KING FAHD UNIVERSITY

Department of Aerospace Engineering

AE540: Flight Dynamics and Control I

Instructor

Dr. Ayman Hamdy Kassem

What is flight dynamics ?

Is the study of aircraft motion and its characteristics.

What is flight control ?

Is to adjust aircraft motion and its characteristics to our needs.

Course Description: Applying classical and modern control analysis and design tools to fixed-wing aircraft autopilots and flight augmentation systems.
Objectives: The objective is to provide the students with the knowledge that will allow them to deal with real aircraft control problems.
Prerequisites: AE 426
Textbook: Nelson, R. C., *Flight Stability and Automatic Control*, 2nd Ed., McGraw-Hill Co., 1998.
References: Etkin, B., and Reid, L. D., *Dynamics of Flight: Stability and Control*, 3rd Ed., John Wiley & Sons, 1996.

Instructor:

Dr. Ayman Kassem

Office Building 22 – Room 161

Class Schedule: UT (5:30 – 6:45).
building 24 - room 110

Office Hours: UT (2:30-3:30).

Email Akassem@kfupm.edu.sa

Learning Objectives:

- Provide students with the knowledge needed to analyze and design a variety of aircraft autopilots and flight augmentation systems using classical and modern control theory techniques.
- Prepare students for graduate studies and professional life through hands-on experience in giving oral presentations and writing technical reports.

Course Outline **Weeks**

• Review of the equations of flight motion (chapter 3) 1-2

• Dynamic stability (chapters 4-5) 3-4

• Response to control or atmospheric inputs (chapter 6) 5-6

• Classical approach for automatic control theory and application to autopilot design (chapters 7-8) 7 -11

• Modern control theory and application to autopilot design (chapter 9-10) 12-15

Project:

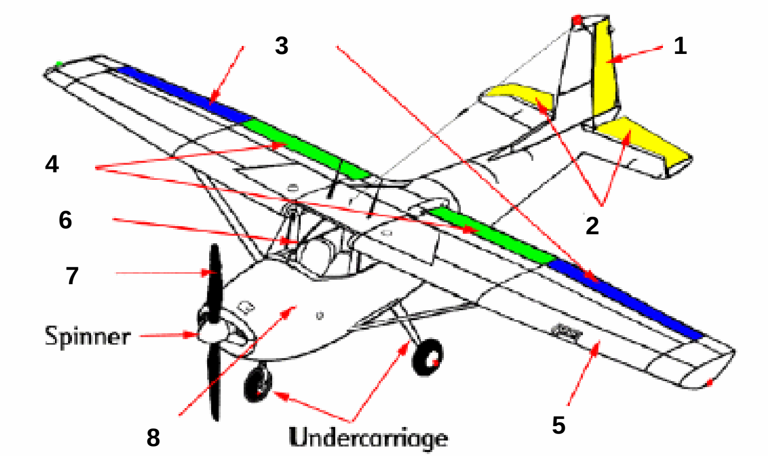
• To enhance learning, the students are required to do Internet search for an aircraft of his choice and do the design and analysis of some of its autopilots with the approval of the instructor.

• Each Student has to submit work-in-progress short reports (a page or two) and a final technical report at the end of the semester and make an oral presentation and defense of his design choices.

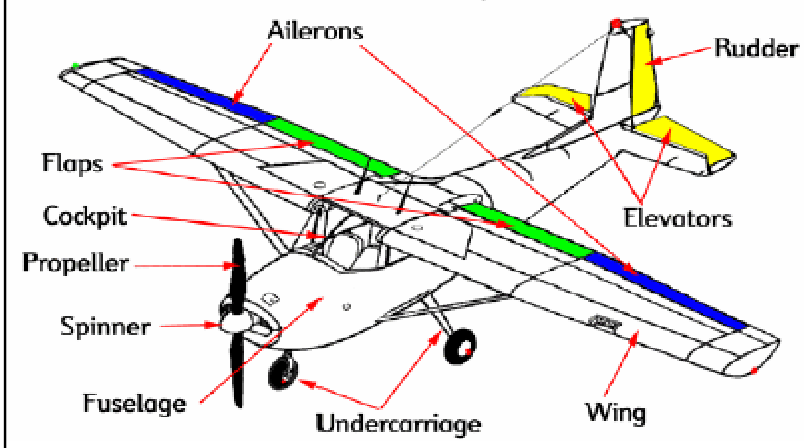
Evaluation Methods:

[1] Project (homework)	30%
[2] Attendance	10%
[3] Midterm exam 1	15%
[4] Midterm exam 2	15%
[5] Final Exam	30%

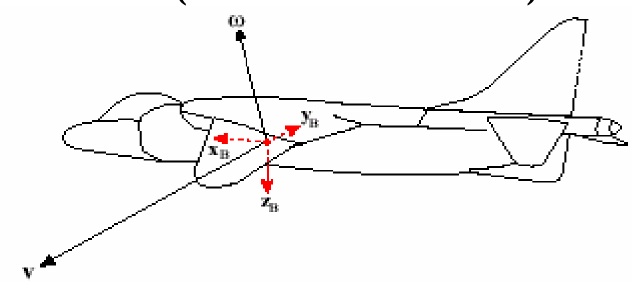
Aircraft Anatomy



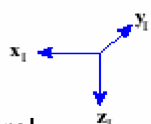
Aircraft Anatomy



AXES (BODY and INERTIAL)

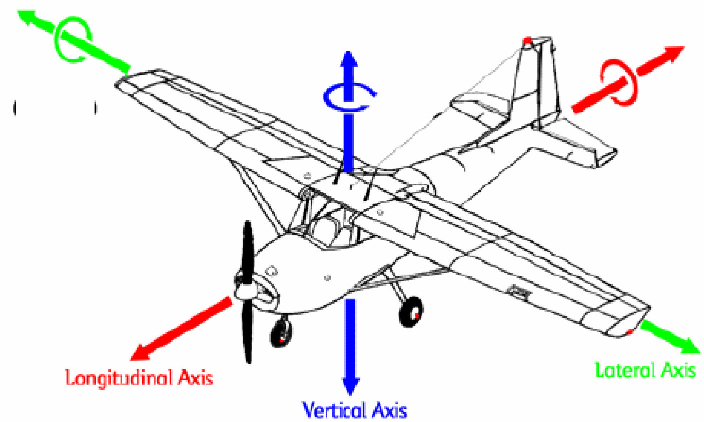


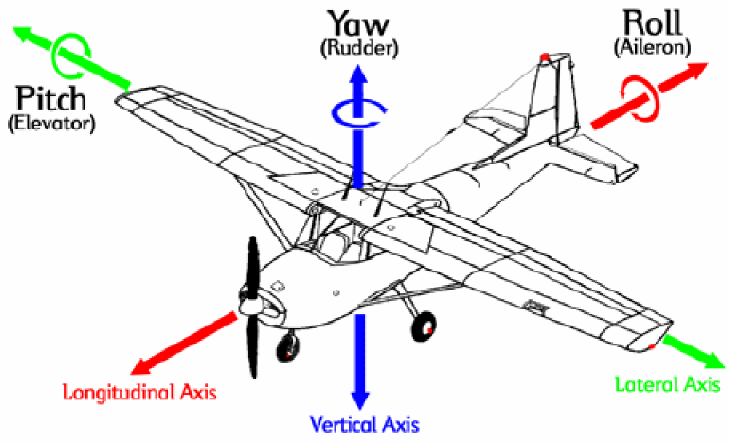
X_B pointing through the nose of the aircraft (longitudinal axis).

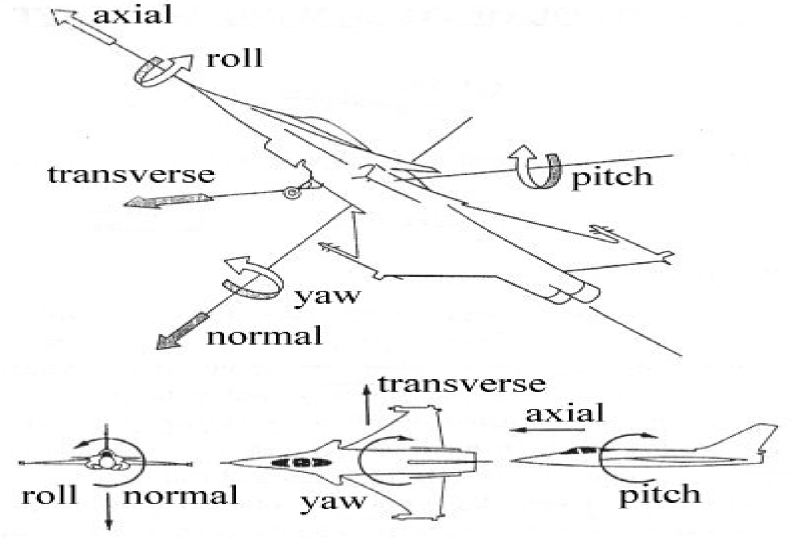


Z_B pointing down (directional axis).

Y_B pointing to the right wing (lateral axis).







Review of Aircraft Metrics

- Wing Area = S
- Wing Span = b
- Mean Chord = $\bar{c} = S/b = (c_t + c_r)/2$
- Root Chord = $c_0 = c_r$
- Tip Chord = c_t
- Taper Ratio = $\lambda = c_r / c_t$
- Aspect Ratio = $AR = b/\bar{c} = b^2/S$

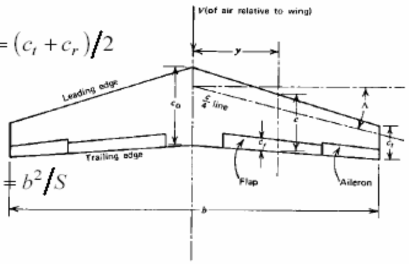
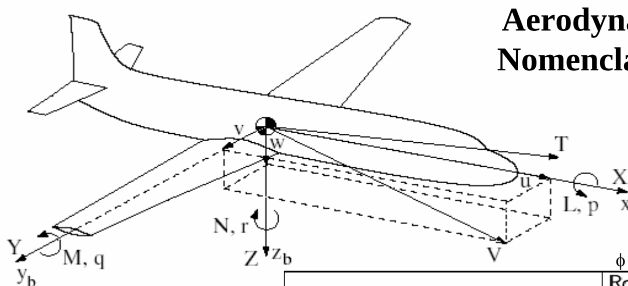


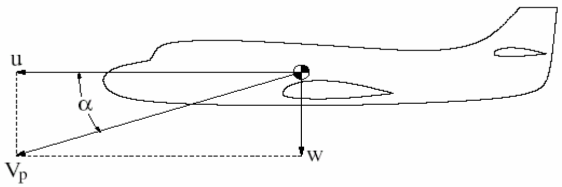
Figure 3.1 Top view of a wing planform.

Aerodynamic Nomenclature



	ϕ Roll axis x_b	θ Pitch axis y_b	φ Yaw axis z_b
Angular rates	p	q	r
Velocity components	u	v	w
Aerodynamic force components	X	Y	Z
Aerodynamic moment components	L	M	N
Moments of inertia	I_x	I_y	I_z
Products of inertia	I_{yz}	I_{xz}	I_{xy}

Angle of attack



V_p is projection of V onto x_b, z_b plane where

$$V = (u^2 + v^2 + w^2)^{1/2}.$$

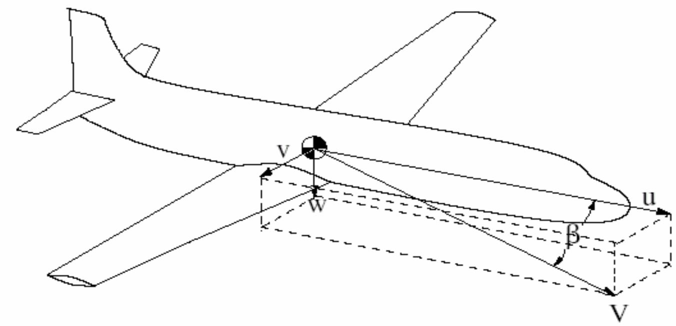
Angle of attack,

$$\alpha = \tan^{-1} \frac{w}{u}.$$

For $\alpha < 15°$

$$\alpha \simeq \frac{w}{u}.$$

Sideslip



$$\beta = \sin^{-1} \frac{v}{V} \simeq \frac{v}{u}$$

Main Topics

- **Equations of Motion.**
- **Stability.**
- **Control.**

Main Topics

- **Equations of Motion.**
  - The aircraft (rigid body) has 6 degrees of freedom.
    - Three translational motions.
    - Three rotational motions.
    - 12 first order differential equations
- **Stability (Static and Dynamic)**
- **Control.**

Main Topics

- **Equations of Motion.**
- **Stability (Static and Dynamic)**
  - Pilot related.
    - Is it stable?
    - Can it do this maneuver? How easy?
    - Flying qualities.
- **Control.**

Main Topics

- **Equations of Motion.**
- **Stability (Static and Dynamic).**
- **Control.**
  - Engineer related. (This is your work!!)
    - Control theories (classical and modern).
    - How to make the A/C stable?
    - Improving flying qualities.
    - Company secrets.

WHY STUDYING AIRCRAFT EQUATIONS OF MOTION?

•To know the action-reaction relation between different inputs and aircraft behavior.

- What will happen if I moved the thruster to 50% power?
- What if I pushed the stick forward 1 cm?
- What if the aircraft struck by a side wind ?

AIRCRAFT EQUATIONS OF MOTION

The rigid body equations of motion are obtained from Newton's second law, which states:

- The summation of all external forces acting on a body is equal to the time rate of change of the momentum of the body.

$$\sum F = \frac{d}{dt}(mv)$$

- The summation of the external moments acting on the body is equal to the time rate of change of the moment of momentum (angular momentum).

$$\sum M = \frac{d}{dt}(H)$$

Stability & Control

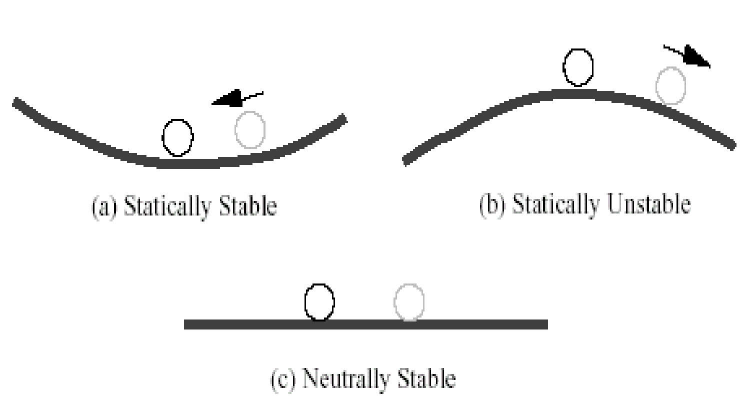
Stability

- Result of small disturbances from equilibrium which arise at ***random*** from external loads. It is categorized as ***static*** or ***dynamic***.
- Stability is a ***characteristic of the vehicle dynamics*** which is independent of the pilot's actions.

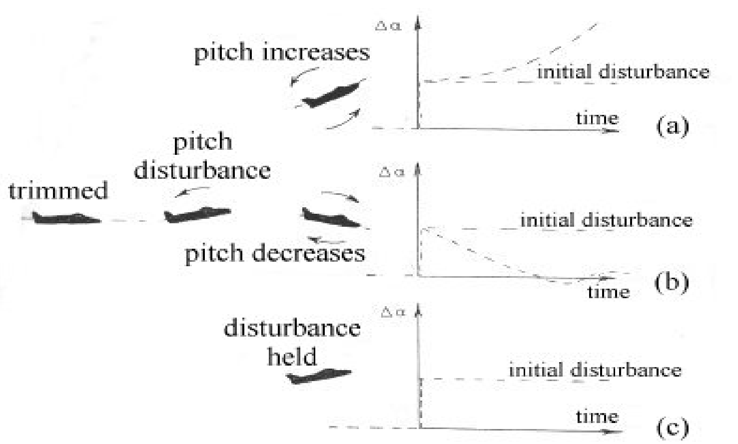
Control

- Response of aircraft to ***intentionally*** applied forces/moments which causes aircraft to deviate from initial equilibrium condition in a desired fashion.
- Control relates to a ***pilot's interaction*** with the aircraft.

Static Stability

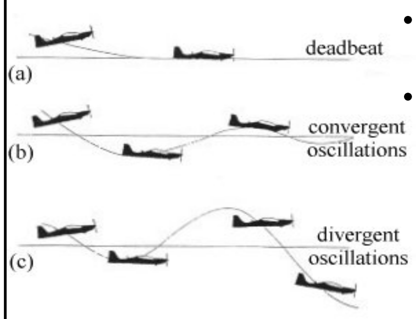


Longitudinal Static Stability



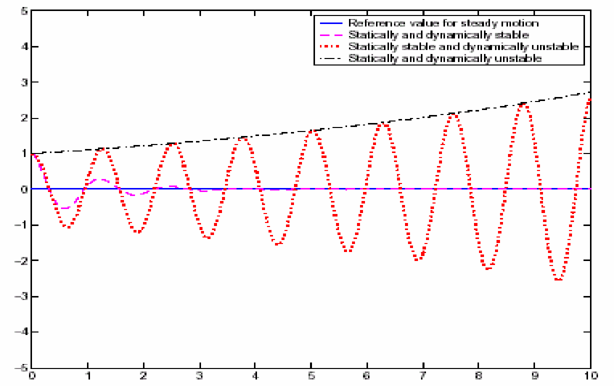
Dynamic Stability

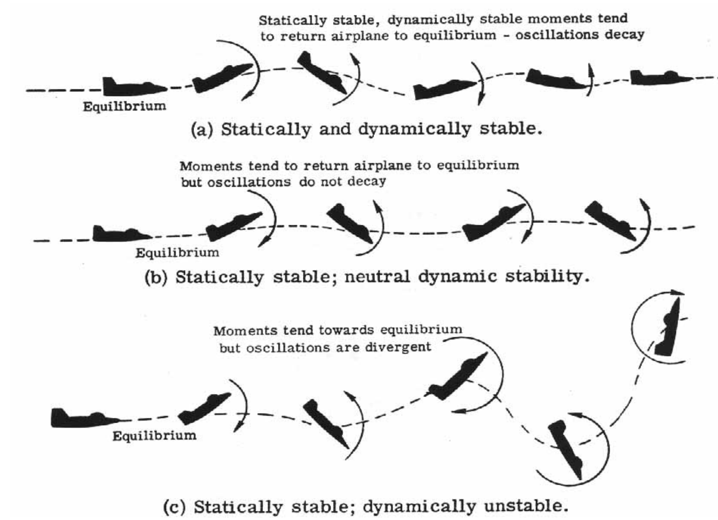
- For dynamic stability, motions have to be ***convergent*** or ***damped out***. (The vehicle will return to its original equilibrium condition after some interval of time).



- If divergent then dynamic instability exists.
- Cases (a) & (b) here are longitudinally dynamically stable, case (c) is longitudinally dynamically unstable (all are statically stable).

It is important to observe that a ***dynamically stable airplane must always be statically stable***. On the other hand, a ***statically stable airplane is not necessary dynamically stable***.





Our particular interest are the following questions:

• Can the aircraft perform its mission? How reliable? (Flying quality comparison).

• How to make the aircraft perform better?

To do that we need to know :

• Aircraft anatomy especially controls (aileron, rudder, throttle, thrust vectoring, etc.) ***What parts do the job?***

•Aircraft equations of motions. ***How is it done?***

• Stability. **Is it done well?**

• Automatic control theory. ***How to do it better?***

Elements of Feedback Control

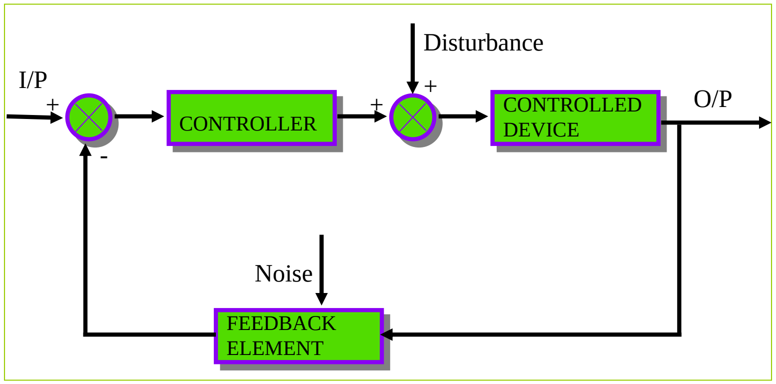
Learning Objectives

- Student will know definitions of following terms:
  - input / output
  - feedback, error
  - open loop, closed loop
- Student will know advantages to close loop control in Aerospace Engineering.

Control System Terminology

- **Input** - Excitation applied to a control system from an external source.
- **Output** - The response obtained from a system
- **Feedback** - The output of a system that is returned to modify the input.
- **Error** - The difference between the input and the output.

Negative Feedback Control System



Types of Control Systems

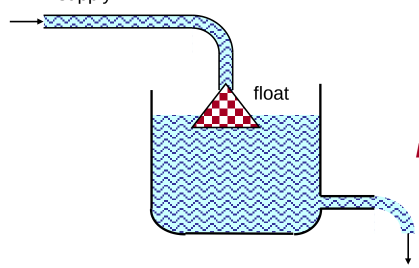
- **Open-Loop**
  - Simple control system which performs its function with-out concerns for initial conditions or external inputs.
  - Must be closely monitored.
- **Closed-Loop (feedback)**
  - Uses the output of the process to modify the process to produce the desired result.
  - Continually adjusts the process.

Control Modes in Feedback Loops

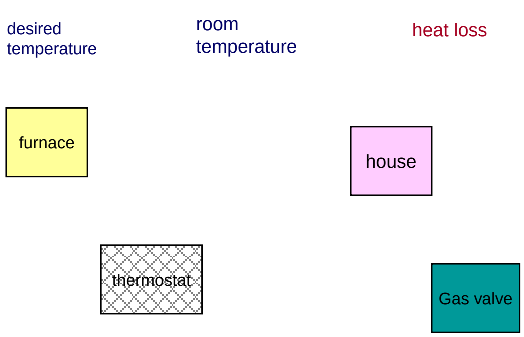
- Regulation
  - Constant set point.
  - Set point normally changed by human
  - Example
    - Level Control in a Tank.
- Servo (Tracking).
  - Dynamically Variable set point
  - Setpoint normally manipulated by another controller
  - Example
    - radar trackers.

Example 1

- Open or closed loop?
- regulation or tracking ?
- Identify the control loop elements?

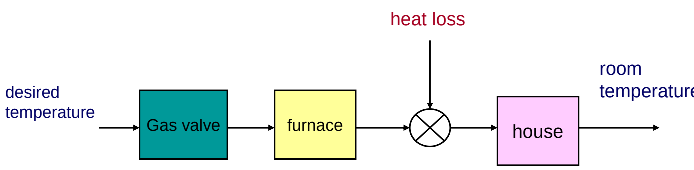


Simple Feedback Systems



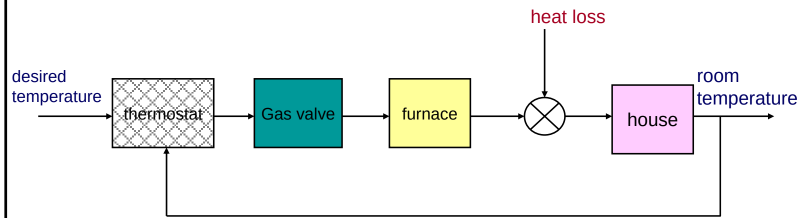
Simple Feedback Systems

OPEN LOOP



Simple Feedback Systems

CLOSED LOOP



What about these systems ?

- Open or closed loop?
- regulation or tracking ?
- Identify the control loop elements?