Control - Overview

- Control requirements & use
- Primary controls
  - Elevator, rudder, ailerons, throttle
- Pilot’s controls
- Other methods of pitch, roll & yaw control
- Controls problems
- Mechanical control systems
- Fly-by-wire & Fly-by-light
Control Requirements

An aircraft must be controlled along & about its 6 degrees of freedom:
- translation along the axial (or longitudinal).
- Transverse
- normal axes
- rotation about the same axes (roll, pitch and yaw respectively).

Use of Controls

- Used to:
  - Set and hold aircraft in equilibrium or trim condition.
  - Initiate, hold & terminate manoeuvres.
- Control power has to be sufficient to cope with all possible flight conditions & speeds, including:
  - Deployment of high lift devices.
  - Cross-wind landings.
  - Engine failure on multi-engined aircraft.
- Cross-coupling effects (e.g. between roll & yaw) complicates control requirements.
Conventional Aircraft - Primary Controls

Aerodynamic surfaces used as primary controls for rotation about 3 axes.

- **Elevator** for pitch.
- **Rudder** for yaw.
- **Ailerons** for roll.

Primary Controls

All primary aerodynamic control surfaces work by changing local camber and hence local lift generation.

*Note increase in effective angle of attack*
Pilot’s Controls

- Pitch (elevator) and roll (ailerons) primary control via arrangement of:
  - Handlebars, spectacle grip, wheel/yoke, control stick
- Pulling back on control produces nose-up pitching moment.
- Push/turn to right produces roll/bank in that direction
  - Control rotation directly affects rate of roll and not angle to which aircraft rolls.

Pilot’s Controls (Cont’d)

- For aircraft with fly-by-wire flight control systems, side-stick controller often used instead
  - Designed for one-handed operation, mounted to side of pilot’s seat.
- Yaw (rudder) control operated by foot pedals on virtually all aircraft
  - Right foot down yaws nose to right.
Pitch Control

Using elevator

Deflection produces:
- Increased camber on tailplane
- Nose-down pitching moment about CG
- Reduced $\alpha$ on main wing
- Less lift on main wing
- Drop in aircraft altitude

Boeing 747

BAe 146 RJ-100
Pitch Control (Cont’d)

Using elevator (cont.)

- Upward deflection of elevator produces opposite to above (i.e. eventual increase in lift and altitude).
- Consequently a finite delay and negative initial response before desired eventual change in $\alpha$ is achieved.
  - Severe effect on large aircraft, many have elevator control directly linked to throttle to counter it (e.g. Concorde).

Pitch Control (Cont’d)

Conventional Elevator in Supersonic Flow

- A conventional elevator performs poorly in supersonic conditions as air ahead of deflection is unaffected by its movement.

![elevator deflection](image1)

![poor control response](image2)
Pitch Control (Cont’d)

**Slab or All-Moving Tailplane or Stabilator**

- Here, lift is affected by $\alpha$ variation rather than less effective camber change for supersonic flight.
- Most supersonic fighters also use differential movement of opposite sides to improve roll rate (then known as tailerons).
- Mass penalty due to large actuation mechanisms.
- Also used on light aircraft due to increase control effectiveness and ease stall recovery.

Pitch Control (Cont’d)

**Aircraft with Slab or All-Moving Tailplanes**

- F/A 18 Hornet
- F-4 Phantom
- F-15 Eagle
- F-16 Fighting Falcon
- BAe Hawk
- Tornado GR4
Pitch Control (Cont’d)

Canards

- Here, pitch control surfaces are mounted independently forward of aircraft CG.
- Main wing surfaces mounted behind CG to give aircraft longitudinal stability (if required) - though often statically unstable nowadays for high manoeuvrability requirements.

Using canard

- Nose-up deflection produces:
  - Increased canard $\alpha$ and lift.
  - Nose-up pitching moment about CG.
  - Increased $\alpha$ on main wing.
  - More lift on main wing.
  - Increased aircraft altitude.
Pitch Control with Canards

Canard Advantages

- Produces immediate response in desired direction and increased total lift increment (high manoeuvrability).
- Negligible trim drag penalty, usually download required on conventional tail surface.
- Possible layout advantage - aft-located wing can pass behind cabin.
- Can be made stall-proof if stall angle of canard is less than that of main wing.
- Better provision for escape from pitch-up (caused by tip-stall on high-sweep wings).

Canard Disadvantages

- De-stabilizing surface.
- Main wing never reaches maximum lifting capability - low speed performance penalty.
- Airflow over canard disturbs flow over main wing.
- Difficult to apply flaps to main wing due to large moment arm and pitching moment produced.
Pitch Control with Canards (Cont’d)

Canard Layout

- Two main categories:
  - Lifting canard – canard provides substantial lift as well as longitudinal trim and control.
  - Control canard - longitudinal trim and control only.
- This is not a new idea – the original Wright Flyer was a control canard configuration.

Pitch Control with Canards (Cont’d)

- Long-Coupled Canard Layout
- Small canard located far enough forward so that interference effects are small.
- Particularly suited to long-range supersonic aircraft designs (bombers, transports, etc.).
- Foreplane effect is beneficial for cruise trim drag reduction and at low speed, particularly for take-off rotation.
Long-Coupled Canard Layout

Aircraft Examples

Rockwell B-70 Valkyrie

Tu-144 Concordski

Pitch Control with Canards

- Short-Coupled Canard Layout
- Foreplane placed just ahead of (& usually above) wing.
- Careful location enables lift effectiveness of pair to exceed that of sum of isolated lifting surfaces.
- Most applicable to high agility combat aircraft designs.

Dassault Rafale

Saab Gripen
Aircraft without tails, especially delta-winged aircraft, use *elevons* for pitch (and also roll) control.

Concorde

B-2 Elevon Layout
Roll Control

Ailerons

- Operated differentially and are conventionally the primary form of roll control on most aircraft.

Spoilers

- Often used as secondary roll control devices in conjunction with ailerons to enhance roll rate.
- Usually comprise hinged flap surfaces located on wing upper surface ahead of trailing edge.
- Deployment destroys much of the lift generated on the wing upper surface.
- Simpler pop-up types often used on gliders.
Roll Control with Spoilers

Avro RJ-100  Airbus A320  Boeing 737

Airbus A319  Boeing 777  Fokker F-28

Roll Control

Wing Warping

- Used on “Wright Flyer” and several other early aircraft.
- Complicated arrangement of wires used to warp wings differentially - alters wing camber and thus lift.
- Use stopped as aircraft speeds increased and surface distortions became too severe for materials used at time.
- Renewed interest nowadays using composite materials with potential benefit of reduced drag.
Roll Control

Inboard Ailerons

- Provided on many aircraft for safety/redundancy reasons and high speed applications.
- Primary outer set could produce unacceptably high bending moments and structural damage if deployed at high speeds.
- Disadvantages include reduced area available for flaps and increased control system complexity.

Roll Control with Inboard Ailerons

Boeing 747
Yaw Control

The primary yaw control surface is the rudder.

Deployment induces a change in camber and lift and thus a yawing moment as it is positioned aft of the CG.

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Engine Control

Piston Engine Aircraft

- Power output controlled by standard throttle arrangement - varies air/fuel mixture input.
- Additionally propeller speed usually adjusted with rpm control lever.
- Boost pressure control usually also possible on turbocharged piston engines.
Engine Control

Gas Turbine Engine Aircraft

- Thrust output controlled by varying fuel flow.
- Complex systems (incorporating adjustable nozzles, multiple spools, etc.) lead to multitude of variables to control/monitor - hence requirement for automatic engine management systems.
- Other possible controls for: reverse thrust, reheat (afterburner), propeller rpm (for turboprop).

Unconventional Control Surfaces

Flaperons

- Combined flaps/aileron operated:
  - Differentially as ailerons.
  - Collectively as flaps.

Vought F-8 Crusader  F-16 Fighting Falcon
Unconventional Control Surfaces

**Taileron**

- All-moving (slab) tail surfaces operated differentially as ailerons or collectively as elevators.
- Used on several fighters, especially those with swing-wing designs when conventional ailerons would be ineffective with wings highly swept.
- Design also reduces wing bending stresses and allows more room for flaps.

**Taylersons**

Unconventional Control Surfaces

- Tornado GR4-1
- F-14 Tomcat
Control Problems

Control at Low Speeds

- Several possible problems, including:
  - Reduced effectiveness due to low dynamic pressures.
  - Increased likelihood of stall.
  - Loss of effectiveness if immersed in separated airflow.
- STOL aircraft particularly susceptible to these problems, leading to use of large control surfaces and degradation of cruise performance.

Control Problems

Control Reversal at Low Speeds

- At low airspeeds wing is close to stall angle.
- Downwards deflection of control surface can induce stall and reduce lift instead of increasing it (control reversal).
- May be overcome using spoilers for low speed control or geared ailerons (down-going surface deflects less than up-going).
Control Problems
V/STOL Aircraft - Reaction Control

- At very low speeds (e.g. VTOL a/c), aerodynamic control forces are weak or non-existent.

- Reaction control then used instead (e.g puffer jets on Harrier using compressed bleed air from main Pegasus powerplant).

Control Problems
Yaw/Roll Cross-Coupling

- Banking an aircraft produces a centripetal force.
  - Causes a/c to move along arc of circle.
  - Upper wing on outside of circle so has to move faster than inside (lower) wing.
  - Produces more drag on upper wing and yaw moment (nose to right).
Control Problems

Yaw/Roll Cross-Coupling (Cont.)

- Cross-coupling effect negated by using rudder simultaneously with ailerons.
- Faster upper wing also experiences more lift as well as drag so has to be adjusted accordingly.
- For correctly banked turn (constant altitude) overall lift must be increased to compensate for centripetal component.

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Control Problems

Control in Transonic Flight

- Changes from subsonic to supersonic flows affect aircraft’s handling characteristics.
- In extreme cases, control operations reverse in functionality.
- Example would be the application of right rudder, causing port wing to travel faster than starboard.
- If aircraft flies at speed corresponding to a loss in lift due to compressibility effects, then faster moving wing will drop.
- Causes banked turn to left, resulting in the aircraft rolling away from the turn.
Mechanical Control Systems

Aerodynamic Balancing

- Control force requirement increases with aircraft speed and size.
- Aerodynamic balancing can reduce control forces down to more manageable levels.

Servo Tabs

- Another means of reducing control forces.
- Small auxiliary trailing edge surface moves opposite & proportional to main surface to produce moment to help pilot.
- Slightly reduces overall control effectiveness.
Trimming Tabs

- Nowadays tabs mainly used for trimming rather than for reducing control forces.
- Small surfaces adjusted to produce “hands-free” flying environment and reduce pilot workload & fatigue.

Powered Controls

- May take one of two basic forms:
  - Servo-assisted
    - Hydraulic pressure transmitted to servo actuator which assists mechanical linkage to move surface.
    - Linkage still available if power is lost but system then very heavy to operate.
  - Fully power-operated
    - Control signals transmitted hydraulically, electrically (fly-by-wire) or optically (fly-by-light).
Powered Controls (Cont’d)

- Feedback/Feel
- Problem with powered controls is pilot’s lack of feel for amount of control force required.
- May be overcome with artificial or q-feel unit.
- Attached to mechanical control linkage to increase stiffness in proportion to increase in dynamic pressure (q).
- Nowadays, more advanced closed-loop or negative feedback systems used.