AE 452 Aeronautical Engineering Design II

Lateral Stability

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February 2016

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Outline

- Directional stability
- Influences of directional stability
  - Influence of vertical tail
  - Influence of fuselage
  - Influence of wing
- Roll stability
- Influences of roll stability
  - Influences of dihedral and anhedral
  - Infuence of vertical tail
  - Influence of wing position
- Roll and directional control

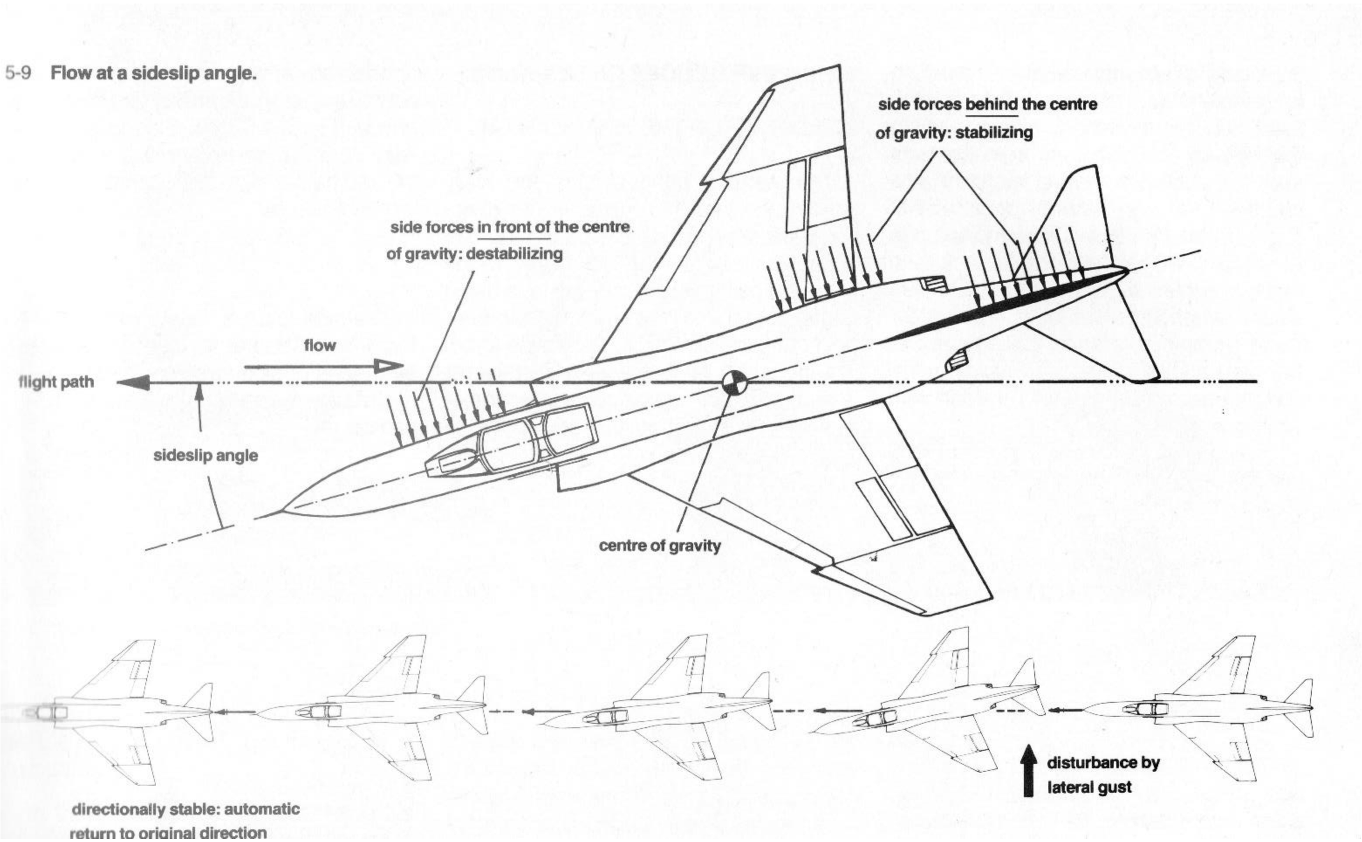
Lateral stability

- In longitudinal flight, the center of gravity of the airplane moves in the **vertical plane**.
- The flight is **symmetrical** and is defined by the angle of attack and the lift coefficient.
- Lateral flight on the other hand is characterized by **unsymmetrical flow.** It includes **roll, yaw and sideslip**.

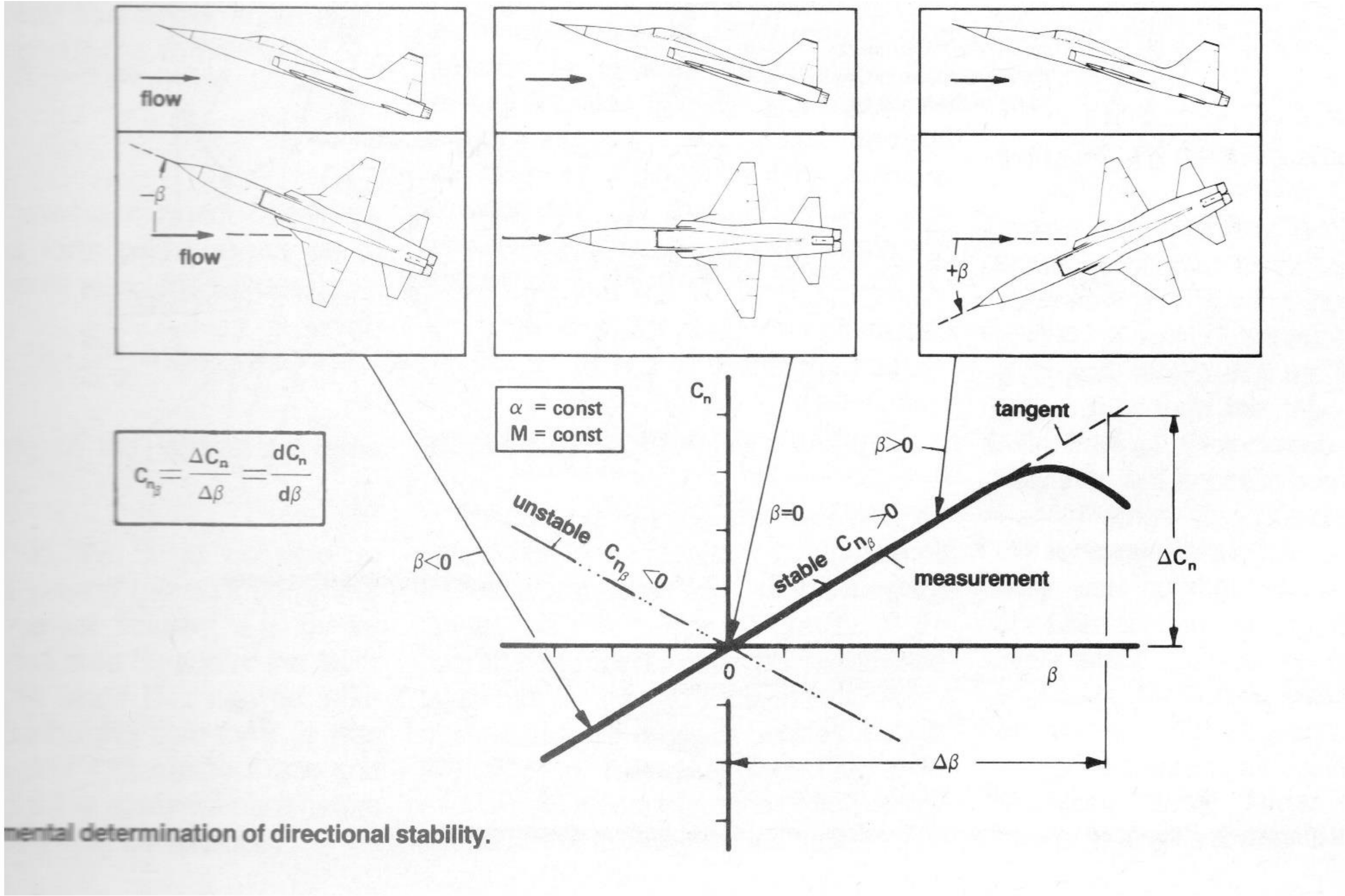
Directional stability

- The **sideslip angle** is the angle that the relative airflow forms with the longitudinal axis of the aircraft.
- The resulting **side forces** are produced mainly by the vertical tail and the fuselage causing moments to act about the center of gravity.
- **Directional stability** is related to the behaviour of the aircraft during a disturbance of the static equilibrium state w.r.t. normal axis.
- **Yawing moment due to sideslip,** $C_{n\beta}$ defines directional (weathercock) stability and $C_{n\beta} > 0$ for stability.

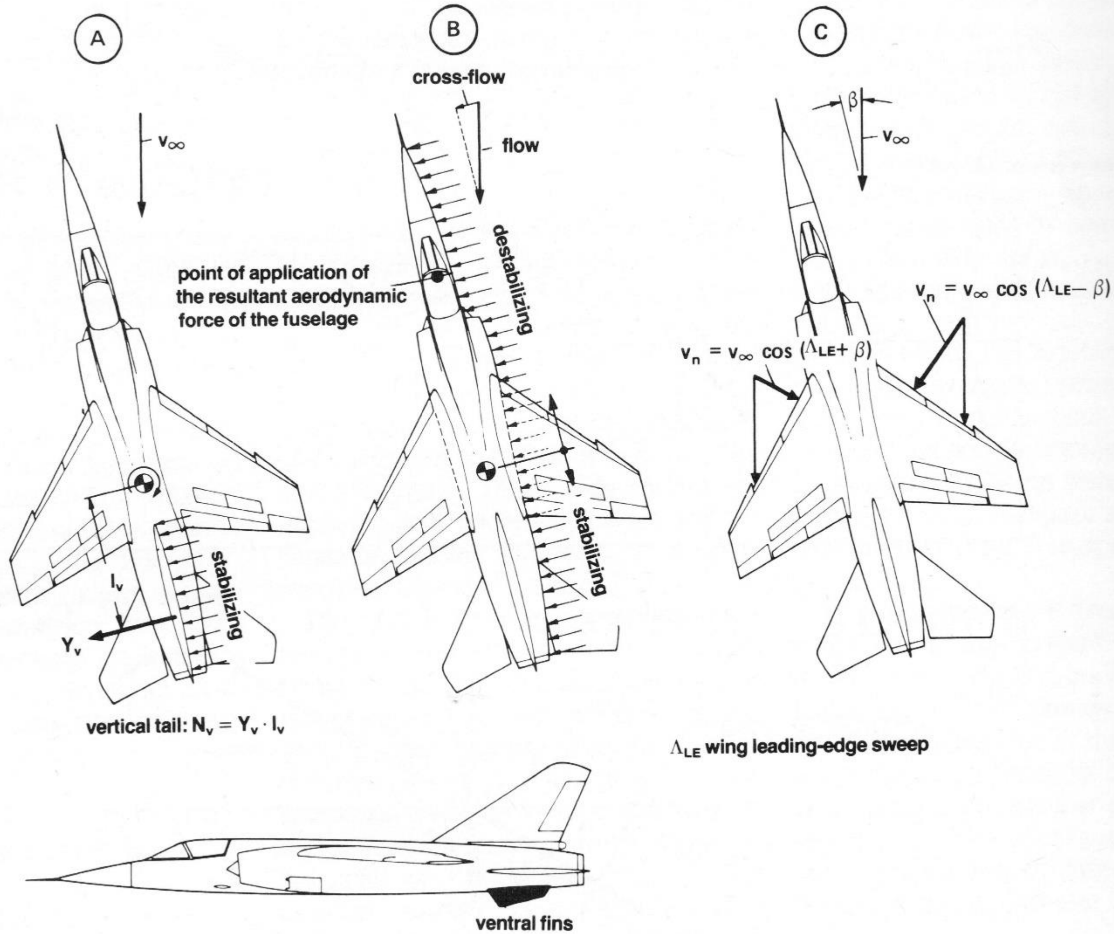
Flow at a sideslip angle



Directional stability



Influences of directional stability



11 **Directional stability is influenced by vertical tail, fuselage, wing sweepback and ventral fins.**

Influences of directional stability

- The **vertical tail** provides the largest contribution to directional stability.
- The sideslip angle acts like an angle of attack to the vertical stabilizer. This causes lift (side force), which produces a stabilizing moment about the center of gravity.
- The magnitude of this moment depends on the distance between the point of application of the side force and the magnitude of the side force (size of vertical tail).

Influences of directional stability

- At subsonic speeds, the resultant aerodynamic force due to sideslip is roughly at about 25% of the fuselage length.
- As the center of gravity of the aircraft lies much further back, **the fuselage has a destabilizing effect**.

Influences of directional stability

- The contribution of the wing to directional stability is small.
- In straight wings, the leeward wing half, which is shielded by the fuselage has a lower drag than the upwind wing half, causing a clockwise (positive) moment about the center of gravity.

Influences of directional stability

- With sweptback wings, the component of the flow perpendicular to the leading edge is larger at the windward wing $\Rightarrow$ windward wing produces more lift and drag producing a stabilizing cloeckwise moment about the center of gravity.
- **Ventral and dorsal fins** may improve directional stability especially at high angles of attack.

Ventral fin on F-16

Roll stability

- Rotations about the longitudinal axis are called **roll.**
- This motion is of great importance for combat aircraft in **combat maneouvres**, for **target acquisition** as well as **evasive maneouvres**.
- Inadequate roll performance restricts combat effectiveness.
- Oversensitive response to roll control commands causes undesirable rotations about the normal and lateral axis.

Roll stability

Typical **roll rate** values:

- Fighter-bomber (strike against ground targets): 140°/s,
- Interceptor: 60°/s,
- Air superiority fighter: 90°/s.

Meeting these values at high speeds is no problem,

At low speeds the dynamic pressure is low and if the roll control surfaces (aileron) lie in separated flow, roll control effectiveness is lost.

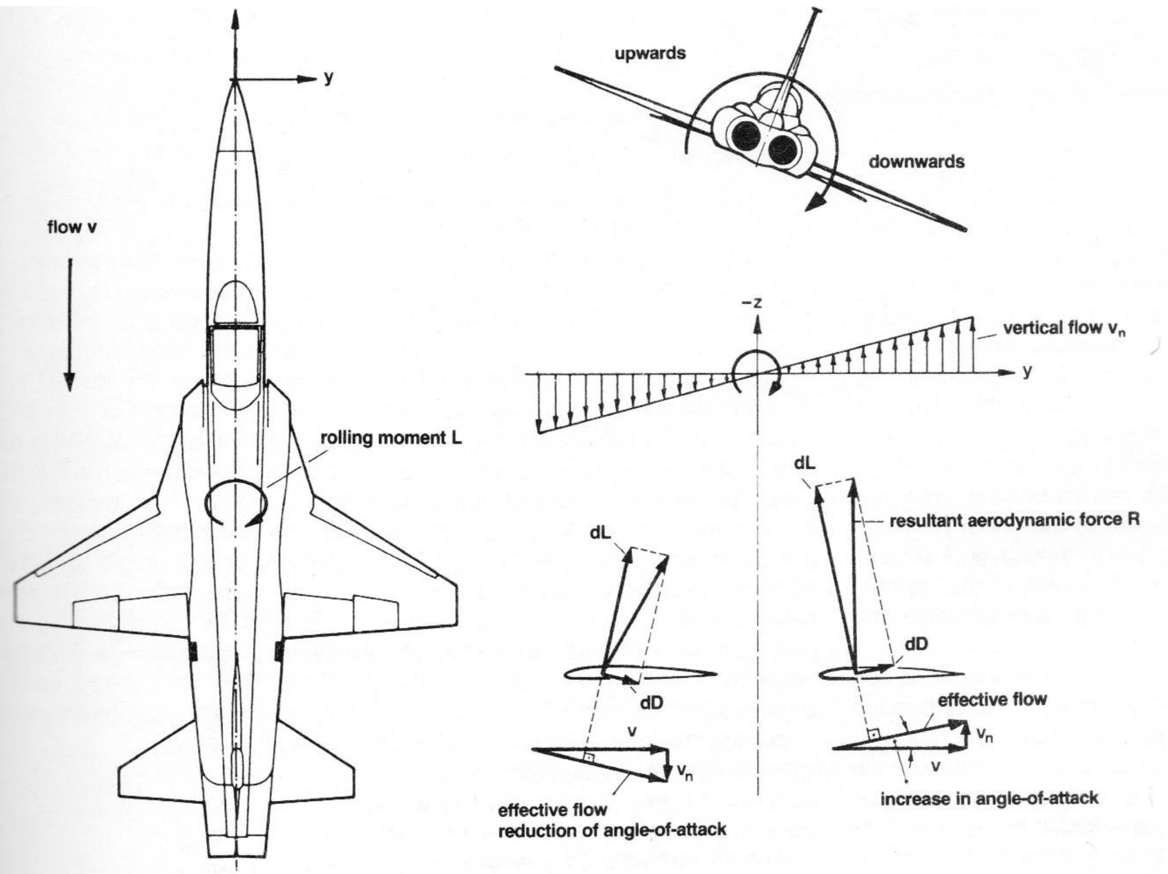
Roll damping

- During rotation about longitudinal axis, a vertical velocity component varying with span occurs at the wing, resulting in an unsymmetrical angle of attack distribution.
- On the downward moving half, this increases the effective angle of attack, whereas on the upward moving wing half, it decreases the effective angle of attack $\Rightarrow$ downward moving wing produces greater lift $\Rightarrow$ creating a moment about the CG in the opposite direction of roll $\Rightarrow$ **roll damping moment.**

Yaw moment due to roll

- A smaller resultant aeroynamic force arises at the upward moving wing half, whereas a larger one arises at the downward moving one.
- The differences in their direction create a **yawing moment.**
- This tries to rotate the downward moving wing forward $\Rightarrow$ **yawing moment due to roll or adverse yaw.**

Wing in roll



The wing in roll.

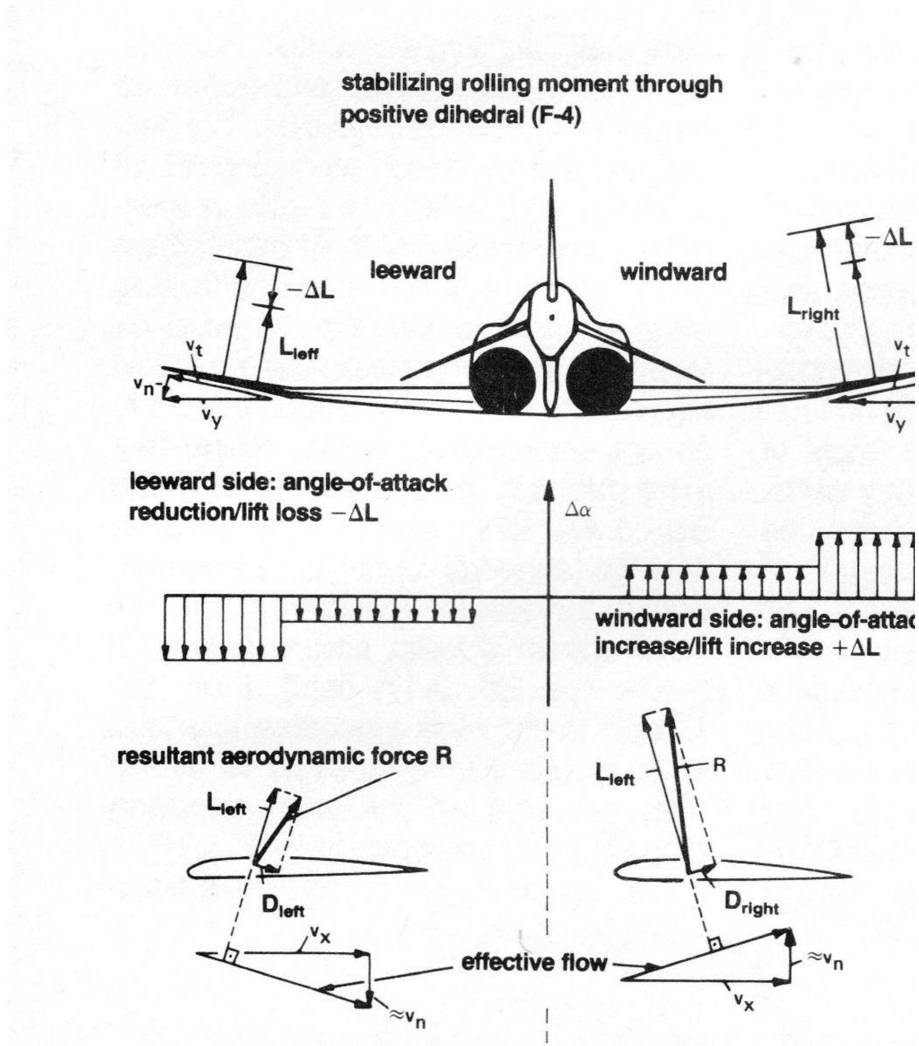
Dihedral effect

- During sideslip, the lateral airflow component can be resolved into a component perpendicular to the wing surface and a component tangential to the wing surface.
- With dihedral, the normal component causes an angle of attack increase on the windward wing half, and a reduction on the leeward wing half $\Rightarrow$ this corresponds to a lift increase and lift loss, respectively $\Rightarrow$ this asymmetry generates a rolling moment called **rolling moment due to sideslip.**

Dihedral effect

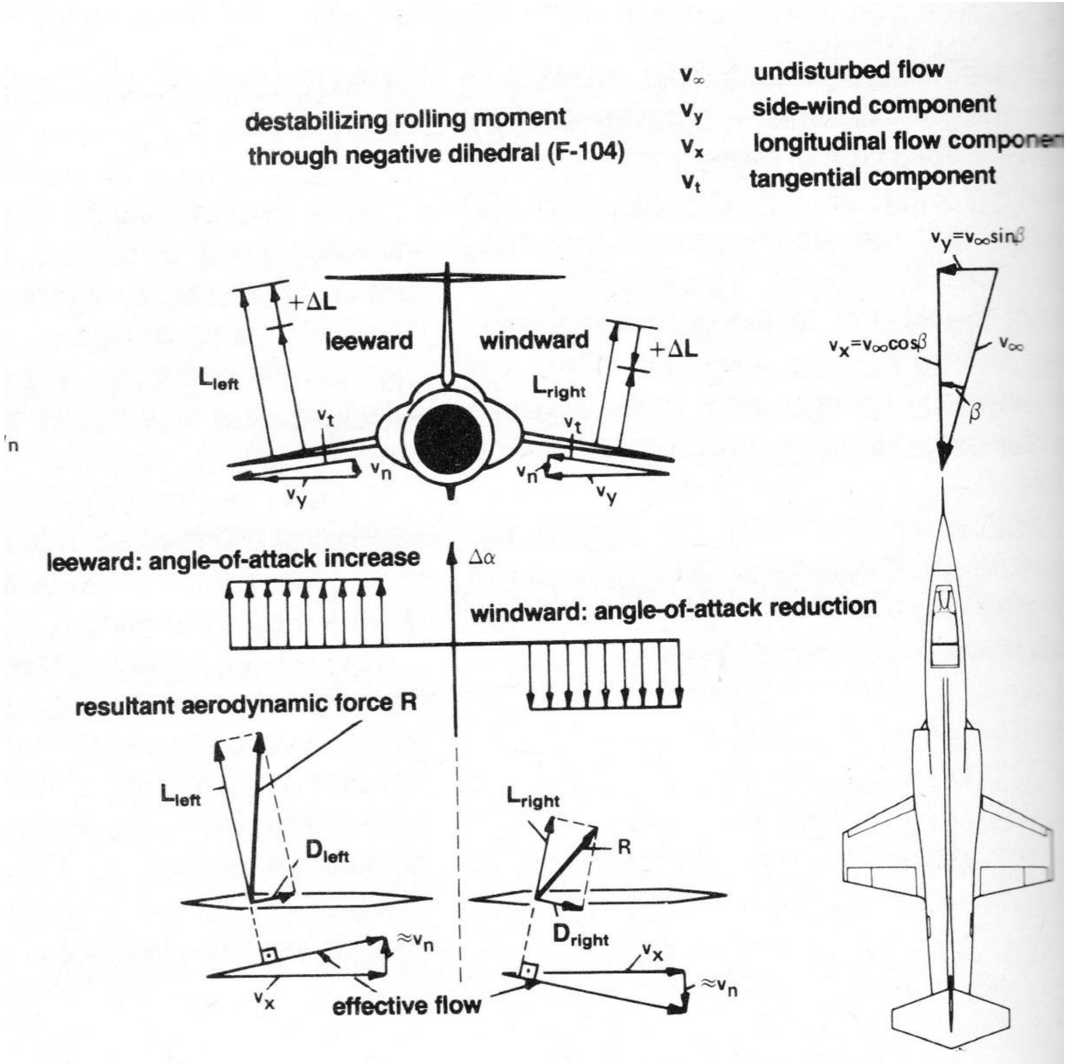
- A wing with **positive dihedral** is stable in roll, while a wing with **negative dihedral (anhedral)** is unstable.
- In modern fighters, dihedral is not used to improve stability. Adequate roll stability can be attained by **sweepback.**

Positive dihedral



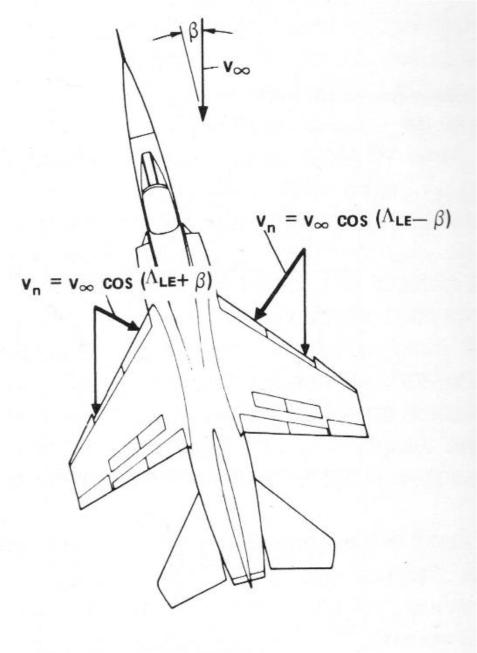
5-17 **Effect of wing dihedral on the lateral motion.**

Negative dihedral



Sweepback effect

- The lift of a sweptback wing is determined by the component of flow velocity perpendicular to the leading edge.



Λ_{LE} wing leading-edge sweep

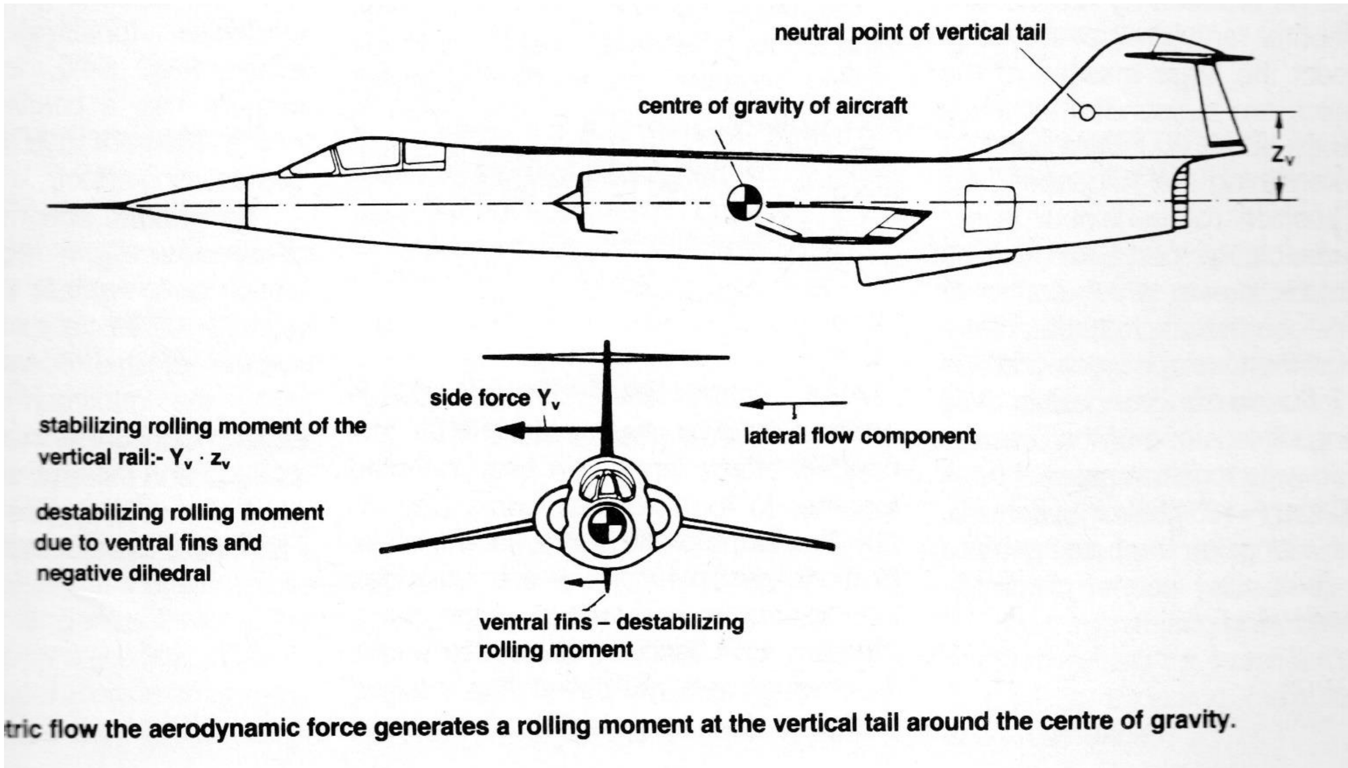
Sweepback effect

- During sideslip, the normal component on the windward wing half is greater than on the leeward wing half, causing different lift forces and a rolling moment which is anti-clockwise (negative) at a positive sideslip angle $\Rightarrow$ sweepback has the same effect as dihedral.

Vertical tail effect

- During sideslip, the lateral flow component acts on the vertical tail as an angle of attack.
- As a result, a laterally directed lift force arises, called the **side force.**
- When the aerodynamic center of the vertical tail is above the CG, the side force generates a negative (anti-clockwise) rolling moment $\Rightarrow$ the vertical tail supplies a stabilizing contribution to the rolling moment due to sideslip.

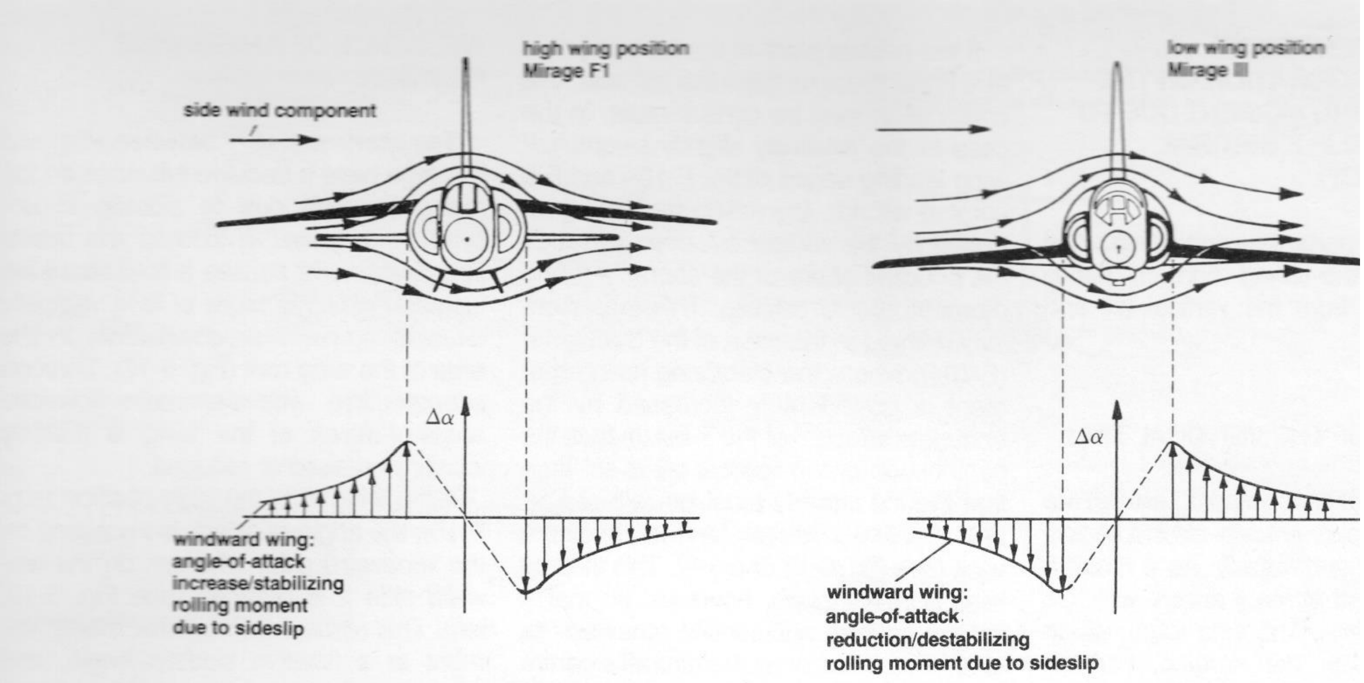
Vertical tail effect



Wing vertical position effect

- When the wing is at a **high position**, the angle of attack is increased on the windward side and decreased on the leeward side, resulting in a negative rolling moment at a positive sideslip angle
$\Rightarrow$ stabilizing contribution.
- The effect is reversed for a **low wing** contribution.

Wing vertical location



5-19 Influence of wing position on rolling moment due to sideslip.