*Spring Semester 2023*

# AIRCRAFT AERODYNAMICS & FLIGHT MECHANICS

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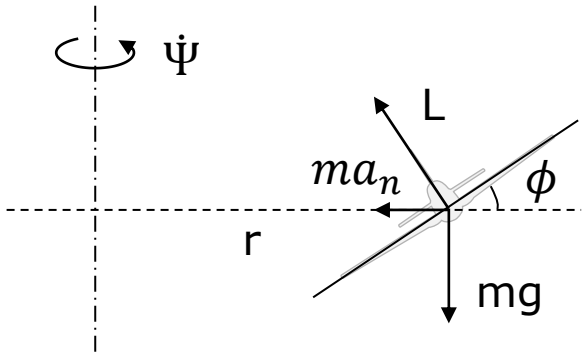
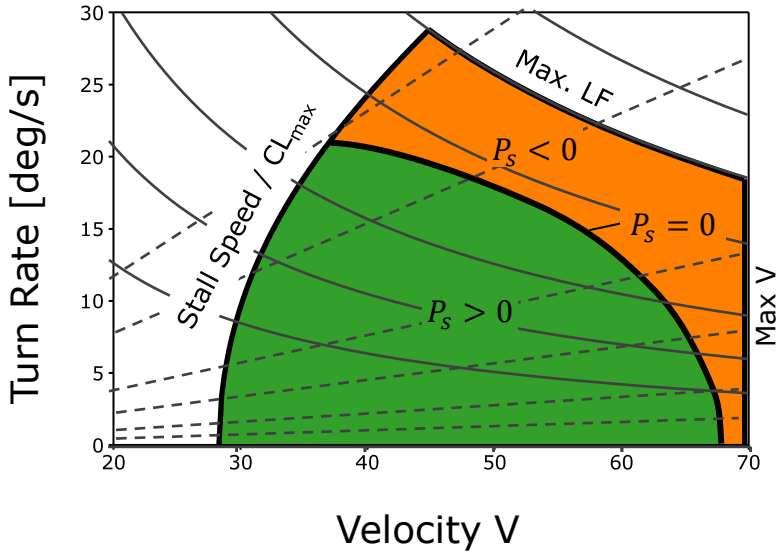
This lecture is adapted with permission from the lecture “Ausgewählte Kapitel der Flugtechnik” by Dr. Jürg Wildi

# Recap

## Maneuver Performance



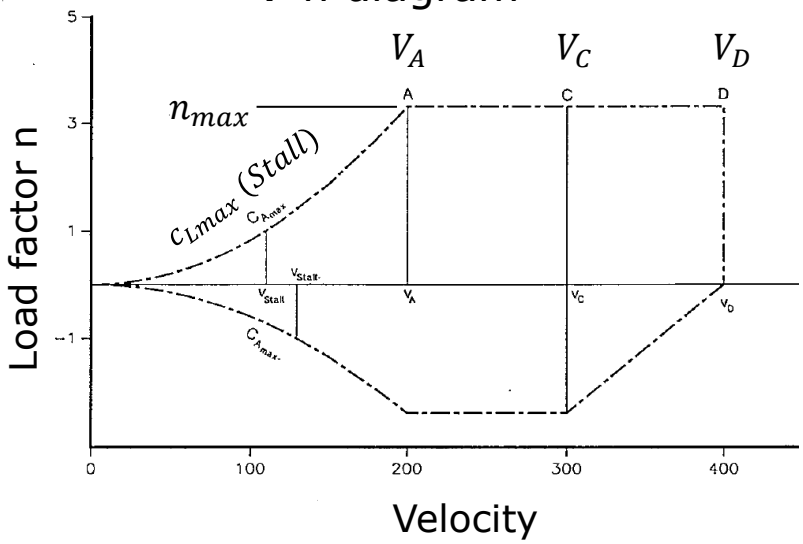

$$a_n = \frac{V^2}{r} = V\dot{\psi}$$



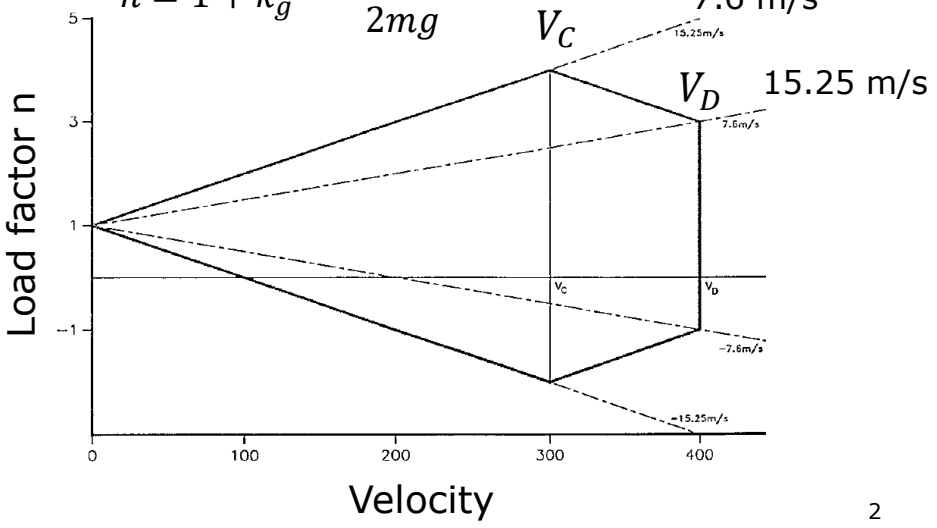

$$\dot{\psi} = \frac{V}{r}$$

$$\dot{\psi} = \frac{g}{V}\sqrt{n^2 - 1}$$

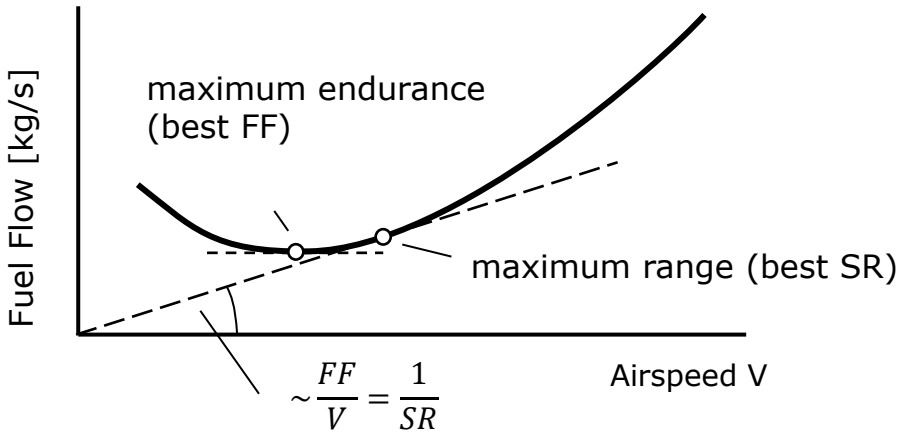
## V-n diagram




$$n = 1 + k_g \frac{\rho V S_{ref} \frac{dc_L}{d\alpha} U}{2mg}$$



# Recap



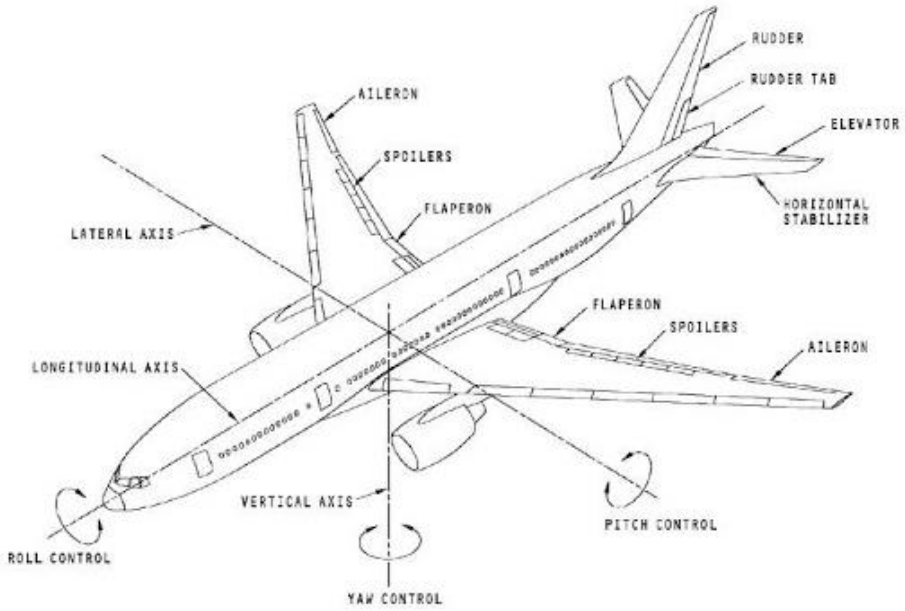

$$BSFC = \frac{FF}{P} \Rightarrow SR_{max} = \left(\frac{V}{P}\right)_{max}$$

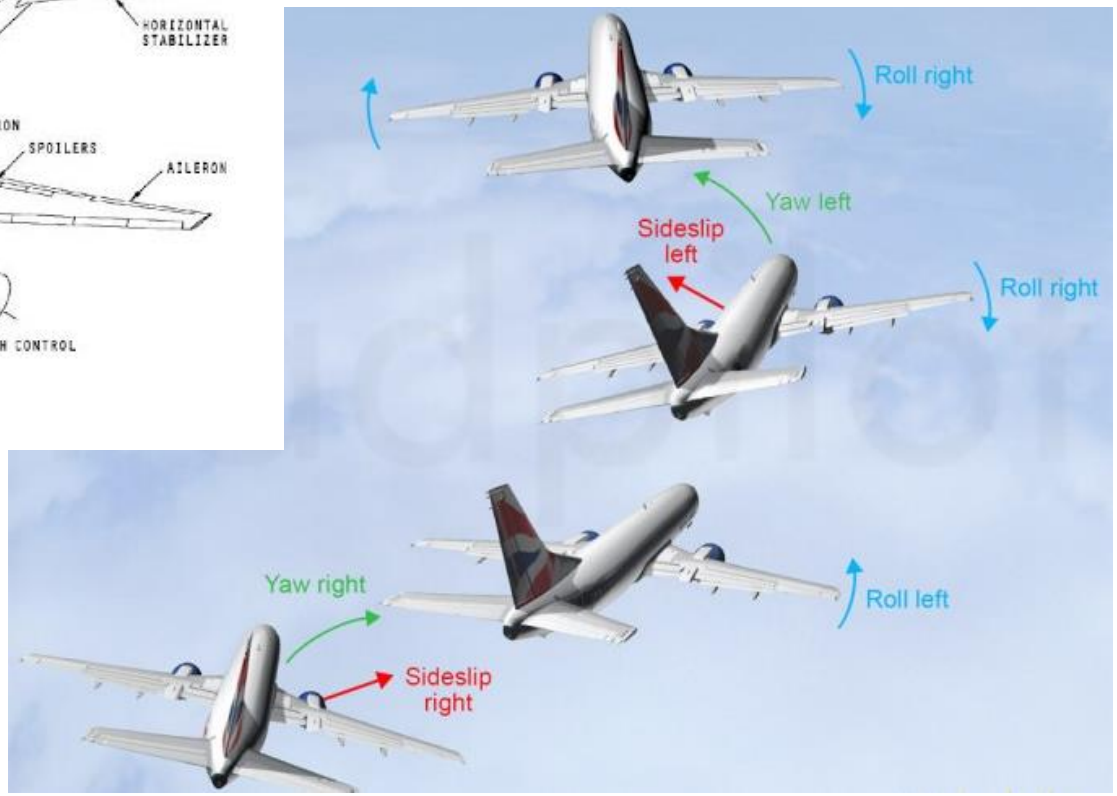
$$TSFC = \frac{FF}{T} \Rightarrow SR_{max} = \left(\frac{V}{D}\right)_{max}$$

Specific Range $SR = \frac{V}{FF}$ [km/kg]

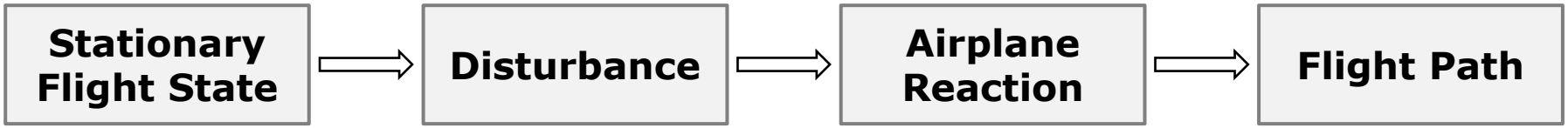
$$R = \int_{W2}^{W1} \frac{V}{TSFC\ g}\frac{L}{D}\frac{1}{W}\ dW \qquad R = \frac{V}{TSFC\ g}\frac{L}{D}\ln\left[\frac{W_1}{W_2}\right]$$

# Stability and Controllability



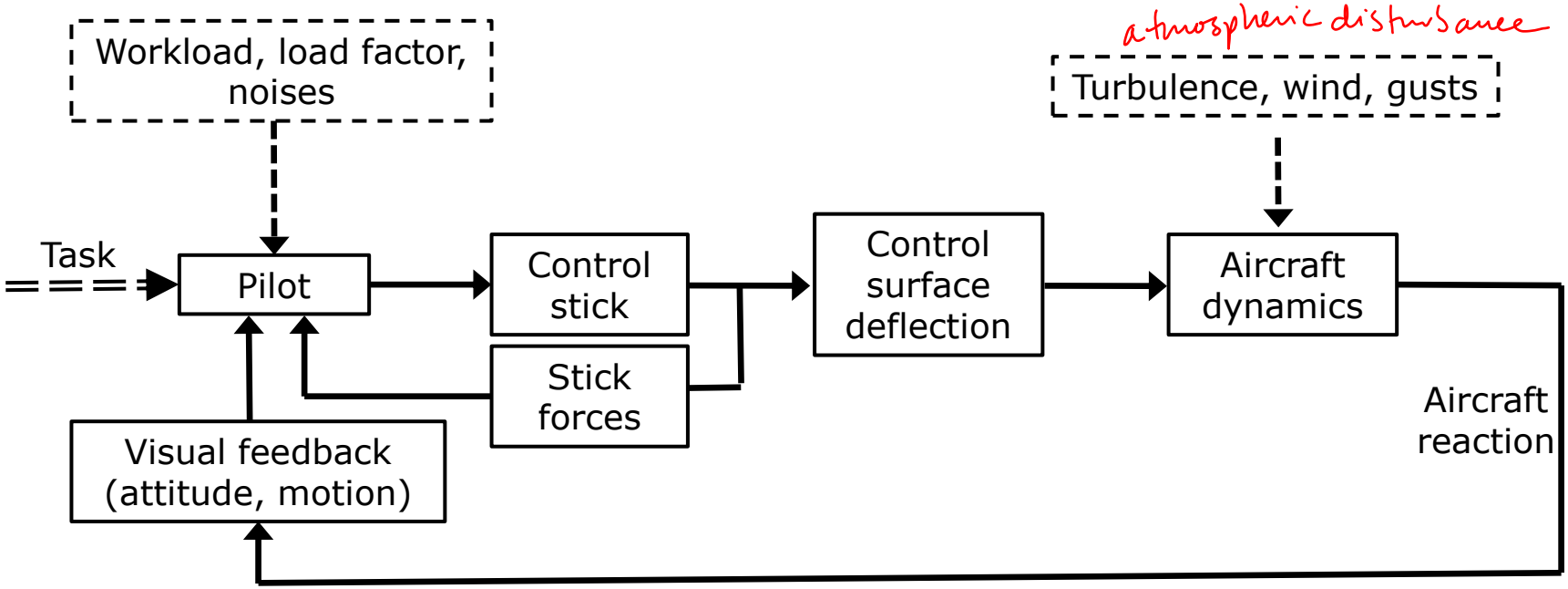
# Introduction




*Example*

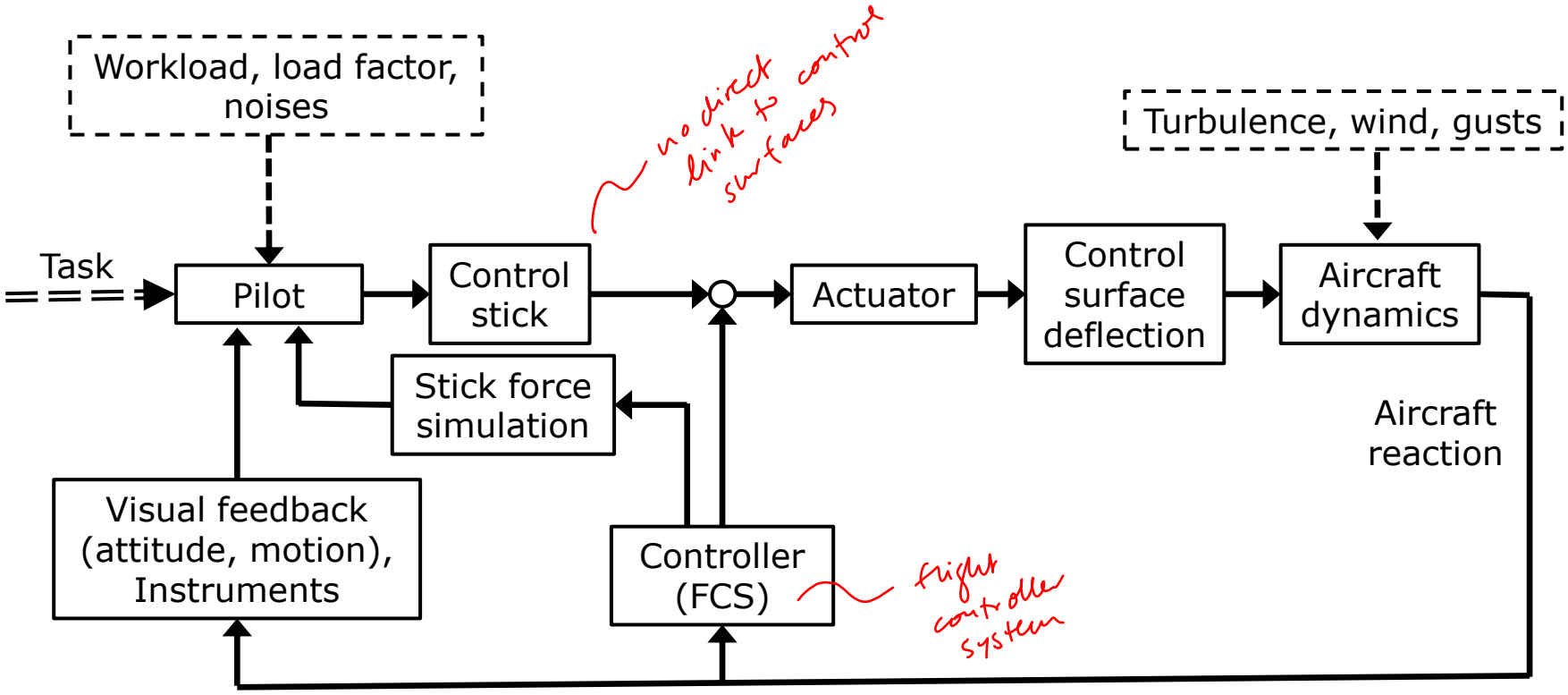
| | | | |
|---|---|---|---|
| Horizontal Cruise | • Elevator deflection<br>• Vertical gust | Pitching moment | ???<br>stable / unstable? |

# Pilot-Aircraft System



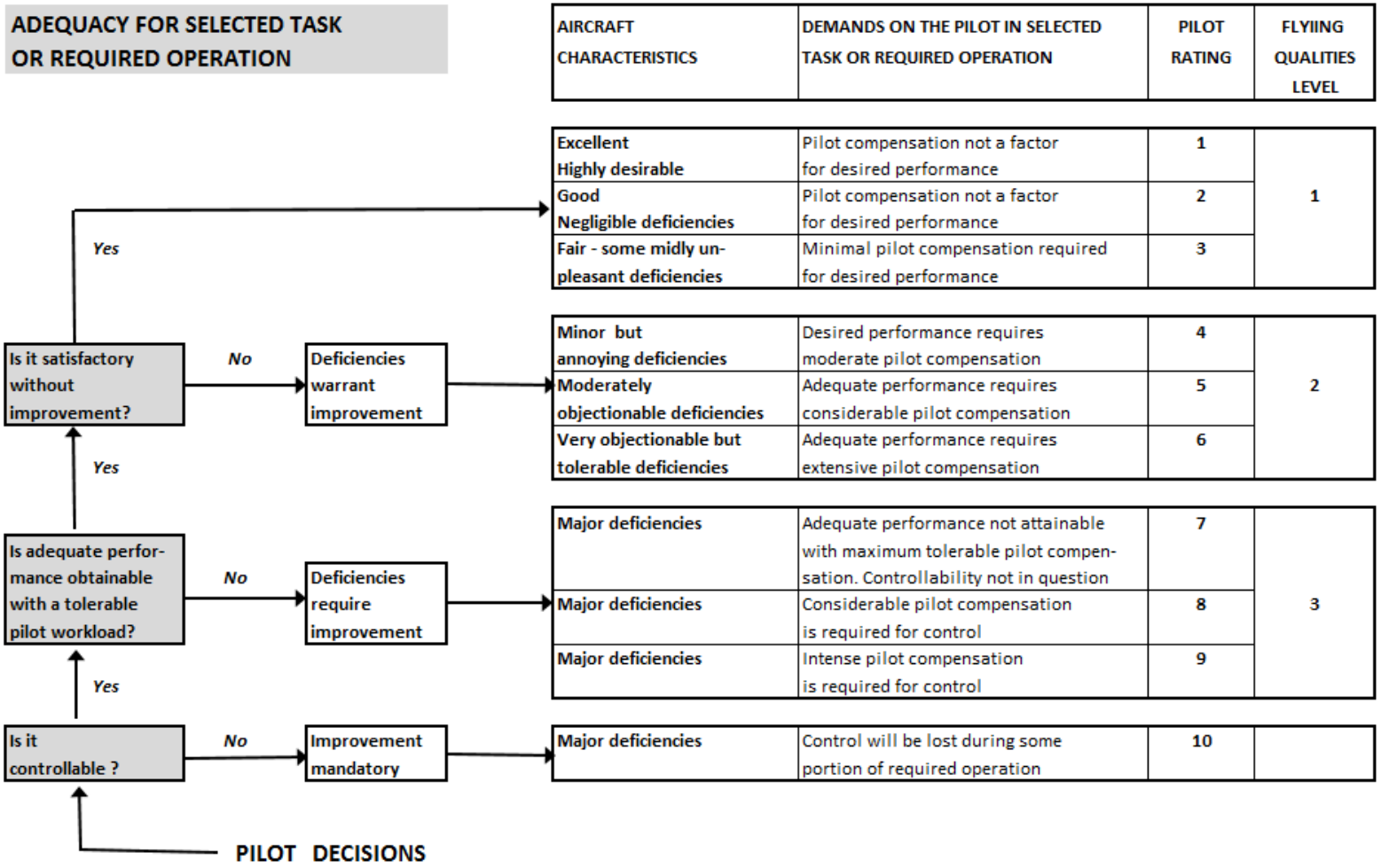
# Pilot-Autopilot-Aircraft System

## Fly-by-Wire



# Handling Qualities

The Cooper-Harper Rating Scale can used to evaluate/rate the handling qualities of an aircraft for a specific task performed during flight testing




| AIRCRAFT CHARACTERISTICS | DEMANDS ON THE PILOT IN SELECTED TASK OR REQUIRED OPERATION | PILOT RATING | FLYIING QUALITIES LEVEL |
|---|---|---|---|
| Excellent Highly desirable | Pilot compensation not a factor for desired performance | 1 | 1 |
| Good Negligible deficiencies | Pilot compensation not a factor for desired performance | 2 | |
| Fair - some midly unpleasant deficiencies | Minimal pilot compensation required for desired performance | 3 | |
| Minor but annoying deficiencies | Desired performance requires moderate pilot compensation | 4 | 2 |
| Moderately objectionable deficiencies | Adequate performance requires considerable pilot compensation | 5 | |
| Very objectionable but tolerable deficiencies | Adequate performance requires extensive pilot compensation | 6 | |
| Major deficiencies | Adequate performance not attainable with maximum tolerable pilot compensation. Controllability not in question | 7 | 3 |
| Major deficiencies | Considerable pilot compensation is required for control | 8 | |
| Major deficiencies | Intense pilot compensation is required for control | 9 | |
| Major deficiencies | Control will be lost during some portion of required operation | 10 | |

# Adapted Cooper-Harper

For example for the ground station of a UAV

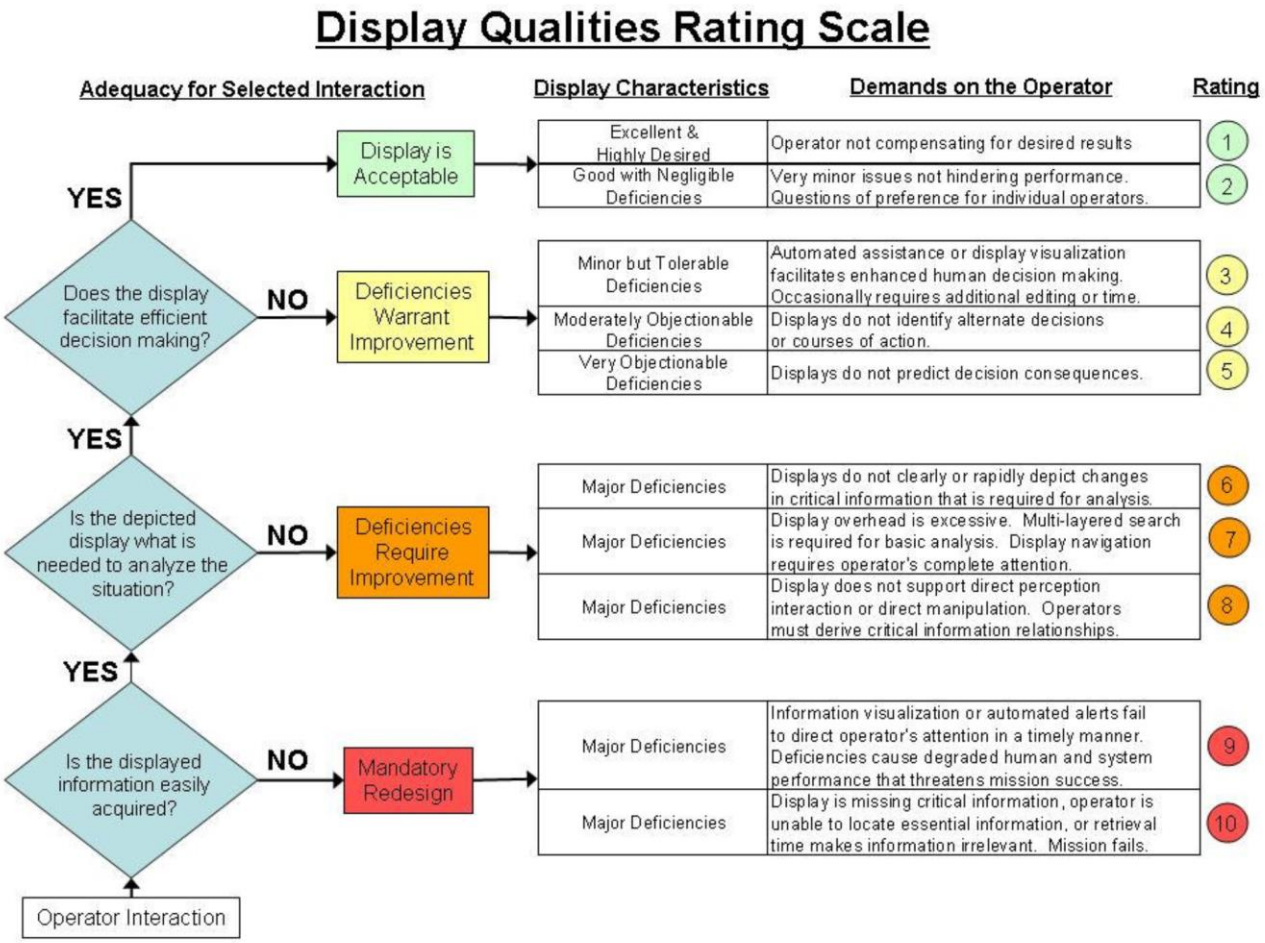
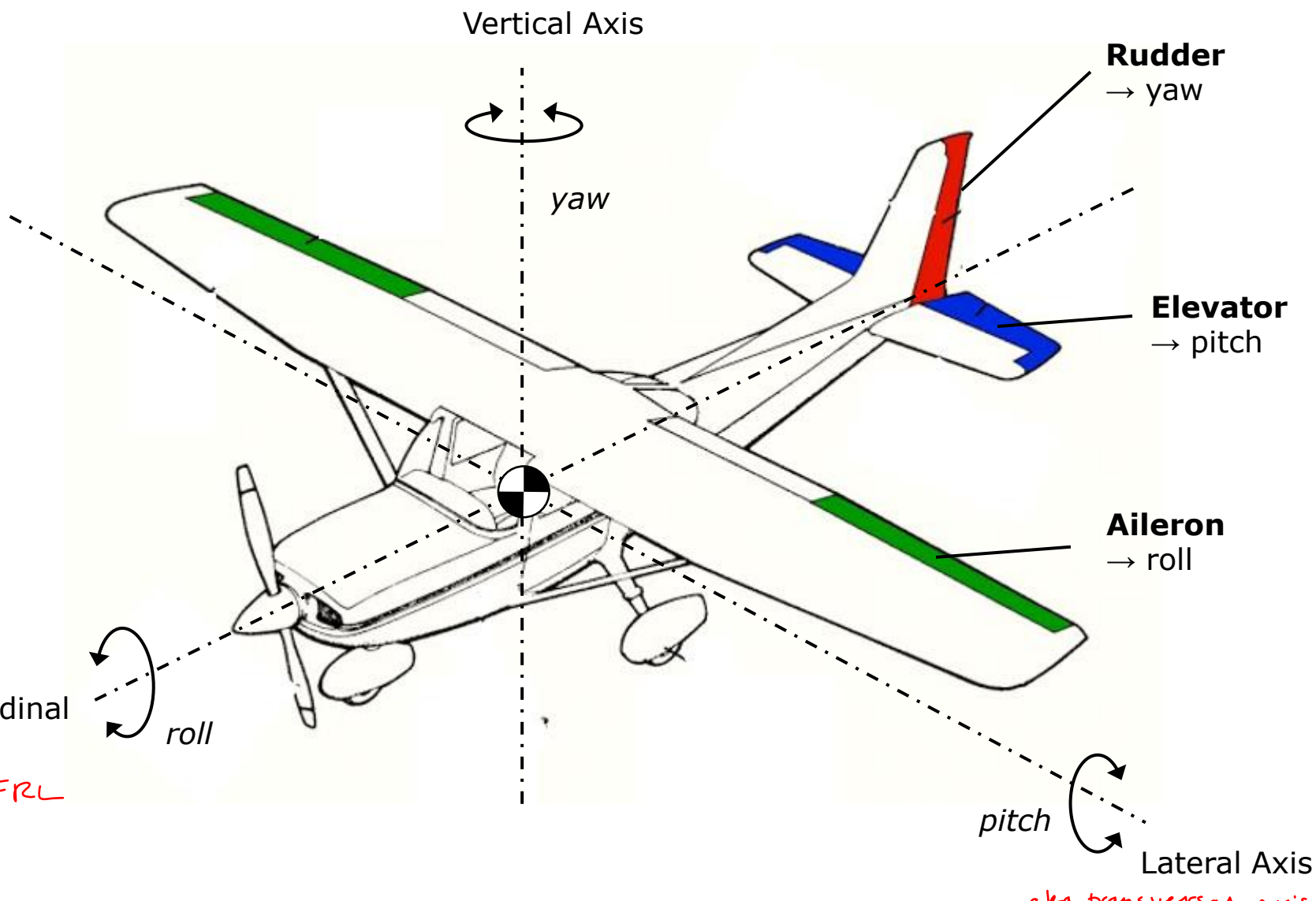


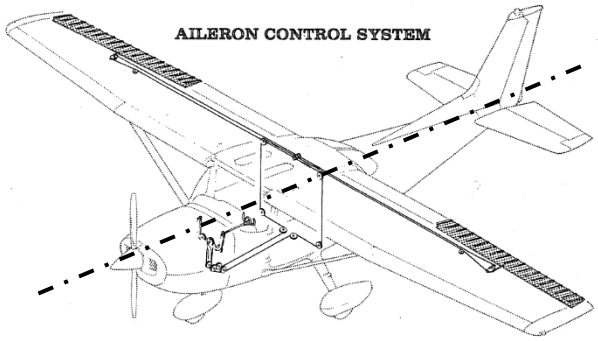

**Figure 2. Hun** **Modified Cooper-Harper for Unmanned Vehicle Display (HF MCH-UVD) evaluation scale (Cummings, et al., 2006).**

# Primary Flight Controls

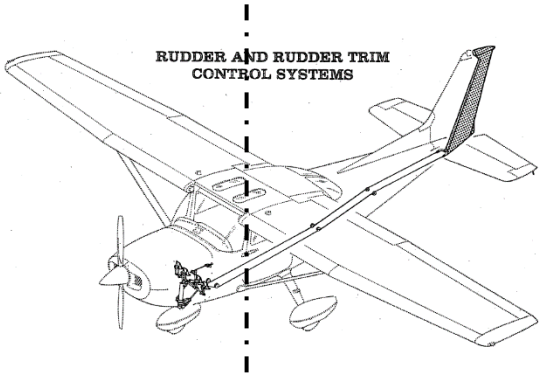


# Primary Flight Controls

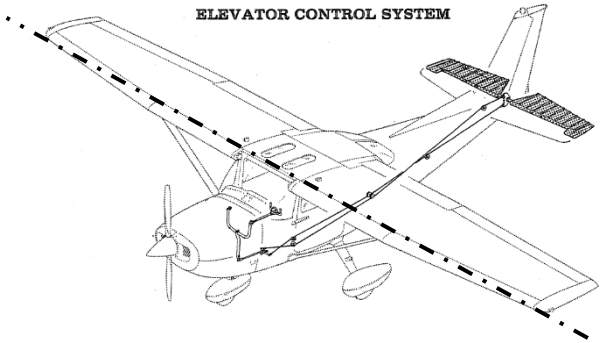
Aileron




Rudder




Elevator



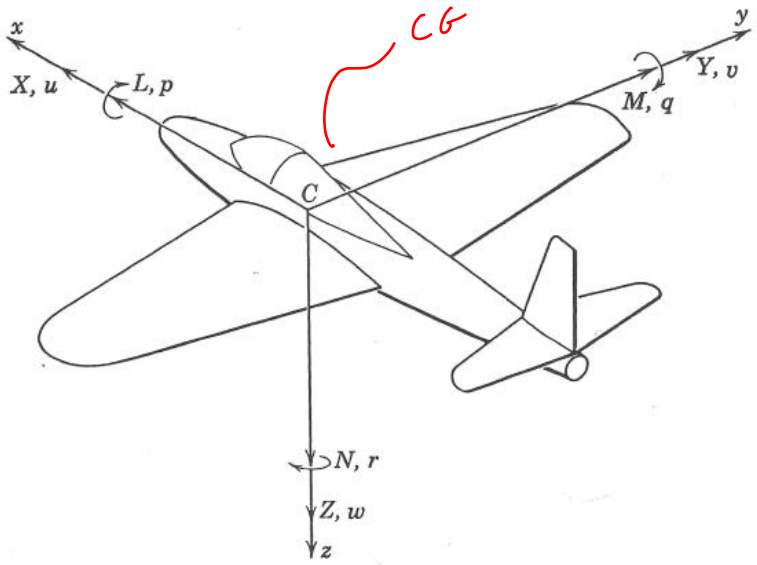

Motion around the

| **Longitudinal Axis** | **Vertical Axis** | **Lateral Axis** |
|---|---|---|
| rolling | yawing | pitching |
| Lateral Stability | Directional Stability | Longitudinal Stability |

# Body Fixed Coordinate System

Sign convention: right-handed coordinate system with the x-axis pointing forwards and y-axis pointing through the right wing

(treats airplane as a rigid body)

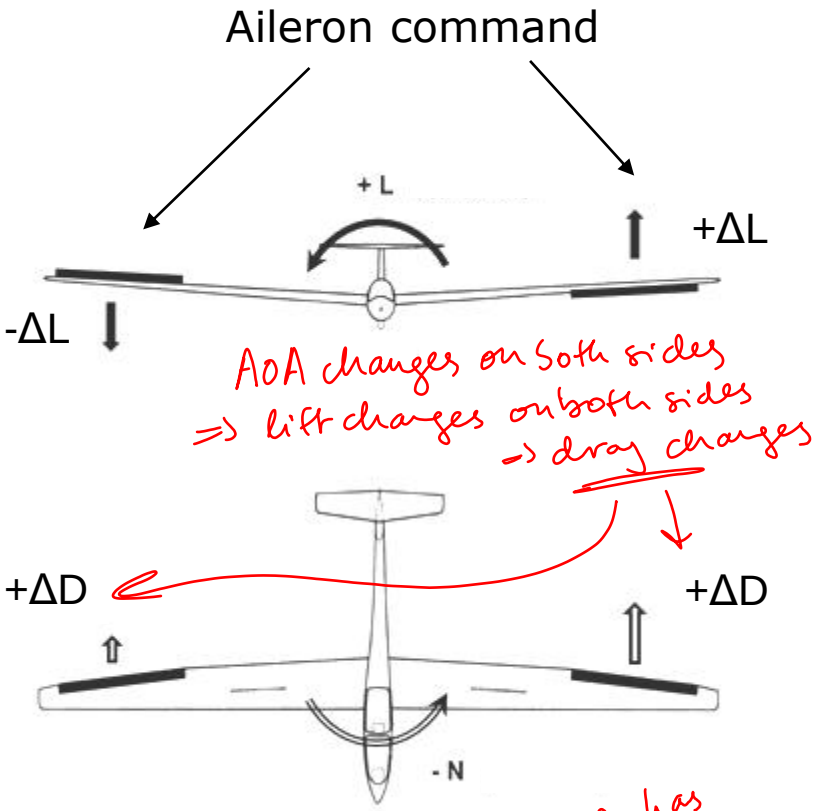



(x, y, z): body axis

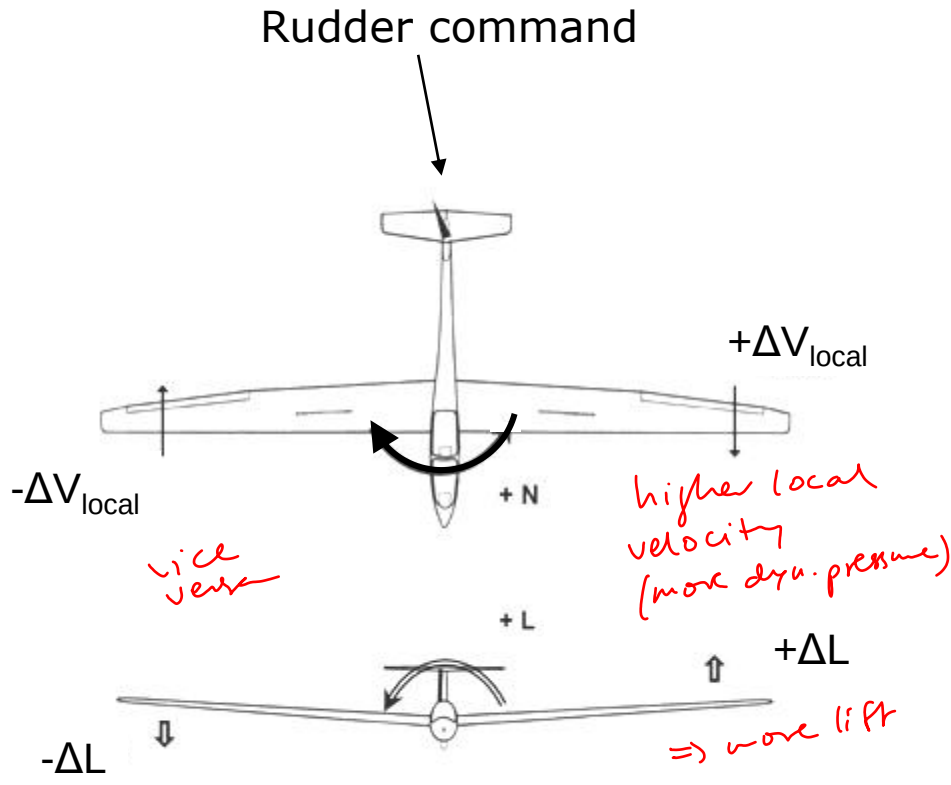
(u, v, w): velocity vector components

| | |
|---|---|
| L: rolling moment | [Nm] |
| M: pitching moment | [Nm] |
| N: yawing moment | [Nm] |
| p: roll rate | [rad/s] |
| q: pitch rate | [rad/s] |
| r: yaw rate | [rad/s] |

# Cross-Coupling

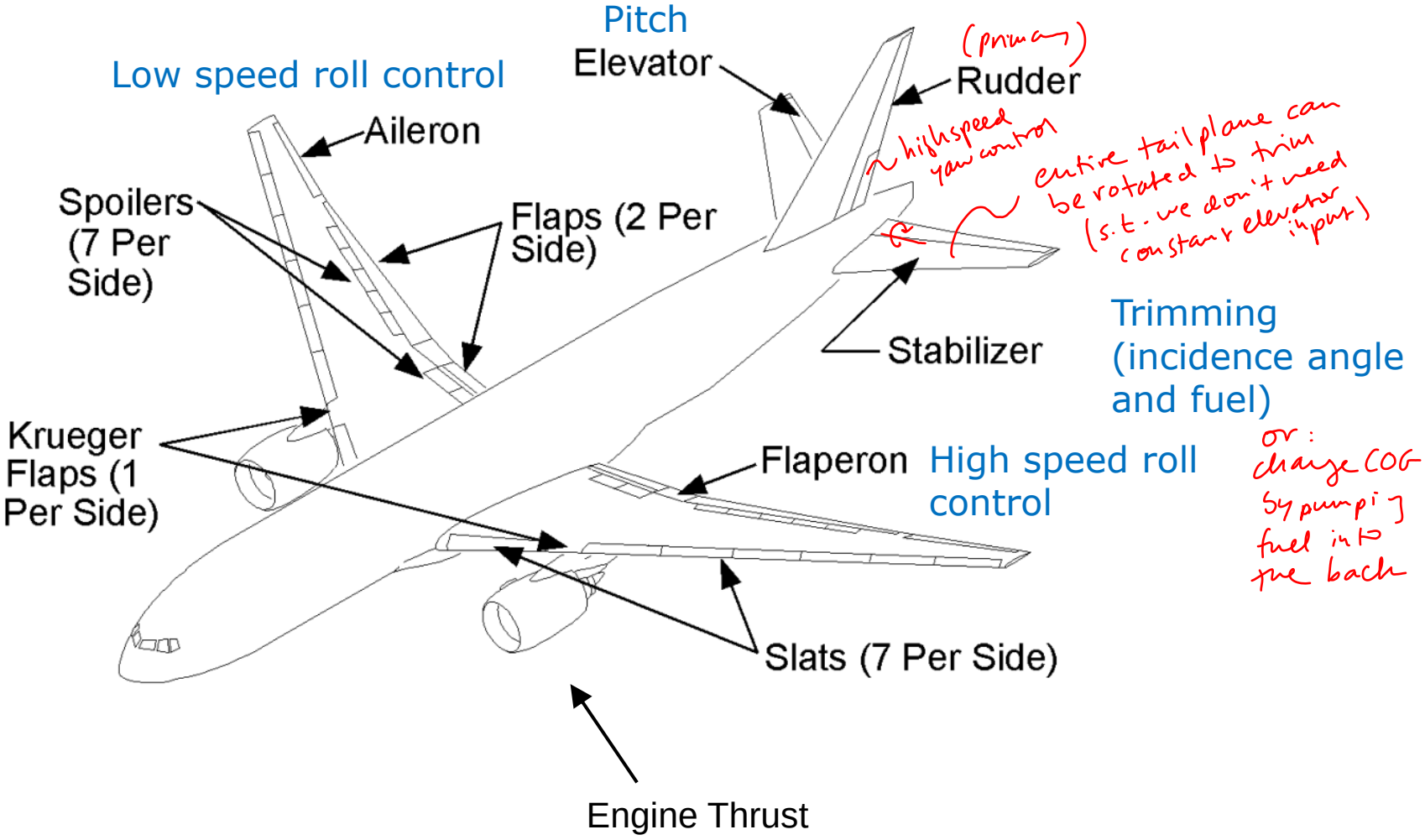



roll-yaw coupling




yaw-roll coupling

# Airliner Primary & Secondary Flight Controls

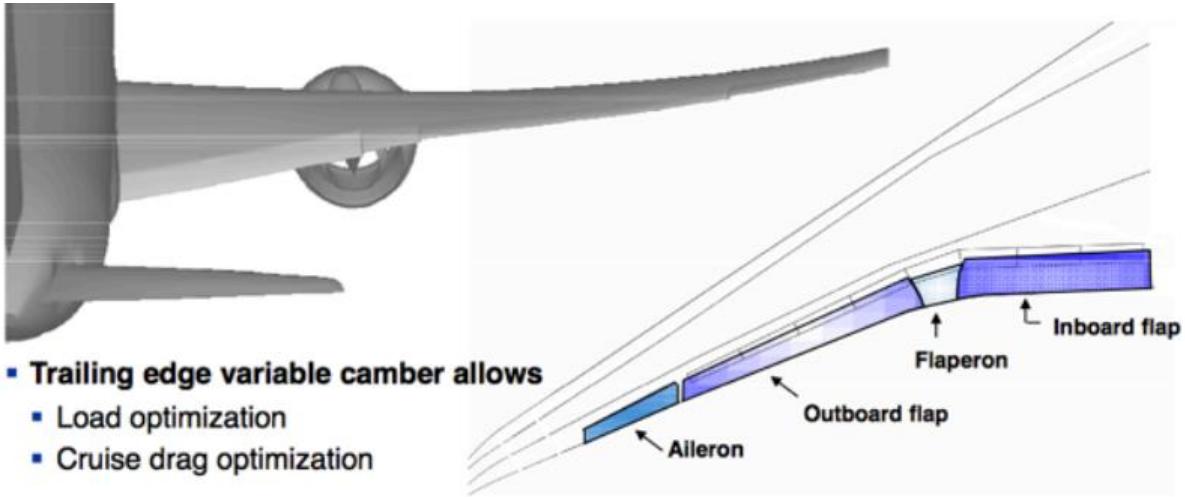



(example B777)

Spoilers: speed brakes or roll control

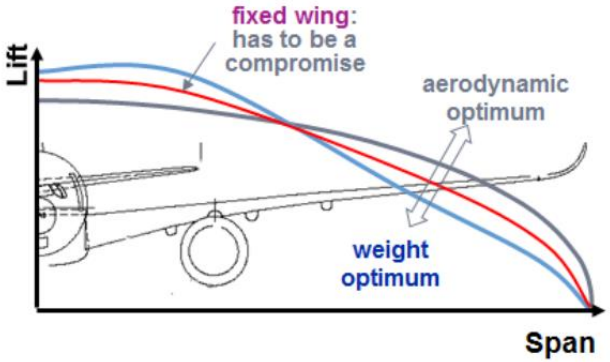
remember: left roll => left aileron comes up
pitch back => elevator up

# Active Load Alleviation




- Trailing edge variable camber allows
  - Load optimization
  - Cruise drag optimization

Boeing 787 Trailing Edge Variable Camber (TEVC)

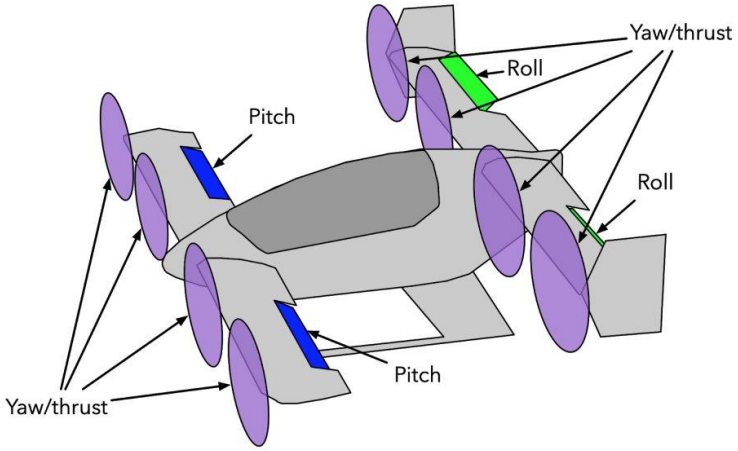


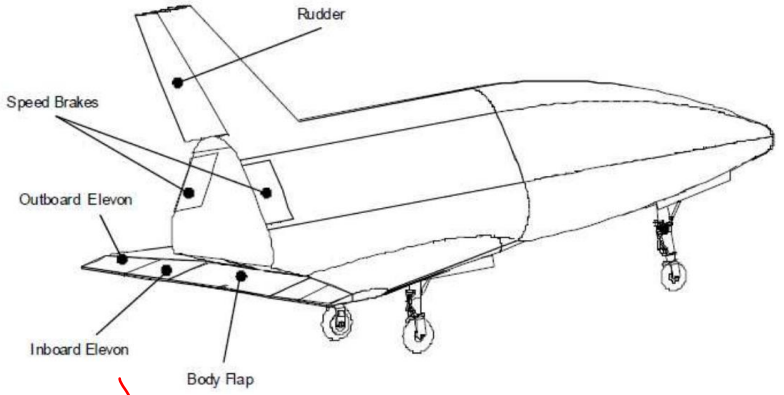

Airbus A350 Adaptive Dropped Hinge Flap (ADHF)

# Control Concept

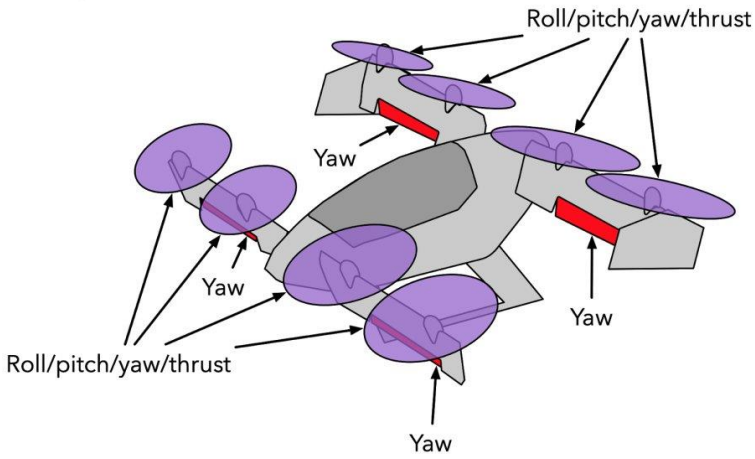
Flight control system (FCS)

Control allocation example



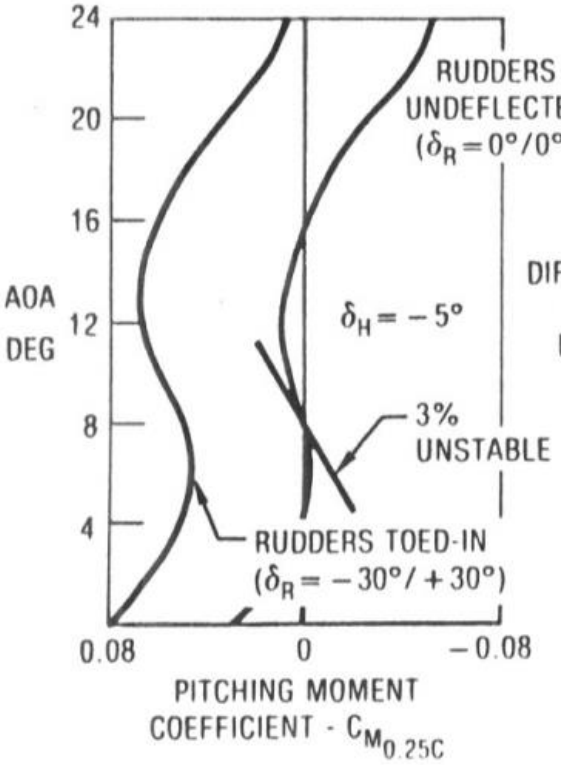

Delta wing example

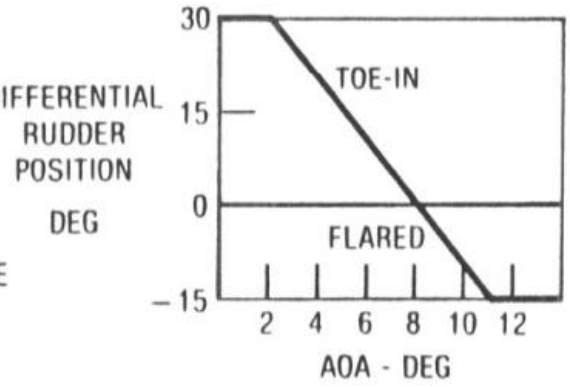


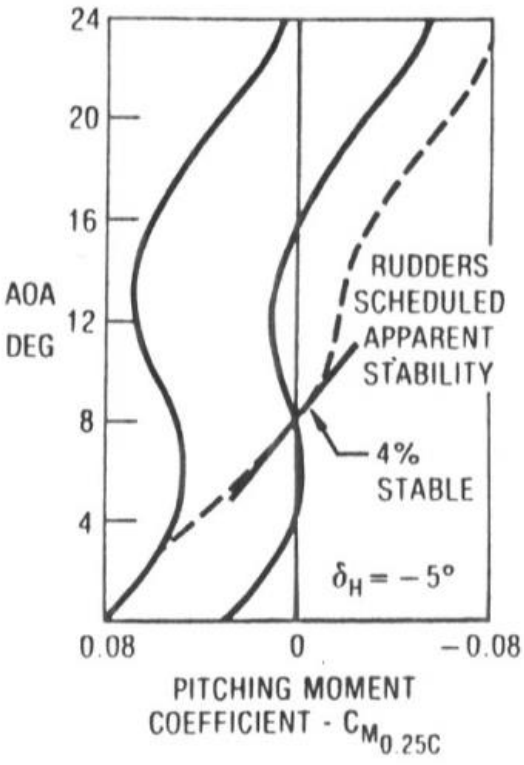

elevon : functions as aileron & elevator

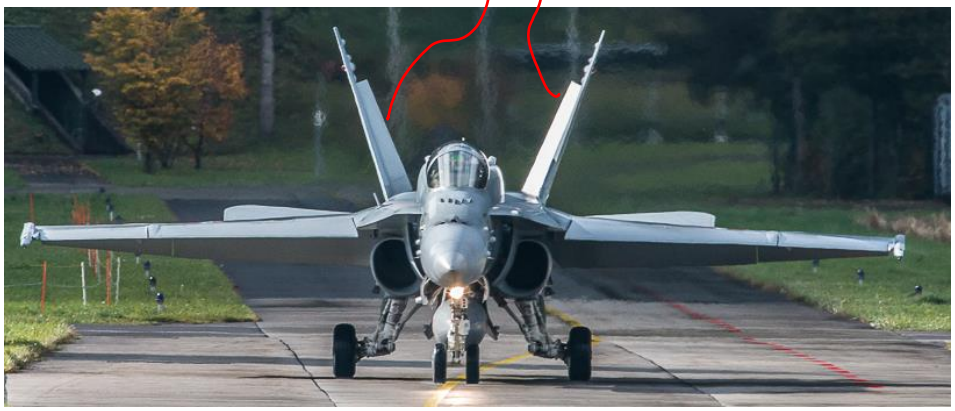
Source: https://acubed.airbus.com/blog/vahana/exploring-control-allocation-for-e-vtol-vehicles/

# Static Stability

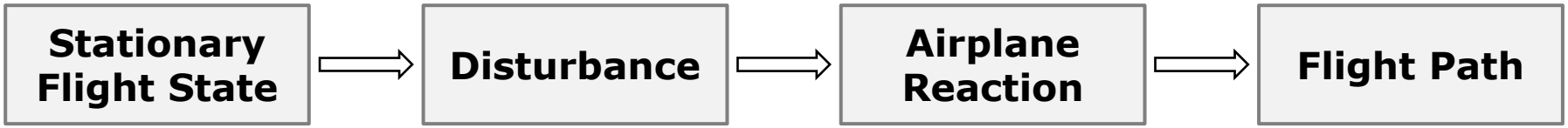

24
20
16
12
8
4
AOA
DEG
RUDDERS
UNDEFLECTED
($\delta_R = 0°/0°$)
$\delta_H = -5°$
3%
UNSTABLE
RUDDERS TOED-IN
($\delta_R = -30°/+30°$)
0.08
0
−0.08
PITCHING MOMENT
COEFFICIENT - $C_{M_{0.25C}}$


30
15
0
−15
DIFFERENTIAL
RUDDER
POSITION
DEG
TOE-IN
FLARED
2
4
6
8
10
12
AOA - DEG


24
20
16
12
8
4
AOA
DEG
RUDDERS
SCHEDULED
APPARENT
STABILITY
4%
STABLE
$\delta_H = -5°$
0.08
0
−0.08
PITCHING MOMENT
COEFFICIENT - $C_{M_{0.25C}}$

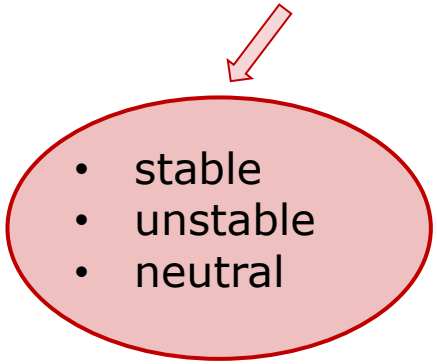

toe in

# Introduction




*Example*

| | | | |
|---|---|---|---|
| Horizontal Cruise | • Elevator deflection<br>• Vertical gust | Pitching moment | ??? |



# Mechanical Equilibrium

static stability : only wrt. to an equilibrium state & the initial reaction to a disturbance

**Stable equilibrium**

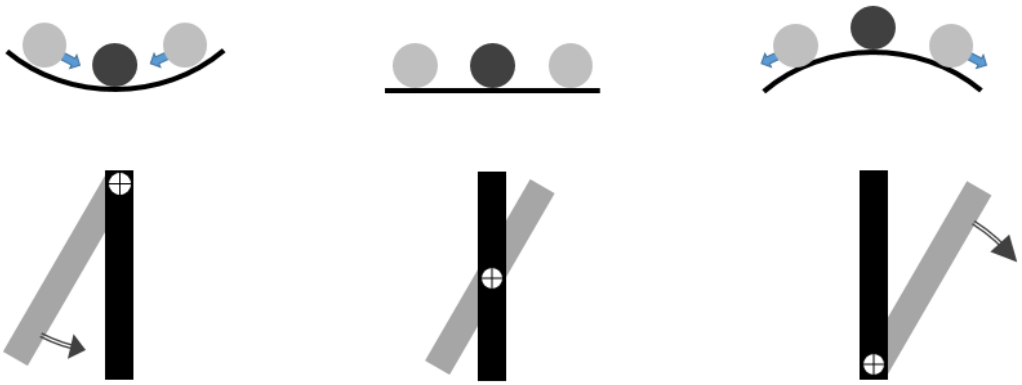
A small disturbance (perturbation) leads to a restoring force/moment, causing the system to return to the original state

**Neutral equilibrium**

A small disturbance moves the system into a different neutral equilibrium

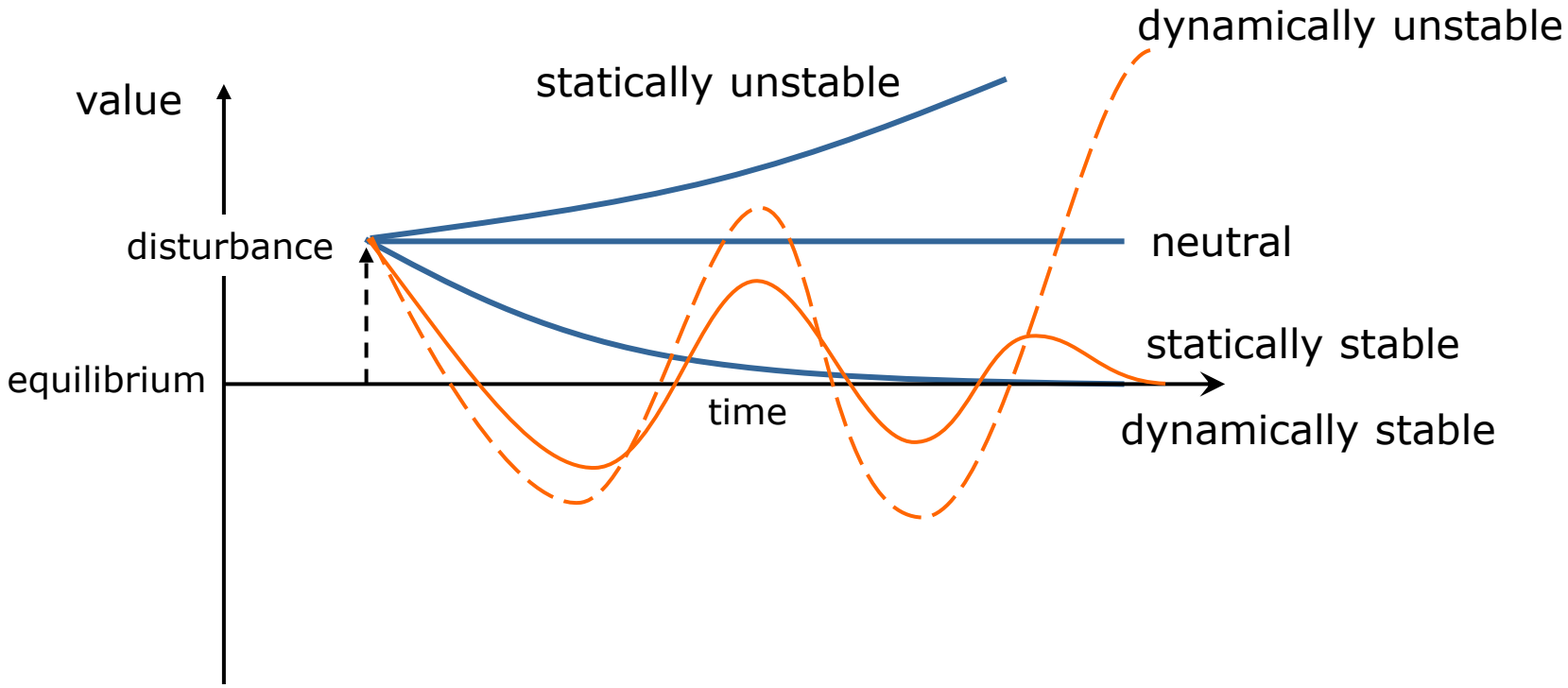
**Unstable equilibrium**

A small disturbance moves the system even further away from the original state



stable neutral unstable

# Static Stability vs. Dynamic Stability




Dynamic stability requires static stability, however a dynamically unstable system can be statically stable

# Determine Static Stability

In general:

Stationary Flight State ⟹ Disturbance ⟹ Airplane Reaction ⟹ Derivative of the reaction w.r.t. disturbance

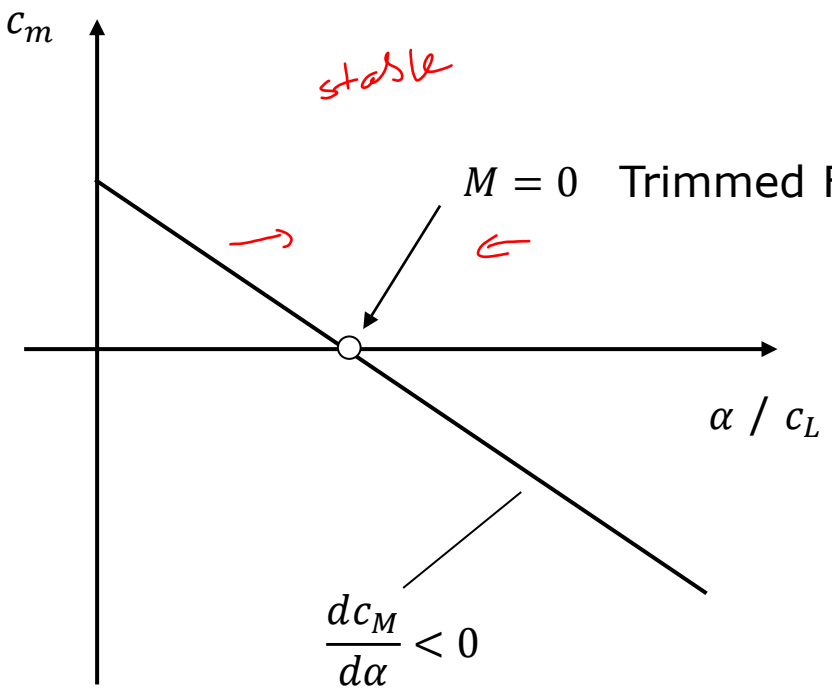
Example: longitudinal static stability (motional around lateral axis (pitching))

Level Cruise ⟹ Increase in AoA Δα ⟹ Pitch moment ΔM, $\Delta C_M$ ⟹ $\frac{\Delta c_M}{\Delta \alpha}$ $\frac{dc_M}{d\alpha}$

V = const.
h = const.
M = 0

(e.g. vertical gust)

# Static Longitudinal Stability




$$c_m = \frac{M}{qS_{ref}l_{ref}}$$

M / $c_m$ positive ⇨ Pitch up

pitch down ⟷ pitch down

! it is super important to know the sign convention!