Welcome to the course

Aircraft design I

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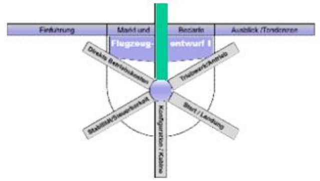
Luftfahrzeugbau
und Leichtbau

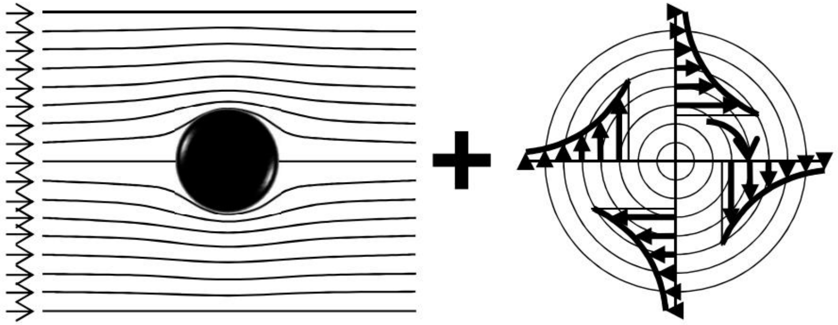


B.3 Influence of important design parameters
Aerodynamics: How does lift arise?

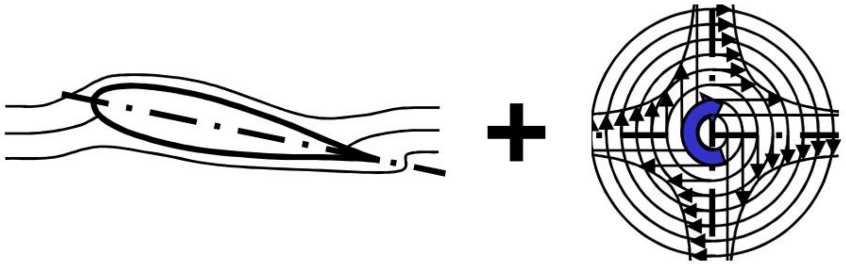
ÿ Mathematical: Application of the circulation

principle ÿ Approach: Superposition of a frictionless flow with a pure Circulation flow

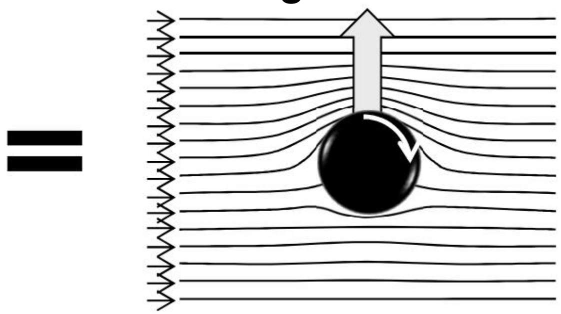
Translational flow + circulation flow



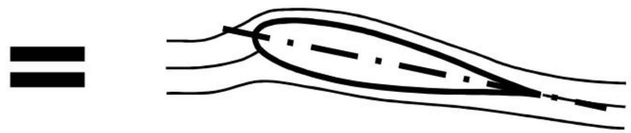
Potential flow (frictionless, no buoyancy) **Potential vortex (Biot-Savart)**



Lift generation



Kutta-Joukowski flow
(Discharge condition: tangential to trailing edge)

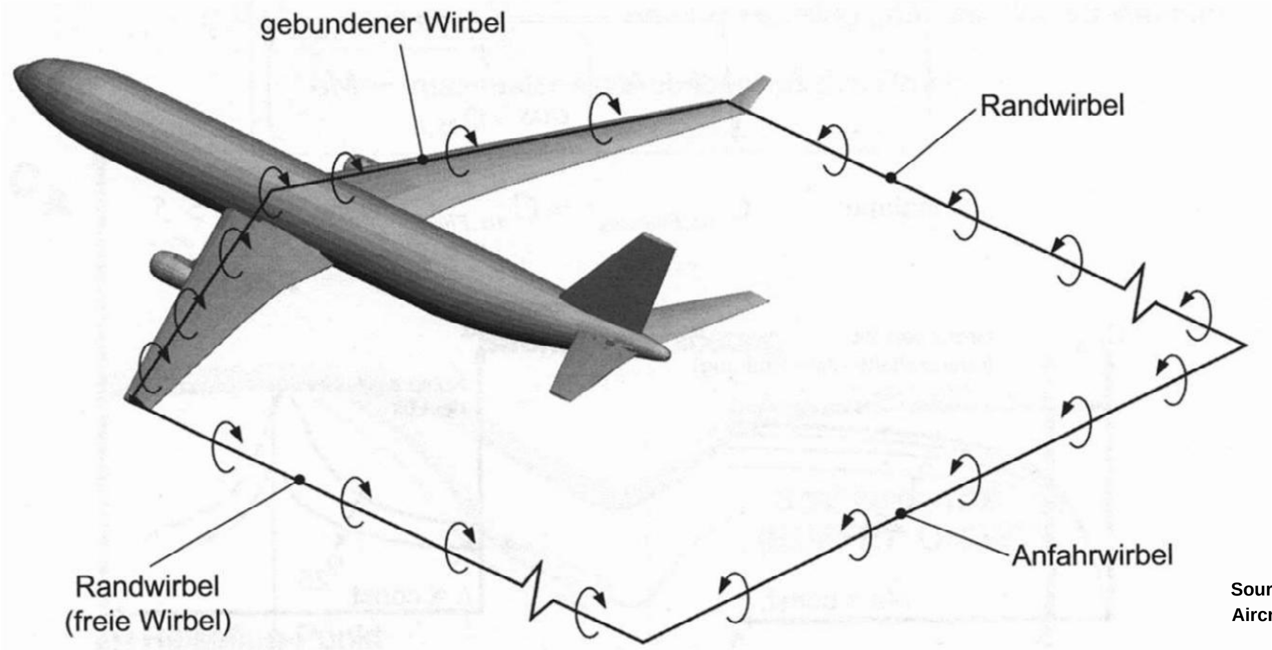


B.3 Influence of important design parameters

Aerodynamics: How is lift created?

ÿ Lift generation has so far been clarified on an infinitely long wing (= wing profile, 2D)

ÿ Transfer to the aircraft (finite wing, 3D)

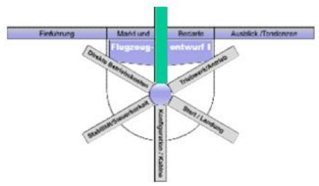


Source: TU Braunschweig, VL
Aircraft Construction I, Dr. Heinze

ÿ Closed vortex system consisting of wing-bound vortex, edge vortex and
Starting vortex

ÿ Only bound vortex provides lift!

ÿ Edge vortices generate drag ÿ induced drag - proportional to the generated lift



B.3 Influence of important design parameters
Aerodynamics: Drag

ÿ Composition of the total drag on the aircraft: I. Frictional drag

(surface, roughness)

II. Pressure resistance •

Form resistance (ÿ relative thickness) •

Wave resistance (Ma > 1)

III. Interference resistance between

aircraft components

Zero resistance cW0

(Buoyancy = 0)

IV. Induced drag (from edge vortices)

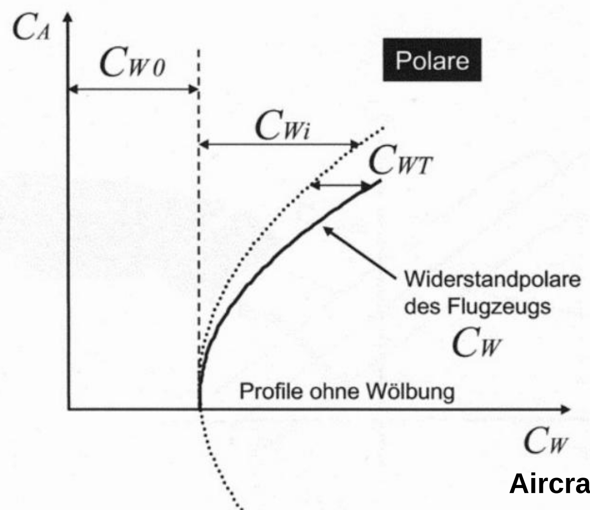
V. Lift-dependent wave drag VI. Trim drag cWT –

Buoyancy dependent

Resistance cWi

drag increase by fulfilling the moment balance on the aircraft:

SM = 0



C_{W0} - Nullwiderstandsbeiwert (abhängig von: Oberflächen, rel. Dicken, Rauhigkeiten, usw.)

C_{Wi} - induzierter Widerstandsbeiwert

C_{WT} - Beiwert des Trimmwiderstandes

e - OSWALD-Zahl
0,75 ... e ... 0,9 (1,0)

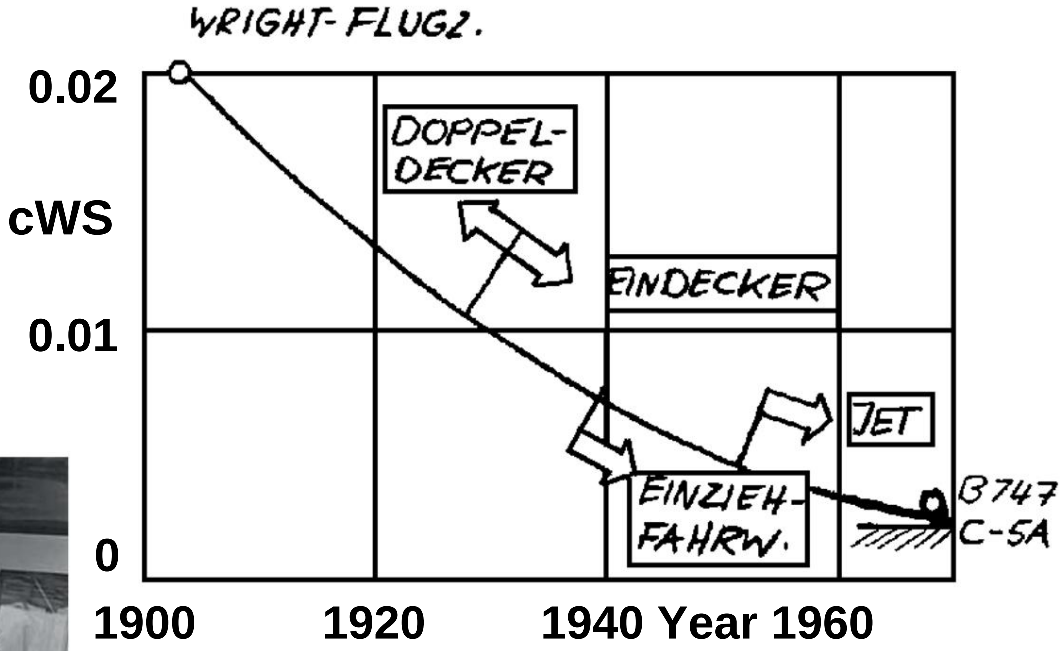
$$\boxed{C_W = C_{W0} + \boxed{\frac{1}{\pi \Lambda_F e}} C_A^2}$$

k-Faktor

Source: TU Braunschweig, VL
Aircraft Construction I, Dr. Heinze

B.3 Influence of important design parameters

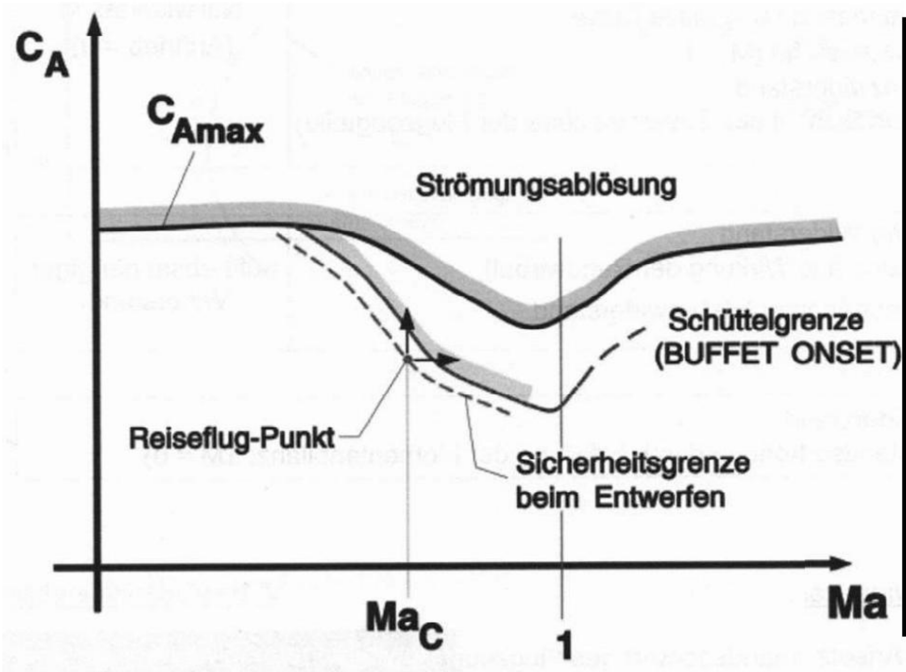
Aerodynamics: reducing harmful drag

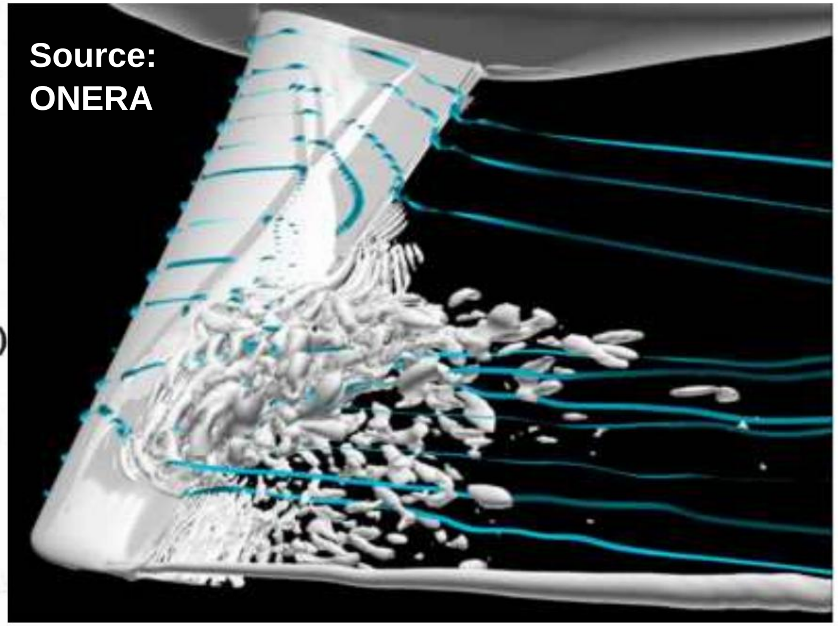


B.3 Influence of important design parameters

Aerodynamics: Influence of flight speed

Influence of the Mach number on the lift coefficient cA





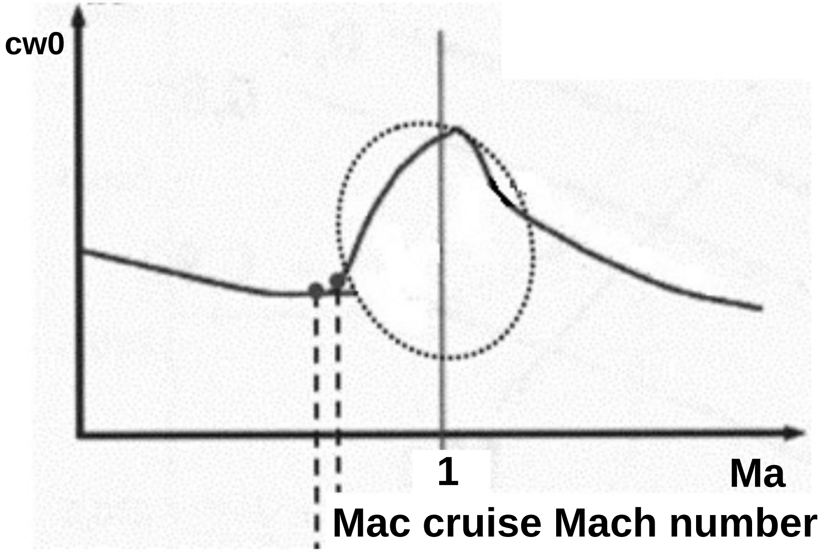
- ÿ Due to increasing flow separation in the transonic range, the maximum achievable lift coefficient **cAmax is reduced**
- ÿ **During maneuvers in cruise flight, unsteady separations, shaking (buffeting).**
- ÿ **Strong shaking can endanger the aircraft structure ÿ usable Lift coefficient cAmax smaller**

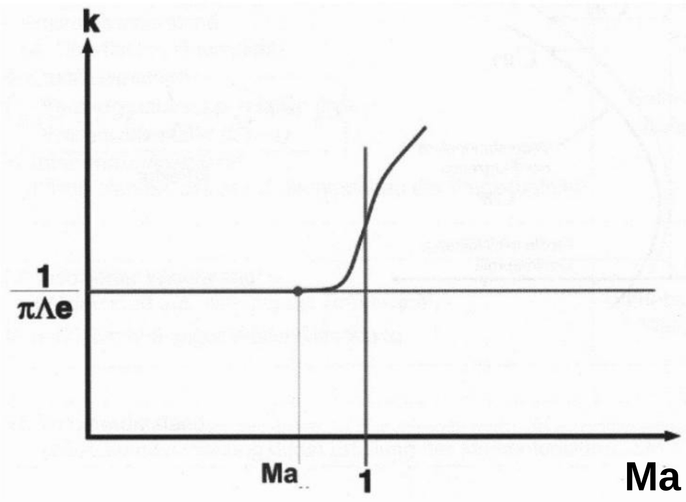
B.3 Influence of important design parameters

Aerodynamics: Influence of flight speed

Influence of the Mach number on the drag coefficient cW

Zero resistance cW0 **Induced resistance cWi = k cA²**





ÿ The zero resistance increases in the transonic range from Ma = 0.7 to about
Ma = 1 (compressibility, local shocks, wave resistance).

ÿ At the critical Mach number Makr, Ma is measured locally on a component for the first time.
= 1 is reached.

ÿ The induced drag cWi also increases in the transonic range

B.3 Influence of important design parameters

Aerodynamics: Influence of flight speed

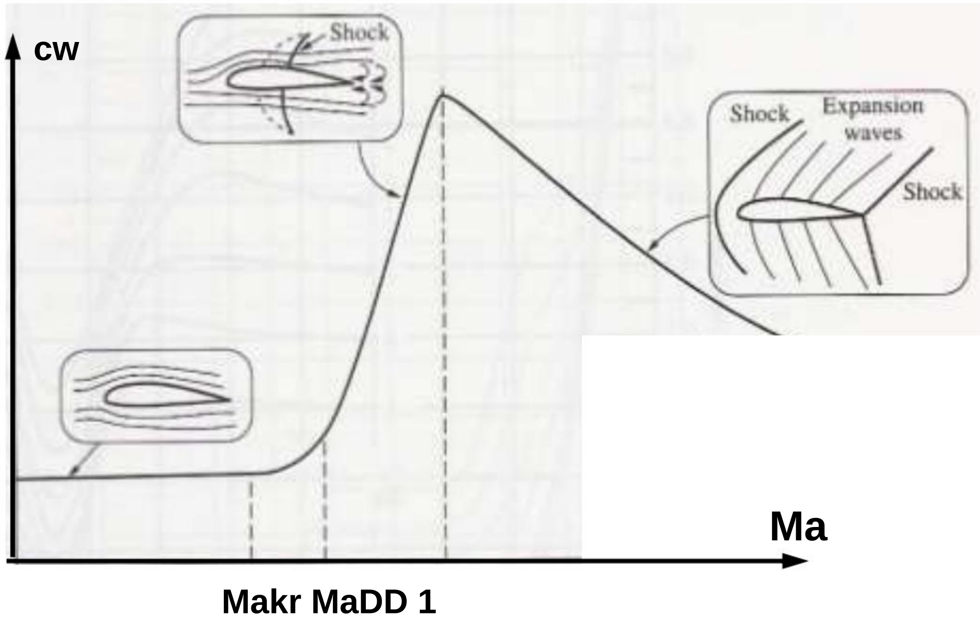
Influence of the Mach number on the drag coefficient cW

- **The resistance increases in the transonic range from Ma = 0.7 to Ma = 1 strongly (compressibility, local shocks, wave resistance).**
- **At the critical Mach number Makr, Ma = is measured locally on a component for the first time. 1 reached.**
- **With MaDD (Drag Divergence) cW** increases **by DcW = 0.002**

B.3 Influence of important design parameters

Aerodynamics: Influence of flight speed

Influence of the Mach number on the drag coefficient cW



ÿ **The resistance increases in the transonic range from Ma = 0.7 to Ma = 1 strongly (compressibility, local shocks, wave resistance).**

ÿ **At the critical Mach number Makr, Ma = is measured locally on a component for the first time. 1 reached.**

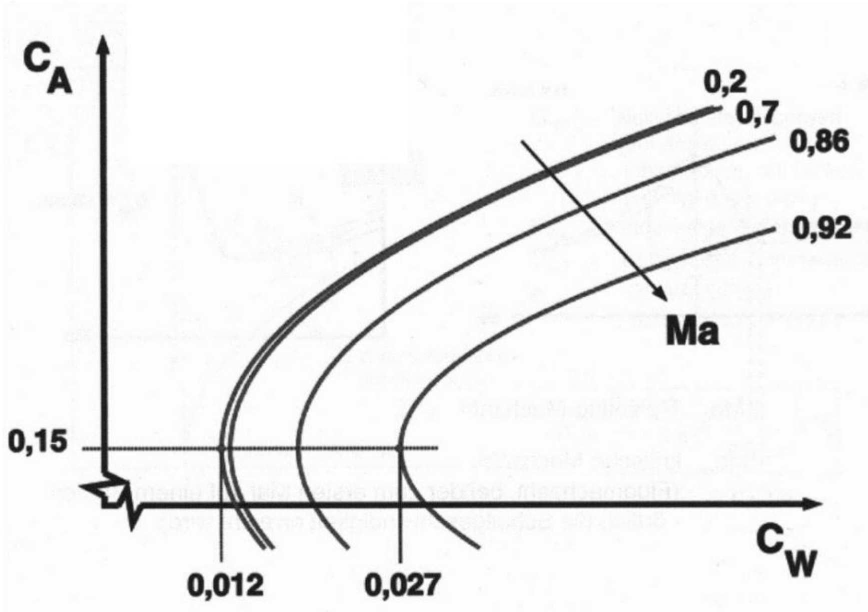
ÿ **With MaDD (Drag Divergence) cW** increases **by DcW = 0.002**

B.3 Influence of important design parameters

Aerodynamics: Influence of flight speed

Influence of the Mach number on the polar cA - cW

ÿ **Example B747**



Important:

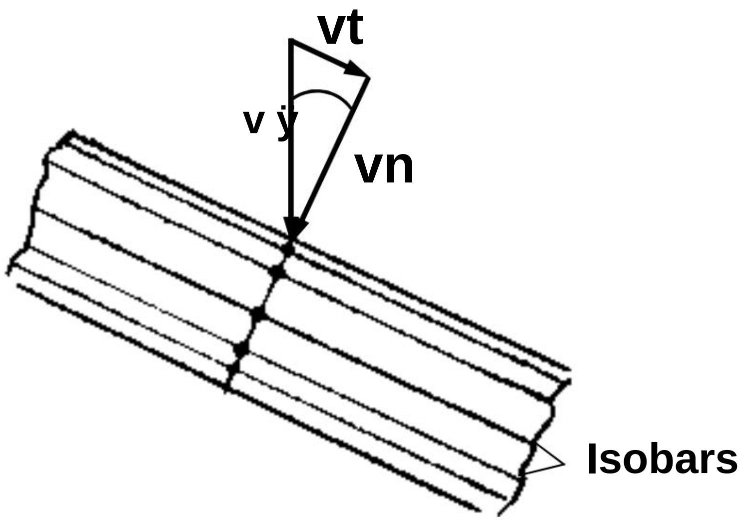
ÿ **The drag increase limit MaDD does not represent a flight physics limit, but merely defines the increased thrust requirement.** ÿ **The buffet limit**

(shaking limit) and the maximum lift limit represent limits that are insurmountable in terms of flight physics.

B.3 Influence of important design parameters

Aerodynamics: Influence of the sweep of the wing

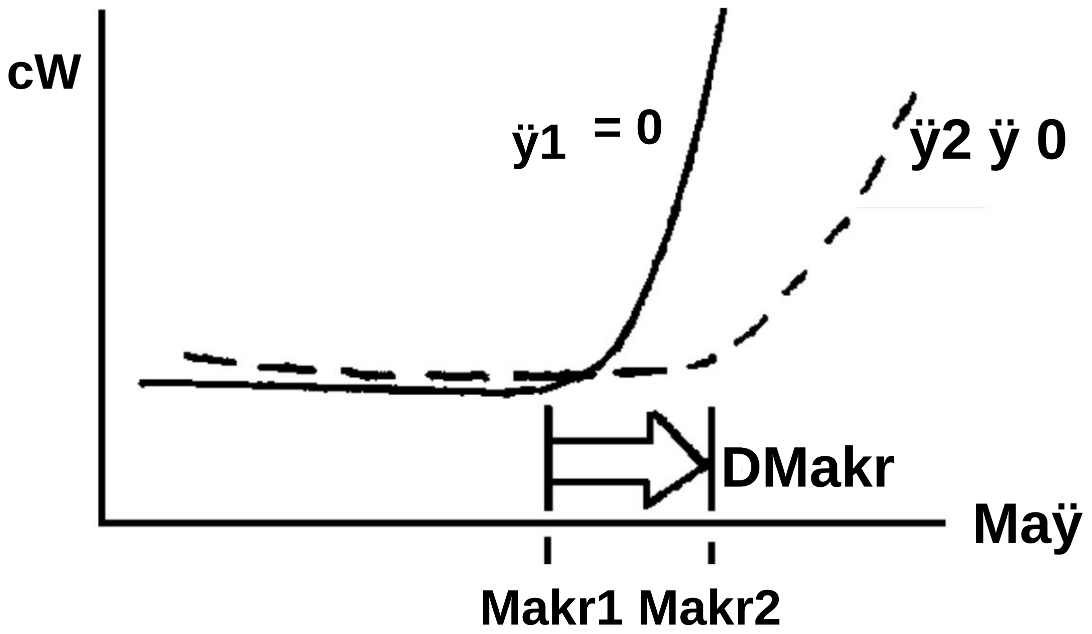
- ÿ The increase in travel speed is achieved by introducing the swept wing possible.
- ÿ Principle: Shift of the critical Mach number Makr (at which the local speed of sound is reached) to higher values
- ÿ Local overspeed depends only on the speed normal to the wing leading edge. component vn of the airspeed vector v.
- ÿ For the pushing wing of infinite length, the critical Mach number by a factor of 1/cos ÿ larger than for the straight wing.



B.3 Influence of important design parameters

Aerodynamics: Influence of the sweep of the wing

- ÿ The sweep also has a similar effect on the Mach number, at which the drag increases sharply due to the formation of a shock on the wing and a boundary layer separation behind the shock.
- ÿ Wave resistance and buffeting limit the flight speed of today's commercial aircraft to the high subsonic range.



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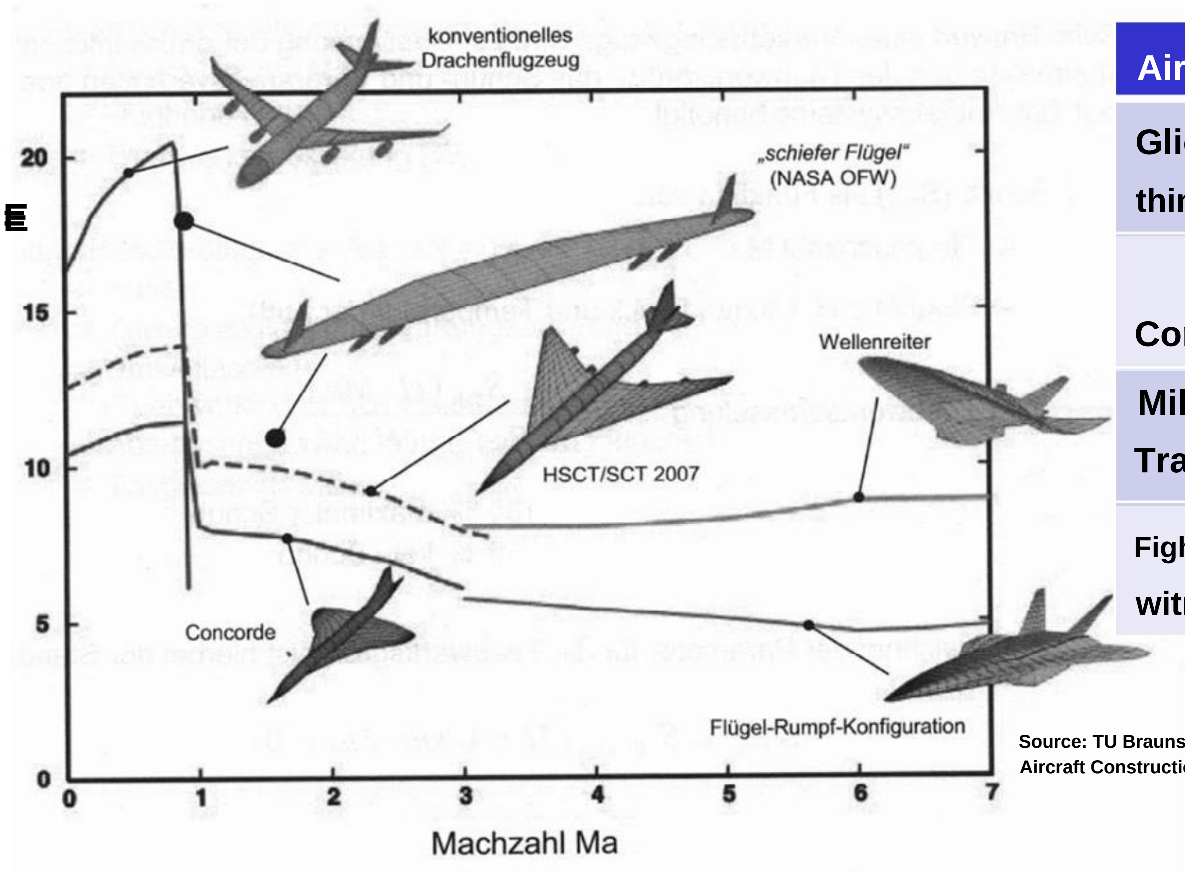
B.3 Influence of important design parameters

Aerodynamics: Achievable aerodynamic efficiency

ÿ The aerodynamic efficiency E = cA /cW is highest for Ma < 1



Aircraft type	E = cA /cW
Gliding things	25 … > 60
Commercial aircraft	12 … 20
Military Trainer	9 … 16
Fighter flight witness	10 … 13 (Ma < 1) … 6 (Ma > 1) 4

Source: TU Braunschweig, VL Aircraft Construction I, Dr. Heinze

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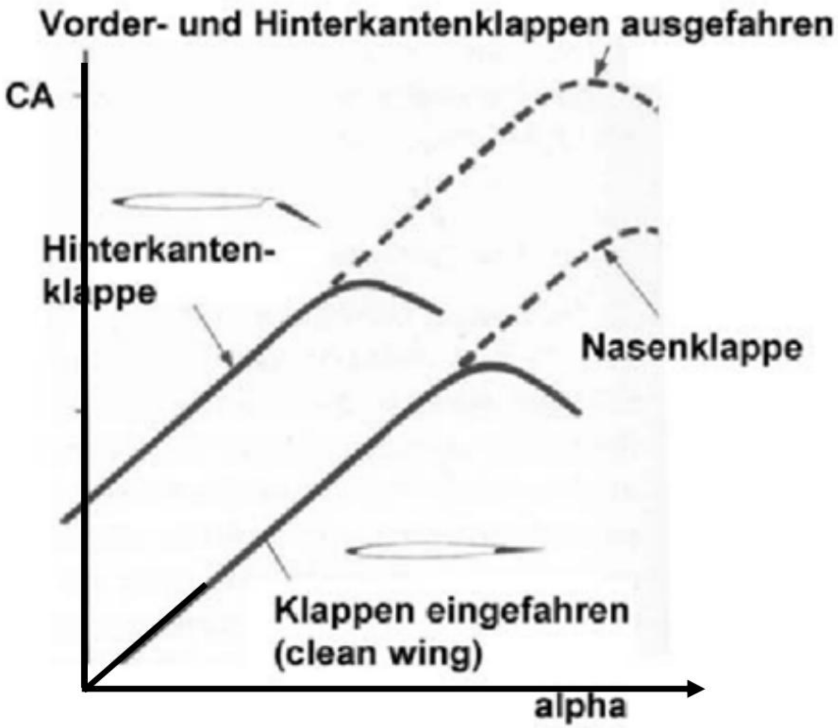
B.3 Influence of important design parameters

Aerodynamics: High-lift aids

ÿ Conflicting requirements in the design of commercial aircraft:

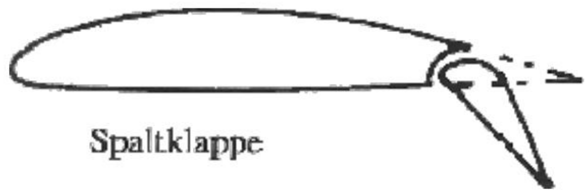
ÿ High cruising speed ÿ CA should be small ÿ Low take-off/landing speed ÿ CA should be large



Solution principle:

ÿ Leading edge flap: increase the usable angle of attack range to increase cAmax

ÿ Trailing edge flap: increase of Curvature of the profile to increase cAmax



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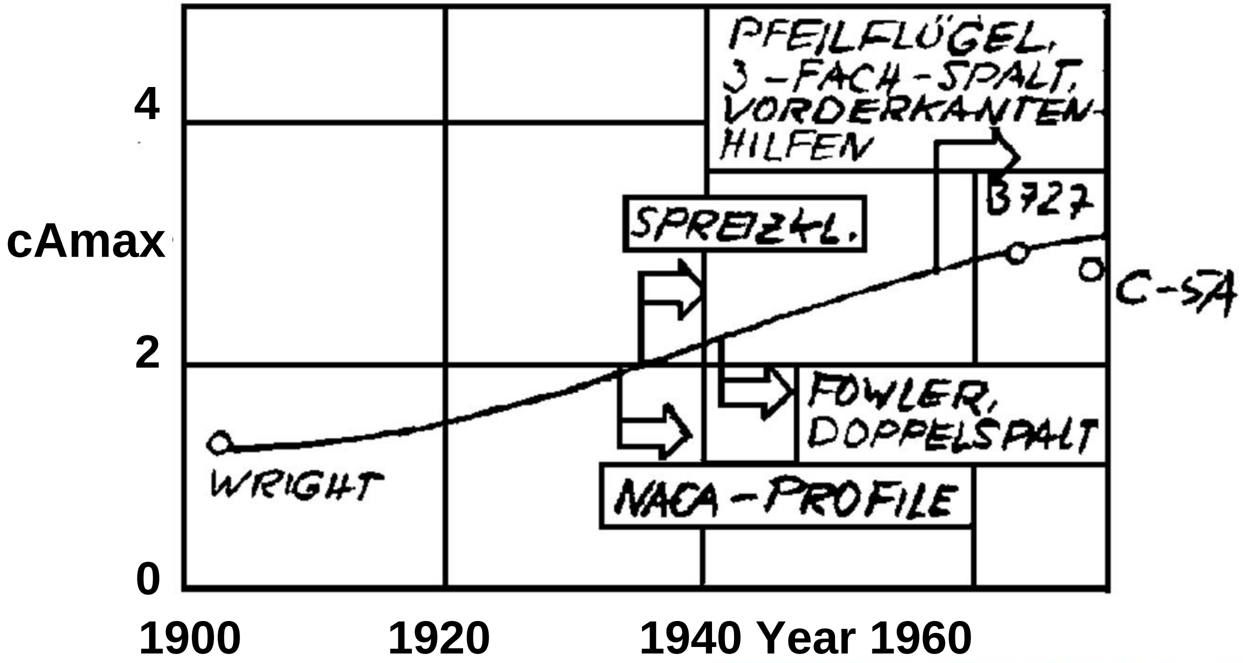
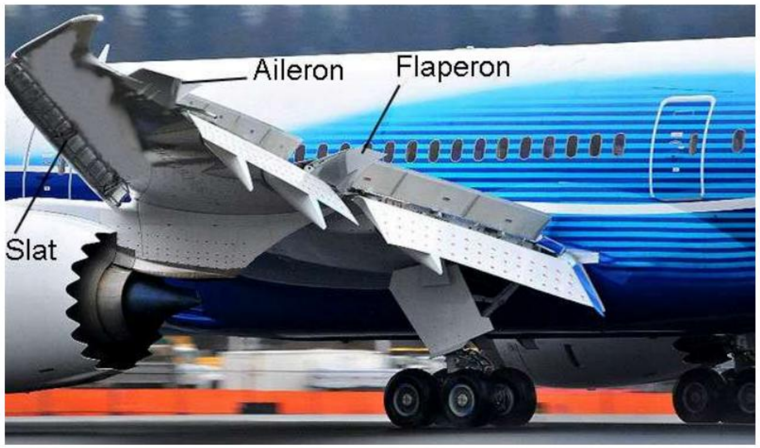
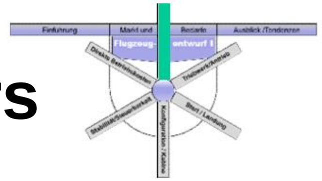
B.3 Influence of important design parameters

Aerodynamics: improving high-lift systems





B.3 Influence of important design parameters



Wing: Influence of the floor plan

- The real, finite wing differs in its properties from the pure wing profile in that it does not have a constant angle of attack over the span, but a variable, induced angle of attack and lift distribution occurs as a result of the pressure equalization at the wing tips.

- The floor plan is described by the extension, arrowing and depth distribution
- The plan view is particularly important for the lift distribution, but also for the profile drag of the wing. • These parameters cannot be determined

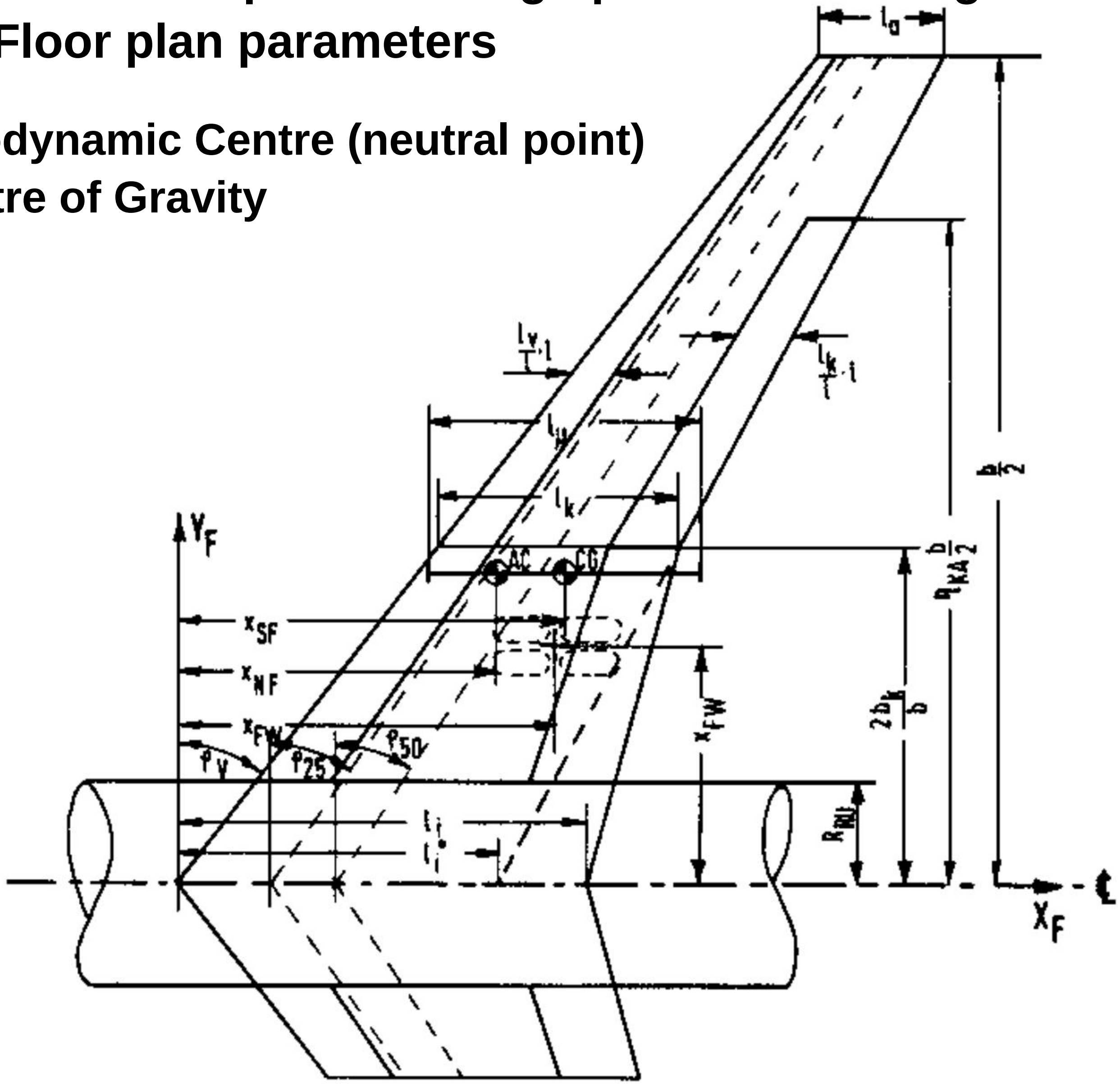
independently of each other.

because they are very complexly interconnected.

B.3 Influence of important design parameters Wing: Floor plan parameters

AC: Aerodynamic Centre (neutral point)

CG: Centre of Gravity



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B.3 Influence of important design parameters

Wing: floor plan parameters

Designation	Generally
Stretching	ÿ ÿ ÿ $\frac{b.b.^2}{F}$ $\frac{}{l_m}$
Middle deep	lm ÿ $\frac{b\ F}{ÿ}$ ÿ ÿ ÿ ÿ ÿ ÿl ÿ ÿ b 1 0
span	b ÿ ÿ ÿ F ÿ ÿ ÿl m
Escalation	ÿ ÿ $\frac{l_a}{l_i}$
Span coordinate	ÿ ÿ $\frac{2\ ÿ\ y}{b}$

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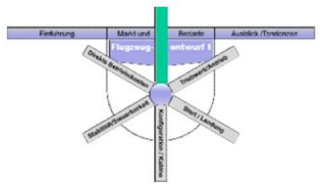
B.3 Influence of important design parameters Wing: Floor plan parameters

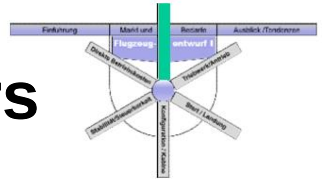
Description	General	Trapezoidal	Double trapezoidal wing ÿ
Area	1 F ÿbl ÿ ÿ ÿ ÿ ÿ ÿd ÿ ÿ 0	F ÿÿ wing b / 2 l_i ÿÿ ÿ 1ÿ ÿ	F ÿÿ b / 2 l_i ÿ b ÿ ÿ ÿ ÿ ÿ1 ÿ ÿ l_k / l_i ÿ ÿ b ÿ ÿ 1 ÿ k ÿ l ÿÿÿ ÿ ÿ ÿ ÿ b ÿ k / l_i ÿ ÿ ÿ ÿ ÿ
Escalation	For concave floor plans: 2 1 lÿ ÿd ÿ 1 ÿ ÿ ÿ ÿ ÿ ÿ ÿ ÿ l i 0 For convex floor plans: ÿ ÿ l_a / 1 ÿ 2 lÿ ÿ ÿd 1 0	l ÿ a / ÿ l_i	ÿ ÿ 2 b kk ÿ l ÿ / b ÿ l ÿ i l_a / l_i l_a / l_i
Internal depth	l ÿ ÿ ll l_i / m m	l_i ÿ 2 · l_m / 1 ÿ ÿ	l_i ÿ 2 litres m / 2 B k / b ÿ 1 ÿ ÿ l_k / l_i ÿ ÿ 1 2 b ÿ k / b ÿ ÿ ll ÿ ÿÿ a ÿ ÿ ÿ ÿ l i k / l_i ÿ ÿ ÿ
Depth gradient		l / l_m ÿ ÿÿ l_i / l_m 1ÿ ÿÿÿ ÿ 1ÿ ÿ ÿ	l / l_m ÿ ÿ ÿ l_i / l_m b ÿ ÿ / 2 · b_k ÿ ÿ ÿ 1 l_k / l_i ÿ ÿ 2 ÿ ÿ for 0 ÿ ÿ ÿ ÿ ÿ ÿ ÿ · b_k / b l / l_m ÿ ÿ ÿ l_i / l_m l_k / l_i 2 ÿ ÿ · b_k / 1 2 · b.b_k / b ÿ l ÿ k / ÿ l ÿ i l_a / l_i ÿ ÿ 2 ÿ ÿ for ÿ ÿ ÿ ÿ · b_k / b ÿ ÿ



B.3 Influence of important design parameters Wing: Floor plan parameters

Designation	General rel.	Trapezoidal	Double trapezoidal wing ÿ ÿ ÿ ÿ ÿ
reference ÿ l ÿ wing depth	d 1 ÿ ÿ ÿ ÿ ÿ 2 / l ÿ ÿ ÿ ÿ ÿ l ÿ m 0 m	wing l 4 1 ÿ ÿ ÿ ÿ 2 ÿ / l m 3 ÿ1 ÿ ÿ ÿ2	l ÿ / l m 1/3 ÿ l i 2 b k ÿ ÿ 1 ÿ ÿ { b ÿ l k 2 ÿ ÿ ÿ ÿ ÿ ÿ l k ÿ ÿ l ÿ ÿ i ÿ ÿ ÿ ÿ ÿ 1 b k / b ÿ ÿ ÿ ÿ l a 2 ÿ ÿ ÿ ÿ ÿ ÿ l k 2 l l k ÿ } i i i i
rel. reference wing position	2 years l ÿ / b 1 ÿ l ÿ d ÿ ÿÿÿ ÿ 0 / 1 4 l d ÿ ÿ ÿ 0	2 years ÿ / b 1/3 1 2 ÿ ÿ / 1 ÿ ÿ	2 years ÿ / b l i / l m ÿ l k l a ÿ ÿ l i l i { 6 1 ÿ k ÿ / b 3 2 B k / b ÿ 2 b k / ÿ ÿ b 2 ÿ ÿ / ÿ ÿ 2 ÿ ÿ ÿ 2 b k / ÿ ÿ b 2 ÿ 1 ÿ l k ÿ / l i 6 ÿ 2 1 l ÿ k / l i }
rel. neutral point position	x N / l m 1 ÿ ÿÿ 1 ÿ 2 ÿ l ÿ d ÿ ÿ ÿ ÿ 0 ÿ ÿ ÿ m	x N / l m ÿ / 2 ÿ ÿ ÿ 2 y l ÿ l 1 ÿ tan ÿ ÿ ÿ ÿ 4 ÿ / b m	x N / l m ÿ / 2 ÿ ÿÿ ÿ y l ÿ / b 2 ÿ ÿ ÿ ÿ 1 ÿ ÿ ÿ ÿ ÿ ÿ 4 l tan ÿ ÿ approximately for straight leading edge l ÿ / m

B.3 Influence of important design parameters



Wing: floor plan parameters

Description	General	Trapezoidal wings	Double trapezoidal wing
Leading edge sweep		tan ÿÿ ÿ ÿ ÿ ÿ tan ÿ 25 ÿ (1ÿ ÿ) / (ÿ ÿÿ 1ÿ ÿ ÿ)	tanÿ ÿ ÿ ÿ ÿ tan ÿ 25 ÿ (1ÿ ÿ) / (ÿ ÿÿ1ÿ ÿ ÿ) approximately for straight leading edge
Centerline arrow		tan ÿÿ ÿ ÿ ÿ ÿ tan ÿ 25 ÿ (1ÿ ÿ) / (ÿÿÿ 1ÿ ÿ ÿ)	tanÿ ÿ ÿ0ÿ ÿ tanÿ 25 ÿ (1ÿ ÿ) / (ÿÿÿ 1ÿ ÿ ÿ) approximately for straight leading edge
General. Swash conversion		tan ÿÿ ÿ ÿ ÿ ÿ tan ÿ ÿn (4x / ÿ) ÿÿ (ÿ / ÿÿ I ÿm) ÿ ÿ (ÿ x ÿ / ÿ I ÿn ÿ) ÿ (1ÿ ÿ / 1ÿ ÿ)	
Linear geometric twist distribution	ÿlin ÿÿÿ ÿ ÿtip ÿÿ		
Progressive torsion distribution	ÿ ÿ ÿ ÿot ÿ ÿtip ÿ (ÿ ÿÿ) / (1 (ÿ ÿ ÿ ÿÿ))		

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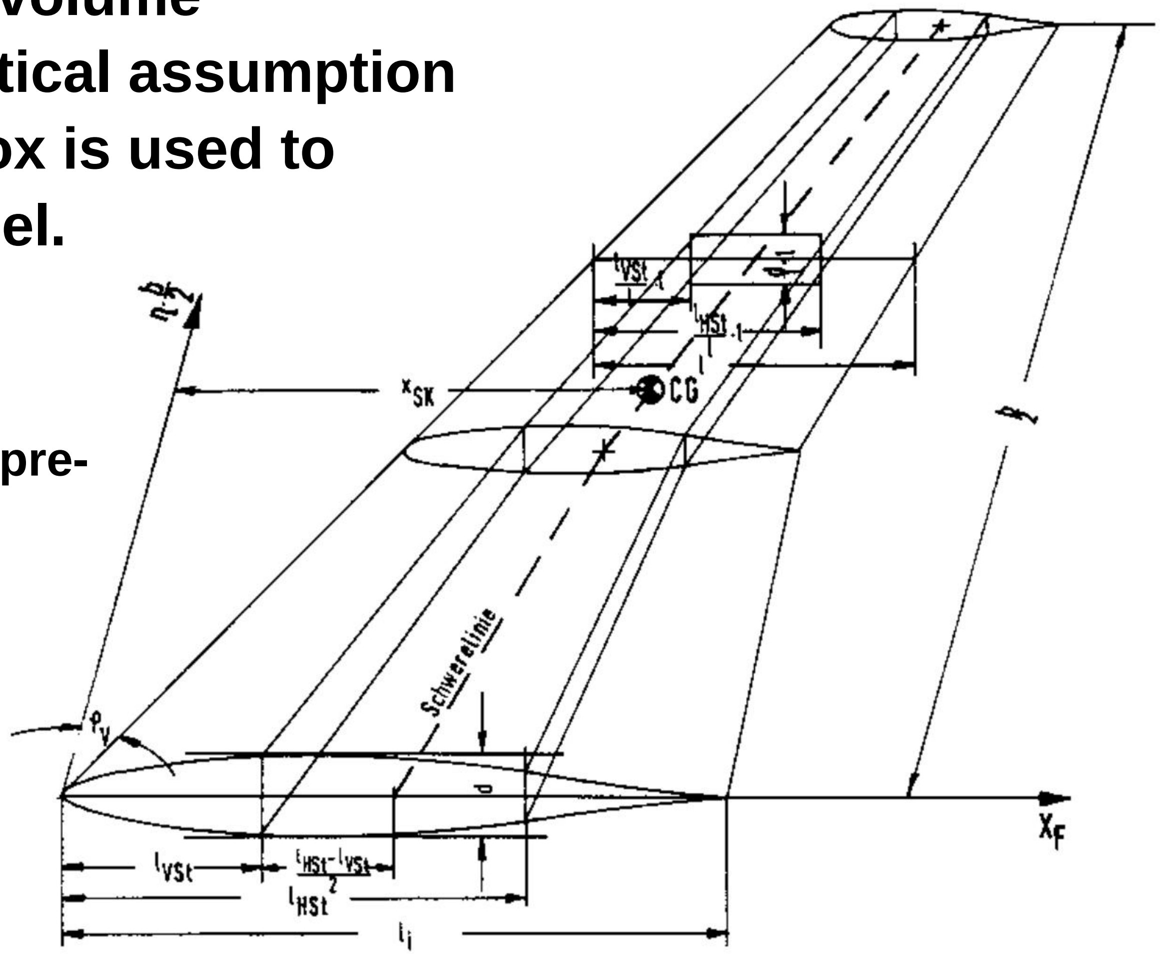
B.3 Influence of important design parameters

Wing: Tank volume

- **Determining the tank volume is based on the practical assumption that only the wing box is used to accommodate the fuel.**

- **If this is done for the entire span, one can use pre-estimated, dimensionless, lateral positions of the front and rear webs to determine the Determine box volume.**



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B.3 Influence of important design parameters

Wing : Tank volume

• The box volume is generally

$$V_K \, 2 \text{ ÿ ÿ } F \, dy \int_0^{b/2} \text{ÿ ÿ} \text{ÿ}_K$$

• If we assume an approximately rectangular wing box, its cross-sectional area is:

$$F_K \text{ ÿ ÿ ÿ ÿ ÿ } l_{HSt} \text{ ÿ ÿ } l_{VSt} \text{ ÿ } d \text{ ÿ} \frac{l_{HSt}}{l} \frac{l_{VSt}}{l} \text{ ÿ ÿÿ ÿ ÿ ÿ } d \text{ÿ} \frac{}{\text{ÿ} \, l \, \text{ÿ}_m} \text{ ÿ } l^2 \text{ ÿ ÿ ÿ}$$

• With dimensionless span coordinates, depth profiles and assuming a constant relative profile thickness, the following applies to the wing with general depth profile:

$$V_K \, b \text{ ÿ ÿ } F \, d \int_0^1 F \, l_K \text{ ÿ ÿ ÿ ÿ } m \, \frac{\text{ÿ}_d \text{ ÿ}}{\text{ÿ ÿ ÿ } l \, \text{ÿ}_m} \, \text{ÿ} \frac{l_{HSt}}{l} \frac{l_{VSt}}{l} \text{ ÿ ÿÿ ÿ } \int_0^1 \text{ÿ} \frac{l}{l_m} \text{ ÿ}^2 \text{ ÿ ÿ } d \text{ÿ}$$

B.3 Influence of important design parameters

Wing: Tank volume

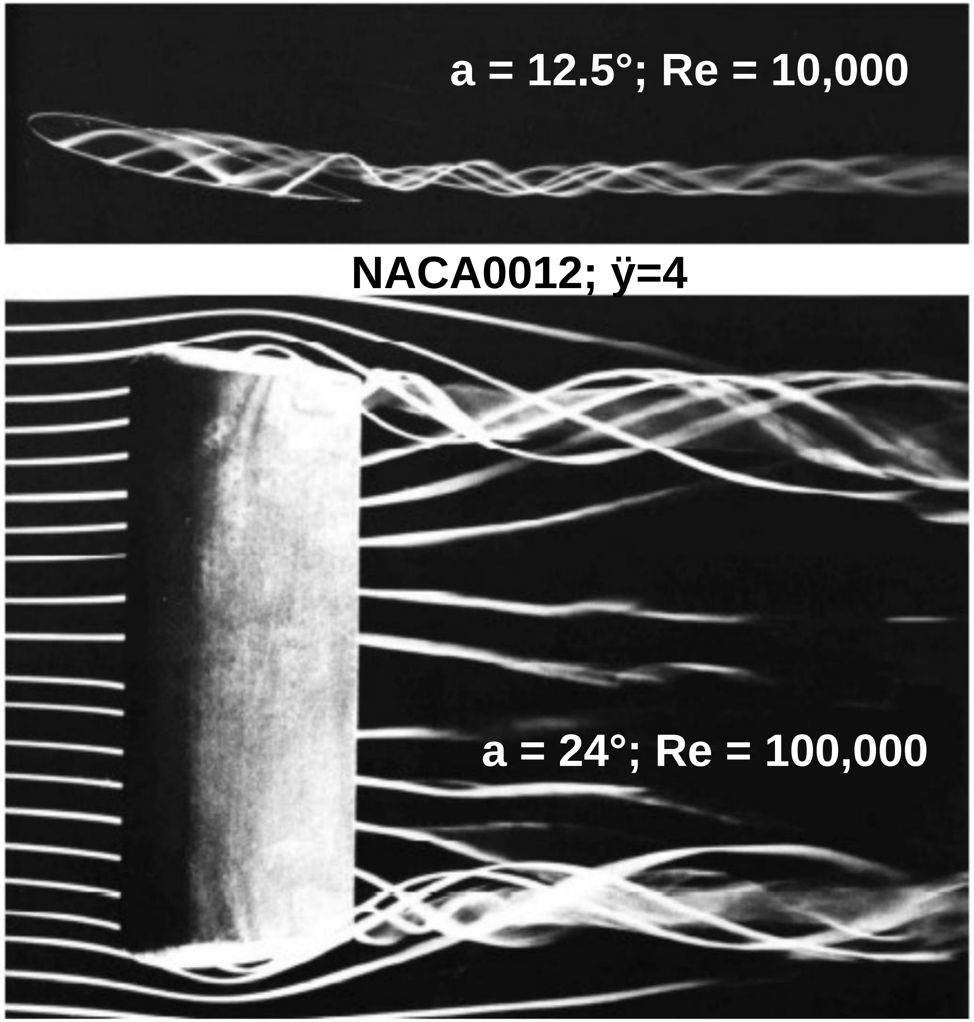
- A reduction factor of 0.8 – 0.9 for the internal structure, the mean deviation of the geometry parameters and the vent tank should be applied to reliably estimate the usable fuel volume.

B.3 Influence of important design parameters

Wing: lift distribution

• The infinite wing or a wing clamped between wind tunnel walls shows parallel streamlines when flowing around it and only curved in the vertical direction. • The visualization of the flow around a wing with a low aspect ratio shows the phenomenon of “finiteness” particularly clearly.

good.



B.3 Influence of important design parameters

Wing: : Lift distribution

Interpretation of the streamline image

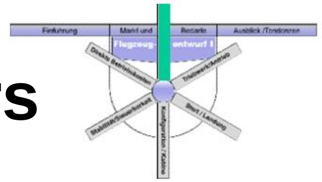
Generation of buoyancy

- The demonstrated experiment of the circulator (Flettner rotor) proves an equivalence of lift and circulation. • The

superposition of a translational and a rotational flow leads to flow deflection, the associated change in momentum to lift.

- The circulation must be large enough to meet the outflow condition at the trailing edge. Without friction, there is therefore no lift. Since the circulation must be maintained, the vortex bound in the wing changes into a horseshoe-shaped free vortex at its edge.

B.3 Influence of important design parameters

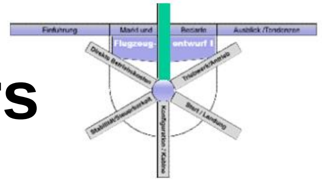


Wing: : Lift distribution

Formation of induced resistance

- **Due to the pressure equalization between the bottom and top A 3-dimensional flow around the wing tip takes place.**
- **The flow is directed towards the wing root on the upper side and deflected outwards on the underside.**
- **This difference in direction creates at the trailing edge of the wing a separation surface that rolls up downstream and merges into two independent, free, conically expanding vortex braids.**

B.3 Influence of important design parameters



Wing: : Lift distribution

Formation of induced resistance

- Energy is required to form and maintain these vortices because the air must be accelerated translationally and rotationally.

- Even with frictionless flow, work must be which is necessary to generate lift on a finite wing.

- The equivalent of this work is the induced resistance.

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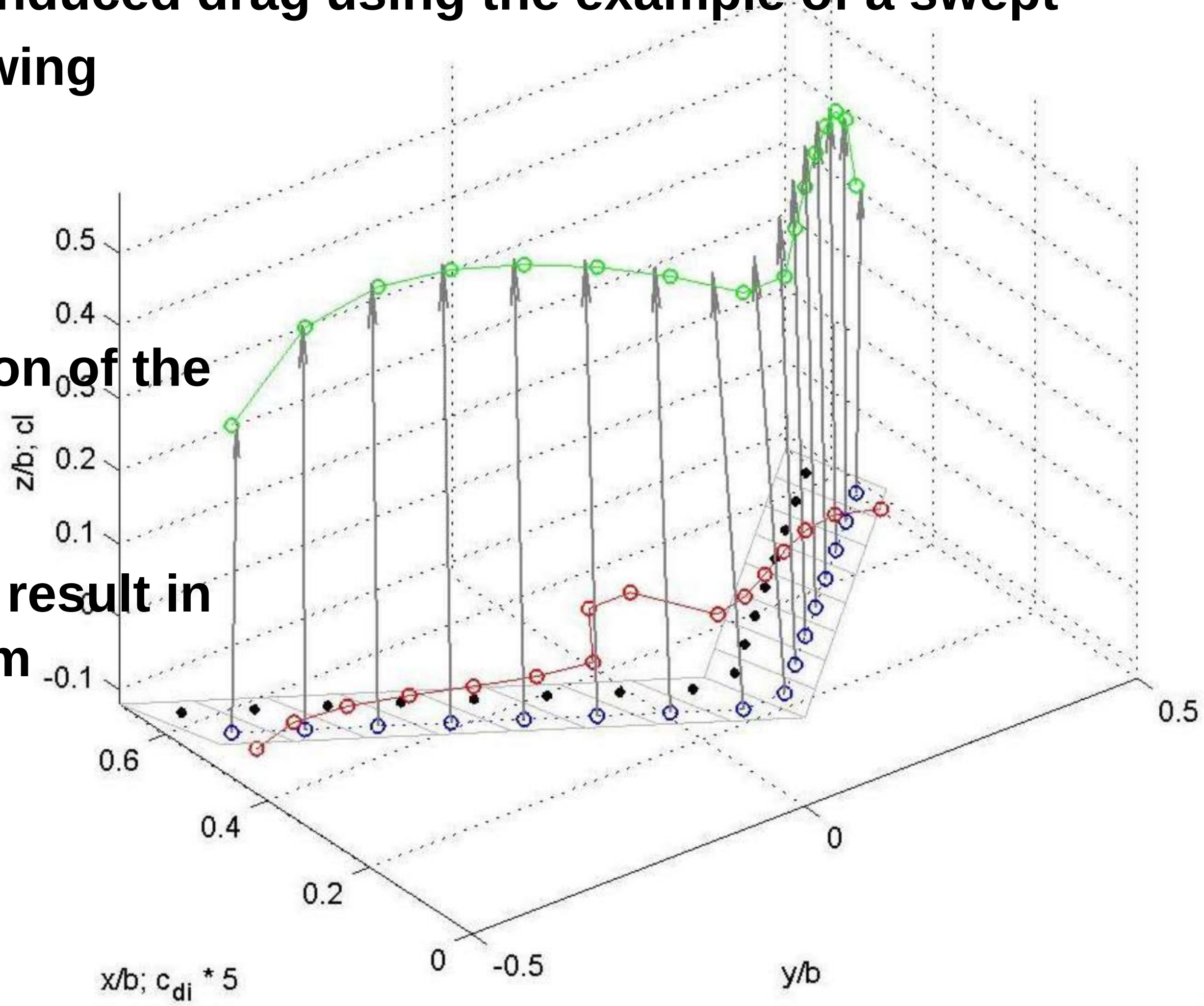
B.3 Influence of important design parameters

Wing: lift distribution & induced drag

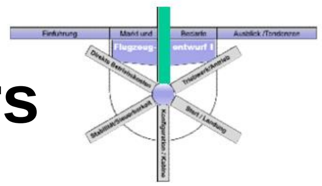
- **Formation of induced drag using the example of a swept rectangular wing**

- **Also one**

Summarization of the horizontal Force components result in a downstream directed Strength, the Induced Resistance!



B.3 Influence of important design parameters



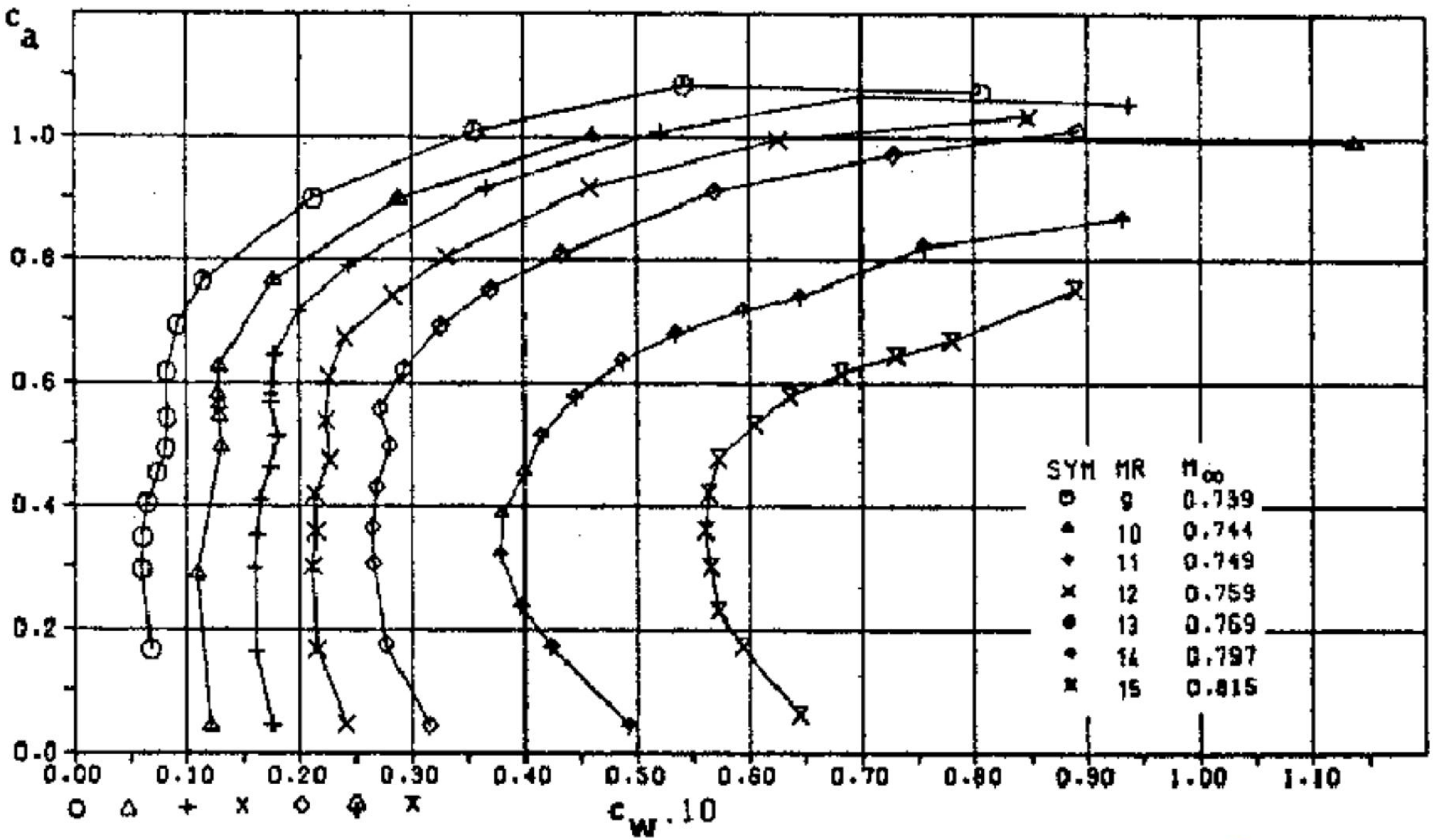
Wing: Resistance

- **The resistance of the wing consists of four parts together:**
  - Frictional resistance
  - (friction-dependent) pressure resistance
  - Wave impedance
  - Induced resistance

- **To determine the friction component, a sufficiently accurate and inexpensive method can be used using the theory of the longitudinally flowing, flat plate.**

B.3 Influence of important design parameters Wing: Profile drag Example:

Profile VA2, d/l = 13% // Wave drag

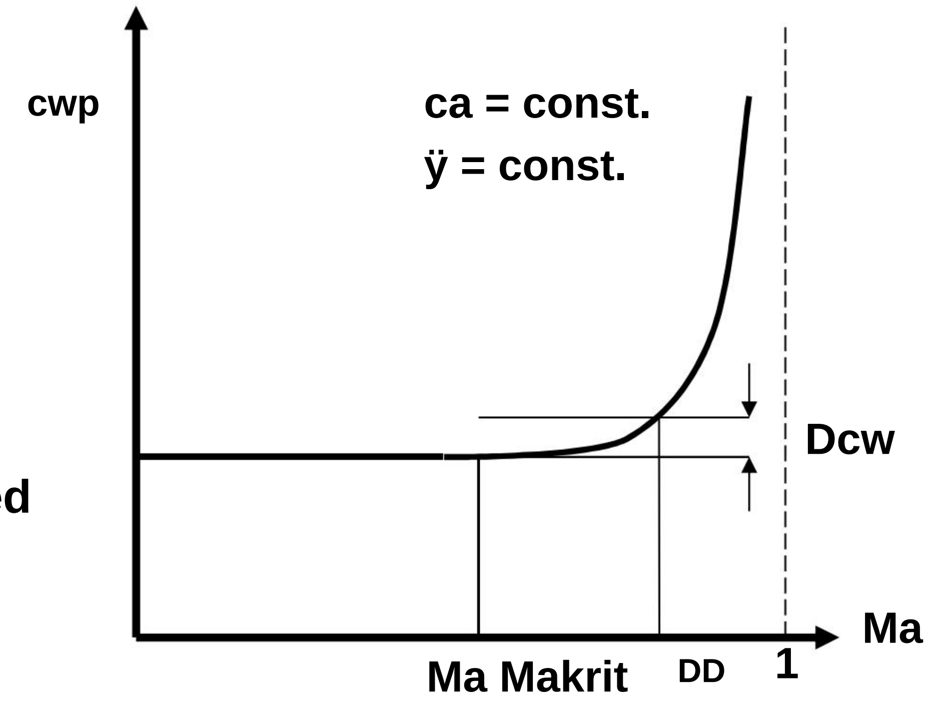


B.3 Influence of important design parameters

Wing: Resistance

- The compressible polar also contains the wave impedance and can be obtained either directly from measured polars (see above) or by means of assumptions for the resistance increase.

- Exponential functions that satisfy the drag-rise point (MaDD) with the defined drag increase (e.g. Dcw = 0.002) and at the same time the point of the critical Mach number (Makrit) can be used with good success in the transonic range.



Luftfahrzeugbau und Leichtbau

B.3 Influence of important design parameters

Wing: Resistance

• In order to arrive at the total drag, the induced drag must finally be determined. • A bi-polynomial approach for the lift

coefficient cA and the wing twist ÿt that is suitable for aspect ratios > 4 **and which largely takes the wing's planar parameters into account is:**

c W 2 i ÿ ÿ c $\frac{c_A^2}{ÿÿÿ}$ ÿ ÿ ccc ÿ ÿ ÿ 1 t A 0 t 2

with

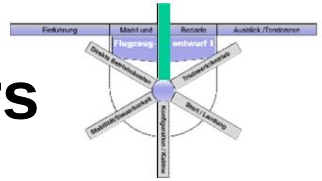
c 2 ÿ $\frac{1 5 ÿ ÿ 0 \quad 6 \quad ÿ ÿ 25 \quad 3}{ÿ}$

and

c 1 ÿ 0.0134 ÿ ÿ ÿ ÿ 0.3 ÿ ÿ 0.0037 ÿ ÿ ÿ ÿ A c ÿ 2

as well as

c ÿ 0 c ÿ ÿ 0.0088 ÿ ÿ ÿ 0.0051 ÿ ÿ ÿ 1 ÿ 6 ÿ 10 ÿ ÿ ÿ 2 A ÿ 2 ÿ ÿ 4 2 ÿ



B.3 Influence of important design parameters

Wing: Influence of aspect ratio

- With a constant area, the height of a wing is increasing stretching smaller.
- This leads to an increase in weight.
- In addition, the tank volume of the wing box decreases, which can lead to range problems.

B.3 Influence of important design parameters

Wing: Influence of aspect ratio

- **The wing with a large aspect ratio is much more efficient in generating lift, as it requires a smaller geometric angle of attack than the wing with a low aspect ratio to generate the same**

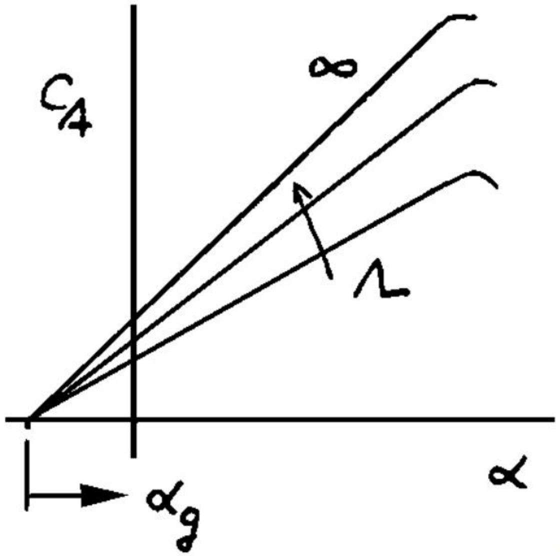
lift. • The influence of the aspect ratio on the lift gradient for the wing with elliptical lift distribution can be derived directly from the airfoil theory, as the potential theory yields:

$$c_A^{\text{ÿ}} \text{ ÿ } \frac{dc_A}{d a} \text{ ÿ } \frac{c_a^{\text{ÿ}}}{1 \text{ ÿ } \frac{c_a^{\text{ÿ}}}{\text{ÿÿÿ}}}$$

For $c_a^{\text{ÿ}}$ 2 ÿ ÿÿ and for ÿ ÿ ÿ

$$c_A^{\text{ÿ}} \text{ ÿ } \frac{2 \text{ ÿÿ}}{1 \text{ ÿ } \frac{2\,1}{\text{ÿ}}} \text{ ÿ } \frac{\text{ÿ}}{\frac{}{2} \text{ ÿ } \frac{1}{\text{ÿ}}}$$

$$c c_A^{\text{ÿ}} a^{\text{ÿ}} \quad \text{ÿ}$$



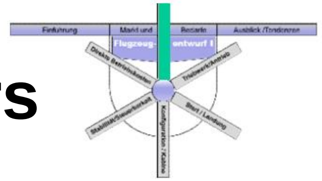
B.3 Influence of important design parameters

Wing: Influence of aspect ratio

- For the real wing, lower values are measured than those described in theory, since an elliptical lift distribution can only be realized with an elliptical floor plan and is not achieved with the usual rectangular, trapezoidal or double trapezoidal wing floor plans.

- Therefore, the so-called outline factor ÿ is introduced to take this effect into account and one can use it for the Write lift increase

$$c_A^{\text{ÿ}} \text{ ÿ } \frac{dc_A}{d\,a} \text{ ÿ } \frac{c_a^{\text{ÿ}}}{1 \text{ ÿ } \frac{c_a^{\text{ÿ}}}{\text{ÿÿÿÿ ÿ}}}$$



B.3 Influence of important design parameters

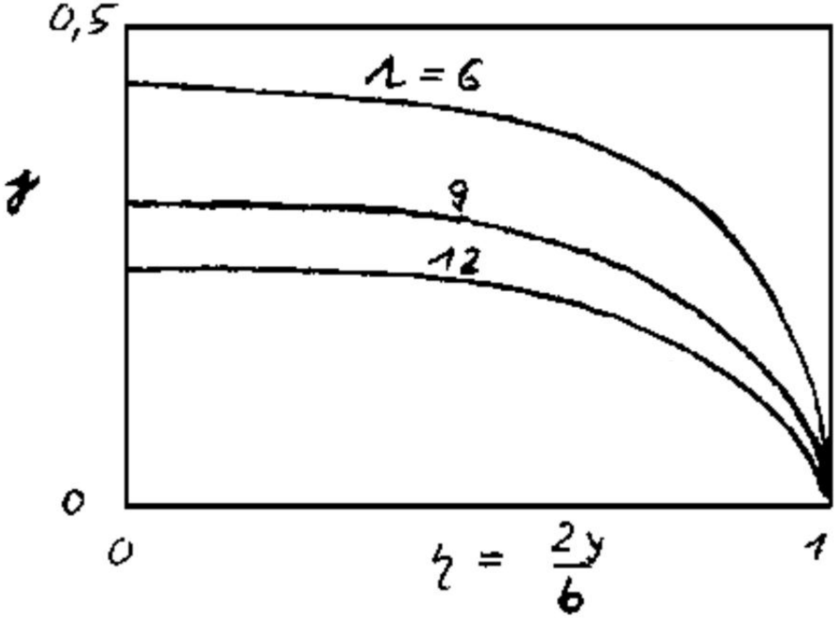
Wing: Influence of aspect ratio

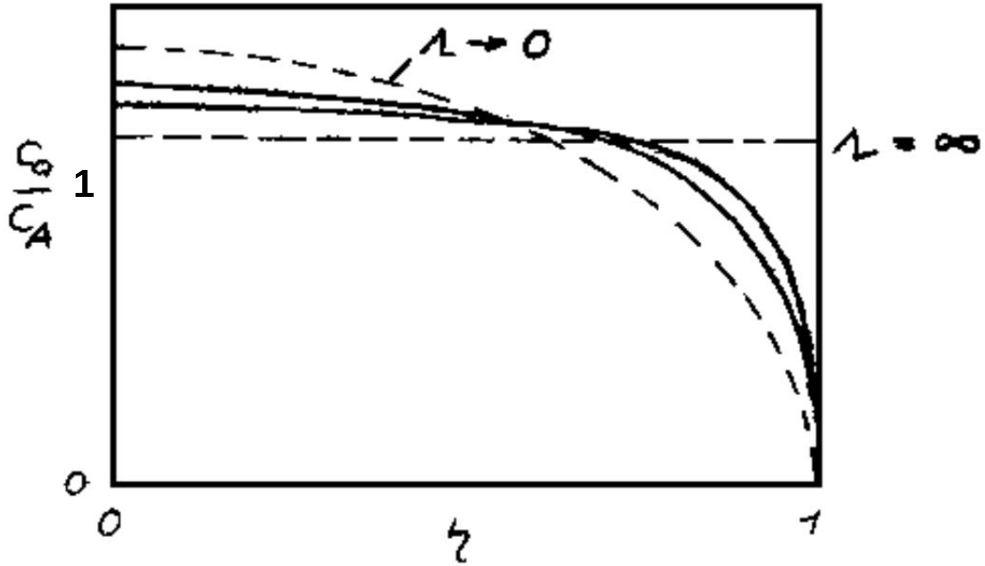
- With increasing stretch
  - the gust sensitivity of the wing increases, as a Increase in angle of attack leads to increasing lift and
  - the change in angle of attack with flight speed becomes smaller, which leads to more demanding landing characteristics.
- However, the lower bending stiffness of a highly stretched wing reduces the effects of gust sensitivity noticeable, which has a positive effect on gliders.

B.3 Influence of important design parameters

Wing: Influence of aspect ratio

- **Influence of aspect ratio on the circulation (g) and lift (ca /cA) coefficient distribution of an unswept rectangular wing**

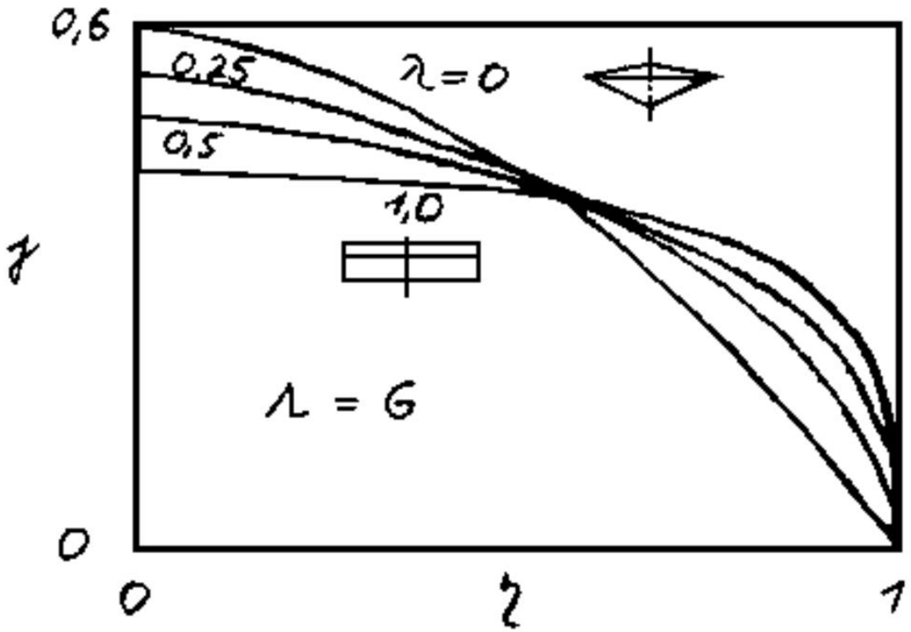


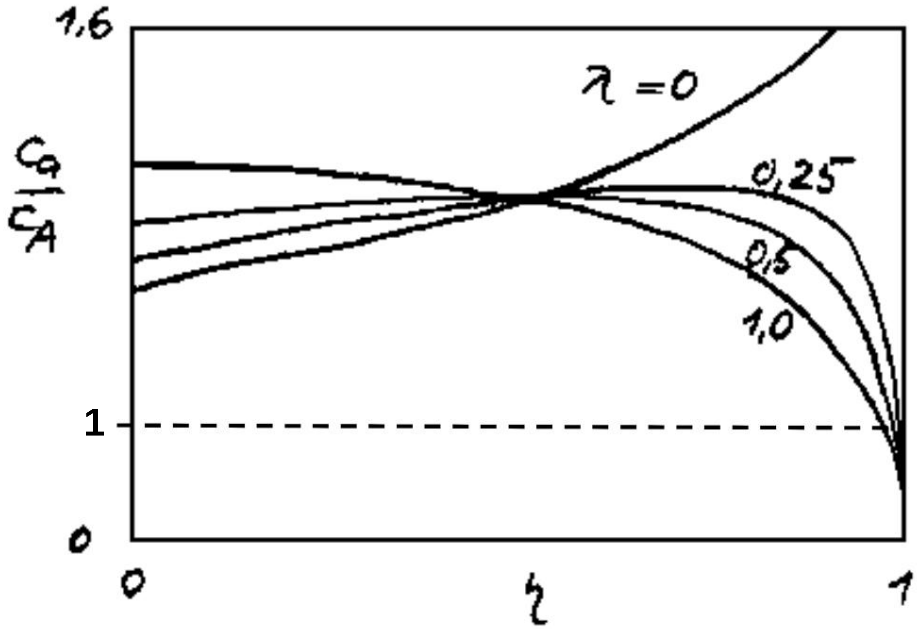


B.3 Influence of important design parameters

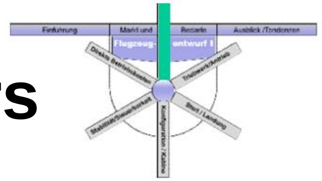
Wings: Influence of the tapering

- **The acuity ÿ is another important measure for the Description of the floor plan.**
- **It is 1 for rectangular wings and 0 for delta wings with vanishing external depth.**





B.3 Influence of important design parameters



Wings: Influence of the tapering

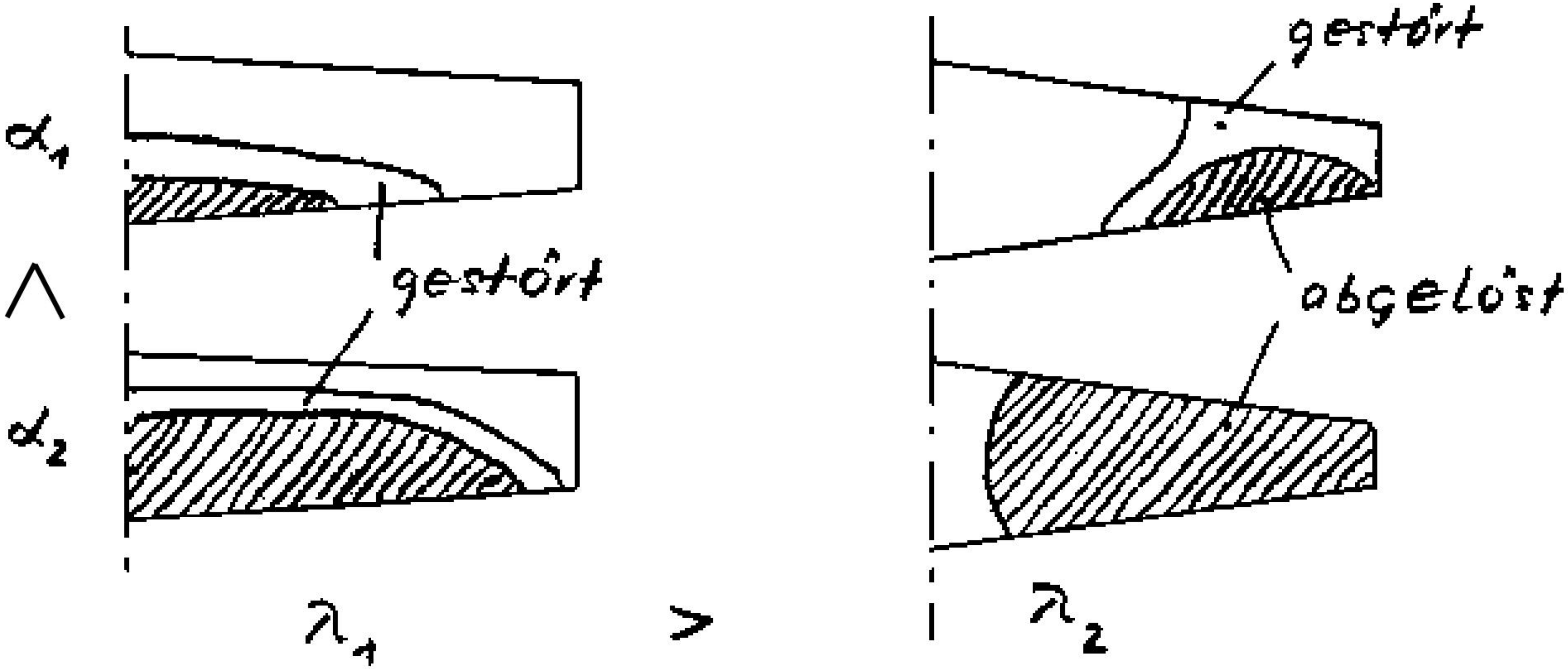
- **Since the local lift coefficient is inversely proportional to the local wing depth, a small taper leads to large lift coefficients in the outer region of the wing.**

- **An optimum can only be determined in conjunction with the other geometry parameters, in particular the sweep and the twist.**

- **Typical values are 0.3 to 0.4 for unswept wings and 0.25 to 0.35 for swept wings.**

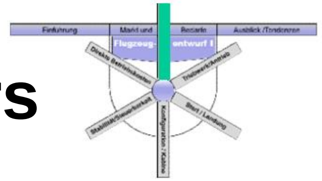
B.3 Influence of important design parameters Wing: Influence of tapering

- **Influence of tapering on stall behavior**



B.3 Influence of important design parameters

Wings: Influence of the tapering



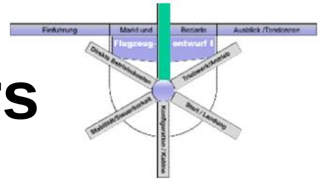
- While the wing with a low taper causes flow separation at the wing root, the strongly pointed wing in the critical outer area detaches first.

- This is not desirable because the only control element for controlling the rotation around the longitudinal axis, the aileron, becomes ineffective in slow flight and at the same time large, uncontrollable moments occur due to the highly unsteady nature of this separation.

- The residual lift (approximately non-hatched area) is on the wing ringer tapering is significantly larger, ie the maximum lift is greater.

- The behaviour of the wing in the high angle of attack range is strongly dependent on the taper, because the onset of boundary layer separation depends on the achievement of the local maximum lift.

B.3 Influence of important design parameters



Wing: Influence of sweep

- Aircraft that operate in the high subsonic range usually have a swept-back wing. • A swept-back wing has structural disadvantages

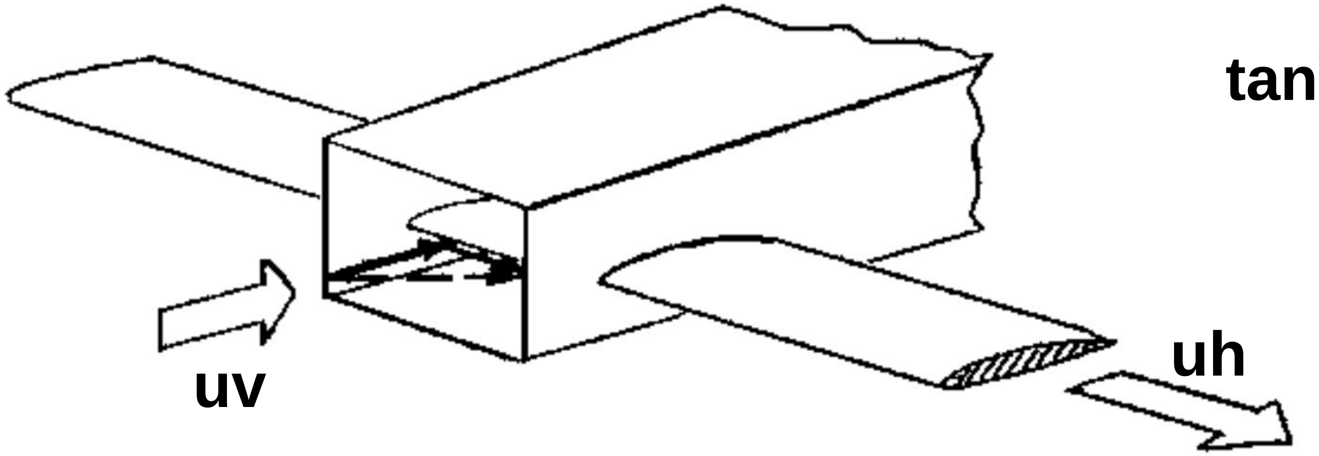
because of the torsion of the wing box, which acts in addition to the profile moment and in the same nose-heavy direction.

- This causes an increase in weight, which only occurs with expected advantages in aerodynamic behavior.

- The sweep actually causes a shift in the critical Mach number to higher values and thus a corresponding shift in the buffet onset and drag divergence Mach numbers. This makes economical cruising at high altitudes possible.

B.3 Influence of important design parameters

Wing: Influence of sweep



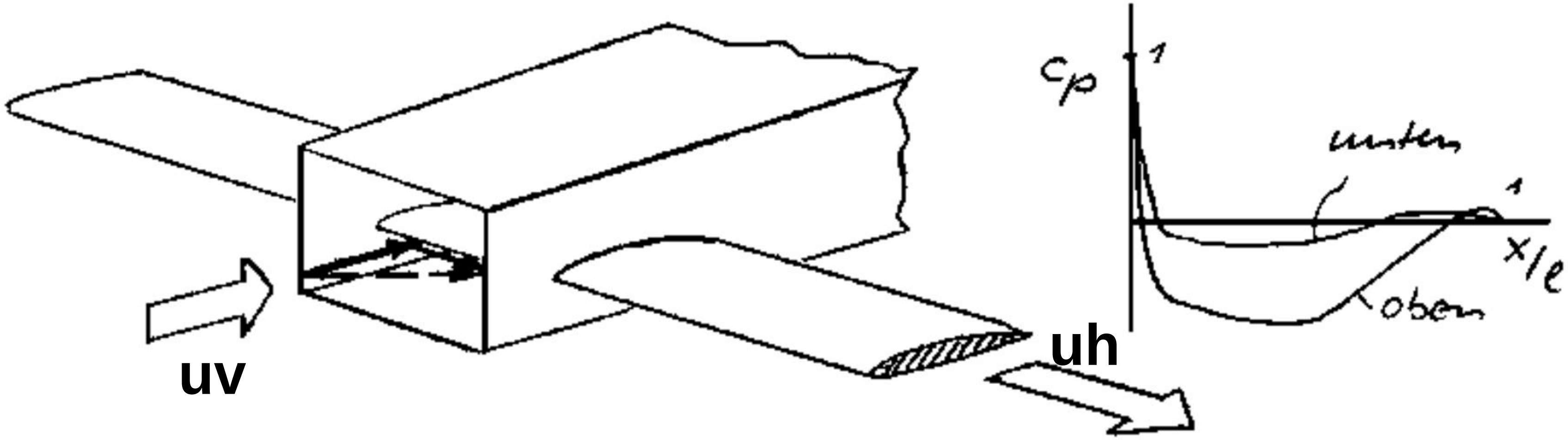
tanÿÿÿ $\frac{u_H}{u_v}$

- If an infinitely long wing is pushed longitudinally through a running wind tunnel at a certain speed, the vectorial flow velocity increases and the flow direction rotates by the virtual sweep angle ÿ.

- uv is the speed component perpendicular to the wing leading edge (here the channel speed) and uh is the sliding speed.

B.3 Influence of important design parameters

Wing: Influence of sweep



- The resulting higher speed does not change the Pressure distribution of the sliding or swept wing:

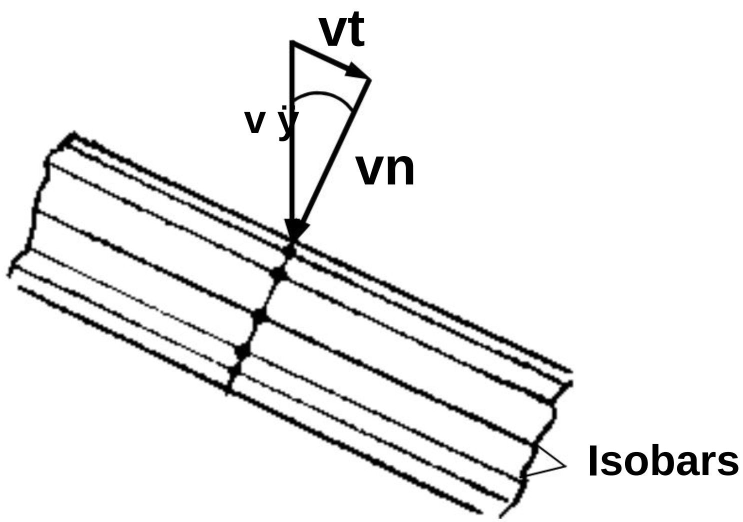
$$u \text{ ÿ } \frac{u_v}{\cos \text{ÿ ÿ ÿ}}$$

- Only the boundary layer with the wing movement.

B.3 Influence of important design parameters

Wing: Influence of sweep

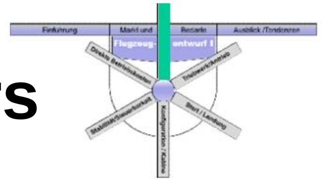
- **This means that a swept wing has higher critical Mach numbers by the reciprocal cosine of the sweep angle for the same critical Mach number of the profile, since only the vertical**



Speed share for the Pressure distribution becomes effective, and therefore:

$$Ma_{kr} \text{ ÿ } \frac{Ma_{kr_{\text{ÿÿ}\,0}}}{\cos_{\text{ÿ ÿ ÿ}}}$$

- **This fact also means that while the structural thickness of the wing remains the same, the aerodynamic thickness decreases due to the sweep.**



B.3 Influence of important design parameters

Wing: Influence of sweep

- This effect not only affects the critical Mach number, but also the associated limiting Mach numbers (buffet onset, drag divergence, lift divergence) as well as the lift increase and the profile drag.

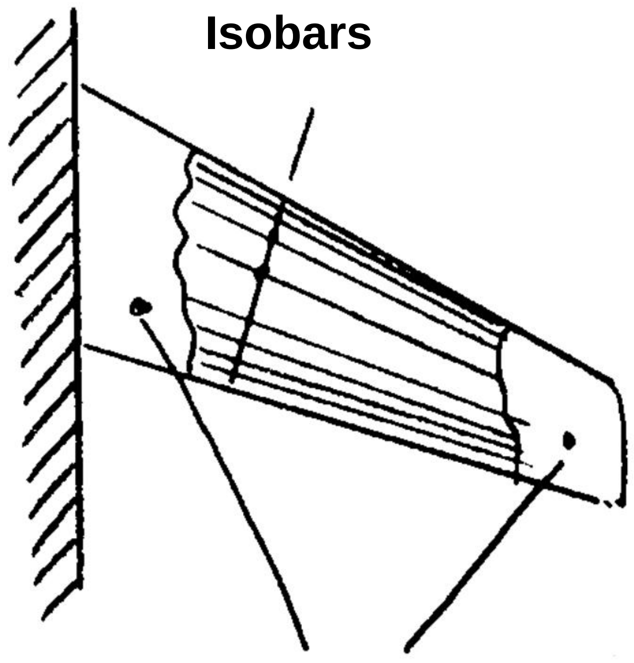
- The sweep can therefore be used to increase the critical Mach numbers and all limiting Mach numbers based on them.

B.3 Influence of important design parameters

Wing: Influence of sweep

- This consideration assumes that the isobars are parallel across the wingspan, so that no 3-dimensional effects (e.g. edge influence) occur.

- In practice, this is not to be expected for a tapered, finite wing, since fuselage, engine nacelle, boundary layer and edge effects come into play.



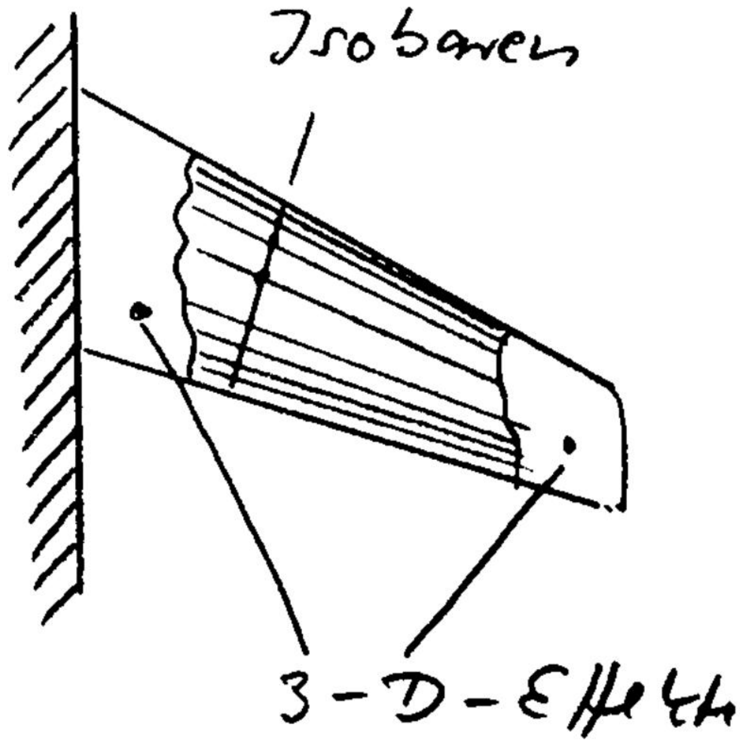
- The span range with pronounced parallel isobar progression is usually limited.

B.3 Influence of important design parameters

Wing: Influence of sweep

- Measurements have shown that for the real wing, the shift in the Mach numbers cannot be determined with sufficient accuracy using the cosine function of the sweep angle, but that a sweep effect cosÿÿÿ

The distortion-reducing √ function leads to more realistic results.



- If the wing plan is well designed, the curvature of the isobars in the fuselage area is kept within limits.

B.3 Influence of important design parameters

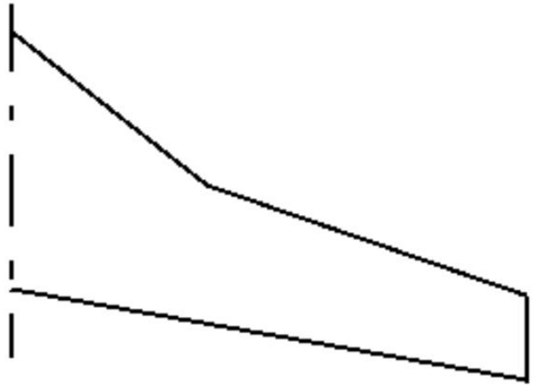
Wing: Influence of sweep

- The task is to use the sweep effect on the shift of the limiting Mach numbers as effectively as possible.

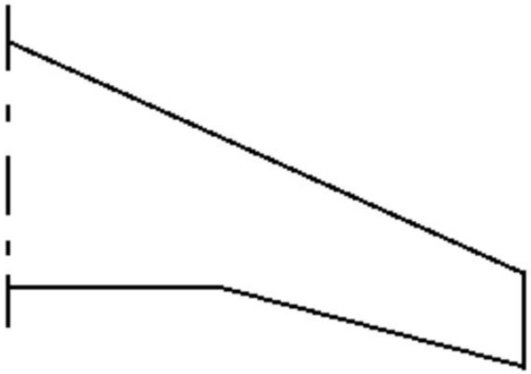
- For the double trapezoidal wing, which here represents the general wing plan, the question arises as to the sweep distribution over the span.

- The following variants are possible in borderline cases:

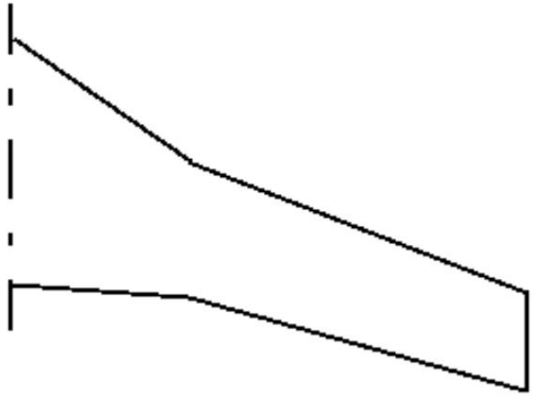
Straight trailing edge

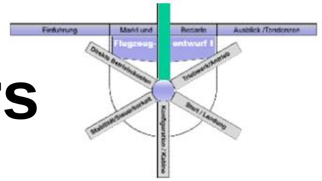


Straight leading edge



Straight quarter point line





B.3 Influence of important design parameters

Wing: Influence of sweep

- The results of 3-dimensional flow analyses determine which configuration will produce the best results. In any case, a kink in the leading or trailing edge will result in increased construction costs, as the corresponding high-lift aids will also have to be interrupted at this point.

- Another aspect concerns the accommodation of the Landing gear on the wing. Since there must be sufficient height behind the wing box for this, today's double trapezoid wings on commercial aircraft are always equipped with a straight leading edge. For this reason, the relative profile thickness is also often increased in the root area.

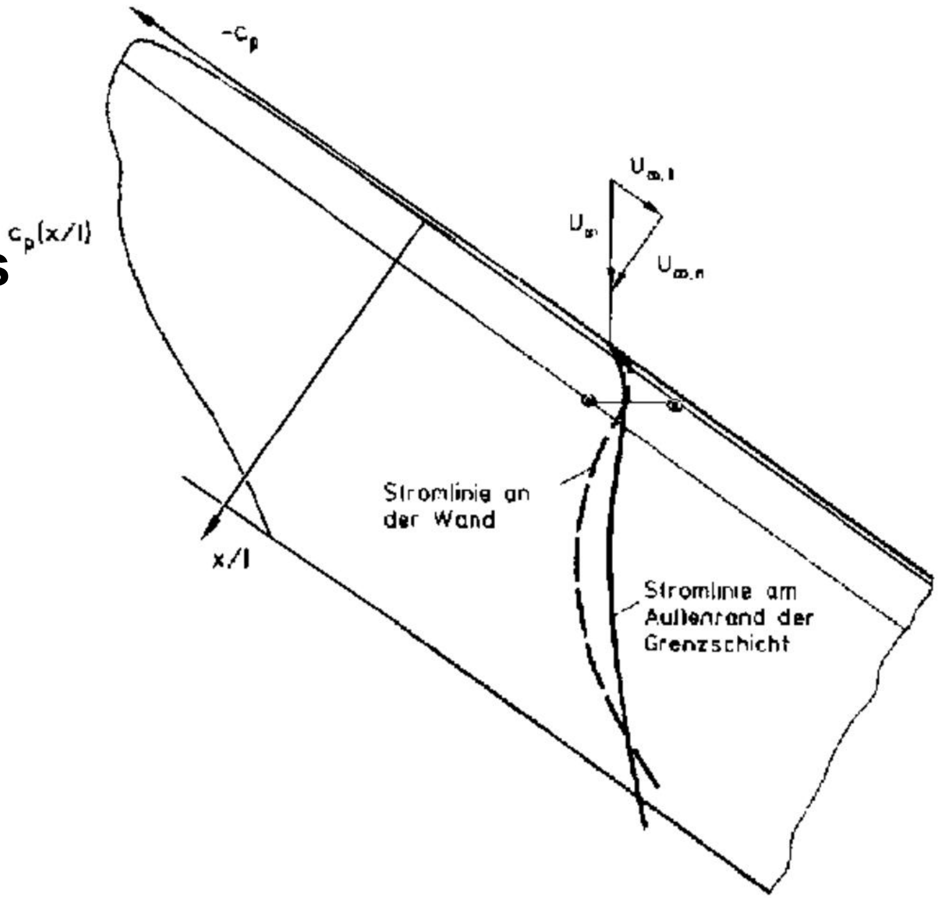
- With “body mounted gears” this aspect is not relevant and therefore these aircraft are usually fitted with shoulder-wing configurations with the aerodynamically better and structurally less complex single trapeze variant.

B.3 Influence of important design parameters

Wing: Influence of sweep

"Out Wash"

- **The arrowed isobar curve basically leads to the effect that the streamlines are deflected.**
- **In the area of pressure drop, the positively swept The streamline is initially bent inwards in the wing before it runs outwards again in the subsequent region of pressure increase.**



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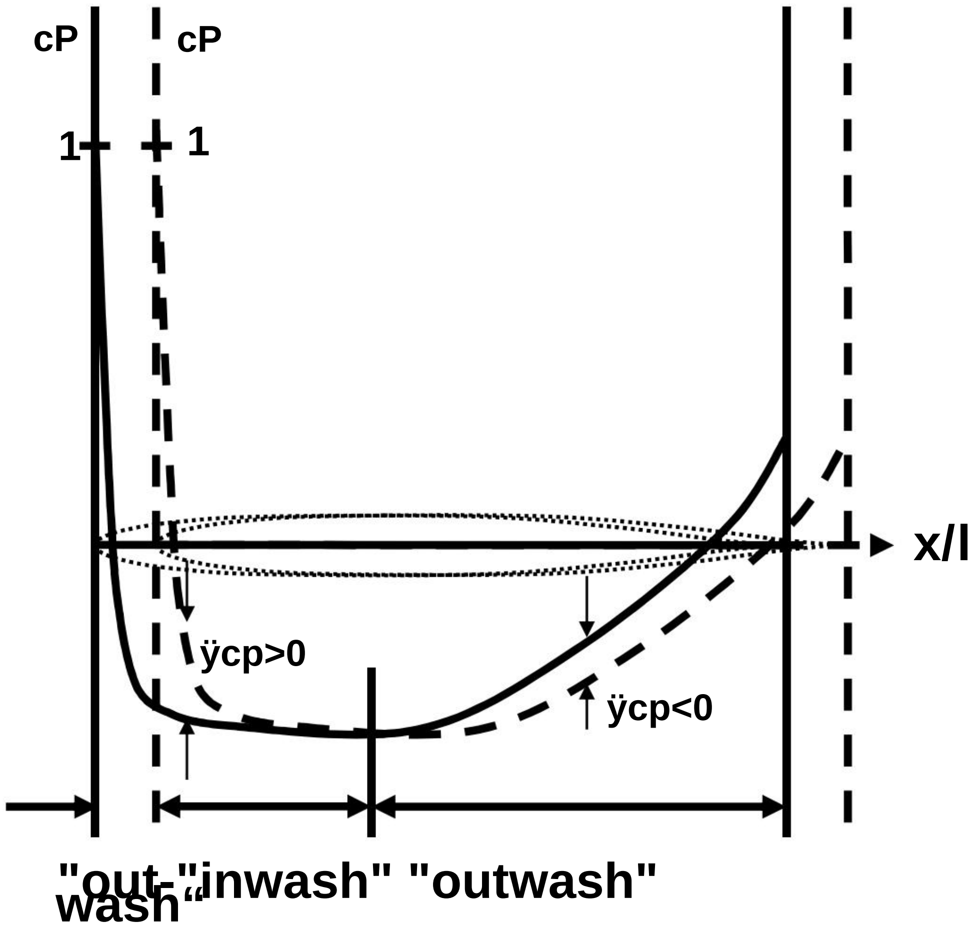
B.3 Influence of important design parameters

Wing: Influence of sweep

- This effect arises from the fact that in the pressure drop area the respective neighboring location in the span direction has a slightly higher pressure towards the outside.

- The effect is more pronounced in the area close to the wall than outside the boundary layer, since there the mass inertia forces are smaller in relation to the pressure forces.

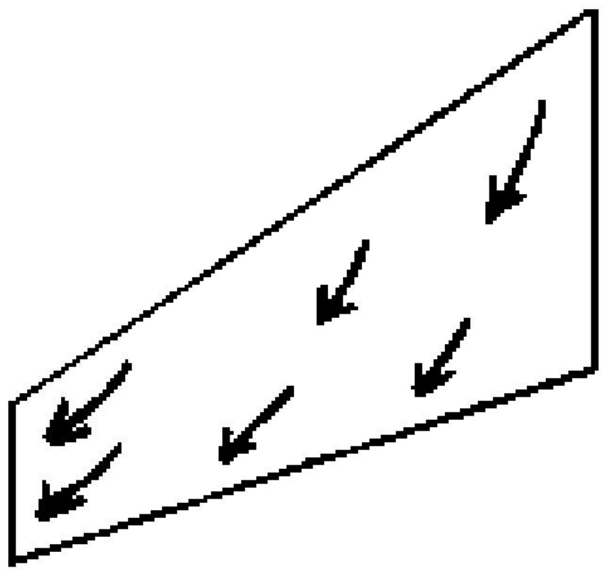


Luftfahrzeugbau und Leichtbau

B.3 Influence of important design parameters

Wing: Influence of sweep

- This effect, known as "out-wash", leads to a tendency for the flow to be deflected towards the wing tip.
- Since this effect is associated with a thickening of the boundary layer in the direction of deflection, an increased risk of separation on the outer wing is to be feared.



B.3 Influence of important design parameters

Wing: Influence of sweep

- Boundary layer fences, vertical sheets aligned around the profile nose in the direction of flow, which prevent outward flow.

- The same applies to a swept wing for the deflection of the streamlines towards the fuselage.

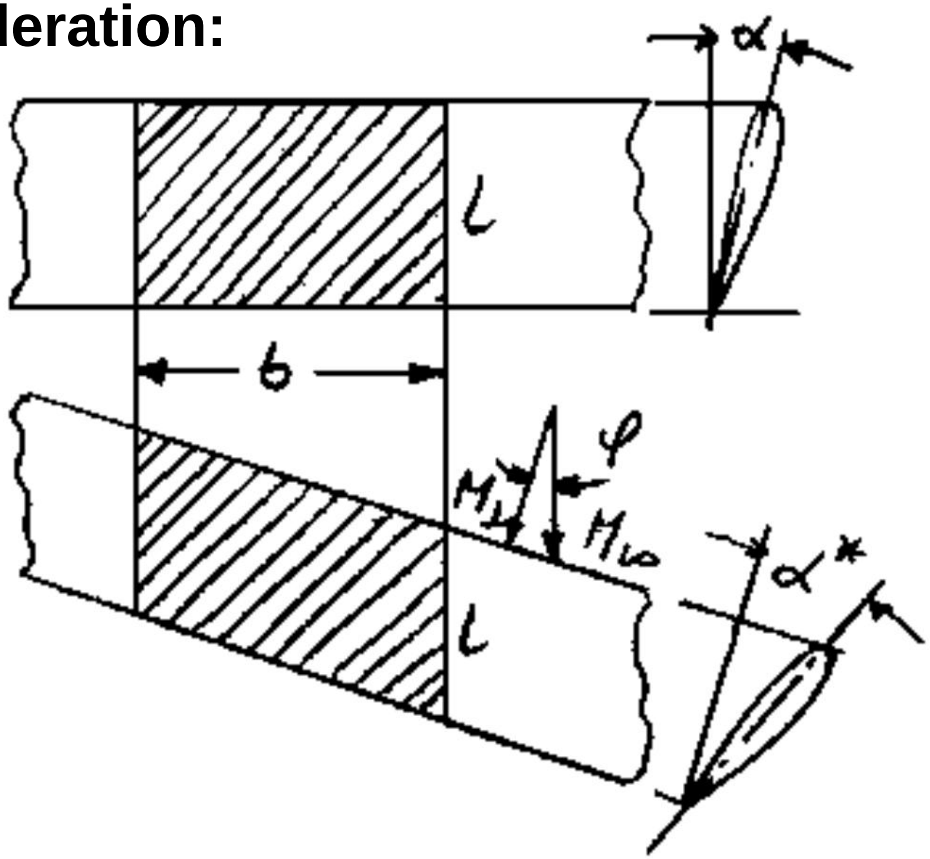
- The following picture shows such an aerodynamic Measure using the example of the Aerospatiale Caravelle:

B.3 Influence of important design parameters

Wing: Influence of sweep

- The influence of the sweep on the angle of attack, the lift coefficient and the lift increase can be determined using the following consideration:

- The source of the
  Pressure distribution
  decisive, acting perpendicular to the leading edge
  larger a^* is 1/cos(ÿ) angle than the angle of attack to the resulting flow direction



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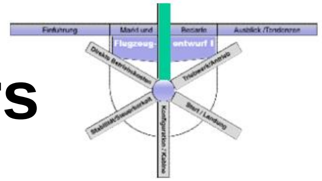


B.3 Influence of important design parameters

Wing: Influence of sweep

- This fact can be used to calculate the buoyancy of the swept wing writing

$$A^{ÿ} \; ÿ \; \frac{ÿ}{2} \cdot ÿ u \cos ÿ \; ÿ \; ÿ \; ÿ \; ÿ \; ÿ \; ÿ^{2} \; F \, c_{A0\,ÿÿ}$$

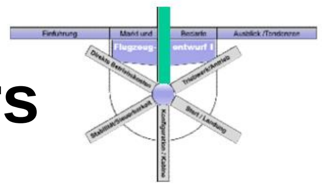
- However, the lift of the unswept wing is

$$A \; c^{ÿÿ}_{A} \; \frac{ÿ}{2} \cdot u^{2} F_{ÿ} \; ÿ$$

- For the same buoyancy (A* = A) the ratio the lift coefficients

$$\frac{A^{ÿ}}{A} \; ÿÿ \; 1 \; \frac{\frac{ÿ}{2} \cdot u^{2}_{ÿ} \cos F c^{2} ÿ ÿ ÿ ÿ ÿ \; / \; ÿ \; A_{ÿÿ0}}{c_{A} \cdot \frac{ÿ}{2} \cdot u^{2}_{ÿ} F \cdot /} \; ÿ \; \frac{c_{A_{ÿÿ0}}}{c_{A}} \cdot \cos^{2} ÿ \; ÿ \; ÿ$$

- and thus $c c^{ÿ}_{AA0} \; ÿÿ \; ÿ \cos^{2} ÿÿÿ$



B.3 Influence of important design parameters

Wing: Influence of sweep

- The unswept profile section must therefore be designed for a lift coefficient that is cos2 (ÿ) larger than the coefficient of the swept, infinitely long rectangular wing.

- Furthermore, the above considerations for the buoyancy increase

$$\frac{\ddot{y} c_A}{\ddot{y} a} \ddot{y} \; \ddot{y}\frac{\ddot{y} c_A}{\ddot{y} a}\ddot{y}_{\ddot{y}\ddot{y}_{\ddot{y}\ddot{y}}\,0} \cos_{\ddot{y}\,\ddot{y}\,\ddot{y}}$$

- The increase in lift therefore decreases with the cosine of the sweep angle, which in practice means, among other things, that the gust sensitivity of a swept wing is much lower than that of a straight wing.

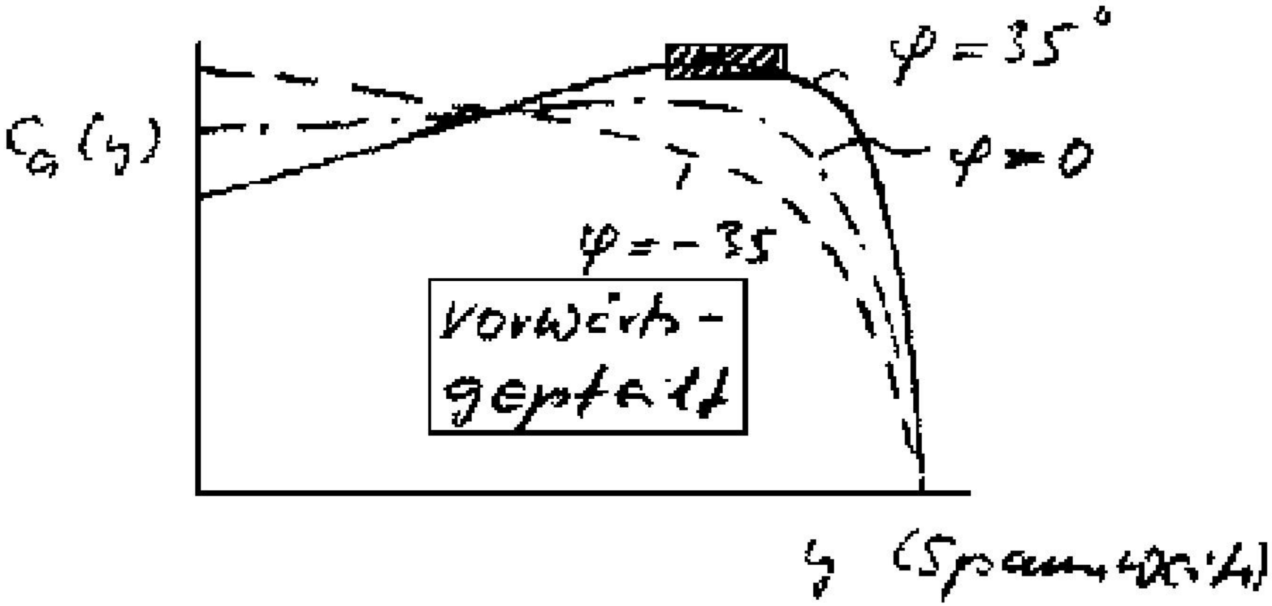
B.3 Influence of important design parameters

Wing: Influence of sweep

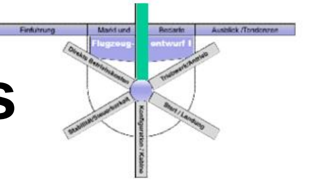
- **An example has already been given above to show the influence of the sweep angle on the lift distribution.**

- **Characteristic here is the increasing return**

The area of maximum lift coefficients is shifted outwards by the sweep.



B.3 Influence of important design parameters



Wing: Influence of sweep

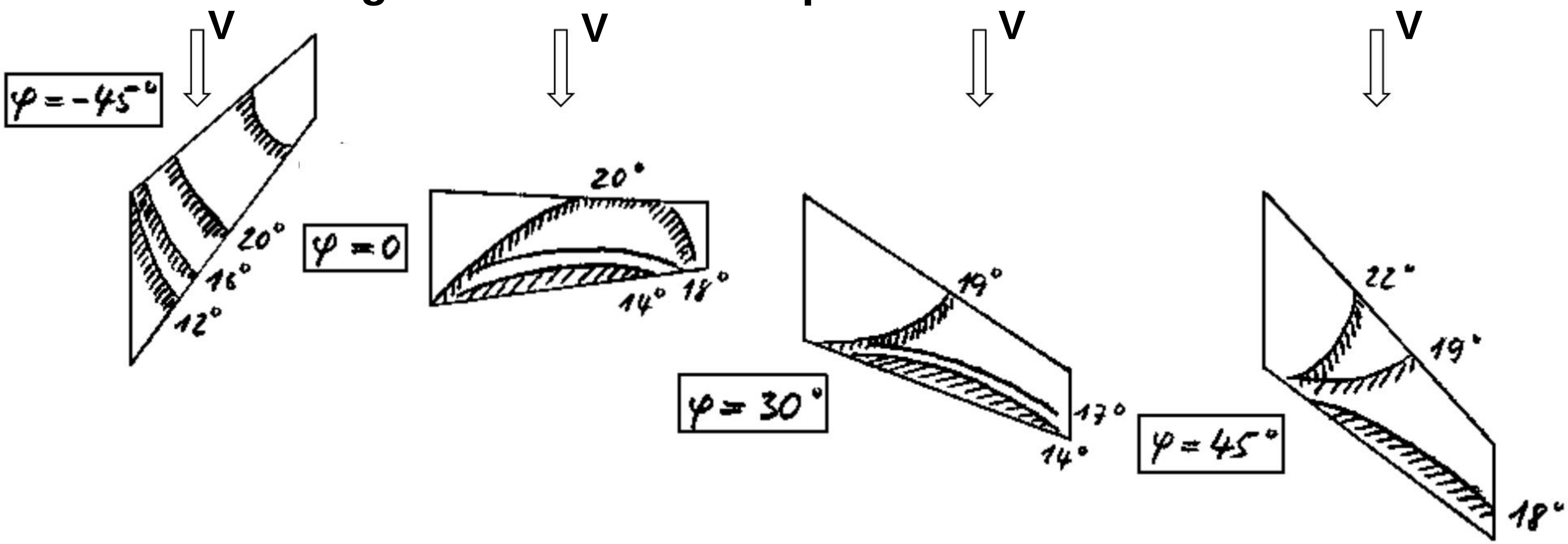
- If you integrate the ca distributions over the span coordinate and divide by the span, you get the total wing lift coefficient cA .

- Comparing the mean values of the above curves, it can be seen that there is a sweep for which the lowest local lift increase and thus the maximum overall lift coefficient is achieved.

- For higher and lower sweep angles this maximum total lift coefficient decreases.

B.3 Influence of important design parameters

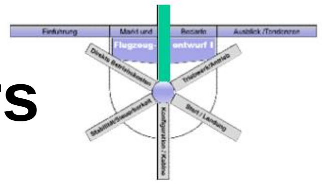
Wing: Influence of sweep



- **As you can see, the swept wing has the Most benevolent behavior: The buoyancy breaks, starting from the Wing root, increasingly outwards and even in the extreme high angle of attack range there remains a sufficient controllability around the longitudinal axis.**

Luftfahrzeugbau und Leichtbau

B.3 Influence of important design parameters



Wing: Influence of sweep

- With an unswept wing, the flow initially tears at the trailing edge in the middle of the wing. The increasing separation extends towards the leading edge and large areas remain inside and outside the wing where the flow still adheres even in the stalled flight condition.

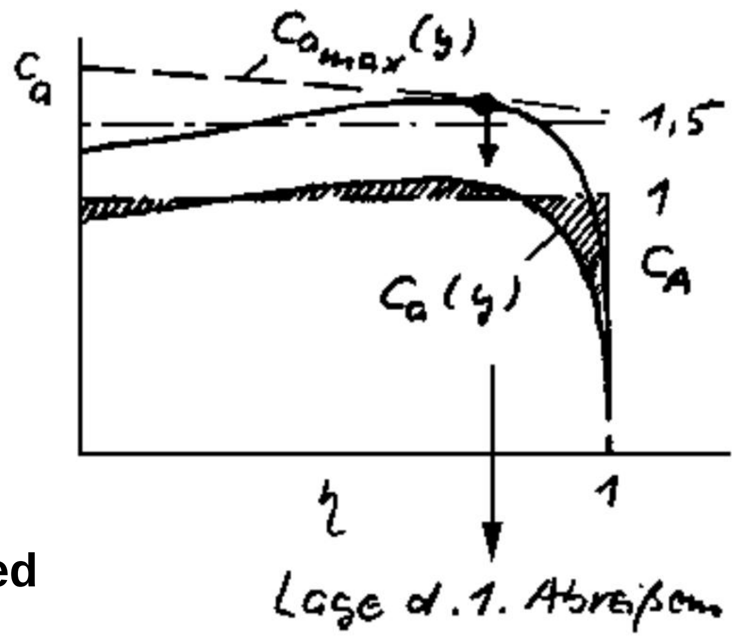
- With increasing sweep, the first separation shifts further and further outwards and the enlargement of the separation area occurs via the outer edge inwards, whereby the controllability is severely impaired already at the beginning of the stall.
The loss of lift in the outer area is also associated with greatly increased tail-heavy moments (risk of super-stall or pitch-up). What was said about the influence of the wing taper also applies to the sweep angle. Here too, the maximum lift is greatly reduced as a result of the cA increase with increasing sweep angle.

B.3 Influence of important design parameters

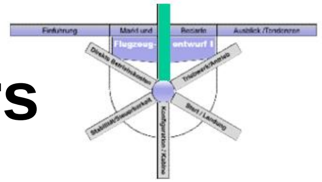
Wing: Influence of sweep

- **Therefore, when designing the wing, tapering, sweep and twisting must be considered together as possible measures to avoid the disadvantageous lift distribution.**

- **Where the maximum lift coefficient (Re number effect) of the profile, which depends on the wing depth and therefore decreases towards the outside, tangent to the ca distribution, lies the separation point of the incipient stall (here referred to as an undesirable "tip Barn").**



B.3 Influence of important design parameters

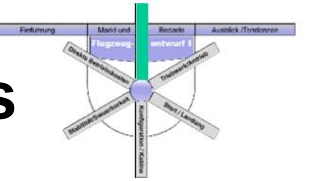


Wing: Influence of sweep

- The centre of lift of the wing, which is shifted backwards as a result of the sweep, causes an additional top-heavy moment, which increases the trim drag and at the same time has a major influence on the torsional load of the wing structure and thus on the weight.

- It is also possible to counteract problems with the aeroelastic behavior by using a swept-back wing. The torsional moment of the swept-back wing, which reduces the angle of attack, leads, for example, to a natural reduction in the angle of attack and, as a result, the bending loads, and thus to a convergent behavior in terms of loading mechanics.

B.3 Influence of important design parameters



Wing: Influence of sweep

- The opposite is the case with a swept wing.

- Here, a small increase in the angle of attack due to the rearward torsion of the wing box leads to a further increased angle of attack and thus to an increased load, which corresponds to a divergent load-mechanical behavior.

Welcome to the course

Aircraft design I

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