EA303 WIND TUNNEL
EXPERIMENT V

EFFECT OF SLATS AND FLAPS ON A FINITE WING

I. Purpose

1. Learn to operate the wind tunnel balance
    - a. measure lift, drag and pitching moment;
    - b. determine tare values;
    - c. correct data for model support effects.
2. Learn to reduce measured forces and moments to non-dimensionalized coefficient form.
3. Determine the effect of leading edge slats and trailing edge flaps on lift, drag and pitching moment coefficients.
6. Measure the effect of angle-of-attack on wing lift and drag and wing pitching moment about the balance center. Determine the effect on wing pitching moment about the aerodynamic center.

II. References

1. Abbott, I.H. and Von Doenhoff, A.E., *Theory of Wing Sections*, Dover Publications, Inc., 1959, Chapter 8.
2. Hurt, *Aerodynamics for Naval Aviators*, pp. 39–47.
3. Anderson, John, *Introduction to Flight*, Sec. 5.13–15, 5.17.
4. Rae, W.H., Jr., and Pope, A., *Low Speed Wind Tunnel Testing*, New York: John Wiley & Sons, 1984, Sec. 4.1–4.16, 5.5.

III. Introduction

The purpose of most wind-tunnel experiments is to determine the aerodynamic forces and moments which act on a model and correct them for tunnel boundary, scale and Mach number effects. The simplest method to achieve this is to use a balance mechanism to measure forces and moments directly.

The behavior of finite wings is an important concern in aircraft design. The variables of sweepback, section variation, geometric twist, taper, aspect ratio, tip shape and high-lift devices offer a wide spectrum of performance characteristics.

Certain flight conditions require a high lift coefficient, for example, slow flight operation to reduce take-off and landing ground roll, and highly banked flight when a tight turn is required. Although both slats and flaps can be used to produce the same increase in $C_{L_{\max}}$, it is important to more closely investigate the aerodynamic effects of these high-lift devices on the C_L, C_D, and C_M characteristics of wings at all angles of attack. For example, a high angle of attack at stall necessitates an excessive aircraft attitude on landing and take-off. This complicates landing gear design and reduces pilot visibility. Increased drag is considered disadvantageous in the aircraft cruise condition (at low C_L's), but it may be advantageous when operating near $C_{L_{\max}}$ during a landing approach for the following reasons:

1. with low L/D, a steeper approach may be made, avoiding obstacles and ground noise in the vicinity of the airfield;
2. operation at high power settings aids in minimizing engine acceleration time when power is added;
3. operation in a high drag condition allows faster deceleration when power is reduced.

IV. Theory

Dimensional analysis indicates that

$$C_L, C_D, C_M = f(\alpha, \text{Æ}, \mathrm{Re}, \mathrm{M}, configuration)$$

where Æ is the aspect ratio. At low subsonic speeds, compressibility effects are negligible. Therefore

$$C_L, C_D, C_M = f(\alpha, \text{Æ}, \mathrm{Re}, configuration)$$

For a given test velocity Reynolds number is a constant, thus

$$C_L, C_D, C_M = f(\alpha, \text{Æ}, configuration)$$

fixing the wing aspect ratio eliminates it as a variable. Thus

$$C_L, C_D, C_M = f(\alpha, configuration)$$

For a given model the configuration is fixed. Consequently

$$C_L, C_D, C_M = f(\alpha)$$

Comparison of C_L, C_D and C_M vs α curves for a finite wing with and without high lift devices and with similar two-dimensional NACA airfoil results reveals the effects of leading edge flaps and trailing edge flaps. Comparison of slopes, intercepts, maxima, minima and general shape are valuable in defining these effects.

In general there are three techniques for increasing the lift on an airfoil: camber line changes, area changes and boundary layer control. Thin airfoil theory shows that both lift and pitching moment increase with increasing airfoil camber. Trailing edge flaps, leading edge flaps and to a much lesser extent leading edge slats use camber line changes to increase airfoil lift.

Deflection of a flap increases the effective camber of an airfoil, thus increasing the lift coefficient at a given angle of attack. Large increases in drag and pitching moment (nose down) about the aerodynamic center along with more negative angles of zero lift are observed.

The value of $C_{m_{\text{ac}}}$ varies with the amount and shape of the camber line. It is approximately zero for symmetrical airfoils and -0.007 for a 23012 airfoil. Flap-down values may exceed -1.0.

Trailing edge Fowler flaps not only move downward but also backward thus increasing the effective airfoil/wing area. Extensible leading edge flaps and extensible leading edge slats are used to increase the effective airfoil/wing area. However, the airfoil/wing coefficients are still based on the original wing planform area. Consequently, large increases in lift coefficient result. Maximum lift coefficients exceeding 3.5 are common.

The location of the aerodynamic center is practically unchanged by flaps. The explanation lies in the manner in which the moment is generated:

$$C_{m_{\text{total}}} = C_{m_{\text{due to changing alpha}}} + C_{m_{\text{due to camber}}}$$

The C_m due to changing angle of attack is constant about the quarter chord. The C_m due to camber is a constant about the half chord. Hence, adding camber in the form of flaps merely increases the value of $C_{m_{\text{ac}}}$ without changing the location of the aerodynamic center as determined by changing angle of attack.

Delaying the separation of the boundary layer on the upper surface of an airfoil or over a trailing edge flap increases the lift on the airfoil. Leading edge slats and leading edge slots are used to delay the separation of the boundary layer over the upper surface of an airfoil. A fixed slat operates the same as a slot, but is different geometrically since it is a small airfoil ahead of the leading edge whereas slots are actually cut through an airfoil. In both cases high pressure air from the lower surface is directed tangential to the upper surface of the airfoil to increase the kinetic energy in the lower regions of the upper surface boundary layer. The effect is to delay upper surface separation until a higher angle of attack is reached. This increases α_{stall} and $C_{l_{\max}}$ without changing $\alpha_{0_{\text{LW}}}$ or $C_{m_{\text{ac}}}$. If a downward movement of the slat is also used, the effective camber is increased with a small increase in drag and an $\alpha_{0_{\text{LW}}}$ shift. A similar effect is used with slotted trailing edge flaps.

Area boundary layer control is also used to either suck the low energy lower regions of the boundary layer off the airfoil surface or to re-energize these layers by actively blowing air tangential to the surface. The result is delayed boundary layer separation and higher airfoil lift.

In general, wing flaps are capable of producing a greater increase in $C_{L_{\max}}$ than slats or slots. Used together the effects are additive as shown in Fig. 5–1.

V. Balance Corrections

All balance readings must be corrected for the zero readings, i.e., the value of the scales under no-load conditions. These values are generally a function of angle-of-attack. The corrected scale readings then represent the aerodynamic forces and moments of the model-support combination. These corrections are discussed in detail in Experiment 4.

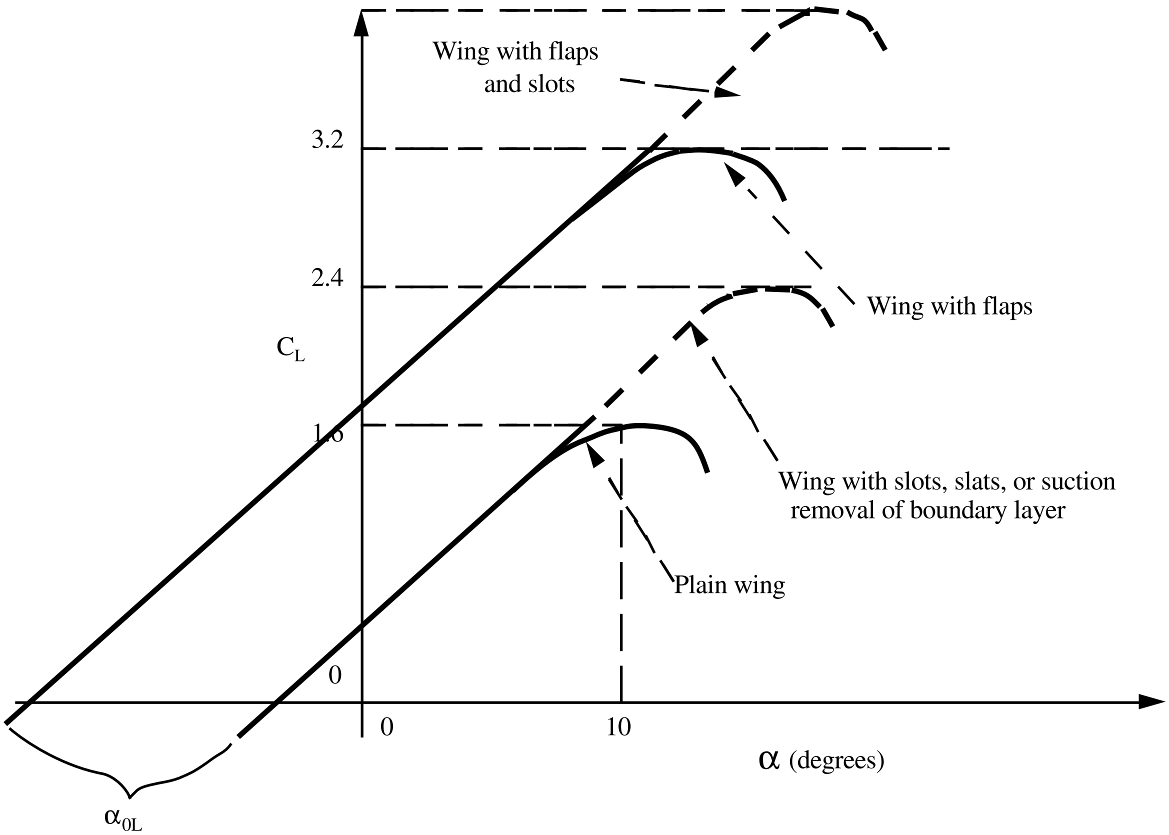

Figure 5–1. Effects of slats and flaps on airfoil lift coefficient.

VI. Physical Set-up

The USNA 44 × 31 subsonic wind tunnel utilizes a pyramidal balance to support the model, to provide for changing its angle of attack and angle of yaw and to transmit the model loads into a system of linkages which separate them into their proper components. A load cell system gives a direct reading of lift, drag and pitching moment in pounds and foot-pounds. These readings are affected by the drag of the exposed supports and by the interference of the struts on the free air flow about the model (and vice versa). Therefore, corrections are required to isolate the loads of the model alone.

An untwisted, rectangular planform wing of constant NACA 4415 section with a full span adjustable, plain flap of 30% chord length and an extensible, full span slat. The wing is floor mounted using a triple strut system that allows the wing to be rotated in pitch. The axis of rotation (or balance center) passes through the two forward support points (trunnions). The wing span is 30.0 inches. The wing chord is 6.0 inches, and the distance from the leading edge to the balance center is 1.75 inches. The room thermometer and barometer and the tunnel inclined manometer are utilized.

VII. Procedure

1. Before starting the wind tunnel perform an auto zero.
2. Also before starting the wind tunnel obtain ‘tare’ values for lift, drag and pitching moment for angles of attack from −6° to +18° in 2° increments.
3. Determine the average lift, drag and moment tare values for each configuration.
4. The following configurations are to be tested:
    a. Plain wing (W).
    b. Wing with slat extended (S).
    c. Wing with slat extended and flap deflected 30° (S/F).
    d. Wing with flap deflected 30° (F).
5. For each configuration, take data for angles of attack settings from −6° to +18° (or until the model stalls) in 2° increments. Take extra data as required in the stall region, and at $\alpha_{0\mathrm{L}}$. Record lift, drag, and pitching moment about the balance center for the wing at all angles of attack. (Note: It will be necessary to shut down the tunnel for a short period in order to change configurations.)
6. For each configuration, make the usual measurements of barometric pressure, initial temperature and final temperature in order to calculate average freestream density and coefficient of viscosity.

VII. Requirements

1. Calculate for the experiment:
    a. average density;
    b. dynamic pressure (utilizing the tunnel constant);
    c. velocity;
    d. effective Reynolds number.
2. Find or calculate for each configuration for each angle of attack:
    a. lift, L;
    b. drag, D;
    c. moment about the balance center, M_{BC};
    d. lift coefficient, C_L;
    e. drag coefficient, C_D;
    f. moment coefficient about the balance center, $C_{M_{BC}}$;
    g. location of the aerodynamic center.
3. Plot
    a. C_L vs α for each configuration on the same graph.
    b. C_D vs α for each configuration on the same graph.
    c. $C_{M_{ac}}$ vs C_L for each configuration on the same graph.

IX. Results

Fill in the following table.

Table 1. (Plain Wing)

Characteristics	Predicted Value	Experiment Values
$dC_L/d\alpha$		
$C_{L\,\max}$		
α_{STALL}		
$C_{\mathrm{D0}_{\min}}$		
a.c. (x/C)		
C_{Mac}		

Table 2. EXPERIMENTAL VALUES

Characteristic	Plain Wing	Slat Extended	Flap Deflected	Slat and Flap Out
$C_{L\,\max}$				
α_{Stall}				
α_{OL}				
$C_{\mathrm{D0}_{\min}}$				
C_D at $C_{L\,\max}$				