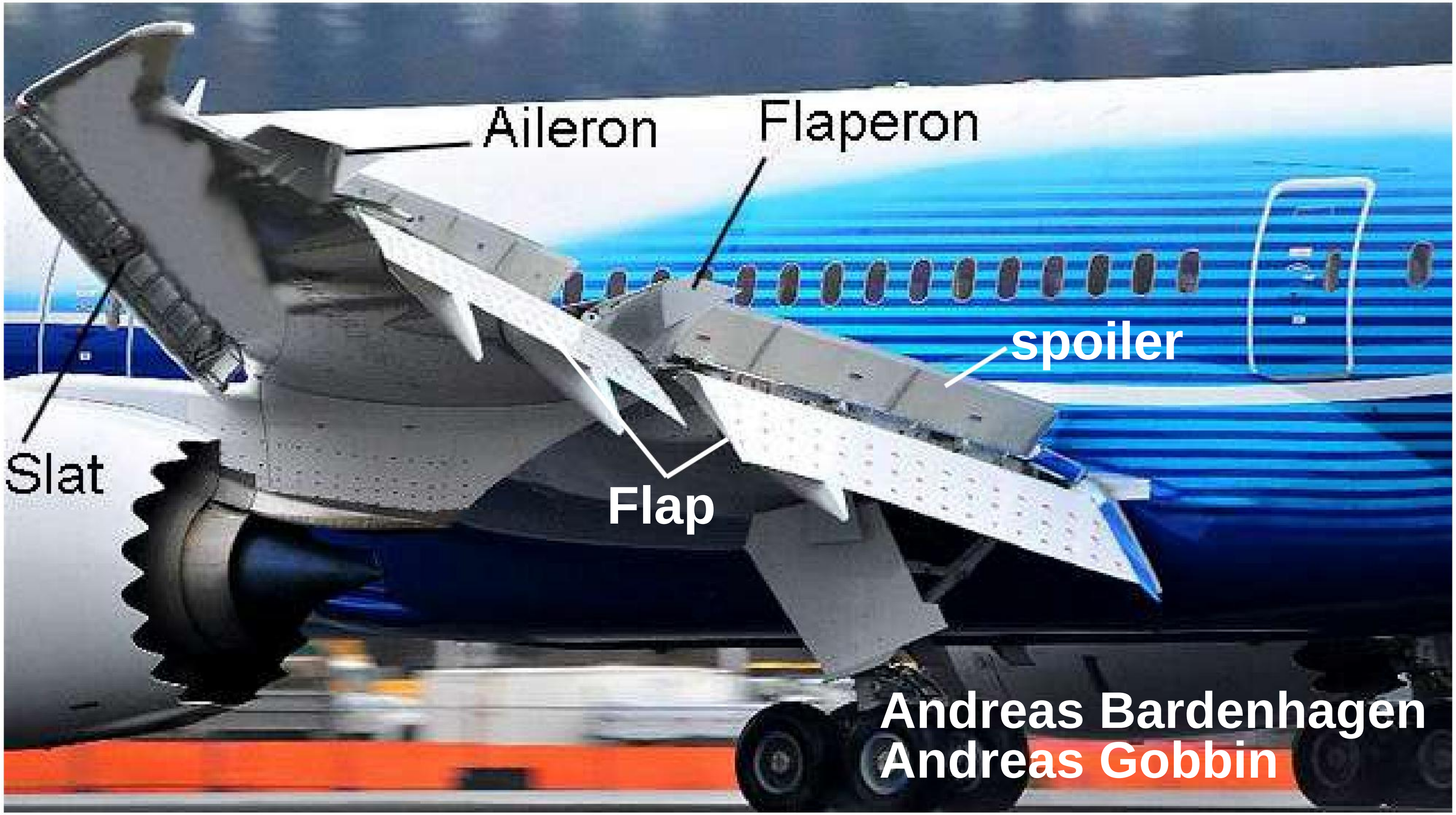
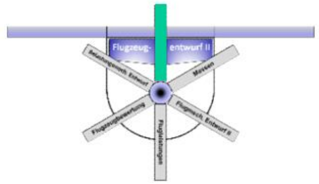
Welcome to the course

Aircraft design II



Andreas Bardenhagen
Andreas Gobbin



D Basics of aerodynamic design Overview

D Basics of aerodynamic design
Overview

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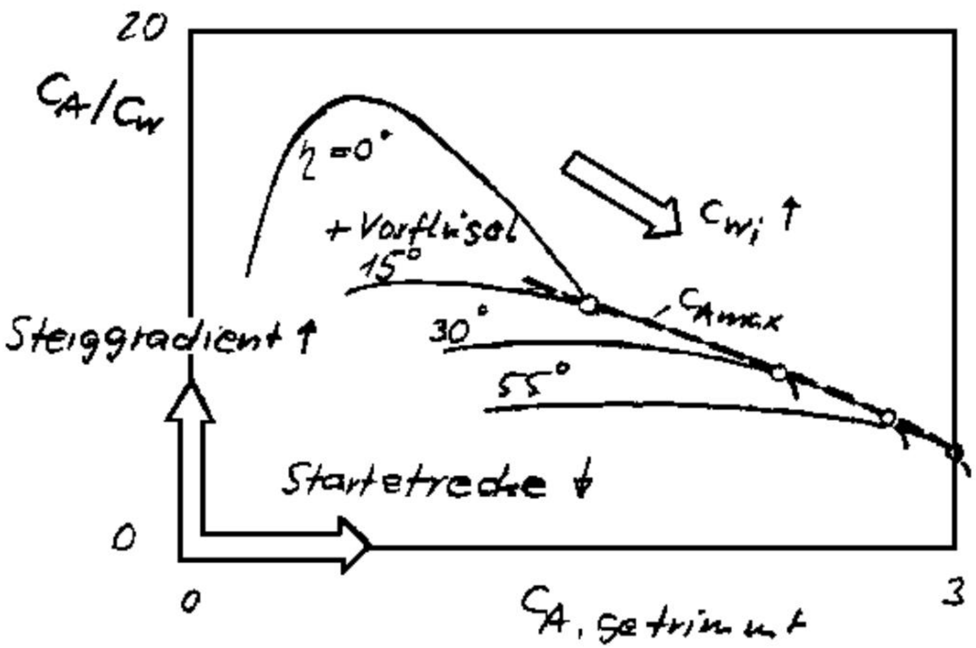
1.6 Lift characteristics during takeoff and landing

- Wings have a small surface area to enable high cruising speeds.
- A low approach speed is required for landing and a low take-off speed with low drag is required for take-off.

- To meet the start-/Landing requirements different flap systems can be used.

- These allow the maximum lift to be adjusted to the respective flight phase.



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1.6 Lift characteristics during takeoff and landing

- Flap systems have the required above requirements varying structural complexity.

- The picture shows the trailing edge flap configuration of a short-haul aircraft (B737)

- This is designed as a triple slotted flap.

- In landing position, the spoilers installed to increase drag after touchdown can also be seen.

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1.6 Lift characteristics during takeoff and landing

- The coordinated guidance of the individual flap elements during extension requires a high mechanical effort for the flap system.

- The complex mechanics required for this are largely based on the so-called Flap Track Fairings (or Canoe Fairings for Wide Bodies).

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1.6 Lift characteristics during takeoff and landing

- The design of the slat (leading edge flap) of the same model is no less complex.

- The access hatches are essential for maintenance work.

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1.6 Lift characteristics during takeoff and landing

- The flap systems of aircraft whose take-off and landing distance requirements are not as high are significantly less complex.

- Here you can, for example, Double-slotted flaps (TU134) generate sufficient maximum lift, the individual segments of which are permanently assigned.

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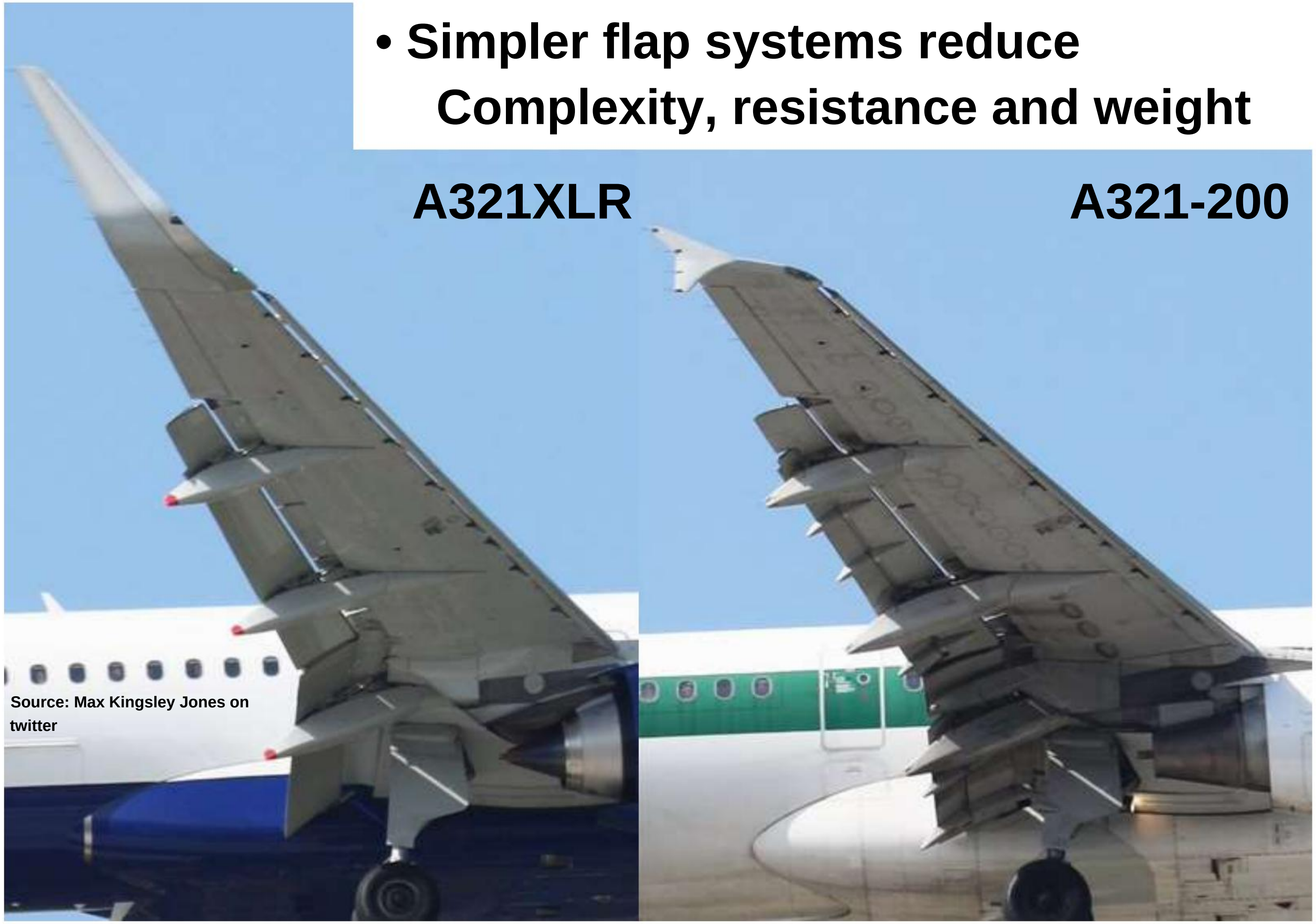
1.6 Lift characteristics during takeoff and landing

- Simpler flap systems reduce Complexity, resistance and weight



Source: Max Kingsley Jones on twitter

D Basics of aerodynamic design 1.6 Lift characteristics during take-off and landing

Source: Stuart H Bourne

Concorde:

- **Wings of small aspect ratio,**

  Delta wing ÿ small—

- **Simple flap system • High angle of attack at**

  landing

Source: Munich Airport

Airbus A380

- **Wings of large aspect ratio, double**

  trapezoidal wing ÿ high •

Effective flap system • Moderate angle of attack at

landing

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1.6 Lift characteristics during takeoff and landing

- This polar also has practical significance for the Pilots and passengers, as it provides information on the position of the horizon as a function of flight speed and on the reaction of the aircraft to changes in angle of attack due to gusts.

- A large lift gradient reduces flight comfort and makes the aircraft sensitive to altitude control inputs, but it increases flight performance.

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1.6 Lift characteristics during takeoff and landing

• The polar of the landing configuration provides information about the Flight attitude during landing and therefore also the pilot's view during approach. •

For this reason, the front part of the fuselage of the "Concorde", an aircraft with a delta wing and very low lift increase, has to be folded down during slow flight.

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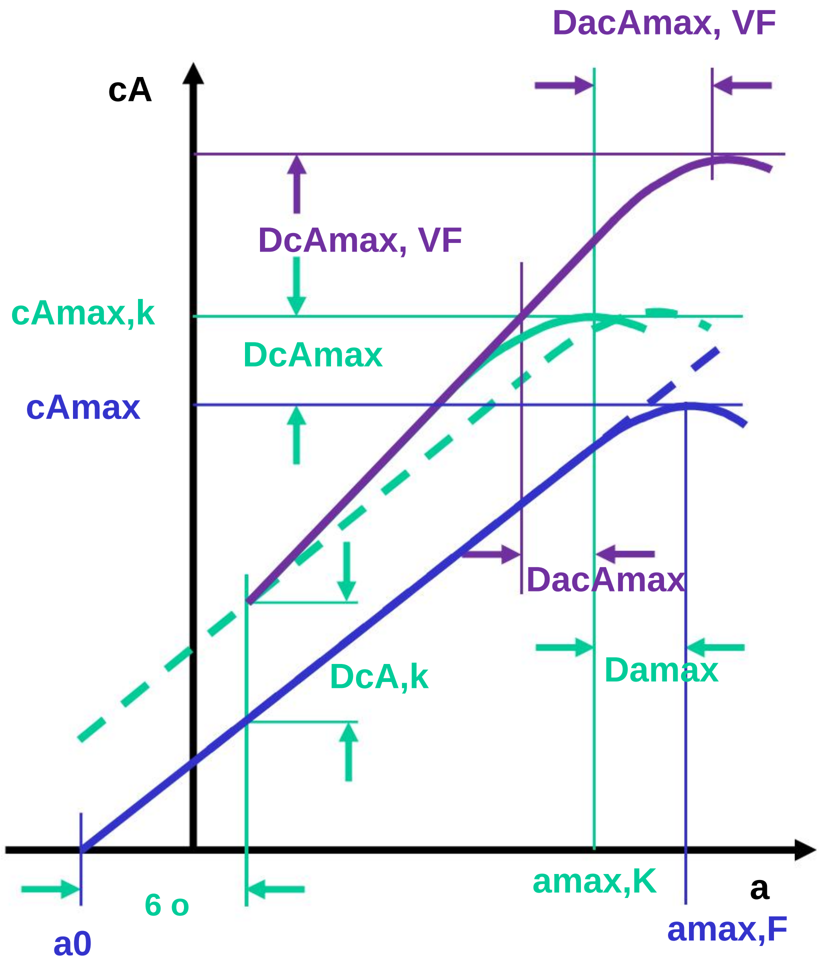
1.6 Lift characteristics during takeoff and landing

Resolved aircraft polars



Buoyancy without extended High-lift devices

Buoyancy with extended Trailing edge flap

Lift with extended trailing edge flap with area enlargement (Fowler class)

Buoyancy with extended Trailing edge flap with area enlargement AND Leading edge flap

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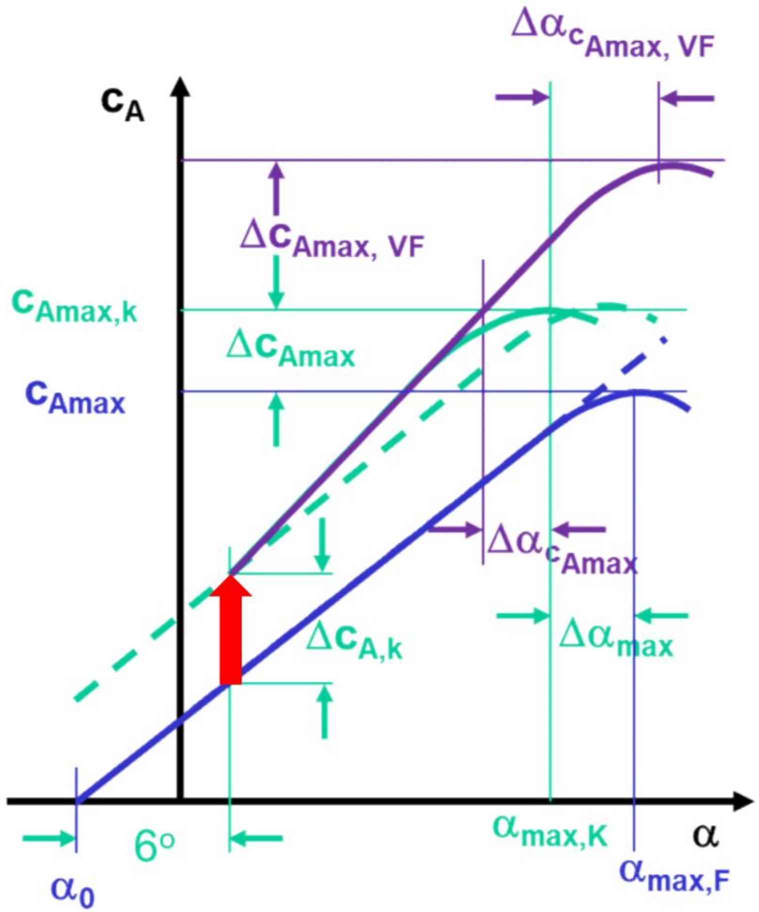
1.6 Lift characteristics during takeoff and landing

The primary effect of high-lift aids is

always the same in principle: •

Primarily, an increased curvature is achieved as a result of the rotation of the flap around its hinge, which causes a parallel shift of the resolved polars upwards.

• This camber increase can also be achieved by leading edge lift aids (ÿ Krueger flaps).



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1.6 Lift characteristics during takeoff and landing

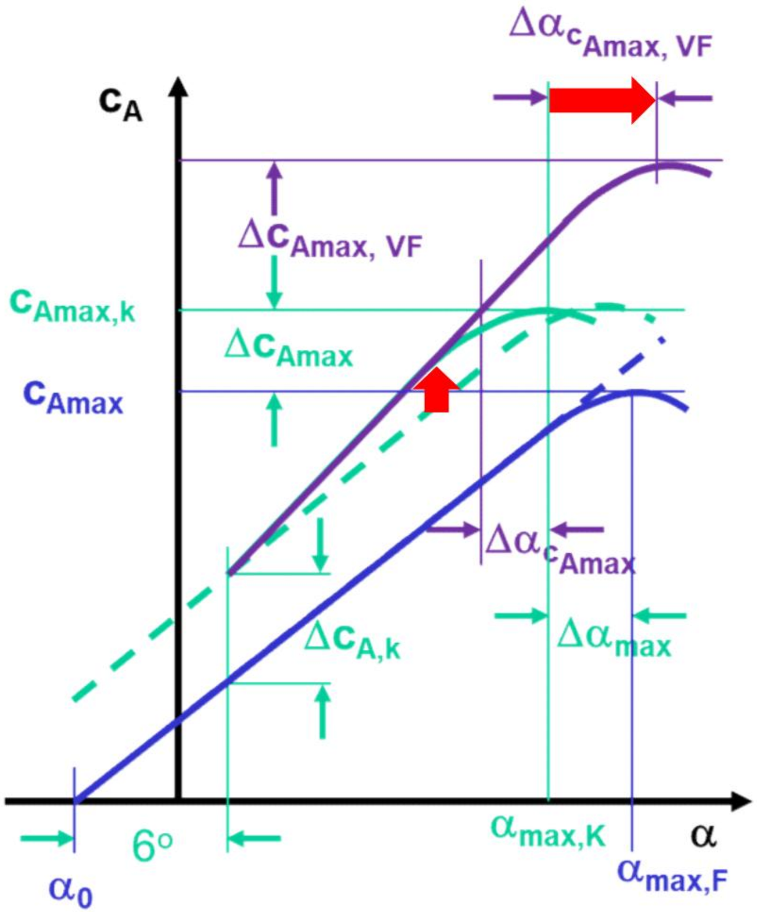
Secondary effect:

- **Flow through the valve system system from bottom to top leads to a boundary layer influence, which leads** to an **increase in the maximum angle of attack**

  (especially slats)

- **Increasing the wing area of flaps that experience translational displacement in addition to rotation (e.g. slats, slotted flaps, Fowler flaps) ÿ**

  Increasing the lift increase



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1.6 Lift characteristics during takeoff and landing

- The combination of all effects through a customized Choosing the type and geometry of the flaps in line with the requirements while minimising the construction effort is a task that cannot be addressed directly.
- Rather, it must be designed with intuition and the respective expectations must be verified in the wind tunnel.
- This phase takes a long time in practical aircraft design and requires large financial expenditure, since a model must be made for each specification and tested in the wind tunnel.
- Today, however, extensive aerodynamic (preliminary) investigations can already be carried out numerically.

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1.6 Lift characteristics during takeoff and landing

- Even after detailed investigations, final clarity about the aerodynamic behavior of the wing in high-lift configuration is often not achieved.

- Therefore, verification must ultimately be carried out in flight tests with the built aircraft!

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1.6 Lift characteristics during takeoff and landing

- **Analytical determination of the buoyancy characteristics of a Aircraft in takeoff and landing configuration is not possible.**
- **Complex influence on lift increase and maximum lift coefficient of**
  - Wing parameters
    - Stretching
    - Escalation
    - Arrowing
    - Depth gradient •

      Twisting
  - Profiling
  - Surface roughness
  - Valve type, length, depth, position
  - Design of the wing-fuselage and pylon-wing transitions

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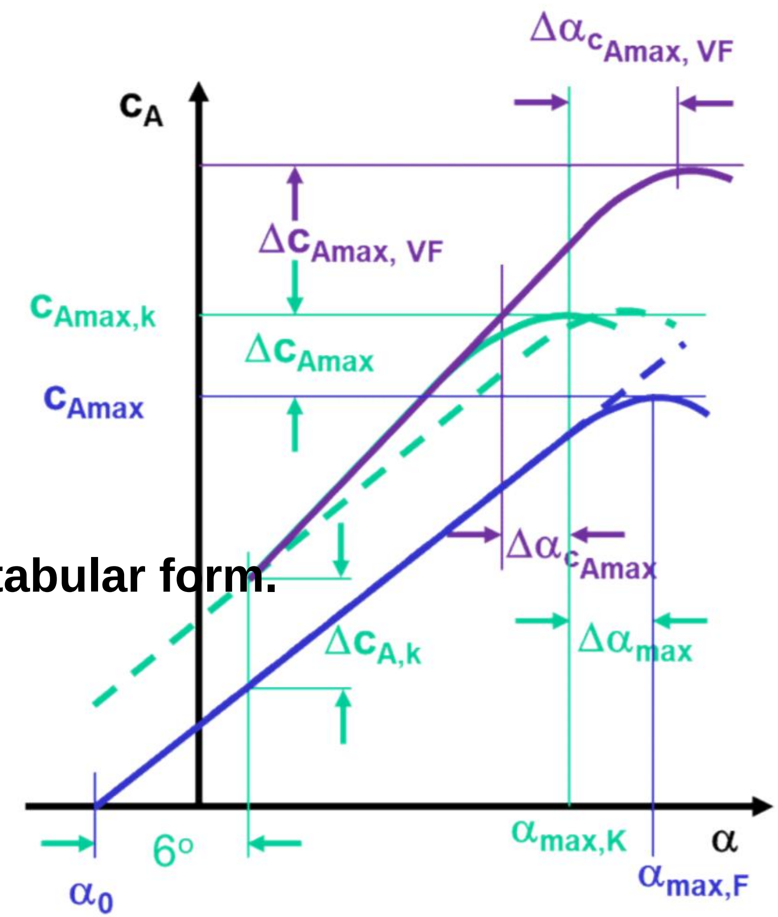
1.6 Lift characteristics during takeoff and landing

- **Here, in FE II, possibilities for estimating the resolved polars are shown.**
- **This procedure is often used with "Manual method".**
- **It is based on a wealth of measurement results for individual influences, which have been presented graphically or in tabular form.**



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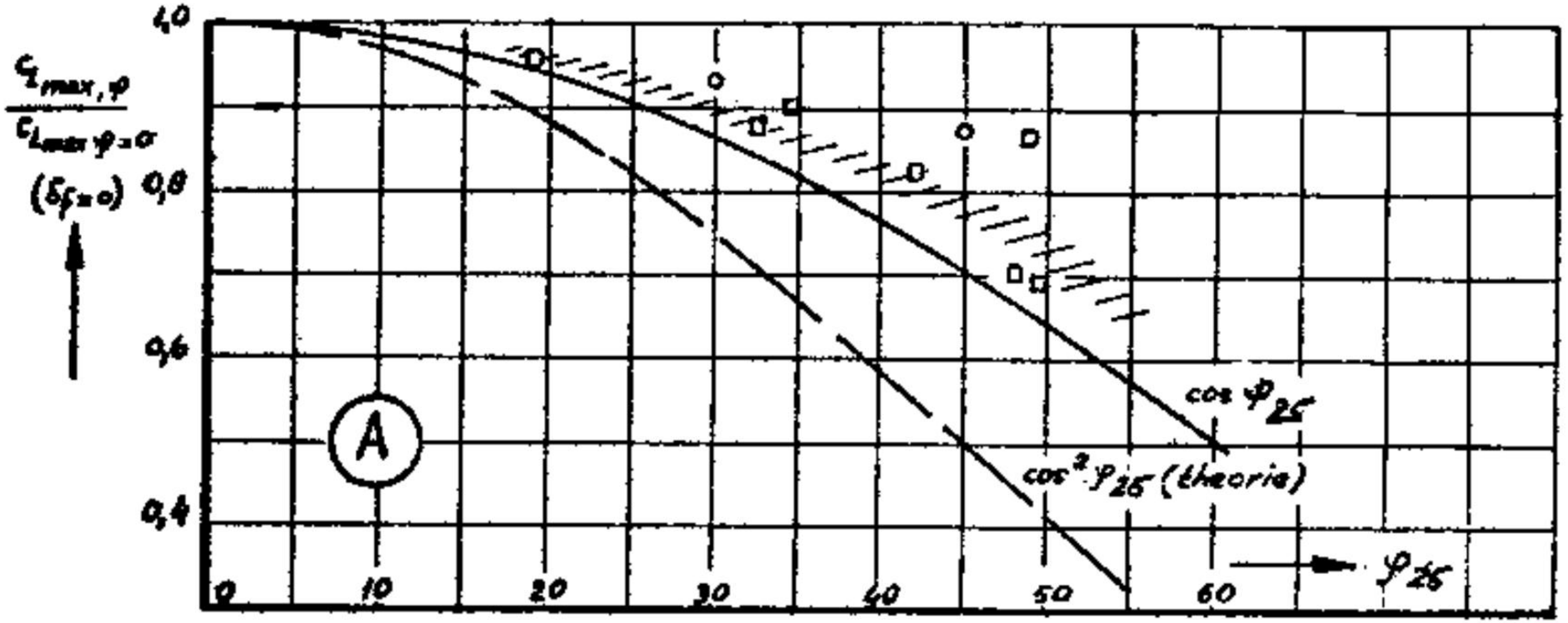
1.7 Wings without lift aids

- The basis for the investigation of the flap wing is knowledge of the lift behavior of the base wing.
- The maximum lift coefficient for the wing without lift aids can be determined approximately by averaging the Re number-dependent local coefficients at the wing root and at the wing tip.



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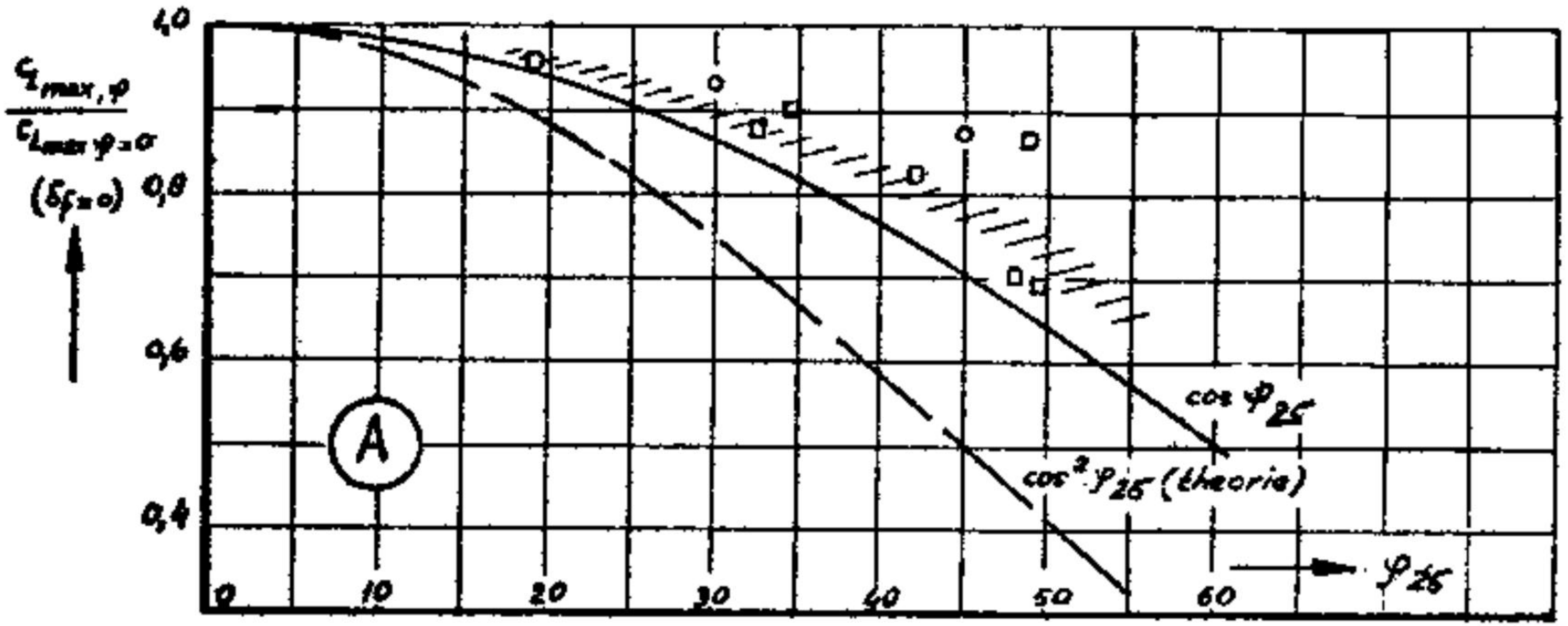
1.7 Wings without lift aids

• The profile polars measured for several Re numbers can be used for this purpose. •

The influence of the wing sweep follows approximately the cos(ÿ) law, although, as shown in Chapter D.1.4.7, theoretically there should be a quadratic dependence on the sweep.



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1.7 Wings without lift aids

- **Approximation: Factor of 0.9 for taper, aspect ratio and roughness influence and effect of an engine nacelle mounted on the wing leads to a greatly simplified approach for the maximum lift coefficient of the aircraft:**

$$c_{A\max,F} \;\text{ÿ ÿ}\; 0.9 \; \frac{c_{a\,\max,i} \;\text{ÿ}\; c_{a\,\max,a}}{2} \;\text{ÿÿ}\cos\text{ÿ} \;\text{ÿ}\; 25$$

- **Maximum angle of attack follows from the known straight line equation plus additional amount for the Ma number influence:**

$$a\,\text{ÿ}_{c_{A\max}} \quad \frac{c_{A_{\mathrm{Max}}}}{c_A^{\text{ÿ}}} \;\text{ÿ}\; a\,\text{ÿ}_0 \mathrm{D}a \quad c_{A\max}$$

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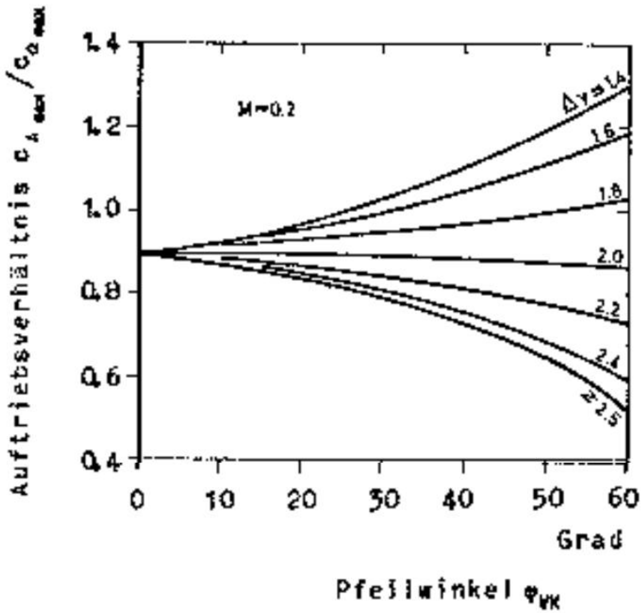
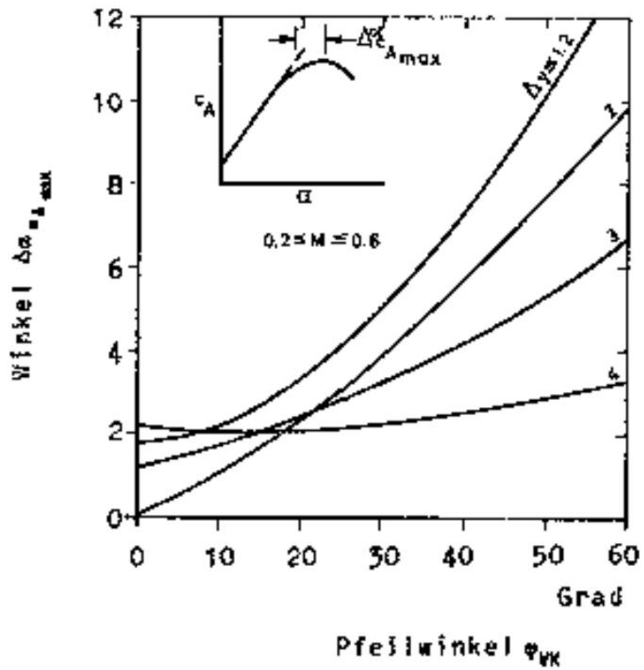
1.7 Wings without lift aids

- The last term DacAmax describes the range of Nonlinearity (partial boundary layer separation)

- It depends on the leading edge sweep and the nose radius of the profile ÿ nose radius parameter Dy. These parameters largely determine the separation mechanism and the length of the separation bubbl





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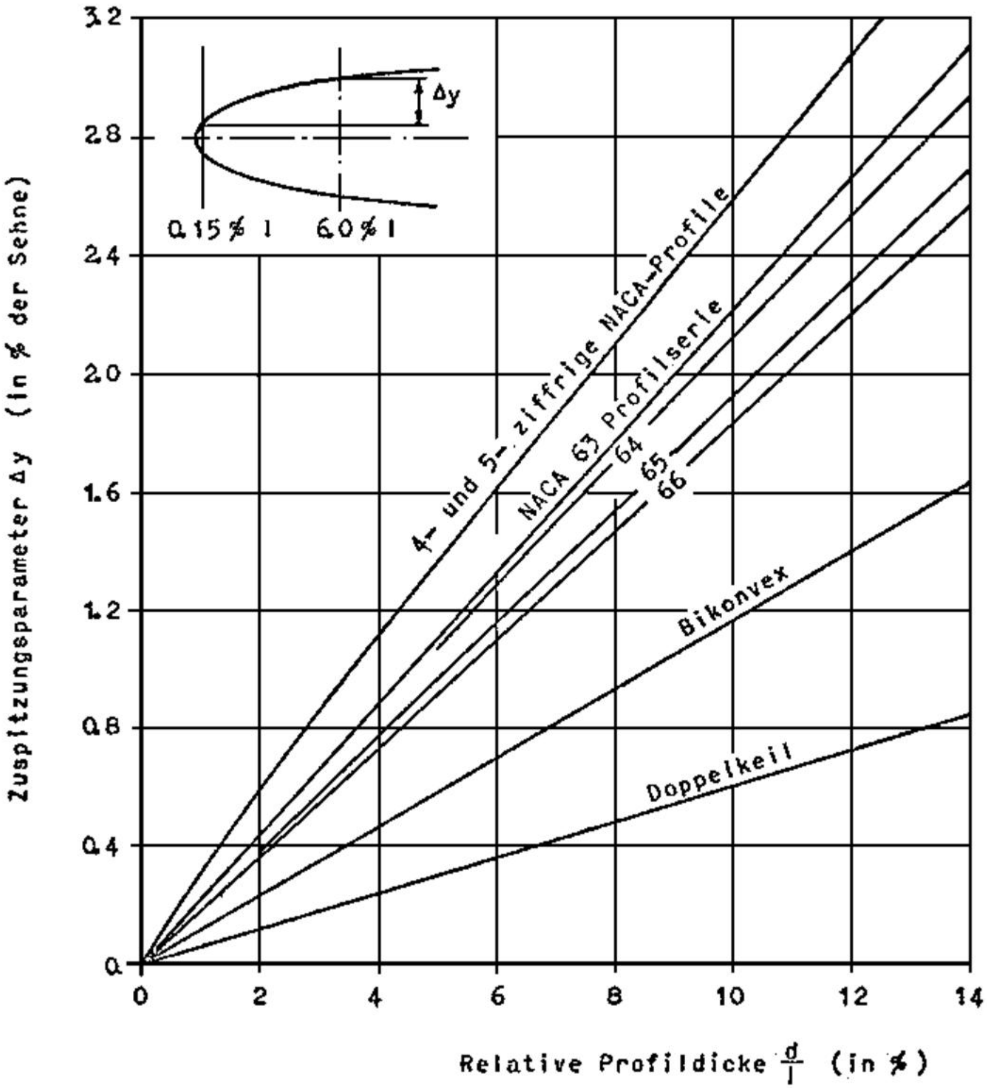
1.7 Wings without lift aids



- **The nose radius**

  Parameter Dy is a representative coordinate value on the upper side of the profile for the nose radius, which is difficult to determine.

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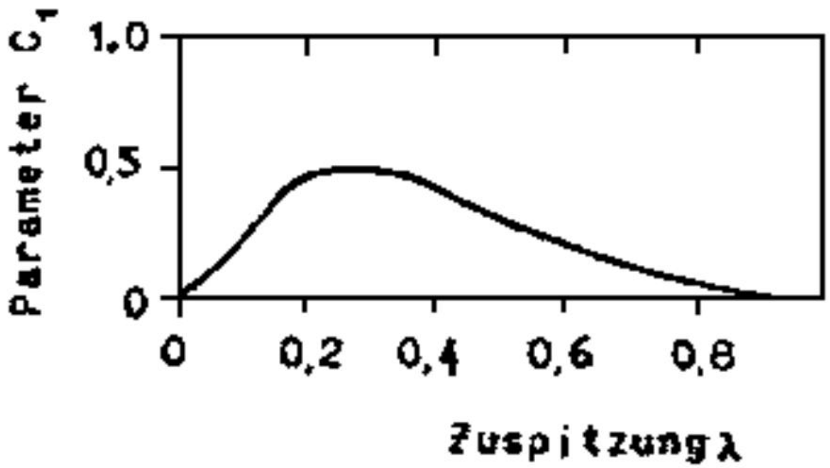
1.7 Wings without lift aids

- The above information applies to wings with a high aspect ratio.
- The prerequisite for a large aspect ratio wing is:

$$ÿ\ ÿ \quad \frac{4}{ÿC\ 1 \cdot cos ÿ_{1ÿÿÿ} \quad ÿ \quad {}_{UK}\ ÿ}$$

- The factor C1 depends on the apex as follows:



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1.7 Wings without lift aids

- The maximum lift coefficient can be determined somewhat more accurately using the following relationship than is possible with the rough estimate given at the beginning

$$c_{A_{Max}} = \left(\frac{c_{A_{Max}}}{c_{a_{Max}}} \right) c_{a_{Max}} + \Delta c_{A_{Max}}$$

- The quotient depends on the leading edge sweep angle and the nose radius coefficient (already explained).
- The second term estimates the Mach number influence on the maximum lift coefficient of the high aspect ratio wing.
- It also depends on the leading edge sweep angle. •

Both influences reduce the maximum lift.

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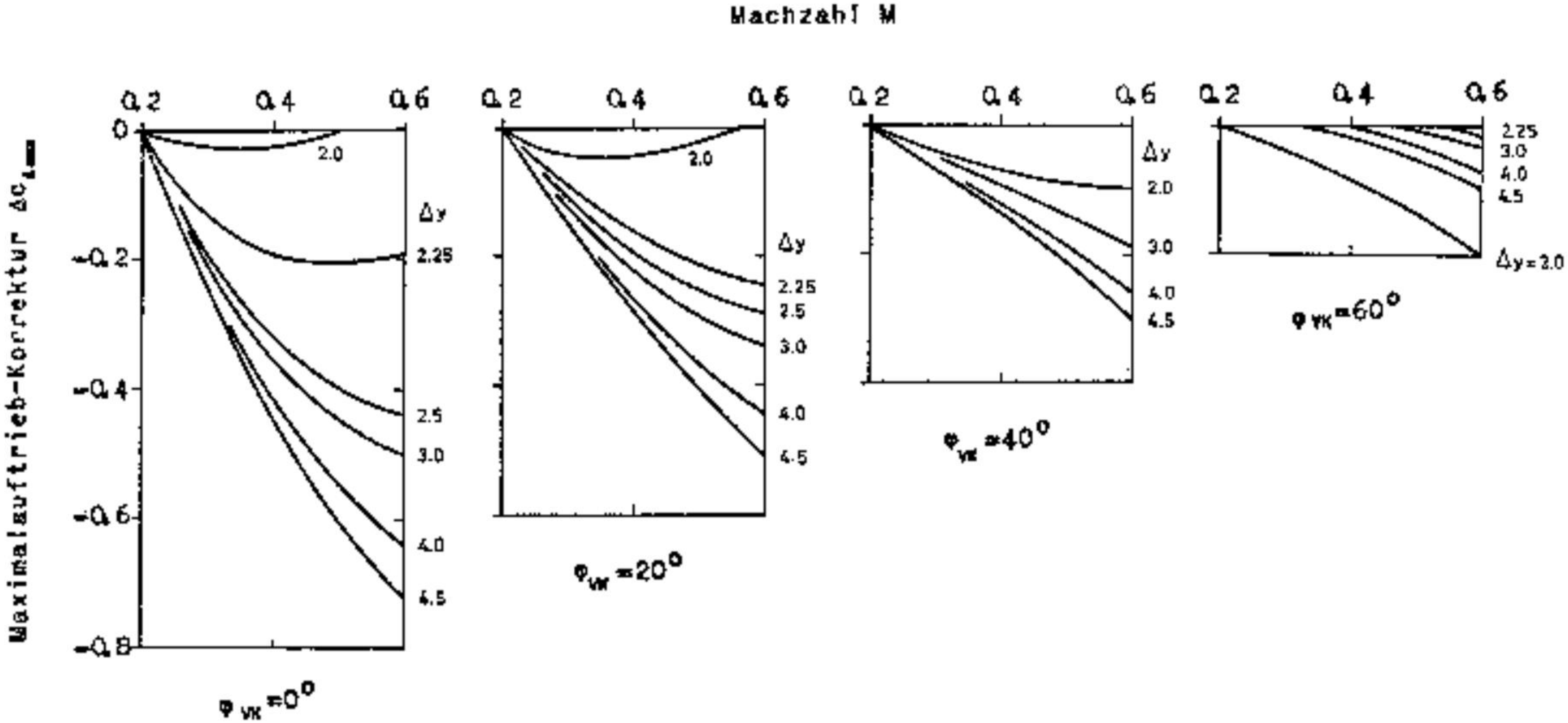
1.7 Wings without lift aids

- **Mach number influence on the maximum lift of wings (DcAmax) with a large aspect ratio in subsonic mode as a function of the nose radius parameter Dy**



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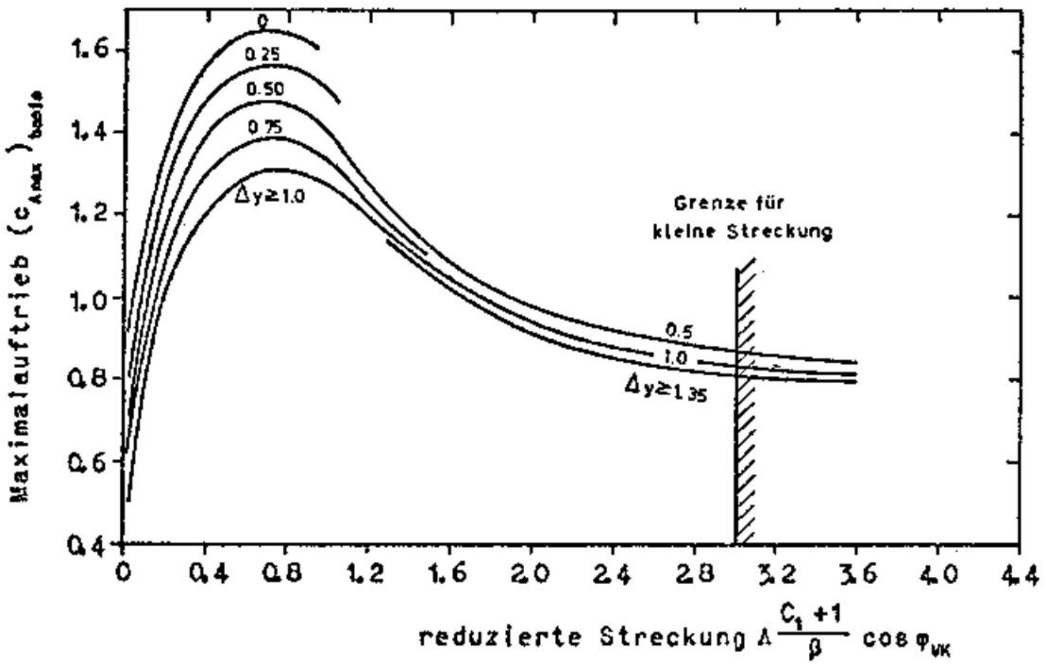
1.7 Wings without lift aids

- For wings with a small aspect ratio (e.g. tail units), the maximum lift coefficient can be easily determined from a base value and the Mach number-dependent additional amount mentioned above



- The underlying value depends functionally on the aspect ratio, leading edge sweep, Mach number (expressed by the Prandtl-Glauert factor ÿ), nose radius parameter Dy and taper factor.

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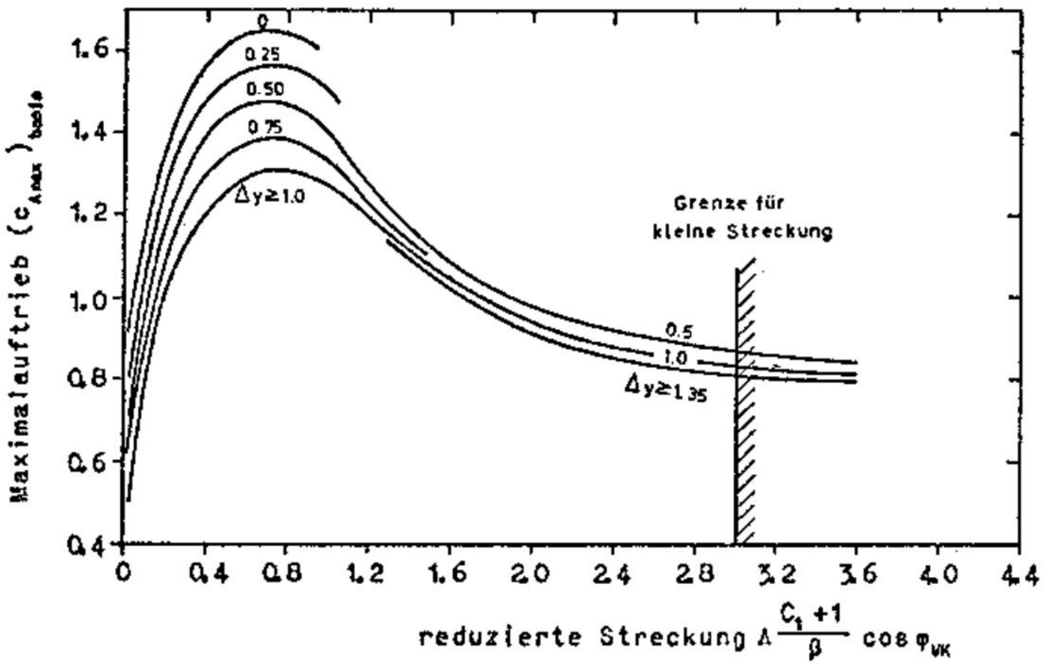
1.7 Wings without lift aids

• With profiles whose thickness offset is between 35 and 50%, the low aspect ratio wing achieves only lower maximum lift coefficients overall.



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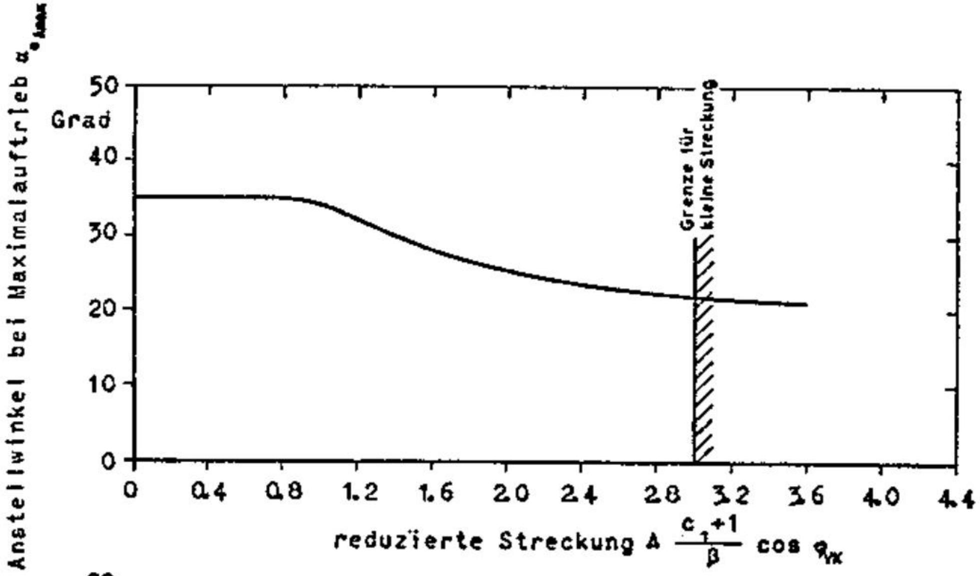
1.7 Wings without lift aids

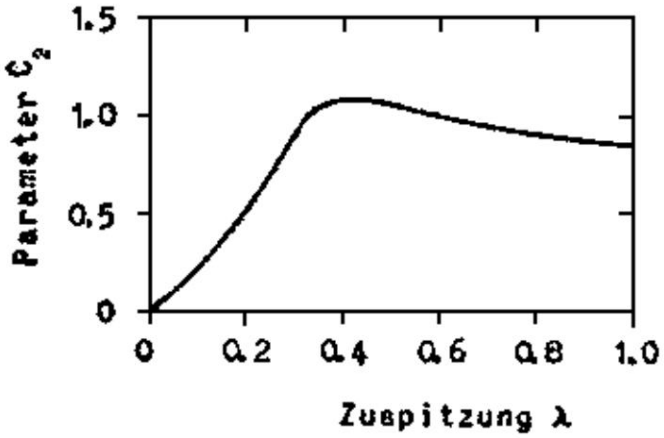
- **Different basic values also apply**

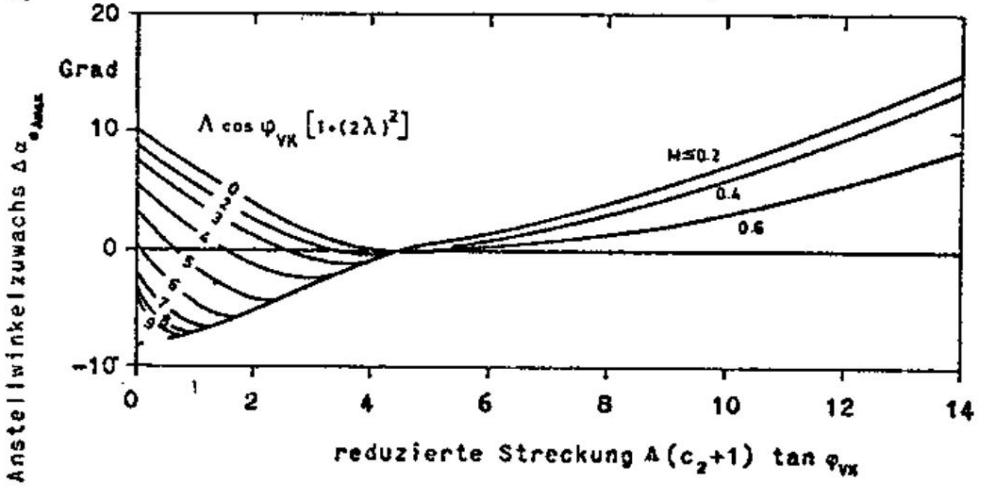
  to the maximum angle of attack

  for the small aspect

  ratio wing.







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1.7 Wings without lift aids

- **Determination of the buoyancy increase up to approx. 0.8 or 0.9 of the max. Lift coefficient for the incompressible wing using a relationship derived from potential theory:**

$$c^{ÿ}_{A,ik} \; ÿ \; \frac{ÿ\, c \cos ÿ\, c^{ÿ}_{a} ÿ\, ÿ \quad ÿ \quad {}_{25}\, ÿ}{ÿ \dfrac{c \cos 1\, c^{ÿ}_{a} ÿ\, ÿ \quad ÿ \quad {}_{25}\, ÿ}{ÿÿÿÿ\; ÿ}} \qquad ÿ\; cÿ \qquad {}_{A}\; ÿ\; cÿ_{A,ik}\; ÿÿ$$

- **But there can also be a more general relationship Weissinger, which also takes into account the Mach effects:**

$$c^{ÿ}_{A} \; ÿ \; \frac{2\; ÿÿÿÿ}{2\; ÿ \sqrt{\dfrac{ÿ^{2}\, ÿÿ^{2}}{k^{2}} \begin{pmatrix} ÿ \\ ÿ_{,} ÿ1 \\ ÿ \end{pmatrix} \dfrac{\tan^{2} ÿ\, ÿ_{50}}{ÿ^{2}} \begin{pmatrix} ÿ \\ ÿ\; ÿÿ\; ÿ \\ ÿ \end{pmatrix} 4}}$$

- **Here,**

$$k \; ÿ \; \frac{c^{ÿ}_{a}}{2\; ÿÿ} \; ÿ \; \frac{c^{ÿ}_{a\,\mathrm{Pr\,ofile}}}{c^{ÿ}_{a\,\mathrm{plate}}}$$

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1.7 Wings without lift aids

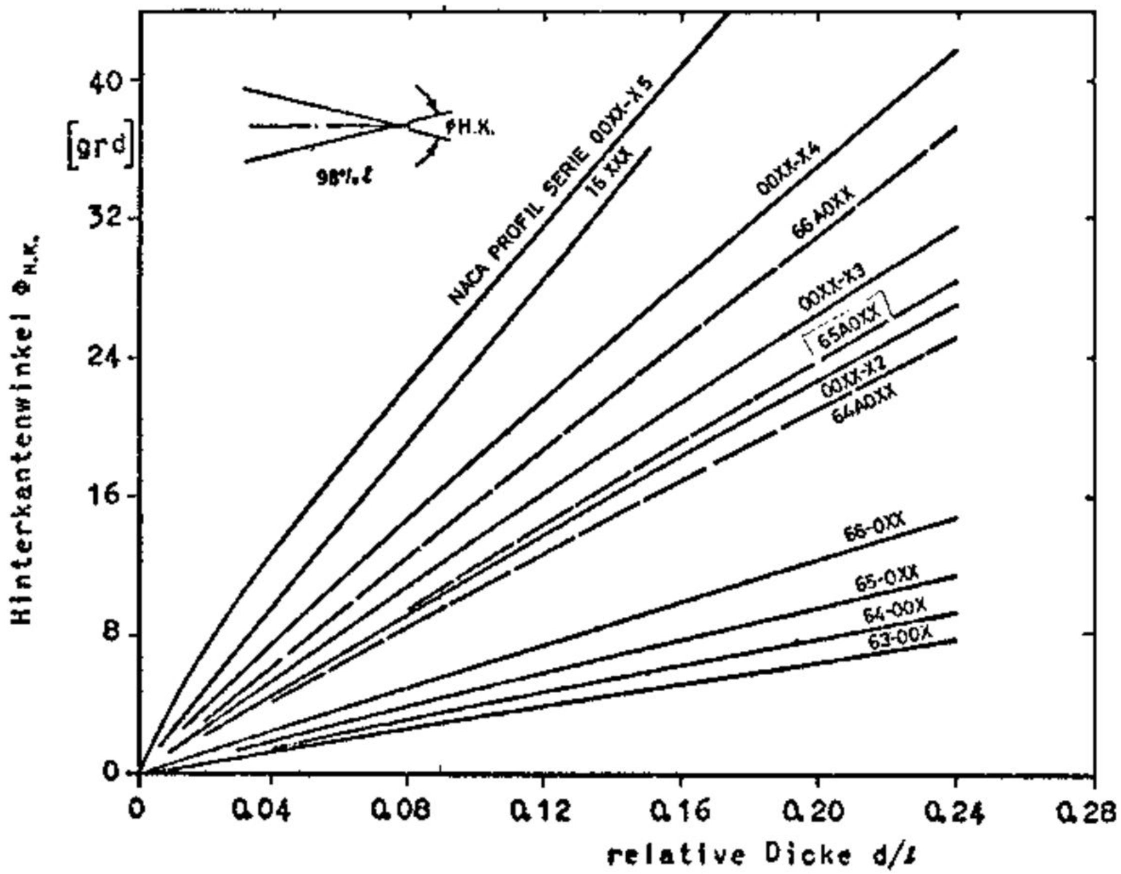
- **The profile lift increase can also be estimated more precisely to**

$$c_a^{ÿ} \; ÿ \; \frac{1.05\,ÿ}{} \cdot \left(\frac{c_a^{ÿ}}{c_{a\,theor.}^{ÿ}} \right) \cdot c_{a\,theor.}^{ÿ}$$

- **with**

$$c^{ÿ}_{a\,theor.} \; ÿ\, ÿ 2\, ÿ\, ÿ\, ÿ\, ÿ\, 4.7 \, \frac{d}{} \; ÿ\, 1\; 0{,}00375 \; ÿÿ_{HK}^{\,ÿ}$$

D Basics of aerodynamic design 1.7 Wings without lift aids • Trailing edge angles for various profiles NACA series



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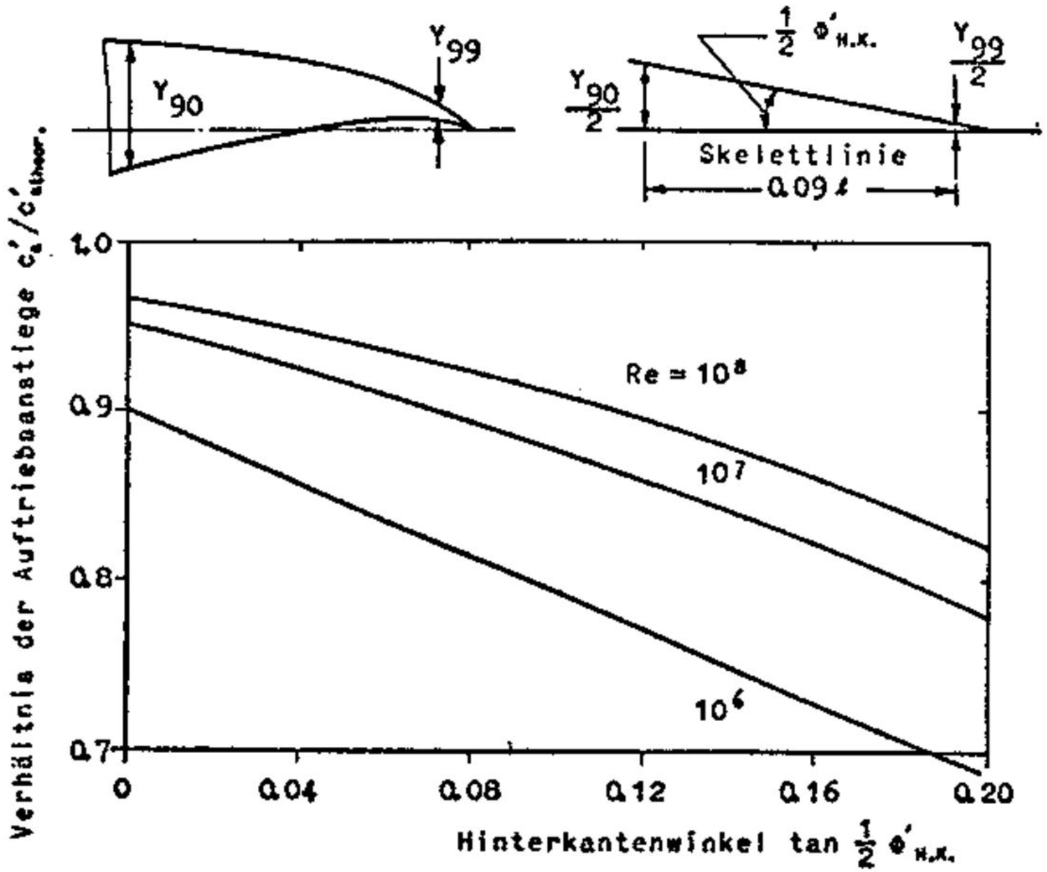
1.7 Wings without lift aids

- **Influence of the Reynolds number on the lift increase of Profiles**



D Basics of aerodynamic design 1.7 Wings without lift aids

• The influence of the wing shape on the zero angle of attack is small • It is influenced by the twist. • In general:

ca ÿ a ÿ 0 $\frac{a}{c^{ÿ}_{a}}$

• For the unwounded wing

a ÿ a 0Wings 0Pr ofil

• For the linear twisted wing must be corrected: ÿ ÿÿÿ ÿ

a ÿ a 0 0Wing root ÿ ÿ There $\frac{0}{ÿ}$ ÿ ÿ

ÿ: Twisting of the wing relative to the root profile

Da0 /ÿ: Zero angle of attack correction related to the linear Twist angle

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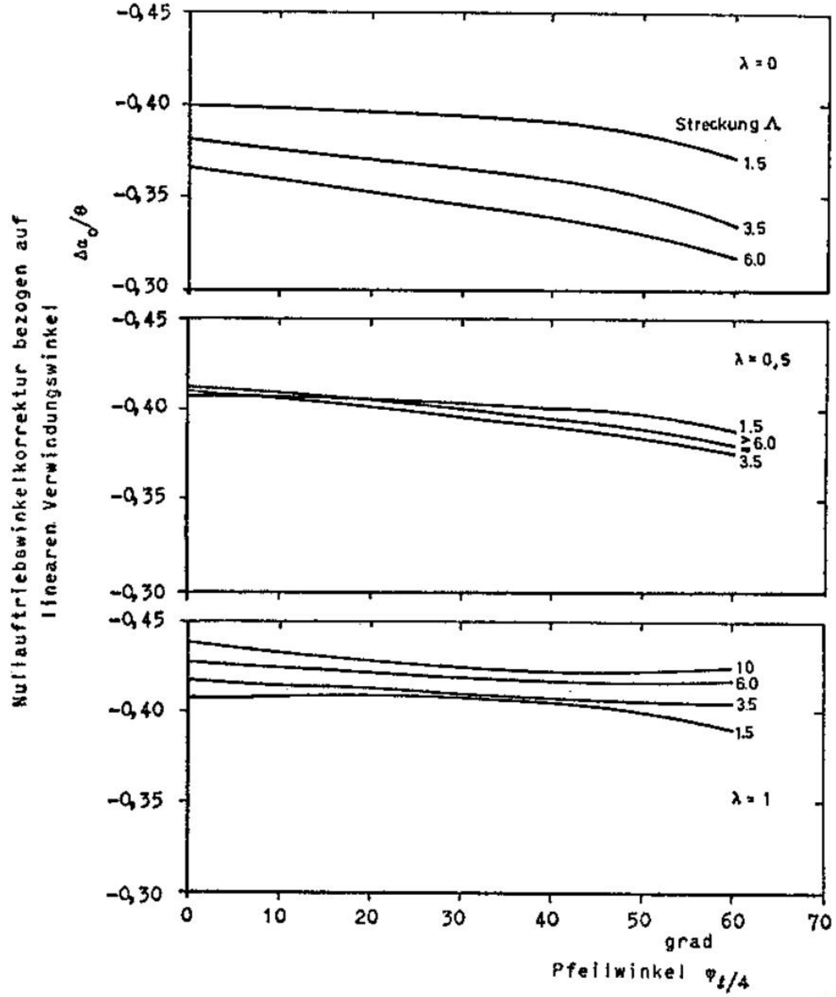
1.7 Wings without lift aids

• **Influence of linear twist, stretch and taper on the zero lift angle**



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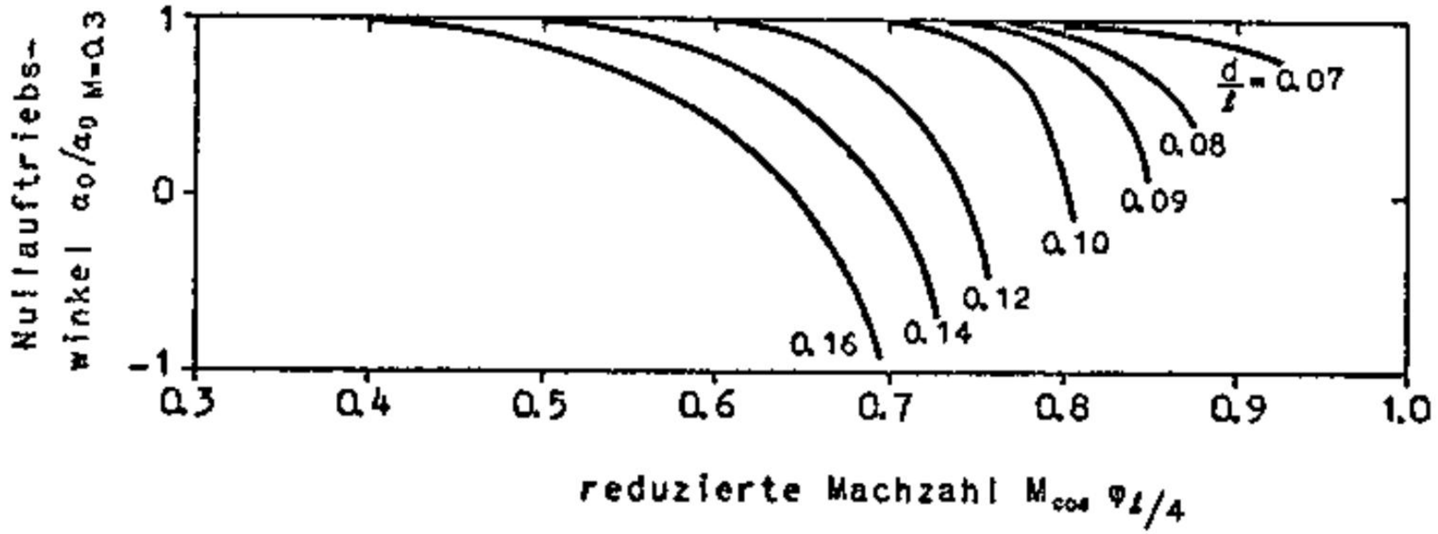
1.7 Wings without lift aids

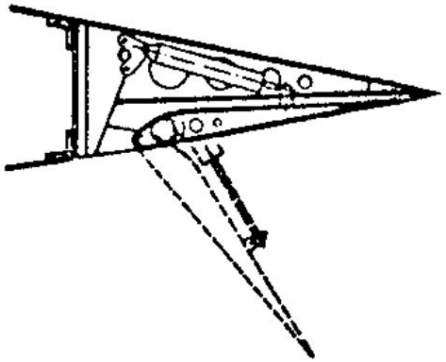
- **Mach number correction for zero lift angle**
  - **In addition, the Mach number also influences the Zero lift angle.**
  - **This effect can be estimated using the correction factor shown.**



D Basics of aerodynamic design

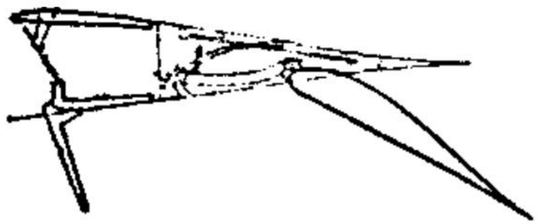
1.8 Wings with lift aids

- There are different designs for flap systems.
- Some configurations are shown here as examples, ordered by effectiveness and complexity:

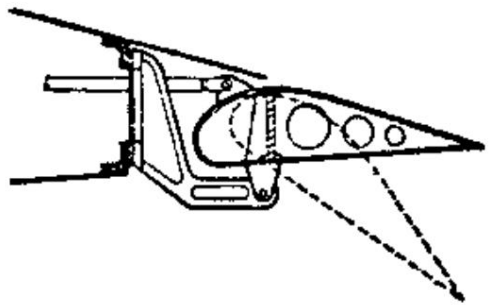


Split flap

Plain flap



Single slotted flap with optimum flap position for each deflection angle (Caravelle)



Single slotted flap with fixed hinge

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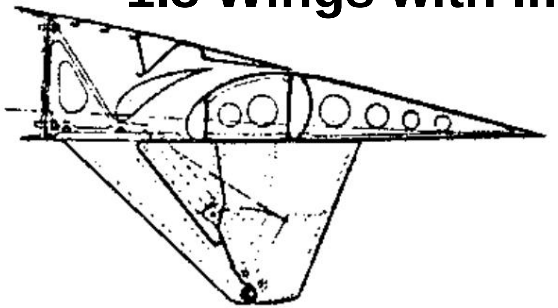
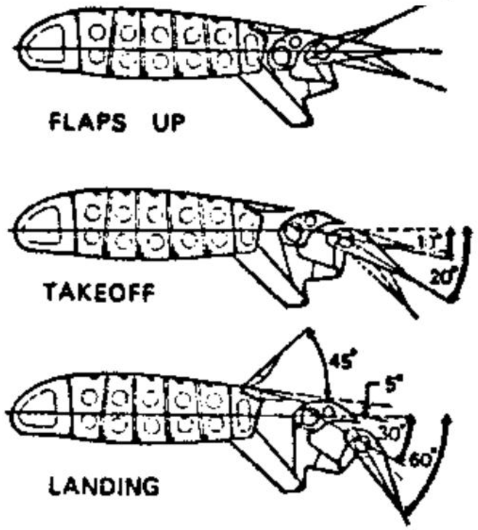
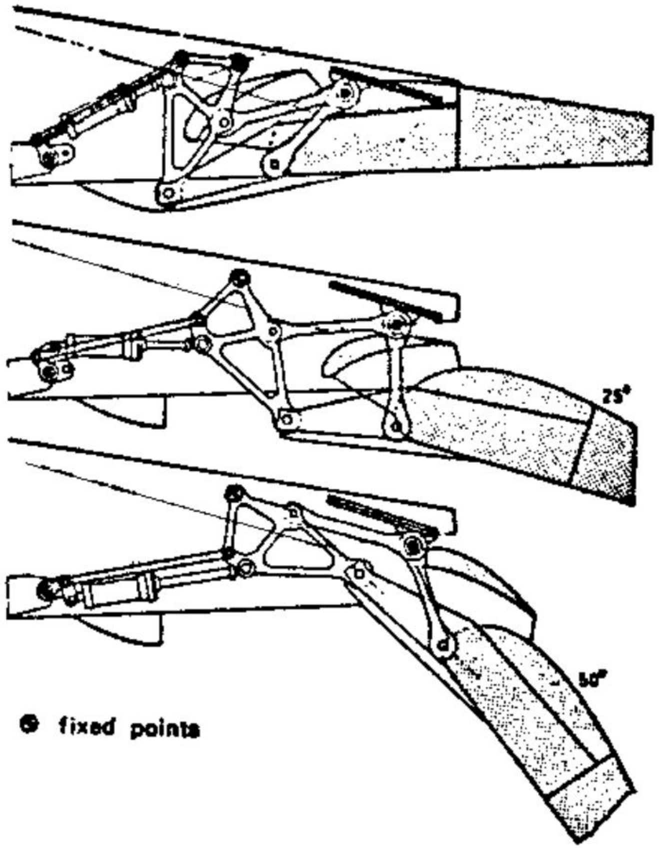
1.8 Wings with lift aids



Double slotted flap with fixed hinge and fixed vane (Douglas DC-9)



Double slotted flaps with individual adjustment of flap segments and drooped aileron (GAF N-22 Nomad)



Double slotted flap with four-bar motion (Douglas DC-8)

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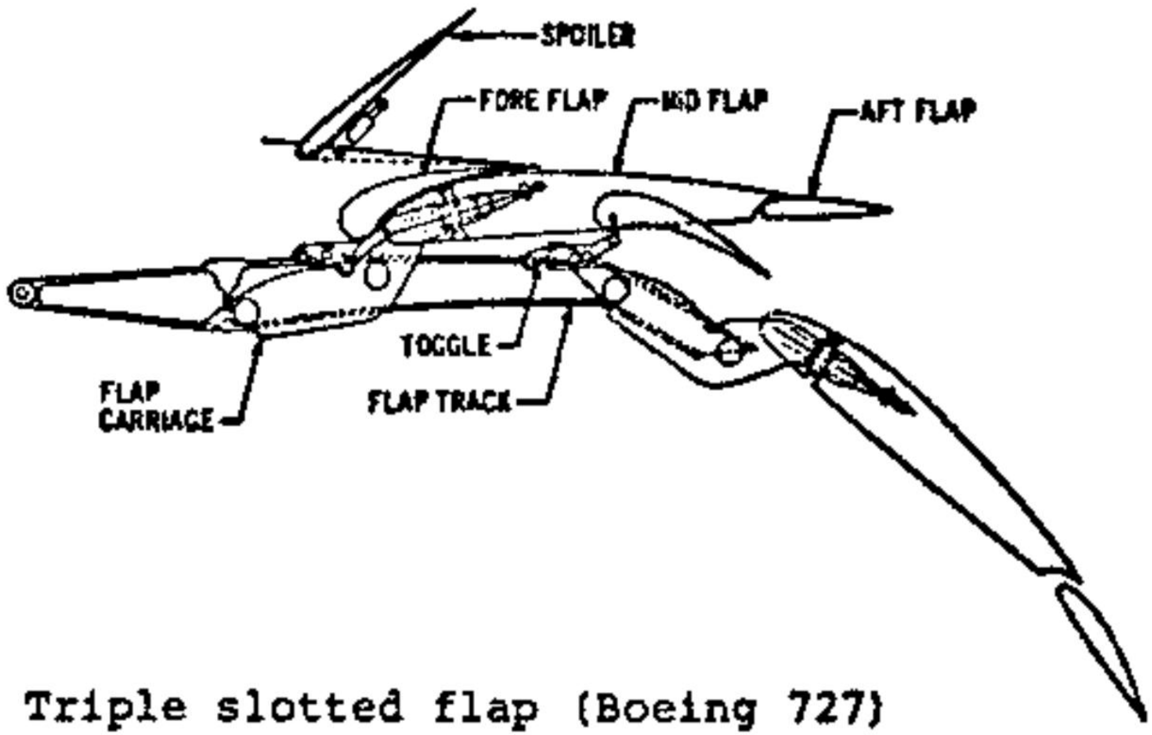
1.8 Wings with lift aids



Triple slotted flap (Boeing 727)

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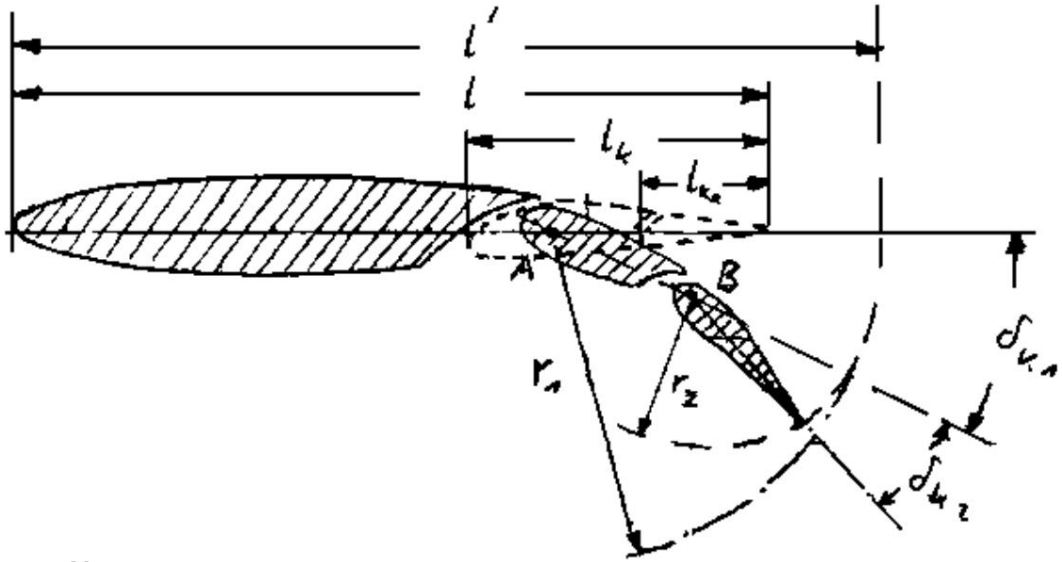
1.8 Wings with lift aids

- **Typical flap deflections for takeoff and landing**

Flap type	begin	Landing
Spread flap	15°	60°
Curved flap	15°	60°
Single slot damper	20°	50°
Double-slit damper with two moving parts	15°/15°	40°/40°
Double slotted damper with fixed guide flap	20°	50°
Fowler flap	15°	45°

- **Definitions for a flap with depth enlargement**



Movement sequence:

1) Rotation of flap 2 by Point B and the angle dk2 with radius r2
2) Rotation of flaps 1 & 2 by Point A and the angle dk1 with radius r1

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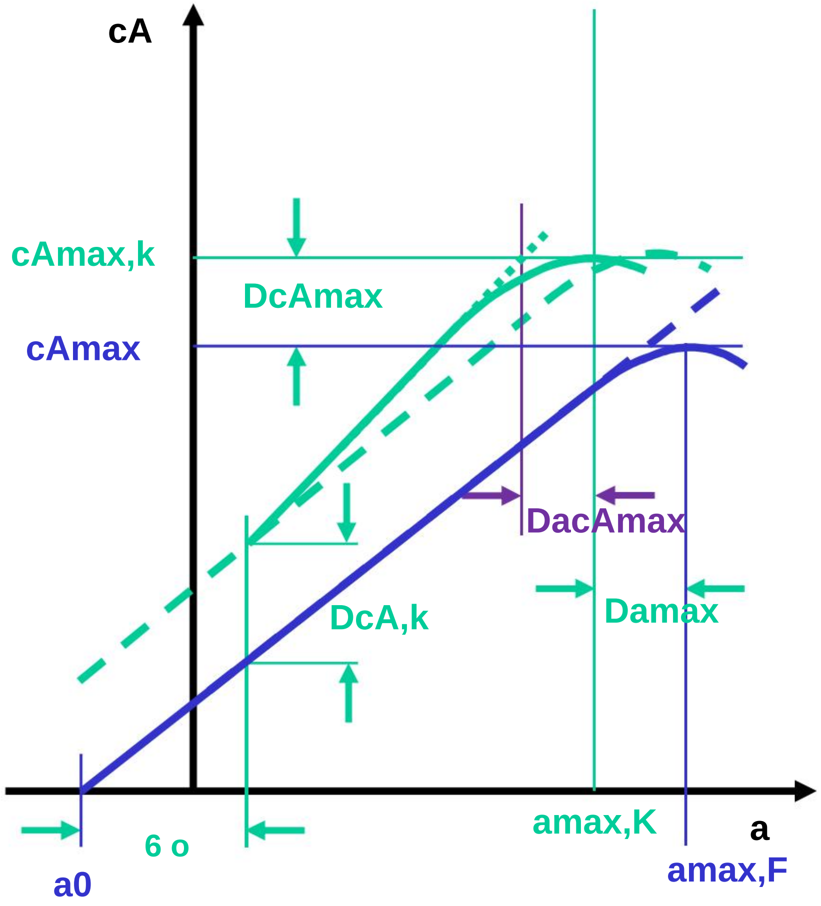
1.8 Wings with lift aids

- **Effect of trailing edge flaps**



Buoyancy without extended High lift center

Buoyancy with extended Trailing edge flap

Lift with extended trailing edge flap with area enlargement (Fowler class)

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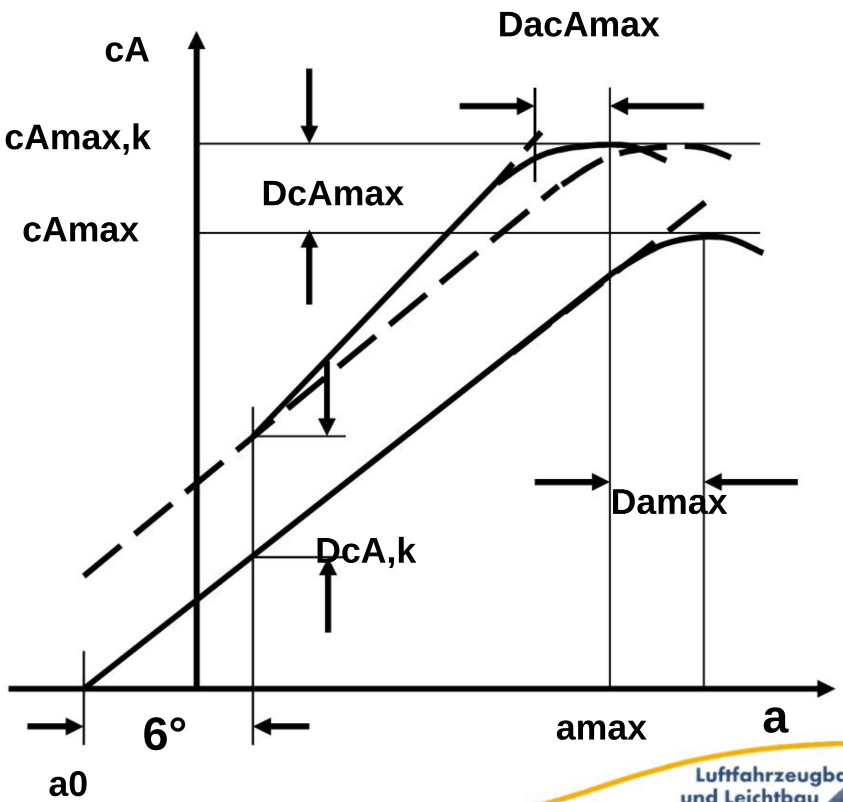
1.8 Wings with lift aids

- **The shift of the resolved polar due to flap**

  Impact is determined by the coefficients cAmax,k or acAmax,DcAmax,k, DcA,k and DacAmax defined.

- **The starting point is again profile values, which are converted to the finite wing using a lift distribution.**



- **If the flap deflection also increases the wing area, the additional lift depends on a.**

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1.8 Wings with lift aids

- The relationship cA =f(a) with extended flaps can be calculated approximately step by step as follows.

- The individual steps are the calculation or determination

mung of 1.

a0 , cA ´, cAmax of the wing

without flap deflection 2.

DcA at a = a0 + 6° 3.

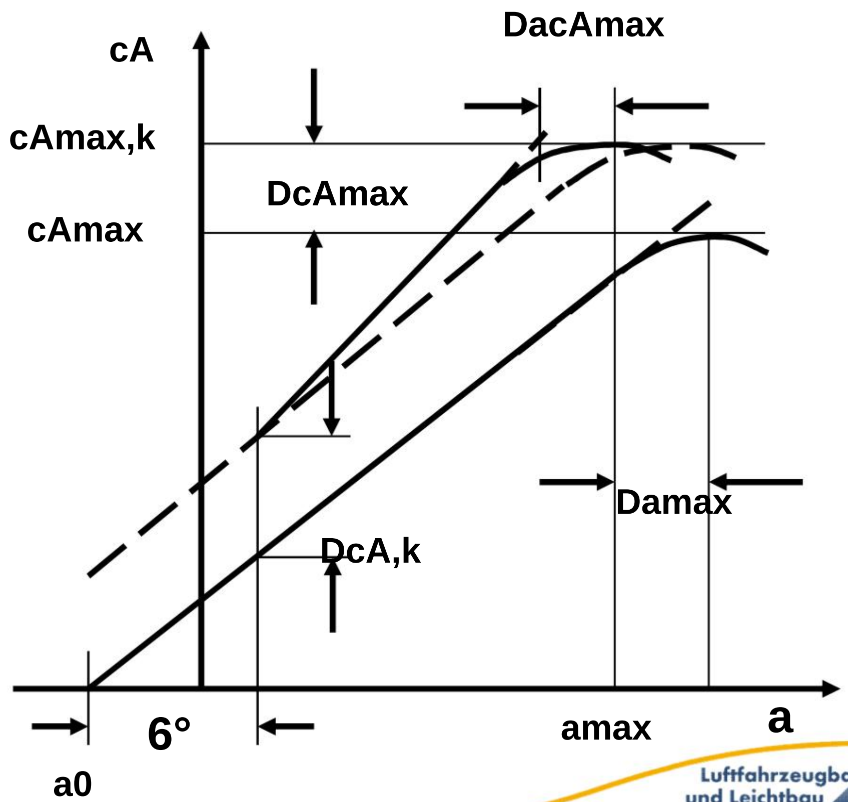
DcAmax by flap deflection

4. cA ´,

cAmax of the wing with flap

deflection 5.

DacAmax and amax



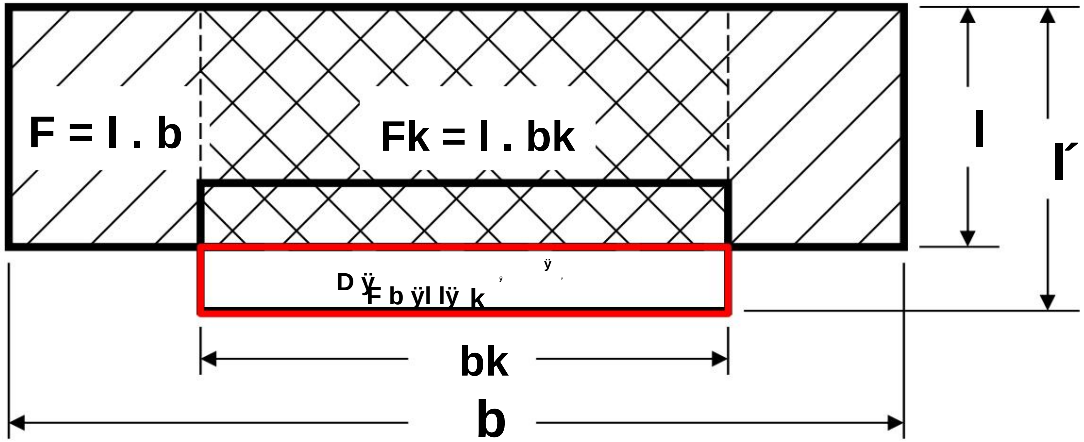
D Basics of aerodynamic design

1.8 Wings with lift aids

- The vertical offset of the polar due to a flap deflection dk is obtained by summing the individual contributions

c ÿ c ÿ Dc
Ak   A d ÿk0   Ak

- The gradient change results from a geometric Consideration:



D ÿ ÿ F bk l   ÿ ÿ ÿ ÿ ÿ ÿ l Fk   ÿ l´ / ÿ l   1 ÿ / ÿ

- This results in the increased air flow due to flap deflection Reference area:

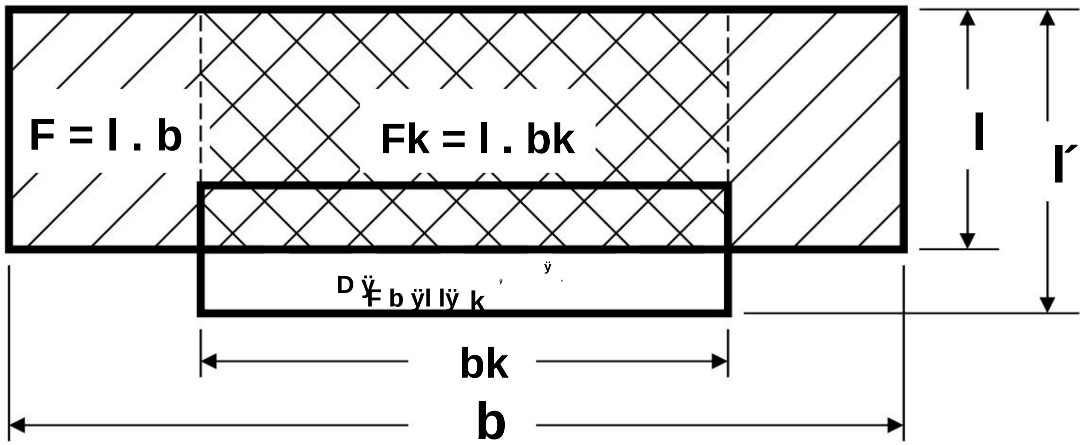
A cq F cq ÿÿ Fÿ Ak   ÿ ÿ   A   ÿ ÿ D

$\frac{c_{Ak}}{c_A}$ ÿ $\frac{F Fÿ D}{F}$ ÿ ÿ1 $\frac{DF}{F}$ ÿ ÿ1 $\frac{ÿ l´}{ÿ l}$ 1ÿ ÿÿ ÿ $\frac{F_k}{F}$

D Basics of aerodynamic design

1.8 Wings with lift aids

- **Furthermore, if the area is increased, c ÿAa ÿ a ÿcÿ0A**
- as well as c ÿ a ÿÿa ÿcÿ ÿ ÿ Ak 0 Ak



- **and thus also** $\frac{c^{ÿ}_{Ak}}{c^{ÿ}_{A}}$ ÿ ÿ ÿ $\frac{c_{A_k}}{c_A}$ 1 $\frac{ÿ l^{ÿ}}{ÿ l}$ 1 ÿ ÿÿ ÿ $\frac{F_k}{F}$

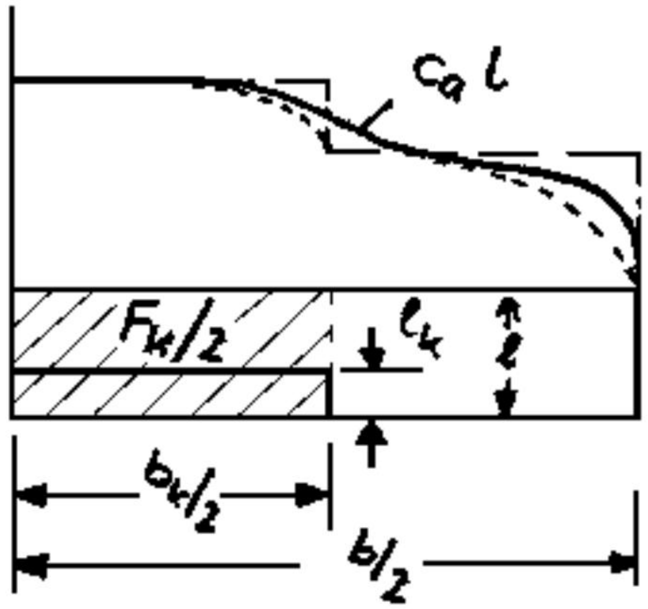
D Basics of aerodynamic design

1.8.1 Change in lift due to flap systems

• For spreading and cambered flaps, l´/l = 1. • This results in a pure parallel shift of the linear region of the polar.

• For slotted and Fowler flaps, the depth increase depends on the geometric design of the flap and the travel path.

• The effectiveness of the flaps depends on the wing plan (depth, sweep) and on their span and position. • The pressure equalization at the end of the flap ensures a smooth transition in the lift distribution.



D Basics of aerodynamic design

1.8.1 Lift change through flap systems

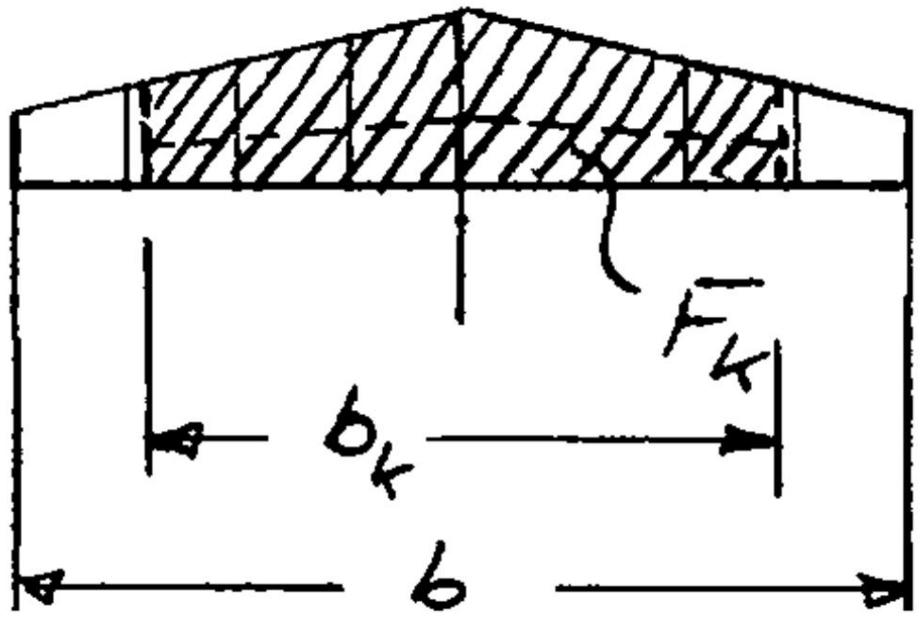
- **If the flaps are not interrupted by the fuselage, a simple area rule applies to the change in the lift and maximum lift coefficient depending on the area of the wing exposed to the flaps. ÿ ÿ D ÿ**

AAA cq F cq F c Total ÿ ÿ ÿ A Total A ÿ ÿ D ÿ q Fk a k ÿ

$c_{A\,Total}$ ÿ ÿ c D ÿ A a k $\frac{F_k}{F}$

D c ÿ D ÿ A k c a k ÿ $\frac{F_k}{F}$ ÿ ÿ ÿ

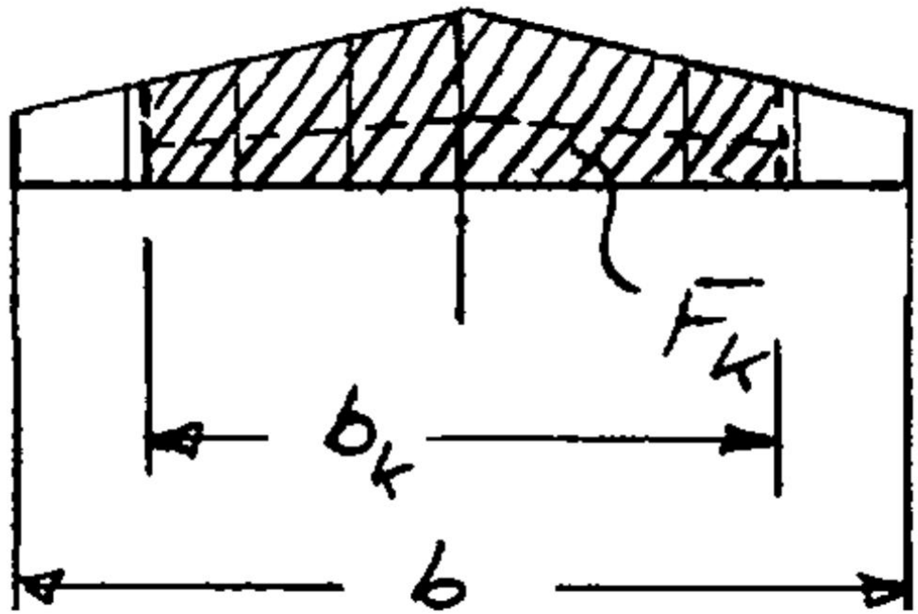
D c Amax ,k ÿ D c amax ,k ÿ $\frac{F_k}{F}$ ÿ ÿ ÿ



D Basics of aerodynamic design 1.8.1 Lift change through flap systems

- **For single trapezoidal wings, the area ratio can be be determined analytically:**

Fk ÿÿ fÿ ÿ ÿ , bk / ÿ bb ÿ ÿ ÿ 1 ÿ ÿ ÿ ÿ ÿ ÿ bk ÿ ÿ 1ÿ 1ÿ ÿ / ÿ ÿ ÿ 1 bk / ÿ b ÿÿ ÿ ÿ ÿ
F



D Basics of aerodynamic design

1.8.1 Lift change through flap systems

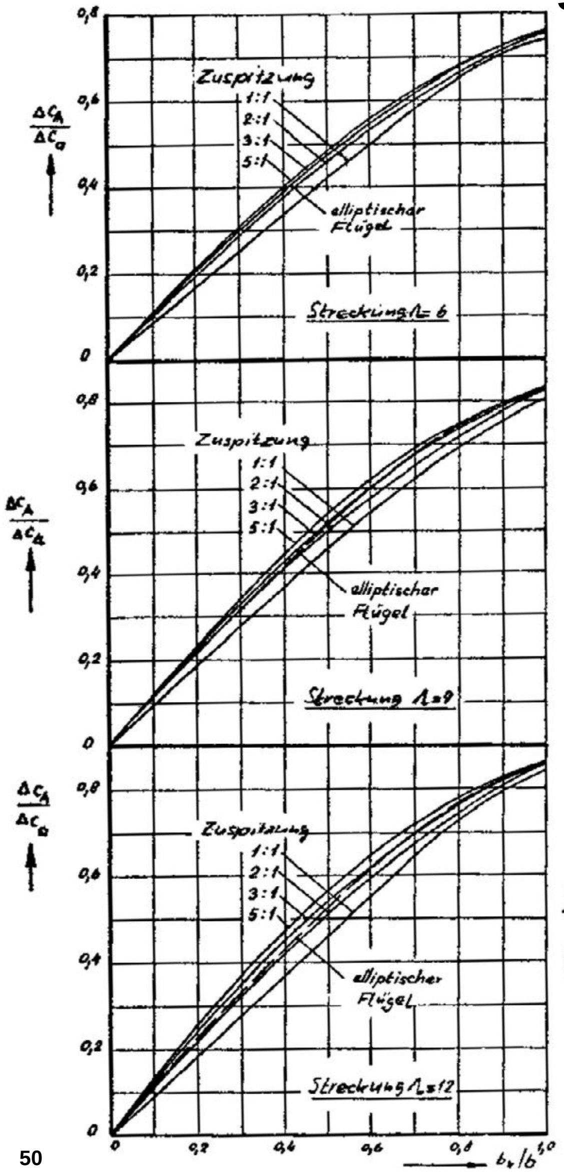


Bild 12:

$$\left(\frac{\Delta c_A}{\Delta c_a}\right)_{theor} = f\left(\Lambda, \lambda, \frac{b_k}{b}\right)$$

- **Influence of wing and flap geometry:**
  - **If the airfoil theory is used to determine the span influence for flaps, the result obtained is too optimistic.**
  - **The increases with increasing bk /b only approach 1 for the infinitely stretched wing.**

D Basics of aerodynamic design

1.8.1 Lift change through flap systems

- **It is sufficiently accurate to use profile coefficients for an average flap span, since – the depth distribution (Re number) usually does not vary greatly and – the elementary information for the lift changes are not very precise anyway.**

- **For flaps that extend over the entire span (eg gliders), can be approximated**

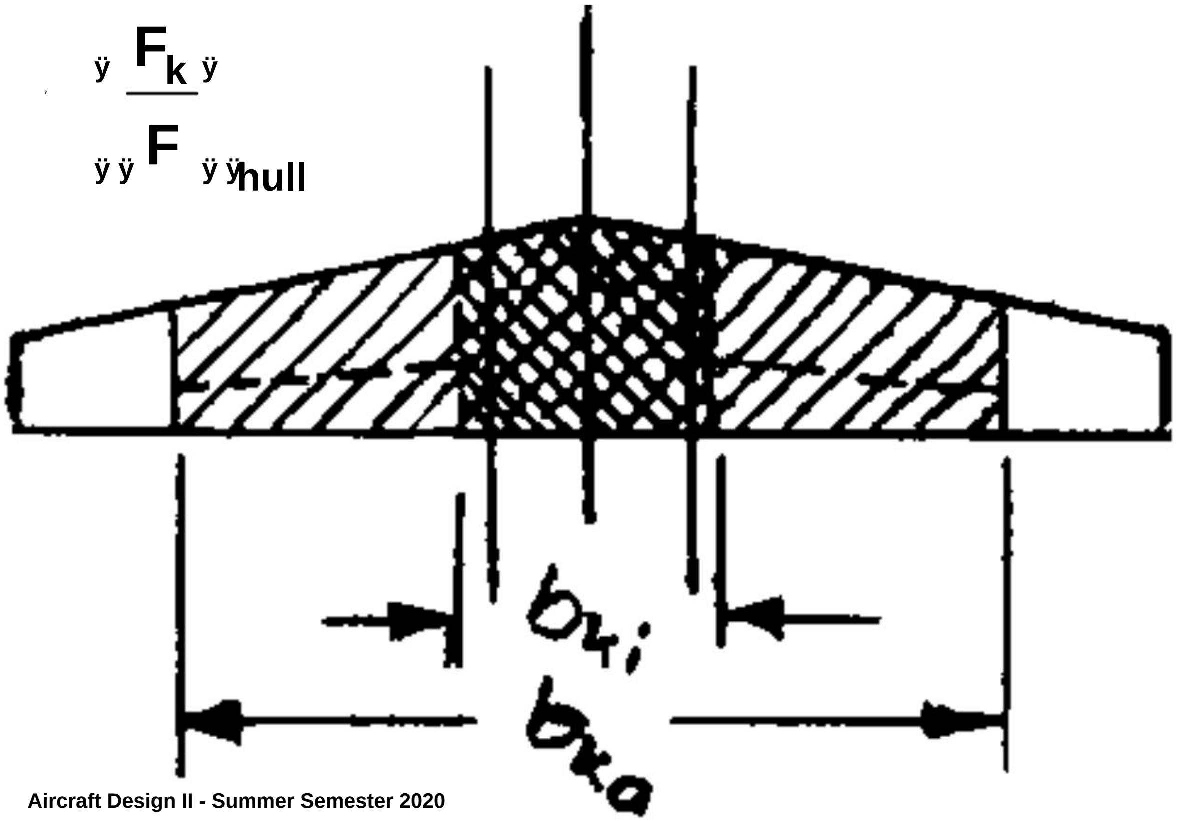
$$Dc_{A_k} \text{ ÿ } 0.92 \text{ÿ} Dc_{a_k} \quad \text{and} \quad Dc_{Amax,k} \text{ ÿ } 0.92 \text{ÿ} Dc_{amax,k}$$

be expected.

D Basics of aerodynamic design 1.8.1 Lift change through flap systems • If the flaps are interrupted by a fuselage (the

Normal case), in a low-wing configuration, the wing area covered by the fuselage is subtracted from the above relationship for the area ratio and one obtains:

$$\frac{F_k}{F} \;\text{ÿ}\; \text{ÿ}\,\text{ÿ}\,\text{ÿ}\frac{F_k}{F}\text{ÿ}\,\text{ÿ}\,\text{ÿ}_{\text{incl.hull}} \;\; \text{ÿ}\,\text{ÿ}\,\text{ÿ}\frac{F_k}{F}\text{ÿ}\,\text{ÿ}\,\text{ÿ}_{\text{hull}}$$



D Basics of aerodynamic design

1.8.1 Change in lift due to flap systems

- For high- and mid-wing aircraft, better flap efficiency can be expected. • Only half the fuselage portion needs to be deducted:

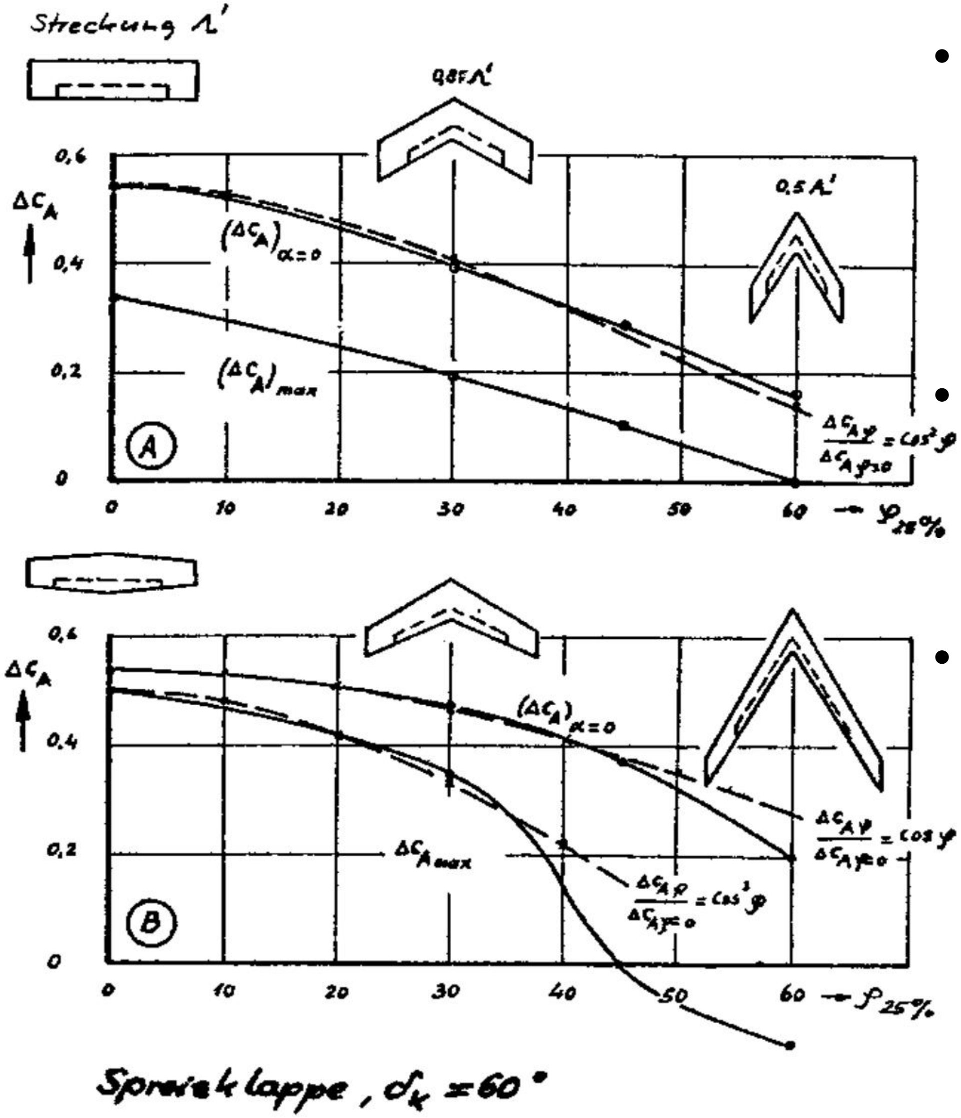
$$\frac{F_k}{F} = \left(\frac{F_k}{F}\right)_{incl.hull} - 0.5 \left(\frac{F_k}{F}\right)_{hull}$$

- If the flaps are connected directly to the fuselage (without pressure loss) and the transitions are optimally designed, the effective flap area can even be calculated.

- The sweep has adverse effects on both maximum lift and lift gain.

D Basics of aerodynamic design

1.8.1 Change in lift due to flap systems



- Example A shows the behaviour of wings of different aspect ratios with the taper 1,
- Example B shows the relationship for a realistic wing geometry.
- For the same aspect ratio, the difference between the lift increase and the maximum lift increase becomes larger with increasing sweep.

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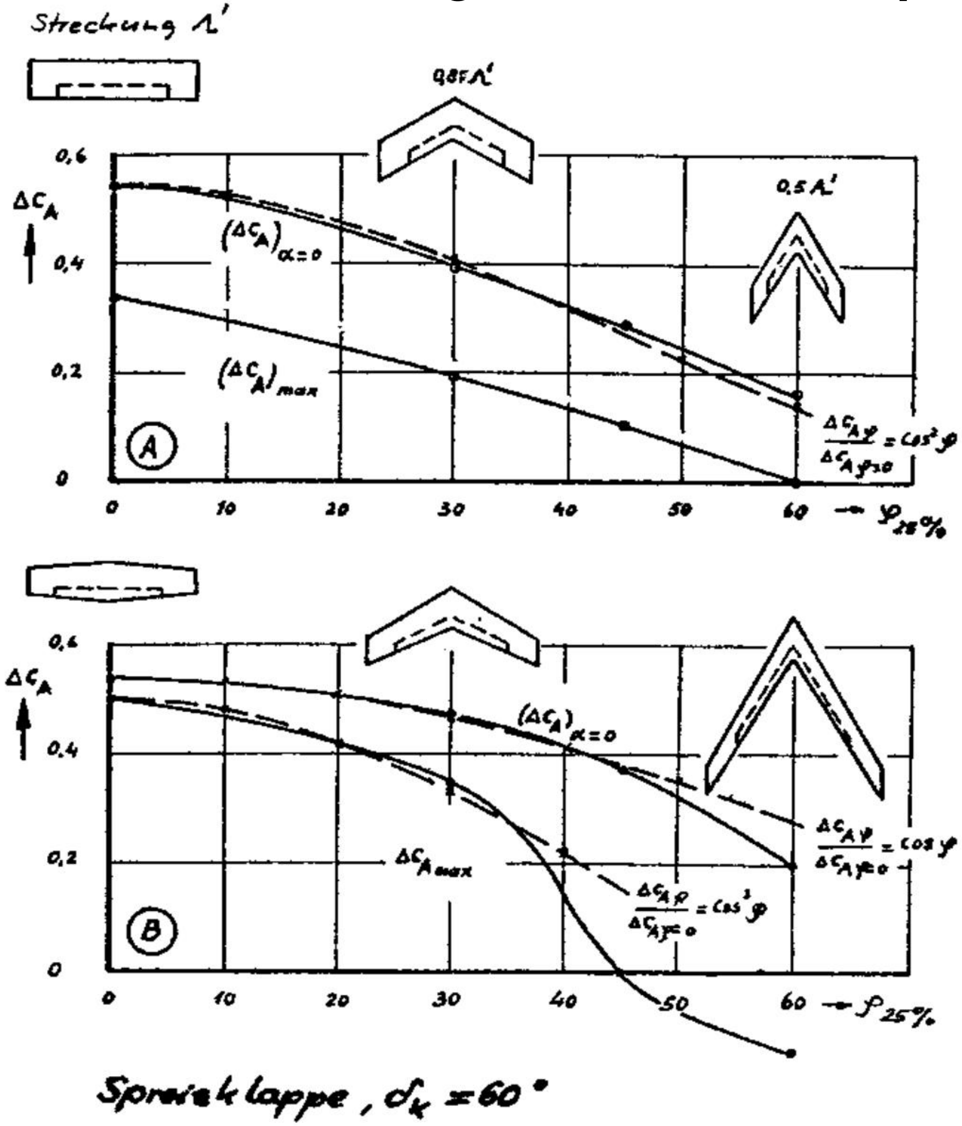
1.8.1 Change in lift due to flap systems



- **The buoyancy gain is**
  so not necessarily usable.

- **The influence of the arrow The effect on the change in lift is again well approximated by the cosÿ law for moderately tapered wings.**

- **This means that:**

$$\frac{Dc_{A_{ÿ}}}{Dc_{A_{ÿÿ0}}} ÿ ÿ ÿ \frac{F_K}{F} \cos ÿ \; ÿ 25$$

D Basics of aerodynamic design 1.8.1 Lift change due to flap systems • Theoretically, the law applies to the change in the maximum lift coefficient

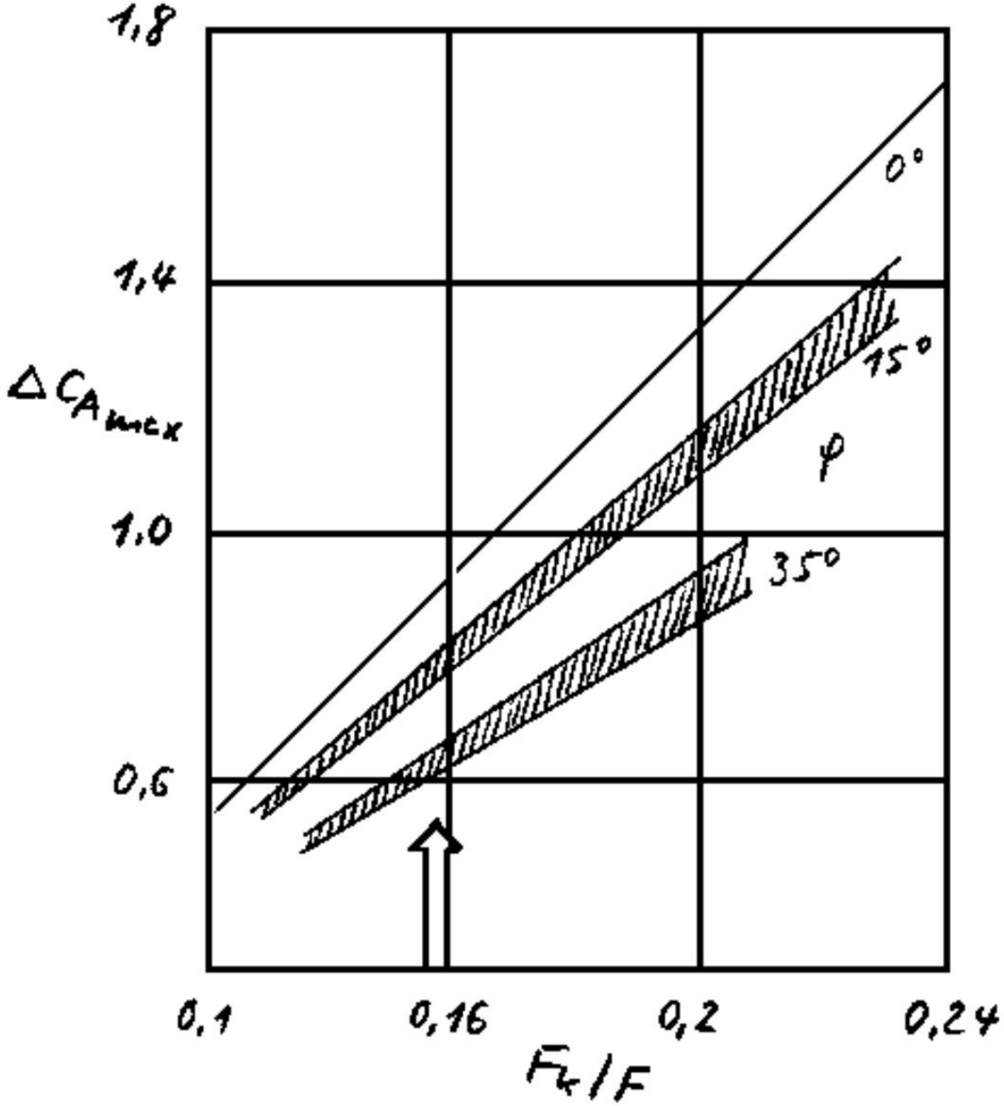
$$\frac{D\,c_{A\,\max,\,ÿ}}{D\,c_{A\max,\,0\,ÿÿ}} \;ÿ\,ÿ\; \frac{F_K}{F}\; 2\cos\, ÿÿ_{ÿ\,25}$$

- Empirical studies also show that the law leads to better results:

$$\frac{D\,c_{A\max,\,ÿ}}{D\,c_{A\max,\,0\,ÿÿ}} \;ÿ\,ÿ\,ÿ\; \frac{F_K}{F}\; \cos\, ÿ_{ÿ\,25}$$

D Basics of aerodynamic design

1.8.1 Change in lift due to flap systems



Therefore, approximately

$$\mathrm{D}\,c_{\ddot{y}_A}\,\mathrm{D}\ \ddot{y}\quad c_{a0_{\ddot{y}\ddot{y}}}\ \frac{F_k}{F}\ \ddot{y}\ddot{y}\cos\ddot{y}\ \ddot{y}\,25$$

and

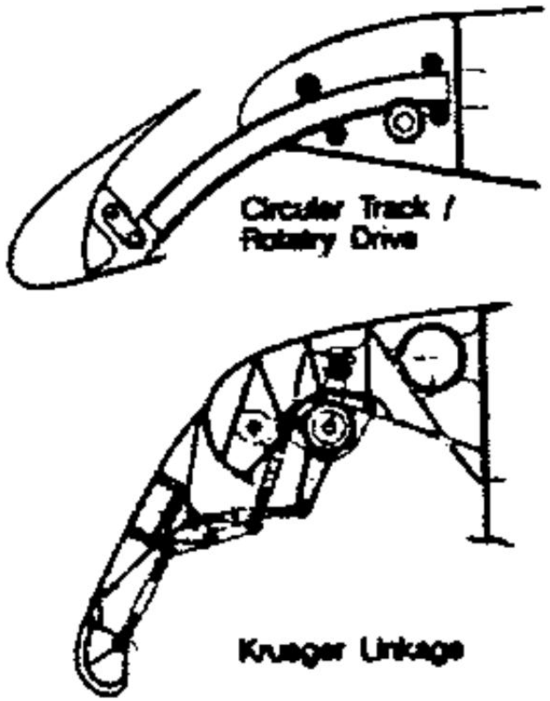
$$\mathrm{D}\,c_{Amax,\,\ddot{y}}\quad \ddot{y}\ \mathrm{D}\,c_{amax,\,0_{\ddot{y}\ddot{y}}}\ \frac{F_k}{F}\ \ddot{y}\ddot{y}\cos\ddot{y}\ \ddot{y}\,25$$

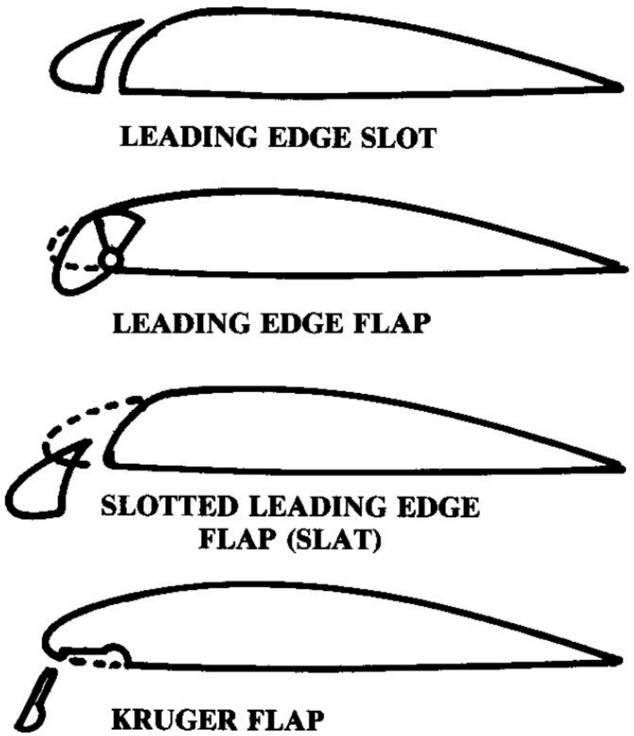
D Basics of aerodynamic design

1.8.2 Leading edge lift aids

- **In principle, the above relationships apply equally to all camber-increasing flaps.**

- **Leading edge flaps can also be taken into account.**

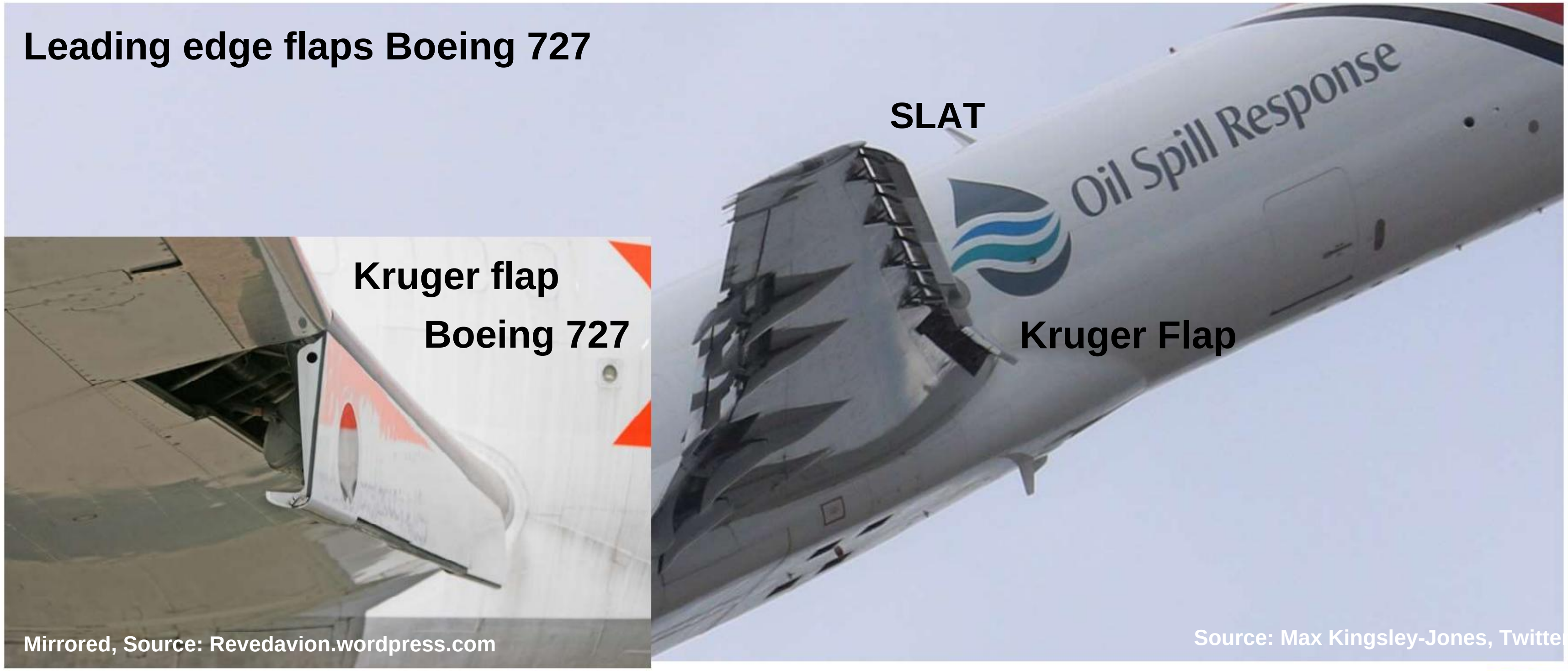




D Basics of aerodynamic design

1.8.2 Leading edge lift aids

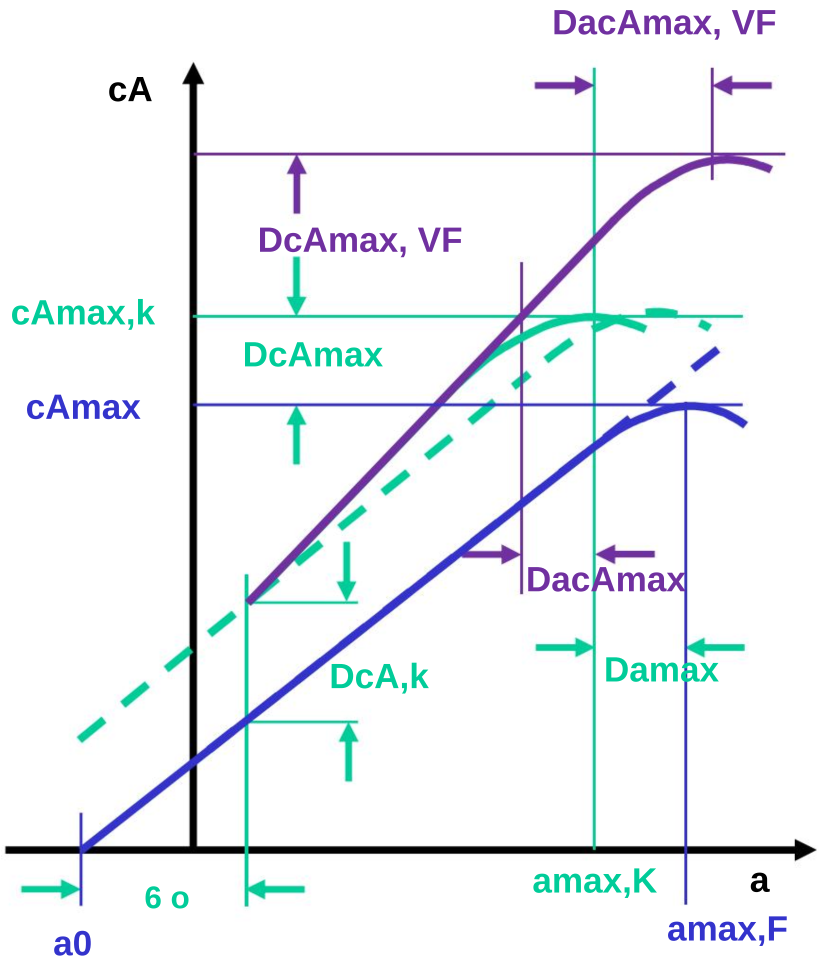
- **The effect of leading edge lift aids (slats) depends, just as with trailing edge flaps, on their geometry (length in span direction, depth), the wing sweep and the deflection angle.**



Luftfahrzeugbau und Leichtbau

D Basics of aerodynamic design

1.8.2 Leading edge lift aids



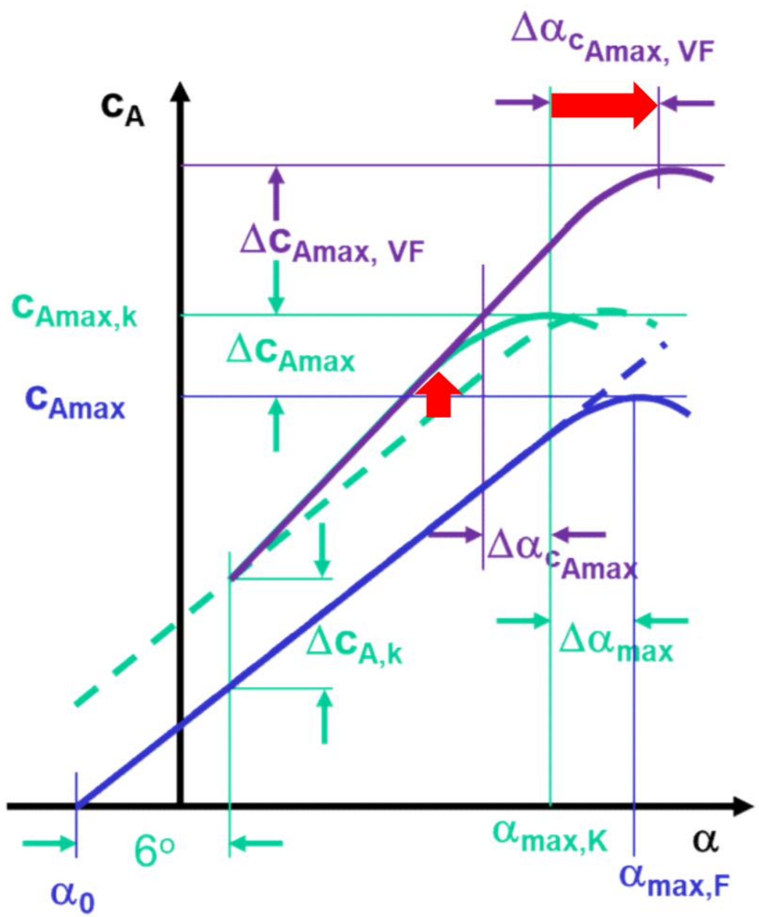
Effect of Leading edge flaps

- Buoyancy without extended High lift center
- Buoyancy with extended Trailing edge flap
- Lift with extended trailing edge flap with area enlargement (Fowler class)
- Buoyancy with extended Trailing edge flap with area enlargement AND Leading edge flap

D Basics of aerodynamic design

1.8.2 Leading edge lift aids

- With a slat, no additional lift is usually generated as a result of an increase in camber, but only the wing depth is increased, which leads to an increase in the lift increase.



- In addition, a border layer influence, which leads to an increase in the maximum angle of attack and thus also in the maximum lift coefficient.

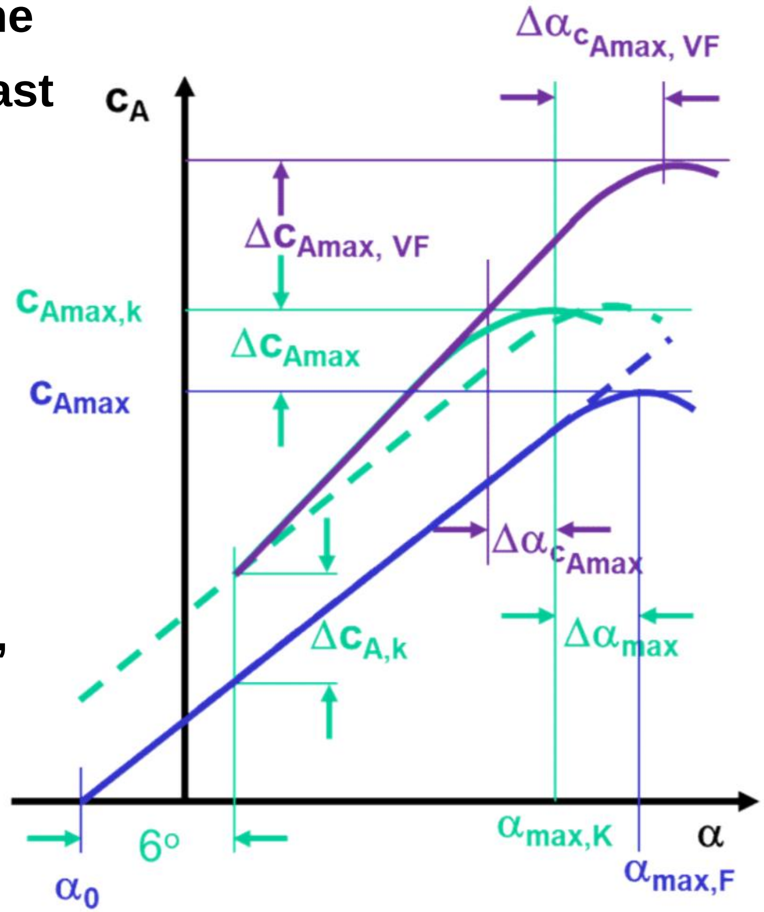
D Basics of aerodynamic design

1.8.2 Leading edge lift aids

- The lack of increase in buoyancy

  coefficient at a given angle of attack is the reason why the slat deflection – in contrast to all camber-increasing flaps –

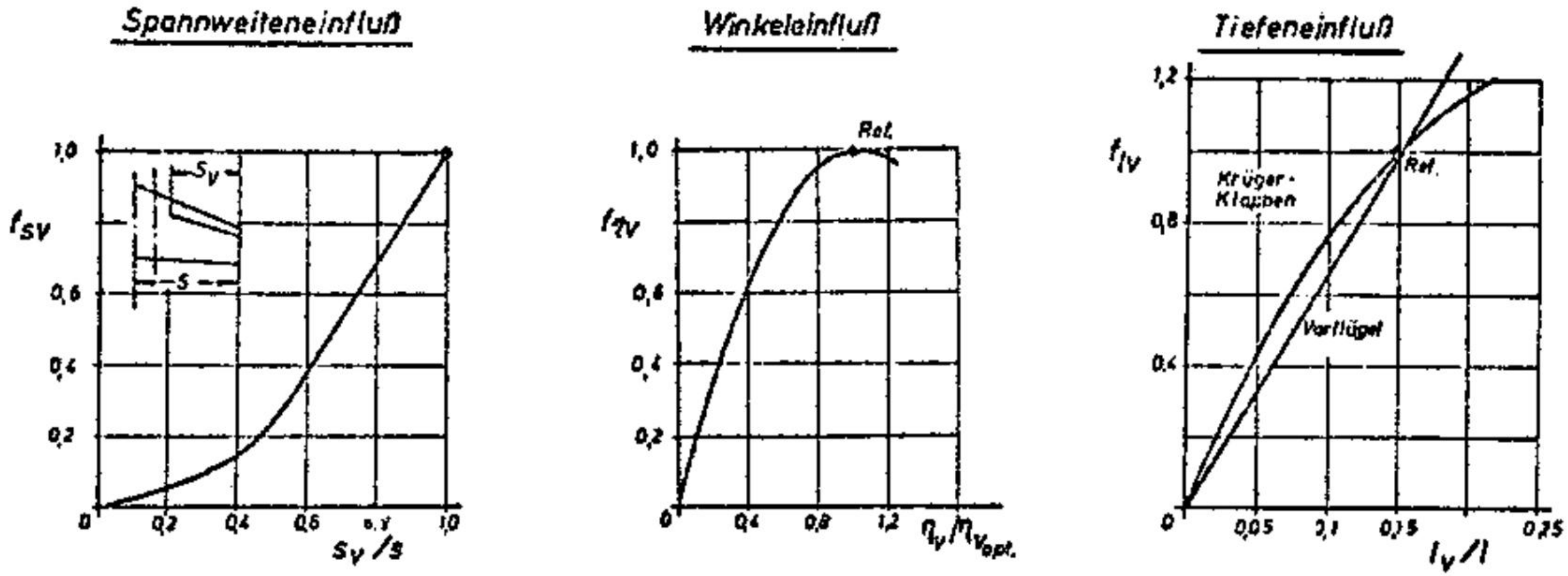
  no change in torque causes.



- Since slats are not used in isolation but always in combination with trailing edge flaps due to the lack of lift increase, there are only few results from wind tunnel tests.

D Basics of aerodynamic design

1.8.2 Leading edge lift aids



$$\boxed{\Delta C_{A\,max\,(V)} = \Delta C_{a\,max\,0} \cdot f_{sV} \cdot f_{\eta V} \cdot f_{lV} \cdot f_{\varphi V}}$$

$$f_{\varphi V} = \cos^3(\varphi_V - 5°)$$

Ref.: Profil NACA 64 A 010

$\Lambda = 12$ $\quad s_V/s = 1{,}0$

$\lambda = 1{,}0$ $\quad l_V/l = 0{,}15$

$\delta = 0{,}1$

$\varphi_{25} = 0$

	$\Delta C_{a\,max\,0}$	$\eta_{V\,opt}$
Vorflügel	0,93	26° ungepfeilt 45°÷60° gepfeilt
Krüger	0,5	40°÷45° ungepfeilt 60° gepfeilt
Knicknase	0,55 ÷ 0,75	30°

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems

- There are countless configurations for flap systems, so there are only a few systematic studies on their properties.

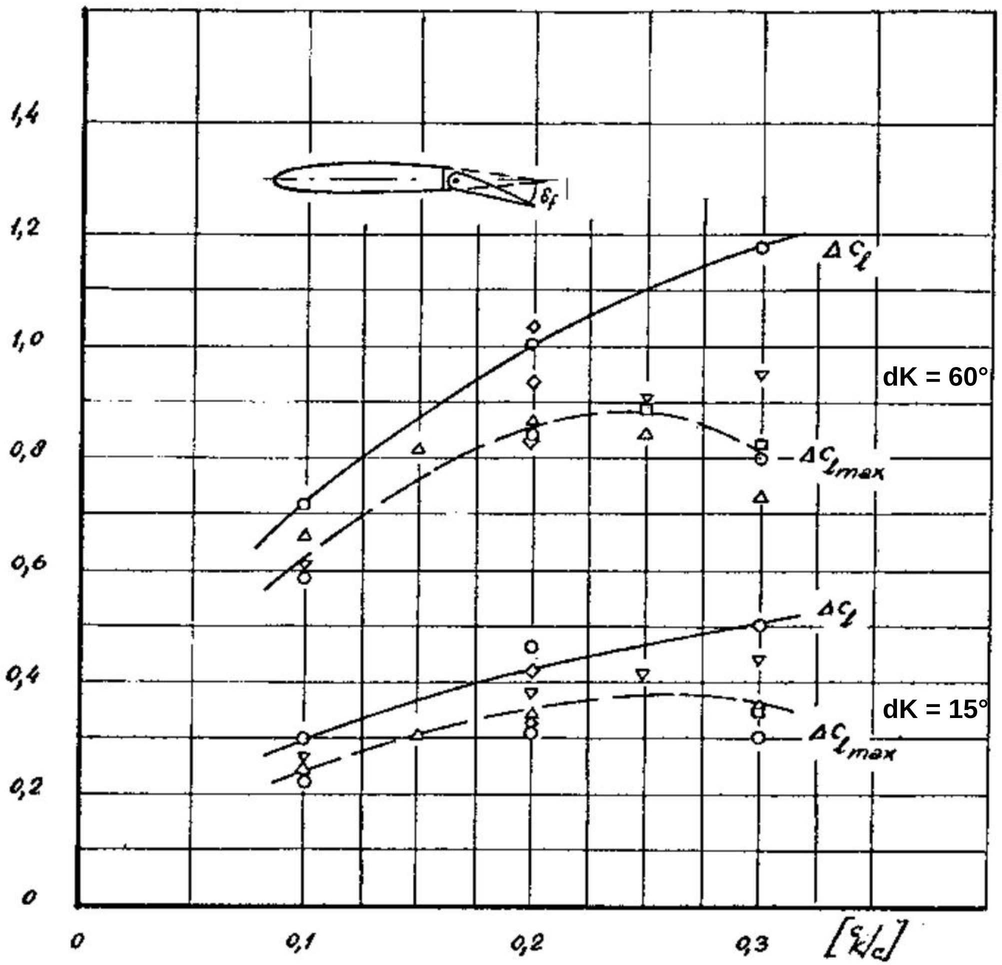
- As examples, test results of the most common valve systems (domed, slit, double-slit and Fowler valves) are presented in a catalogue format.

- This provides a basis for estimating the high lift properties of the wing.

- The aerodynamic coefficients or their changes are plotted continuously over the two remaining geometry parameters not previously considered: – Relative flap depth
  – Flap angle

D Basics of aerodynamic design

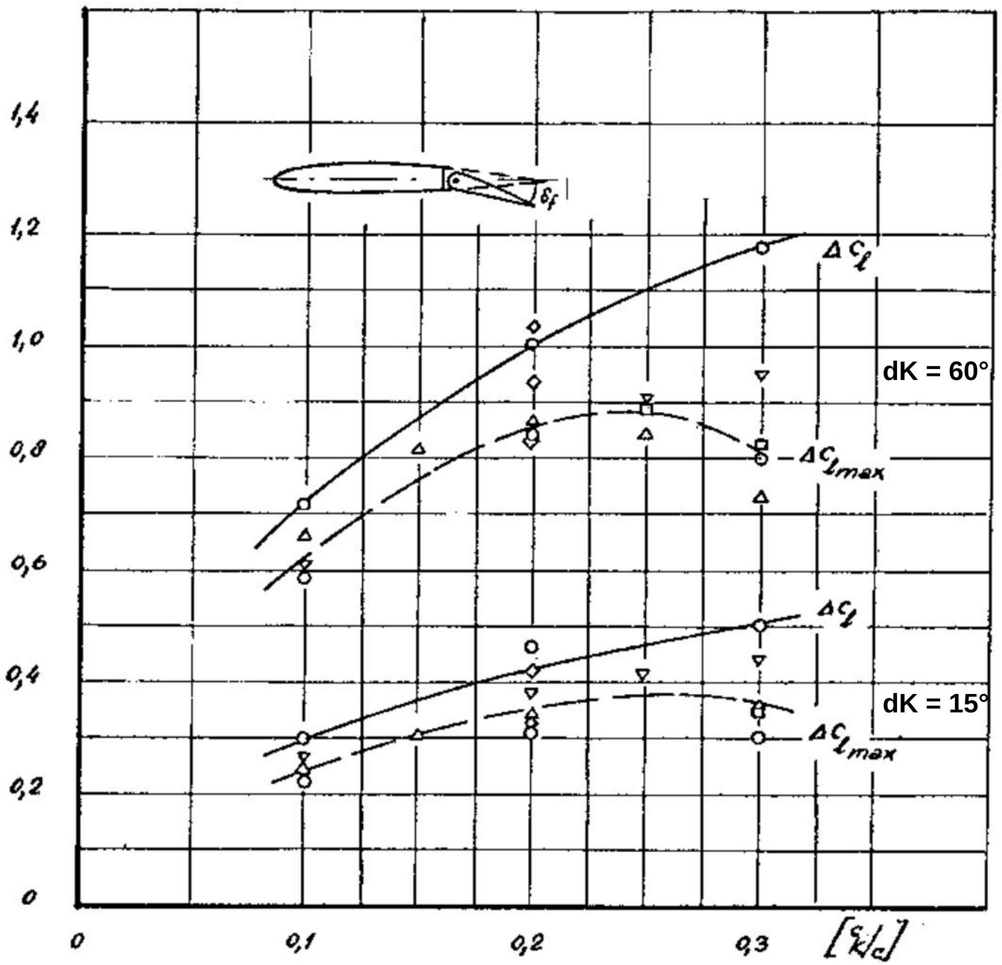
1.8.3 Profile values for different flap systems



- The mechanically with very A camber flap that can be implemented with little effort increases lift solely by increasing the camber, whereby no change in the wing depth (profile chord extension) occurs with the deflection.

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems



- It is mainly used on the wings of small aircraft and gliders.

- It is the classic Control element on the tail units of all aircraft!

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems

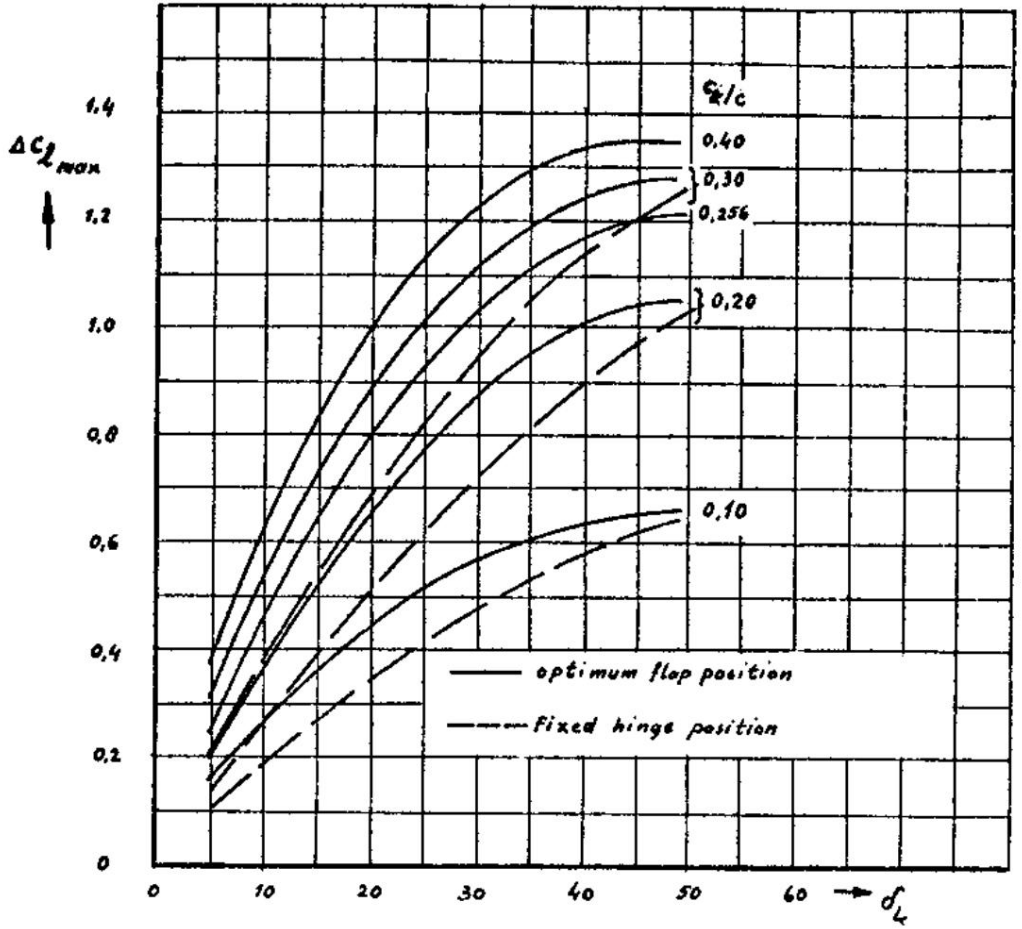


Bild 16 : Einfache Spaltklappe, $\Delta c_{a_{max}} = f(\delta_K, c_k/c), (c'/c = 1.1)$

- The single-slit flap is used in two different configurations:
  - – with fixed pivot point
  - – with variable pivot point
- In the latter case In this variant, the optimal flap position is determined by a rotary and translational Travel component realized.

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems

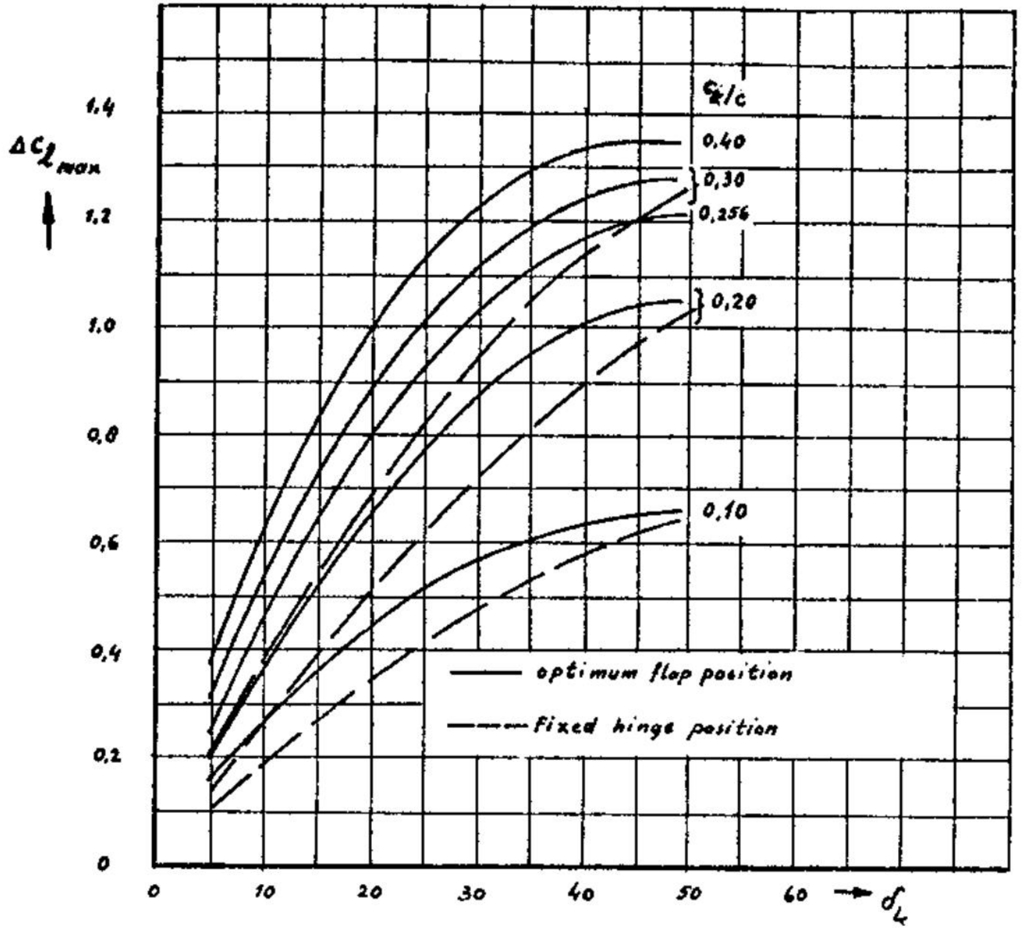


Bild 16: Einfache Spaltklappe, $\Delta c_{a_{max}} = f(\delta_K, c_k/c)$, $(c'/c = 1.1)$

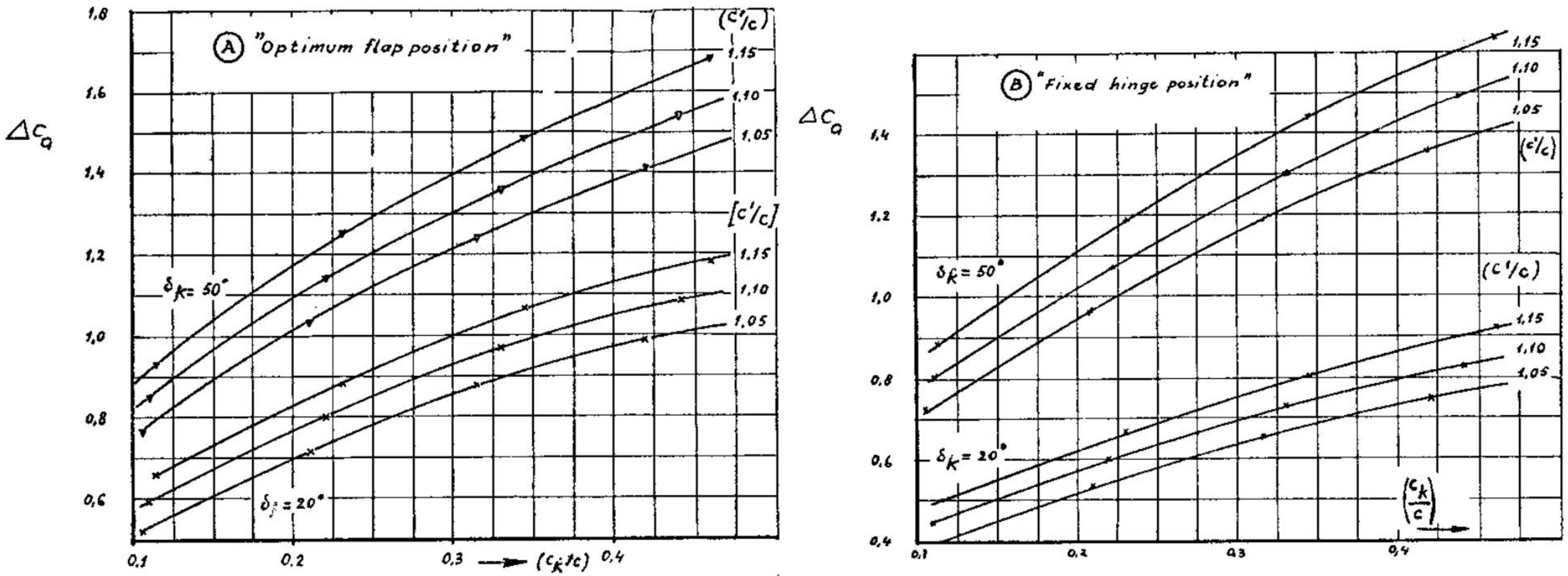
- The difference in properties is small for large flap deflections, since flaps with a fixed pivot point are generally designed for landing.

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems

- **Single slot damper**

Einfache Spaltklappe, $\Delta c_a|_{\alpha_0+6°} = f(c_k/c, c'/c, \delta_k)$



Luftfahrzeugbau und Leichtbau

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems

- The double slotted flap has one more element than the slotted flap.

- This increases the number of constructive degrees of freedom considerably.

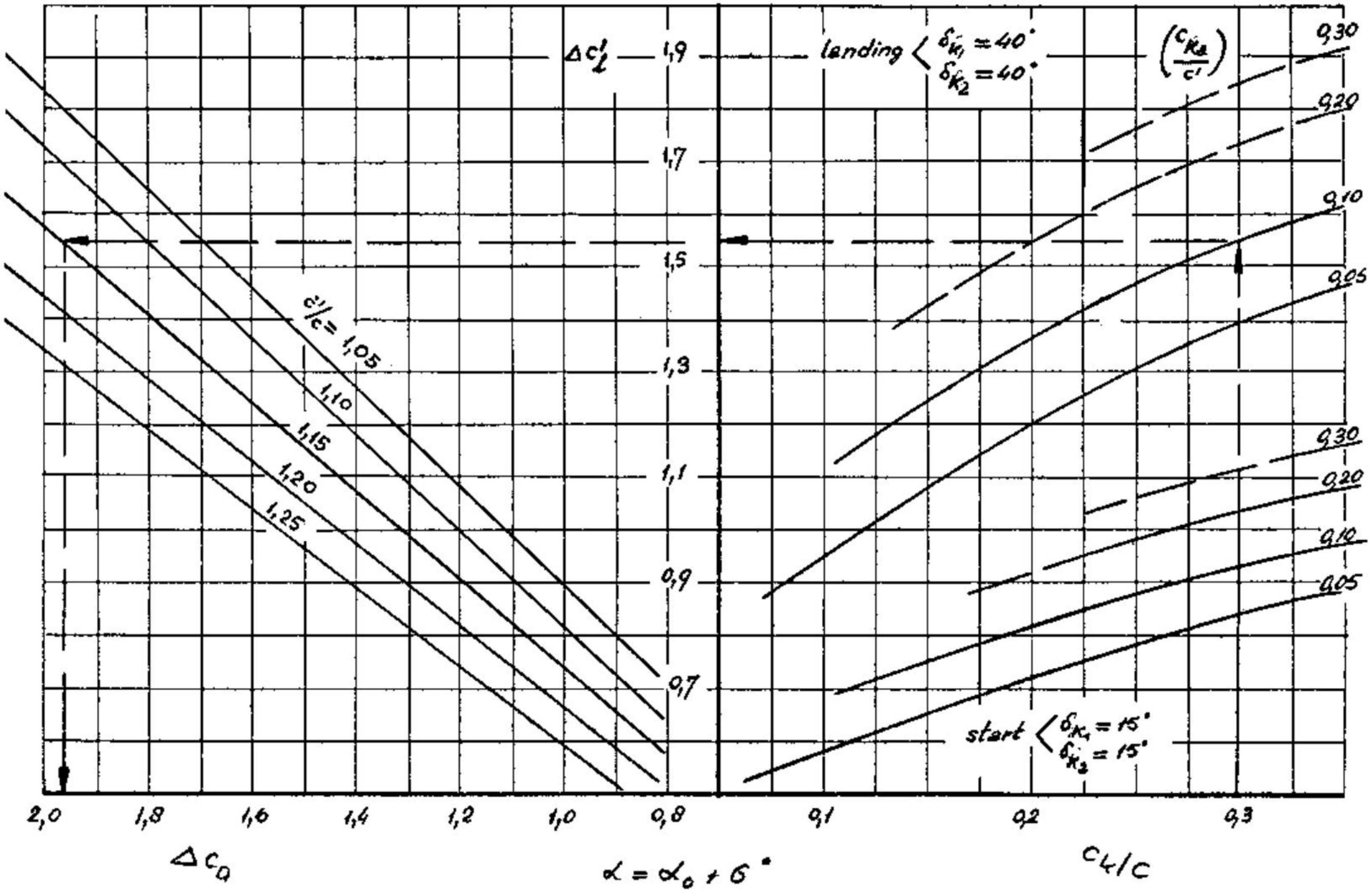
- Basically, two variants are encountered in practice:
  - The double-slit damper with fixed guide flap, where the first and second flap elements are in fixed geometric Assignment and
  - The double-slit flap with two movable elements, whereby each element has its own travel path.

- The complexity of the mechanism is particularly evident in the last variant up.

- The increase in the lift coefficient for this system depends depends on many parameters.

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems



cl = ca

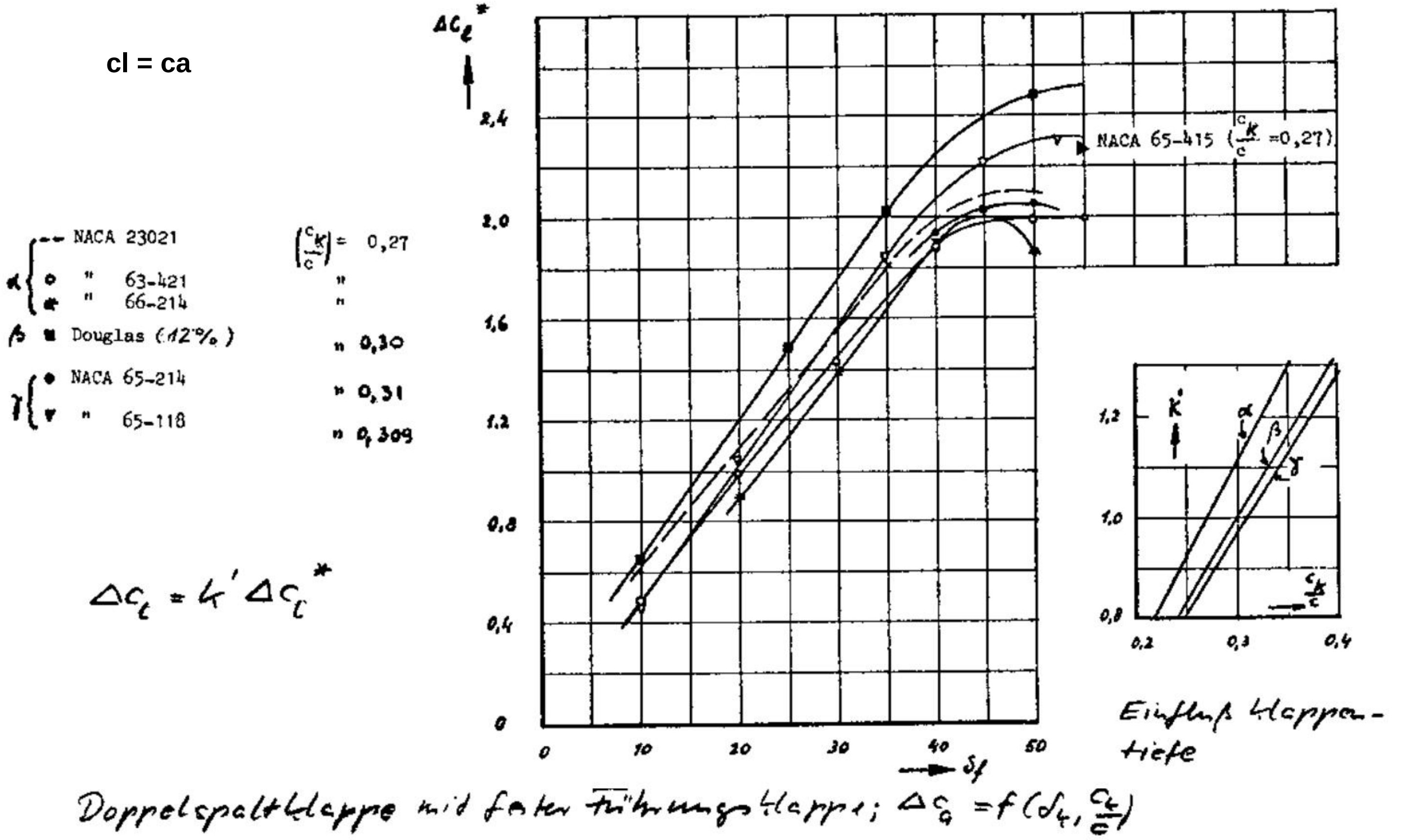
Bild 19: Doppelte Spaltklappe (2 beweg. Teile); $\Delta c_a = f\left(\frac{c_k}{c}, \frac{c'}{c}, \frac{c_{k2}}{c'}\right)$

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems

- **The double slotted flap with fixed guide flap offers almost the same increase in lift, has a simpler retraction mechanism and better space utilization.**

cl = ca



$\alpha = \alpha_0 + 6^\circ$

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems

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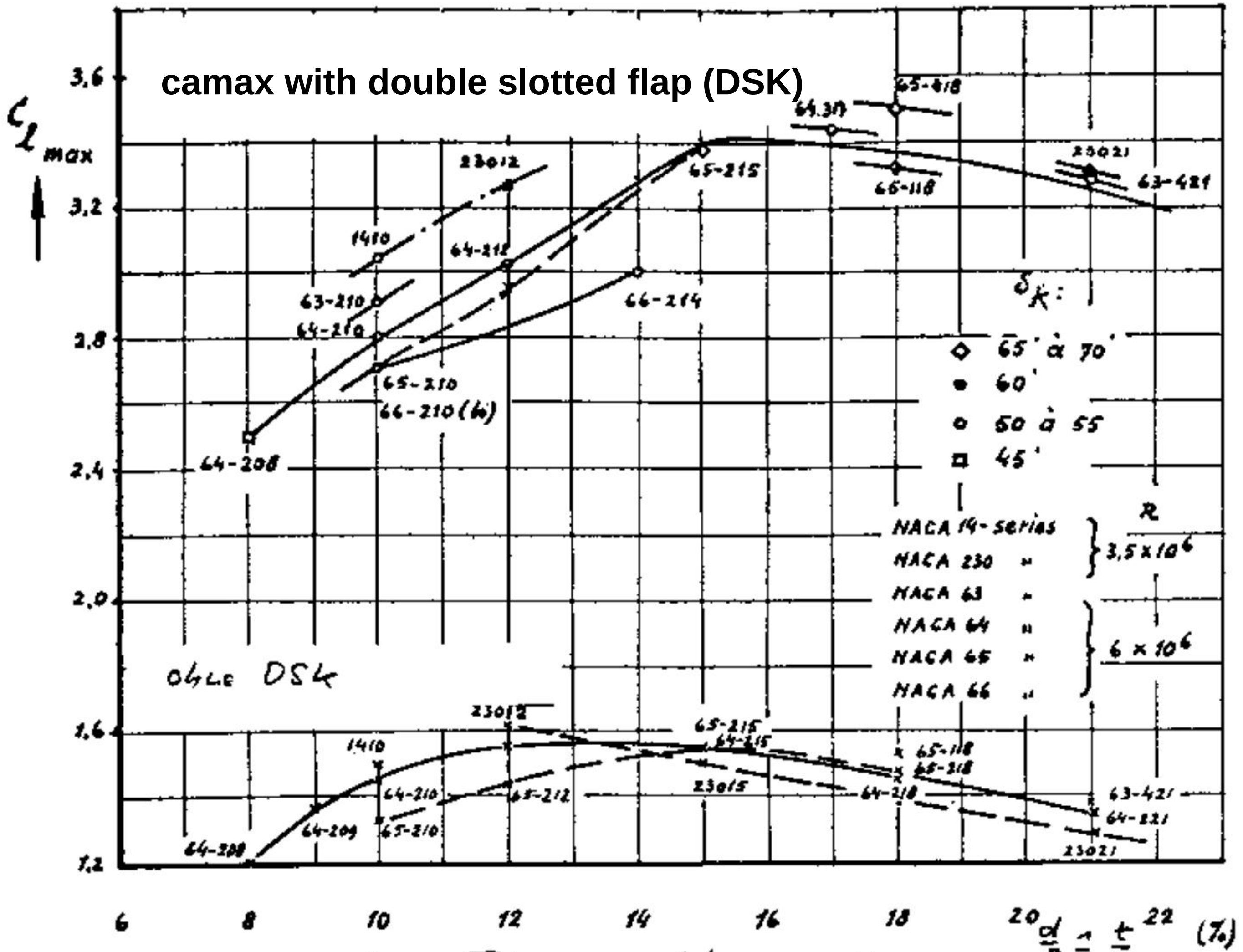


$C_K/c = 0{,}3$

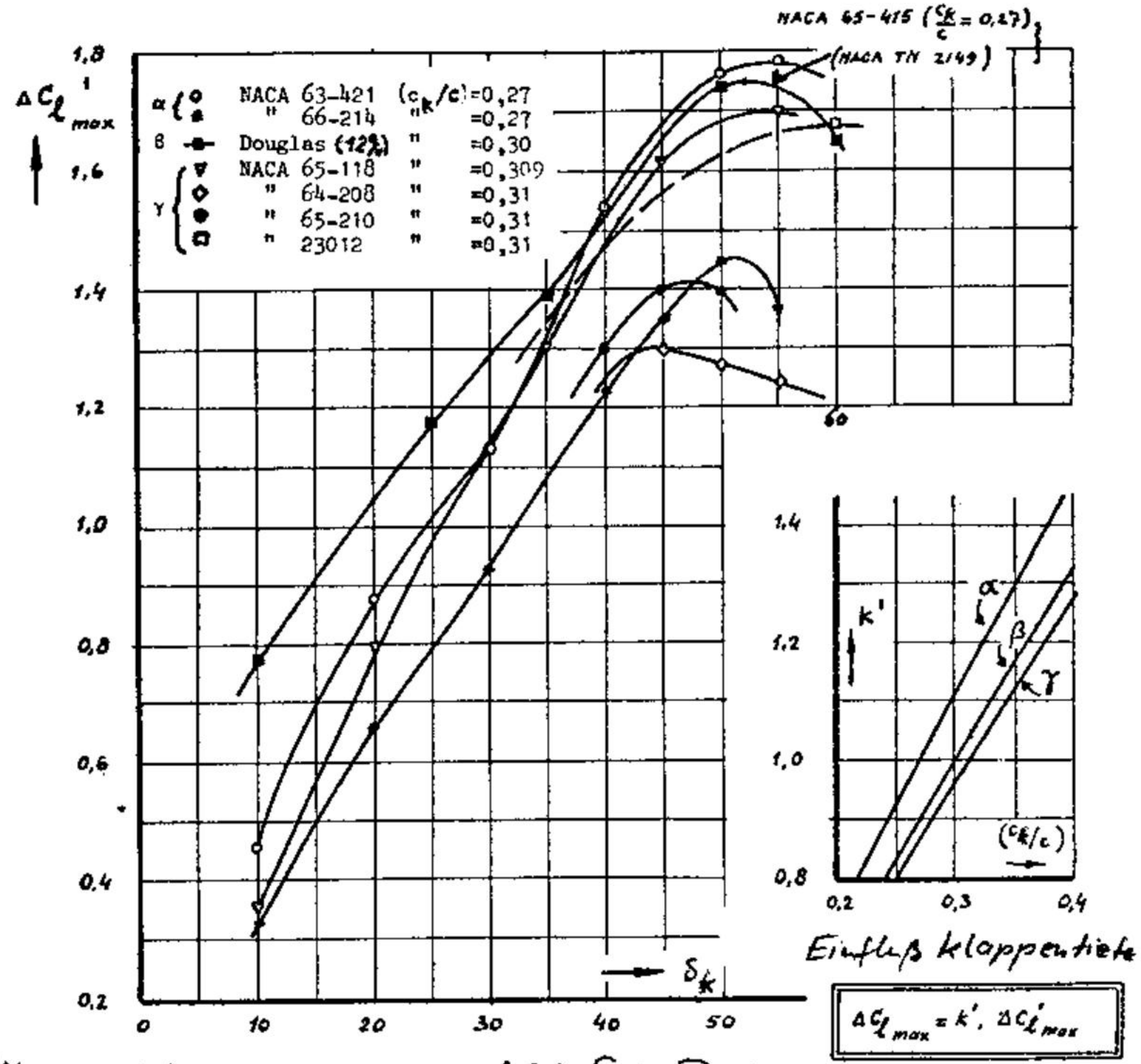
Doppelspaltklappe mit fest. Führungsklappe; $c_{a\,max}$

Luftfahrzeugbau und Leichtbau

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems

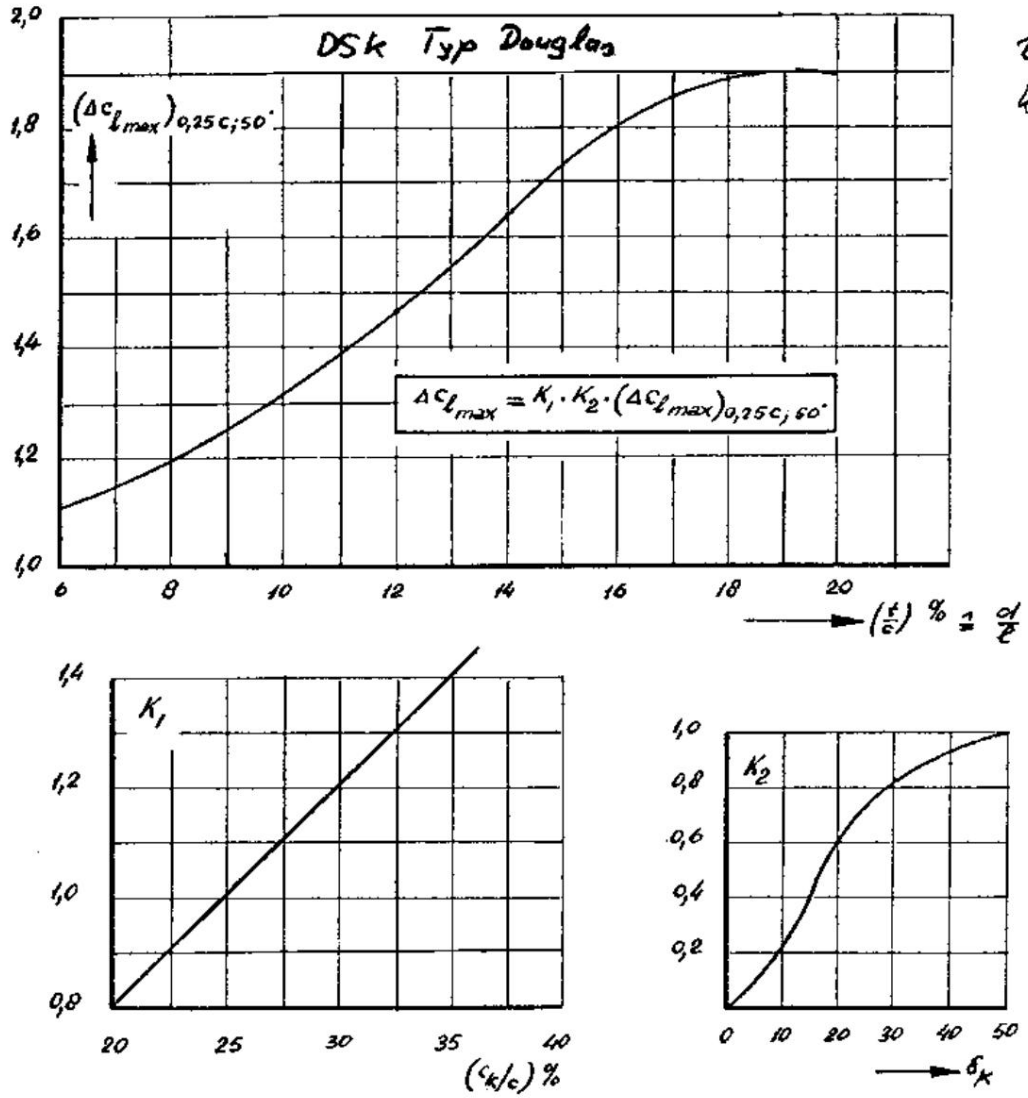
cl = ca



DSt mit fester Führungsklappe ; $\Delta c_{a_{max}} = f(\delta_k, c_k/c, \text{Profil})$

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems



Doppelspaltklappe mit fester Führungsklappe (Douglas); $\Delta c_{a_{max}} = f(\frac{d}{l}, \frac{c_k}{c}, \delta_k)$

cl = ca

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems

- The fundamental difference between the Fowler flap and the slit valve lies in the much larger translational displacement of the Fowler valve (see below)

- In practical implementation, the differences are sometimes blurred.

- Slotted flap

- Fowler flap

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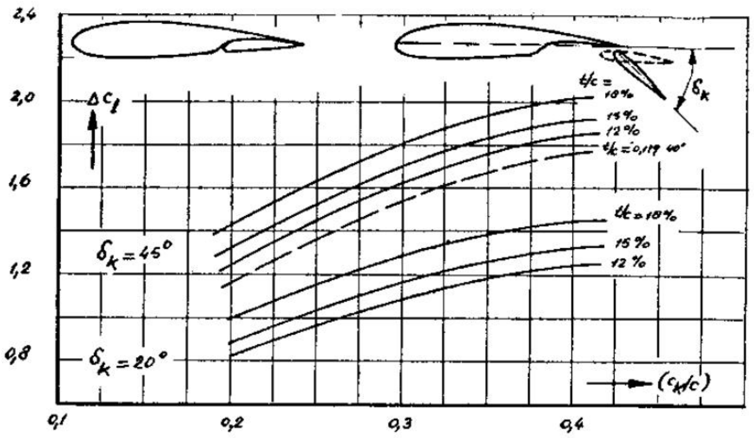
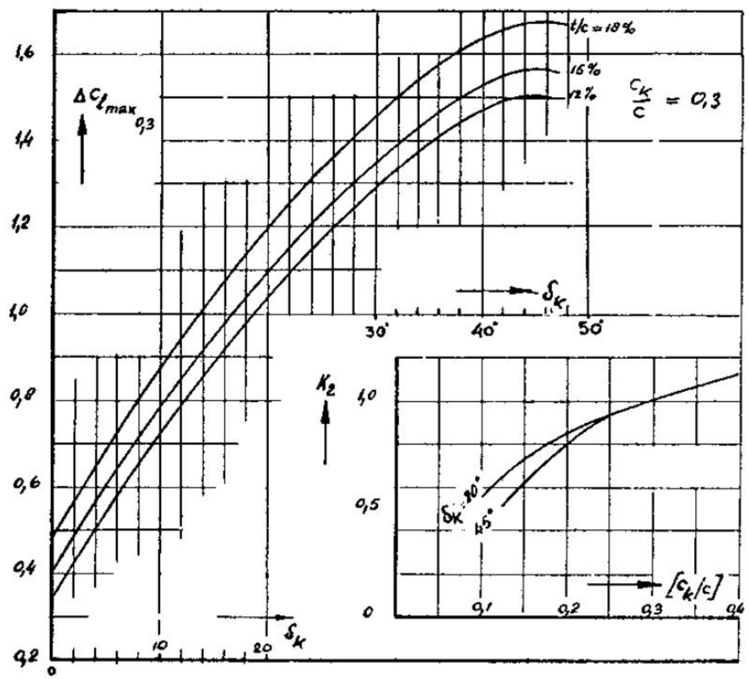
1.8.3 Profile values for different flap systems



$\alpha = \alpha_0 + 6°$



cl = ca

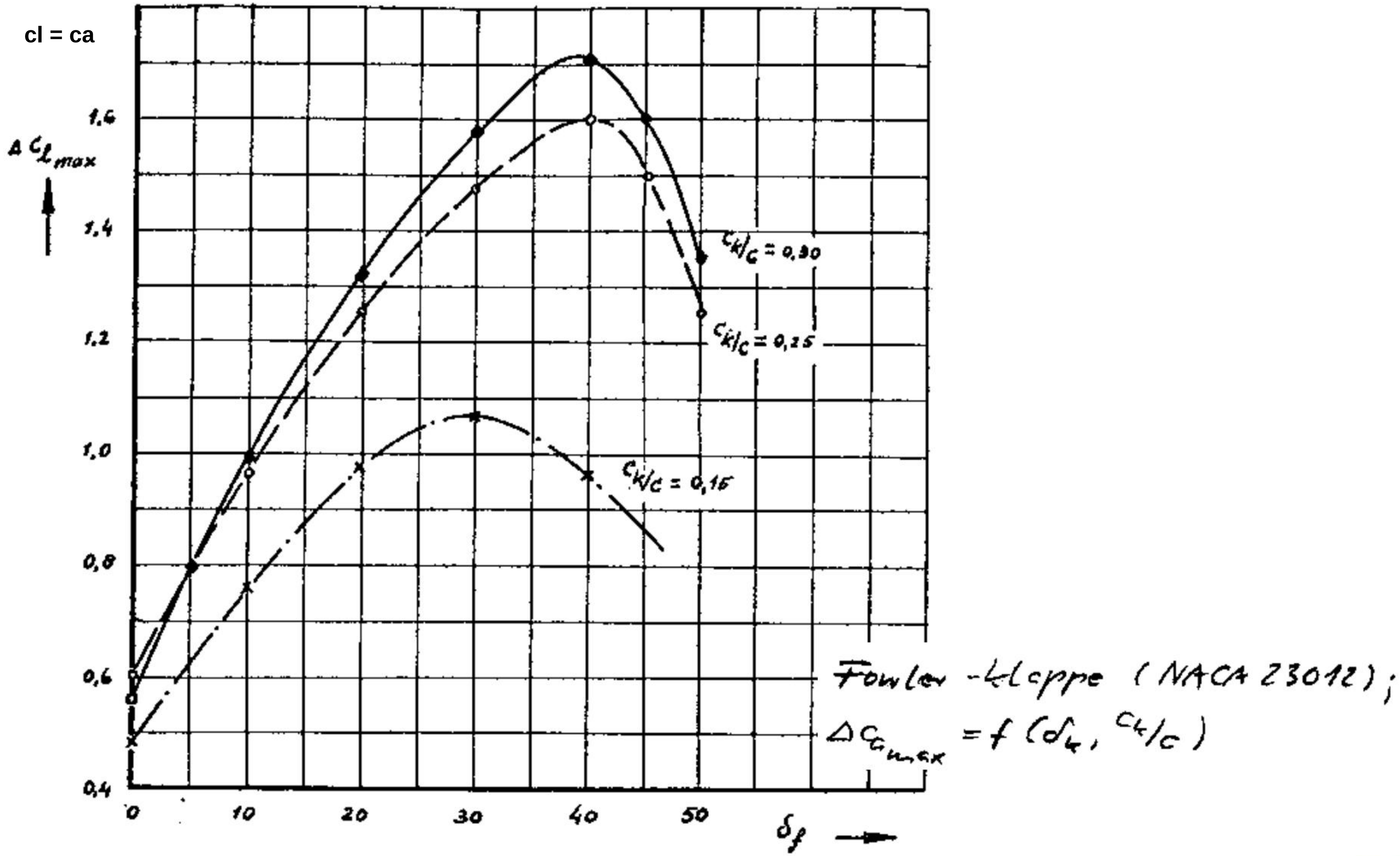
Dc ÿ k ÿDc
a_{Max} 2 amax ,0,3

Fowlerklappe ; Δc_a , $\Delta c_{a_{max}} = f(\frac{d}{l}, \frac{c_k}{c}, \delta_k)$

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems

cl = ca



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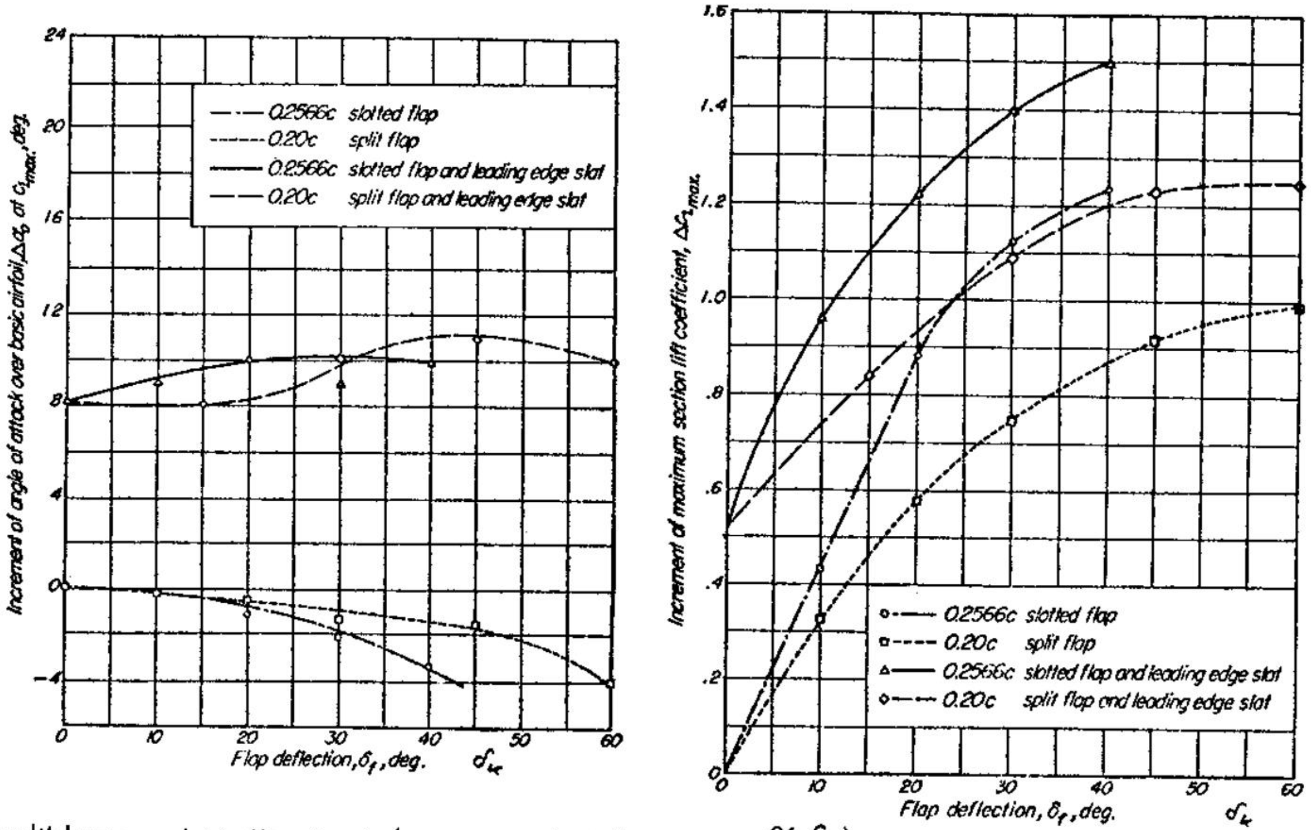
1.8.3 Profile values for different flap systems

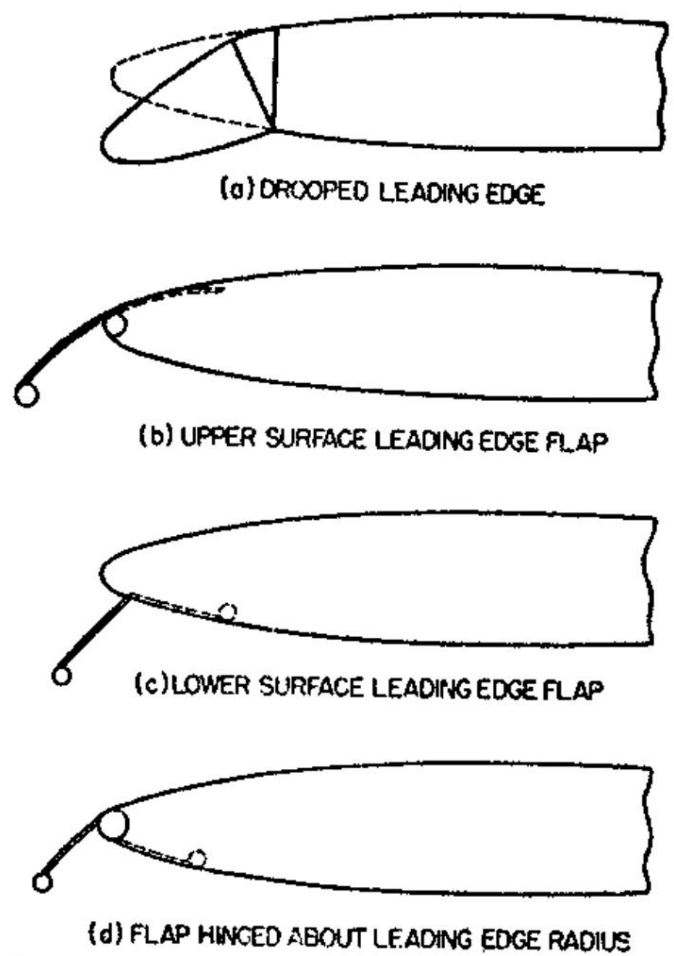
- **The Kruger flap is a widely used leading edge flap drive aid that is characterized by mechanical simplicity.**
- **It only causes warping and no boundary layer influence flow.**

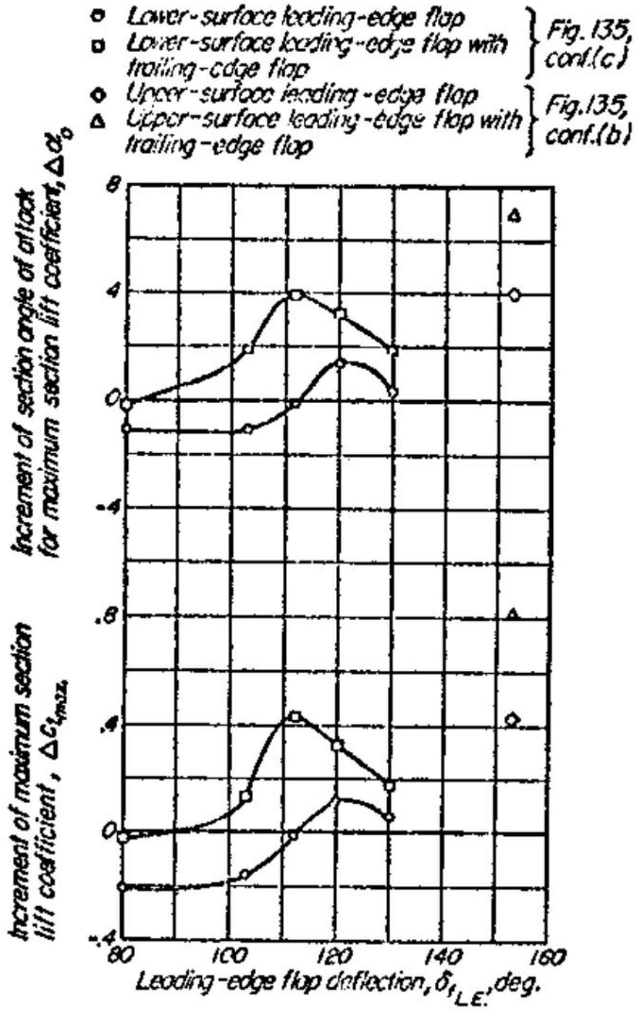


Spaltklappe und Vorflügel, $\Delta\alpha_{c_{a\,max}}$ und $\Delta c_{a\,max\,VF} = f(\delta_k)$

D Basics of aerodynamic design

1.8.3 Profile values for different flap systems





$\delta_{K\,\text{Vorderkante}}$

Nasenklappen, $\Delta c_{a_{max}}$ und $\Delta \alpha_{c_{a\,max}\,NK} = f(\delta_{K_{VK}})$

D Basics of aerodynamic design

1.8.3 Statistical verification of the cAmax estimate

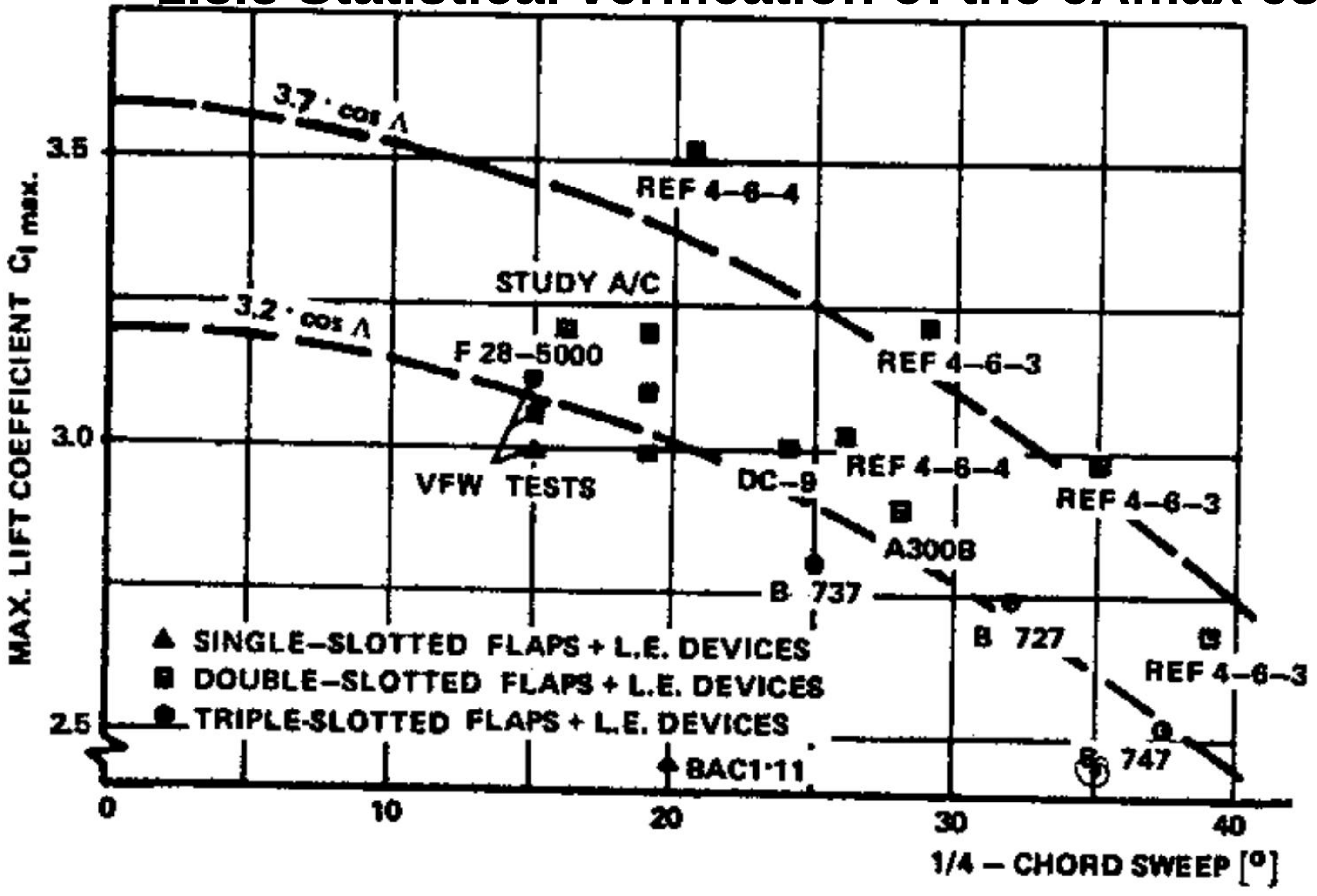


Bild 15: $c_{A_{max}} = f(\varphi)$, aufgeführte Flugzeuge und Projekte

D Basics of aerodynamic design

1.8.4 Thrust-assisted high-lift devices

- **The lift gains of the above flap systems can be significantly increased if they are used for jet deflection.**

- **The resulting beam impulse in the vertical direction is particularly effective during short landings, as the propulsion of the engines is not fully required anyway. • There are various**

concepts for jet flaps, which are based on the use of the Coanda effect (ÿUSB) as well as on jet deflection by guide flaps. • The problem with these systems is that the maximum lift is directly

related to the thrust development.

- **In case of engine failure, sufficient maximum lift and to ensure a controllable symmetry of the buoyancy distribution ÿ large construction costs!**

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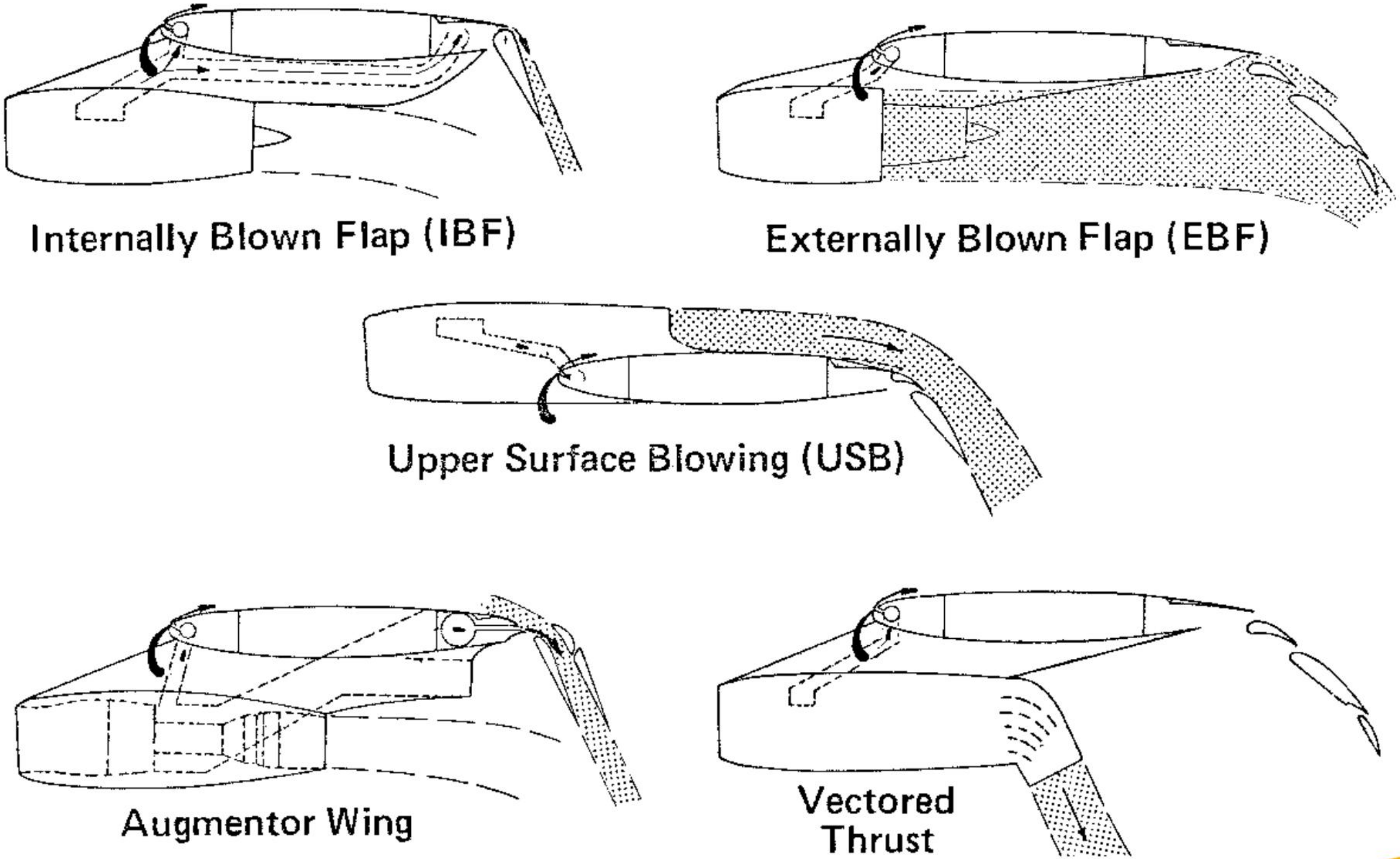
1.8.4 Thrust-assisted high-lift devices



Internally Blown Flap (IBF)

Externally Blown Flap (EBF)

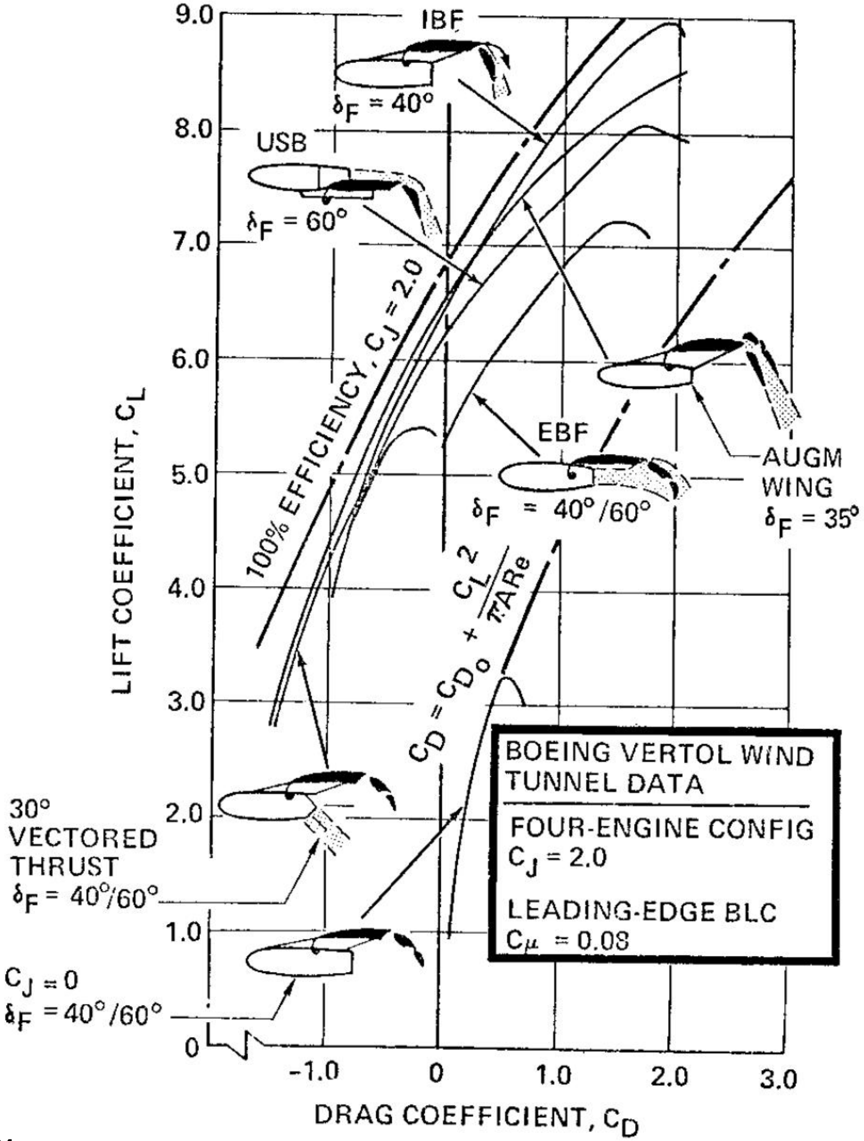
Upper Surface Blowing (USB)

Augmentor Wing

Vectored Thrust

D Basics of aerodynamic design

1.8.4 Thrust-assisted high-lift devices



- **The illustration shows the results of a wind tunnel test on a 4-engine configuration study.**
- **cJ is the jet coefficient of the trailing edge flap and cÿ is the jet coefficient of the VK flap.**
- **It is clear that the horizontal zontal jet momentum component leads to a strong reduction of the drag coefficient into the negative range (propulsion).**

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1.9 Increase in resistance during flap deflection

- The flap deflection shifts the resistance polar to higher values. Three resistance components must be taken into account here:

1. the profile drag increase
2. the increase in induced resistance 3. the increase in interference resistance

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1.9.1 Profile drag at flap deflection

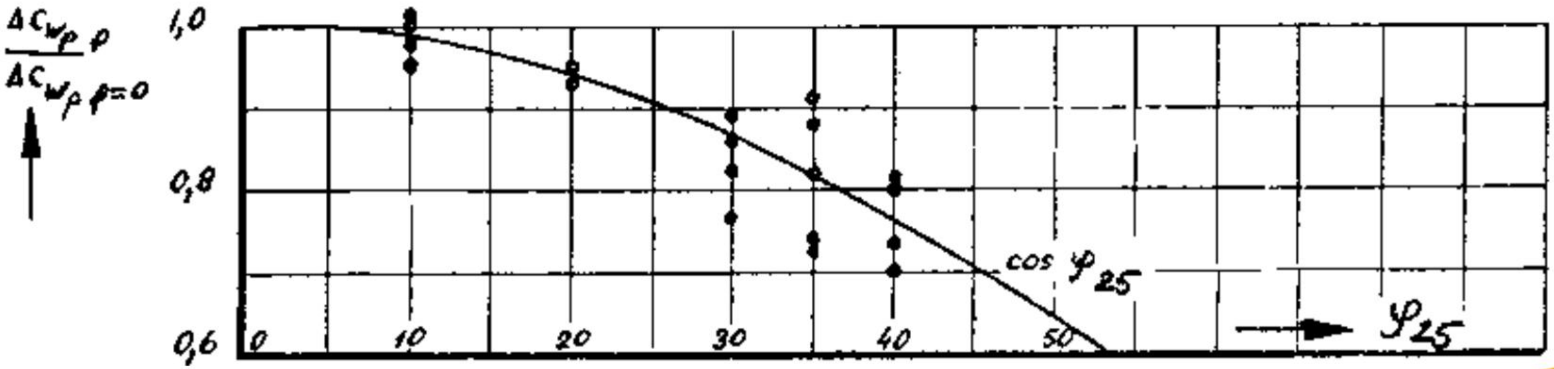
- **The change in the drag coefficient of the wing due to Flap deflection, like the lift coefficient, can be described using the area rule.**

- **The following therefore applies:**

$$\Delta c_{W_{F,k}} = \Delta c_{w_{p,k}} \cdot \left(\frac{F_k}{F} \right) \cdot \cos \varphi_{25}$$

- **The same rules for the area ratio apply as used in the buoyancy considerations.**

- **The sweep influence is well approximated by the cosine-ÿ law:**



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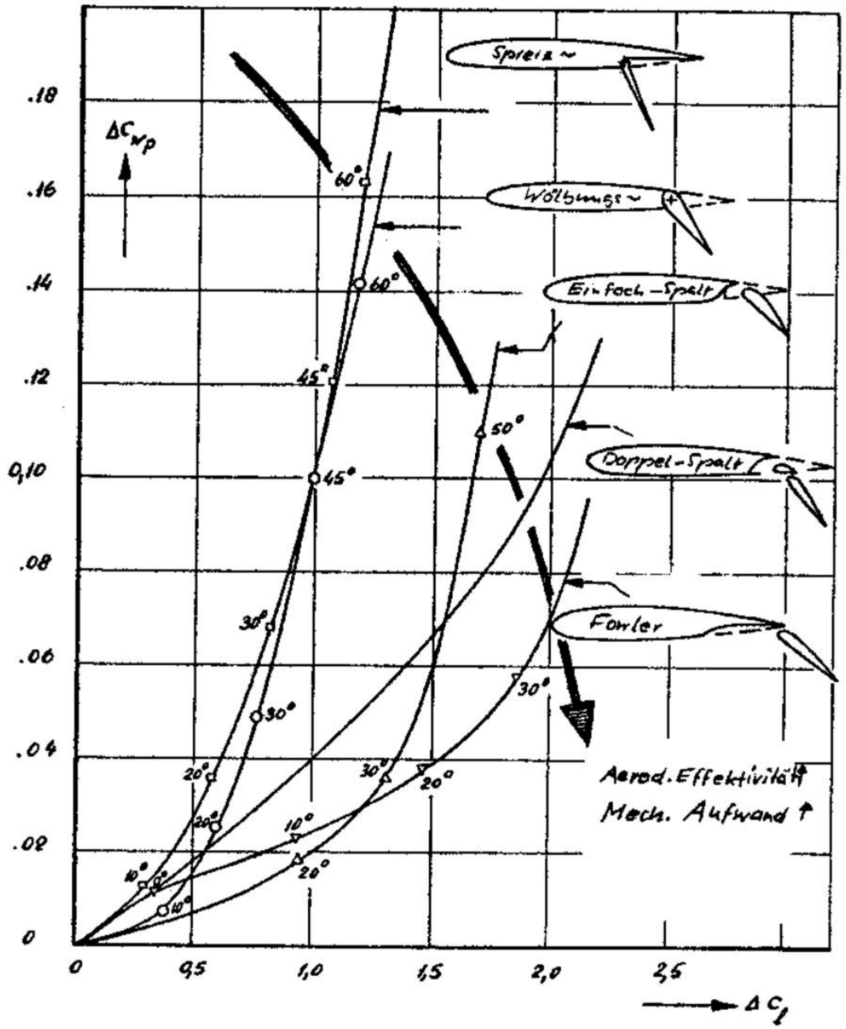
1.9.1 Profile drag at flap deflection



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- **Spread and camber flaps have relatively low aerodynamic effectiveness.**
- **The reason for this is that the detachment area behind the flap expands as the deflection increases.**
- **They require the least construction effort of all systems.**

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1.9.1 Profile drag at flap deflection

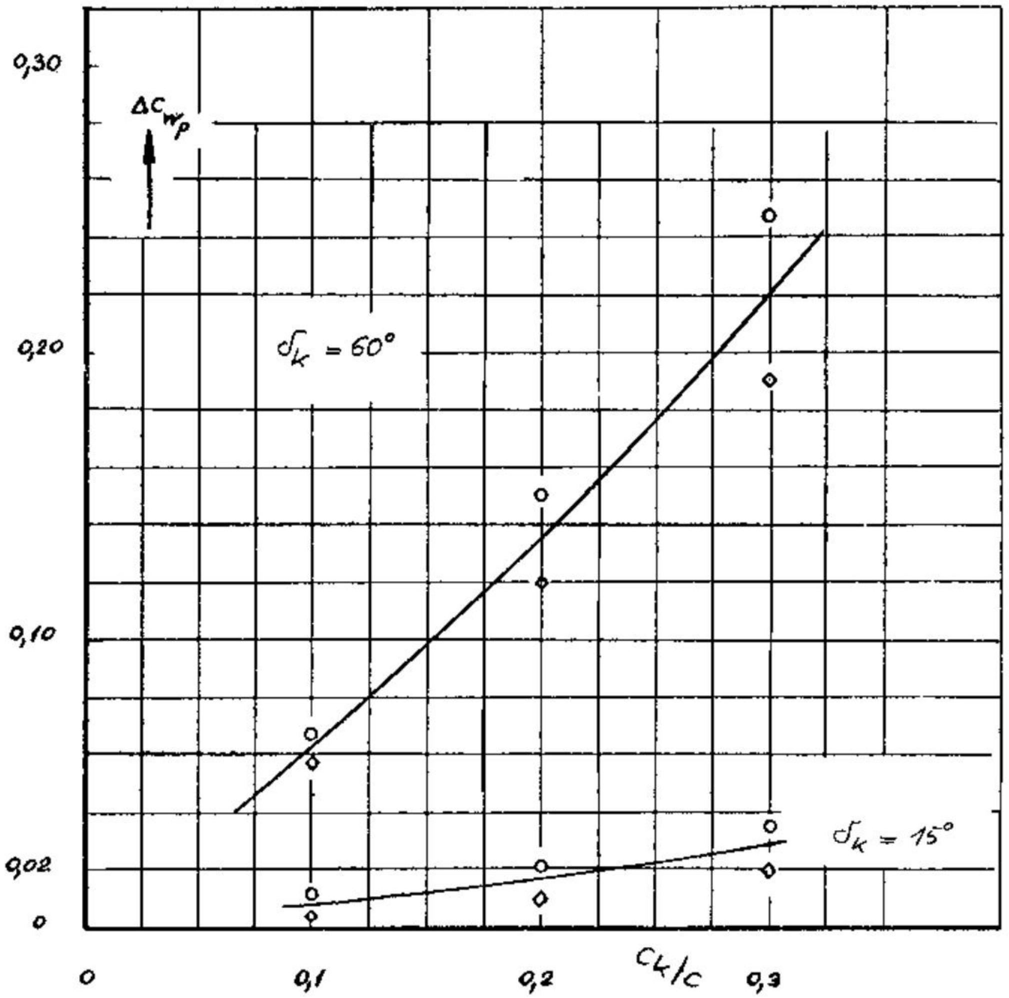

Bild 29: Wölbungsklappe; $\Delta c_{wp} = f(c_k/c, \delta_k)$

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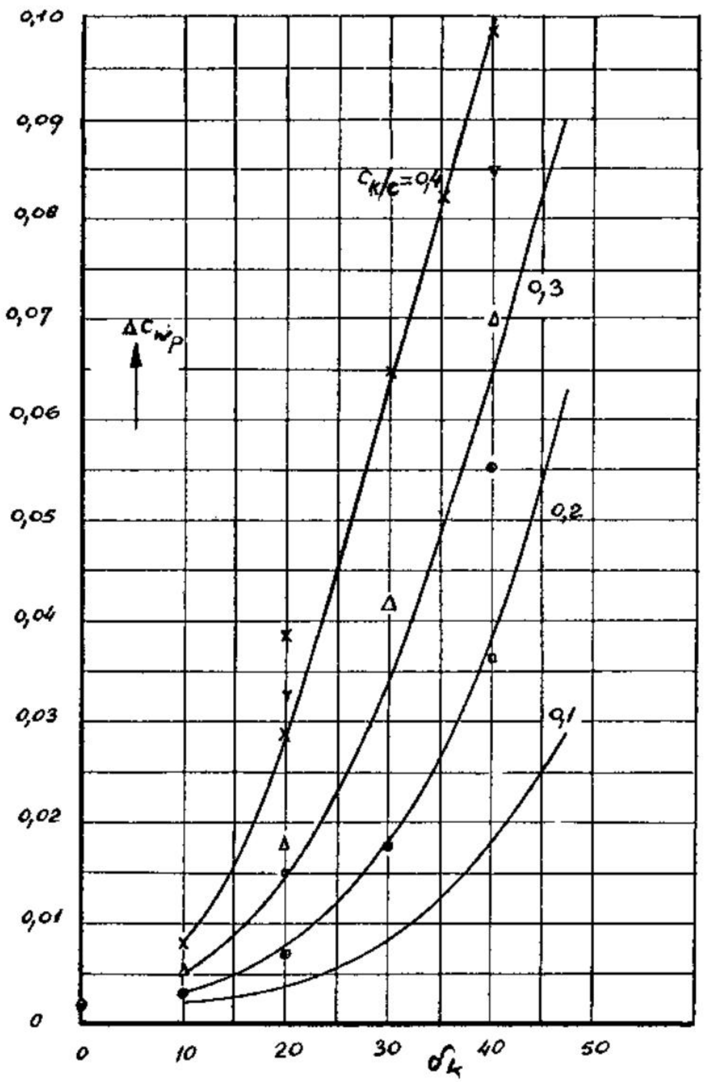
1.9.1 Profile drag at flap deflection



- **Fowler flaps are a compromise between the mechanical complexity of multiple slotted flaps (advantages especially in the area of smaller flap angles) and the simpler construction of a single-element system (advantages in a dramatic way with large flap deflections).**

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1.9.1 Profile drag at flap deflection

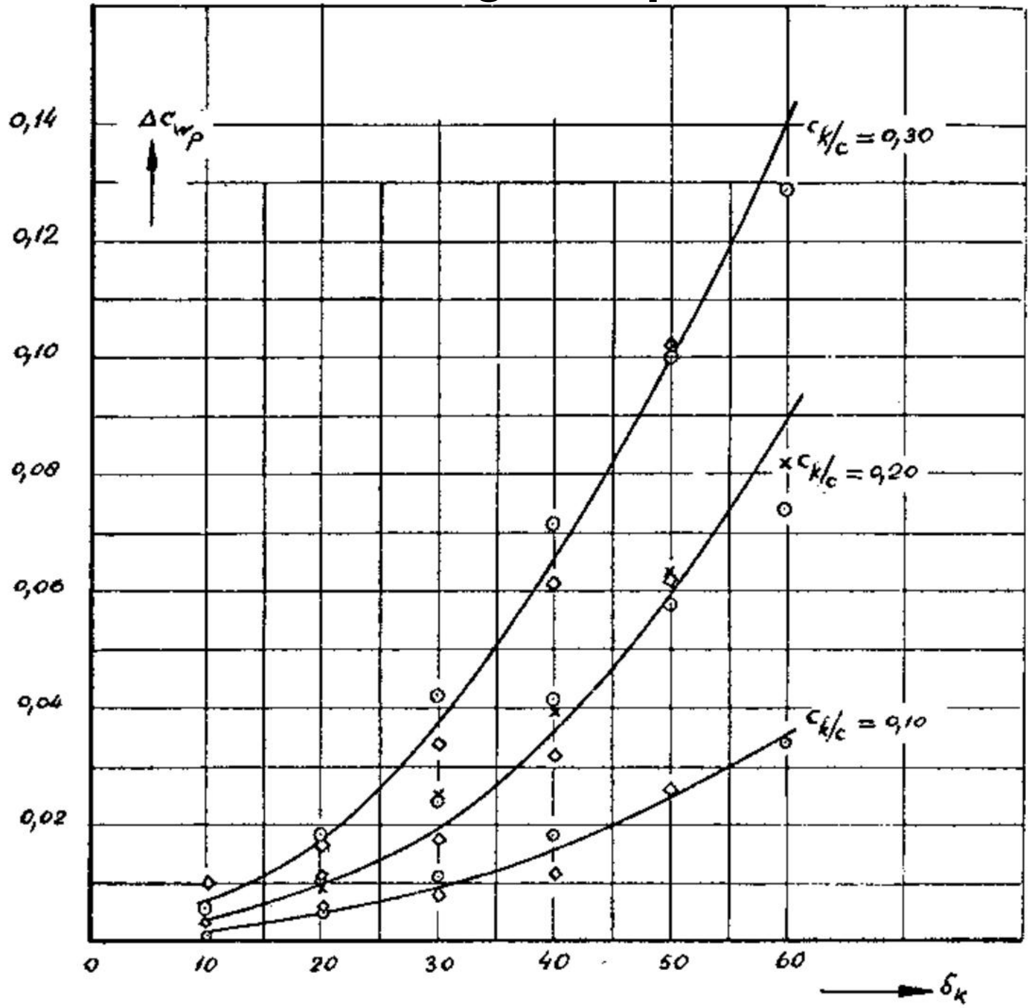
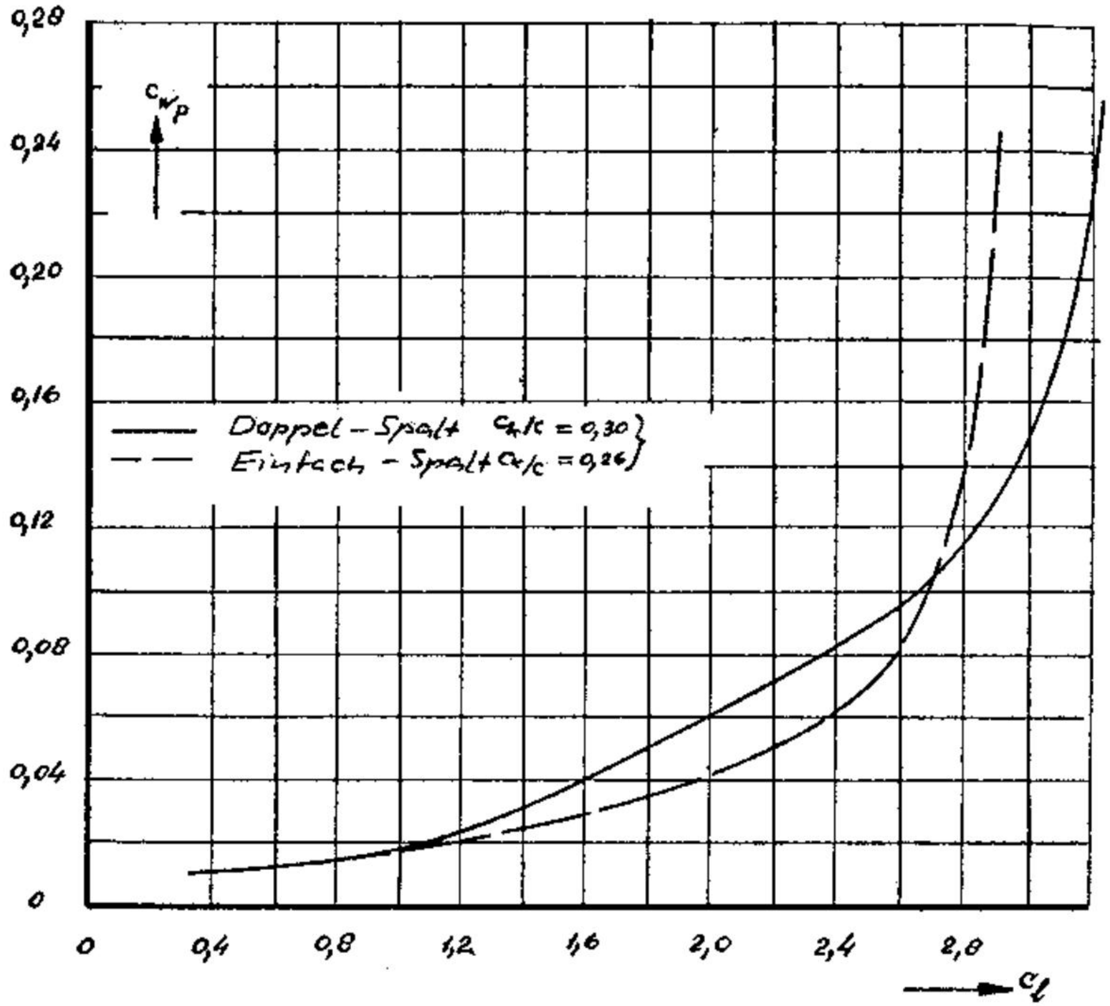


Bild 30: Einfach-Spaltklappe; $\Delta c_{w_p} = f(\delta_k, c_k/c)$

D Basics of aerodynamic design 1.9.1 Profile drag at flap deflection



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NACA 23012 mit Einfach- u. Doppelspaltklappe; $c_{wp} = f(c_a)$

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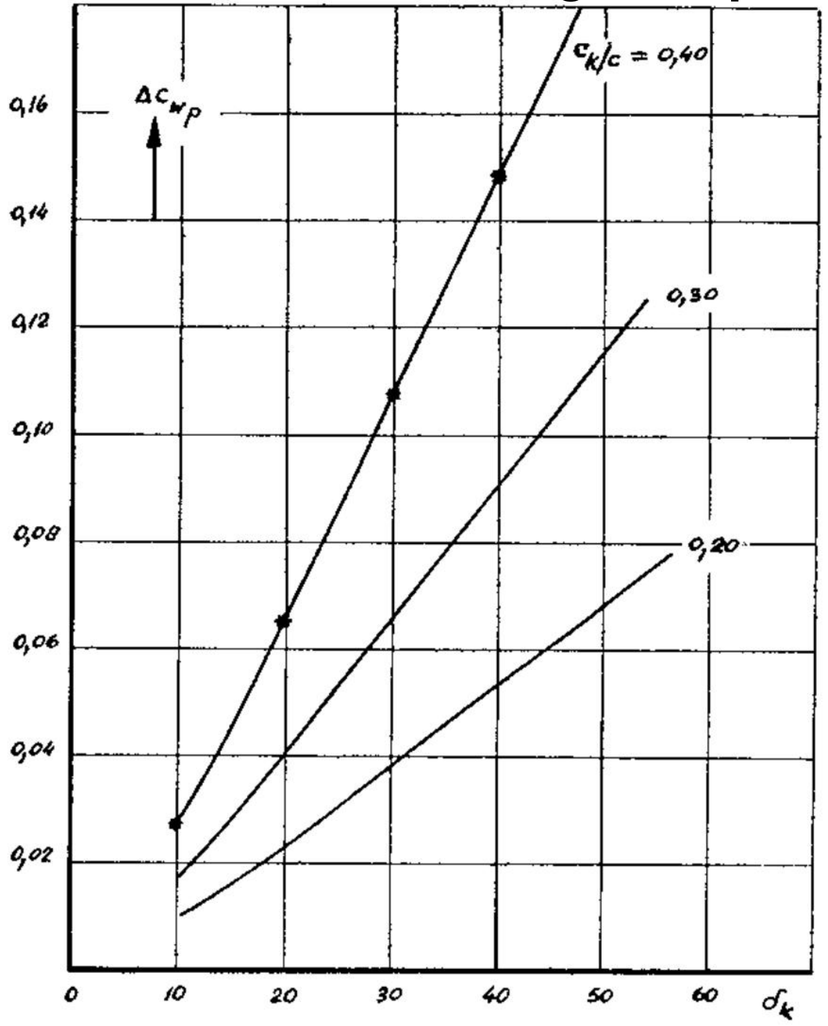
1.9.1 Profile drag at flap deflection



: DSK mit fester Führungsklappe ; $\Delta c_{w_p} = f(\delta_k, c_k/c)$

- The flow in double-slotted flaps (DSK) breaks only with larger flap deflections.
- The reason for this is the multiple energy enrichment at the columns.
- This type of flap has a relatively low drag and a large increase in lift.

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1.9.2 Induced resistance during flap deflection

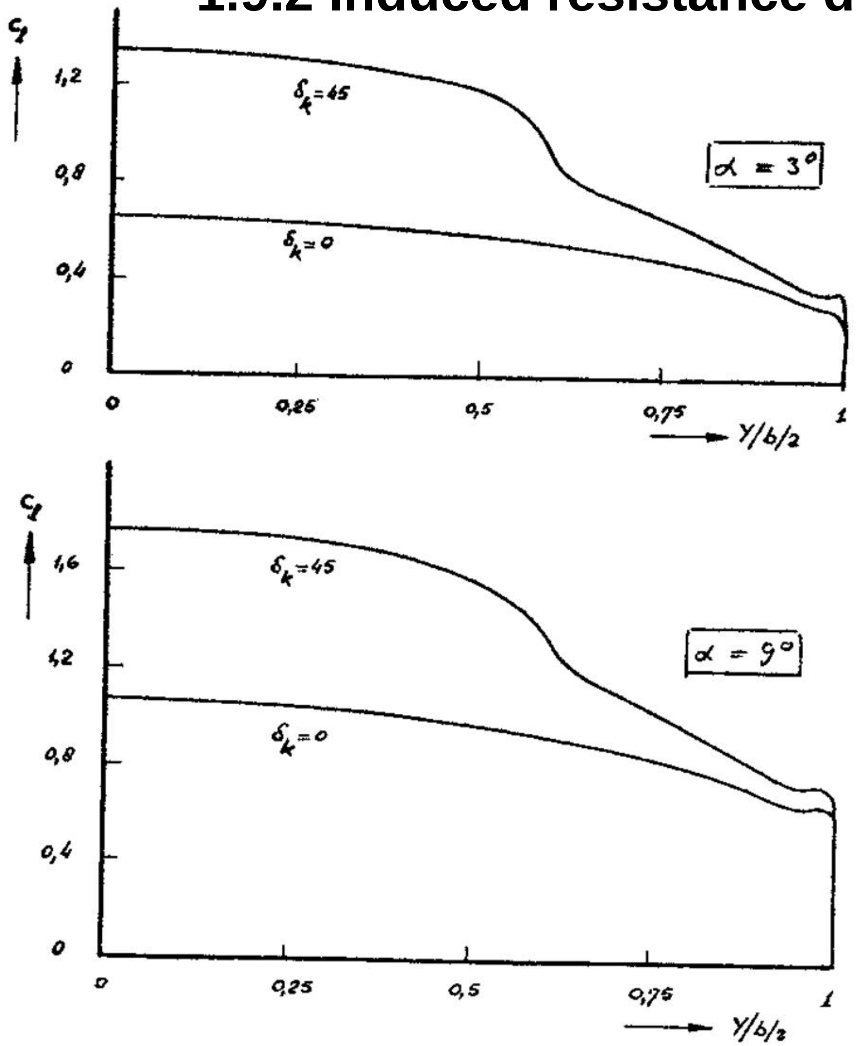

Bild 34 : Auftriebsverteilung für Flügel mit Spreizklappe, $b_k / b = 0.6$

- The valve deflection causes a change in the Lift distribution over the Span on
- This also changes the induced resistance depending on the deflection and flap geometry, which is described by the flap depth and length.

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D Basics of aerodynamic design

1.9.2 Induced resistance during flap deflection

- For the elliptical wing, the increase in induced drag can be approximately described by

$$D\,\ddot{y}\,\ddot{y}D\; cW_i\; kc^{2}\; A^{2}$$

- The factor k is a function of the flap span, the wing aspect ratio and the fuselage coverage.

- This estimate is sufficiently accurate for trapezoidal wings with Peak values between 0.25 and 0.5.

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1.9.2 Induced resistance during flap deflection

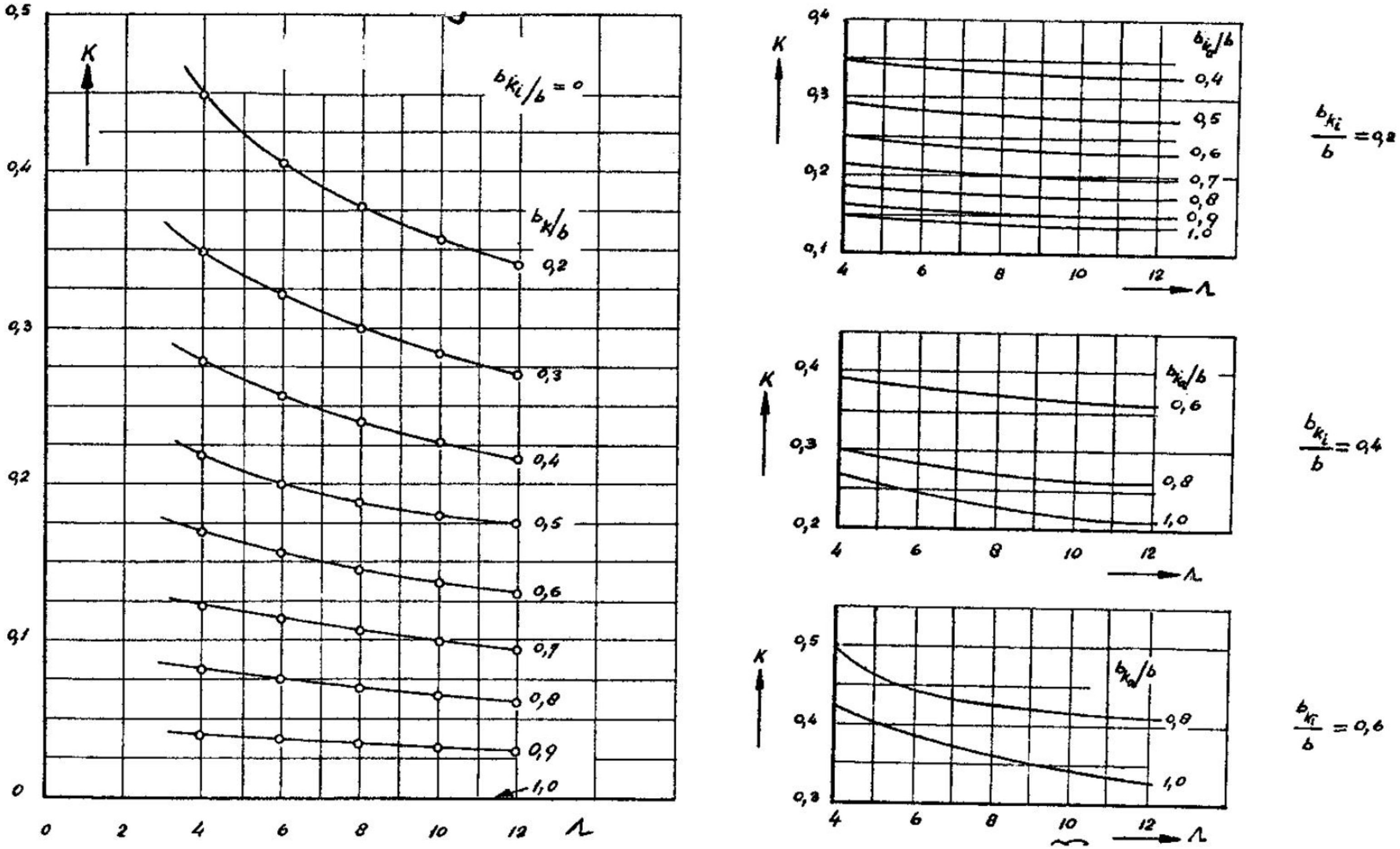

Bild 35 : Faktor k zur Bestimmung von Δw_i (Bedeutung b_{ka}/b, b_{ki}/b siehe Skizze S. 4)

ohne Unterbrechung durch Rumpf

mit Unterbrechung durch Rumpf

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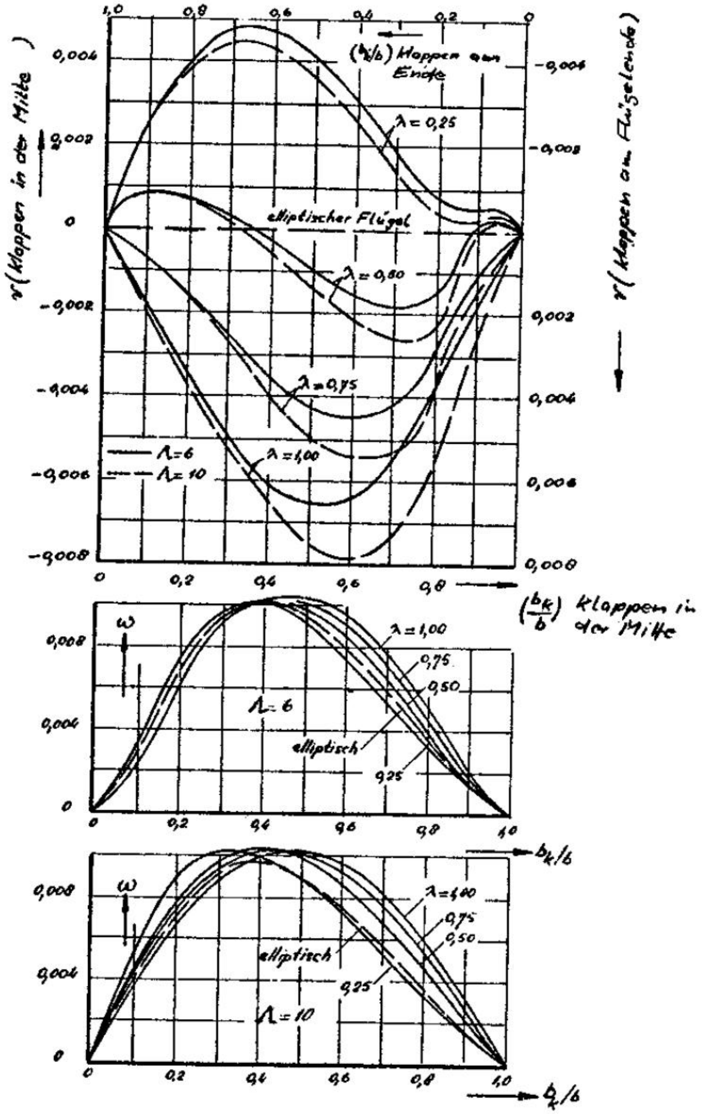
1.9.2 Induced resistance during flap deflection



- **Another method for Estimation of the induced resistance increase also takes into account the cA -dependent component**

- **Then, with the factors v and w from the adjacent equation,**

  Illustration:

  D ÿ ÿD ÿ ÿ D ÿ cvcw $D\ddot{y}_{We}\ \ddot{y}D\ \ddot{y}\ddot{y}_{A}\ D\ \ddot{y}\ cvcw_{a}\ {}^{2}_{A}$

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1.9.3 Interference resistance during flap deflection

- **The calculation of the interference resistance for double-slit flaps can be carried out in rough approximation according to Fiecke with the following relationship:**

Dc_{Winter} ÿ 0.4ÿDc_{Wp}

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1.10 Moment change during flap deflection

- The change in the wing moment when flaps are deflected at the leading or trailing edge of the wing depends on
  - the flap geometry,
  - the travel path of the flaps and
  - profiling
- It is so complex that a direct determination is not possible is possible.
- A simple determination of the additional moment via an additional lift acting on the quarter line of the flap is therefore not permissible, since the flap deflection causes a changed pressure distribution on the entire profile.

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1.10 Moment change during flap deflection

• Glauert suggests a simple analytical approach.

• This is based on the change in the effective angle of attack of a profile, as this is decisive for the change in moment.

• For this purpose, the change in the effective angle of attack of a profile due to a flap deflection is first determined for a bent plate using the linear potential theory.

• However, experiments show that this approximation is too optimistic with regard to the nonlinear influence of the flap deflection.

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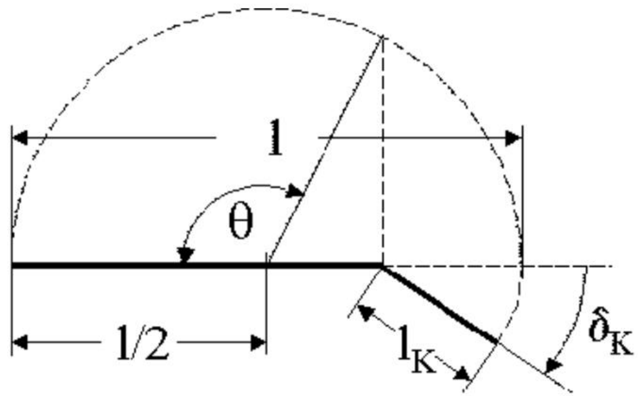
1.10 Moment change during flap deflection



- The valve effectiveness da/ddk is

$$\frac{da}{dd_k} \;ÿÿ\; 1 \;\frac{ÿÿÿsin}{ÿ}$$

- The angle ÿ is determined using

$$90 \;ÿÿÿÿ\;^{0}ÿ\; \frac{l/2 \quad l_K}{l}\; ÿ1ÿ2ÿ\frac{l_K}{l}ÿ\;ÿ\;ÿcos\;ÿ\;ÿ$$

calculated: $ÿÿ \arccos \begin{matrix}ÿ\\2\\ÿ\end{matrix}\; ÿ\frac{l}{l}ÿ1 \;\begin{matrix}ÿ\\ \\ÿ\end{matrix}$

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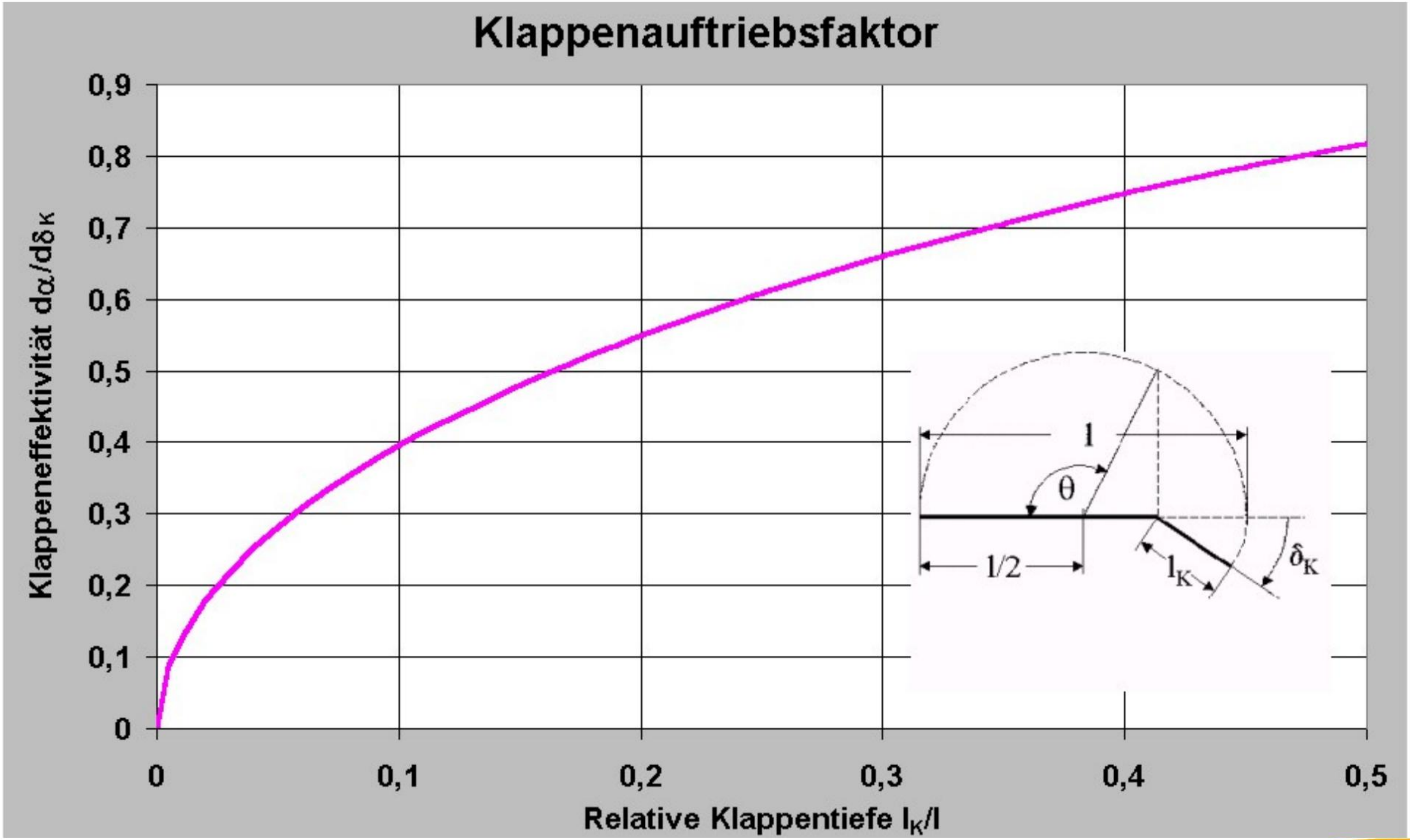
1.10 Moment change during flap deflection



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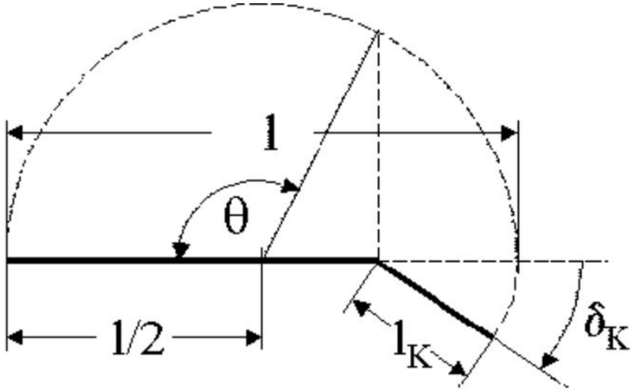
1.10 Moment change during flap deflection

- **The increase in lift coefficient can now be determined.**
- **For this purpose, the expression for the angle of attack change due to flap deflection is expanded:**



$$\frac{da}{dd_k} \text{ ÿ } \frac{da}{dd_k} \text{ ÿ } \frac{dc_a}{dc_a} \text{ ÿ } \frac{\frac{dc_a}{dd_k}}{\frac{dc_a}{da}}$$

- **The increase in lift coefficient is:**

$$D \text{ ÿ } c_{a\,k} \quad \frac{dc_a}{dd_k} \text{ ÿDdÿ}_k\text{d} \quad \frac{da}{d_K} \text{ ÿ } \frac{dc_a}{da} \text{ ÿDdÿ}_k\text{d} \quad \frac{da}{d_K} \text{ ÿ } c_a \text{ ÿDd}_k$$

D Basics of aerodynamic design

1.10 Moment change during flap deflection

- According to Glauert, the change in the moment coefficient by valve deflection using the linear theory of the relationship:

$$D\ddot{y}_{m_k}\ddot{y}\;\ddot{y}\,dc\,\frac{dc_{m_k}}{a_k}\,\ddot{y}D\ddot{y}_{a_k}\ddot{y}\;\ddot{y}\,dc\,\frac{dc_{m_k}}{a_k}\,\ddot{y}\,\frac{da}{dd_K}\,\ddot{y}\;\ddot{y}\,c_a\;\ddot{y}Dd_k$$

- The torque differential according to the theory of bent plate results in:

$$\frac{dc_{m_k}}{dc_{a_k}}\;\ddot{y}\ddot{y}\ddot{y}\;\frac{1}{2}\;\frac{\ddot{y}}{\ddot{y}}_1\;\ddot{y}\;\frac{l_k}{l}\;\ddot{y}\ddot{y}\ddot{y}\;\ddot{y}\ddot{y}\ddot{y}\;\frac{\sin\ddot{y}}{\ddot{y}\;\ddot{y}\;\ddot{y}\sin}\;\ddot{y}$$

- However, experiments show that this approximation is too optimistic with regard to the nonlinear influence of the flap deflection.

D Basics of aerodynamic design 1.10 Moment change during flap deflection

- The extended theory shows much better results, whereby the following approach is used: dc

D ÿ ÿ c dc m k — m k / a k ; a k

ÿ ÿ'lÿ ÿ ÿ ÿ ÿD ÿ c ÿ ÿ l' ; ÿ ll 4 ; 2 ; a ; ÿ ÿ l

ÿ ÿ ÿ ÿ ÿ ÿ 1 c 1ÿÿ ÿ ÿ ÿ ÿ ÿ ÿ l' ÿ ÿ ; 2 ; ÿ ÿ l ÿ ÿ ÿ ; m

- The torque increase is
  - from the depth increase l´/l and also – from the additional buoyancy and
  - depends on the lift and moment coefficient.
- The last term can often be neglected because of its small influence.

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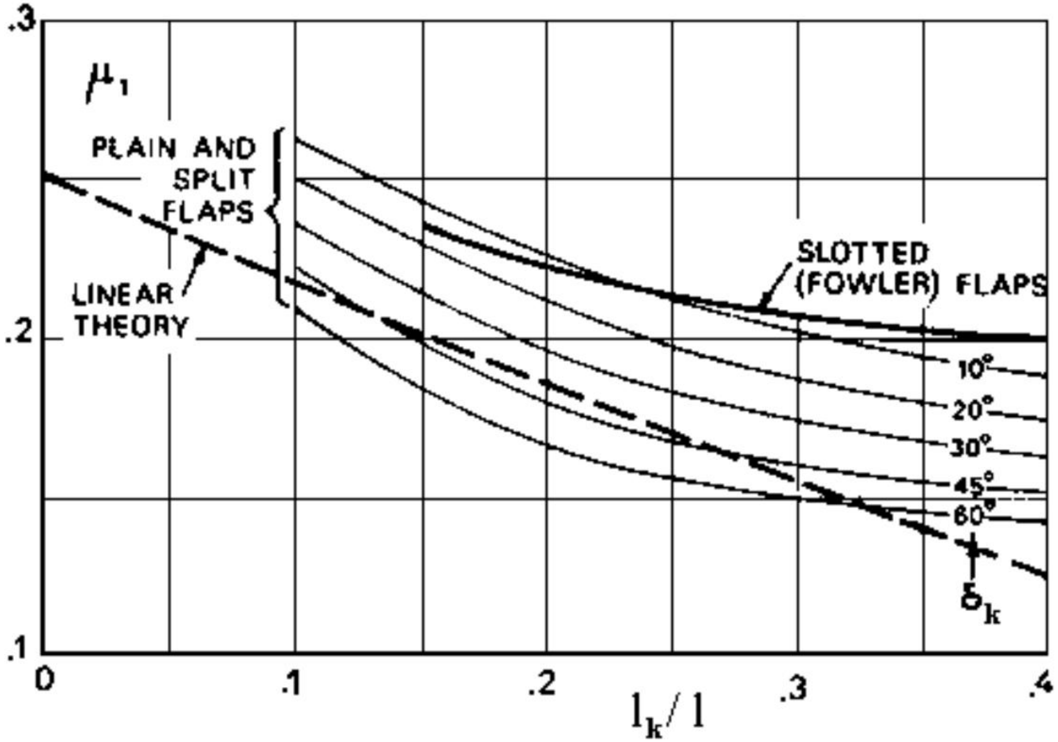
1.10 Moment change during flap deflection

- **For flaps with boundary layer influence (slot and Fowler flaps), the moment change is almost independent of the flap deflection.**

- **For spread and camber flaps, the flap deflection has a significant influence on the moment.**



$$\frac{dc_{m_k}}{dc_{a_k}} \text{ ÿ ÿ }_1$$

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1.10 Moment change during flap deflection

- As in the determination of the change in buoyancy and The drag coefficient of the wing must also be converted to the profile coefficient of the finite wing when calculating the moment coefficient

- However, no simple area rule can be applied here. be detected.

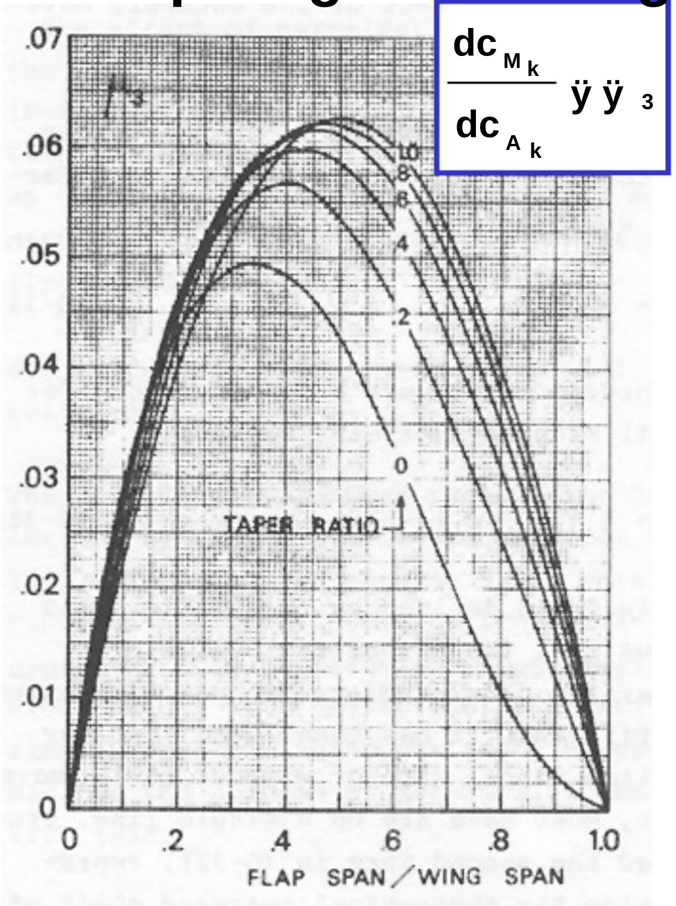
- The influence of wing geometry on the growth of The moment coefficient of the wing due to flap deflection can be described using an approximate relationship:

$$D\,\text{ÿ}\,c_{M_k} \boxed{\frac{dc_{M_k}}{dc\;m_k}}\;\text{ÿ}\,D\,\text{ÿ}\,\text{ÿ}\,c_{m_k}\,1\,2\;\;0.7\;\frac{\text{ÿ}}{\text{ÿ}\,/\,\text{ÿ}}\;\boxed{\frac{dc_{M_k}}{dc_{A_k}}}\;\text{ÿ}\,D\,\text{ÿ}\,c_{A_k}\,\tan\,\text{ÿ} \qquad 25$$

D Basics of aerodynamic design 1.10 Moment change during flap deflection

- **The two differentials describe the influence of the Flap length and wing taper.**

$$\frac{dc_{M_k}}{dc_{A_k}} \text{ ÿ ÿ } _3$$



$$\frac{dc_{M_k}}{dc_{m_k}} \text{ ÿ ÿ } _2$$