AE 430 - Stability and Control of Aerospace Vehicles

Introduction

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Welcome to AE 430 - Stability and Control of Aerospace Vehicles

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- **CAMP 234, MAE Department**
- **MW 10:00 - 12:30, CAMP 234 or by appointment**
- **(315) 268-3875**

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Course Outline

- Prerequisites: AE 455/ME 455, MA 231 (Calculus III), MA 232 (Differential Equations) or equivalent
- An introduction to atmosphere flight vehicle dynamics. Static stability and control. Equations of motion. Dynamic stability and control. Classical control theory. Transfer functions and block diagrams. Routh's criterion, Root locus techniques, Bode plots. Modern control theory. State space techniques. Observability, and controllability. Flying qualities, ratings and regulations. Application to aircraft autopilot design

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Textbook and References

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
- Pamadi, B. N., *Performance, Stability, Dynamics, and Control of Airplanes*, AIAA Education Series, 1998

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Atmospheric Flight Mechanics

- **Performance**
  - **Performance characteristics (range, endurance, rate of climb, takeoff and landing distances, flight path optimization)**
- **Flight Dynamics**
  - **Motion of the aircraft due to disturbances**
  - **Stability and Control**
- **Aeroelasticity**
  - **Static and Dynamic Aeroelastic phenomena (control reversal, wing divergence, flutter, aeroelastic response)**

The aerodynamic forces and moment as well as the trust and weight have to be accurately determined

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Learning Objectives

- Introduce students to the fundamental concepts of atmospheric flight dynamics
- Enable students to analytically estimate static and dynamic stability derivatives
- Enable students to study the stability of longitudinal and lateral motions using the linearized equations
- Enable students to obtain responses to actuation of open-loop and closed-loop controls
- Enhance the students' written, oral, and graphical communication skills

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Course Goals

- Overview principles of flight and the classical/modern theory of stability and control
- Present conventional and unified notation for flight mechanics variables, forces, and moments
- Derive classical, uncoupled rigid body equations of motion used for S&C analysis of aircraft

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Course Goals (Cont'd)

- Define and physically explain the static and dynamic stability and control derivatives
- Understand the concepts of equilibrium, neutral point, trim, etc.
- Introduce transfer function representation, dynamic stability, and modes of motion
- Present examples of flight models used in analysis and design

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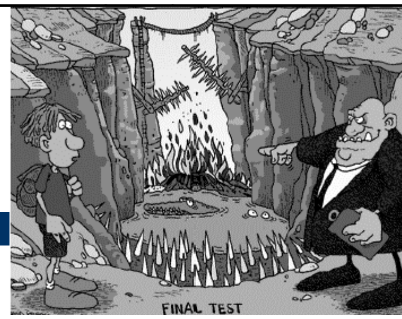
Grades



- All tests will be closed book, closed notes, and held during the class period (1 hr 15 min).
- [1] Homework 15%
- [2] Test 1 20% (~ end Sep)
- [3] Test 2 20% (~ end Oct)
- [4] Test 3 20% (~ end Nov)
- [5] Project 25% (Project report and oral presentation)

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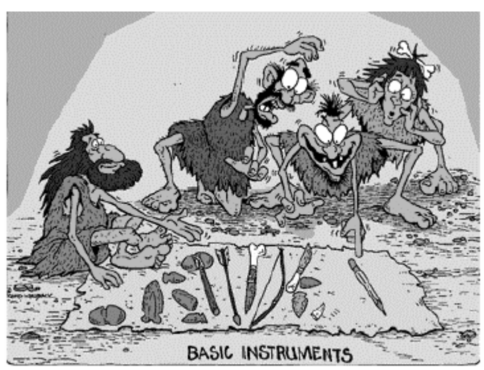
Aircraft Stability and Control

- Will it fly?
- How well does it fly?
- How easily can be controlled?
- Week 1:

The Fundamentals



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Week 1 - 5

- Flight Mechanics
  - Atmospheric flight mechanics
  - aerodynamic nomenclature
  - reference frames
- Static Stability and Control — Chapter 2
  - Longitudinal static stability
  - Pitch control
  - Lateral / directional static stability
  - Roll & yaw control
  - Stick forces

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Week 6 - 10

- Aircraft Equations of Motion — Chapter 3
  - Nonlinear formulation
  - Linearized equations of motion
  - Dynamic stability
- Longitudinal Motion — Chapter 4
  - Pure pitching motion
  - Longitudinal EOM
  - Phugoid and short-period modes
  - Longitudinal flying qualities
- Lateral Motion — Chapter 5
  - Pure rolling motion
  - Pure yawing motion
  - Lateral EOM
  - Spiral, roll, and Dutch roll approximations
  - Lateral flying qualities
  - Aeroelastic effects

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Week 11 - 12

- Introduction to Modern Control Theory — Chapter 9
  - State-space modeling; Solution of state equations
  - Controllability and observability
  - State feedback design
- Aircraft Autopilot Design Using Modern Control Theory — Chapter 10
  - Longitudinal stability augmentation
  - Lateral stability augmentation

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History of Airplane

- The dream of flying is as old as mankind itself. However, the concept of the *airplane* has only been around for two centuries. Before that time, men and women tried to navigate the air by imitating the birds. They built machines with flapping wings called ***Ornithopters***. On the surface, it seemed like a good plan. After all, there are plenty of birds in the air to show that the concept *does* work.

Ornithopters

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- The trouble is, it works better at bird-scale than it does at the much larger scale needed to lift both a man and a machine off the ground. So folks began to look for other ways to fly. Beginning in 1783, a few aeronauts made daring, uncontrolled flights in *lighter-than-air* **balloons**, but this was hardly a practical way to fly. There was no way to get from here to there unless the wind was blowing in the desired direction.

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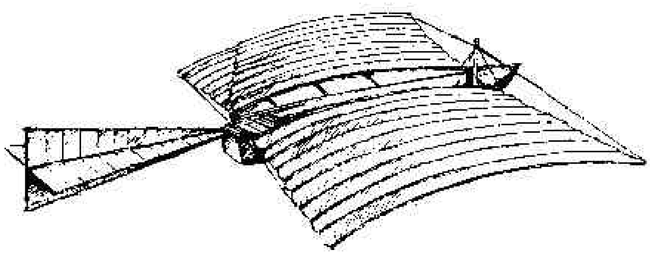
- It wasn't until the turn of the nineteenth century that an English baronet from the gloomy moors of Yorkshire conceived a flying machine with *fixed wings*, a *propulsion system*, and movable *control surfaces*. This was the fundamental concept of the **airplane**. Sir George Cayley also built the first true airplane — a kite mounted on a stick with a movable tail. It was crude, but it proved his idea worked, and from that first humble glider evolved the amazing machines that have taken us to the edge of space at speeds faster than sound.



Sir George Cayley's 1799 design for an airplane -- fixed wings for lift, a movable tail for control, and rows of "flappers" beneath the wings for thrust.

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Inherent Stability and the Early Machines

Stability is defined as the ability of an aircraft to return to a given equilibrium state after a disturbance (it is a property of the equilibrium state)

- Pioneer airplane and glider builders who came before the Wright brothers recognized the importance of airplane stability.
- They had discovered that some degree of inherent stability in flight could be obtained with an appropriate combination of:
  - Center of gravity location (Lilienthal)
  - Wing dihedral angle or lateral area distribution (Langley and Lanchester)
  - Alf mounted tail surfaces (Cayley and Pénaud)
- Very little thought have been given to the problem of control except for the provision of horizontal and vertical rudders (Langley)

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Only the Wrights recognized that:

- An airplane has to be banked to turn in an horizontal plane
- An interaction exists the banking or roll control and the yawing motion of the airplane
- Excessive dihedral effects hinder pilot control unless sideslip is suppressed and makes the machine unduly sensitive to atmospheric turbulence
- Wings can be stalled, leading to loss in control
- Control can be regained after stall, by reducing the angle of attack

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Stable vs. Unstable Flight

Lilienthal's Flyer
Stable Flight

Wright Flyer
Unstable Flight

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Stable vs. Unstable Flight

- Flight **Too Stable** for Lilienthal
  - Not maneuverable
  - On August 9, 1896, Lilienthal was killed when he stalled and crashed to the ground while gliding.
- **Unstable** Flight, a success for Wrights
  - Problem was one of **"CONTROL"**

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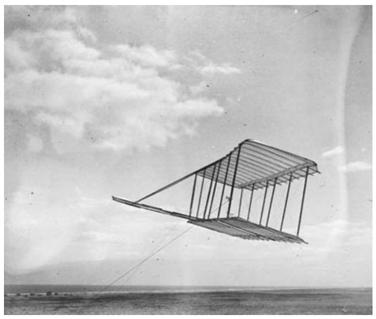
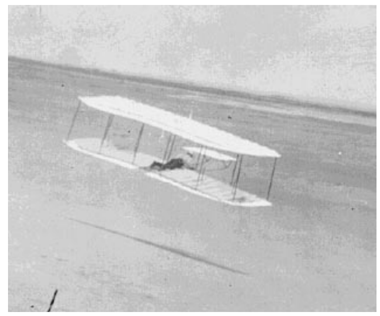
Movies of Wright brothers' 1900 and 1901 gliders



1900



1901

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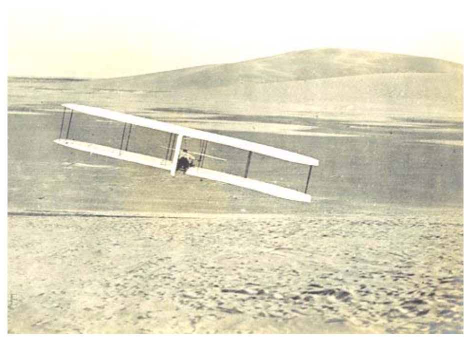
Wright brothers' 1902 aircraft (third unpowered aircraft built by the brothers).

- The aircraft was flown as a piloted glider and as a kite. They used this aircraft to develop their piloting skills because this was the first aircraft in the world that had active controls for all three axis; roll, pitch, and yaw.
- The 1902 aircraft has two wings and an elevator/stabilizer mounted in the front like the 1901 aircraft. As with previous aircraft, the pilot lies on the bottom wing and controls the roll of the aircraft by warping the wing shape. On the 1902 aircraft, and on all later flyers, the warping was controlled by a hip cradle instead of the pedals on the 1900 and 1901 aircraft.
- There were, however, some major differences between this aircraft and its predecessors. Data from the 1901 wind tunnel experiments showed that a longer, thinner wing gave less drag and a better L/D ratio than a short thick wing. So the aspect ratio (ratio of wing span to wing chord or width) was changed from 3:1 on the 1901 aircraft to 6:1 on the 1902 aircraft. In an attempt to solve the problem of adverse yaw from the 1901 glider, two 6-foot rudders were added to the rear of the craft. Initially, these rudders were fixed to their struts to keep the nose pointed straight ahead.



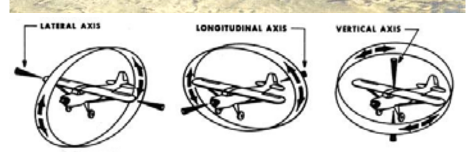


Figure 17-21 Axes of an Airplane

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Wright brothers' 1902 aircraft (third unpowered aircraft built by the brothers).

Test flight went better than in 1901, but in about one glide in 50 the glider would spin out of control on recovering from a turn at low speed. His solution was to replace the twin fixed rudders with a single moveable rudder. The next morning Wilbur agreed and offered the idea to tie the rudder turning into the wing warping system. Once done, the glider worked beautifully, keeping the nose of the aircraft pointed into the curved flight path. On the 1902 aircraft, the pilot could also change the angle of the elevator to control the up/down position or pitch of the nose of the aircraft. For the first time in history a craft could be controlled in three dimensions. With this new aircraft, the brothers completed gliding flights of over 650 feet.

The 1902 aircraft was the largest glider flown to that time. The aircraft had a thirty two foot wing span, a five foot chord and five feet between the wings. Without the pilot, the 1902 craft weighed about a hundred twenty pounds. This photo taken in 1902 clearly shows the new rudder of the aircraft.

At the end of 1902, it seemed that all that remained for the first successful airplane was the development of the propulsion system. During that winter and spring the brothers built their small engine and perfected their propellers for the 1903 flyer.

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Blériot and Lavavasseur

- Designer and constructor of the Blériot and Antoinette machines
- Pioneers in developing tractor monoplanes with normal tail surfaces and wing dihedral angles
- These two airplane had a fair amount of inherent stability, unlike the Wrights biplanes
- Superior speed, which helped establish the aft tail as normal arrangement (WW1 plane)

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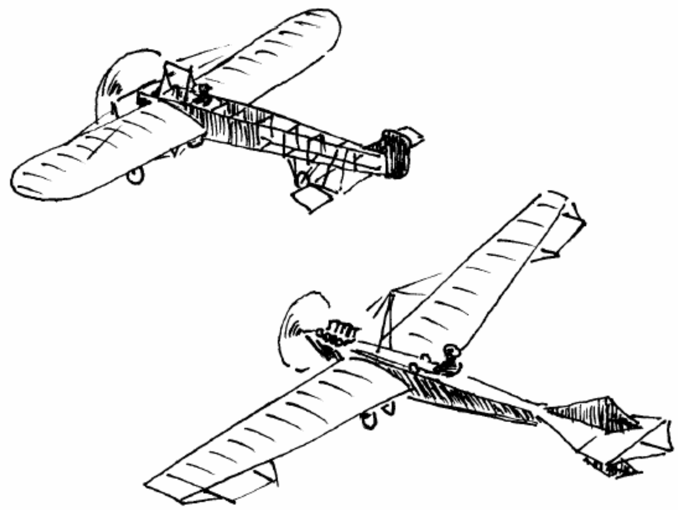

Figure 1.1 Two early flying machines with inherent longitudinal and lateral stability, the Blériot XI Cross-Channel airplane (*above*) and the Levavasseur Antoinette IV (*below*). Both used pronounced wing dihedral, unlike the Wright Flyers.

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Blériot and Déperdussin Controls

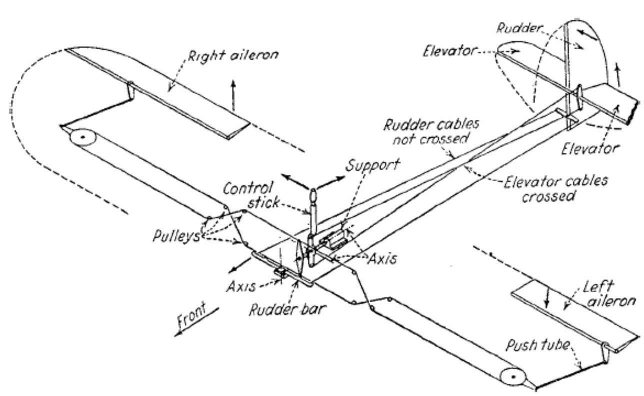

Figure 1.3 Diagrammatic sketch of a simple airplane control system. When the controls are moved as shown by arrows on the stick and rudder bar, the surfaces move as shown by the arrows. (From Chatfield, Taylor, and Ober, *The Airplane and Its Engine*, McGraw-Hill, 1936)

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Control Theory: The Classical Approach

- Classical Control Theory
  - Frequency response methods
  - Root locus technique
  - Transfer functions
  - Laplace Transforms

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Control Theory: Modern Approach

- Modern Control Theory
  - State-space techniques
  - State feedback, state observer
  - Optimal control, optimal estimation
  - Robust control

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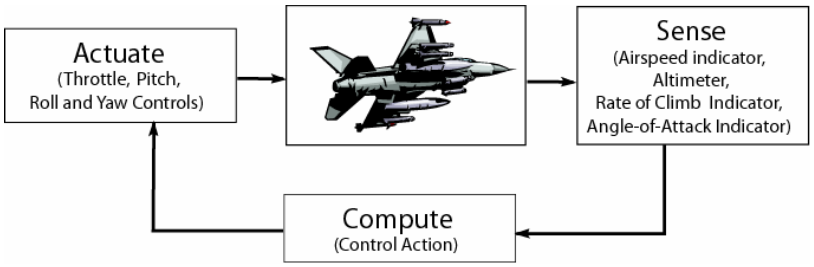
Control = Sensing + Computation + Actuation = *Feedback*



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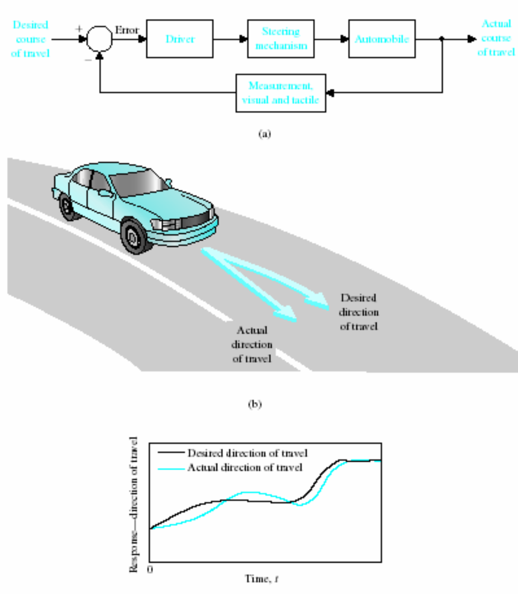

(a) Automobile steering control system.

(b) The driver uses the difference between the actual and the desired direction of travel to generate a controlled adjustment of the steering wheel.

(c) Typical direction-of-travel response.

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Aeroelastic Phenomena

Tacoma's bridge, 1940

Flutter test at NASA Dryden

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Welcome to AE430 - SCAV

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