportunities to re-examine assumptions and model fidelity. They seemed to understand that optimal design is constrained by assumptions, experimental bounds, and tradeoffs rather than defined solely by maximizing a single performance metric. Representative excerpts demonstrates this:

> *"Through our repeated tests, we found that having a swept leading edge contributed to a more successful flight of the object."*

"We didn't want too much of a sweep since we need the lift, but also enough of a sweep to not be a victim to drag."

"Through trials with the prototype, we saw that using tape as an adhesive is unreliable and deteriorates quickly. Also, using tape can quickly skew the center of mass (COM) calculations. The group's results show how small changes in material choice and mass distribution can significantly influence a glider's performance. These results highlight the importance of the engineering design process and prototyping."

Introducing this realization at the first-year level is particularly valuable, as it establishes early that successful engineering outcomes depend not only on analytical prediction, but on careful consideration of fabrication realities, uncertainty, and system-level interactions. The lab sequence was very effective in both teaching these concepts and improving their fabrication capabilities in preparation for the rest of the college curriculum.

6. Limitations & Conclusion

The primary instructional value of the sequence lies in its deliberate structure. By introducing design of experiments and optimization through analytical interpretation before physical construction, students are encouraged to engage in predictive reasoning. Fabrication and flight testing then serve as mechanisms for validating assumptions and confronting real-world variability, reinforcing the iterative nature of engineering design.

Some limitations should be acknowledged. Flight testing introduces unavoidable environmental variability, including minor changes in launch conditions and airflow. While standardized procedures were employed, such as general constrains on chassis length/launch points and a repeatable launch mechanism (shown in Figure 4), other factors may influence observed performance.

Figure 4: Demonstration of systematic launch conditions.

Additionally, aerodynamic behavior was modeled using simplified assumptions appropriate for first-year instruction. The intent of the laboratory was conceptual understanding rather than high-fidelity aerodynamic prediction, and results should be interpreted accordingly.
Despite the limitations, assessment results suggest the laboratory sequence effectively supports early development of experimental reasoning, optimization processes, and fabrication skills.

Early exposure to experimentation, modeling, and stability concepts supports development of engineering judgment at a formative stage in the curriculum. Students begin to recognize that analytical tools provide guidance rather than certainty and that physical behavior often reveals limitations in assumptions and simplifications. When fabrication is treated as an integral component of planned design rather than an improvised end-stage, students develop a more mature understanding of engineering practice.

The laboratory sequence presented in this paper offers a practical and transferable approach for introducing foundational mechanical engineering concepts through structured experimentation, data-informed decision making, and observable system behavior. By intentionally integrating analysis, fabrication, and performance evaluation within the first year, the sequence supports development of both technical understanding and professional engineering mindset.

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8. Appendix A

Design of Experiment: Drag Sensitivity Analysis

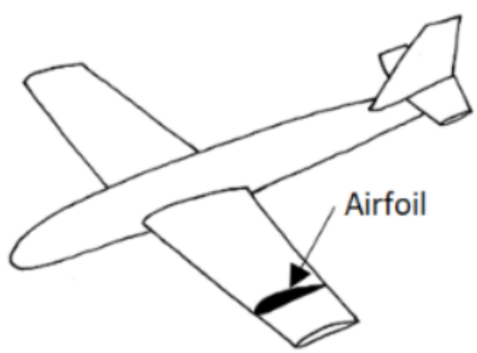
Lab Overview

In this lab, we practice the usage of Design of Experiment (DOE) protocol in analyzing data from a set of wind tunnel experiments.

Preliminary Terminology & Aerodynamic Forces

First let's define terms and concepts that we will be using. Refer to the images for the following terms.

- **Airfoil:** The specific curved cross-sectional shape of a wing.



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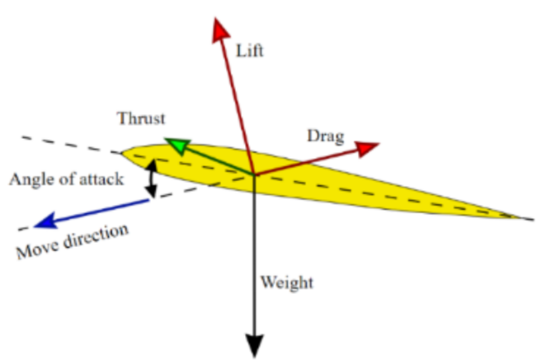
- **Airfoil Chord:** A straight reference line connecting the leading edge (the front-most point) to the trailing edge (the rear-most point) of the airfoil. This is shown as a dashed line in the image below.
- **Angle of Attack:** The angle formed between the airfoil's chord line and the direction of the aircraft's motion through the air.



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- **Lift:** The component of aerodynamic force acting perpendicular to the direction of motion. It is generated by pressure differentials; the air below the wing is compressed (higher pressure), while the air above the wing has lower pressure, resulting in an upward force.
- **Drag:** The component of aerodynamic force acting parallel to the direction of motion but in the opposite direction. It consists of:
    - **Pressure Drag:** Caused by the pressure difference between the front and back of the aircraft.
    - **Skin Friction Drag:** Caused by air friction on the airplane surface.
- **Thrust:** The forward force generated by an engine. In the context of gliders, which lack an engine, this force is absent during flight.
- **Weight:** The downward force acting on the aircraft due to gravity.

The force that we focus on in this lab is drag.

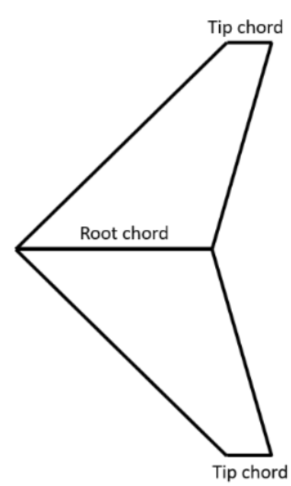
Design of Experiment Setup

The shape of a wing and the angle of attack have effects on the drag force of the wing. In this lab, we design a full factorial set of experiments to analyze the effect of these factors. Questions we want to answer using the set of experiments:

- How does a small deviation from nominal values of each factor affect drag? This is helpful for optimization.
- Is the drag more sensitive to angle of attack or to various geometric dimensions of the wing?
- Is there interaction between the factors? (Would the effect of tip chord change, for example, depend on angle of attack?)
- Can we develop an experimental formula that predicts the drag change for small deviations from the nominal wing?

The Swept Wing

We are using a symmetrical tapered wing as shown in the image.



Variables and the Nominal Values

Factors that we can change in this design are: Root chord (R), Tip chord (T), and the angle of attack (AOA). Nominal values for each factor are listed below.

Nominal Wing Values

Factor	Nominal value
Root chord (R)	63 mm
Tip chord (T)	21 mm
Angle of attack (AOA)	5.25 degrees

Process Overview

Design of experiment (DOE) protocol, as covered in class, is a method for answering questions, such as the ones mentioned in the DOE set up section, using a minimal number of tests. The technique allows us to approximate complex relationships with linear models in the vicinity of the operational point of interest. It is important to note that the actual formula can be non-linear and much more complex. For that reason, the linear approximation will be valid only for small deviations from the nominal case. For the description of the method and a detailed example, please refer to the lecture slides.

Lab Procedure

1. Use an Excel spreadsheet to set up a full factorial DOE table for three varying factors of R, T, and AOA. How many experiments are needed?
2. Watch the video of a test performed using a small-scale wind tunnel, and fill the table with the data provided from these tests.
3. DOE analysis: Calculate the effects (slopes) for each factor and all interactions.
4. Plot results on a cartesian coordinate plane to compare the linear slopes.
5. Write the linear approximation formula for drag near the nominal wing's point of operation.
6. Your team will receive two mystery wings. Measure the wings to determine their R and T values. The tested AOA is written on the wings.
7. Determine which mystery wing falls in the acceptable range for using the formula and which will not be within range.
8. Predict the drag force for both wings using your approximate formula. (Only one of them will provide a viable answer.)
9. Your TA will reveal the test results for the wings. Use them to calculate the percent error for each mystery wing's drag prediction. Discuss sources of error.

%Error = 100 |Experimental value - Approximate formula value| / Experimental value.

9. Appendix B

Delta Wing Design Challenge

Lab Overview

In this lab, the team will design, prototype, test, and fabricate a final delta wing airplane! After completing this lab, you will be able to:

- Understand and apply the basics of wing aerodynamics.
- Design for and utilize a laser cutter.
- Practice CAD modeling skills and locate center of mass.
- Experience the full design cycle, including protype fabrication, testing, and optimization.

A design report will be compiled to summarize the team's experience, process, engineering decisions, and final solution to the challenge.

Overall Process

Week 1: Exploratory Prototyping and Wing Design

1. During lab, the team will first create a simple prototype to learn hands-on the basics of applying aerodynamic principles involved in flight.
2. Applying the experience from Step 1, the team will design an optimized delta wing design for a standard fuselage, which will be tested next week in the Flight Competition.

- **Homework**: The team will utilize the laser cutters in the Maker Space to manufacture the fuselage, and the optimized delta wing. Ideally, the team will balance and assemble the parts in preparation for the Flight Competition (to be held during the following lab session).

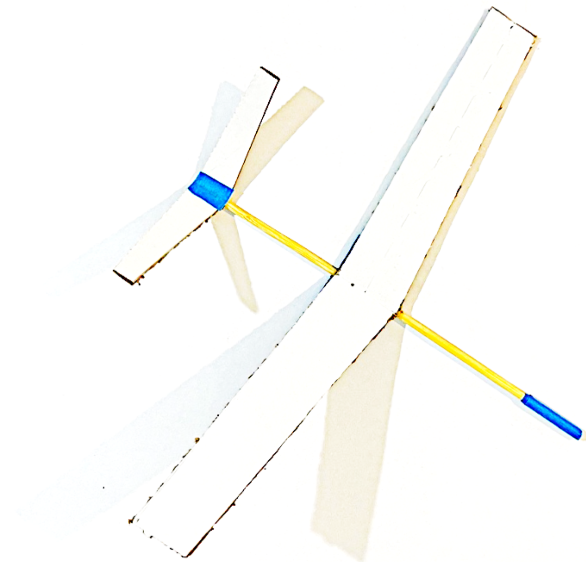
Week 2: Flight Competition

- There will be ~30 minutes dedicated to any remaining assembly and/or balancing.
- The Flight Competition will commence. Teams will take turns launching their delta wing planes and measuring how far it traveled and how stable the flight path was.
- **Homework**: The team will compile a design report that summarizes the approach to the design challenge, the engineering decisions made, final solution, fabrication process, and the results of the Flight Competition.

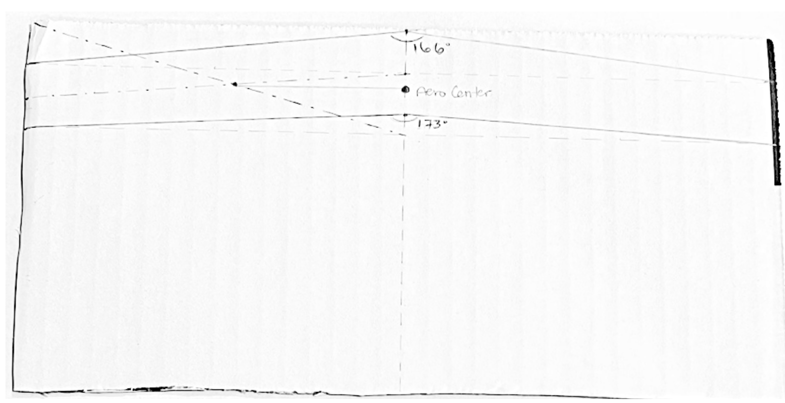
Week 1: Exploratory Prototyping & Wing Design Details

Part 1: Exploratory Simple Prototype (~25 minutes)

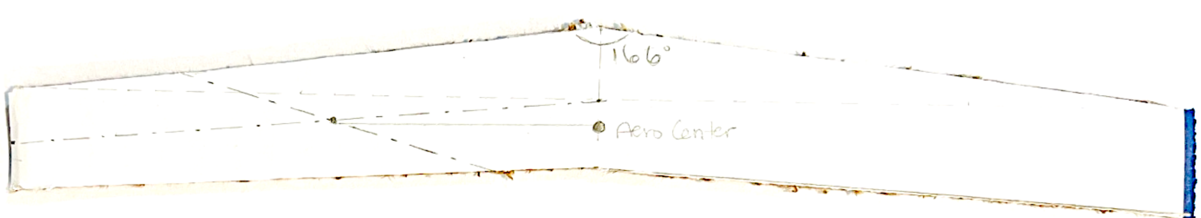
If this is the first time experimenting with creating functional aerodynamic gliders, it can greatly help to create the following simple model to get acclimated.



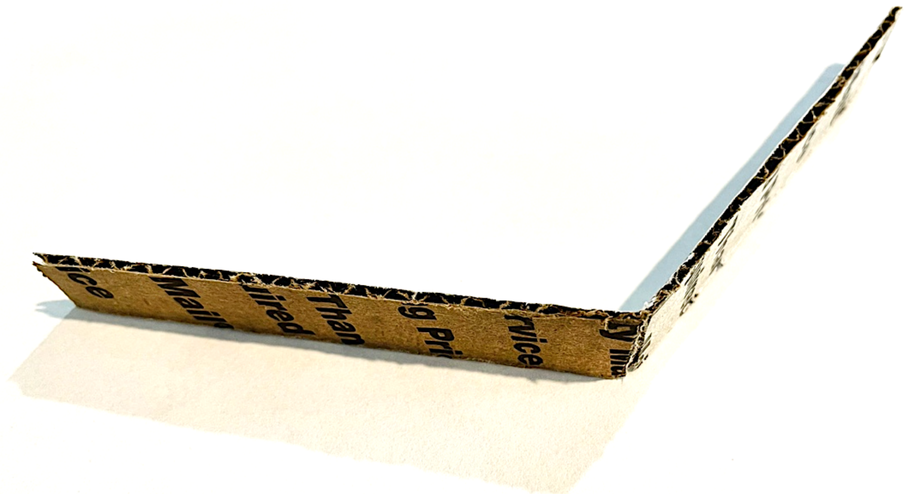
Step 1: Sketch out a simple, narrow delta wing on a piece of cardboard, and locate the aerodynamic center. A graphical method was used in the example.



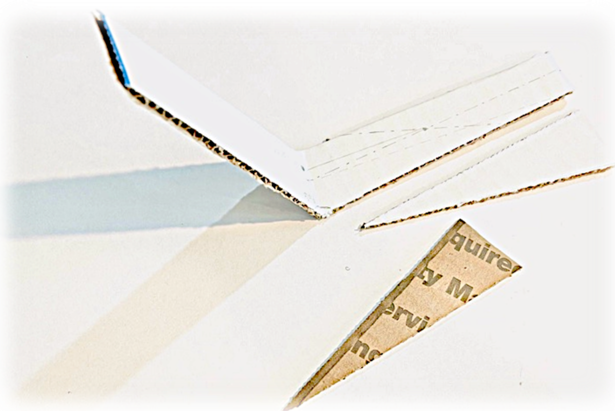
Step 2: Cut the wing out.

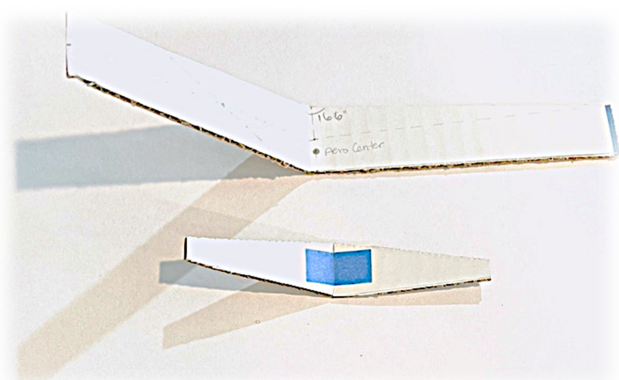


Step 3: The delta wing should be scored on the bottom to allow for an accurate bend.



Step 4: There will be angled scraps from the delta wing cutout. These can be utilized to create a two-piece tail, or another option is to create a one-piece tail that is bent into the proper angle.

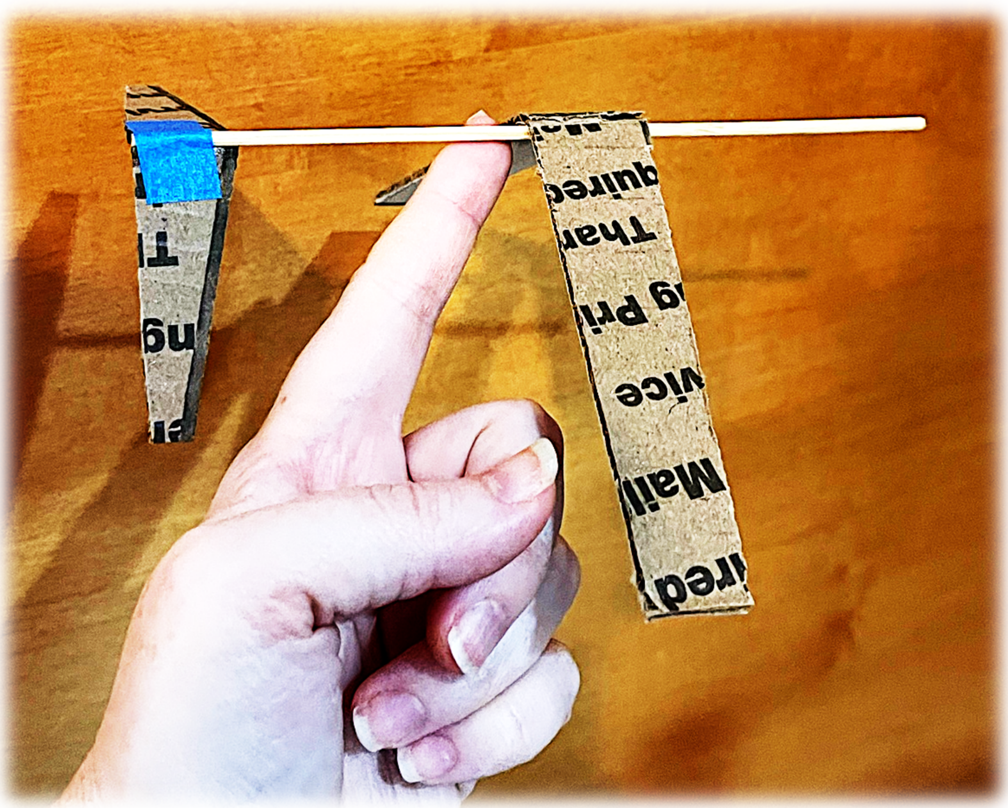




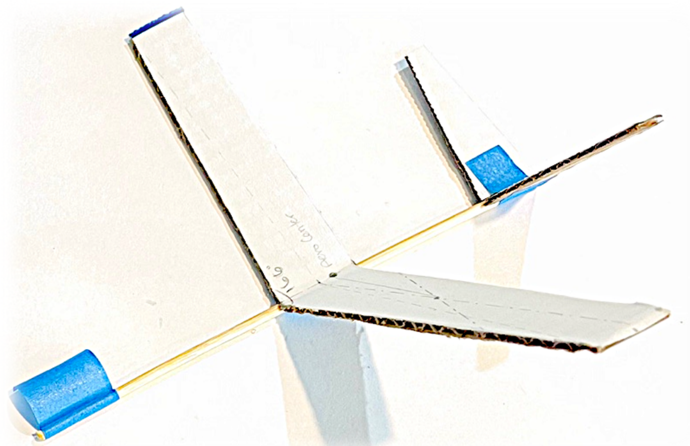
Step 5: Trim a bamboo skewer to length. The delta wingspan should be at least 25% longer than the skewer length.

Step 6: Glue and/or tape the tail onto the end of the skewer. The bend should be ~90º.

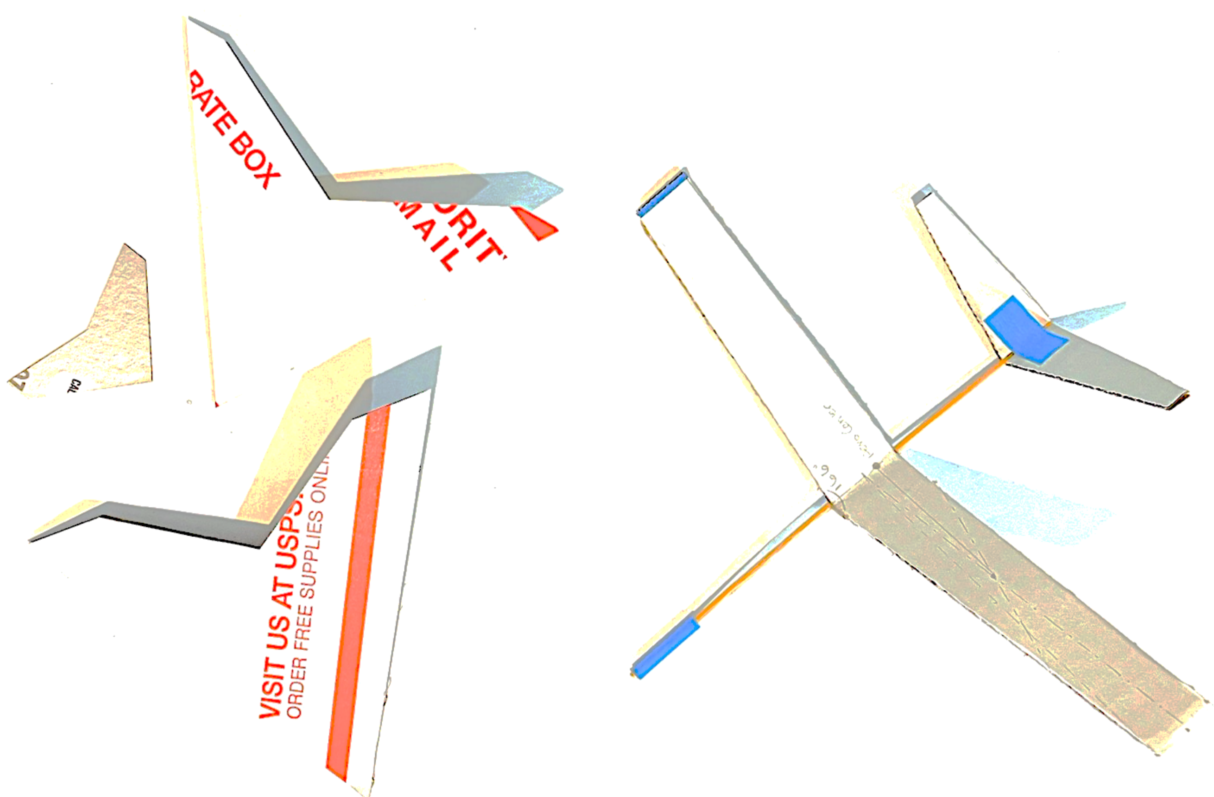
Step 7: Test the balance by sliding the wing along the skewer length to find the proper location. Once that location is found, glue the delta wing on. The balance will be finetuned in a later step.



Step 8: Glue the wing into place. Finally, finetune the balance by adding tape to the nose. If more weight is needed, a paperclip can be taped to the nose as well. Notice that the point of balance should be at or just behind the aerodynamic center of the wing, as it generates a slight lift. The dihedral wings atop of the fuselage will assist flight by self-leveling.



Step 9: Fly the plane! Observe the behavior and adjust the balance as necessary. This is also an easy method to test different wing designs before committing to fabricating a more advanced model.



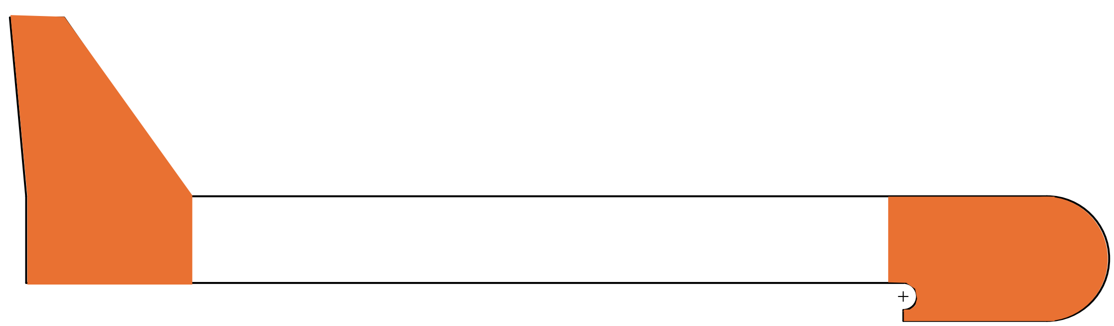
Part 2: Advanced Delta Wing Design

Challenge: Design and optimize a delta wing that maximizes flight distance and stability, for a cargo of ¼" washers.

A standardized fuselage design is provided, which the team must manufacture via laser cutting. The fuselage has a hook on the nose to facilitate a speedy launch. The delta wing may be of any size/orientation, provided it assembles onto the standardized fuselage.

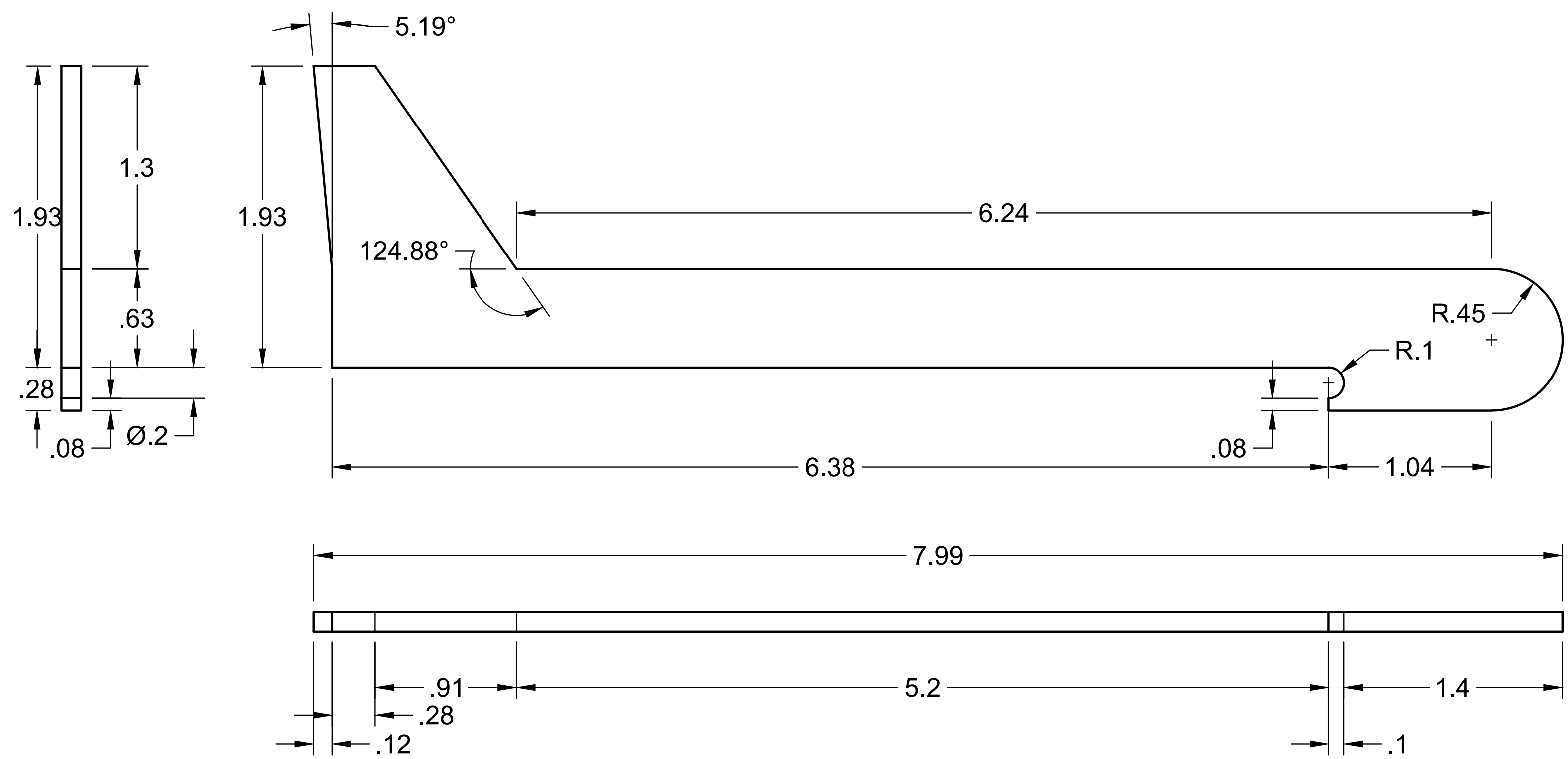
Fuselage Constraints

- An engineering drawing of the standardized fuselage is provided on the next page.
- The team must model the fuselage in CAD as an 1/8" thick sheet.
- The fuselage must be fabricated via laser cutting.
- The fuselage may be laser cut from 1/8" thick basswood, balsawood, or acrylic. Cardboard and other materials for the fuselage are disallowed.
- Minor modifications are permitted on the fuselage to facilitate lightweighting, assembly, etc. However, to maintain the standardized fit/loading into the launcher (to standardize launch conditions between teams), the *overall length and the areas in orange must remain unaltered* and true to the provided schematic. The other areas not in orange may be altered to suit the team's design.
- The fuselage must remain in one single piece.
- The fuselage and/or wing must carry 2-6 washers, attached anywhere/anyhow.



Delta Wing Constrains

- The wing style must be a delta wing design.
- The wing may be of any size and orientation; *i.e.* the wing may be flat, dihedral, anhedral, and/or possess an airfoil.
- The wing may be laser cut from cardstock, cardboard, bass wood, balsa wood, or acrylic of any thickness.
- The wing may be assembled and/or stiffened with glue, paper, and/or tape.

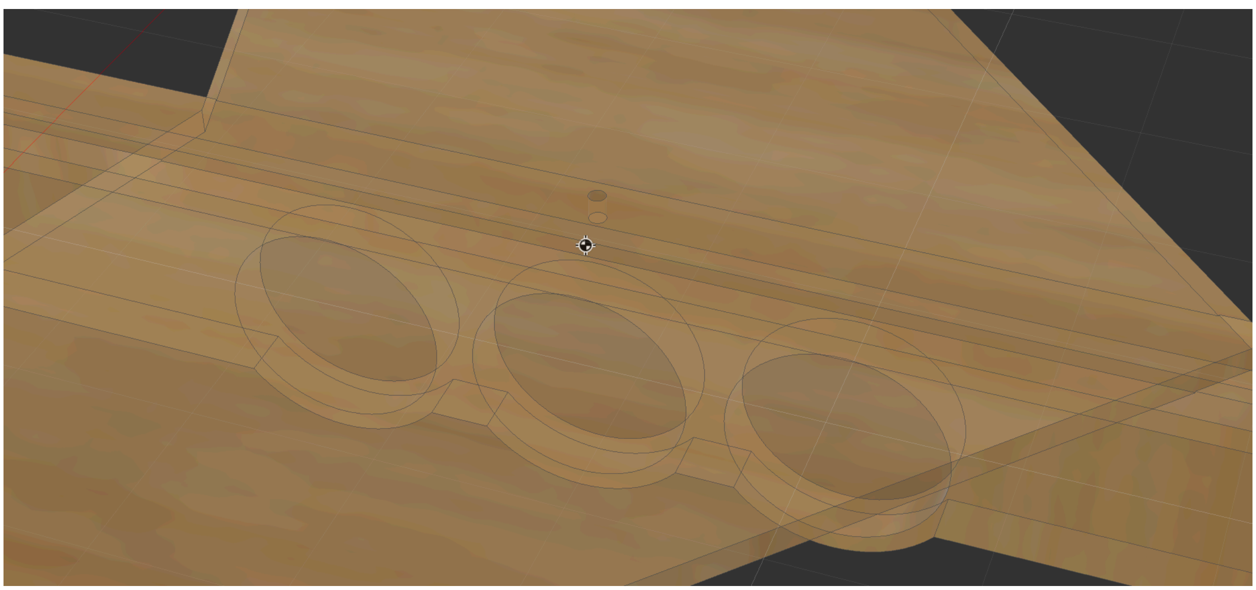


PROJECT: ENGR 1110				
TITLE: Standardized Fuselage				
All Units Are In INCHES.				
APPROVED	SIZE: A	CODE: N/A	DWG NO: 001	REV
CHECKED				
DRAWN: Dr. Sterling, 2026	SCALE 1:1	WEIGHT N/A	SHEET 1/1	

Utilizing CAD to Balance the Assembly

Leverage CAD modeling to identify the approximate center of mass of the intended fuselage and wing assembly to optimize general positioning.

- Begin by designing the fuselage and delta wing in CAD. Choose an assembly method that suits the parts, and perform any modifications deemed beneficial for the cargo and/or intended assembly process.
- It is very useful to cut a small hole into the delta wing at the aerodynamic center. This will show up on the laser cut part as well as a useful gage.
- Based on the experience gained from Part 1 (the simple prototype), make an educated guess as to where the wing should be installed for a good balance.
- Merge the parts into a single working body and use the CAD function to locate the center of mass.
- Compare the aerodynamic center mark to the location of the center of mass. The center of mass should be just under or slightly behind the aerodynamic center of the wing.



  - Note: If the initial positioning is too far apart, “undo” the merge function and reposition. Remerge the parts to assess the new position.
  - Pro Tip: This is just an estimate, as there may be slight changes in the weight/density of materials used in fabrication, and the CAD model does not account for adhesives used in assembly. Finetuning the balance will be done post-fabrication.

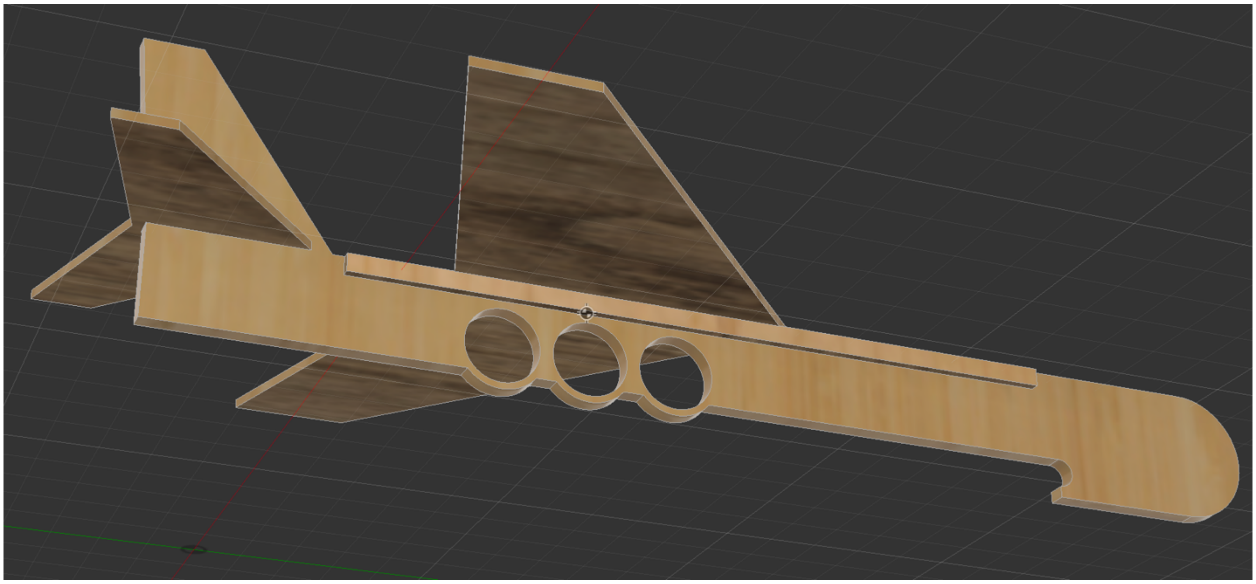


Figure 1: Merged assembly with associated wood properties. Fuselage 1/8" thick basswood; delta wing and stabilizers 1/16" basswood.

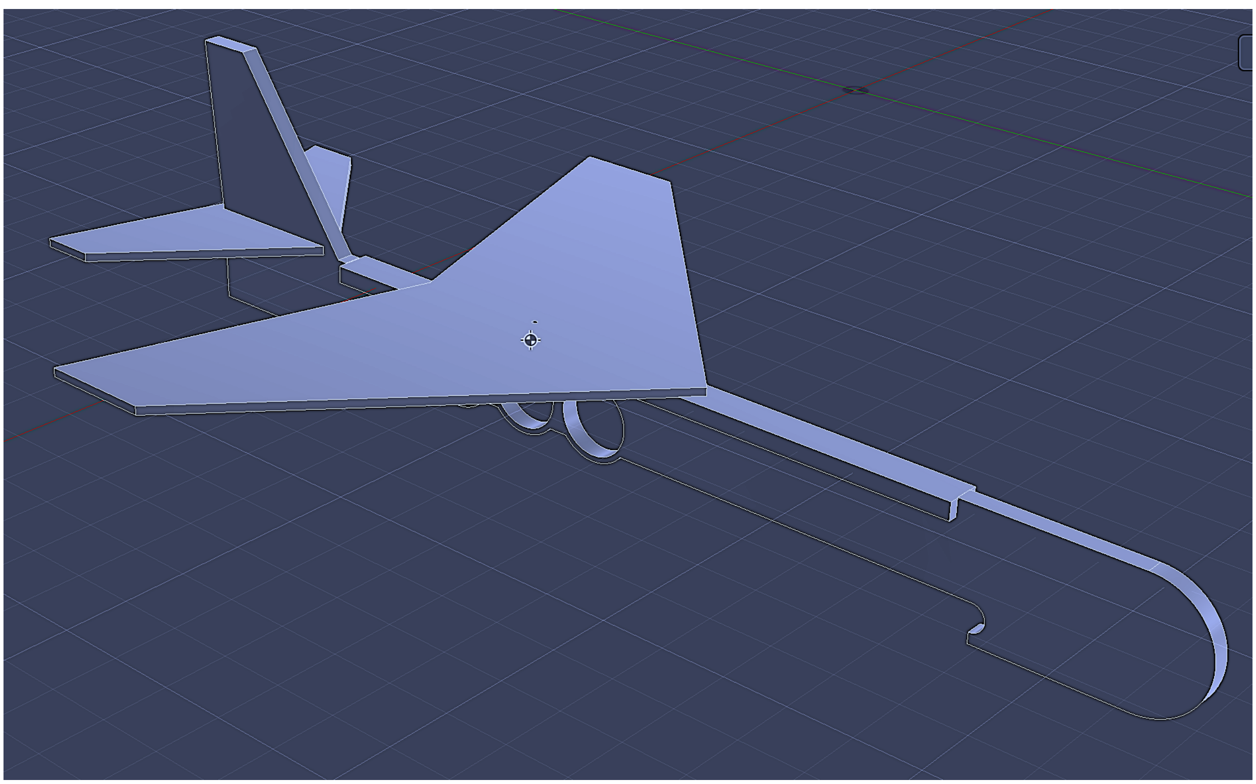
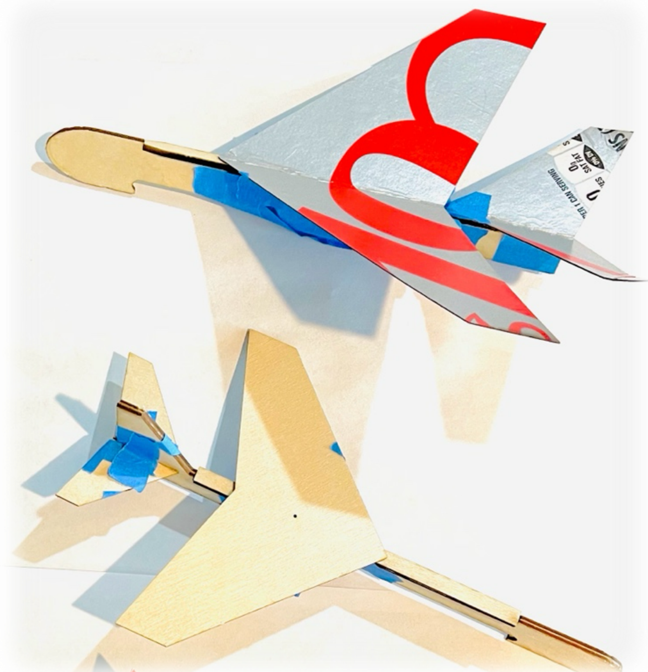


Figure 2: Assembly without properties indicating the center of mass.

Fabrication and Assembly

- The fuselage must be laser cut from 1/8" thick basswood, balsa wood, or acrylic. While doing so, it may be useful to create a balance tool, as shown below:



- It may be useful to temporarily tape the wings in place and test the flight prior to permanent assembly methods such as adhesive.
- Attach 2-6 washers to the wing and/or fuselage with any of the permitted materials (basswood, balsawood, acrylic, tape, glue, carboard, cardstock, and/or paper).

Test the plane! Based on the performance, adjust the weight distribution or even the wing shape. Design is an iterative process. It is natural that more than one attempt need be made until success is achieved.

Week 2: Flight Competition

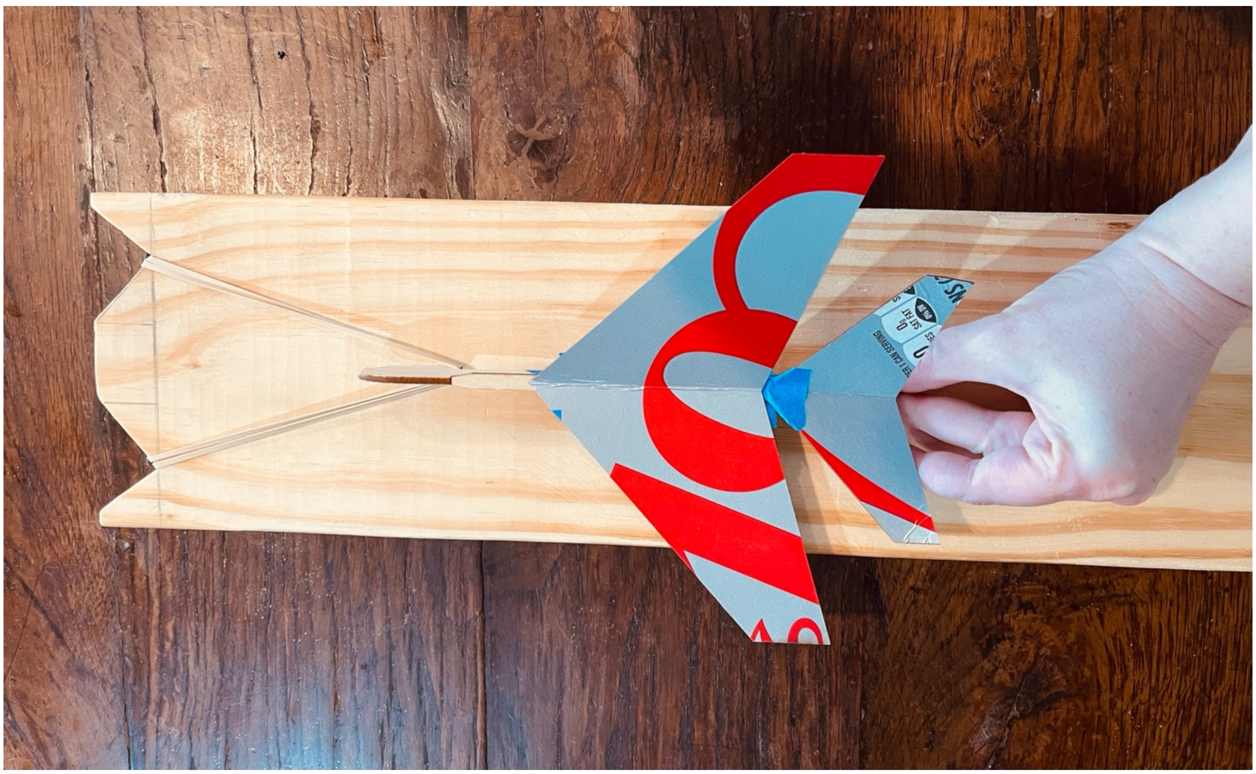
Part 1: Participate in the Flight Competition

Bring your fabricated and assembled delta wing glider to the next lab session to enter it into the Flight Competition!

Launcher Details

The launcher is comprised of a 2" in thick board with a runway 5.5" wide and 21" long. An elastic band is stretched across the end, that will hook onto the nose of the fuselage and provide a launch velocity.

The launch procedure is to hook the nose onto the center of the rubber band and pull the plane back until the tail end touched the marker point.



Target Competition Metrics

Once the plane has been launched and has landed, the following metrics will be assessed:

- Radial distance from the launch point (i.e. distance between the launcher and where the plane first hit the ground).
- Lateral distance from the ideal straight line flight path extending directly out from the launcher.

- The competition Score will be calculated by the Lateral Distance Lat subtracted from the Radial Distance Rad.

Score = Rad – Lat

- Ties will be broken in favor of the team carrying the most washers.
- Secondary ties will be broken in favor of the team with the lightest aircraft.

Part 2: Design Report

Compile a design report that summarizes the approach to the design challenge, the engineering decisions made, final solution, fabrication process, and the results of the Flight Competition. The lab report should follow standard practice and organization.

The following topics are required to be discussed:

- Present the delta wing design and dimensions the team chose and discuss why those decisions were made. Support all choices with engineering logic.
- Provide an image of the graphical method locating the aerodynamic center.
- Provide a screenshot of the CAD model clearly showing the approximate center of mass for the assembly.
- Discuss any fuselage changes made, and the assembly process undertaken for the delta wing glider.
- Provide a photograph of the completed, fully assembled glider (Including the washers).
- Present the results/metrics of the Flight Competition. Discuss how well the glider performed and make note of any improvements that could be made to increase the competition performance score.