ASEN 2004 Aero Lab: Foundations of Aircraft Design (Milestone 2)

Administration

- Milestone Timelines:
  - Individual Concept Design: 12 Feb, 5pm
  - Final Design Video: 26 Feb, 5pm
- Collaboration Guidance: Team Assignment (Same teams as Milestone 1)
- Software Requirement:
  - Any computational/programming tool (MATLAB, Excel, Python, etc). Must provide code or file with submission
  - Any word processing software

Overall Learning Objectives

1. Demonstrate an adaptive engineering mindset and good engineering judgement towards the open-ended design of a basic aerospace system
   1.1. Engineering Judgement: Be able to explain the advantages and limitations of theoretically and empirically derived first-order aerodynamic models for estimating the lift characteristics, drag polar and performance in the design of new aircraft
   1.2. Adaptive Mindset: Demonstrate the ability to identify assumptions and unknowns and seek out knowledge to apply new and theoretically sound models when needed
2. Practice the application of a structured design methodology towards a complex engineering problem.
   2.1. Demonstrate the ability to translate design requirements to a clearly defined design space in terms of key design variables.
   2.2. Demonstrate the ability to quantifiably analyze, evaluate, and select from design alternatives
3. Reinforce understanding of aerodynamic coefficients (lift, drag, moments) and the underlying impact and inter-related aspects of key aerodynamic parameters and design variables such as:
   3.1. Reynolds Number
   3.2. Wing planform geometry and airfoil

  3.3. Oswalds and span efficiency factor
  3.4. Weight
  3.5. Wing Loading and Thrust-to-Weight Ratios
4. (BONUS) Understand and describe the basic concepts of longitudinal and lateral stability through the design, fabrication, and test flight of a sub-scaled glider.

Required Milestone 2 Deliverables

- (100 pts) Milestone 2: Glider Design (Team Deliverable)
  - 10% Individual Concept Design (Individual Sub-Deliverable)
  - 75% Final Presentation
  - 15% Peer Eval Grade
- (10 bonus pts) Prototype Glider Build and Fly (Optional Team Bonus Points allocated at end of semester)

MILESTONE 2: GLIDER DESIGN

Glider Design Requirements Table

The following table represents the customer requirements for your glider. Requirements translate the customer's needs into measurable values and are usually given in terms of "must have" or threshold measures and "like to have" or objective measures. The weighting of each requirement by the customer is critical to give the designer a better understanding of what measures are most important and guide the designer in making design tradeoffs. Make sure you read and understand the customer's weighting and be able to discuss how it affected your design choices.

Table 1. Summary of Glider Prototype Requirements
(7 m launch height, 1.5 km Standard Atmosphere)

System Requirements	Threshold	Objective	Min or Max
Max Glide Range (meters)	70 m	100 m	Max
Max Glide Range Velocity (meters/second)	12 m/s	7 m/s	Min
Max Glide Endurance (seconds)	7 sec	10 sec	Max
Elevator Pitch Control (degrees)	+/- 8 deg	+/- 10 deg	Max
Longitudinal Stability (x_{cg} location measured from leading edge of wing)	$0c < x_{cg} < 1.0c$ (inside chord of wing)	$x_{cg} = 0.25c$	-
Longitudinal Stability (Horz Tail Volume)	$V_H = 0.3$	$V_H = 0.6$	-
Lateral Stability (Vert Tail Volume / Spiral)	$V_V = 0.02$ $B \geq 5$	$V_V = 0.05$ $B \geq 5$	-
Maximum Wingspan (meters)	1.0 m	N/A	Min

Payload Requirement	Must securely & safely transport the payload outlined in Appendix 3. • Camera must be secured where it cannot shift in flight or upon impact with ground. • At least one "lens" must be able to see the ground (both lenses exposed is preferred but not required). • Camera or Lens cover should not be subject to direct impact forces during landing or a crash. • Aircraft must be flight certified with a "dummy payload" before an actual payload is used in flight	-
Unit Cost (Fake dollars) using the formula: Empty Weight (in grams) * $1 = Cost	No "limit", but will be used as a discriminator between designs.	Min

The General Design Process

There are many aircraft design processes, but all are generally similar. The following design process for this lab is a simple, but effective process that we will utilize to help you through this process for your glider design. Note that this process is iterative to both refine and optimize a given design as well as attempt to fully explore the design space. While lab is time limited, each individual on a team should accomplish at least 2 iterations of your conceptual designs which combined with the design iterations of your teammates will expand the level of design iterations per team within a reasonably short period of time to ensure you have explored your design space.

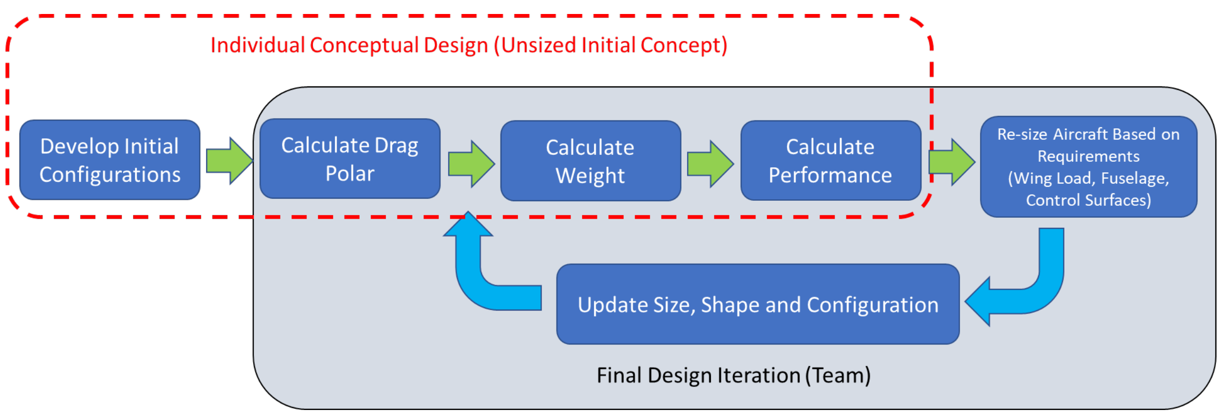

Figure 1: Milestone 2 Design Process

The individual conceptual design portion (red dashed box), is an individual task where you develop an initial configuration for your aircraft. **As a team, you should explore a wide range of configurations (i.e. all designs should not be similar)!** If everyone examines a traditional glider configuration, then you will not be exploring the design space effectively. At this stage, it is not necessary that you meet requirements, you are just looking for the most promising design among your team. Because you have not sized the aircraft against requirements yet, you will just need to establish an initial guess at the size of your glider to enable you to estimate the weight and performance.

After comparing designs, select the most promising or decide on a new configuration that combines aspects of different team member's initial designs to conduct the iterative portion of the lab as a team (grey box). This is where you will size and optimize the aircraft design to meet the specific requirements outlined in Table 1.

Developing your Aircraft Design

In a very simplistic approach to the initial stages of conceptual aircraft design, the primary focus is to develop an initial configuration of your design, estimate the drag polar and initial weight for this design, and then size the aircraft based on the design requirements. Sounds simple, however, you will quickly realize that dependencies across the many design parameters can make this a difficult process.

Overall Aircraft Configuration, Drag Polar and Weight Estimation

Based on your understanding of the problem and the information you gathered on both existing aircraft and design elements as well as your analysis of the analytical design variables you can adjust, select design features you deem most beneficial to your requirements. You don't need refined dimensions yet as you will continue to work on those as you iterate your design, but you'll need to have a general sense of the dimensions to aid in your weight estimation.

<u>Determine range of general configurations to explore design space:</u>

In selecting the general configuration of your aircraft, there are endless options; however a few are shown below as examples. Each configuration has advantages and disadvantages, and it will be left to you and your team to research what configuration or combination of configurations best supports your customer requirements.

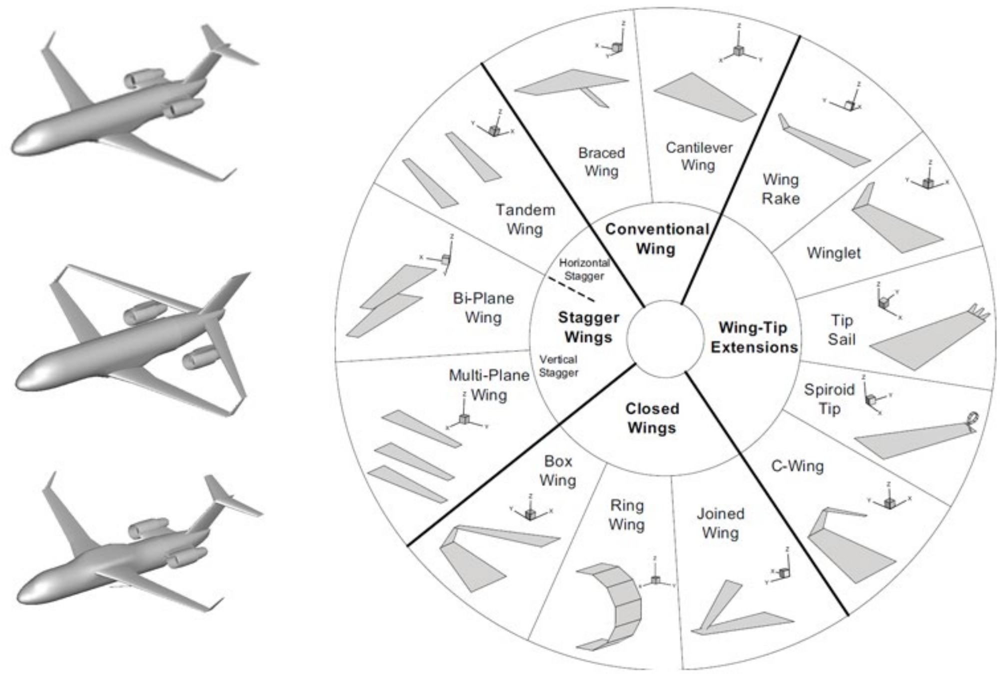

Figure 2: Example Aircraft Configurations (Source: Advanced Aircraft Design Lab Royal Military College of Canada[1])

The choice of overall configuration can be broken down further into the choice of a wing planform shape, airfoil selection, and control surface configuration.

Wing Planform Design

In determining the general wing planform shape, the general parameters which you need to define are:

1) Wing Planform Area (S_{ref} will be used in this lab to distinguish this value from wetted area S_{wet})
2) Aspect Ratio (AR)
3) Taper Ratio (λ)
4) Sweep Angle (Λ)

As well as the positioning of the wing relative to the fuselage:

1) Low wing
2) Mid-wing
3) High-wing

[1] Advanced Aircraft Design Lab Royal Military College of Canada, http://www.aircraftdesign.ca/research/research.html

Recall your lecture material on finite wings and the impact of wing planform shape on induced drag (span efficiency) as well as stall. Wing planform shape also impacts the location of your wing aerodynamic center and therefore has an impact on your longitudinal static stability. The full scope of the equations and variables that define your wing planform geometry can be reviewed in the appendix of this lab writeup.

Wing Airfoil Selection

You will not be selecting an airfoil shape for your wing design. Instead, all wing designs will utilize "flat plate" wings as your glider will be fabricated from flat stock foam board. Milestone 2 will involve a "deep dive" into understanding the unique aspects of flat plate wings for use in low Reynolds Number applications. The aerodynamics of even "simple" geometries such as flat plates highlights the complexity in modeling the aerodynamics of aircraft. All designs will utilizes "flat plate" wings. The experimental 2D Flat Plat Wing lift curve data you will use for this design is provided in the Appendix 2 of this lab writeup.

To inform your design of a flat plate wing and fully understand the complexities of low Reynolds number aircraft, it is recommended that your team read the following references that will be provided on Canvas:

- Mueller, T.J.; Aerodynamic Measurements at Low Reynolds Numbers for Fixed Wing Micro-Air Vehicles; Hesert Center for Aerospace Research, University of Notre Dame; 1999.
- Ananda, G.K; Sukumar, P.P.; Selig, M.S.; Measured Aerodynamic Characteristics of Wings at Low Reynolds Numbers; Department of Aerospace Engineering, University of Illinois at Urbana-Champaign; 2014.

Finally, a flat plate wing is considered a "symmetric airfoil" and therefore for your glider design, you will be using the general form of the whole aircraft drag polar equation for your glider design:

$$C_D = C_{D_O} + kC_L^2$$

Control Surface Configuration

Choice in your control configuration (horizontal and vertical tail or canards) is vital in that this will have a large impact on your stability as well as your ability to set a trim velocity and angle of attack for your glider. **As with your overall consideration, each control configuration has advantages and disadvantages, and it will be left to you and your team to research what configuration or combination of configurations best supports your customer requirements.**

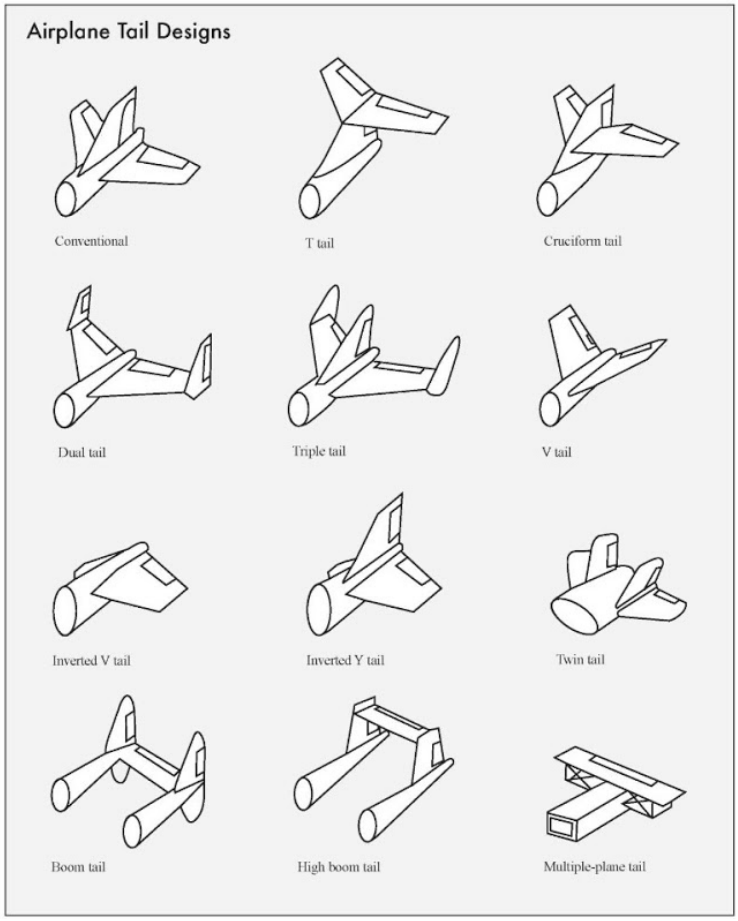

Figure 3: Example Airplane Tail Configurations[1]

At the end of this stage, you should have established an initial estimate for the following:

1) Wing Planform Area (S_{ref})
2) Wing Aspect Ratio (AR)
3) Wing Taper Ratio (λ)
4) Wing Sweep Angle (Λ)
5) Whole Aircraft Wetted Area (S_{wet}) to include control surfaces and fuselage

Drag Polar Estimation:

Once your configuration (or shape) of your aircraft is determined, you can now estimate your drag polar based on the methods and models you developed in milestone 1. To do your drag polar estimation, you also require an initial "guess" at the size and dimensions of your aircraft. An informed guess based on typical aircraft in the same category of your design is usually a decent starting point, and you will size the aircraft based on your specific requirements later.

[1] http://what-when-how.com/flight/tail-designs/

Weight/Mass Estimation & Initial Sizing:

Based on your initial guess at the size / dimensions of your aircraft, estimate your weight using the material properties of materials you can expect to use. You will be provided foam board (otherwise known as "Dollar Tree Foam" and foam safe CA glue to build at no cost; however, if you want to use other materials you can but you must supply it yourself and determine their weight properties. **Dollar Tree Foam's approximate weight is 0.295 kg_f / m^2.** **NOTE: Most of the weight properties of lightweight materials used are provided in terms of kg force (kg_f) or gram-force (g_f). To ensure consistent units in your calculations, you MUST convert these to newtons (1 kg_f = 9.81 N).**

The following website provides good descriptions of other material characteristics as you consider you options: http://www.rcplanesguru.org/2015/09/materials-and-hardware-used-for-rc.html. Note that these materials densities are based on areas, not volumes due to their small thicknesses.

The estimated weight of your aircraft will be simply the sum:

$$W_{TO} = W_{fuselage} + W_{wing} + W_{horz\ tail\ or\ canard} + W_{vert\ tail} + W_{ballast} + W_{payload}$$

The ballast weight ($W_{ballast}$) is weight required (generally on the nose of your glider) to ensure that the center of gravity (cg) of your glider is located in a position for static longitudinal stability (stability in pitch). A good design should require minimal ballast as ballast is "dead weight" that doesn't contribute to the mission of your aircraft. To determine the amount of ballast weight you need, you will need to calculate the location of your cg based on the configuration of your glider using your weight estimates and an estimate of your cg location for your individual components. For aircraft, the reference origin for longitudinal location is at the leading edge of your wing (x = 0). The following picture and calculations demonstrates how to locate your cg:

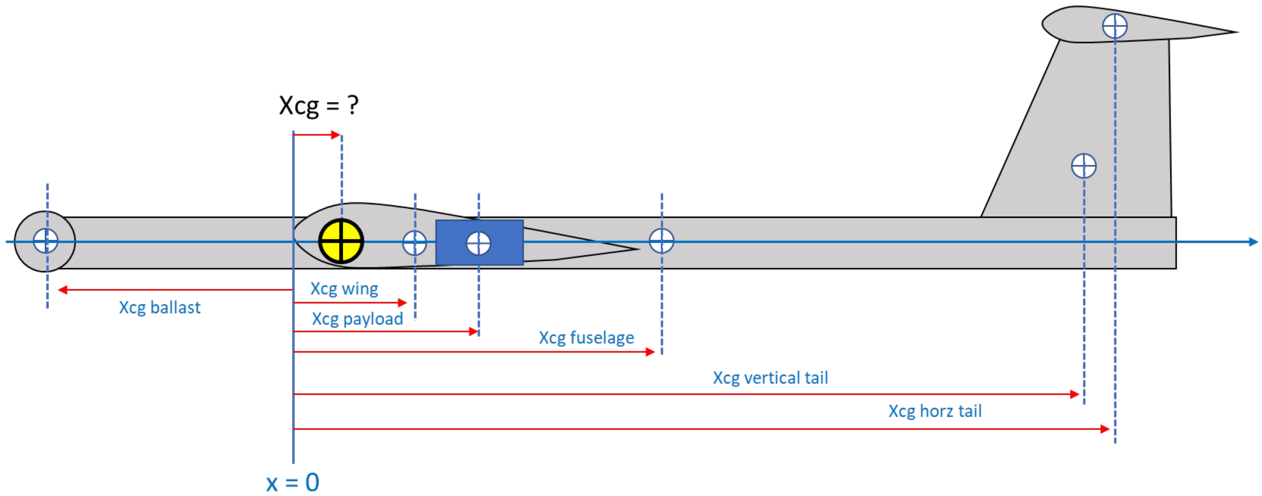

Figure 4: Center of Gravity Determination Reference Geometry

$$\sum M_{cg} = W_{TO}x_{cg}$$
$$= W_{wing}x_{cg\ wing} + W_{fuse}x_{cg\ fuse} + W_{vert}x_{cg\ vert} + W_{horz}x_{cg\ horz} + W_{ballast}x_{cg\ ballast} + W_{payload}x_{cg\ payload}$$

For symmetric components, assume the cg location is at the middle point of the component. For the wing (airfoil shape), assume that the wing cg is located at 50% of the mean aerodynamic chord. For other basic geometric shapes, you can calculate the centroid to locate the cg. ***Note that since the distance x is referenced relative to the leading edge of the wing, anything in front of the wing will have a negative value for x.*** To meet basic longitudinal stability requirements, your overall aircraft cg (x_{cg}) should be located between the leading edge of your wing and no further back than the chord length of your wing (although 25% chord is a safer value to aim for) for conventional configuration aircraft (as shown above). If you have a canard configuration, the location of the aircraft cg to ensure pitch stability is a bit more complex but initial location should generally be forward of the leading edge of your wing (i.e. a negative value).

You'll find that in many of your calculations later, wing loading (W_{TO}/S_{ref}) will appear. This ratio is an important one when it comes to correctly sizing your aircraft. From your weight estimation equation, wing loading is simply:

$$\frac{W_{TO}}{S_{ref}} = \frac{W_{fuselage} + W_{wing} + W_{horz\ tail/canard} + W_{vert\ tail} + W_{ballast} + W_{payload}}{S_{ref}}$$

Where:

- Wing Planform Area: $S_{ref} = b \cdot \bar{c} = \frac{b}{2} \cdot c_r \cdot (1 + \lambda)$

- Mean Aerodynamic Chord: $\bar{c} = \frac{2}{3} c_r \frac{1+\lambda+\lambda^2}{1+\lambda}$

- Taper Ratio: $\lambda = \frac{c_t}{c_r}$

- See the full trapezoidal wing geometry diagram and equations in the appendix of this lab writeup for a better description of your wing planform.

It is important to note that your wing weight (W_{wing}) is also a function of your S_{ref}! Therefore, any adjustment to your wing size will impact weight as well. Taking your geometry and weight estimations from the prior stages, you can now “size” your aircraft based on your range and velocity requirements.

Sizing Your Aircraft’s Wing

How big your aircraft should be is determined by analyzing its performance versus the requirements. Typically, the primary sizing parameters are wing loading (W_{TO}/S_{ref}) and thrust-to-weight ratio (T/W); however, since this is a glider design, you will not be sizing T/W and focusing on W_{TO}/S_{ref}. Specifically in this case, we are focused on sizing the wing of the aircraft since the fuselage size will largely be determined by payload requirements and stability and you will size your control surfaces based on stability requirements later. The primary performance requirements that will dictate your wing loading (and thus the size of your aircraft) are your glide range and endurance requirements listed in Table 1. The general process for sizing is as follows:

1. Derive equations for the variation in max range, max endurance, velocity for max range and endurance, and aircraft cost in terms of wing loading (W_{TO}/S_{ref}). Note that both your parasite drag term (C_{Do}) and your weight (W_{TO}) will vary based on your S_{ref}!
2. Plot the variation of max range, max endurance, and velocity for max range and endurance against variations in your wing loading (WTO/Sref).
3. Identify what range of design wing loading (WTO/Sref) will satisfy all requirements (your design space). Note, you should also consider aerodynamic limits such as CLmax (Stall).
4. Identify where you current design wing loading falls on all the plots. Does it meet all requirements? Is it optimal?
5. If required, select a new wing loading for your next design iteration (this is the actual act of sizing your aircraft’s wing). Note, you may need to adjust your

AR and Oswalds efficiency factor model as well if you find you don't have a suitable design space (i.e. no wing loading satisfy your requirements).
6. Re-accomplish your drag polar and weight estimations for your updated aircraft size.
7. Re-accomplish these sizing steps as required.

This initial sizing will get you in the right ballpark for your design, but now that you have an initial aircraft configuration and wing sizing, you can refine your design using the tools you developed in lab milestone 1. Before moving on from this stage, you should have:

1) An initial estimate of zero-lift drag coefficient (C_{Do})
2) An initial total weight estimate (W_{TO}) and component weights
3) An initially sized wing planform area (S_{ref})
4) An initial estimate of your aircraft cg location (x_{cg})
5) An initial estimation of your required ballast weight to be stable in pitch ($W_{ballast}$)
6) Desired value for L/D_{max} based on your goal range
7) Required value for C_L to achieve L/D_{max}
8) Required value for C_L to achieve min power required for max endurance
9) An initial wing loading that meets C_L requirements (W_{TO}/S_{ref})
10) An initial estimate of your glide velocity for L/D_{max} ($V_{L/Dmax}$)
11) An initial estimate of your glide velocity for max endurance

Control Surface Sizing and Location (Horizontal and Vertical Tails)

The tail surfaces of an aircraft have two main purposes 1) enable stability and 2) provide enough control authority to fly throughout the required operating flight envelope of the aircraft. For your glider, this translates to having good longitudinal (pitch) and lateral-directional (roll and yaw) stability so it can fly straight and maximize its range.

For stability, our main concern at this point is static stability. Static stability is the initial tendency of your aircraft to return to equilibrium—which for an aircraft is straight and level flight. We will not be concerned too much with dynamic stability which is the behavior of the aircraft over time (does it converge on an equilibrium state?). The terminology we will use to indicate our equilibrium point is "trimmed" flight. In terms of control, the only focus of your glider will be to have pitch authority. Therefore, you will need elevators, but no ailerons or rudder are required. Your glider will required the ability to balance (trim) the glider at different angles of attack in order for you to establish the different C_L (and thus angle of attack) required to achieve max range and max endurance.

Per the requirements in Table 1, at a minimum, your elevator should be designed to provide -8 deg to 8 deg of travel to support controlling the glider in pitch. How you will ensure your tail surfaces are large enough and positioned correctly to provide both stability and control is the subject of the following sections.

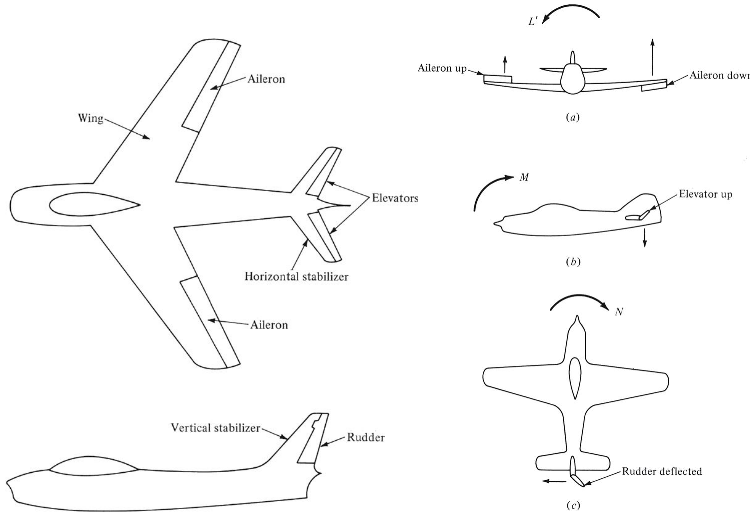

Figure 5: Control Surfaces (Source: Anderson)

Longitudinal Static Stability and Trim

The design fundamentals behind longitudinal stability have already been discussed in the prior sections on determining the location of your aircraft's center of gravity; however, the other major component to longitudinal stability is the size and location of your horizontal control surfaces. For this requirement, we're going to use some basic rules of thumb compiled by Drela[1] at MIT using a parameter called the horizontal tail volume coefficient (V_H):

$$V_H = \frac{S_h \cdot (x_{ac_{ht}} - x_{cg})}{S_{ref} \cdot c}$$

Where:

- S_h= Planform Area of your horizontal tail
- $(x_{ac_{ht}} - x_{cg})$= distance between your aircraft cg and the horizontal tail aerodynamic center
- c = chord of the wing

The criteria for basic sizing of V_H is:

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[1] Mark Drela, Steven Hall, Paul Lagace, Ingrid Lundqvist, Gustaf Naeser, Heidi Perry, Raúl Radovitzky, Ian Waitz, Peter Young, and Jennifer Craig. 16.01 Unified Engineering I, II, III, & IV. Fall 2005 - Spring 2006. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA.

$$0.30 \leq V_H \leq 0.60$$

You should aim to bias towards the higher end of this scale to ensure you also have enough pitch control authority for your glider to trim at different angles of attack and velocities. The tradeoff is a larger horizontal tail surface (or increased length of your glider to expand the moment arm) which increase your weight and drag. Meeting this horizontal tail volume coefficient criteria while keeping your aircraft cg location (x_{cg}) located between your leading edge of your wing and the quarter chord of your wing should keep you in safe territory with regards to longitudinal stability.

In order to determine your required elevator deflection to trim your aircraft at the appropriate speed for both max range and max endurance, you will need to conduct a moment balance of your glider's aerodynamic forces. For these calculations, we'll assume the only forces contributing to the pitching moment of your glider are the lift generated by the wing (L_w) and the lift generated by your horizontal tail (L_{ht}). If you recall from ASEN 2002, the location of our lift forces for an airfoil was located at the aerodynamic center (ac) of the airfoil because at this point, the moment generated by the pressure and shear distributions around the airfoil was constant as you varied the angle of attack. From our airfoil data, we know that for much of the linear range of an airfoil's lift curve, the location of the aerodynamic center can be approximated by the quarter chord ($0.25\bar{c}$) of the wing's mean aerodynamic chord ($\bar{c}$). Below is the simplified force and moment diagram for a conventionally configured aircraft:

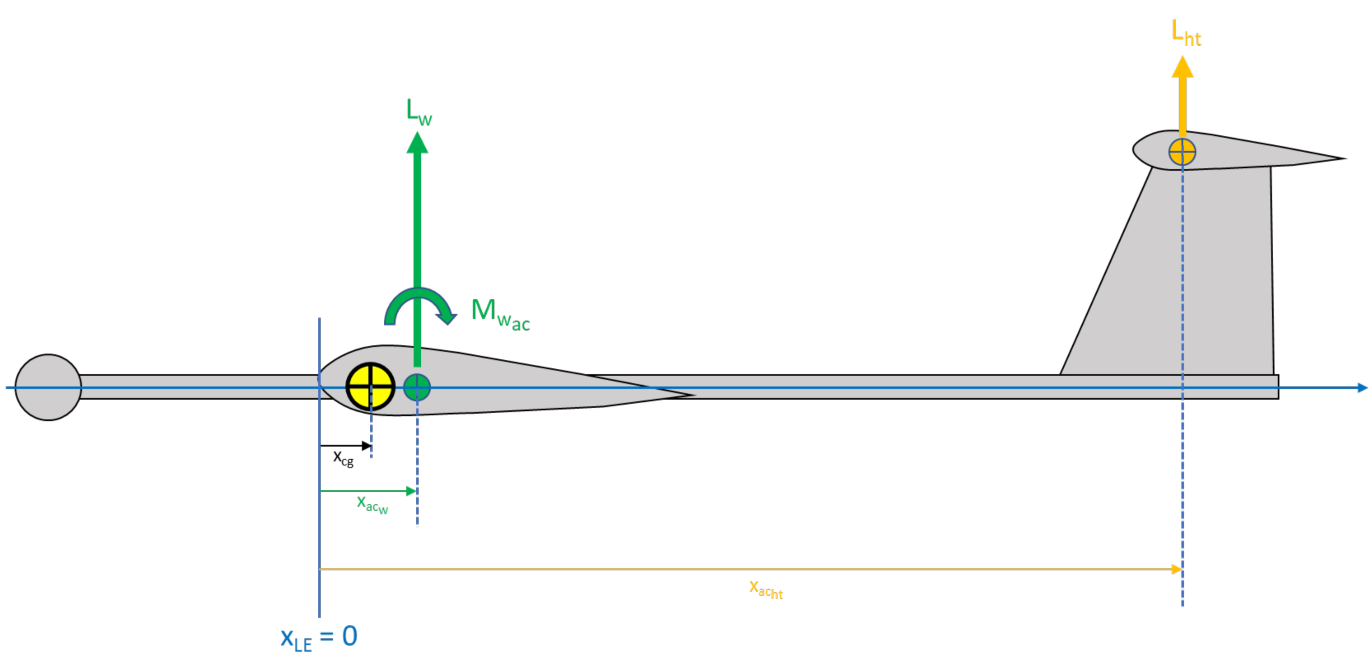


Figure 6: Simplified Longitudinal Force & Moment Diagram

When the moments due to both the wing lift and horizontal tail lift about the center of gravity of the glider are equal to zero, we can say that the aircraft is trimmed in pitch. Notice that the horizontal tail does not produce a moment about its aerodynamic center. This is because most control surfaces are built with symmetric airfoils which do not produce moments when lift is located at the aerodynamic center. From Anderson, the general formula for the coefficient of total pitching moment about an aircraft's cg is:

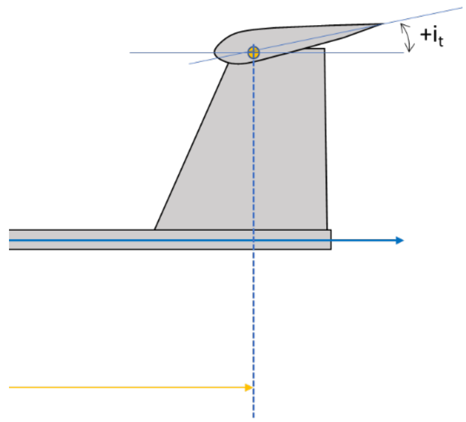
$$C_{m_{cg}} = C_{m_{ac,w}} + C_{L_w}\left(\frac{x_{cg}}{\bar{c}} - \frac{x_{ac_w}}{\bar{c}}\right) - V_H C_{L_{ht}}$$

Where:

- $C_{m_{cg}}$= coefficient of moment about the cg; this will be equal to zero for trimmed flight
- $C_{m_{ac,w}}$= coefficient of moment about the aerodynamic center for your wing; approximate with your 2D airfoil value
- C_{L_w}= coefficient of lift required for your wing at either max range or max endurance (per our assumptions, equal to our whole aircraft C_L)
- $\left(\frac{x_{cg}}{\bar{c}} - \frac{x_{ac_w}}{\bar{c}}\right)$ = distance between your aircraft cg and the wing's mean aerodynamic center ($0.25\bar{c}$) in percent chord.
- V_H = horizontal tail volume coefficient
- $C_{L_{ht}}$= coefficient of lift for your horizontal tail (flat plate approximation)

Where $C_{m_{ac,w}}$ can be approximated using your 2-D flat plate data, the lift from your wing can be determined from your C_L required for max range and max endurance, and your tail volume coefficient V_H is determined via your geometry. For simplicity of design at smaller scales, you will only use flap plate control surfaces (not airfoils) for your glider design. Just like for your wing, use the 2D flat plate aerodynamic data in Appendix 2 to determine the 3D lift curve slope for your horizontal and vertical stabilizers.

Utilizing this information, you can calculate the required lift coefficient for your horizontal tail to trim your glider at the desired C_L to obtain both max range and max endurance by setting your coefficient of total pitching moment equal to zero and solving for $C_{L_{ht}}$. From there, utilize the horizontal tail 3D lift curve slope you calculated to determine the required tail angle of attack ($\propto_{tail}$) and calculate the required tail incident angle (i_t) using the equation from Anderson below:



$$\propto_{tail} = \propto_w - i_t - \varepsilon_o$$

Where:

- $\propto_w$ is the angle of attack required to get the C_L required for your wing for L/D_{max}
- i_t is your horizontal tail incident angle (positive trailing edge up)
- ε_o is the downwash on your tail when your wing is at zero lift (we will assume this value is zero for this lab)

NOTE: The tail incident angle is measure as ***positive with trailing edge up*** from a line parallel to the centerline of your glider. If you cannot achieve the desired $C_{L_{ht}}$ with your tail or it requires too high of an tail angle of attack (you should aim to for as low a trim angle of attack as possible), you will need to either resize your tail or move the moment arm further back. ***Note that like any other change to your aircraft design, this will require you to update your weight, drag, and lift calculations!***

Lateral Directional Stability

The primary mechanism to ensure directional stability (sometimes also referred to as yaw stability or weather-vane stability) is your vertical tail. The desired behavior for an aircraft is to track back "into the wind" similar to a weather-vane in response to any disturbance that results in a yaw to the aircraft. To ensure basic directional stability, we'll utilize some rules of thumb based on vertical tail volume coefficient (V_v). From Drela, the formulation for the vertical tail volume coefficient and general stability criteria are:

$$V_v = \frac{S_v \cdot (x_{ac_v} - x_{cg})}{S_{ref} \cdot b}$$

Where:

- S_v= Planform Area of your vertical tail

- $(x_{ac_v} - x_{cg})$= distance between your aircraft cg and the vertical tail aerodynamic center
- b = span of the wing

The criteria for basic sizing of V_v is:

$$0.02 \leq V_v \leq 0.05$$

Unlike V_H, it can be dangerous for a glider to have too large of a vertical tail as this can contribute to "death spirals" as the aircraft continually attempts to chase the wind like a weather vane and any directional disturbance of gust will cause the glider to spiral to its demise. With this in mind, you should aim for a "middle" ground V_v between the values shown above.

Our final concern in terms of stability is lateral stability (or sometimes referred to as roll stability). The desired behavior for an aircraft is to return to "wings level" in response to any disturbance that causes the aircraft to roll. Although there are many ways to impact lateral stability, the primary method is called dihedral (Γ). Dihedral angle is the angle the wing is canted in the y-z plane (looking nose on of an aircraft) relative to horizontal.

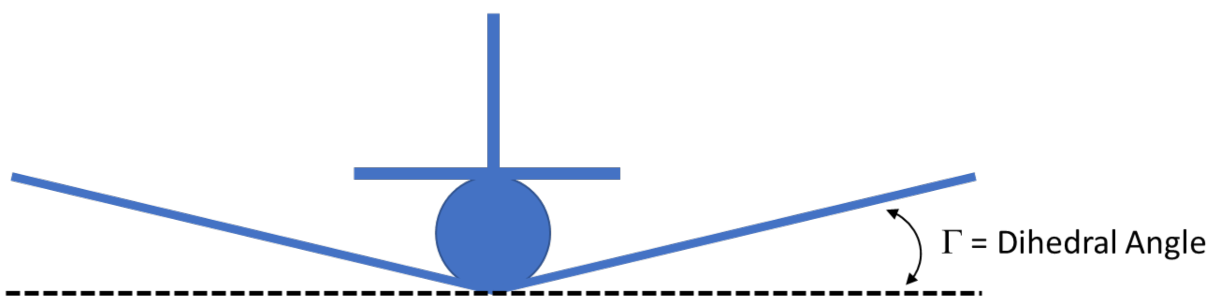


Figure 8: Dihedral Angle

Again, a basic rule of thumb will be provided via Drela using the spiral parameter (B):

$$B = \frac{(x_{ac_v} - x_{cg})}{b} \frac{\Gamma}{C_L}$$

Where:
- $(x_{ac_v} - x_{cg})$= distance between your aircraft cg and the vertical tail aerodynamic center
- Γ = Dihedral Angle (in degrees)

- b = span of the wing
- C_L= desired coefficient of lift for your airplane

The criteria for basic sizing of B is:

Stable Spiral: B > 5
Neutral Spiral: B = 5
Unstable Spiral: B < 5

Although aircraft with marginal lateral stability can be flown without major difficulties, any aircraft (such as your glider) which must be stable without a pilot in the loop must be naturally stable. It is also important to note that dihedral will not impact your measurement of wing planform area (S_{ref}) which is sometimes referred to as the area of the “shadow” of the wing. Dihedral would effect this measurement if that statement was taken literally; however, the determination of your wing planform area S_{ref} is not impacted by the dihedral you choose.

Fabrication and Glider Flight (Bonus)
Materials will be provided for you to build your glider and evaluate the accuracy of your engineering models experimentally. More information on this aspect of the lab will be provided by your instructor during lab.

Required Discussion & Tasks

Individual Conceptual Design Turn-In
Format: Slides uploaded to Gradescope

1. SLIDE #1: Geometry
    a. Tri-View of your final design with dimensions, S_{ref}, S_{wet}, Weight, and AR, stated (see Tempest example from Aero Lab Milestone 1 Data spreadsheet)
2. SLIDE #2: Estimated Lift Curve and Whole Aircraft Drag Polar Plots
    a. Drag Polar Equation estimate should be explicitly stated on slide
3. SLIDE #3: Estimated Performance
    a. Design requirements table with a column added showing how your design performance compares (Only for the following requirements):

System Requirements	Threshold	Objective	Min or Max
Max Glide Range (meters)	70 m	100 m	Max
Max Glide Range Velocity (meters/second)	12 m/s	7 m/s	Min
Max Glide Endurance (seconds)	7 sec	10 sec	Max

Maximum Wingspan (meters)	1.0 m	N/A	Min
Unit Cost (Fake dollars) using the formula: Empty Weight (in grams) * $1 = Cost	No “limit”, but will be used as a discriminator between designs.	Min	

Final Presentation Video

1. Format: Video Uploaded to Gradescope
2. Time Limit: 10-15 min
3. Presentation Requirements:
    a. Design Overview
        i. Discussion of individual team designs and rationale behind the initial design concept you selected before sizing/iterations.
        ii. Review of key design features of your final design after you completed your team iterations and sizing
        iii. Final design drawing: Make sure key aircraft geometry, dimensions, and weight information are shown / provided. Tri-View provided of Tempest in milestone 1 data is a good example figure.
    b. Aerodynamics Analysis
        i. Lift curve slope (CL vs α) for your glider 3D wing design and your 2D flat plate (same plot)
        ii. Drag Polar (CL vs CD) for your glider design
    c. Performance Analysis vs Requirements
        i. Show and discuss plots used in sizing your aircraft.
            1. Step through the process of sizing and how your aircraft evolved.
            2. Talk to what requirements were most constraining and how they impacted your design iterations.
        ii. Provide a summary table comparing your calculated glider design performance vs all requirements in Table 1.
    d. Conclusion
        i. If you could continue to iterate on your glider design, what would you change about it?
        ii. What were the biggest things you learned about aircraft design?
        iii. Are you planning on building your glider?

References

Lab derived from:
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Additional References:

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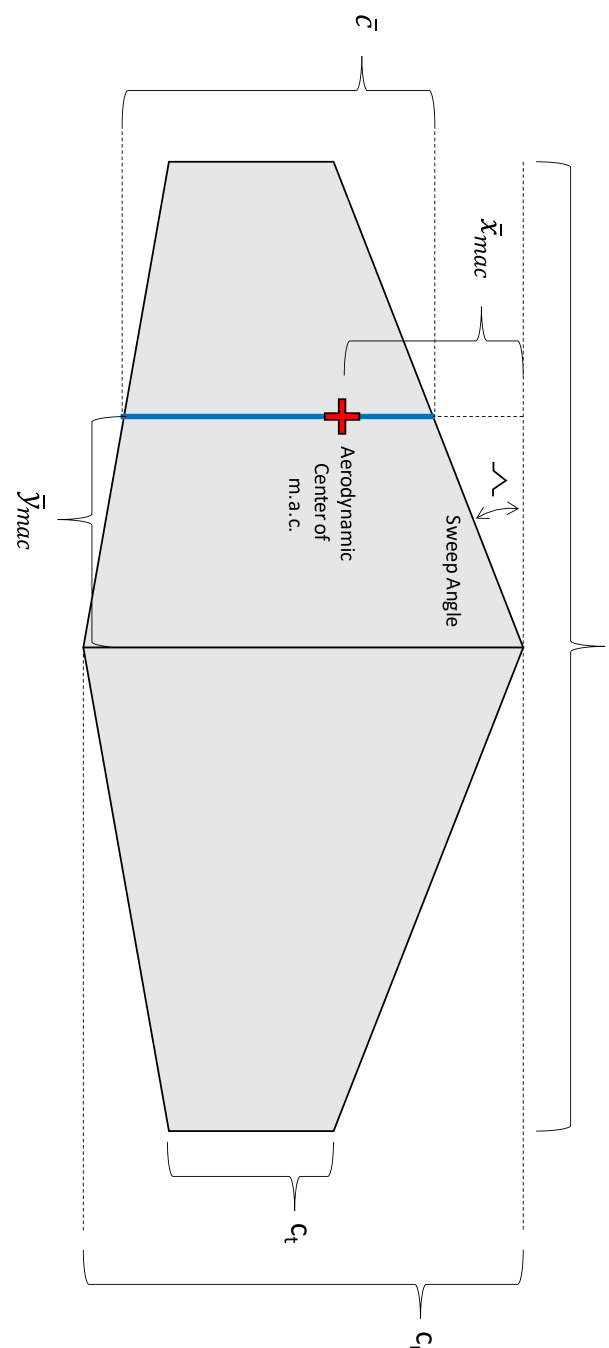
APPENDIX 1: TRAPAZOIDAL WING GEOMETRY

Trapezoidal Wing Geometry



$S = \frac{b}{2}(c_r + c_t)$ *Wing Planform Area*

$\lambda = \frac{c_t}{c_r}$ *taper ratio*

$AR = \frac{b^2}{S}$ *Wing Aspect Ratio*

$\bar{c} = \frac{2}{3} c_r \frac{1 + \lambda + \lambda^2}{1 + \lambda}$ *mean aerodynamic chord*

$\bar{y}_{mac} = \frac{b}{6}\left(\frac{1 + 2\lambda}{1 + \lambda}\right)$ *span distance to m.a.c.*

x position from leading edge of wing (at root) to a.c. of m.a.c

$\bar{x}_{mac} = \bar{y}_{mac} \cdot \tan(Sweep\ Angle) + 0.25\bar{c}$

APPENDIX 2: 2-D Flat Plate Aerodynamic Data

Source: Mueller, T.J.; Aerodynamic Measurements at Low Reynolds Numbers for Fixed Wing Micro-Air Vehicles; Hesert Center for Aerospace Research, University of Notre Dame; 1999.

NOTE: ONLY USE THE "2D" DATA FROM THE FOLLOWING FIGURES

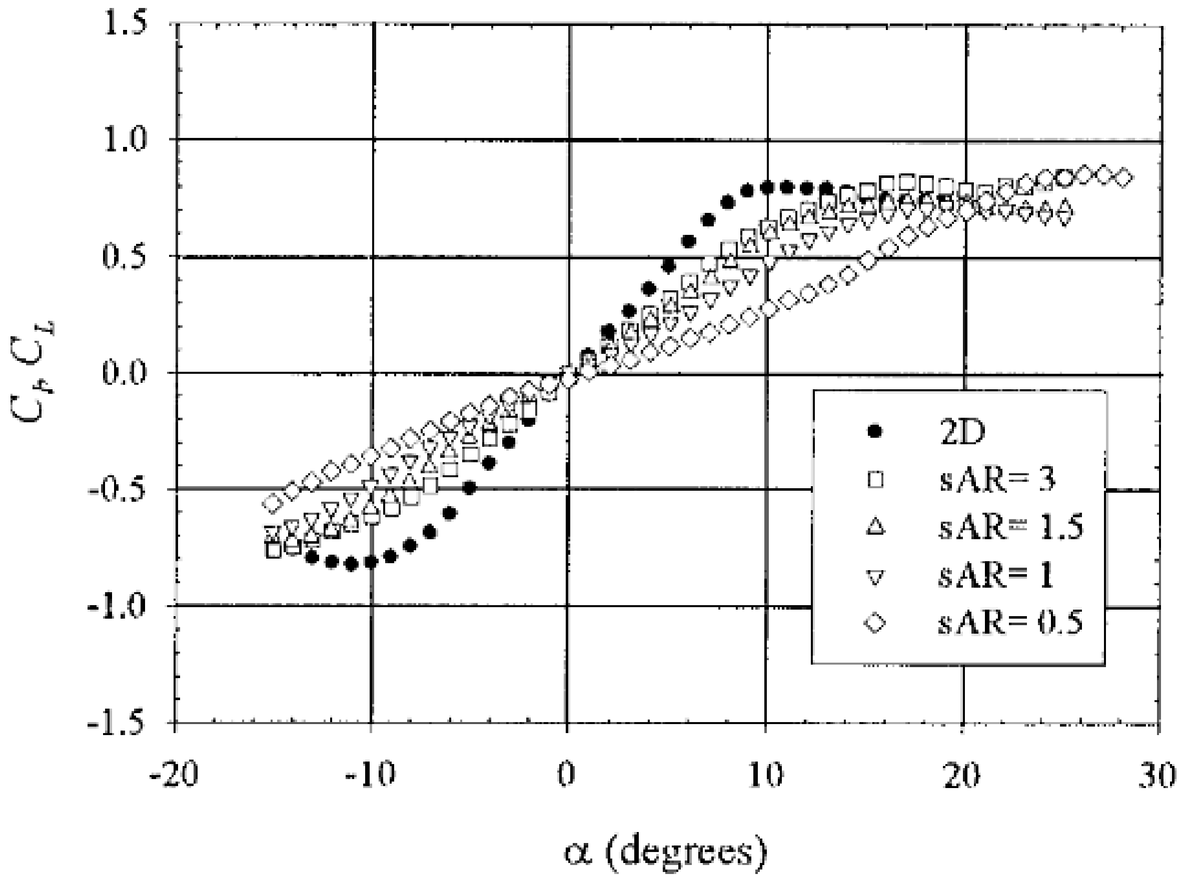


Figure 37: Lift coefficient on flat plates at $Re_c = 140,000$ with UND-FB1

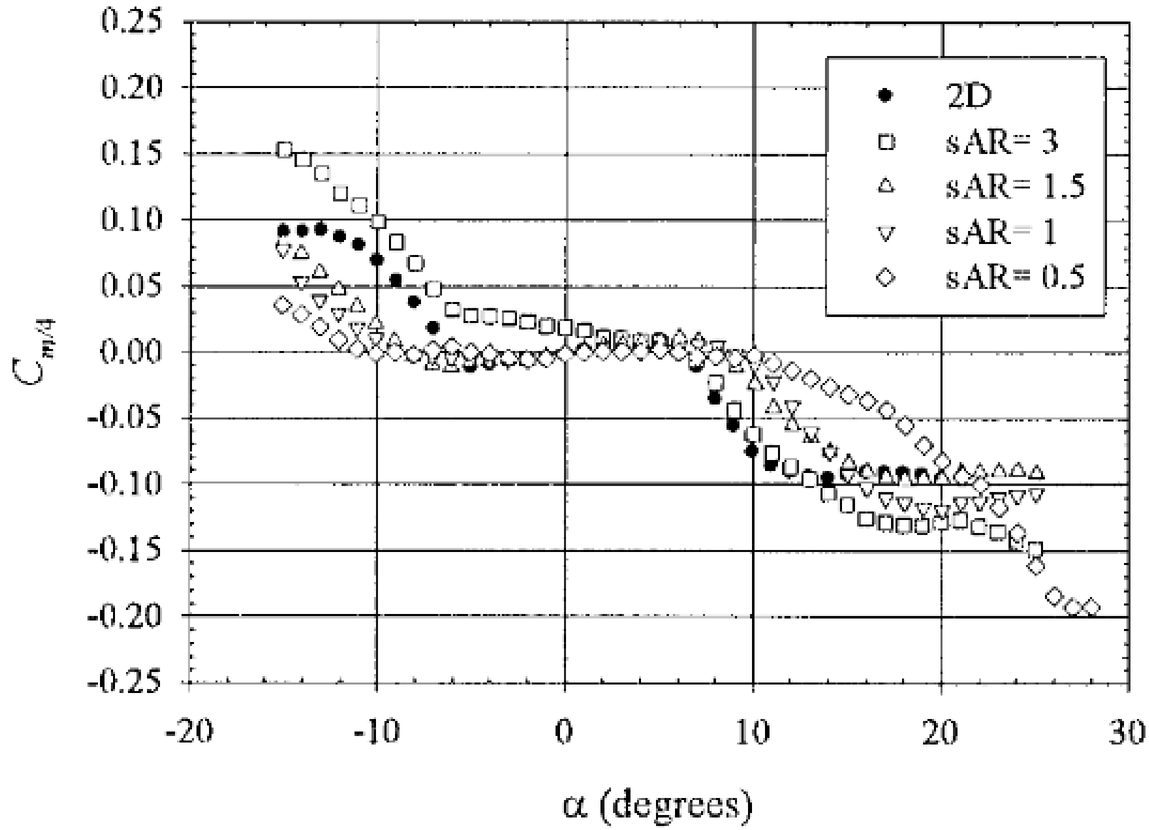


Figure 39: Pitching moment coefficient on flat plates at $Re_c = 140,000$ with UND-FB1

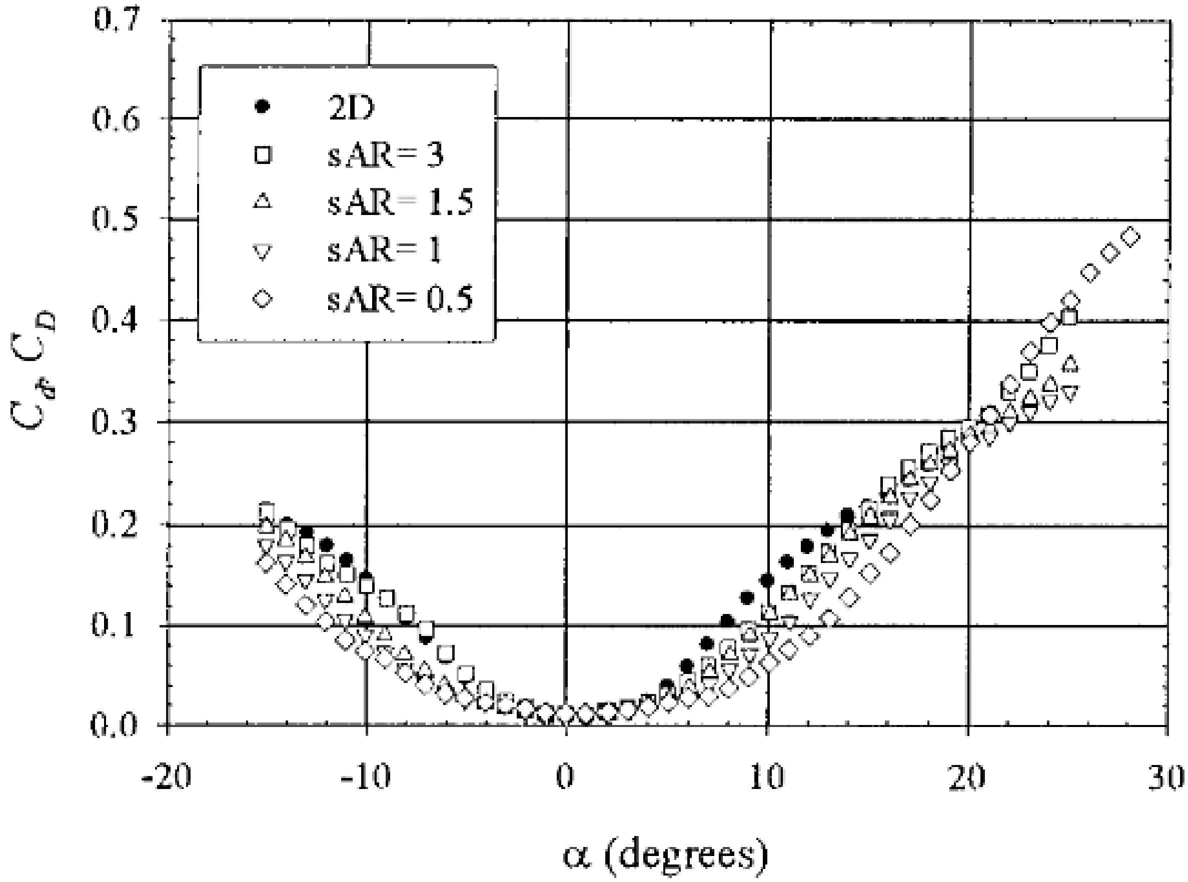


Figure 38: Drag coefficient on flat plates at $Re_c = 140,000$ *with UND-FB1*

APPENDIX 3: Glider Payload Information


SEE ASEN 2004 CANVAS PAGE FOR CAD FILE OF THE PAYLOAD

DIMENSIONS	
Weight	133 g without battery; 160 g with battery
Unit size (HxWxD)	39.0 x 59.3 x 69.8 mm
VIDEO	
Video resolution	5.7K/30FPS, unstitched; 5K/30 FPS, unstiched; 4K/30FPS, stitched; 3K/60FPS, unstitched
Spherical stabilization (up to 4K)[1]	3 modes: stabilize, lock, follow
G-METRIX	
Augmented reality data(G-Metrix)[2]	yes
GPS/GLONASS	10 Hz location capture
Accelerometer	yes
Barometer	yes
Gyroscope	yes
Compass	yes