# Control & Guidance

**2011**

**Enginyeria Tècnica d'Aeronàutica**
**esp. en Aeronavegació**
Escola d'Enginyeria de Telecomunicació
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## *Auto-Pilot*



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1. Longitudinal auto-pilot
2. Lateral auto-pilot
3. AP basic principles
4. Flight Management System

# 1. Longitudinal auto-pilot

Introduction

1 Displacement auto-pilot

2 Pitch speed control system

3 Acceleration control system

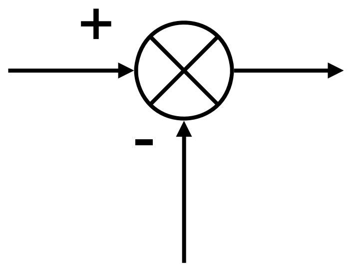
4 Vertical speed control

5 Mach speed control

6 Altitude control

## Introduction

Note: in all block diagrams, all sum blocks are with a feedback as:




even if + & - symbols do not appear.

## Introduction

**Control surface actuator**:

so far, various Transfer Functions (TF) that represent the aircraft dynamics have been seen, still missing some control systems:

- **Servo actuators** are used to deflect the aerodynamic control surfaces: either electrical, hydraulic, pneumatic or some combination of the 3. Typically their TF is of a $1^{st}$ order system.

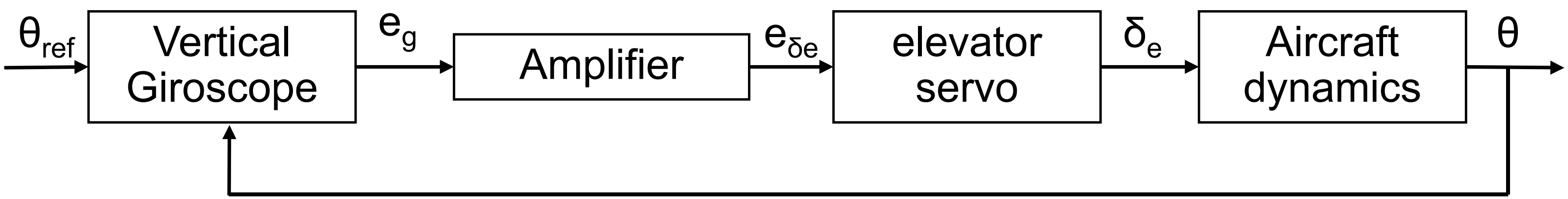
- Transfer functions for any **sensors** in the control loop: attitude gyro, rate gyro, altimeter or velocity sensor: TF for most sensors can been approximated by a gain K.

## Displacement AP

- first auto-pilot was developed by Sperry Corporation
- linked a gyroscopic attitude with a magneto-compass to the rudder, the elevator and the flaps (with hydraulic system)
- allowed the plane to flight straight and leveled without pilot’s attention
- “straight-and-level” AP is the most common and thus the cheapest
- low error due to the use of simple control systems

## Displacement AP

- pitch/attitude angle: between horizontal and longitudinal axis




- plane *trimmed* to reference pitch→ turned on AP
- if pitch angle varies, voltage $e_g$ is generated → amplified → servo-elevator (hydraulic for ex.), positions the elevator

→ pitch movement so that the aircraft moves with the desired pitch angle

## Displacement AP

**Transfer function represents aircraft dynamics**

**Remember: 6 hypothesis:**

1. X and Z axis in the plane of symmetry of the aircraft and its gravity center = origin of the system of axis
2. Aircraft has a constant mass
3. Aircraft = rigid solid
4. Earth = inertial reference frame
5. Small perturbations with respect to the equilibrium
6. Leveled, non accelerated, non turbulent flight

## Displacement AP

**Longitudinal model transfer function**

**Elevator's movement:**

$$(13.78s + 0.088)\, u(s) - 0.392\, \alpha(s) + 0.74\, \theta(s) = 0$$

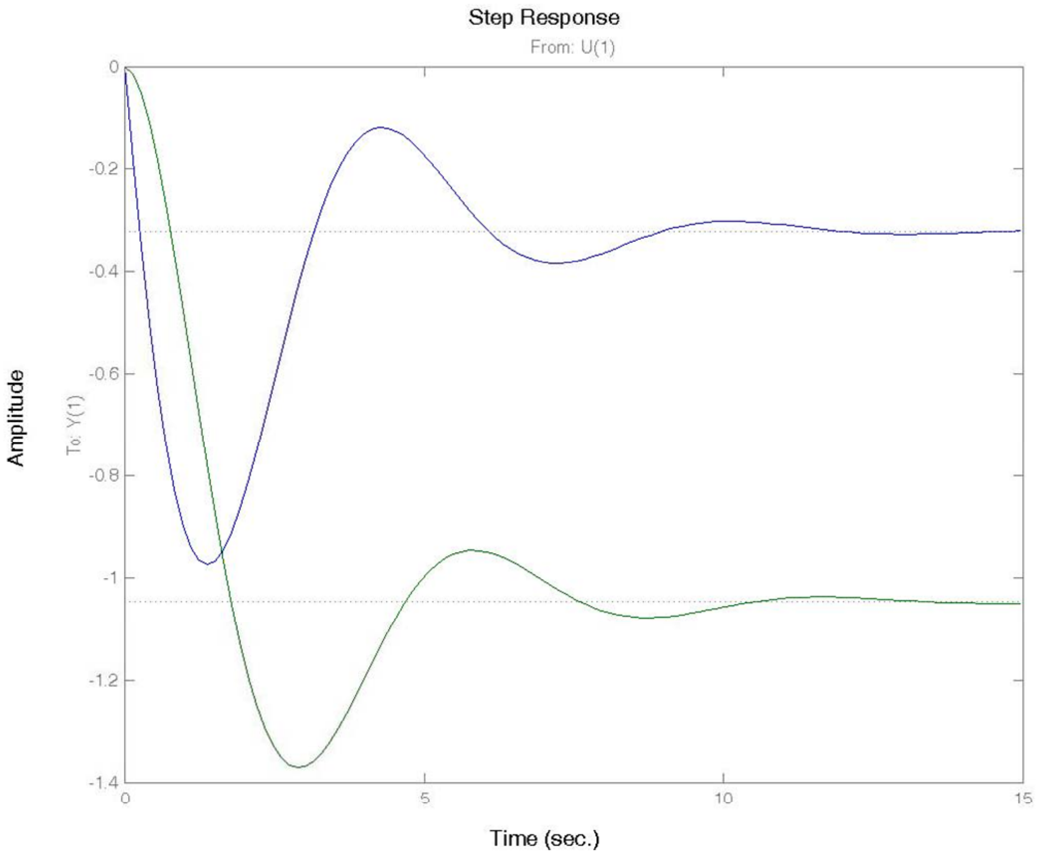
$$1.48\, u(s) + (13.78s + 4.46)\, \alpha(s) - 13.78s\, \theta(s) = -0.246\, \delta_e(s)$$

$$(0.0552s + 0.619)\, \alpha(s) + (0.514s^2 + 0.192s)\theta(s) = -0.710\, \delta_e(s)$$

# 1. Longitudinal auto-pilot

## Displacement AP

**Short period oscillation mode**




Angle of attack α in green

Attitude angle θ in blue

- study of the oscillation frequency and damping factor after the perturbation
- fast damping without effort from the pilot

## Displacement AP

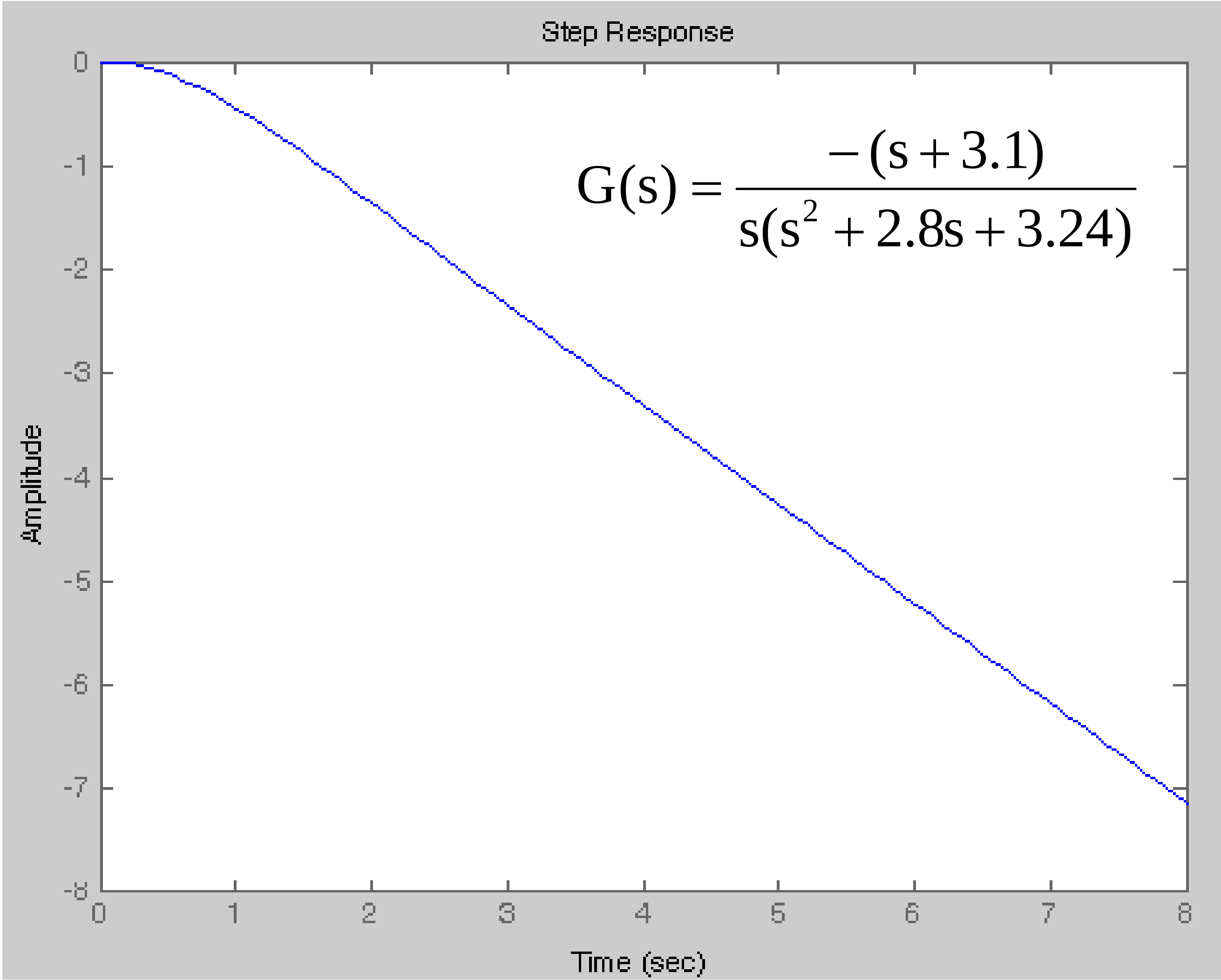
**Short period oscillation mode considered for:**

2 examples:

- conventional transport aircraft flying at 150mph at sea level
- jet flying at 600 ft/sec at 40,000 ft

# 1. Longitudinal auto-pilot

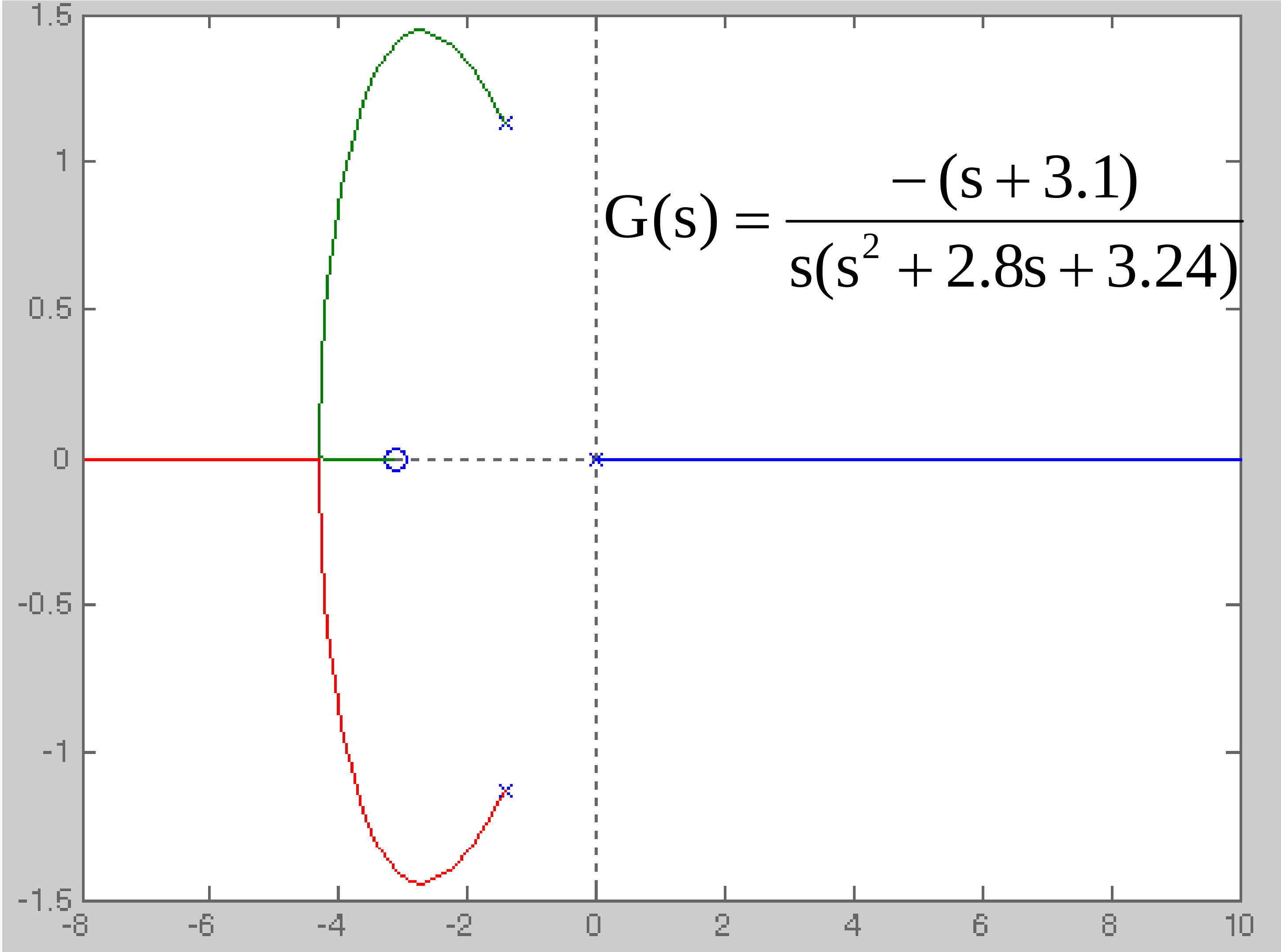
First aircraft




Response to a step entry for a non-corrected TF, in open loop

# 1. Longitudinal auto-pilot

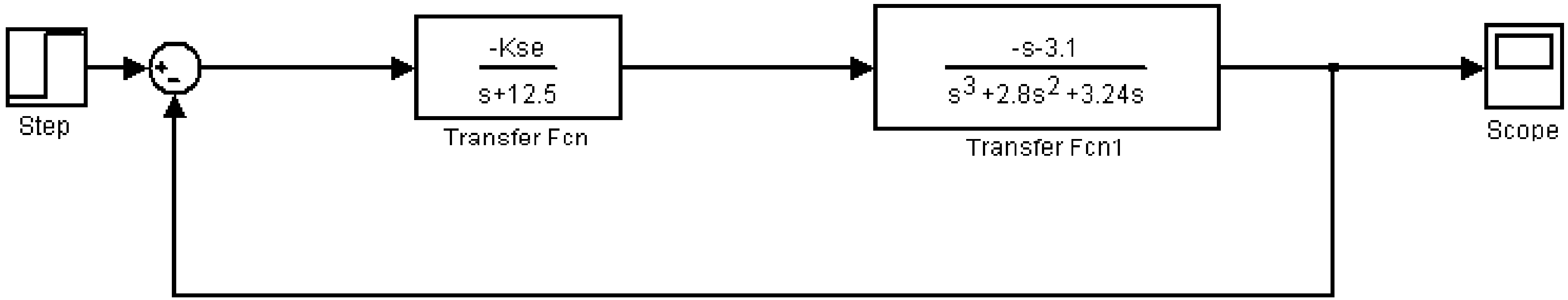
## First aircraft




$$G(s) = \frac{-(s+3.1)}{s(s^2+2.8s+3.24)}$$

Aircraft #1 rootlocus (non-corrected)

## First aircraft, basic correction



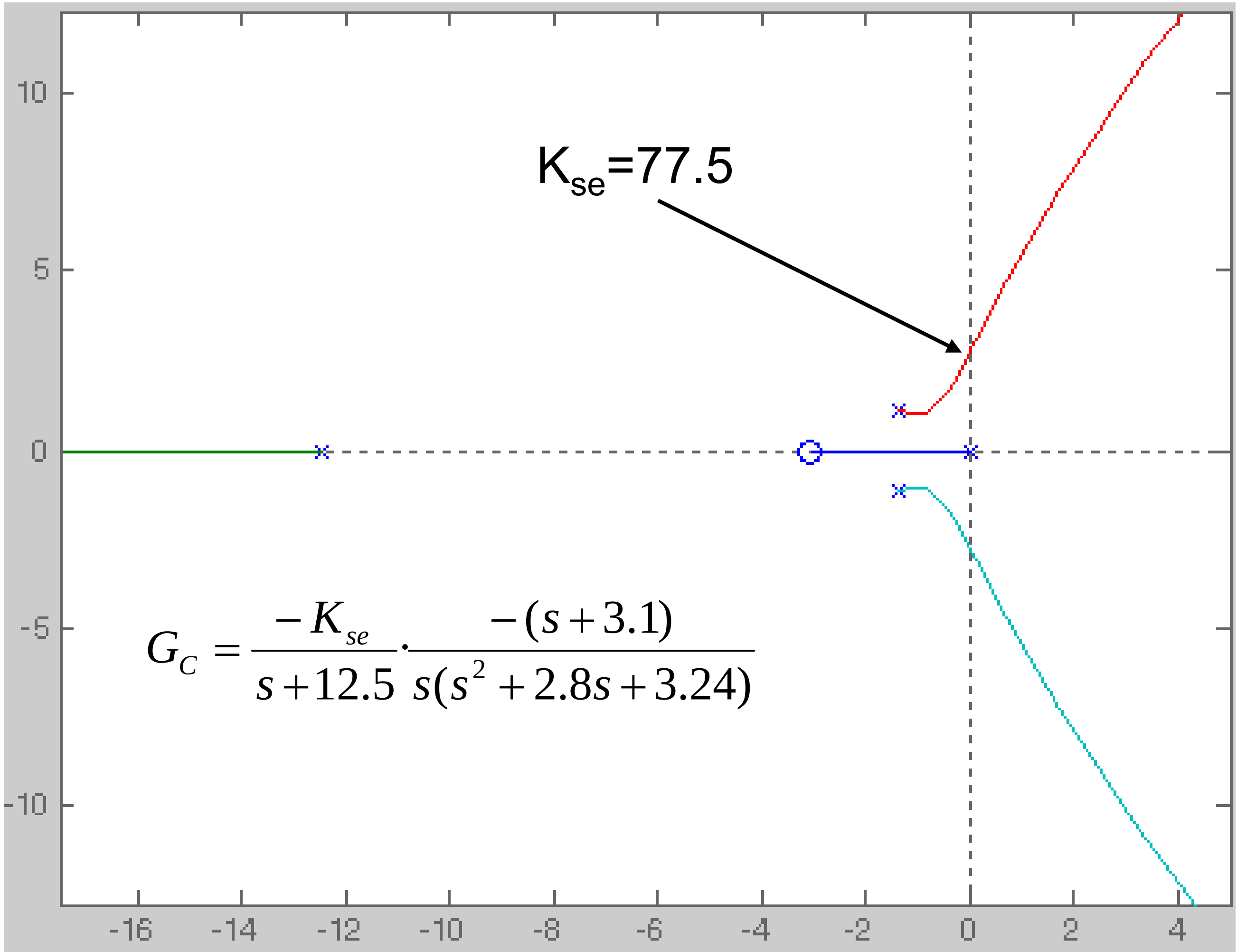

- amplifier: proportional controller: K gain
- servo-elevator: first order system

} 1 block

- vertical gyroscope: sum + sensor (not represented)

# First aircraft,

# basic correction

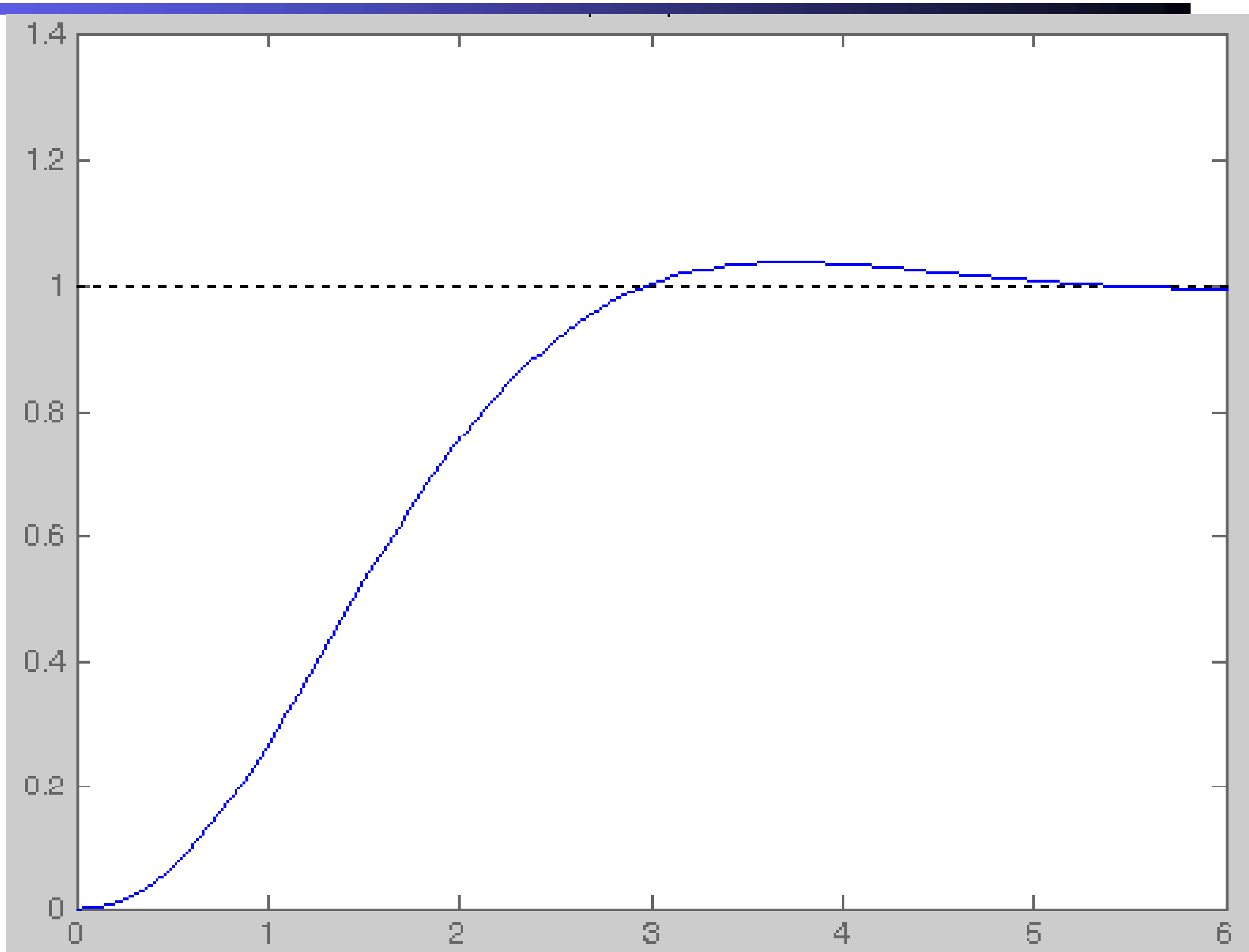



rootlocus, corrected

# 1. Longitudinal auto-pilot

First aircraft,

basic correction

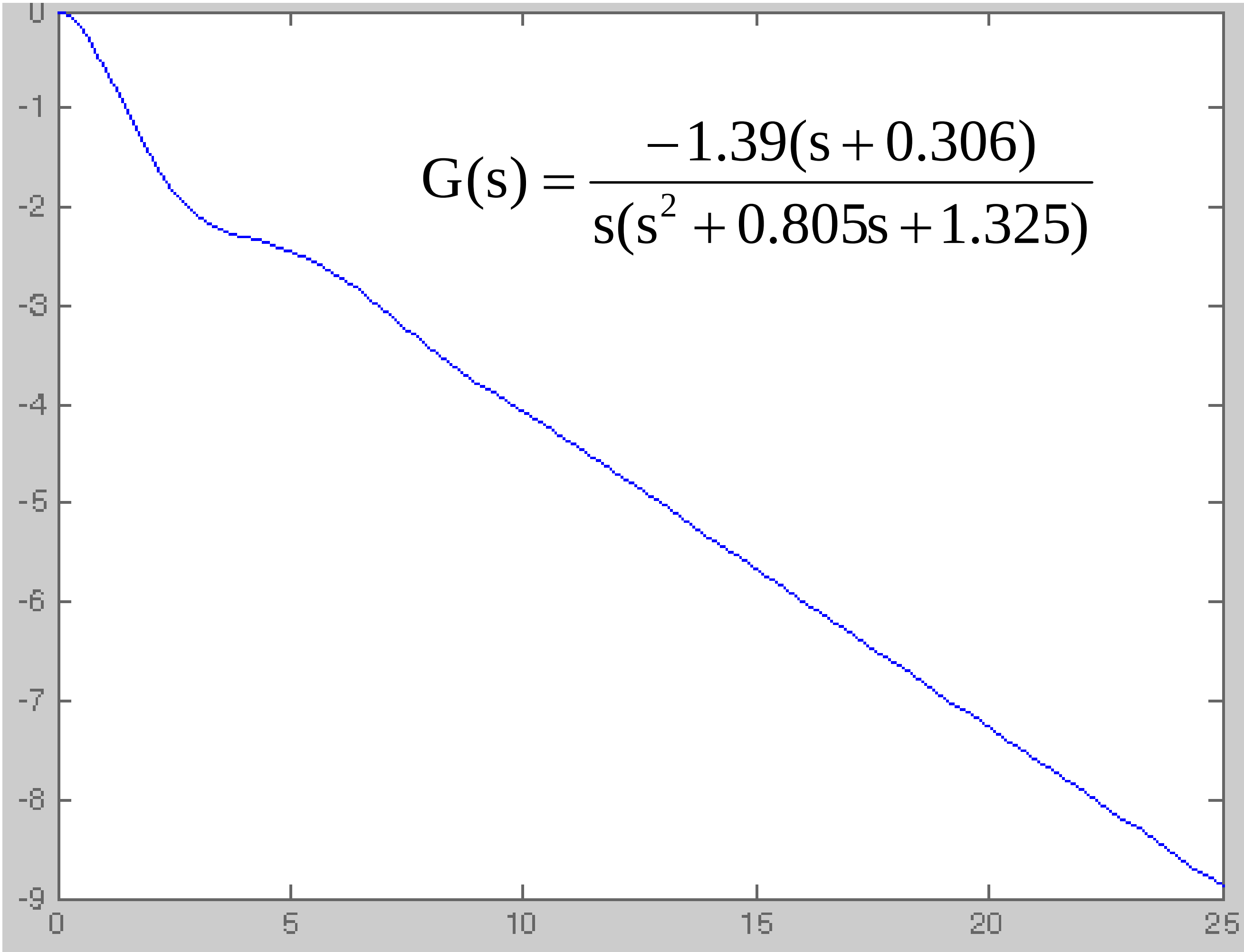



Closed loop response to a step entry,

for $\xi=0.6 \rightarrow K_{se}=8.8$

# 1. Longitudinal auto-pilot

## Second aircraft

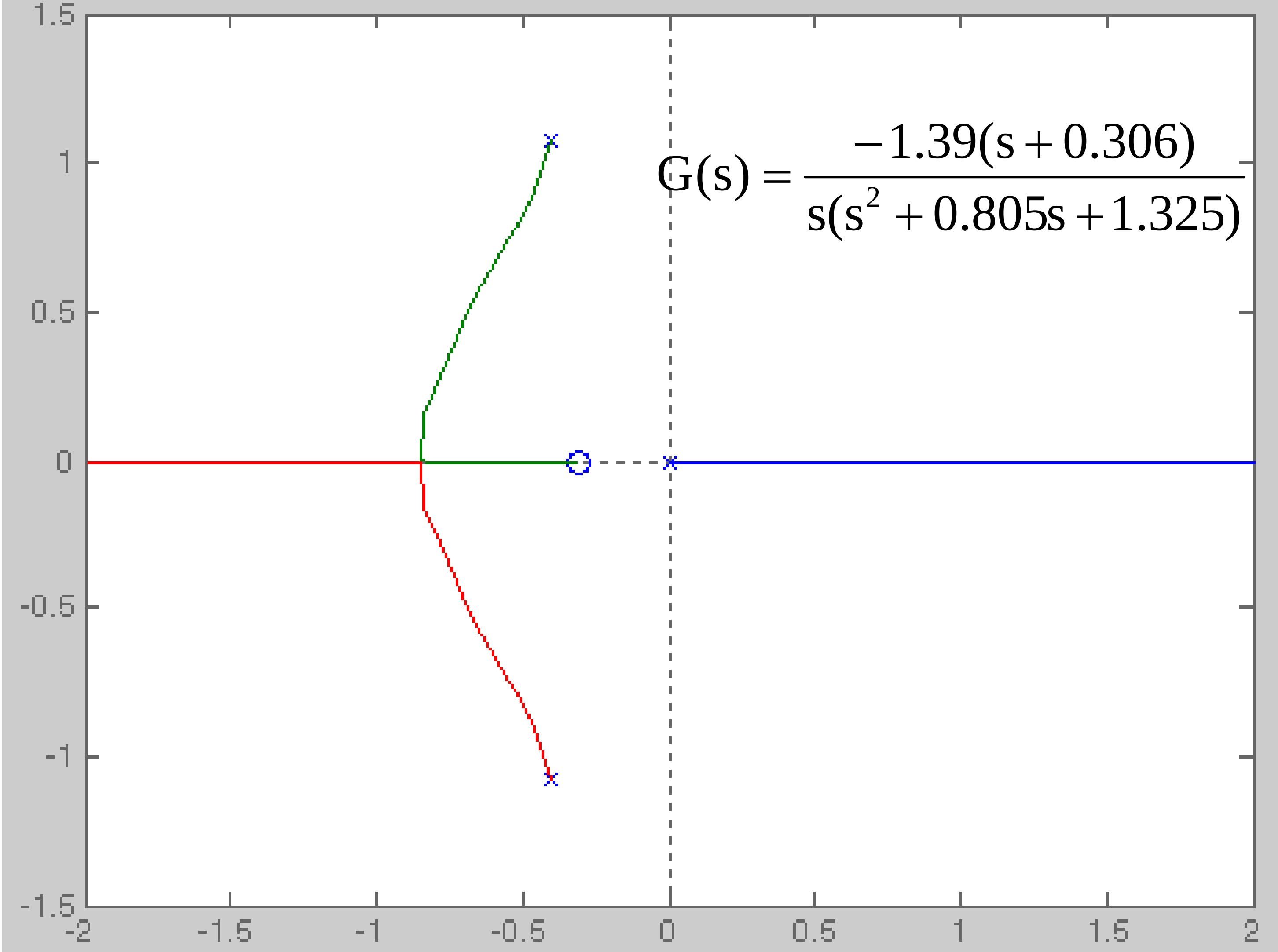



$$G(s) = \frac{-1.39(s+0.306)}{s(s^2+0.805s+1.325)}$$

Step response for a non-corrected TF, in open loop

# 1. Longitudinal auto-pilot

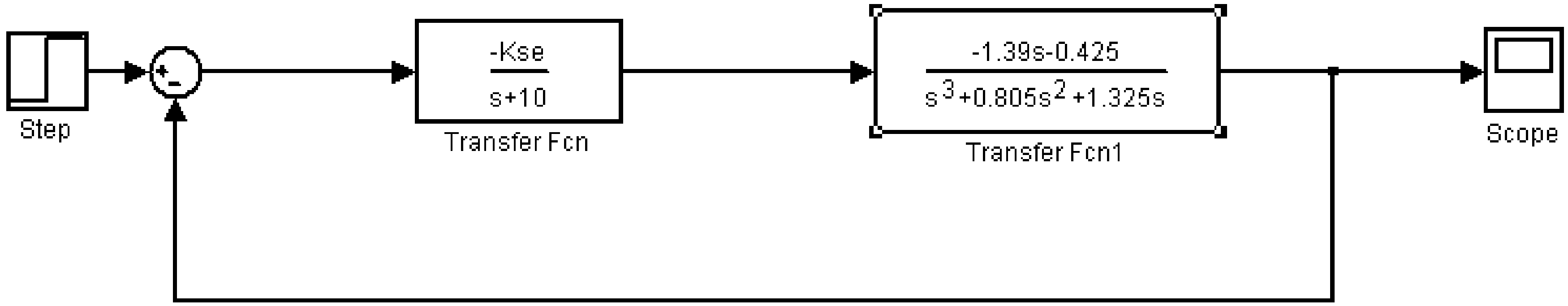
## Second aircraft




$$G(s) = \frac{-1.39(s+0.306)}{s(s^2+0.805s+1.325)}$$

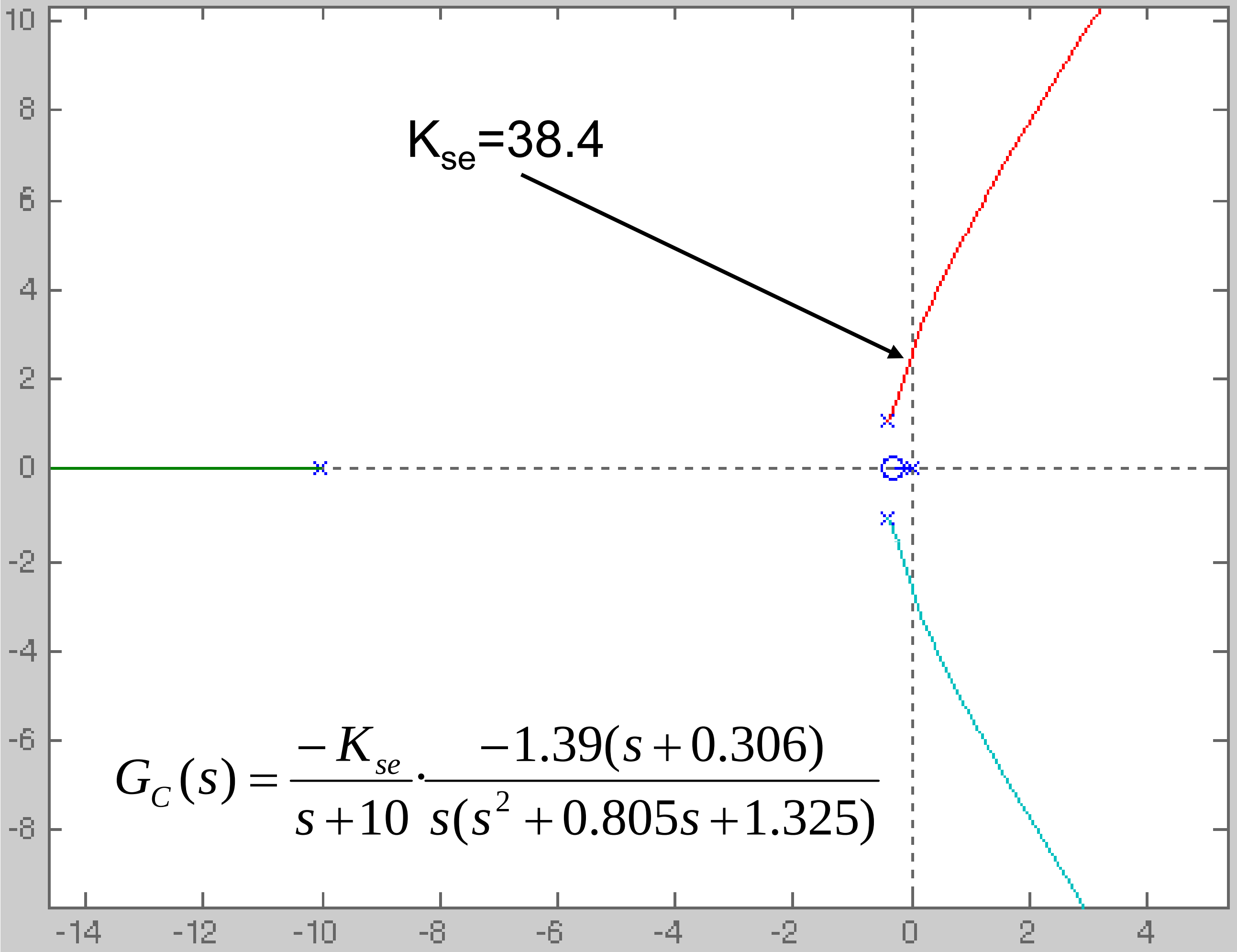
root locus (non-corrected)

## Second aircraft, basic correction



Second Plane,

Basic correction



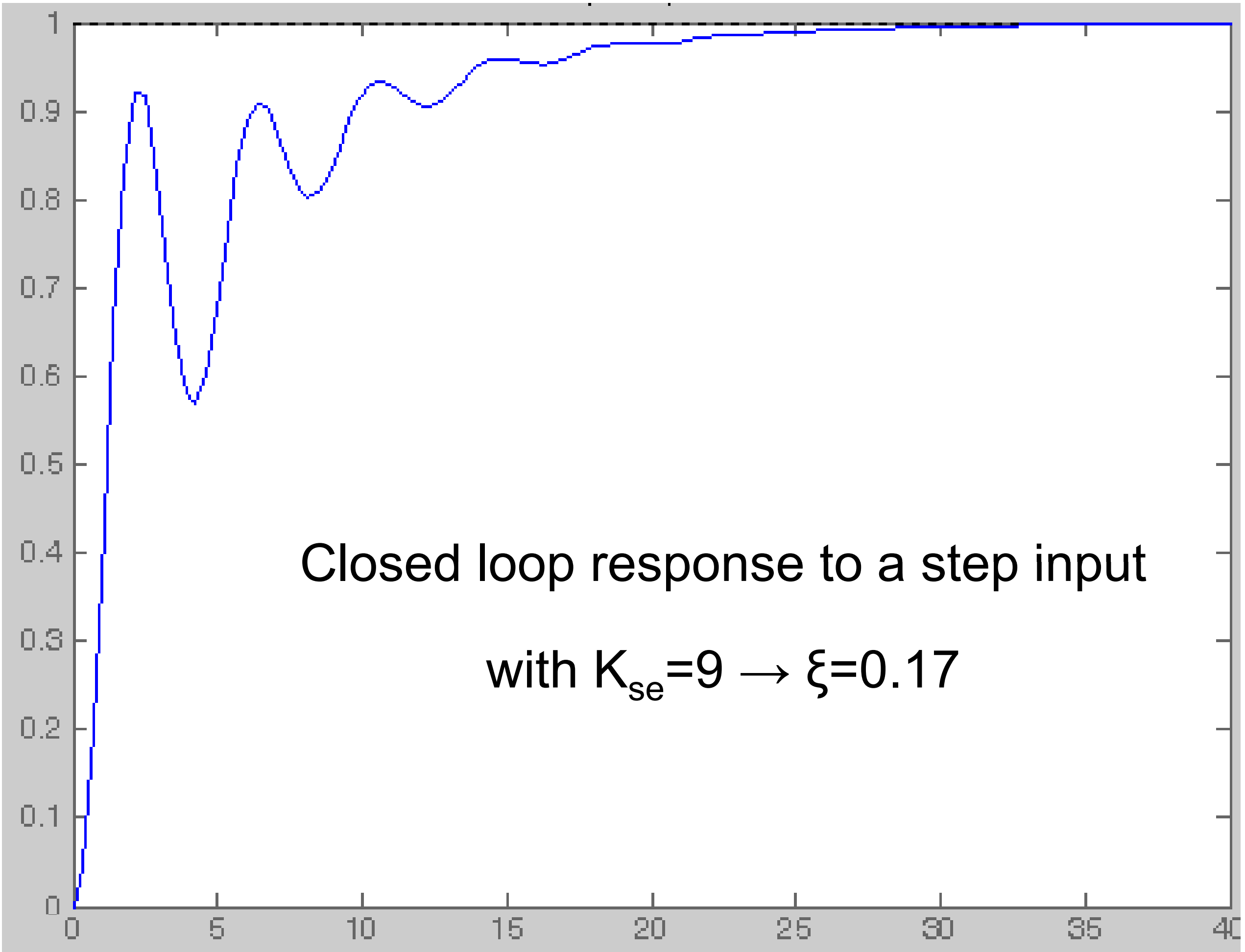

$$G_C(s) = \frac{-K_{se}}{s+10} \cdot \frac{-1.39(s+0.306)}{s(s^2+0.805s+1.325)}$$

corrected rootlocus

# 1. Longitudinal auto-pilot

Second aircraft,

Basic correction

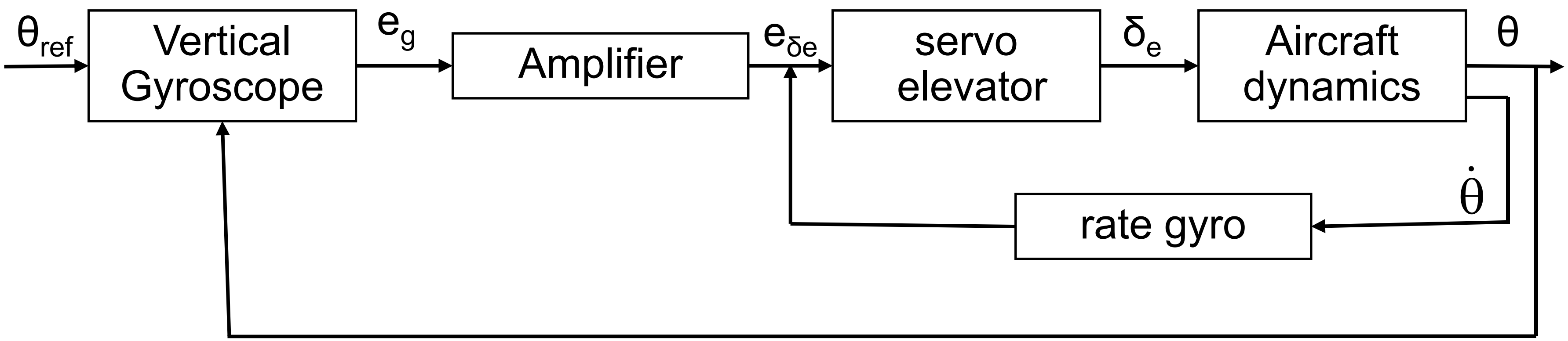



→ **unacceptable response, airplane has very little natural damping and AP is not efficient enough**

# Displacement AP

## Pitch rate feedback

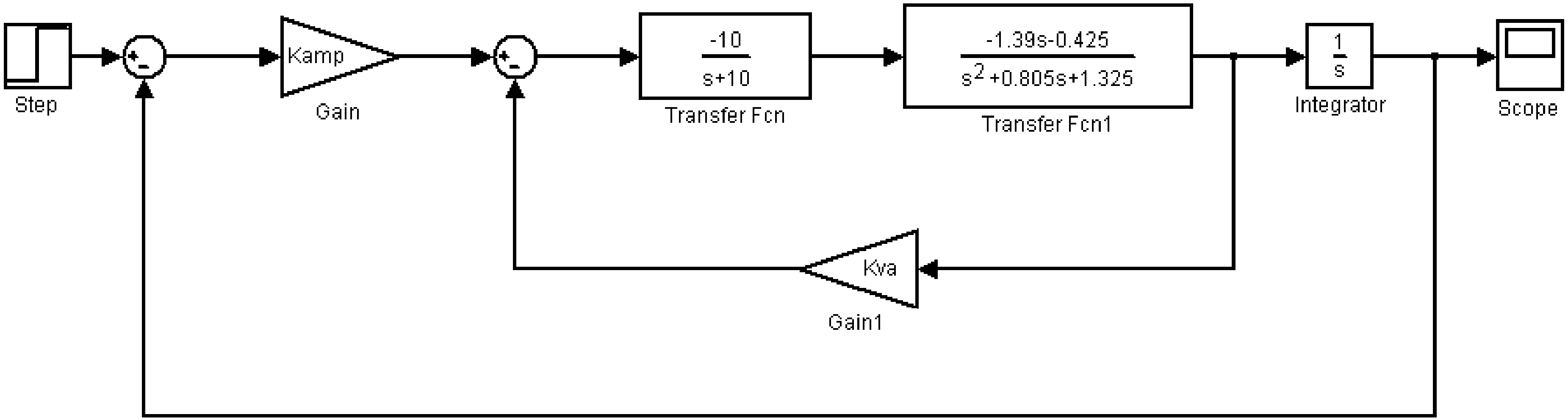
Need to increase damping of the short oscillation mode by adding an inner feedback loop




→ **feedback is added affecting pitch rate**

# Displacement AP

## Pitch rate feedback



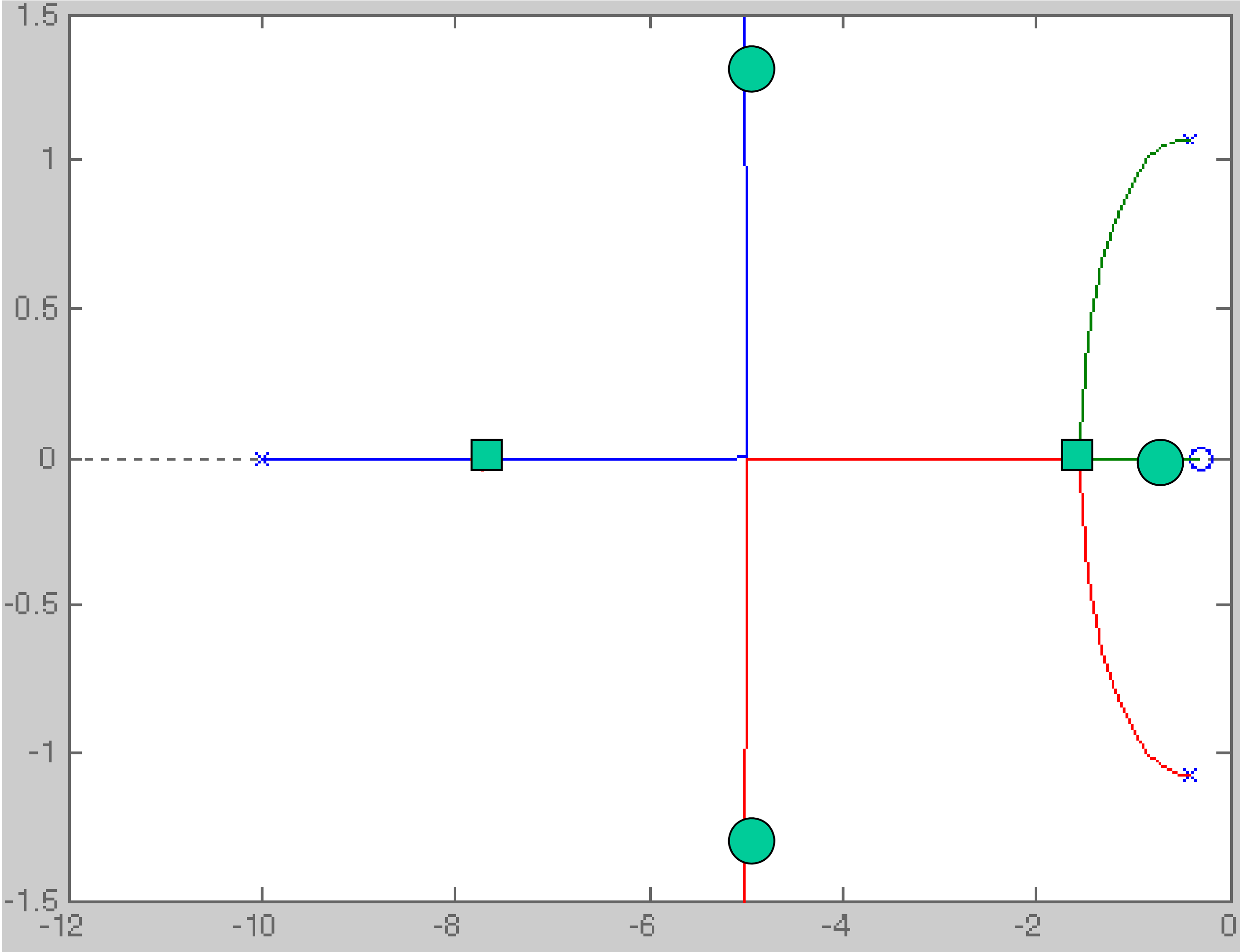

for this problem we now have 2 parameters to select,

using root locus method and trial and error procedure

## Pitch rate feedback

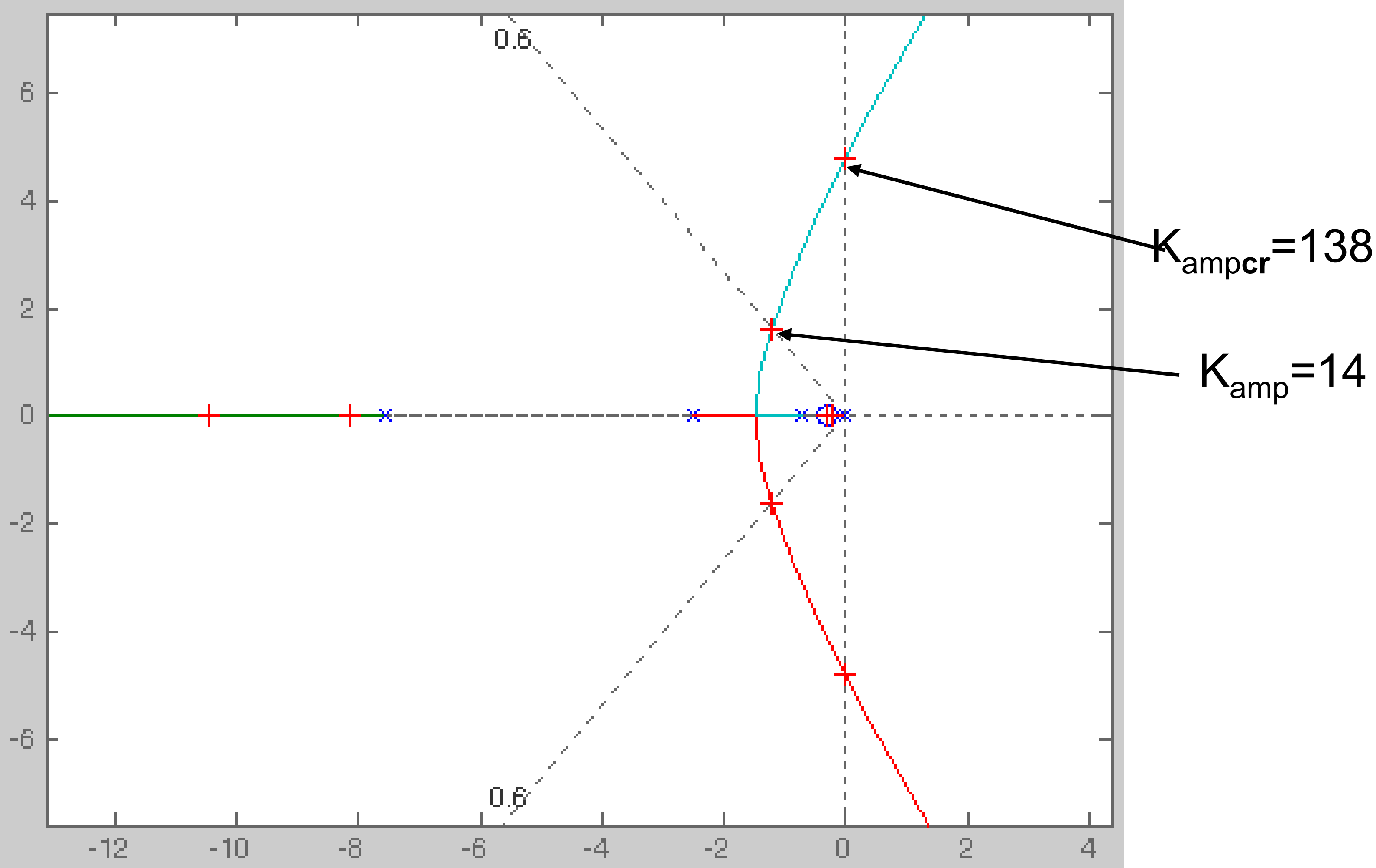
● $K_{va}$=1.82

■ $K_{va}$=1.21



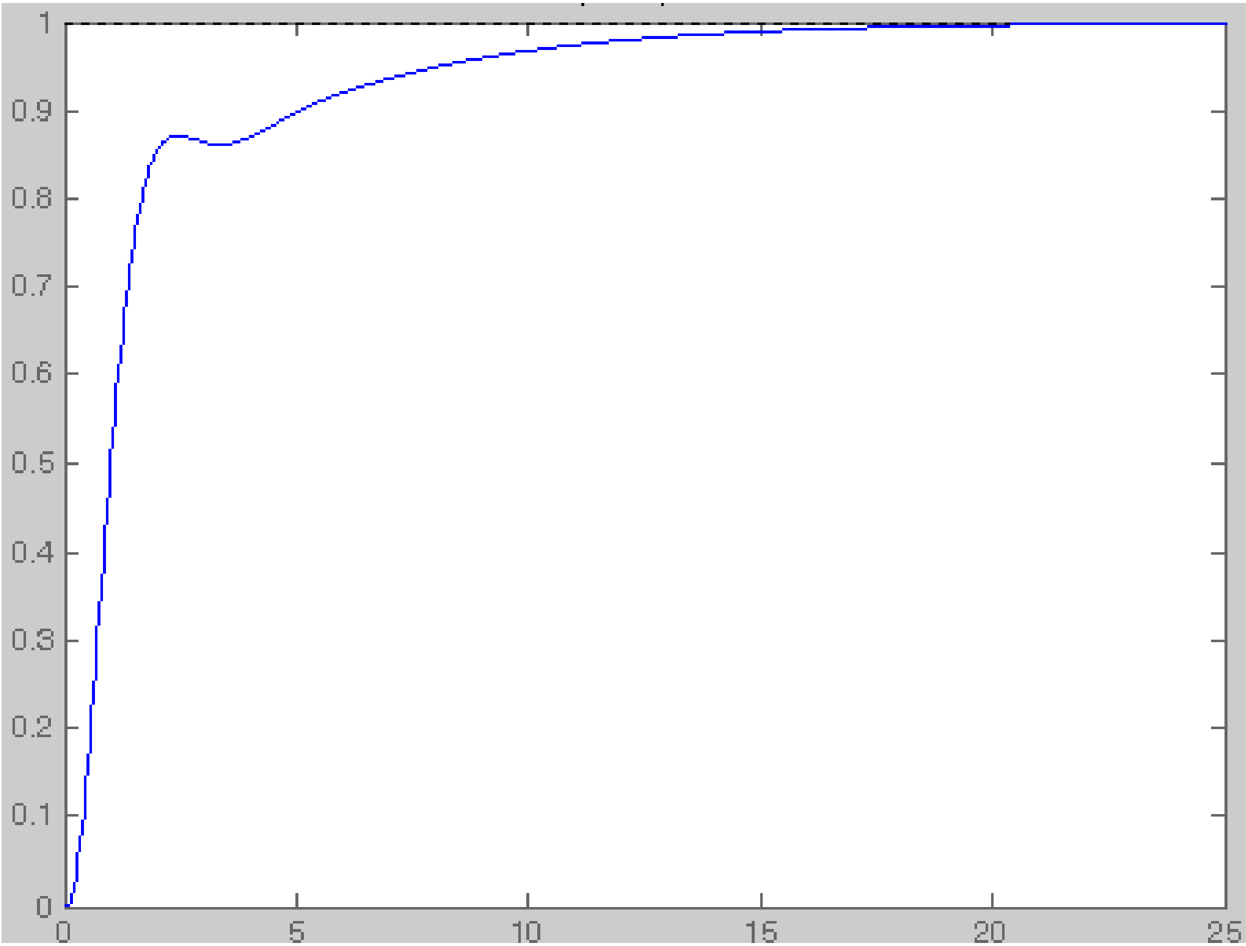

Aircraft 2, rootlocus of the inner loop

## Pitch rate feedback



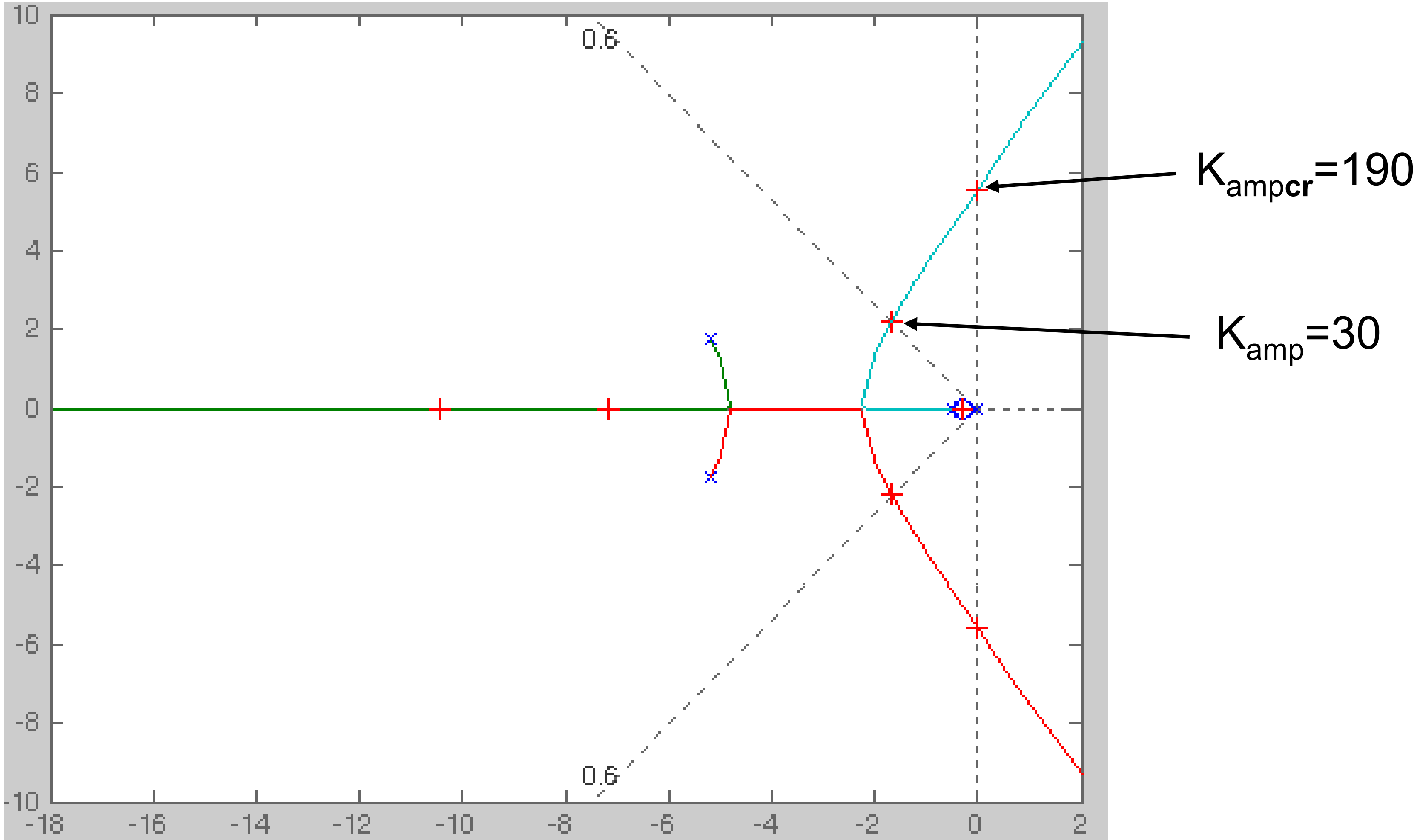

Aircraft 2 rootlocus in the outer loop for $K_{va}$=1.21

## Pitch rate feedback



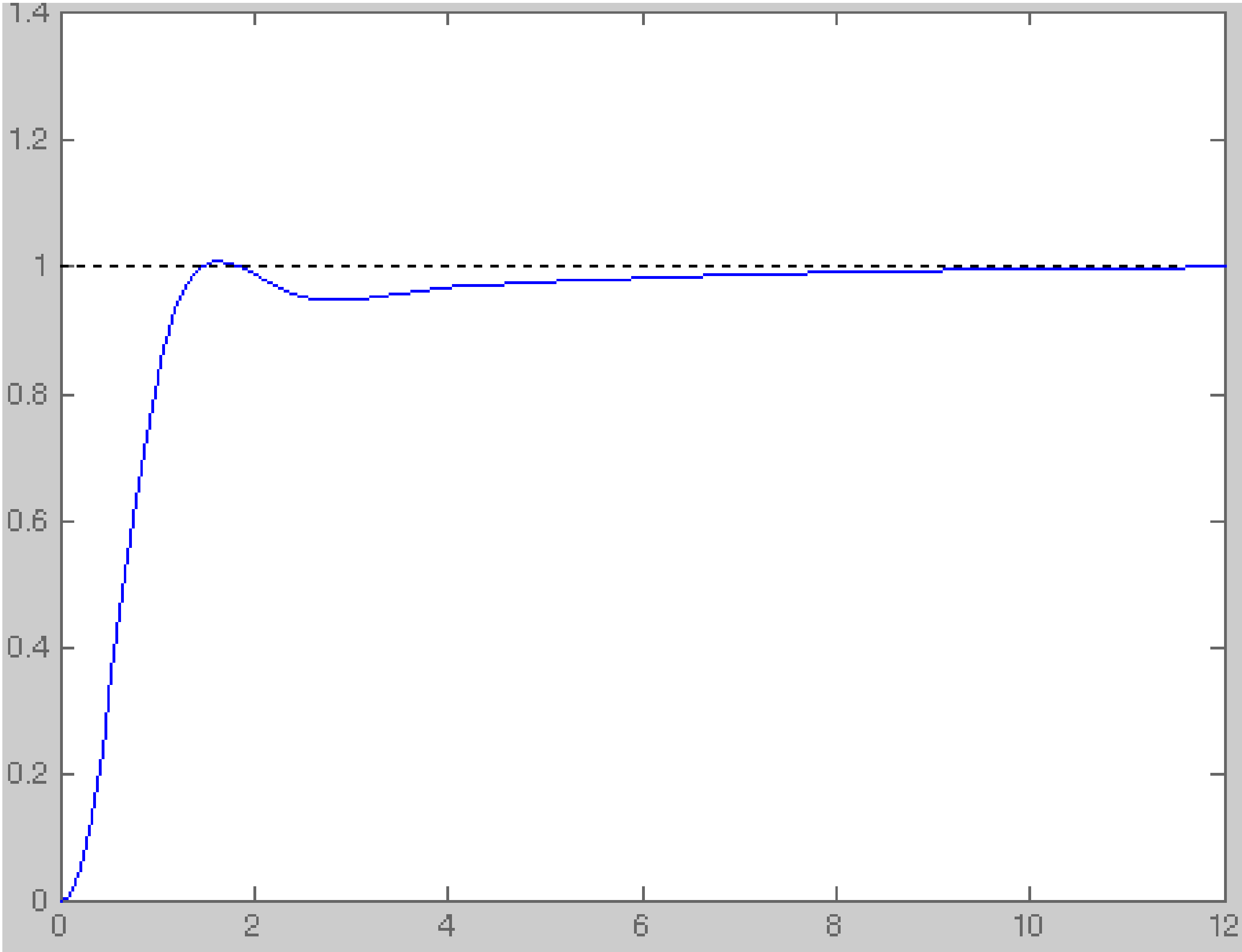

Step response for $K_{amp}$=14

## Pitch rate feedback



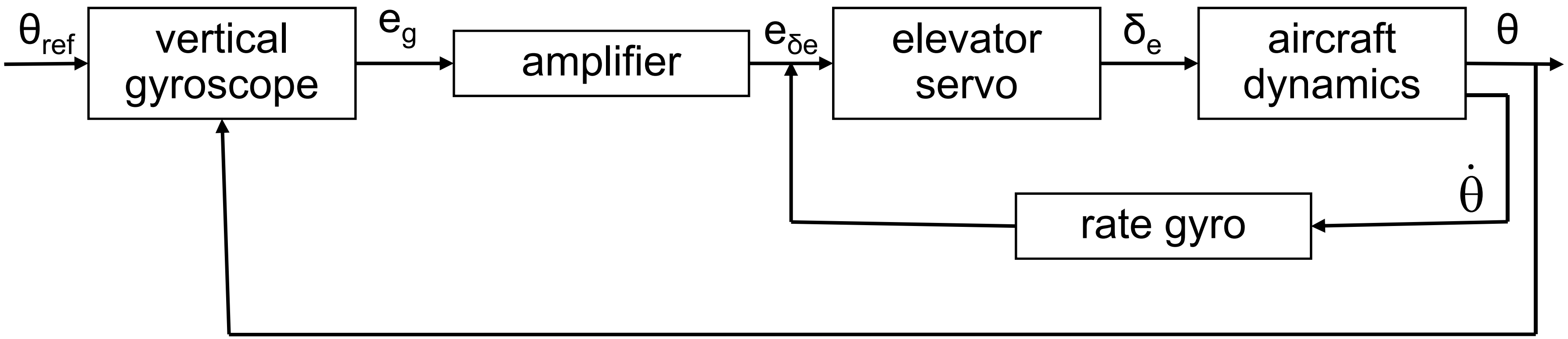

Aircraft 2 rootlocus in the outer loop for $K_{va}$=1.82

## Pitch rate feedback




Step response for $K_{amp}$=30

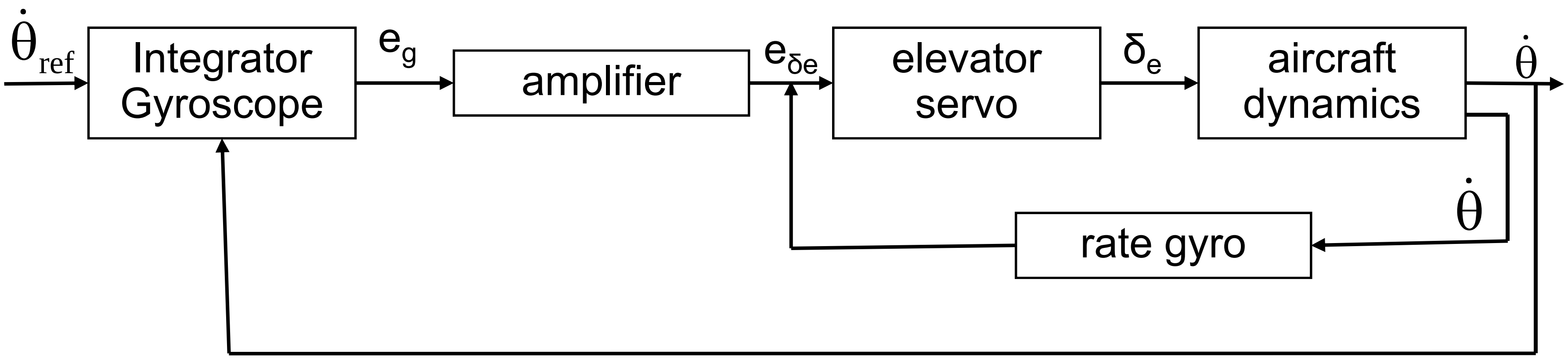
## Displacement AP




- no rule to select $K_{va}$ but, for a bigger $K_{va}$ value, bigger stability margin and faster response is obtained
- pitch rate feedback controls the jet well enough, but is always better to have a Type I system (here we had it already) to cancel the position error in steady state

## Speed AP

Input: desired pitch rate; to obtain a type I system a integrator gyro is added through a direct loop




*Control stick steering* used to position the elevator, and keeping pressure on the stick, pitch rate is maintained

## Speed AP

Used in aircraft with bad longitudinal stability

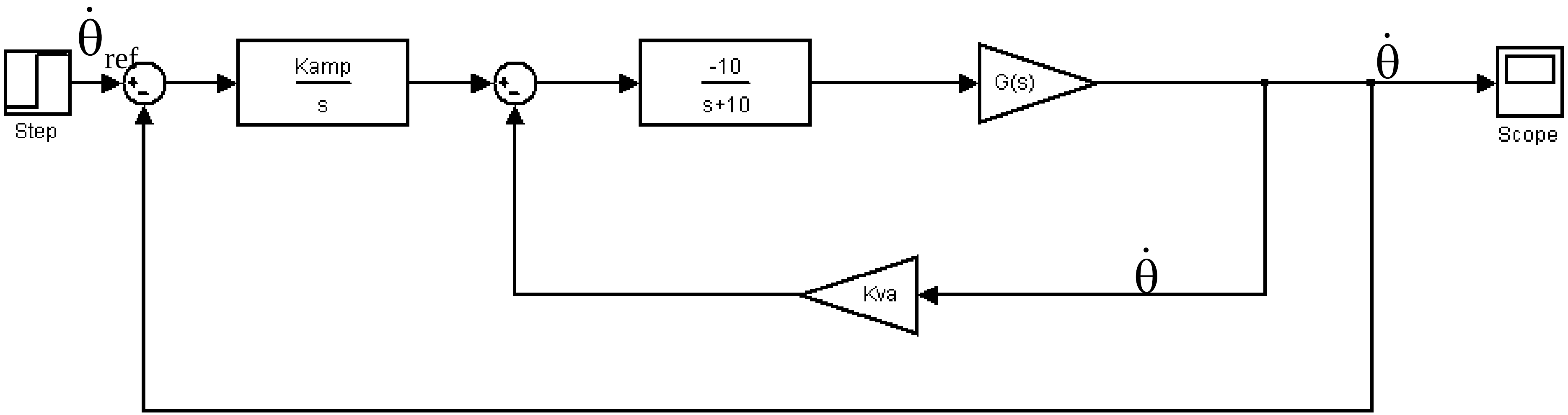
→ *pitch up* occurs, which causes stall for great angles of attack

→ either you use a limiter of angle of attack

→ or a automatic control system is used, which would allow the aircraft to fly with angles of attack higher than the critical one

## Speed AP

Study case: *high performance combat fighter*:




$$G_1(s) = \frac{\dot{\theta}}{\delta_e} = \frac{-15(s+0.4)}{s^2+0.9s+8}$$

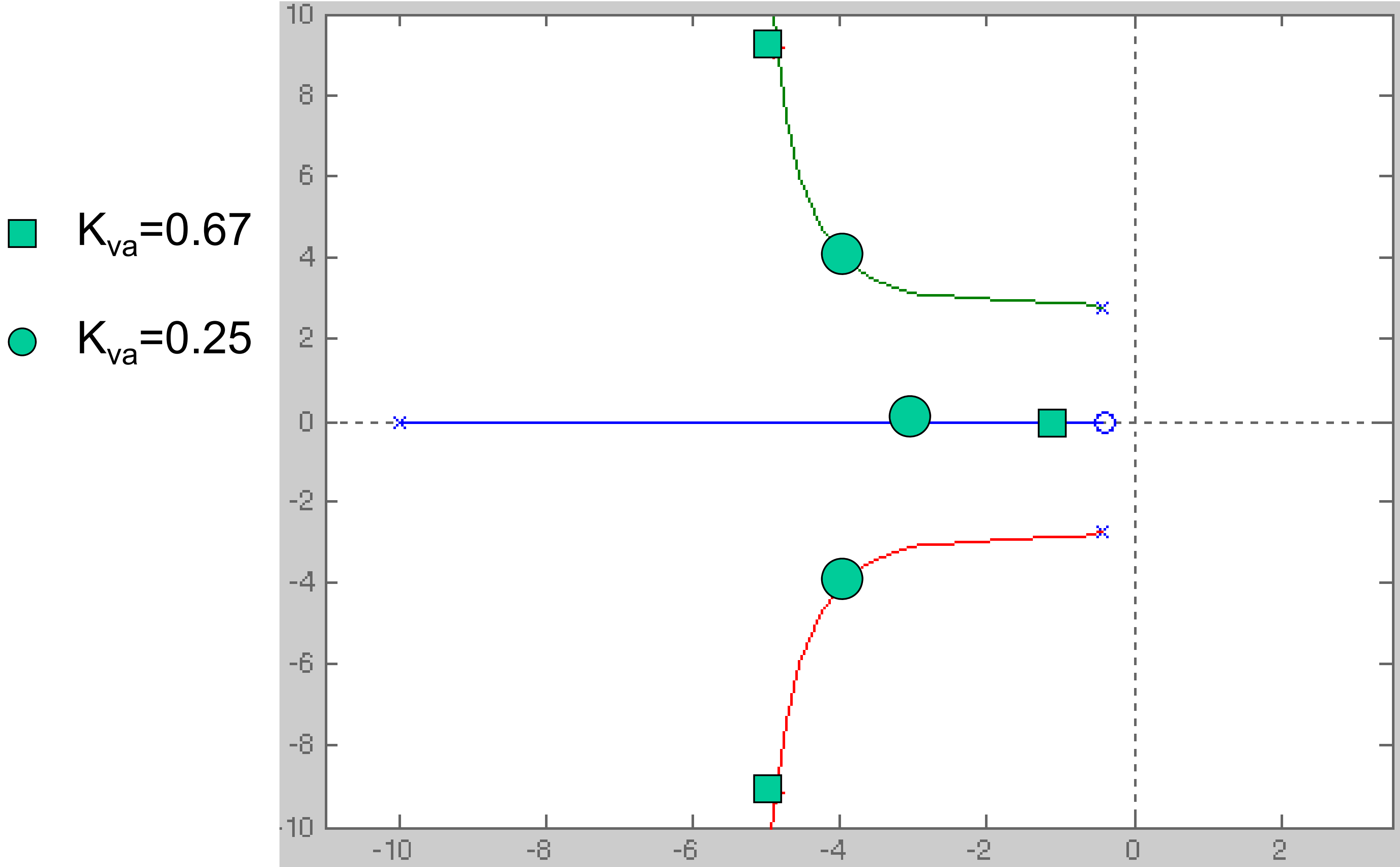
For low angles of attack (stable condition)

$$G_2(s) = \frac{\dot{\theta}}{\delta_e} = \frac{-9(s+0.3)}{(s+3.8)(s-2.9)}$$

For high angles of attack (unstable condition)

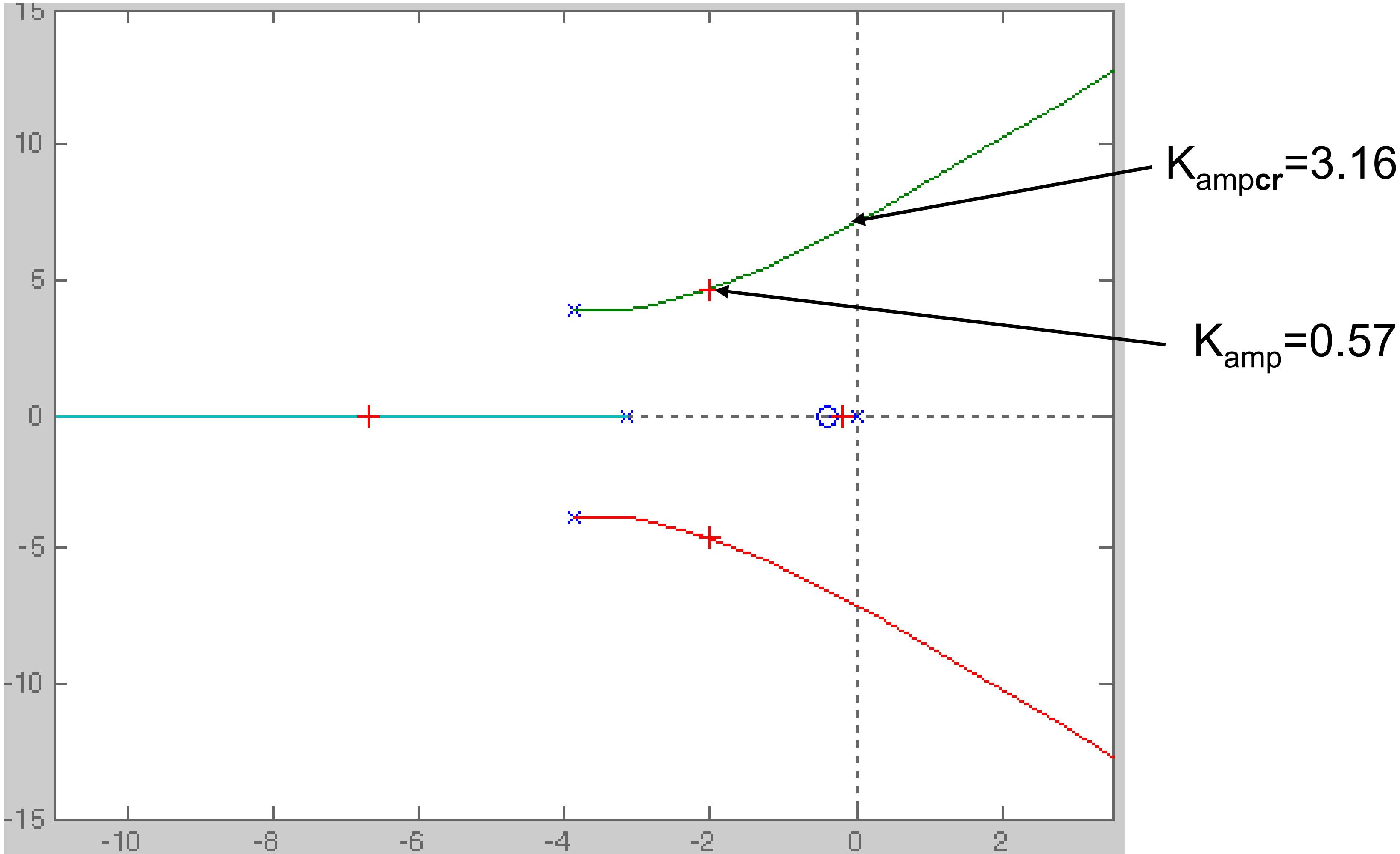
# 1. Longitudinal auto-pilot

## Stable condition, internal loop



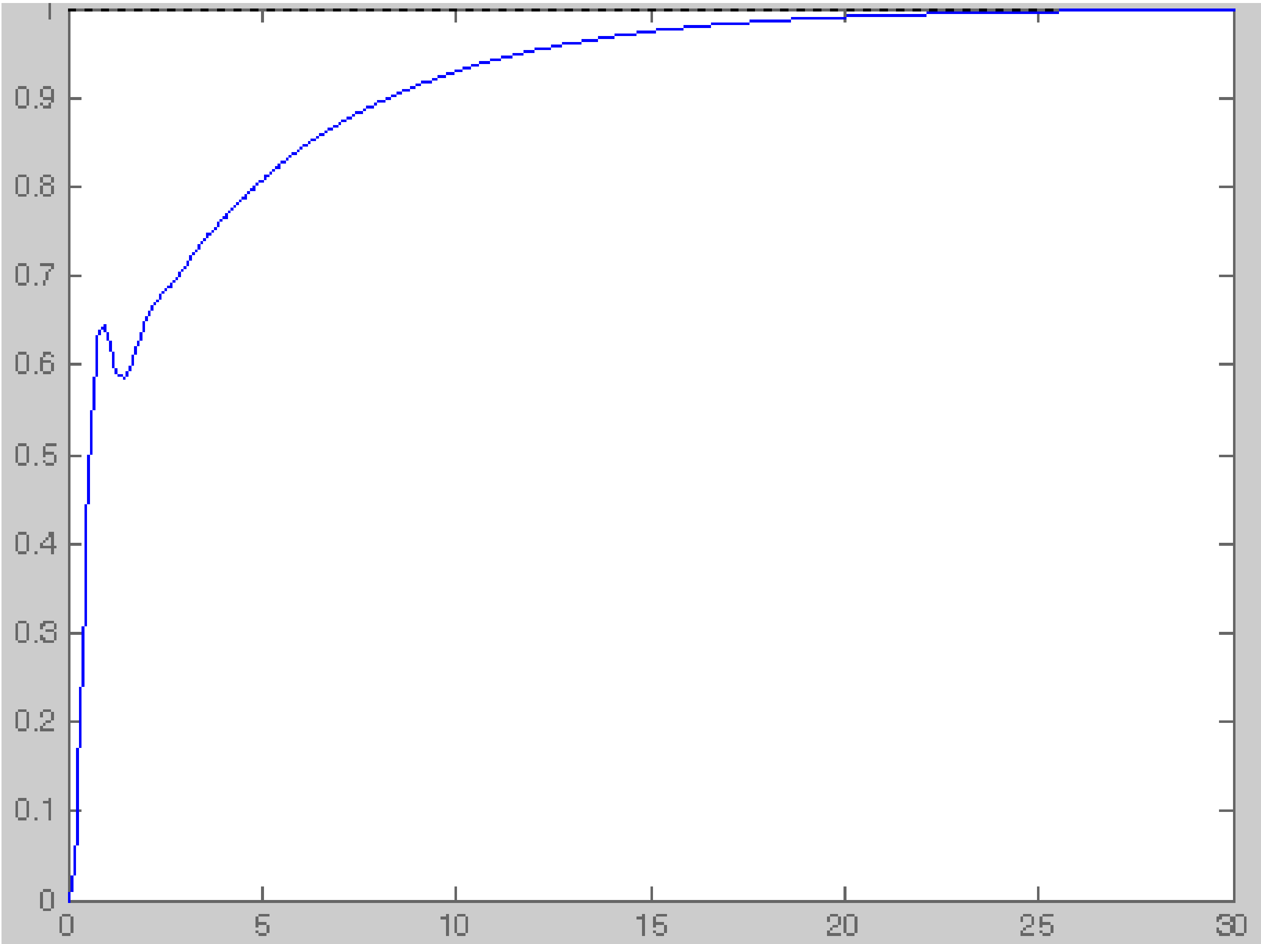

Root locus of the inner loop for low angles of attack

## Stable condition, external loop




Outer loop root locus, for $K_{va}$=0.25

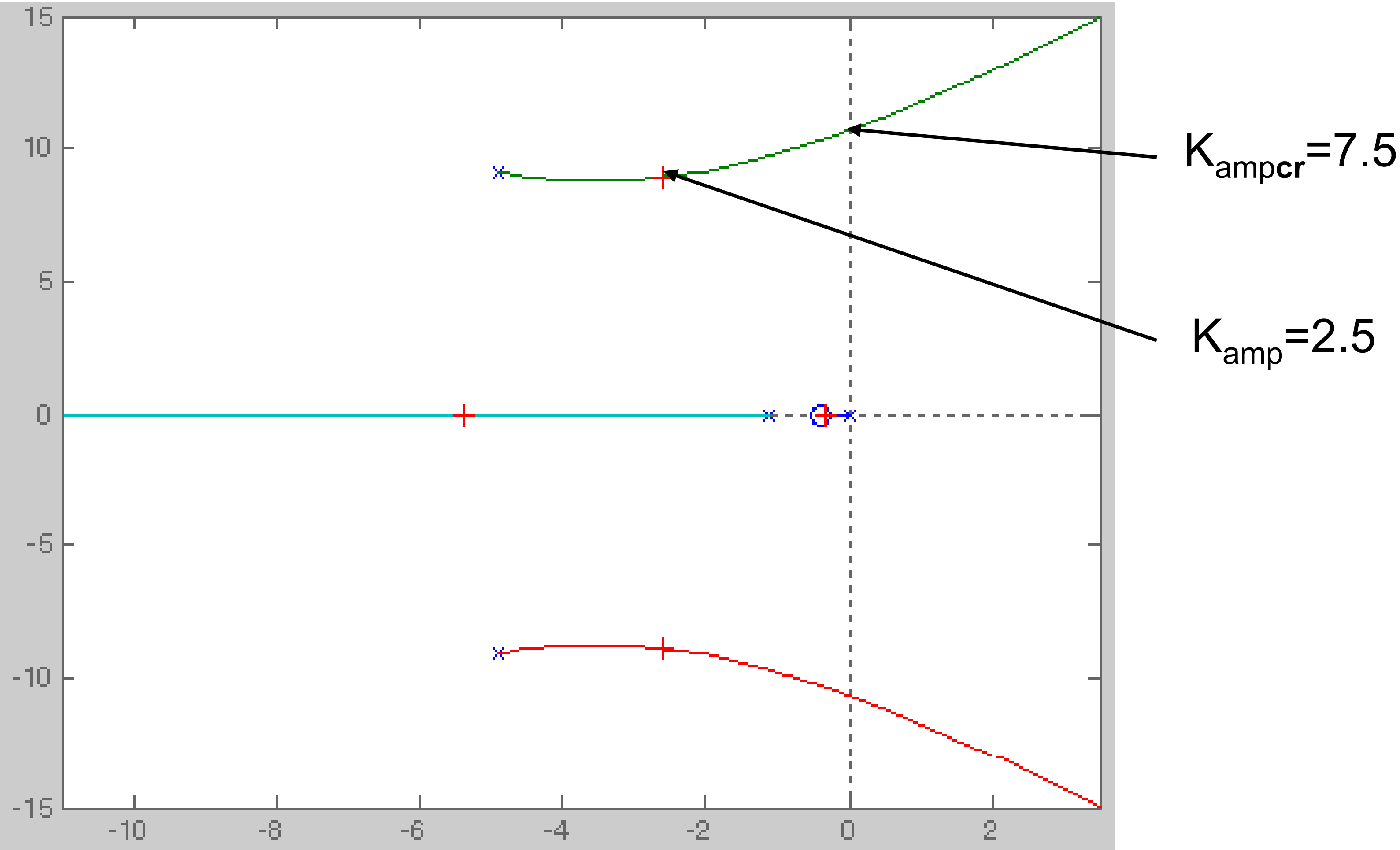
## Stable condition, step response




Step response for $K_{va}$=0.25 and $K_{amp}$=0.57

# 1. Longitudinal auto-pilot

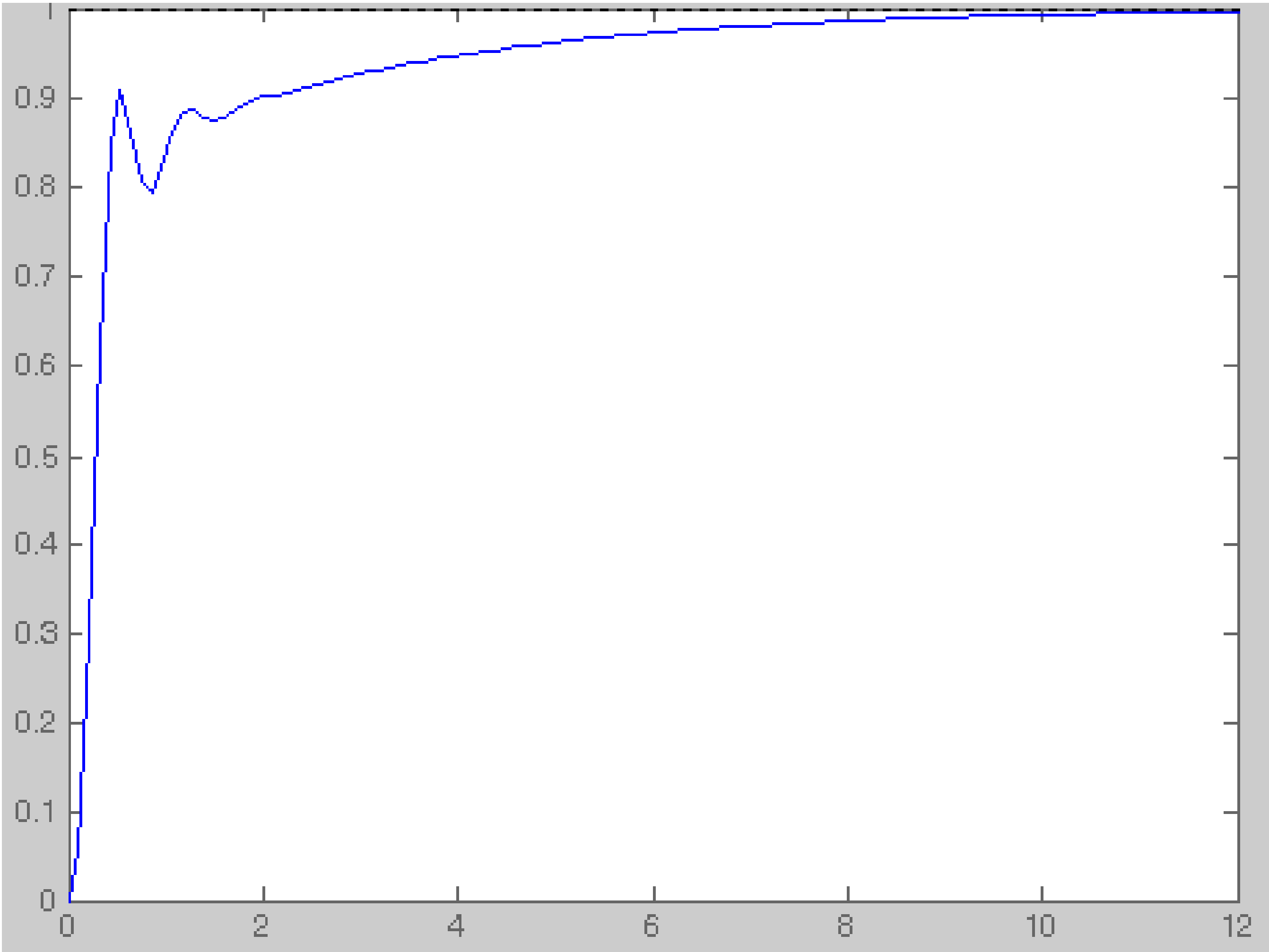
## Stable condition, external loop




Outer loop root locus, for $K_{va}$=0.67

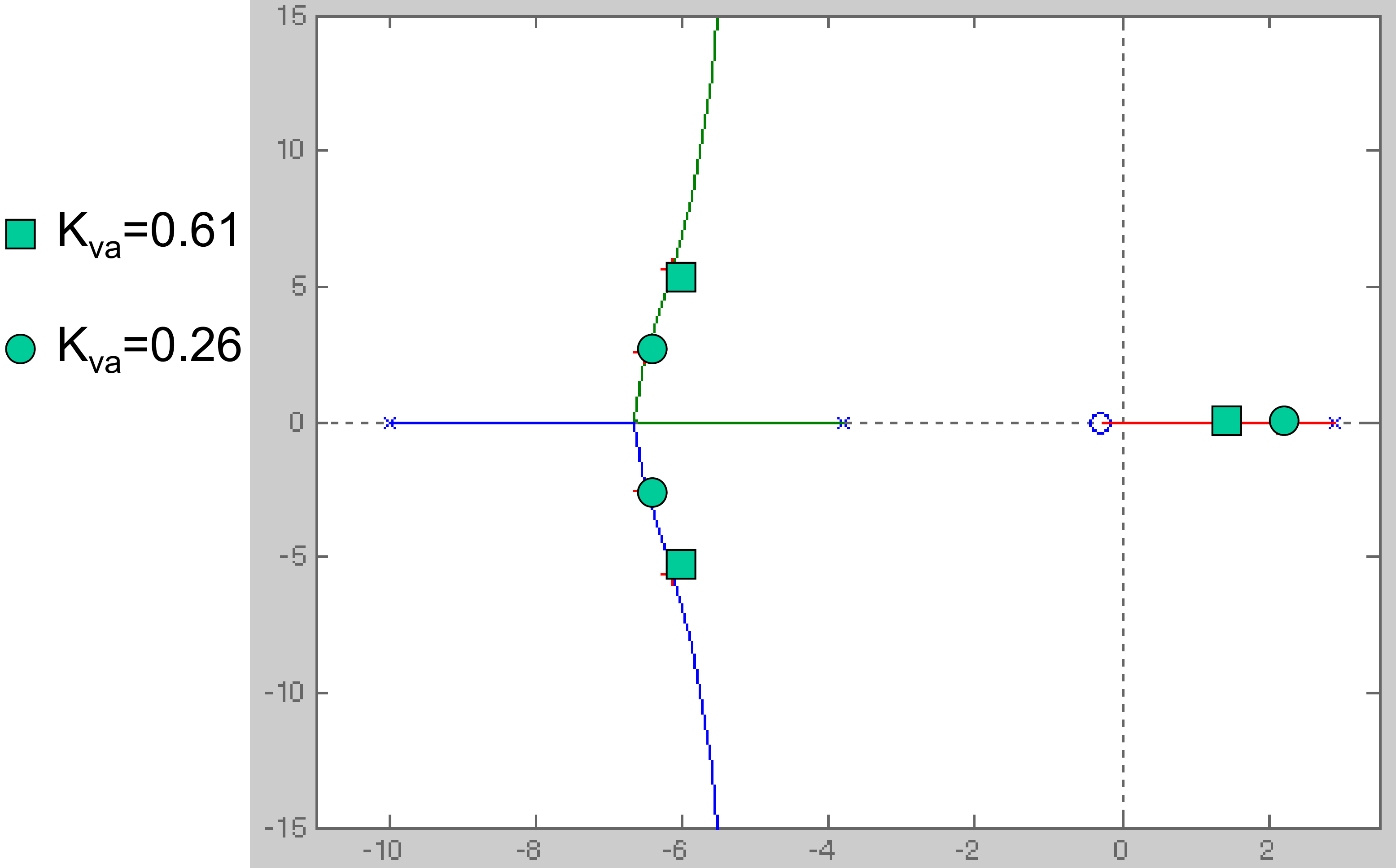
# 1. Longitudinal auto-pilot

## Stable condition, step response



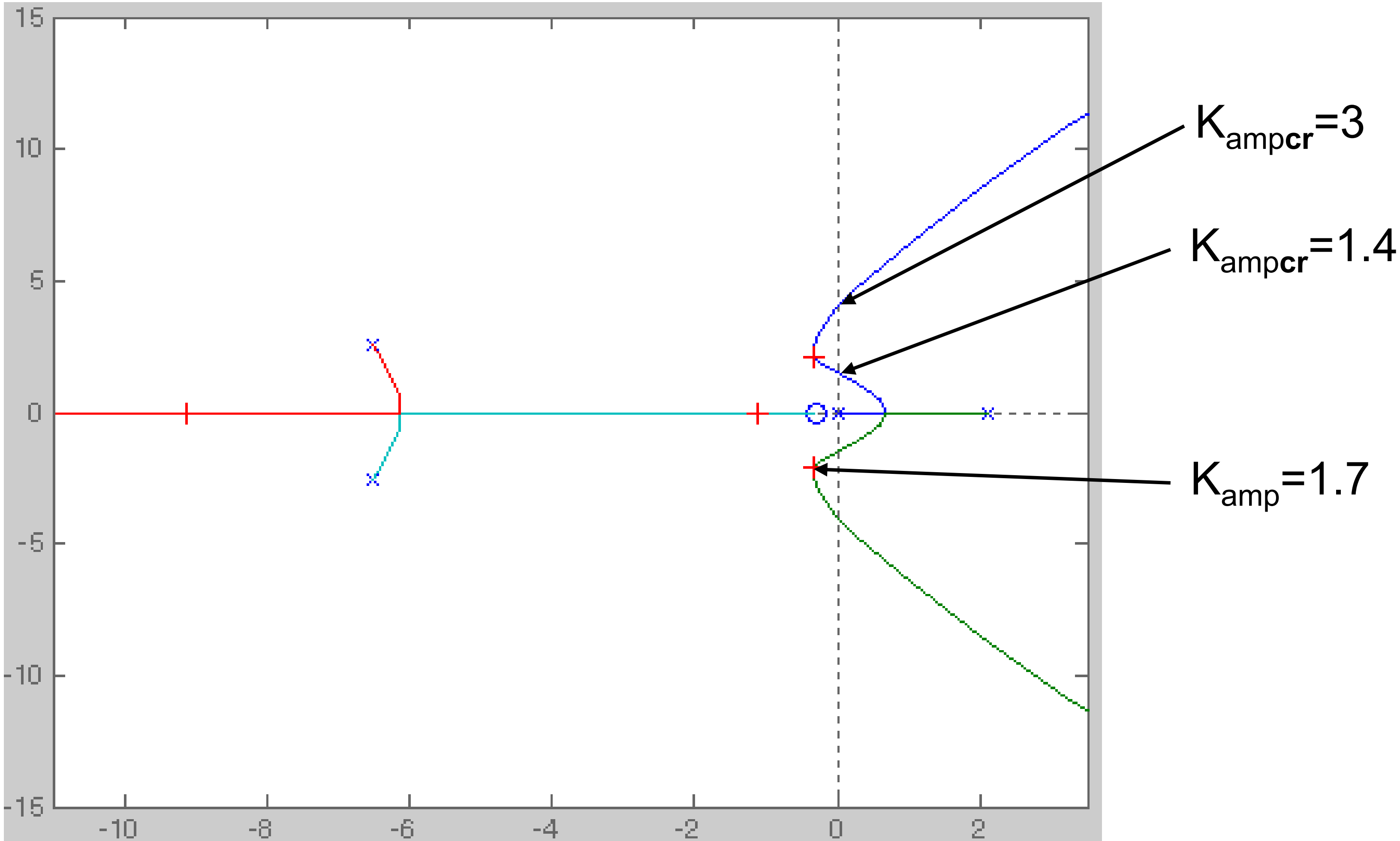

Step response for $K_{va}$=0.67 and $K_{amp}$=2.5

## Unstable condition, internal loop




Inner loop root locus for high angle of attack

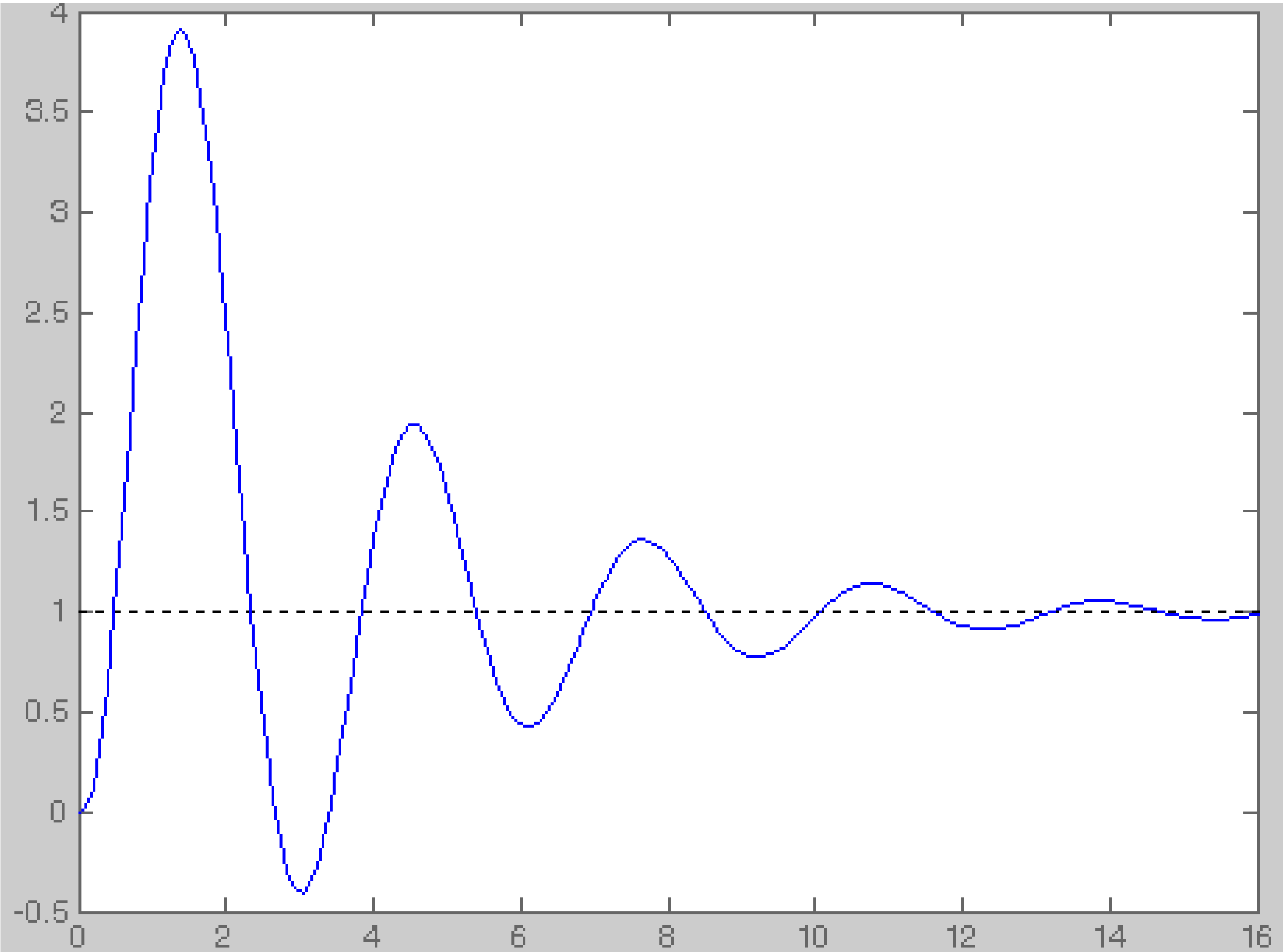
## Unstable condition, external loop




Outer loop root locus for $K_{va}$=0.26

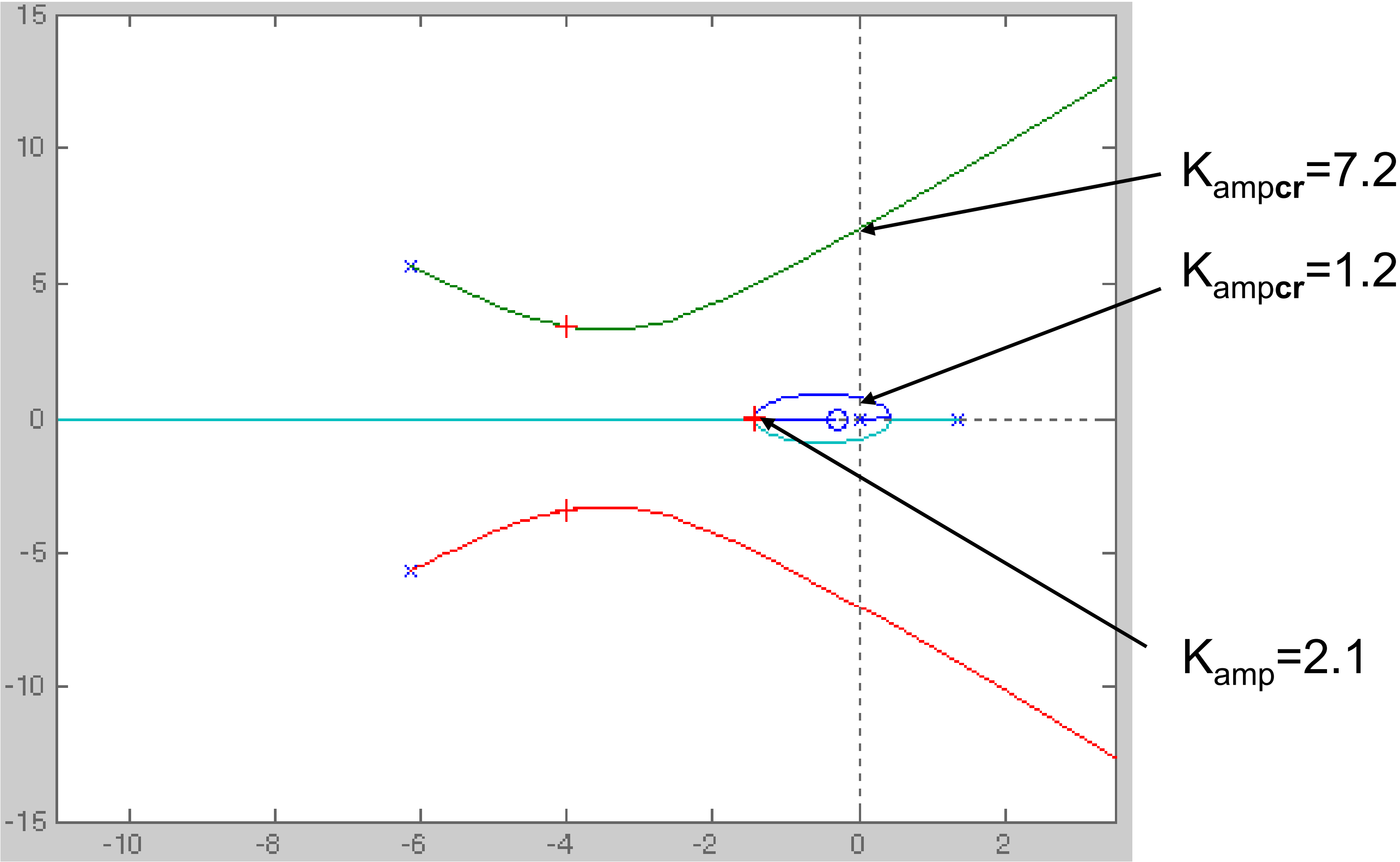
# 1. Longitudinal auto-pilot

## Unstable condition, step response




Step response for $K_{va}$=0.26 and $K_{amp}$=1.7

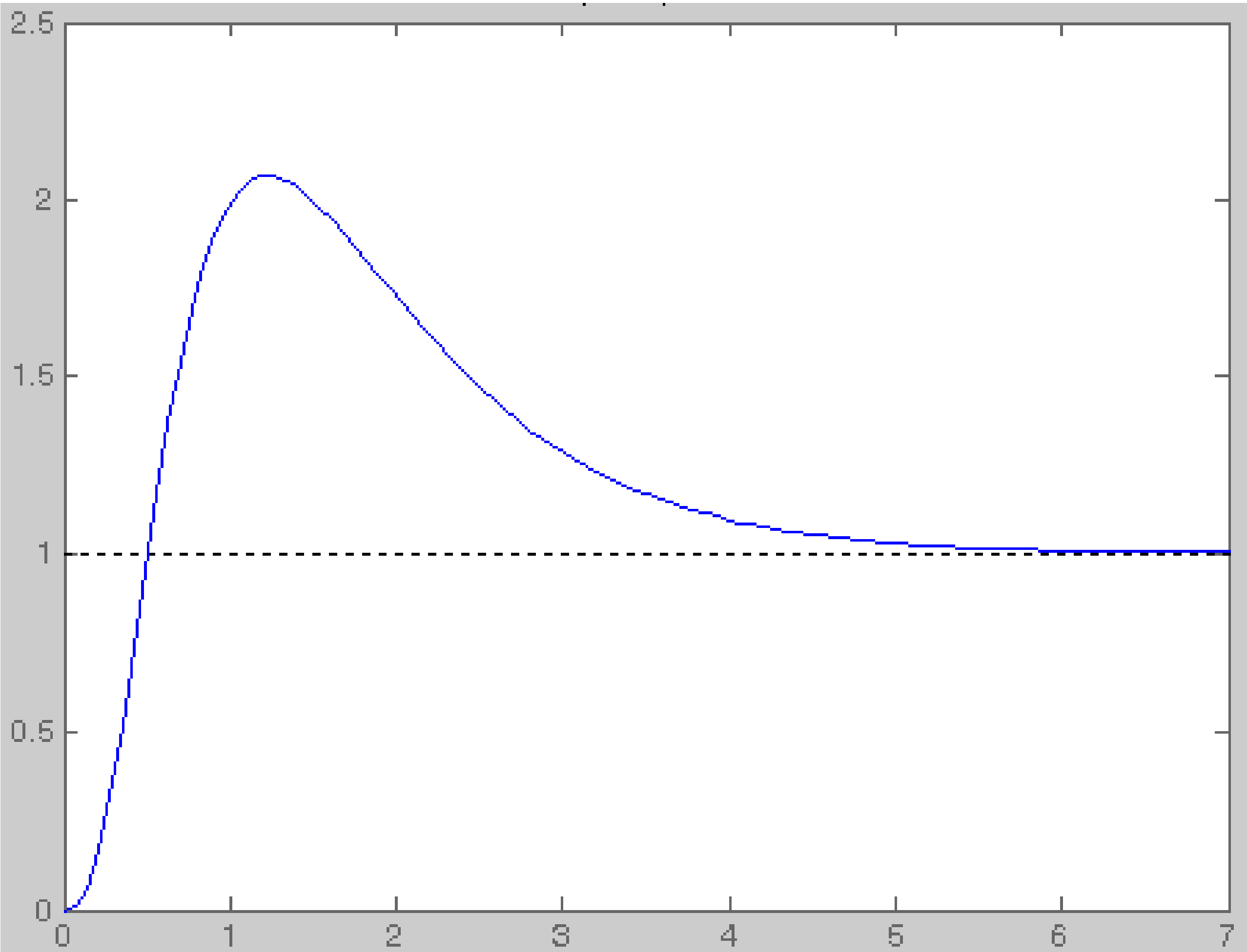
## Unstable condition, external loop




Outer loop root locus for $K_{va}$=0.61

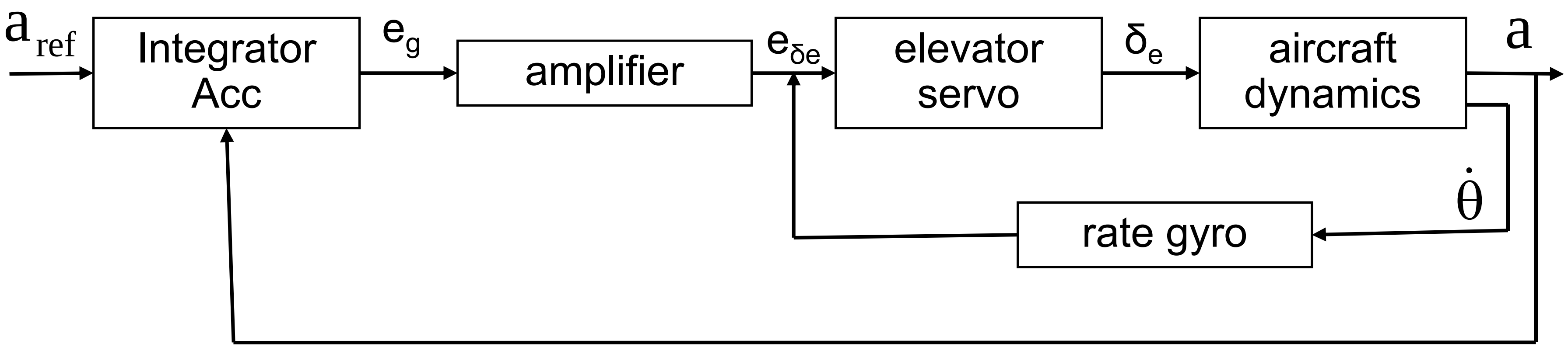
# 1. Longitudinal auto-pilot

## Unstable condition, step response

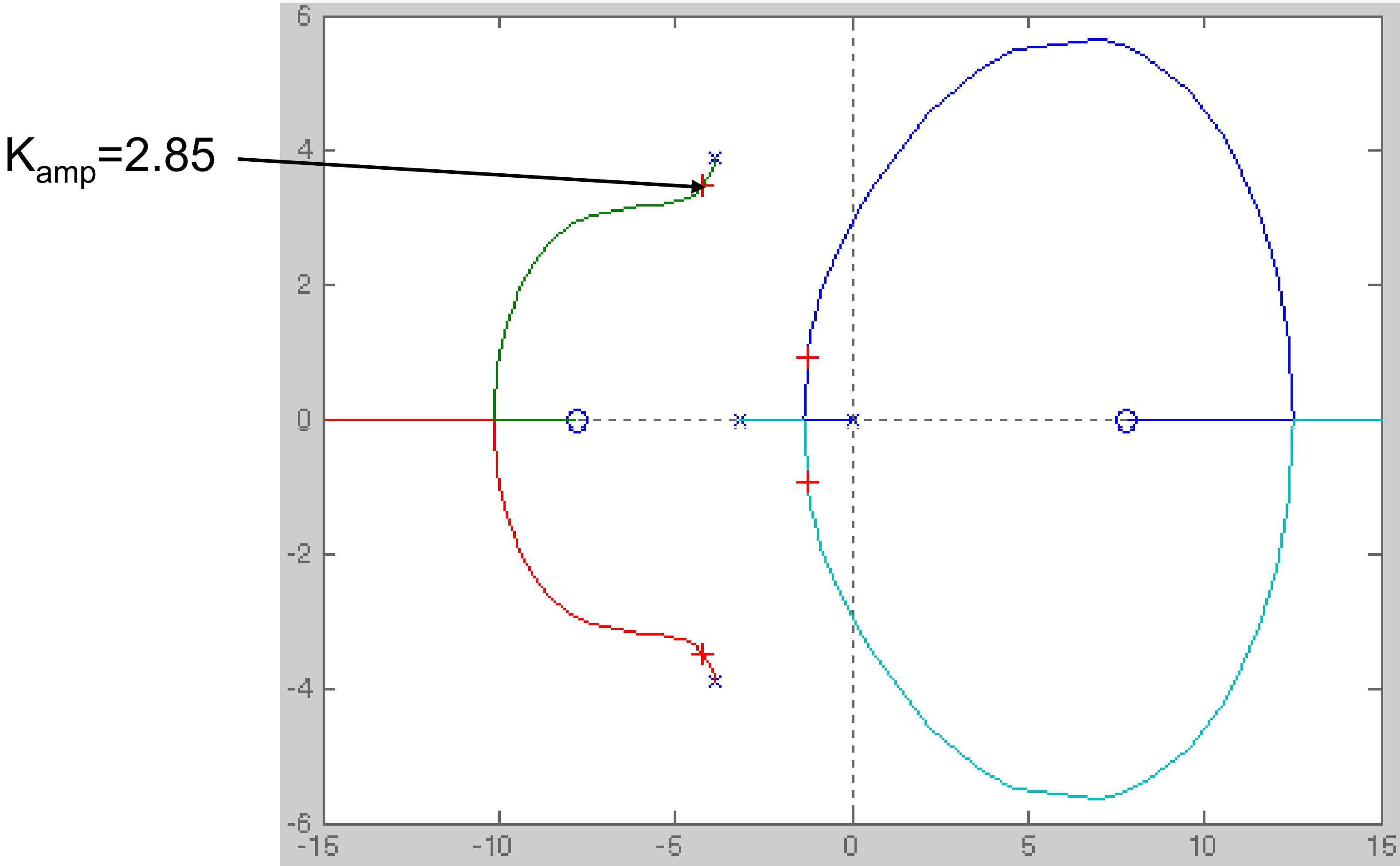



Step response for $K_{va}$=0.61 and $K_{amp}$=2.1

## Acceleration control system

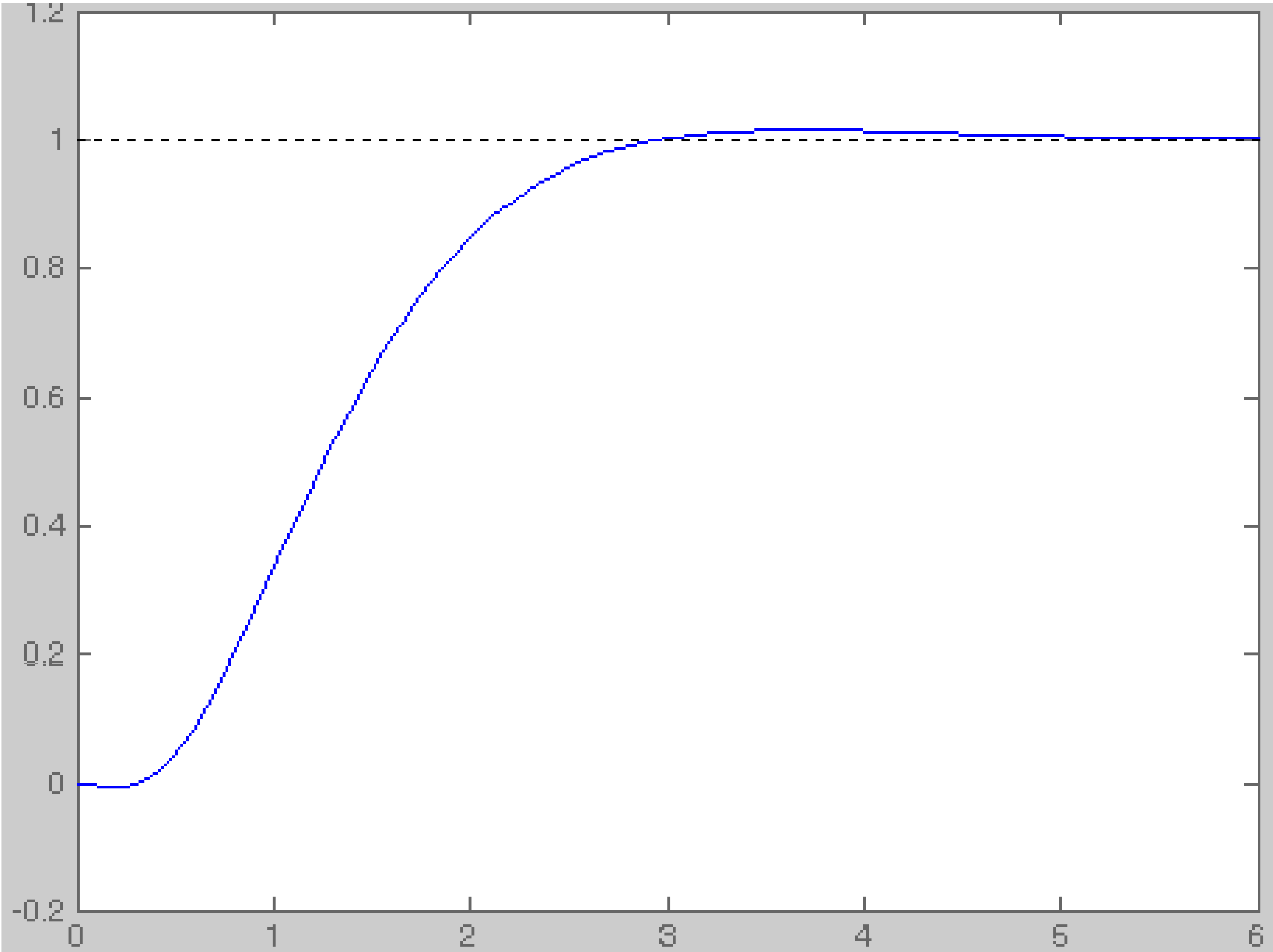


## Acceleration control system




Outer loop root locus

## Acceleration control system




Response for $K_{amp}$=2.85

## Acceleration control system

Control is done through an *accelerometer*: correction is good but:

• acceleration control system can't distinguish between the acceleration of gravity and the acceleration due to the movement of the aircraft → it has to be insensitive to small accelerations

• non desired turbulence acceleration → noise, has to be filtered

These problems + there are not so many requirements needing the aircraft to fly at constant acceleration → acceleration AP scarcely used

Sometimes used for tactical maneuvers and missile control

## AP basic configurations

- maintain **pitch angle** constant
- maintain **pitch rate** constant
- maintain **pitch acceleration** constant

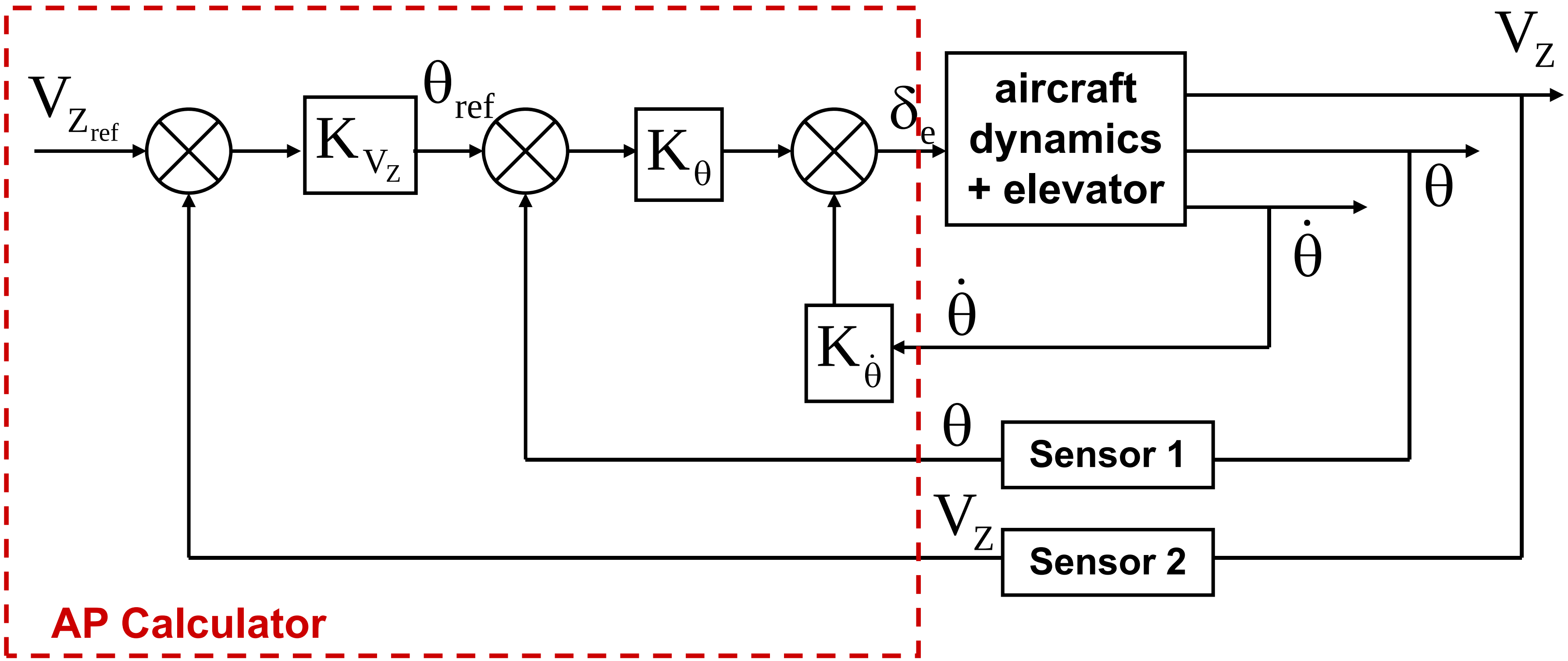
} + used for fight aircrafts (bad stability, good maneuverability)

Both cases: **add an inner loop over pitch rate increases damping of short period oscillations**

**Basic modes**: when pilot turns on AP, are activated by default

## Vertical Speed AP

Another basic mode: maintain constant vertical speed



## Vertical speed AP

**2 loops:**

- outer loop: sends θ associated to piloting functions

  → *input control*

- greater loop: controls trajectory parameters

  → guidance function (maintains pitch desired for the aircraft based on flight info: instrumentation, vision…)

  → stabilizing function

- inner loop corresponds to servo (stabilizer)

**Sensors**: Vertical gyro measures pitch angle

Variometer measures vertical speed

**Control laws:** (choice of $K_{Vz}$ based on FL (flight level))

## Superior modes

Selected in AP command: Flight Control Unit (FCU)

3 phases:

- turn on the mode
- identify the reference value
- maintain it

## Speed AP (Mach)

Used during cruise flight

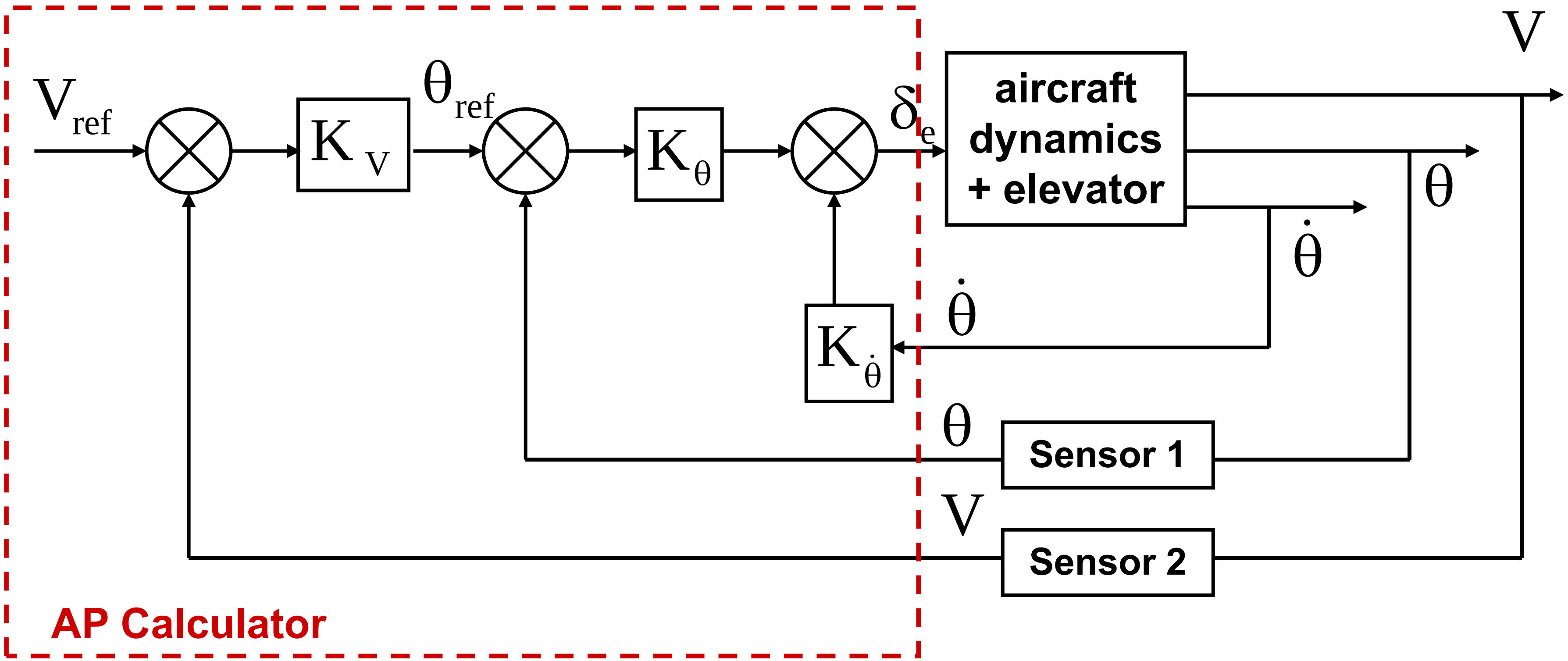
In *Mach hold* mode, aircraft flies at constant Mach speed through automatic control of pitch angle by the elevator

Aircraft flies → fuel is burned → weight decreases→ speed tends to increase

Speed increase detected by control system → corrected by elevator → aircraft rises

Making plane rise slowly due to burned fuel (constant Mach #), beneficial effect in long term flights (fuel consumption lowers with altitude)

## Speed AP (Mach)




sensor 1: Vertical gyro, sensor 2: Anemometer

control laws (integrator can be added)

## Altitude control AP

Constant altitude is needed due to:

- terrain topography
- vertical distance between planes in flight

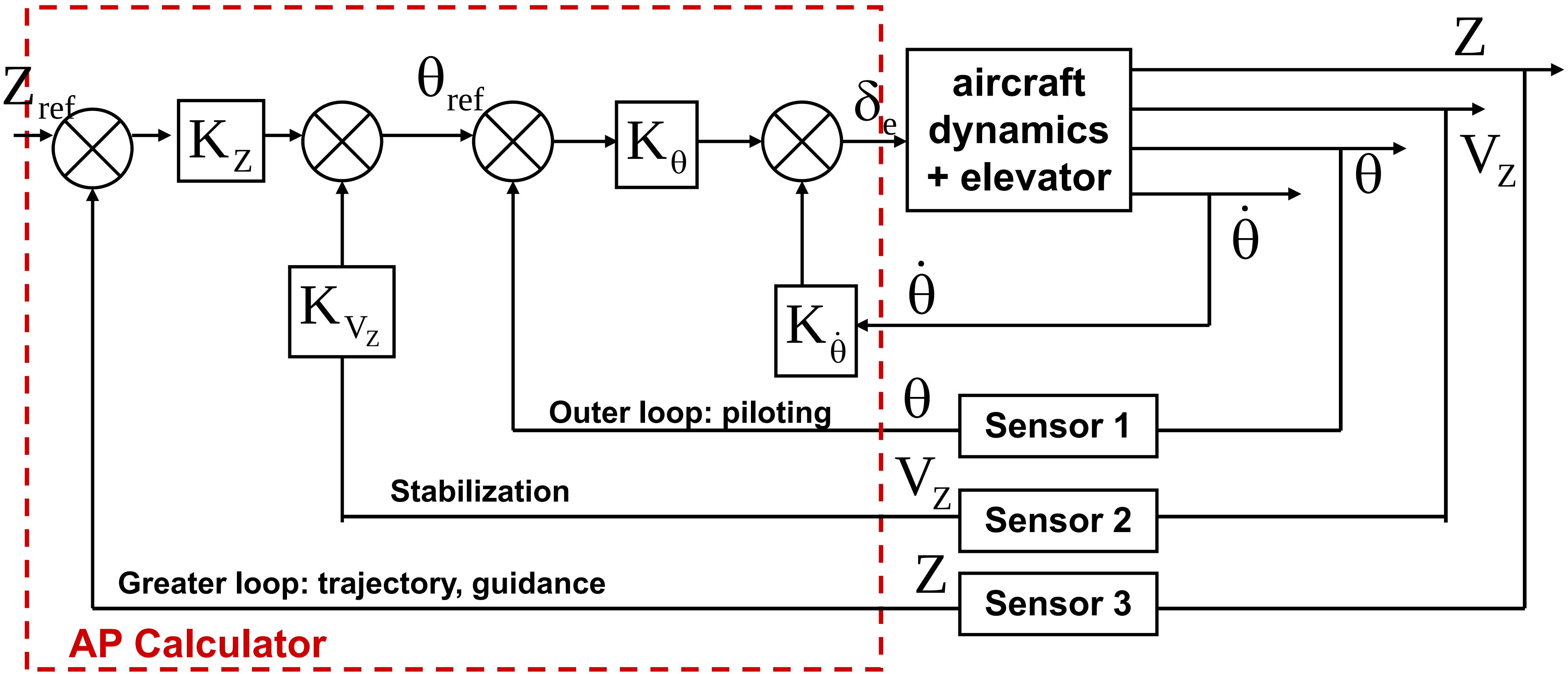
Maintain altitude during cruise flight: manual piloting is a monotone and tedious job → interesting to use AP

Mach number is being controlled, manual or automatically by thrust

Visual and noise alarm: warns the crew that aircraft's trajectory is closer or further from the selected one

# 1. Longitudinal auto-pilot

## Altitude control AP




sensor 1: Vertical gyro, sensor 2: Variometer, sensor 3: Altimeter

Control laws (+ integrator over $Z_{ref}$-Z, to reduce position error)

# 2 Lateral AP

1 Roll attitude AP

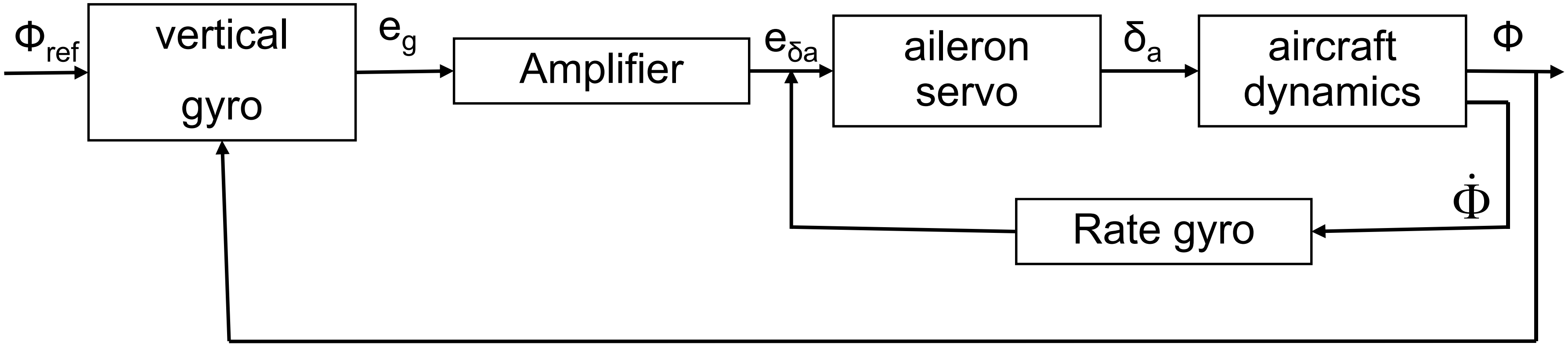
2 Heading AP

3 VOR Mode

4 Navigation mode

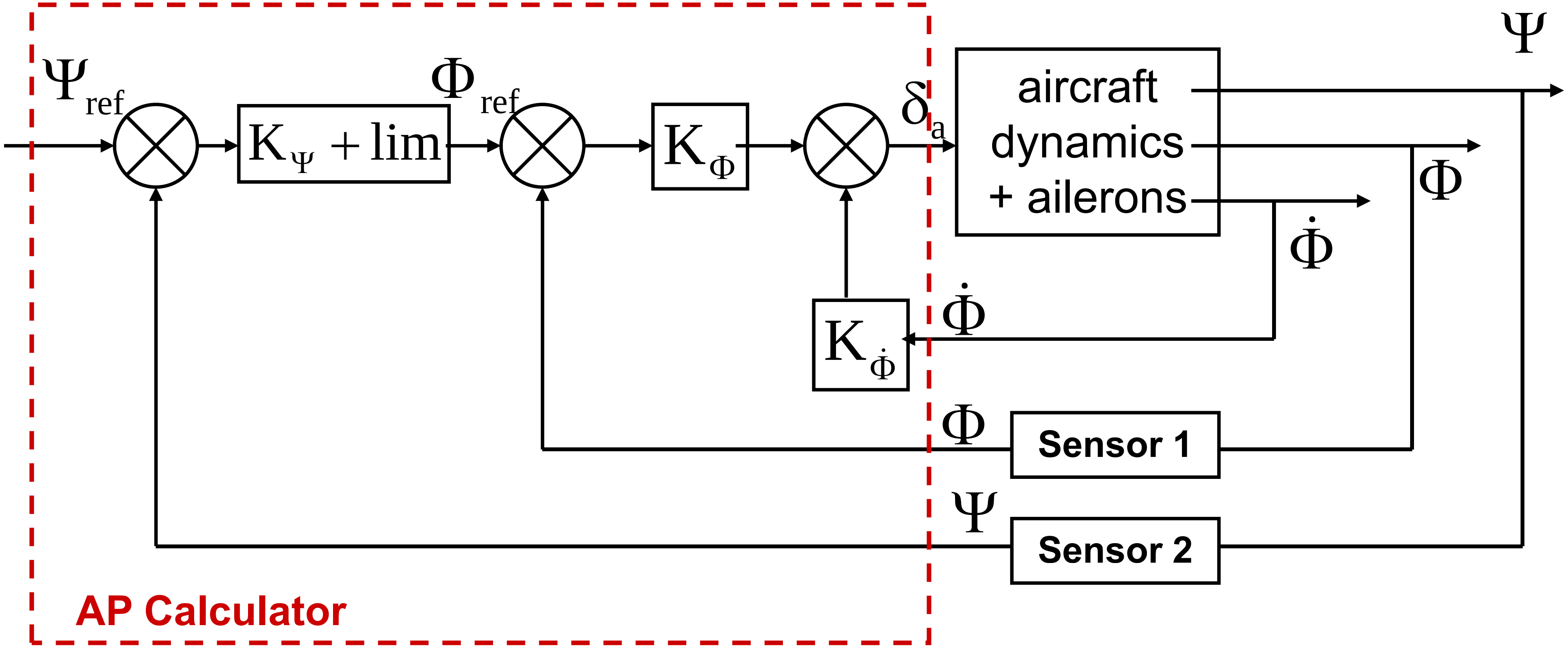
# 2 Lateral auto-pilot

## Roll attitude AP




- basic mode: bank angle AP ON when AP is turned ON
- + integral correction (accuracy) + bank angle and bank rate limitation
- AP designed to maintain straight and leveled flight path
- control laws

## Heading AP




- basic mode
- sensor 1: vertical gyro
- sensor 2: directional gyro

## Heading AP

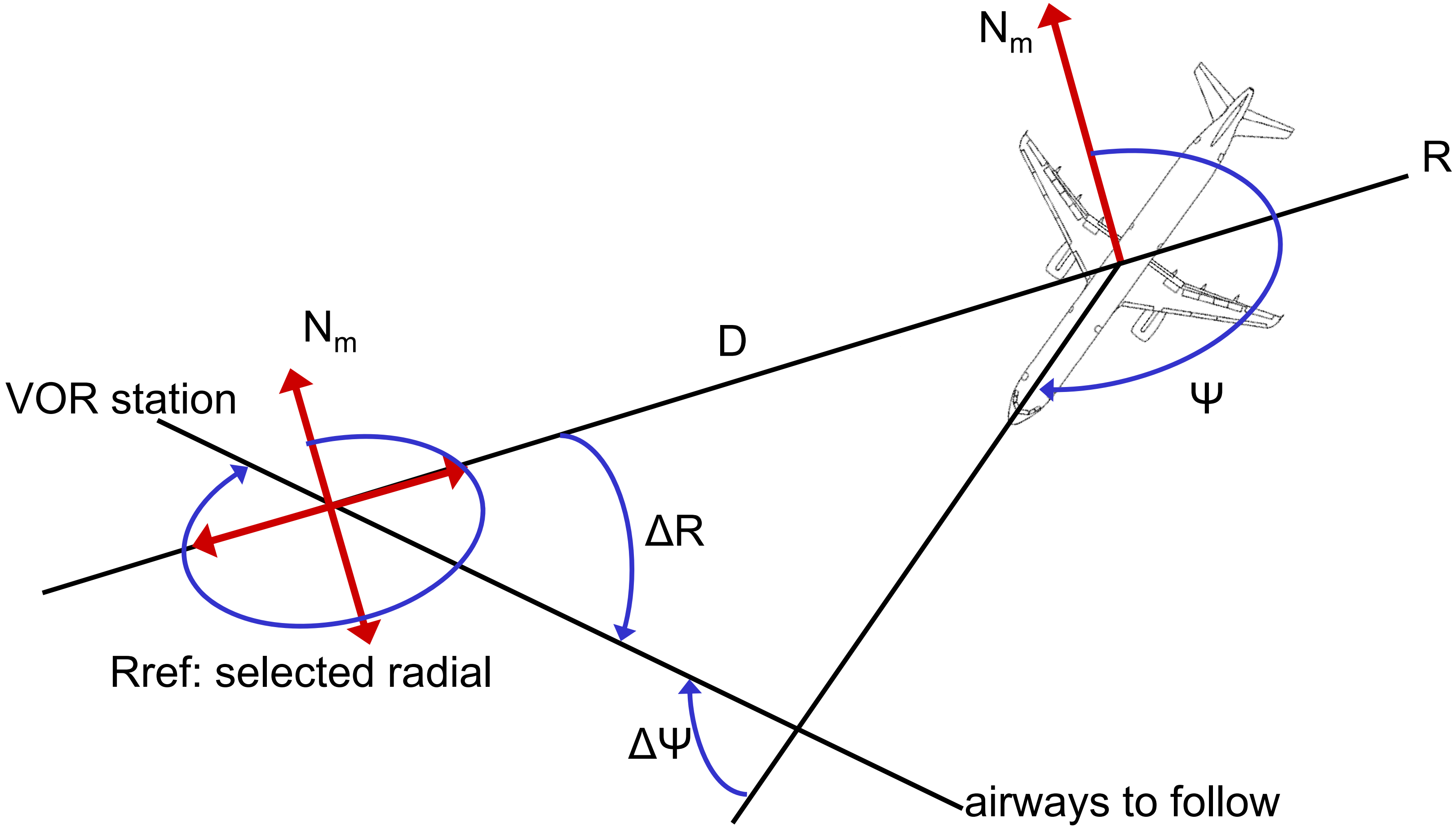
- control laws
- position and speed limitations

$$\left.\begin{aligned}\Phi_{max} &= 30^{o} \\ \dot{\Phi}_{max} &= 5^{o}/s\end{aligned}\right\} \text{A310}$$

- limited roll movements even though the difference between actual and selected heading is big
- → ensure passenger's comfort + limit lateral and longitudinal coupling

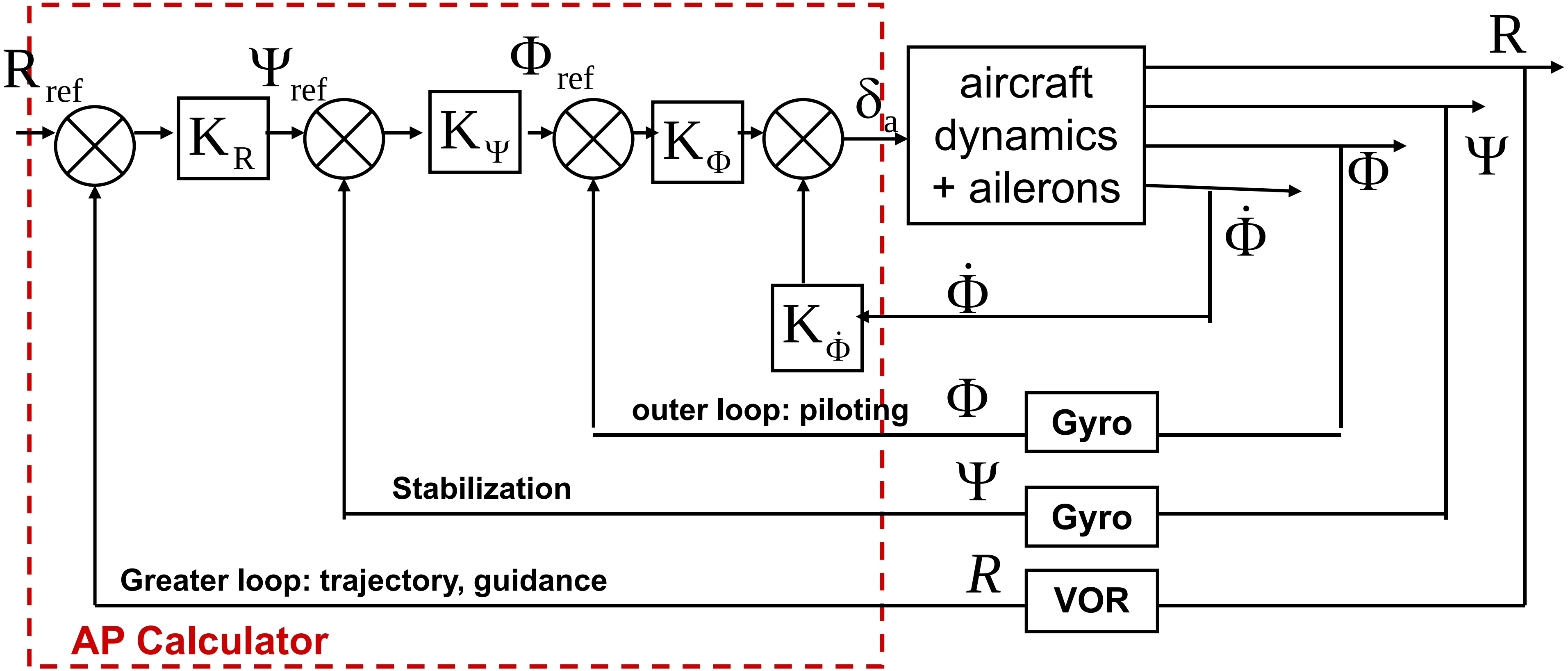
## VOR Mode

- superior modes: select and maintain magnetic heading



## VOR Mode

- superior modes: select and maintain magnetic heading



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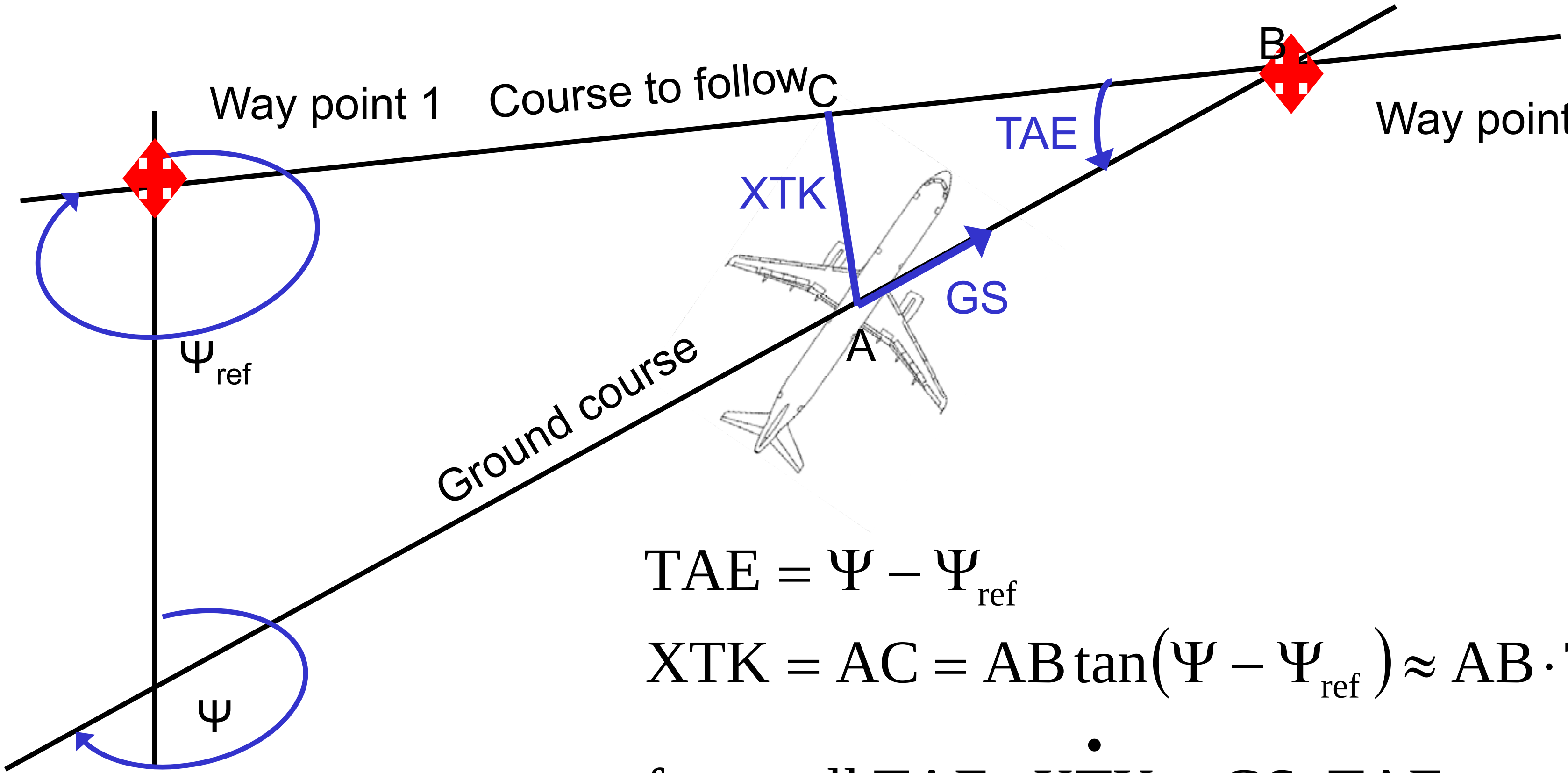
## VOR Mode

- If there is wind, when the plane is following its determined airways, $\Psi$-$\Psi_{ref}$ won't be cancelled.
- In order to maintain the airways, an integral factor is added.

## Navigation Mode

- This mode allows to follow a route described by the flight plan: composed of a series of *waypoints.*
- The crew introduces route in the flight calculator or in the *Flight Management System*.
- An inertial central gives the actual aircraft position information.
- Flight calculator calculates differences and track:
  - Position guidance of the route (XTK)
  - Ground  speed (*GS) of the route.*
  - Angle and attitude of the route (TAE- Track Angler Error)

# Navigation Mode

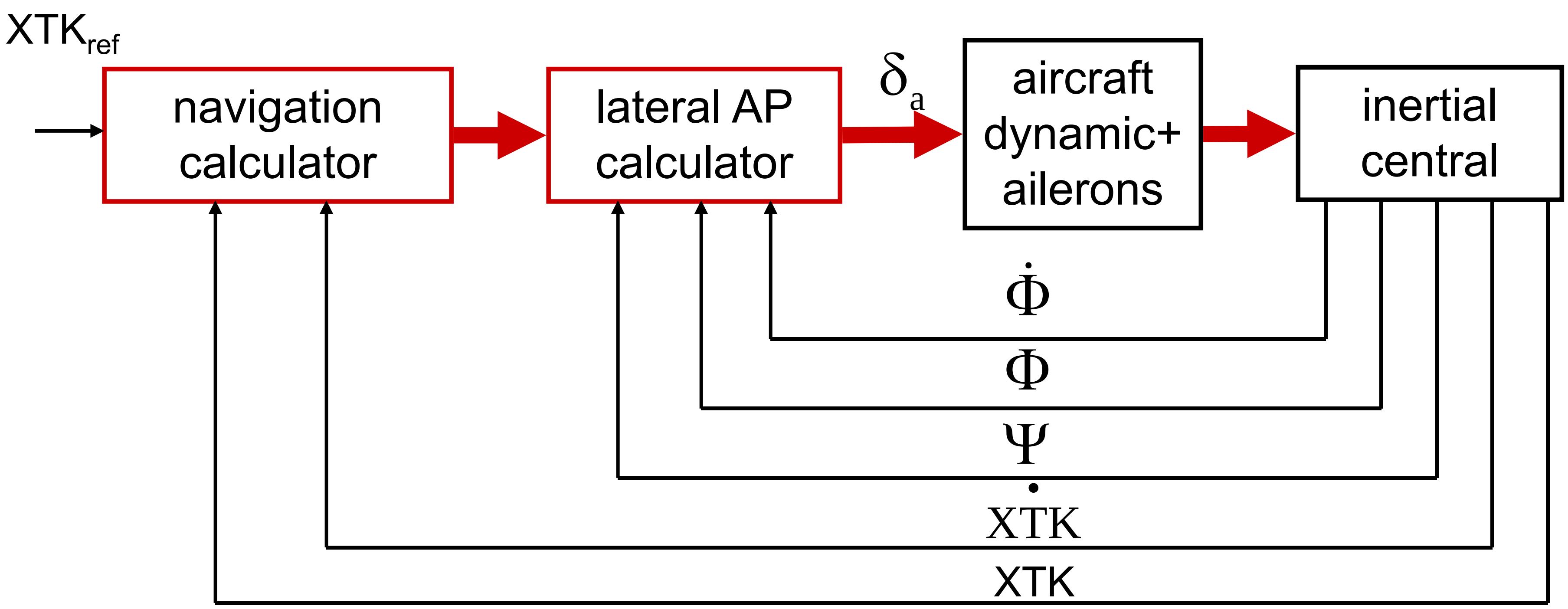



$$TAE = \Psi - \Psi_{ref}$$

$$XTK = AC = AB\tan(\Psi - \Psi_{ref}) \approx AB \cdot TAE$$

$$\text{for small TAE}: \dot{XTK} = GS \cdot TAE$$

## Navigation Mode




control laws + limits

# 3 AP basic principles



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# 3. AP basic principles

- Auto Pilot mission: make the aircraft evolve from a static equilibrium position to another
- 1st principle: separate the small movements of the aircraft around an equilibrium point in longitudinal and lateral planes
- Longitudinal modes affect the aircraft in its vertical plane
- Lateral modes affect the aircraft in its horizontal plane

# 3. AP basic principles

- Interesting to decouple the automatic command chains

  → thus making easier the PA tasks

- For basic modes:

  - *longitudinal:* attitude commands

    speed control

  - *lateral:* bank angle control

    yaw control

# 3. AP basic principles

- A lot of couplings exist between longitudinal and lateral movements of the aircraft (ex.: turning), within longitudinal mode (maintaining a constant descent rate and decreasing speed) and within lateral modes (stabilized turn)

→ Command laws should include these couplings

either with more correcting terms

or with introduction of limitation to ensure only small movements

# 3. AP basic principles

- 2nd principle: in automatics, system signals are classified in function of their speed or frequency (their bandwith).

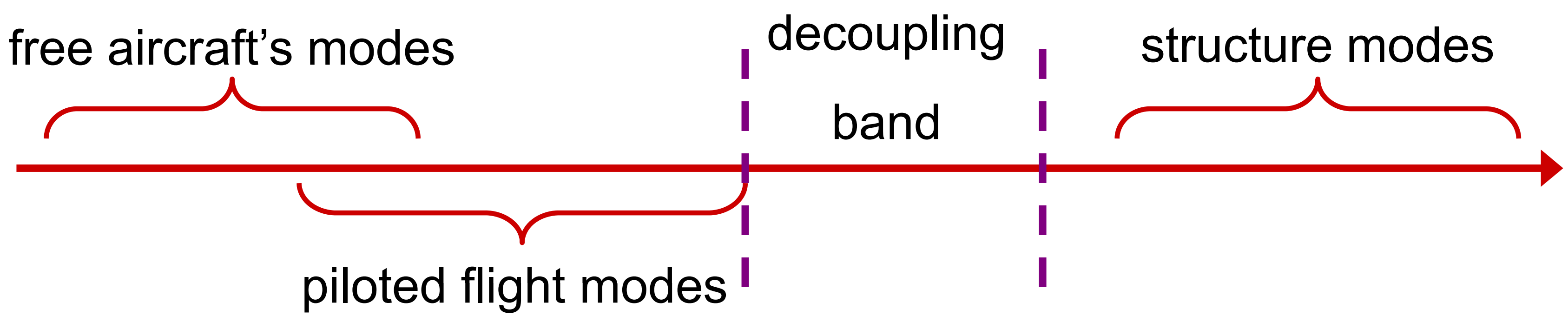
  → They are processed separately

For aircrafts:

- o Aircraft's structure vibration modes (fast >10Hz)
- o Normal modes associated to flight quality: short term oscillations, phugoid, spiral divergence, Dutch roll (slower <2Hz, + damped)

# 3. AP basic principles

- There should be no frequency coupling between these 2 type of modes.
- Auto Pilot system creates its own modes (due to feedback loop) making flight quality modes faster and with the possibility of exciting the vibration modes of the aircraft's structure.
- The control engineer should ensure frequency decoupling



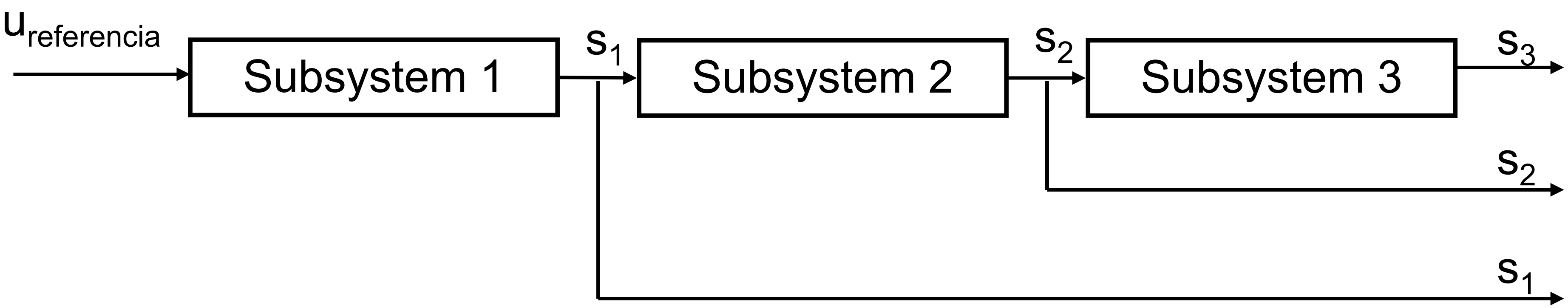
# 3. AP basic principles

- 1st Autopilot: principal limitation: systems 1 input, 1 output
- Aircraft is a complex system: 1 input (aileron or elevator deflection) → various outputs
- Example: ***input:*** elevator deflection

  ***output:*** variation of: attitude, pitch velocity, attack angle, climbing angle, vertical speed, altitude
- Solution: order signals to be sent in function of its variation speed:

  → Superposition principle

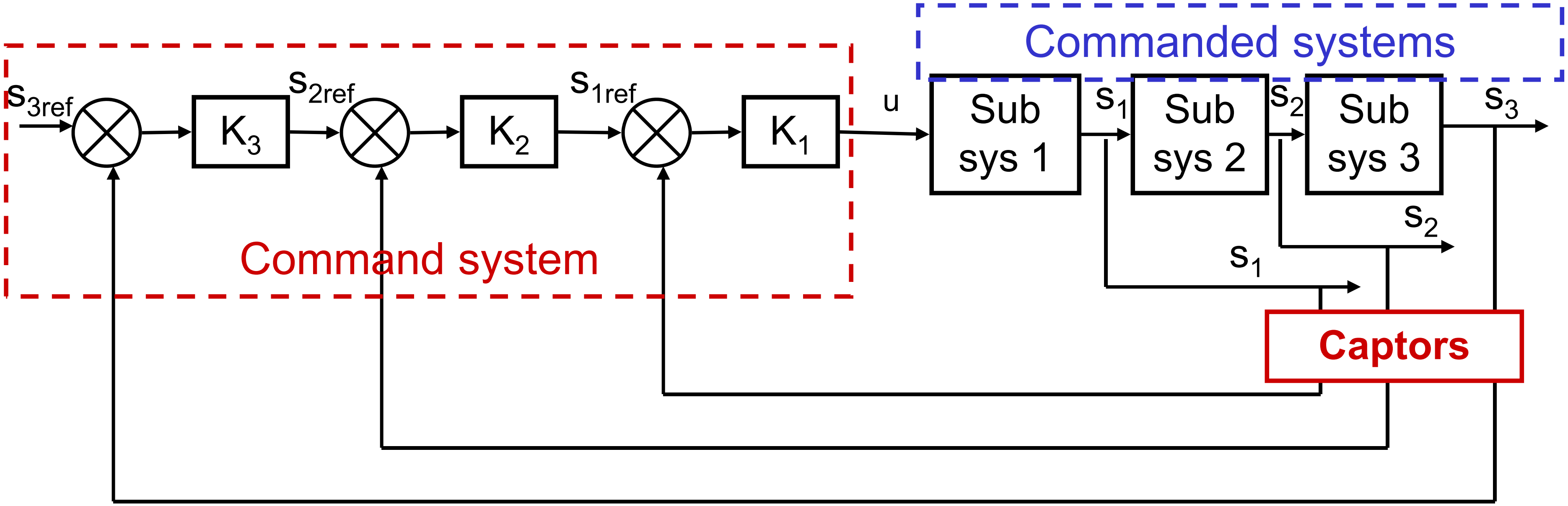
# 3. AP basic principles




Fast signal $s_1$ affects $s_2$ (which is slower).

$s_2$ affects output $s_3$ (which is the slowest signal).

Control laws act in cascade taking into account speed of subsystems




Fast signal $s_1$ affects $s_2$ (which is slower). $s_2$ affects output $s_3$ (which is the slowest signal).

# 3. AP basic principles

**Improvements**:

- Feedback correction (improves stability)
- Integration correction (improves accuracy)
- Position or speed limiters for input signals
- Readjustment of $K_1$, $K_2$ and $K_3$ (controllers)

**AP Organization in 2 loops**:

- inner loop: servo actuator
- Outer loop: sends $\theta$ and $\Phi$ : **piloting function**
- Greater loop: controls trajectory parameters: **guidance**

# 3. AP basic principles

- These solutions were created in the analog calculator era, but they have been later applied to AP with digital calculators.
- Progress (capacity, calculation speed)

→ multidimensional piloting laws (considers multiple input / output, MIMO systems)

→ allows delicate maneuvers with strong coupling between command chains or non-linear phenomenon, and performs unstable maneuvers thanks to correction speed

# Autopilot composition

AP composed by the following elements:

1. A **pilot-machine interface** composed by:

    - AP activation handle
    - Flight Control Unit: to choose the AP active modes and show the instructions.

# FCU


SPD
HDG
LAT
HDG V/S
ALT
LVL/CH
V/S
3000
SPD
MACH
HDG
TRK
V/S
FPA
100
1000
UP
PUSH
TO
LEVEL
OFF
METRIC
ALT
AP 1
AP 2
LOC
A/THR
EXPED
APPR

FCU A320

## FCU: Selection of the altitude reference


1. Visualization of the current altitude reference (1013mb) and the selected mode (QNH or STD)

2. Selection button: (PULL: STD mode,  PUSH: QNH mode)

3. Flight Director ON/OFF

4. Landing System ON/OFF

# FCU: Navigation Display control case


1: Selection of the database elements to be visualized (VOR, ...)

2: ND Mode selector: (ILS, VOR, NAV, ARC, PLAN)

3: ND scale selector (from 10 to 320Nm)

4: NAV1/NAV2 Selector (VOR or ADF: Automatic Direction Finder)

# FCU: Speed selection

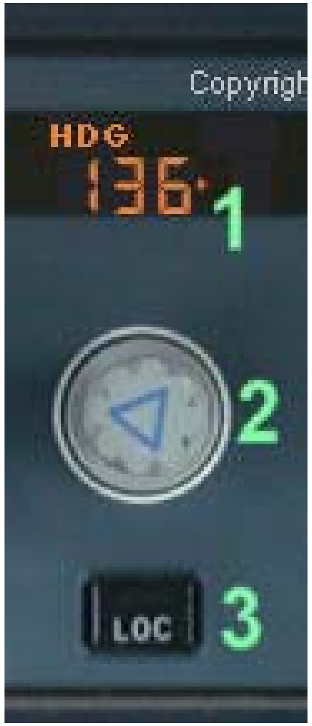

1: Visualization of the selected speed

2: Selection button (PULL: Selected Mode, PUSH: Managed Mode )

3: Speed/Mach selection button

4: Timer

## FCU: Heading/Track window




1: Selected heading or track

2: HDG/TRK Selection button (PULL: Selected Mode, PUSH: Managed Mode )

3: Localizer mode ON/OFF

# FCU: AP/ATHR Heading/Track window


1: HDG-VS or TRK-FPA(Flight Path Angle) modes selection

2: Visualization of the selected mode (HDG-VS or TRK-FPA)

3: AP 1 On/Off

4: AP 2 On/Off

5: Auto-Thrust On/Off (A/THR)

# FCU: Altitude management window


1: Selected altitude

2: Altitude selector (PULL: Selected Mode, PUSH: Managed Mode )

3: Increasing step selector (100ft or 1000ft)

4: Expedite function: It selects between the ascend or descend parameters the more efficient to reach a level depending on the instantaneous airplane configuration.

# FCU: Vertical/Slope speed window


1: Selected VS/FPA

2: VS/FPA selector

3: Approach mode ON/OFF (Localizer+Glide path)

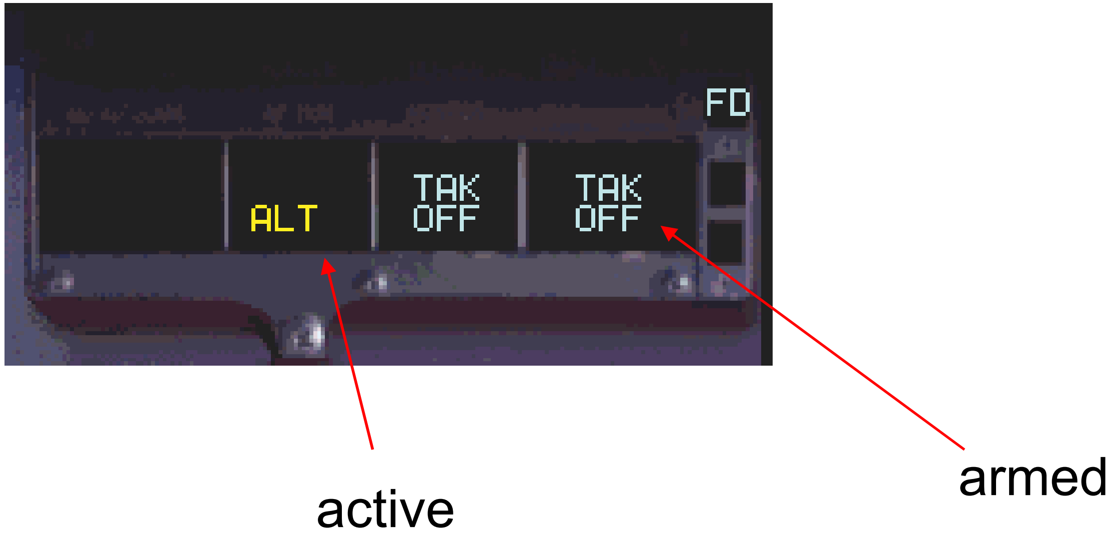
## FCU Reproduction


Key features:

- C167CR-LM Siemens microcontroller (18.432 MHz)
- RAM: 8 Ko
- EEPROM: 32 Ko
- RS232 asynchronous serial interface (from 19.2 to 115.2 Kbauds)
- Synchronous serial interface (1 MHz)

# 3. AP basic principles

- A mode indicator: Flight Mode Annunciator-FMA: informs the pilot of the AP operation (operating modes, waiting or "armed")



## Autopilot composition

2. **Measure chains** (aerodynamic, inertial, radio navigation data)→ system calculation elements and flight parameter values to be watched (=sensors)

3. **Electronic calculators** that receive the pilot instructions (selected modes) or the flight management ones (managed modes), and the values of the measure chains → to apply corresponding control signals

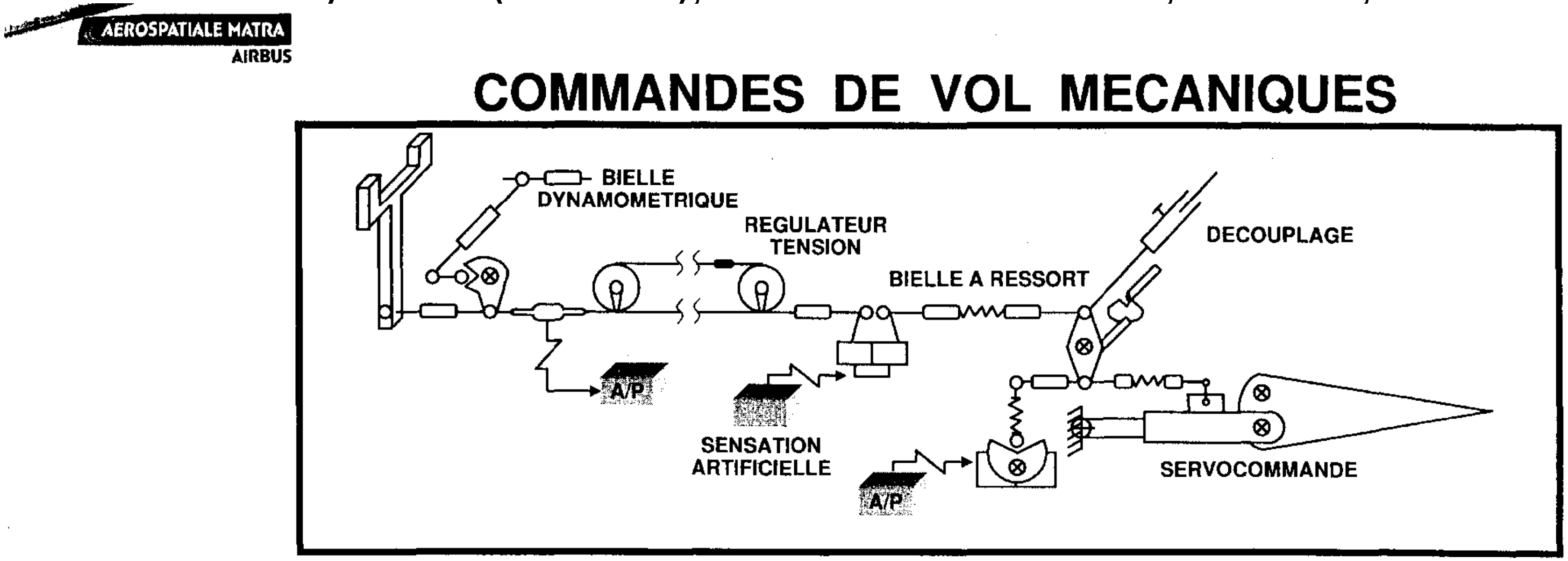
4. **Transmission chains** of the control signals to the servo-actuators that act on the control surfaces and the fuel arrival to the engines (=control systems)

## Aircraft flight control systems

Devices that transform the movements done by the pilot on the airplane controls into deflections in the control surfaces

**1 Mechanic control systems**

The pilot, by the actions made on the stick and the pedals through classic mechanic systems (wires…), moves the elevators, rudders, ailerons.



# Aircraft flight control systems

## 2 Power-boosted control systems

The pilot supplies only a part of the control force: there is a parallel power system (pneumatic or hydraulical).

Example: Boeing 707

## Aircraft flight control systems

**3 Control systems completely operated with power (hydromechanical)**

When the pilot moves a control, he activates an electronic or hydraulic device that moves the control surface

→ **irreversible system**

→ **need of artificial sensation: pilot feels forces proportional to the surface deflection**

→ **big airplanes of first generation: Boeing 747, 767, A300, A 310 and fighter jets of the 60s: Mirage III, Mirage F1, F15**

→ **triple hydraulic system requisite: redundancy in case of failure**

## Aircraft flight control systems

**4 Fly-By-Wire**

The pilot controls the airplane movement by electric signals

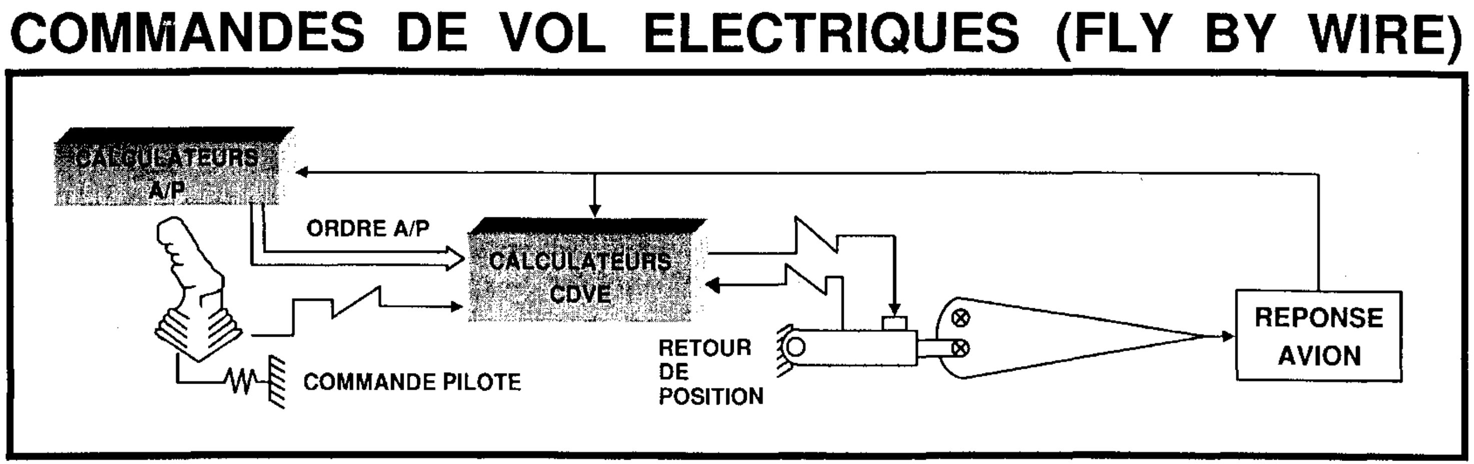
**→ it saves weight + possibility of flight control laws creation including artificial stability (adjustment speed)**

**→ redundant system (quadruple: 4 computers, or similar, A320 or A340 case: 3 primary comp. + 2 secondary)**

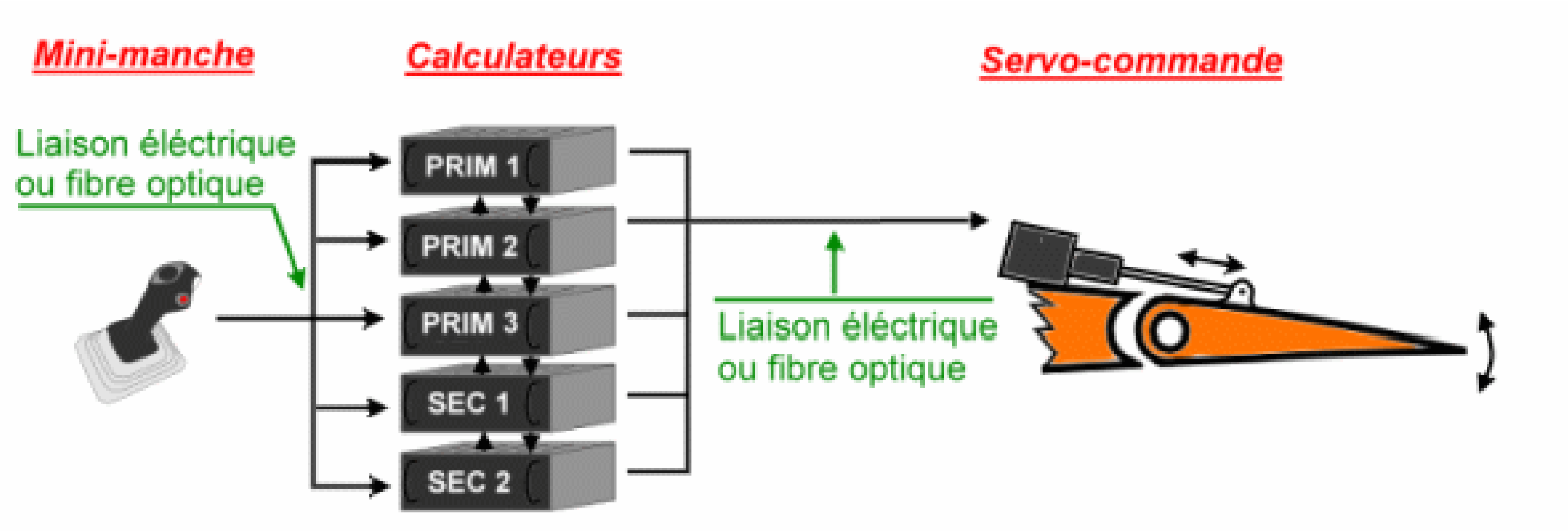
**→ last generation of fighter and transport aircrafts: Mirage 2000, Rafale, F-16, F-22, Eurofighter, A320, A330, A340, A380, B777**

# 3. AP basic principles

## Aircraft flight control systems




 Mars 2000 | Physique Générale de l'Avion CDVE - 18 Centre Compétence Technique



## Aircraft flight control systems

### 4 Fly-By-Wire: analog signals

Fly-by-wire flight control systems eliminate the complexity, fragility and weight of the mechanical circuits of the hydraulic/mechanical control systems and they replace them with an electric circuit.

Cockpit sends orders to the control surfaces using electric signals processed by an analogical controller (Autopilot)

Analogical computers allow the selection of flight control characteristics like the artificial stability.



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# Aircraft flight control systems

## 4 Fly-By-Wire

Concorde: one of the first airline airplanes using analogue fly-by-wire

# Aircraft flight control systems

## 4 Fly-By-Wire: digital

"Digital fly-by-wire" control system is similar to the analogical one but the signal is processed by digital calculators.

Increases the flexibility, because the calculator can receive inputs of any airplane sensor.

Calculator

1. it reads the positions and forces from
   - cockpit (where it receives the pilot orders)
   - airplane sensors
2. it computes differential equations to act on the control surfaces in order to carry out the pilot intentions

## Aircraft flight control systems

### 4. Fly-By-Wire: digital

Thanks to the computers that continuously fly the airplane, the work load of the crew is reduced.

1. For very unstable airplanes → advantage for the maneuverability of the military airplanes (+ FBW avoids leaks in the hydraulic system that can produce the airplane loss)

   Examples:

- Lockheed Martin F-117 Nighthawk

- Airbus A320: first airline airplane with digital FBW

## Aircraft flight control systems

### 4. Fly-By-Wire

Note that Boeing and Airbus differ in their FBW philosophy:

- In Airbus aircraft, the computer always retains ultimate control and will not permit the pilot to fly outside the normal flight envelope
- In a Boeing 777, the pilot can override the system, allowing the aircraft to be flown outside this envelope in emergencies

# Example: Auto-thrust

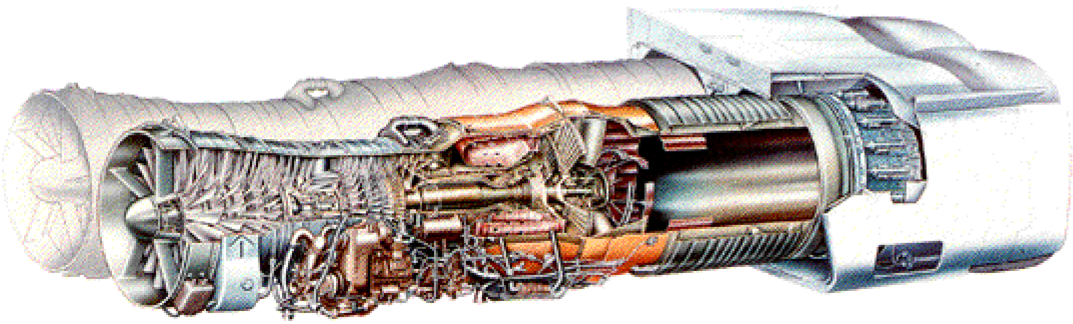
**FADEC: Full Authority Digital Engine Control**.

digital computer to control all aspects of aircraft engine performance.

FADECs for both piston engines and jet engines: difference in the different ways of controlling the engines.

Electronics' superior accuracy led to early generation analogue electronic control

1: First used in Concorde's Rolls-Royce Olympus 593 in the 1960s.



2: Later the Pratt & Whitney PW4000 as the first commercial "Dual FADEC" engine

# Auto-thrust

## Operation modes

SPD/MACH MODE


THRUST MODE


The auto-thrust has 2 different operation modes:

- Thrust mode (THR): system maintains the pre-calculated power.
- SPD/MACH mode: auto-thrust adjusts the power to maintain a certain airspeed or Mach number.

# Present achievements of the autopilot

From the initial ascension to the landing and the final stop

1. **Longitudinal modes**:
   - Pitch angle control, θ=θref
   - Vertical speed control, Vz=Vzref
   - Altitude control, Z=Zref
   - Vertical path tracking (ascension, cruise, descent)<br>→ FMS connection
   - Speed / Mach control<br>→ auto-thrust connection
   - Slope control

## Present achievements of the autopilot

**2. Lateral modes**:

- bank angle control
- Heading control
- VOR radial or magnetic route tracking
- Inertial route tracking (horizontal navigation)
  → FMS connection

# Present achievements of the autopilot

3. **Common modes**:

- Automatic landing
- Taking off → Flight Director

It implies a simultaneous action around the pitch, roll and/or yaw axes

# 4. Flight Management System

1 Objectives and functions

2 Flight Management System composition

3 Use of the Flight Management System

# FMS: Objectives

Important economical factor in the air transport

→ look for maximum efficiency of the aircraft

→ try to reduce costs

1. At the end of the 70s: piloting assistance (safety + regularity)
2. Very soon, technology applied to flight management problems (1984: 1st certified FMS)

2 advantages:

1. Decrease the crew's workload (otherwise more and more complex management tasks)
2. Minimization of the exploitation costs: to help the pilot in every flight stage to minimize the fuel consumption and the flight time

# FMS: Objectives

Example: Iberia: January 2008-September 2008:

Iberia: 1,201.4 million euros in fuel (29% of total operating expenses)

50 millions L of kerosene per week

Fuel: second cost in relevance (after staff)

**1% of saving in fuel → 12 millions euros**

→ How can you avoid 1% increase in fuel consumption?

→ Flight Management System optimizes

## FMS: Objectives

How can you reduce the consumption of 1%?

- choosing for a 500 nm route a more direct path of only 6 or 7 nm
- choosing a lower Flight Level if the wind is lower there

How can the consumption be increased of 1%?

- beginning the descent one minute too early
- flying one Mach point (0.01) too fast at the optimum altitude
- flying 1000 feet too low at cruise speed
- transporting 1 additional fuel tone in the A320



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## FMS: Functions

- Flight plan design
- Flight plan sequence
- Development of forecasts and performance optimization
- Initialization of the inertial centrals
- Selection of the RNAV environment
- Emission of information for the crew
- **Emission of piloting order and guidance to the autopilot**

## Composition

The Flight Management Computer (FMC), **interacts with**:

- A **database** (inside the system)
- The **crew** through the “Control Display Unit” - CDU,
  the “Navigation Display” - ND,
  and the “Primary Flight Display” - PFD
- The **navigation assistance systems** (VOR, DME, ILS, GPS…)
- The **measurements of the fuel consumed by the engines**
- The **AP and thrust calculators**

# 4. Flight Management System

## Control and Display Unit

# 4. Flight Management System

## Control and Display Unit



Cost Index

Route management

Transition

Approximation

Management of the temporary flight plan

Access to all vertical and

lateral revision pages

Instructions insertion

## Control and Display Unit


Route change management


Radio Nav page:

Management of the radio navigation systems

## N.D: Navigation Display

Next to the PFD.

Visualization of the navigation information: horizontal or vertical flight plan.

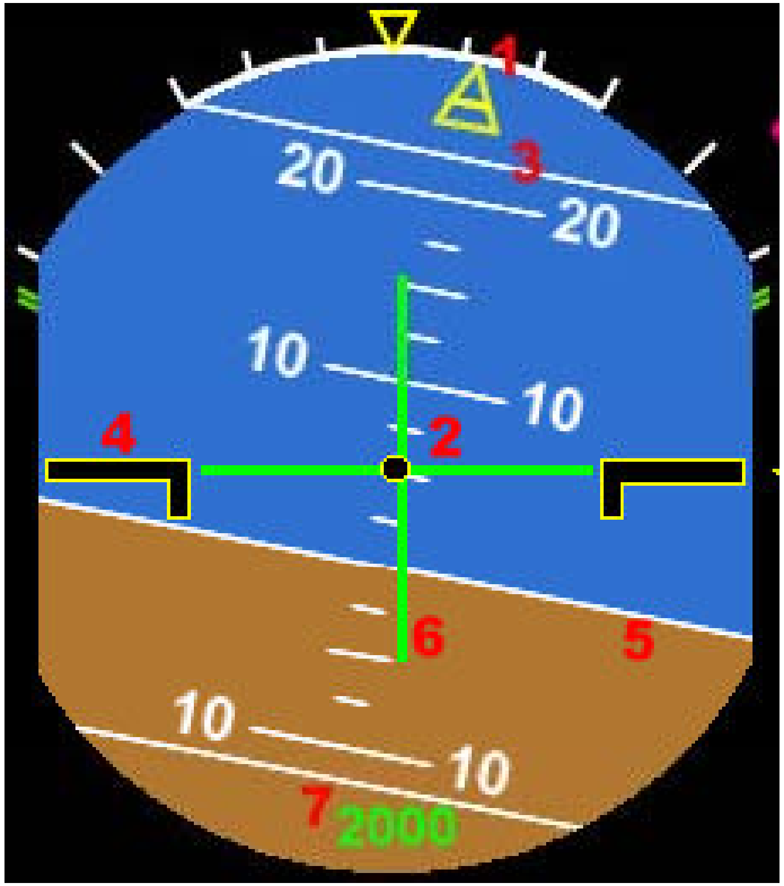
Visualization of the images from the meteo radar, the TCAS (traffic collision avoidance system) information with the position of the other airplanes, and the navigation instruments

## N.D: Navigation Display


# PFD: Primary Flight Display

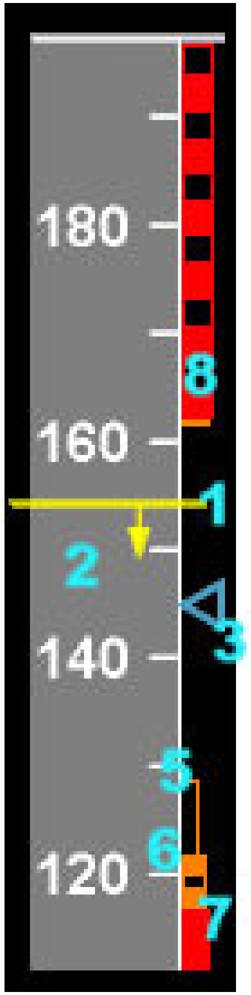

On-board principal instrument used to pilot the airplane

## PFD: Artificial horizon




1. Roll (11° left turn)
2. Attitude (5°)
3. Ball
4. Airplane model
5. Horizon line
6. Flight director
7. Radar altimeter (2000ft)

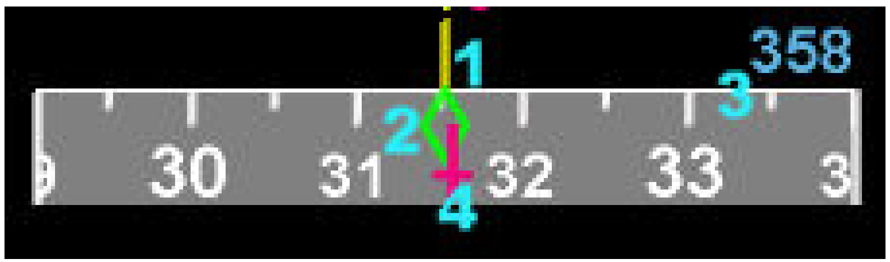
## PFD: Anemometer




1. Indicated speed (154 kts)
2. Speed tendency in 10 sec (150kts)
3. Objective speed (145 kts)
5. Alpha Floor speed
6. Alpha Protection speed
7. Stall speed
8. Max speed

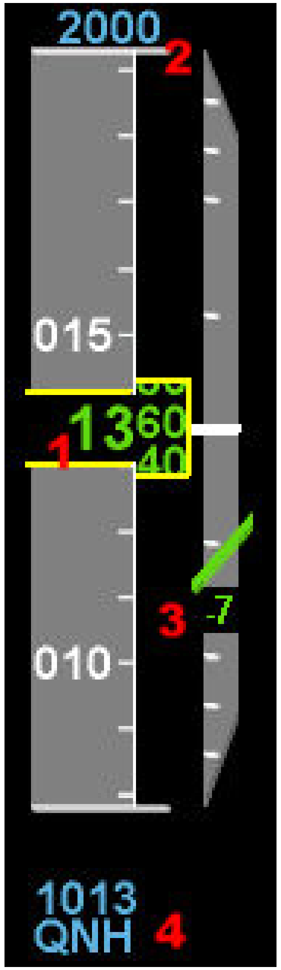
# 4. Flight Management System

## PFD: Compass



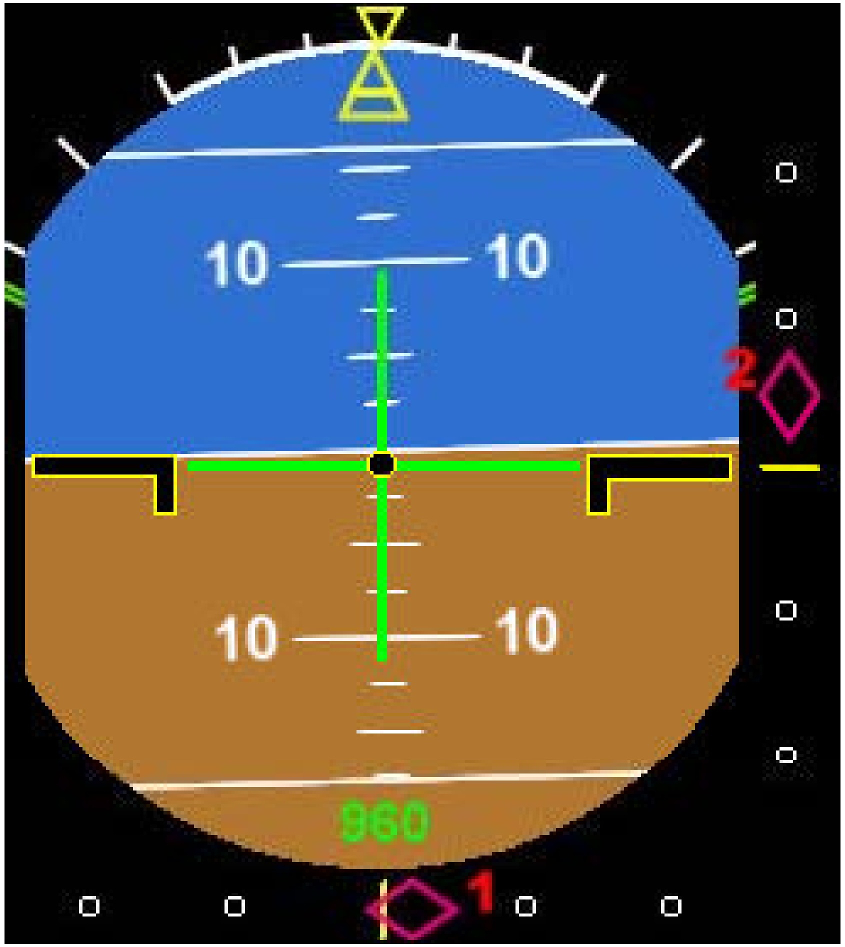

1. Heading(315°)
2. Route (315°)
3. Heading or route objective
4. ILS course

## PFD: Altimeter



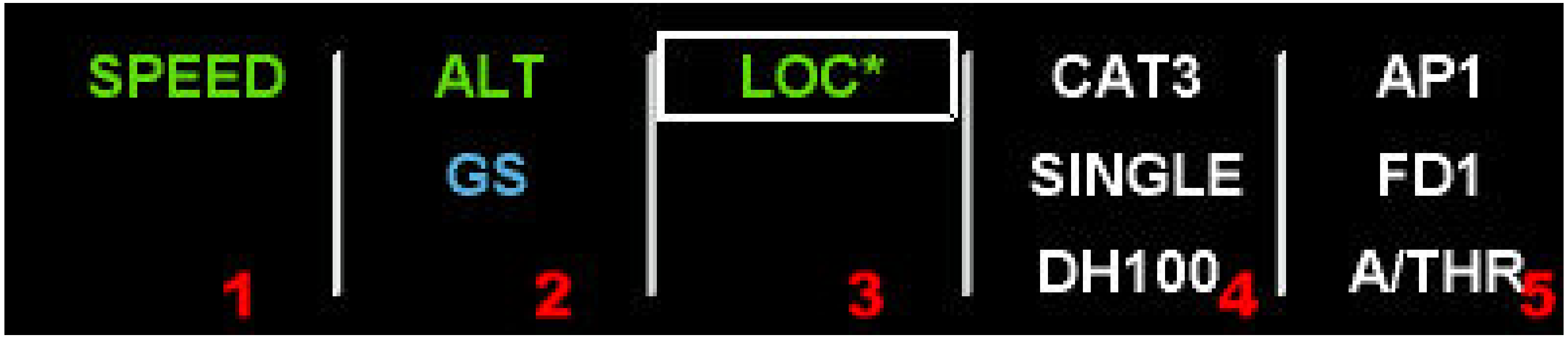

1. Altitude (1360ft)
2. Objective altitude(2000ft)
3. Variometer (-700 ft/mn)
4. Altitude reference

## PFD: Localizer and Glide indicator



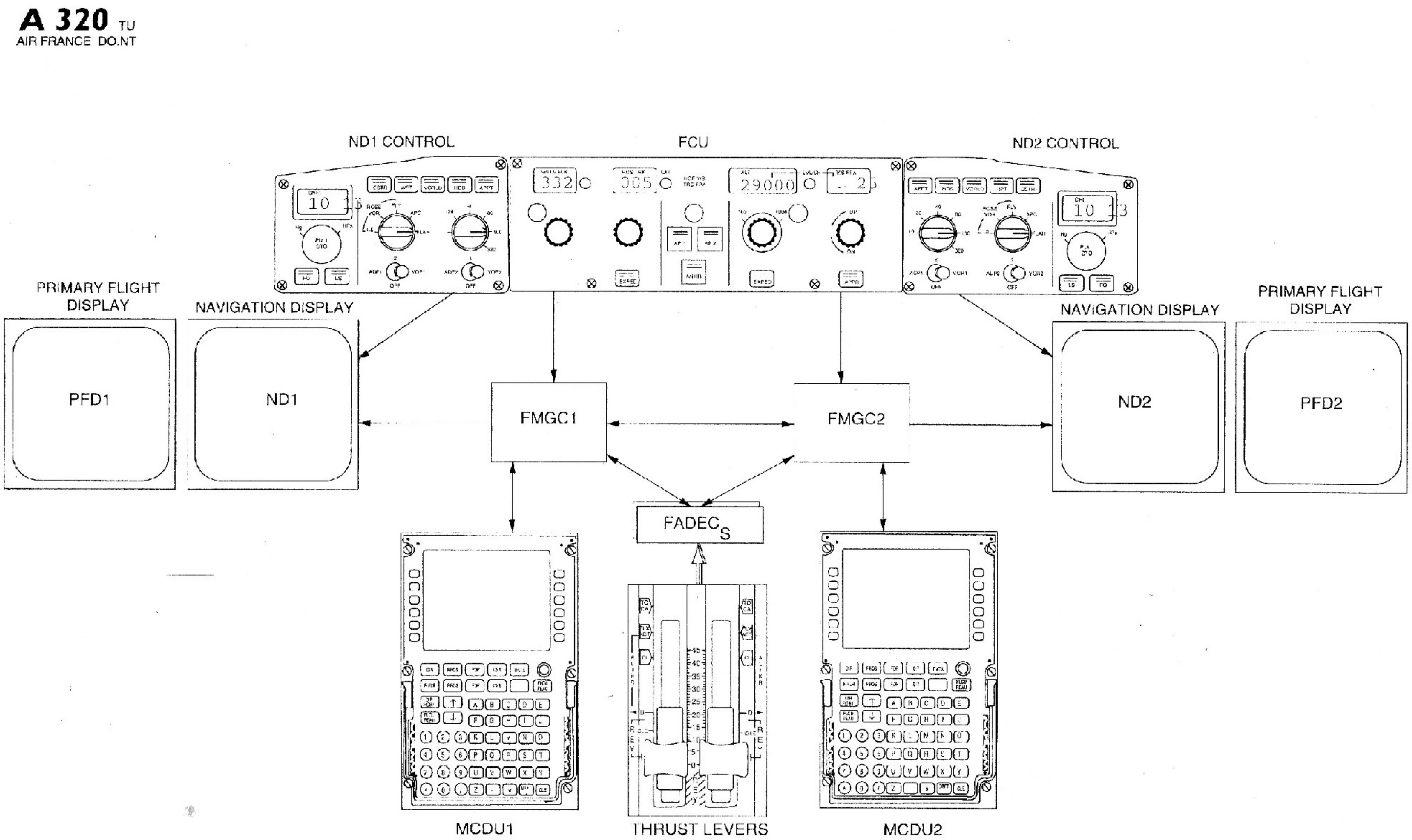

1. Localizer
2. Glide

## PFD: Flight Mode Annunciator




1. Mach hold mode (speed holding)
2. Longitudinal mode (altitude holding)
3. Lateral mode (LOC*: Localizer interception )
4. Approximation capacity
5. AP, FD, and A/THR state

# 4. Flight Management System




INTERFACE EQUIPAGE/FMGS

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