Closed Loop Control

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What is Control Engineering?

Control Engineering is concerned with the study (analysis) and subsequent modification of the behaviour (design) of systems.

System

A system is a collection of elements that perform a specific function:

e.g. Hydraulic actuator (Relatively simple)

e.g. Fighter aircraft (Complex)

A system normally has an *input*, or *inputs* and always has an *output* or *outputs*.

Control Engineering

1 - System Modeling

2 - System Analysis

3 - Controller Design

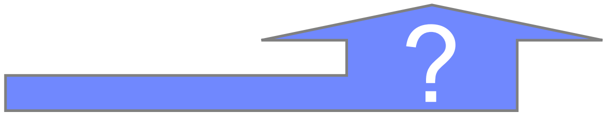
Systems Analysis

- Examine the behaviour of the system in terms of how the input/s affect the output/s.
- Is there a need to modify this behaviour by automatically adjusting the system input/s based on knowledge of the evolution of the system output/s.

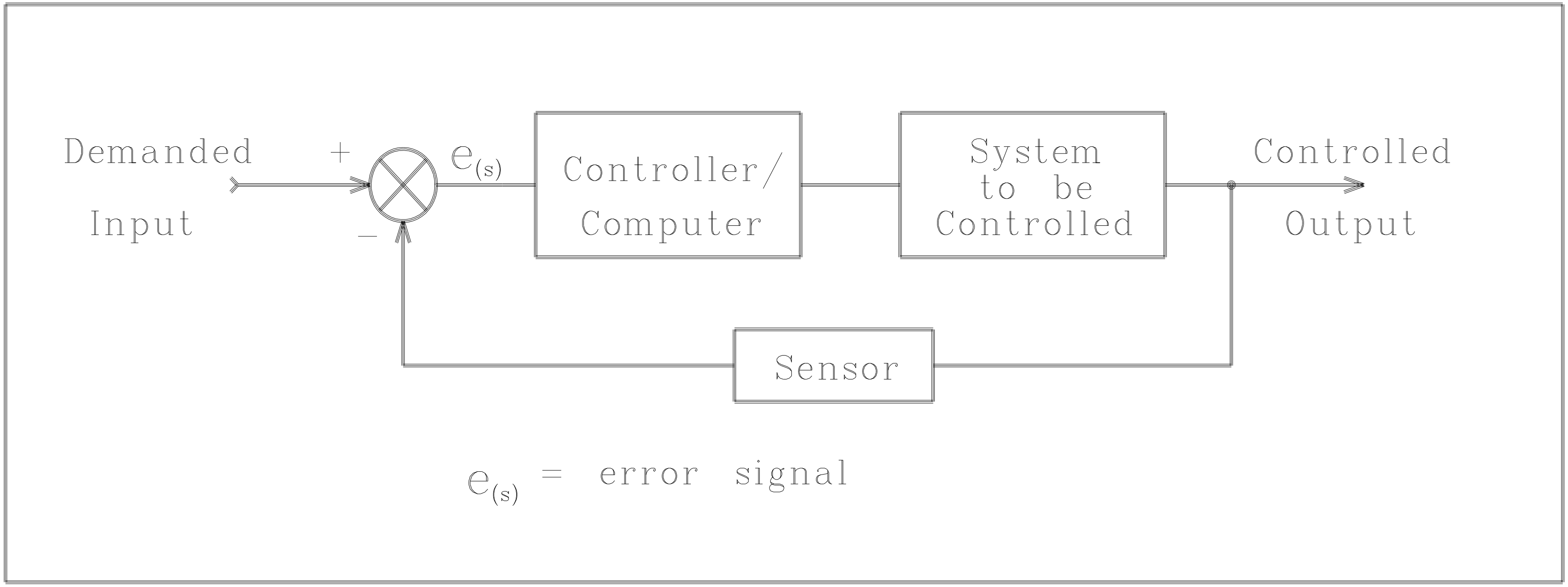
Control System Design

Design the controller to take the system from where it is now to where you would like it to be, in a way which is in some sense *better* than without automatic adjustment.

Implement the controller



Generalised Control System Block Diagram



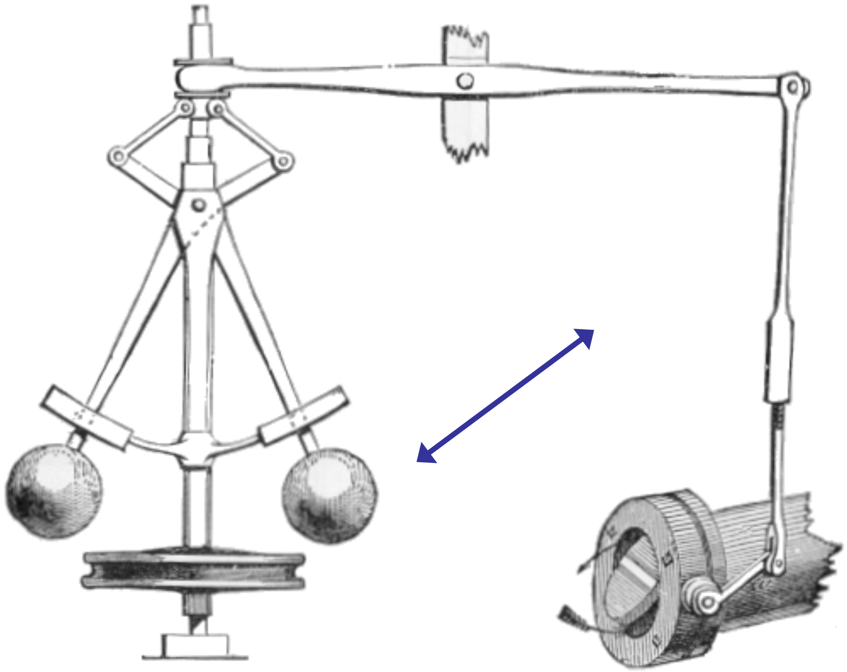
Change in state of the system is made to take place by processing an error signal which represents the difference between the input demand and a signal representing the output.

Input demand - where you would like the system to be.
Output - where the system is.

Historical Examples

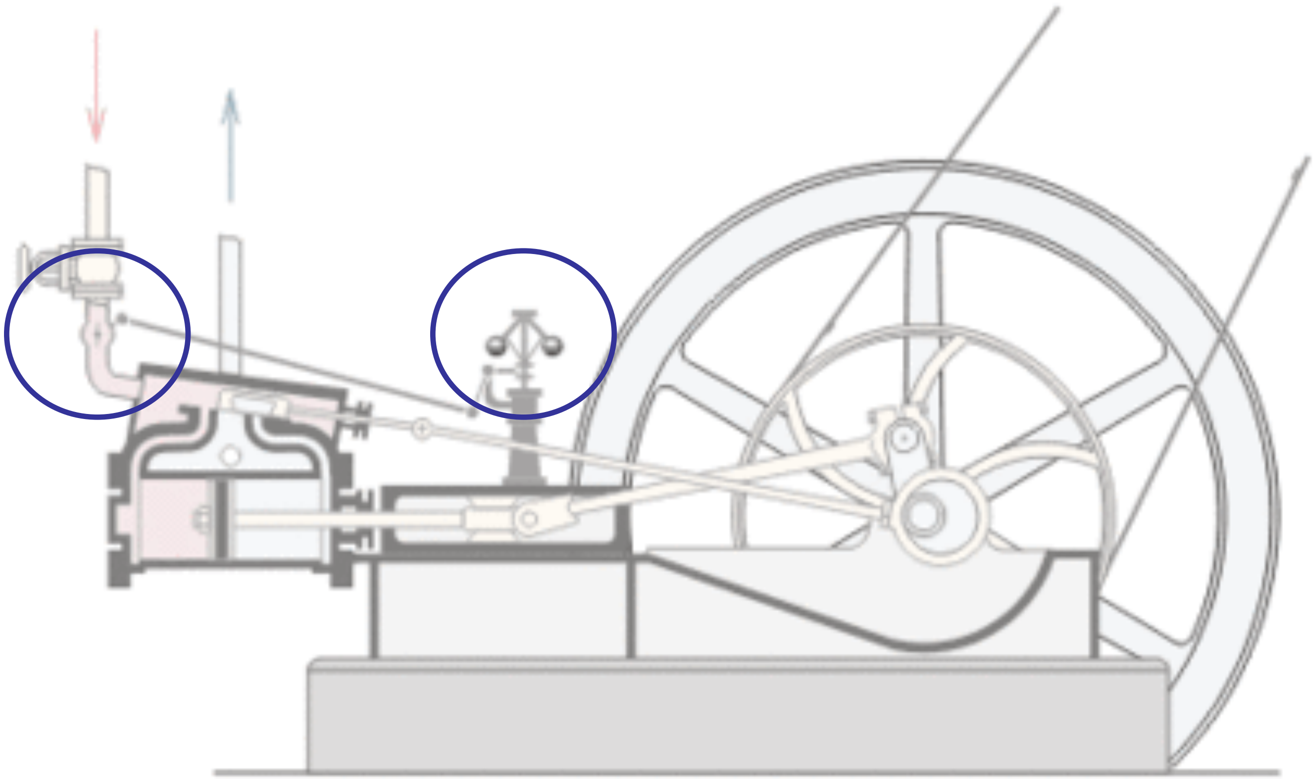
Watts steam engine - 1788

- First recorded application of closed loop control
- Flow of steam was regulated by a simple mechanical arrangement.
- Note: Hunting of the steam engine



'Speed Governor'

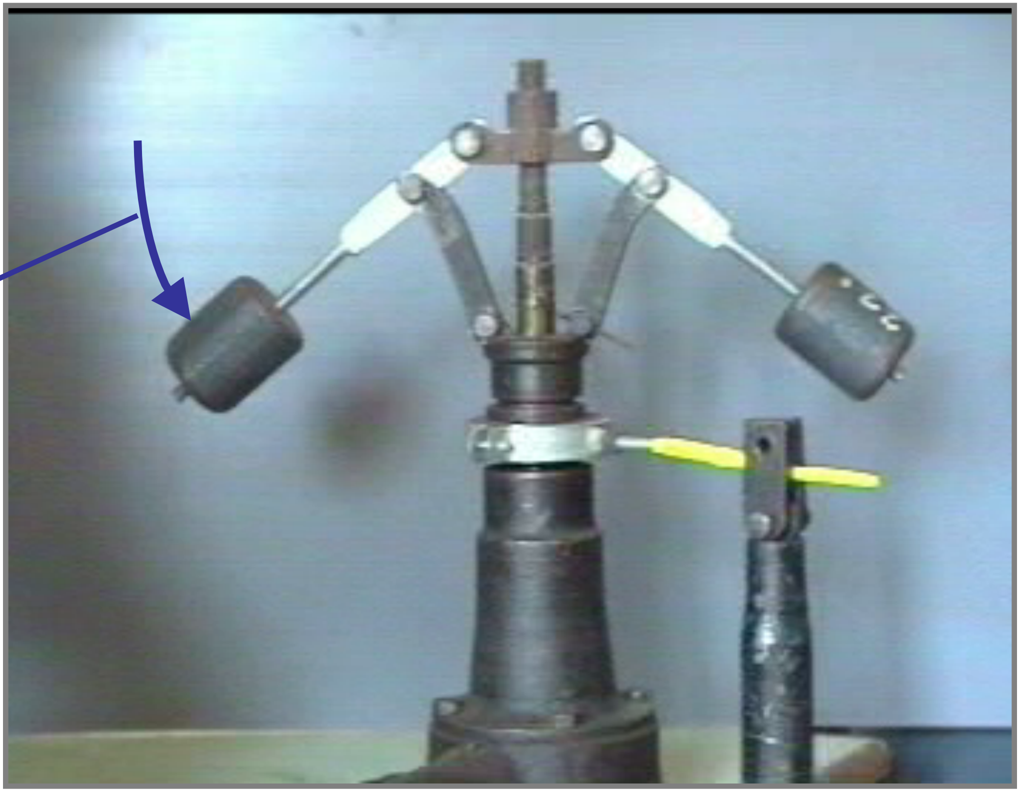
Historical Examples



Source: Wikipedia!

Steam Engine Governor

Reduced Speed



Early Aircraft Applications

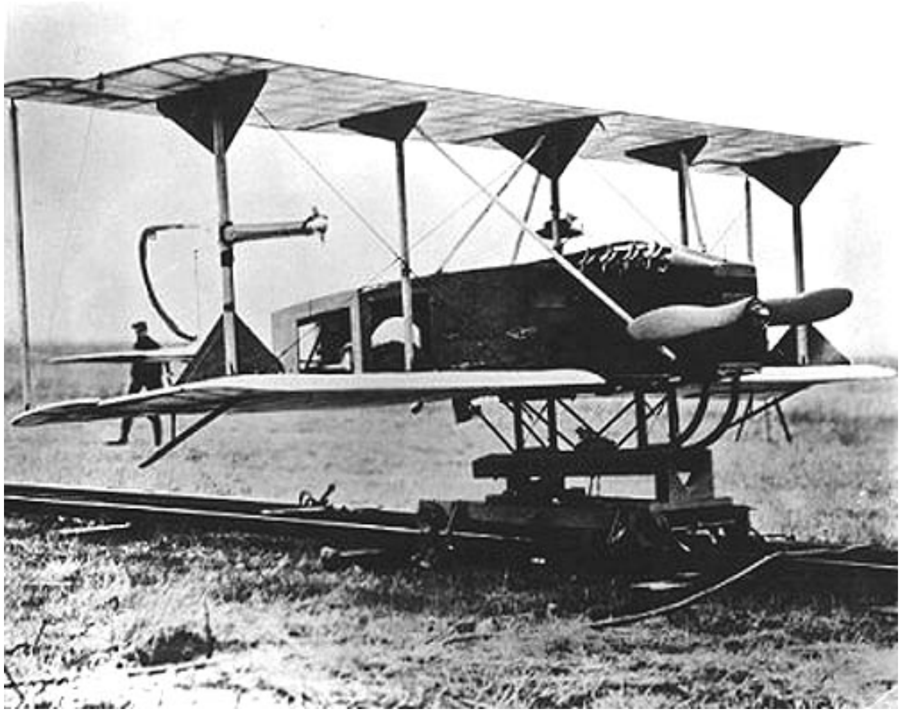
- ‘Sperry Aeroplane Stabilizer’.
- Autopilot was installed in a Glenn Curtis Flying boat
- (First tested 1912).
- Used gyros to sense deviation of the aircraft from the desired
- attitude and servo motors to activate the elevators and ailerons.

Early Aircraft Applications

- On the 18th June 1914 won the prize offered by the Aero Club of France for the most stable aircraft.
- During the demonstration the pilot Lawrence Sperry stood in the cockpit with both hands above his head with the mechanic walking back and forth on the wing. *Final run – both on the wings…*

Early Aircraft Applications

- Example: Curtiss Sperry Aerial Torpedo
  - 6th March 1918: 1000yds straight unmanned flight
  - World's first UAV/Drone



Application to Modern Aircraft

Relaxed stability - Enhanced agility
Efficiency
e.g. Typhoon

- Aircraft response - fast and aggressive
- Vehicle becomes pilot uncontrollable

Computers control the basic aircraft response and the pilot controls the vehicle at a higher level with stick displacements commanding manoeuvre rather that control surface deflection.

Closed Loop Control can:

1. Improve dynamic performance
2. Reduce system errors
3. Reduce the effect of external disturbances
4. Reduce the effect of parameter variation on the output

Note: *An inherent feature of closed loop control is often a tendency towards instability!*

Types of Control System

Two basic categories

Single **I**nput **S**ingle **O**utput
(*SISO*) e.g. Actuator Model

Multiple **I**nput **M**ultiple **O**utput
(*MIMO*) e.g. Fixed wing aircraft / Helicopter
(Multivariable Control Systems)

Control Systems Engineering Terminology

Open Loop - System Configuration with all feedback loops broken

Closed Loop - System configuration with feedback loops closed

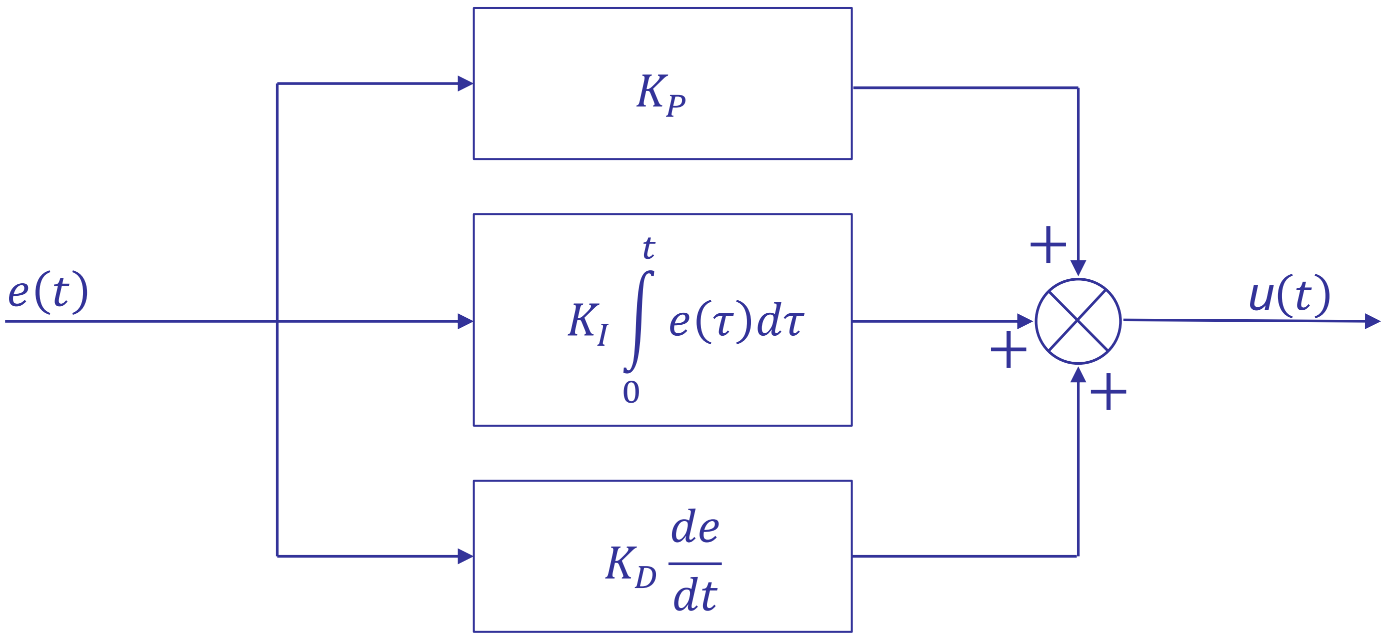
Control? – F-22

PID Control

$$u(t) = K_P e(t) + K_I \int_0^t e(\tau)d\tau + K_D \frac{de}{dt}$$

– Proportional – Integral – Derivative Control
– Widely used in industry, including aviation
– Popular for simplicity and ease of understanding

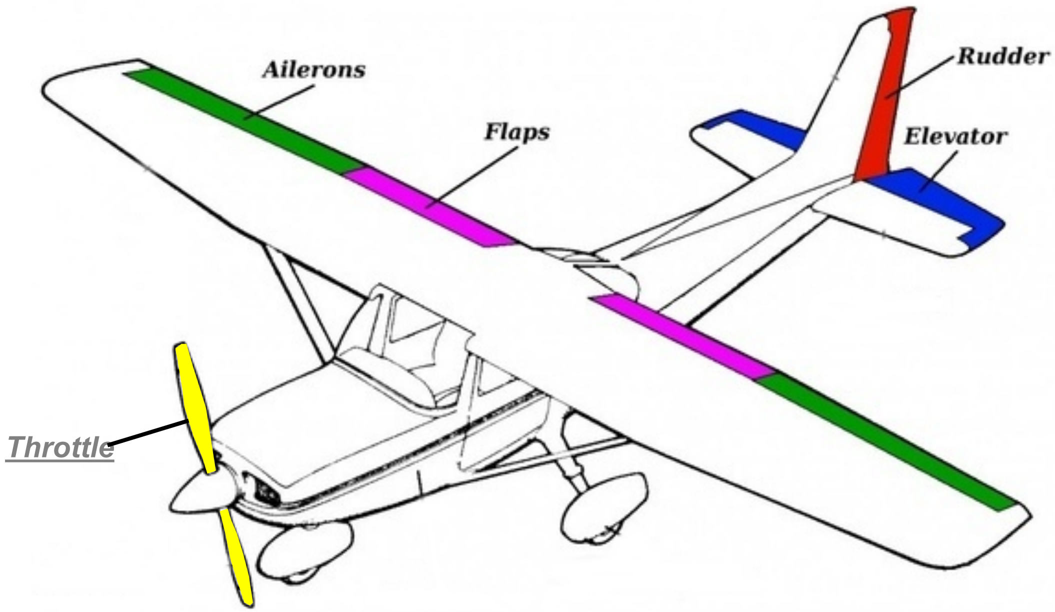
PID Control



PID Cautions

- PID comes with *no guarantee of stability*
  - It's just popular and easy to use
- PID is *not necessarily the best* controller
  - Dynamics and performance not guaranteed

Aircraft Control



Pitch up/down

Roll left/right

Increase/Decrease Speed up/down

Manual mode

Autopilot

Sensors

Ailerons

Elevator

Throttle

Rudder

UAS/Drone Control

Standard External inputs
- GPS + Magnetometer
- Airspeed

Multiple power options

Pilot inputs
- PPM
- SBUS

Telemetry ports
- TTL Serial
- I2C
- USB

PWM Outputs
- Servos
- Speed controllers
- Payload?

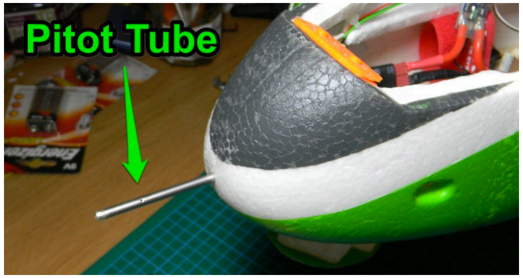
Internal sensors
- IMU (accelerometers + Gyro)
- 2^{nd} Magnetometer
- Barometer

Magnetometers, Gyros & Accelerometers

Magnetometer
- Low current draw
- Gives compass heading/bearing
- Affected by magnetic fields
- Local calibration needed
- Check correct direction, then rapidly turn by 90°

Gyros & Accelerometers
- Gyros measure rotation
  Accelerometers measure acceleration
  Extremely small piezoelectric units
  Calibration & checks are critical – the aircraft corrects to what it thinks is straight and level!

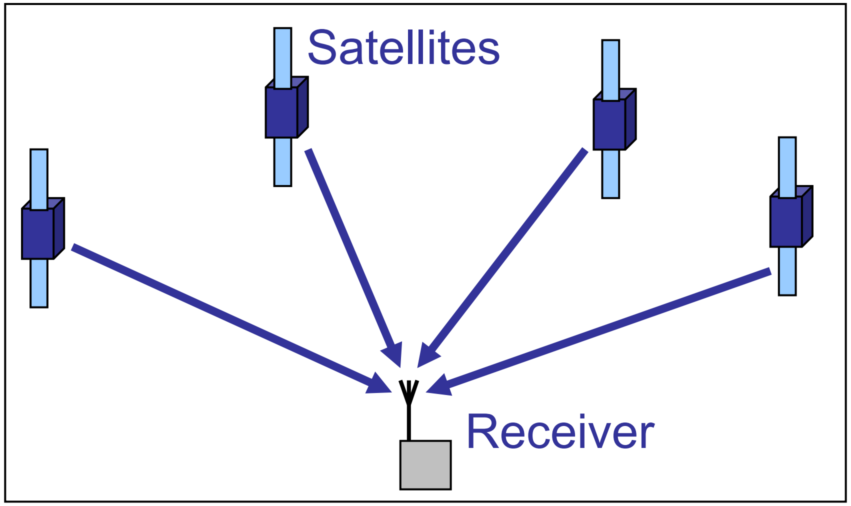
Other Sensors
- Pitot Tube (Airspeed)
- Laser Rangefinder (Height & Obstacle Avoidance)



GPS

Basic Theory

- Many satellites orbit the Earth
- GPS satellites broadcast their ID, location, and time at intervals
- Receivers converts time delay to distance
- Four unknowns; x, y, z, clock error
- Processing gives co-ordinates



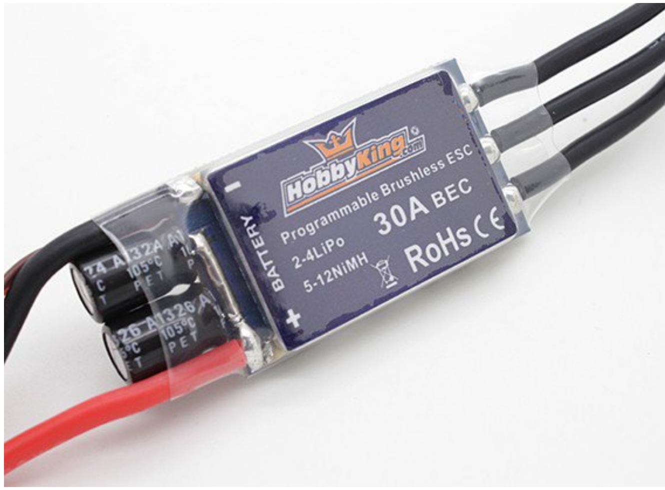
Operation

- GPS Status – limited signal?
- Number of Satellites – >4 satellites for 4 unknowns. Ideally >6.
- HDOP – Horizontal Dilution of Position. A measure of the geometric layout of satellites in the sky. Smaller means better horizontal accuracy. Usually <2, and <1 is good.

Speed Controllers and Servos

Electronic Speed Controller (ESC) Specs.

- Maximum continuous current
- Voltage range – stated in LiPo cells
- UBEC or OPTO
- Connections usually include 3 wires to motor, 2 wires to battery, speed control via a standard servo connector carrying a PWM signal
- PWM input from flight computer sets the RPM



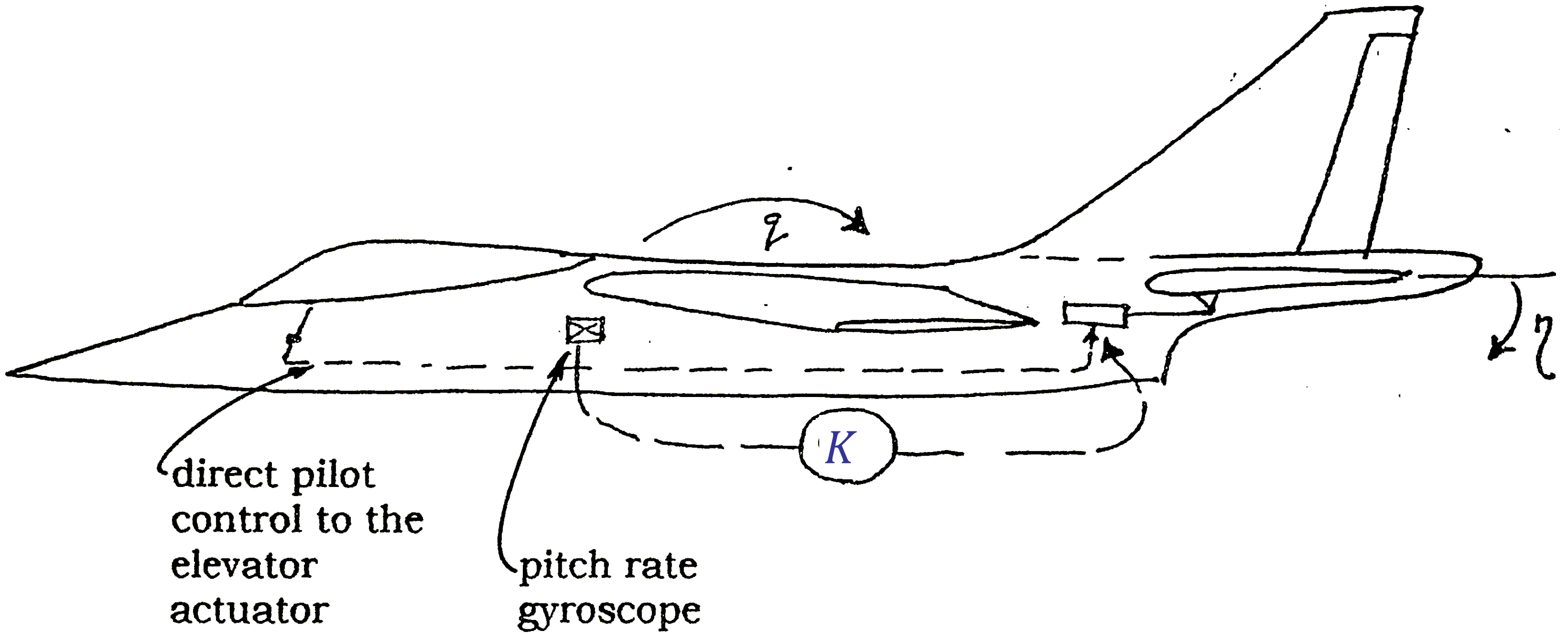
Hobbyking ESC
30A, 2-4S LiPo, UBEC

HiTec HS7655TG
High torque, 4.8 – 6V

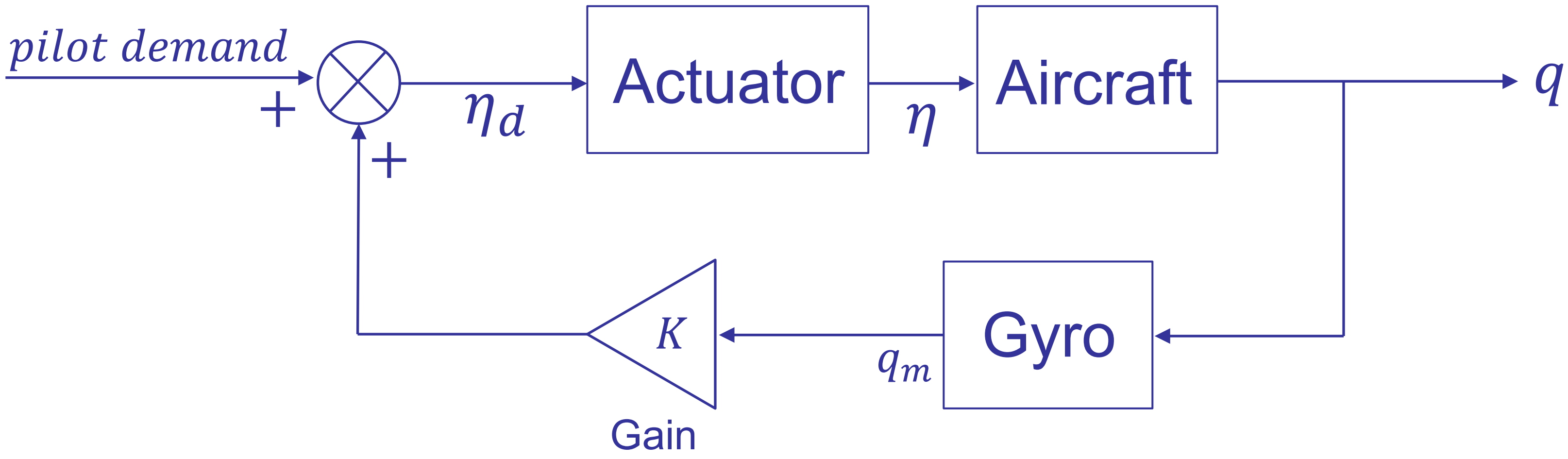
Servos

- Torque and speed – internal gear ratio is designed for either high torque or high speed
- Voltage range – normally 5 – 7.5V
- Usually a single servo connector for power and PWM control signal
- PWN input from flight computer controls the arm rotational position

Pitch Rate Damper



Pitch Rate Damper



Pitch Rate Damper

Example

- One example of the approximate short-period roots for an aircraft with and without pitch damping augmentation:

- For $K_q = 0$
- $s^2 + 0.925s + 7.6 = 0$ for which the short-period roots are $s = -0.462 \pm j2.72$
- For which the damping ratio is $\zeta = \frac{0.925}{2\times2.76} = 0.168$

- For $K_q = 1.2$
- $s^2 + 3.425s + 9.6 = 0$ for which the short-period roots are $s = -1.713 \pm j2.58$
- For which the damping ratio is $\zeta = \frac{3.425}{2\times3.1} = 0.553$

- Can you plot these roots?
- What are the associated undamped natural frequencies, ω_0 ?

References

- Ogata, "Modern Control Engineering"
  - Prentice Hall; Library class mark TJ213 OGA
- Dorf & Bishop, "Modern Control Systems"
  - Pearson; class mark TJ213 DOR
- Roskam, "Airplane Flight Dynamics & Automatic Flight Controls"

Next Lecture

Revision Lecture