High lift devices

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For the glory of God

This question was given to me from Kevin. I wanted to summarize this topic because I didn't study this part before.

High lift devices

a) Introduction

· There are many different types of high lift devices used to increase the maximum lift coefficient for low speed flight.
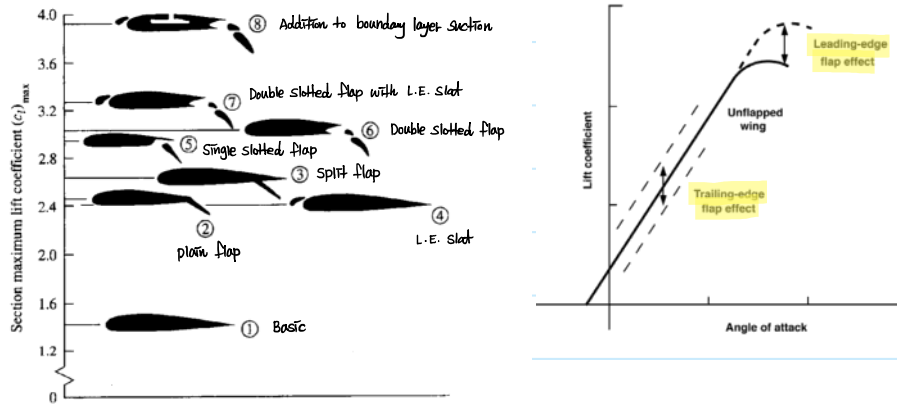

Figure 5.28   Typical values of airfoil maximum lift coefficient for various types of high-lift devices: (1) airfoil only, (2) plain flap, (3) split flap, (4) leading-edge slat, (5) single-slotted flap, (6) double-slotted flap, (7) double-slotted flap in combination with a leading-edge slat, (8) addition of boundary-layer suction at the top of the airfoil. (From Loftin, Ref. 13.)

↳ It can lead to a substantial increase in $\alpha_{L,max}$

b) Trailing Edge High lift devices

· It is simply a portion of the T.E. section of the airfoil that is hinged and which can be deflected upward or downward.

· It is usually applied to 15 to 25 percent of the chord.

· The basic idea behind of design concept is as following ;

; where
$\alpha' > \alpha$
↓
$C_l \propto \alpha$
(i.e. $C_l = 2\pi\alpha$)

→ The deflection of a flap causes large nose down moments, which create important twisting loads on the structure

(we must consider it with a choice of flap in design)

– When the flap is deflected downward, C_l is increased.

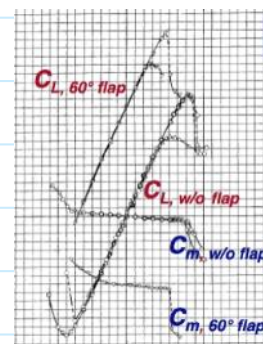(∵ Due to an effective increase in the camber of the airfoil)

1. Plain flap

· It creates more lift than basic airfoil by mechanically increasing the effective camber.

· It also increases the drag and pitching moment.

· In addition, the zero-lift angle changes to a more negative value.

2. Split flap

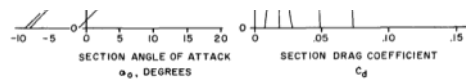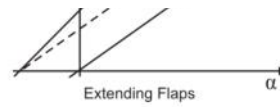· Only the bottom surface of the airfoil is hinged.

· It is slightly higher $C_{l,max}$ than a plain flap.

· It usually produces more drag than others, so that it rarely used on modern airplanes.

  ↳ It results from the great turbulent wake produced by this type of flap.

· It may be good when a pilot wants to use air-brake when landing.

3. Slotted flap

(d) Single-slotted flap

· Unlike the plain flap, the slotted flap allows a gap between the top and bottom surfaces.

  ↳ This allows higher-pressure air on the bottom surface to flow through the gap, stabilizing BL on the top surface.

· It is commonly used for general aviation airplanes.

· The high energy air from the gap (slot) accelerates the upper surface boundary layer and delays airflow separation.

· There are double-slotted and triple-slotted flap such as for Boeing 747. (The more, the better)

  However, we need to know that this benefit is achieved at the cost of increased mechanical complexity.

Slotted Flaps - Extended
Boundary Layer
High pressure air flows through slot

This may complicate the choice of a flap configuration.

4. Fowler flap

· It is similar to the slotted flap but the difference is ;

  - When it is deployed, { not only increasing effective camber   ∴ further increasing lift
                          but also increasing exposed wing area

Hence, in summary, in terms of T.E. high lift devices,

The additional separation occurs because of the deflection which experiences a stronger adverse pressure gradients.

BASIC SECTION
PLAIN FLAP   SPLIT FLAP
SLOTTED FLAP   FOWLER FLAP

EFFECT ON SECTION-LIFT AND DRAG CHARACTERISTICS OF A 25% CHORD FLAP DEFLECTED 30°

Some slope (∵ same reference area)

Slope increases

C_L
ΔC$_{L,max}$
Slotted Flap
Plain Flap
Clean
Nonextending Flaps
α

C_L
Clean
Extending Flaps
α

SECTION LIFT COEFFICIENT, c_l
3.0 FOWLER SLOTTED
2.5   SPLIT
2.0   PLAIN
1.5
1.0   BASIC SECTION
.5
-10 -5 0 5 10 15 20
SECTION ANGLE OF ATTACK
α₀, DEGREES

3.0   FOWLER
2.5 SLOTTED
2.0   SPLIT PLAIN
1.5
1.0   BASIC SECTION
.5
0 .05 .10 .15
SECTION DRAG COEFFICIENT
c_d

Figure 1.17. Flap Configurations

Figure 1.17. Flap Configurations

Extending Flaps

· Before we move on L.E. flap/slat, let's talk a little bit more about the slope, α_{stall}, and $\alpha_{zero-lift}$.

　- In terms of $\alpha_{zero-lift}$

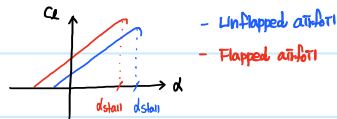　　· When the flap is deflected downward, the effective camber of the airfoil is increased.

　　· A more highly cambered airfoil has a more negative zero-lift angle of attack. (e.g. Symmetric vs. Cambered)

　- In terms of α_{stall}

　　· When the flap is deflected downward, we know that:

　　∴ where
　　$\alpha' > \alpha$ (α' = virtual angle of attack)

　　· Let's say:

　　　─ Unflapped airfoil
　　　─ Flapped airfoil

　　The airfoil is flying at 15° { unflapped airfoil feels it is literally 15°

　　flapped airfoil feels it is higher than 15° (effective) because of the camber effect. ∴ stall earlier

　- In terms of slope

　　　　　　　　　　　　　　　　　　　　　　　　(unchanged)
　　· Lift coefficient slope between flapped and un-flapped airfoil is essentially the same except for fowler flap.

　　· Then, why does the extended flap increases the lift slope?

(e) Extended trailing-edge flap
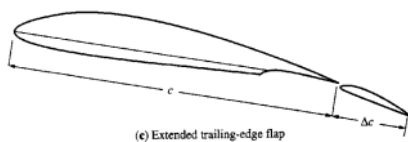
Note that:

Fowler flaps increases the actual lifting area of the wing when they are extended, but the lift coefficient is defined as the same reference area when the flaps are retracted.

　─ For the basic airfoil with no extension, $L = q_\infty \, c \, C_\ell$

　─ For the airfoil with flap extension, $L = q_\infty \, (c+\Delta c) \, C_\ell$

⇒ Hence, they have same lift coefficient (C_ℓ)

$$\Leftrightarrow \frac{L}{q_\infty c} = \left(1 + \frac{\Delta c}{c}\right) C_\ell$$

─ Let $C_\ell = \dfrac{L}{q_\infty c}$, then we have

$$C_\ell = \left(1 + \frac{\Delta c}{c}\right) C_\ell \quad ; \text{ where } C_\ell = \text{ Lift coefficient for the airfoil extended flap on the chord of the}$$
$$\text{basic airfoil with no extension}$$

─ By differentiating with respect to α, we have
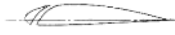
$$\frac{dC_\ell}{d\alpha} = \left(1 + \frac{\Delta c}{c}\right) \frac{dC_\ell}{d\alpha} \quad ; \text{ where } \frac{dC_\ell}{d\alpha} = \text{ lift coefficient slope for an airfoil with no flap extension}$$

∴ Hence, the lift curve is increased by the amount $\dfrac{\Delta c}{c}$ with the flap extension { $\Delta c = 0$, same slope

$\Delta c \neq 0$, slope is increased

c) Leading Edge High lift devices

1. Leading edge slot

- There is a gap between the flap and leading edge.

↳ flowing high energy air into BL on the upper surface

- It modifies the pressure distribution over the top surface of the airfoil mitigating the adverse pressure gradient and delaying flow separation.

- $C_{\ell,max}$ is increased with no significant increase in drag.

- Since the slot alone effects no change in camber, the higher maximum C_{ℓ} will be obtained at a higher angle of attack.

   ↳ Also, it doesn't effect the lift curve slope and zero-lift angle of attack

2. Leading edge flap

- It increases the curvature of the top of the airfoil.

- In this case, the virtual angle of attack becomes smaller than α. (opposite effect compared to T.E. plain flap)

- It results in a higher $C_{\ell,max}$.   ↳ The curve should move right side.

α

"Virtual" angle of attack

V_∞
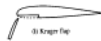
(d) Deflected leading-edge flap
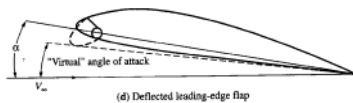
3. Leading edge slat (slotted leading edge flap)

- It is like as fowler flap - increases the lift through a combination of increased wing area and camber - but implemented at L.E.

- In similar way, it results in a small increase in the lift curve slope.

c_l

Leading edge
slot

Leading-edge
slat

Unflapped
airfoil

Leading-edge flap

α

(c)
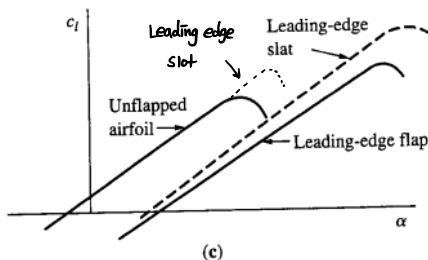
4. Kruger flap

- It forces the flow to run more over the top of the airfoil.

- However, it causes high level of drag at small angle of attack.

- It is suitable for thinner airfoils.

- Unlike others, the main wing upper surface and its nose is not changed.

- It may be similar to leading edge flap in $C_{\ell,max}$ effect but they are deployed differently.

(Aerodynamic effect)   ↳ It increases maximum lift coefficient (move to right)

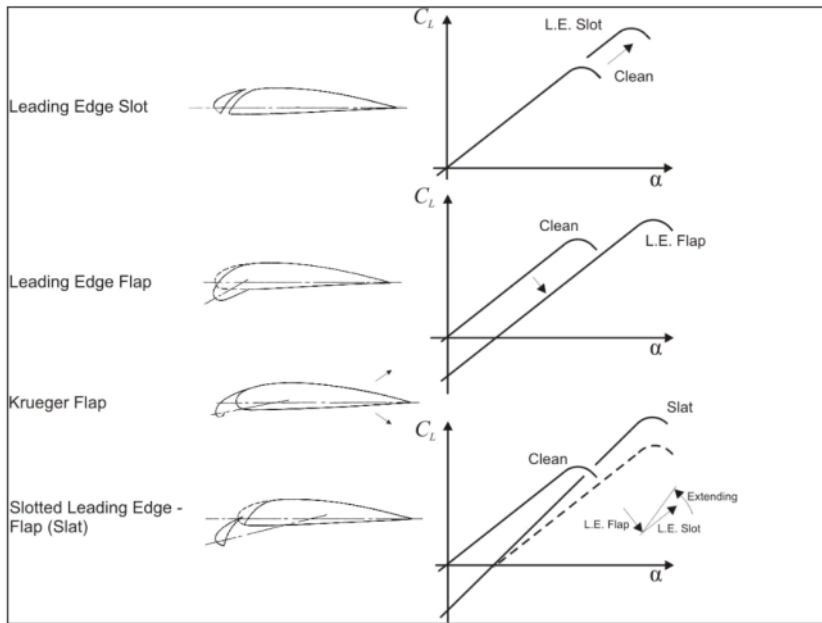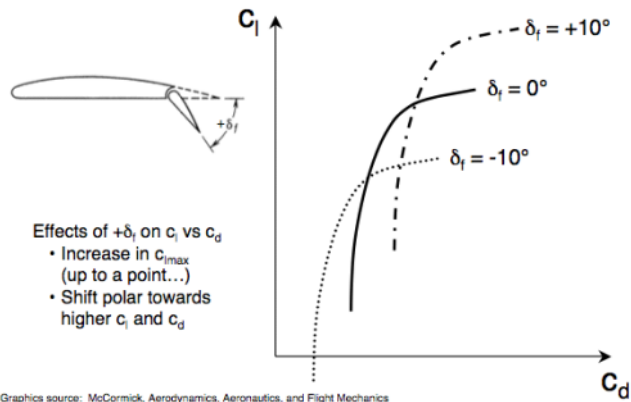Hence, in summary, in terms of L.E. high lift devices

Fig. 8.3 Different leading edge high lift systems (airfoils from **DATCOM 1978**)

Control Surface Effects on Lift Curve - c_l vs c_d [21]

Effects of $+\delta_f$ on c_l vs c_d
- Increase in $c_{l_{max}}$ (up to a point...)
- Shift polar towards higher c_l and c_d

$\delta_f = +10°$

$\delta_f = 0°$

$\delta_f = -10°$

Graphics source: McCormick, Aerodynamics, Aeronautics, and Flight Mechanics

Control Surface Effects on Lift Curve - $c_{mc/4}$ vs α [22]

Effects of $+\delta_f$ on $c_{mc/4}$ vs α
- Decrease in $c_{mc/4}$

$\delta_f = 0°$

$\delta_f = +10°$