

MAE 253 - Experimental Aerodynamics I  
 Lab 6 – Wing Aerodynamics  
 Final report due date: 04/19/2019

**Objective:** Using different wing models and the ATI Gamma load cell:

- Calculate the lift, drag, and moment coefficients of each of the wings testes at various angles of attack.
- Conduct a detailed parametric study to analyze the effect of aspect ratio, sweep, dihedral, and planform shape on the force and moment polars.

**Theory:** A wing is an extrusion of an airfoil with a finite length. The forces acting on the wing are similar to that of an airfoil:  $F_N$  and  $F_T$  are the forces perpendicular and parallel to the chord (or chordwise forces) and  $F_L$  and  $F_D$  are the lift and drag forces perpendicular and parallel to the oncoming flow direction. The pitching moment ( $M$ ) is the moment produced by the aerodynamic forces on the wing and is constant at the aerodynamic center. The forces and moments on a wing section are represented in Fig. 1.

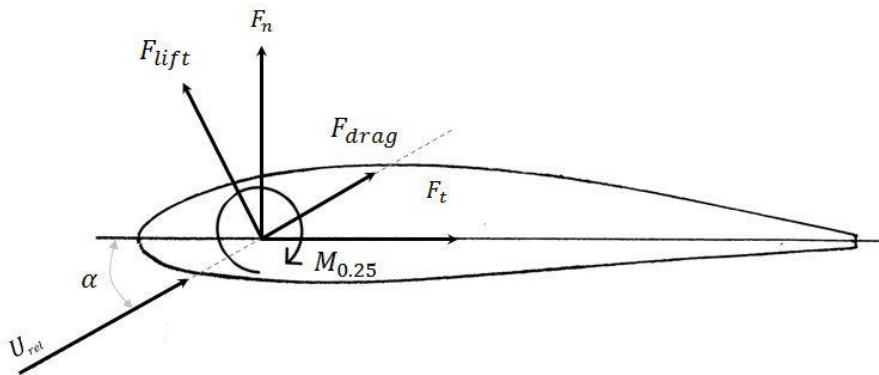


Figure 1: Forces on a wing section.

Aerodynamicists represent the forces and moments acting on a wing in terms of their non-dimensional coefficients,

$$C_L = \frac{F_L}{qS}$$

$$C_D = \frac{F_D}{qS}$$

$$C_M = \frac{M}{qSc}$$

where  $C_L$ ,  $C_D$ , and  $C_M$  are the lift, drag, and moment coefficients,  $q$  is the dynamic pressure,  $S$  is the wing area, and  $c$  is the chord of the wing. The forces and moments required to calculate the coefficients are generally measured using 6-axis force sensors that give the forces and moments in and about the x-y-z axes respectively. Generally, the forces and moments measured by the load sensors are the chordwise forces, which can then be resolved in the flow direction to determine the aerodynamic forces and moments.

Based on design requirements, various aspects of the wing geometry can be varied in order to achieve the desired aerodynamic performance. The most common geometric parameters that are varied are the aspect ratio ( $AR$ ), sweep, dihedral, and planform shape.

Aspect ratio is the ratio of a wing's length to its chord and is given by the equation,

$$AR = \frac{b^2}{S}$$

where  $b$  is the span of the wing (shown in Fig. 2). Note that a change in aspect ratio can be designated as a modification

to the wing planform. High aspect ratio wings have one major advantage: because the wingtip has less area, there is less vortex induced downwash, which means a lot less induced drag. Induced drag is most significant at low speeds and high altitudes (anywhere you have a high angle of attack), and since high aspect ratio wings have lesser induced drag, they perform very well in takeoff, landing, climb, and cruise. However, high aspect ratio wings need to be stronger structurally as they encounter higher airloads, which create more bending moment. To overcome the bending, a stronger wing is needed, which in turn results in more material. Consequently, more material to the wing causes an increase to the overall weight of the aircraft. Eventually, the structural needs of a high aspect ratio design outweigh the benefits of the design.

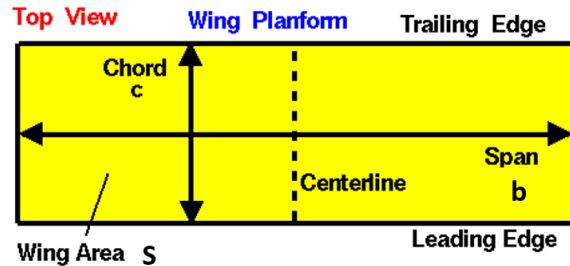


Figure 2: Wing planform.

A swept wing is a wing that angles either backward or occasionally forward from its root rather than in a straight sideways direction. The greatest benefit of wing sweep is a reduction in the strength of and delay in the onset of shock formation. The shock formation will not only cause a sharp increase in drag; it also changes the chordwise pressure distribution on the airfoil, causing the center of lift to move from approximately the airfoil’s quarter-chord to mid-chord. The consequence of this is called “Mach-tuck,” a severe increase in nose-down pitching moment. Figure 3 shows how the leading edge sweep increases the critical Mach number,  $M_{crit}$ , and delays the onset of the peak of the compressibility drag coefficient. This is helpful as it allows thicker and more structurally efficient airfoils to be used in the wing.

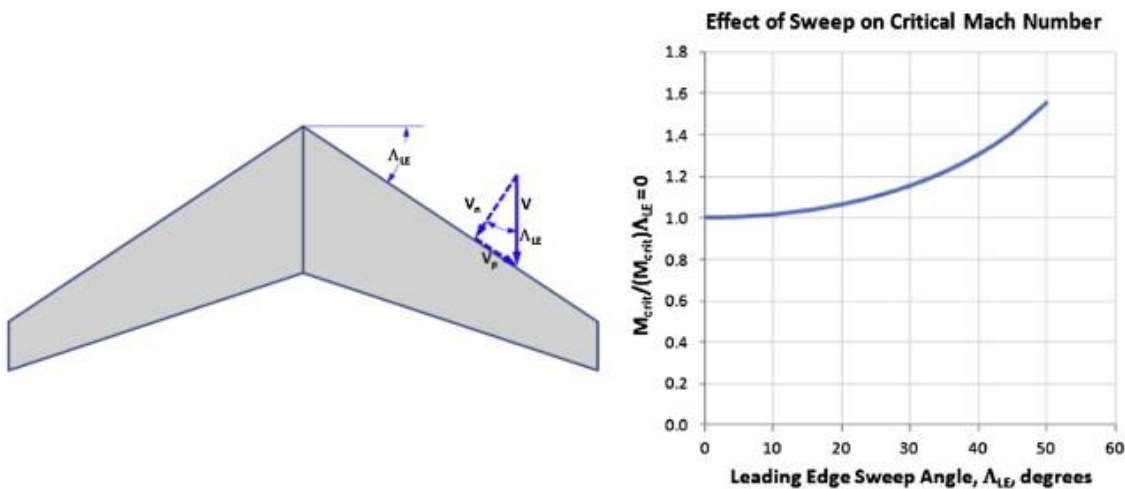


Figure 3: Effect of wing sweep.

Wing dihedral is the upward angle of an aircraft's wing, from the wing root to the wing tip, and is shown in Fig. 4. The amount of dihedral determines the amount of inherent stability along the roll axis. Although an increase of dihedral will increase inherent stability, it will also decrease lift, increase drag, and decreased the axial roll rate. As roll stability is increased, an aircraft will naturally return to its original position if it is subject to a brief or slight roll displacement. Most large airliner wings are designed with dihedral.

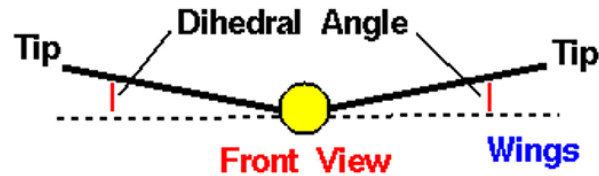


Figure 4: Wing dihedral.

The wing planform is the silhouette of the wing when viewed from above or below. While variation in aspect ratio can be classified as a variation in wing planform, some of the other common wing planforms are the elliptical, delta, and trapezoidal wings, as shown in Fig. 5.

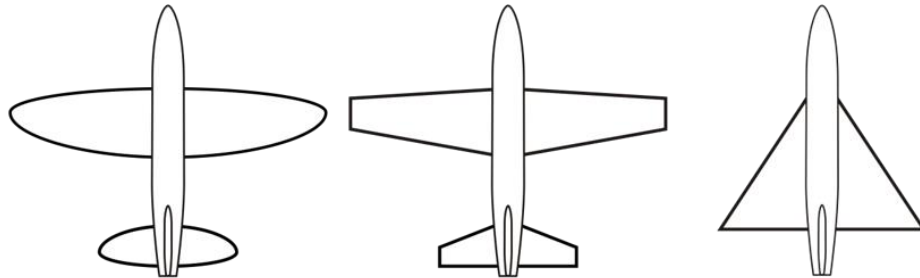


Figure 5: Wing planforms.

Experiment: Using the different 3D-printed wing models and the ATI Gamma load cell set-up, collect the following data at Reynolds numbers  $1.5 \times 10^5$ ,  $2 \times 10^5$ ,  $2.5 \times 10^5$ , and  $3 \times 10^5$ :

Table 1: Data collected to evaluate chordwise wing forces for a given angle of attack.

$F_x$ (lbf)	$F_y$ (lbf)	$F_z$ (lbf)	$M_x$ (lbf)	$M_y$ (lbf)	$M_z$ (lbf)	$P_{\text{transducer}}$ (psf)	$T_{\text{transducer}}$ (°F)
from ATI Gamma load cell	from ATI Gamma load cell	from ATI Gamma load cell	from ATI Gamma load cell	from ATI Gamma load cell	from ATI Gamma load cell	from WT transducer (dynamic pressure)	from WT transducer

The following constants can be used to help with your analysis:

1. Wing chord,  $c = 0.127$  m
2. Length of support sting,  $l = 0.4112$  m
3. Area of delta wing =  $0.0363$  m<sup>2</sup>

In the final report,

- Conduct a parametric analysis to study the variation of  $C_L$ ,  $C_D$ ,  $C_{M/pitch}$ ,  $C_{yaw}$ ,  $C_{roll}$ , and  $C_{slip}$  (with error bars) based on:
  - aspect ratio (AR = 3, 4, and 5; sweep = 0°; dihedral = 0°).
  - sweep (AR = 4; sweep = 0°, 10°, and 30°; dihedral = 0°).
  - dihedral (AR = 4; sweep = 0°; dihedral = 0°, and 10°).
  - wing planform (delta wing and rectangle wing (AR = 4; sweep = 0°; dihedral = 0°)).
- An example of the expected plots is shown in Fig. 6.
- Show the experimental flow diagram for the experiment in your methodology sections.
- NOTE:
  - All data collected is for the (wing + sting) configuration. You will have to negate the forces and moments due to the sting alone to calculate the forces and moments for just the wing.

- As the load-cell was not re-biased after a change in angle of attack, the load cell also measures a static load due to the weight of the setup. To calculate the static load, we simply record the data at all angles of attack without any wind flowing. Before processing, subtract the mean static forces/moments from the corresponding forces/moments in the dynamic data files.
- The turbulence factor correction has already been incorporated while setting our dynamic pressure during the experiment. You will not need to correct for the same during post-processing.
- The coordinate system for the load-cell with respect to the wind tunnel is shown in Fig. 7.
- Present your code in the Appendix.

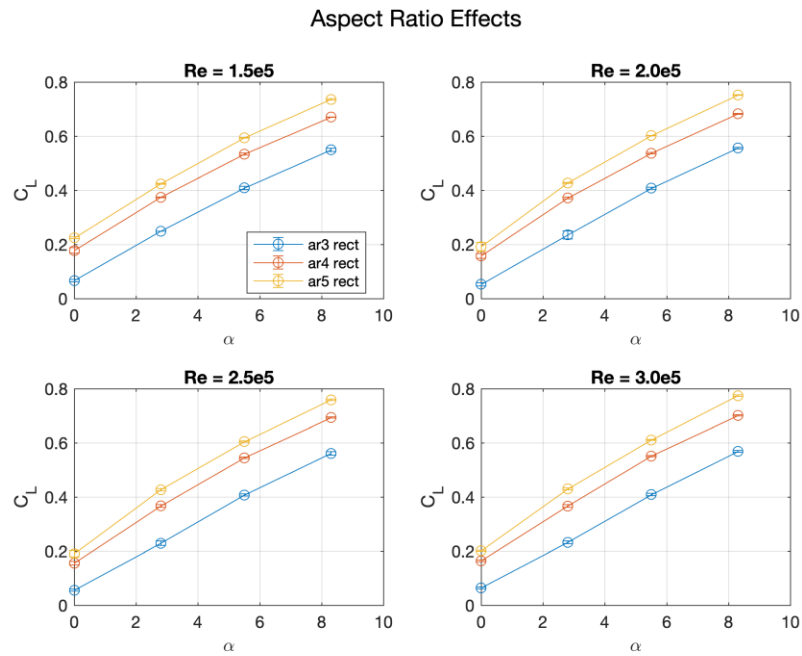


Figure 6:  $C_L$  trends for varying aspect ratio.

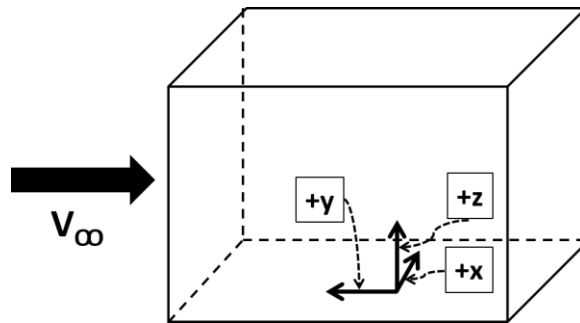


Figure 7: Coordinate system of the load-cell with respect to the wind tunnel.