University of BRISTOL

EQUATIONS OF MOTION 4

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Tug Aircraft: 141hp EuroFox 2K

Control Surfaces - Introduction

- Before considering how to represent the variations in aerodynamic force and moment in the equations of motion (which depend on the aircraft geometry and its operating envelope), we consider the physical means by which the aircraft can be controlled/manoeuvred.
- This is most commonly achieved through aerodynamic means, using control surfaces.
- Conventional control surfaces are built as moveable parts of the lifting surfaces, connected through a hinge that is nominally parallel with the "span" of the surface.

Conventional Control Surfaces

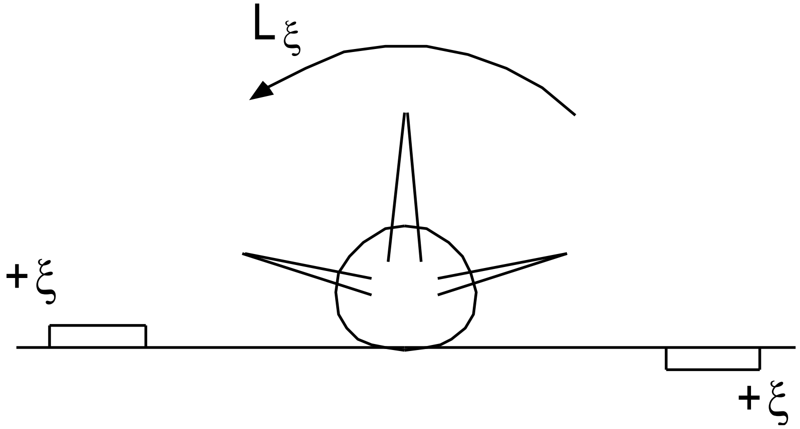
Tony Hisgett: https://commons.wikimedia.org/

Conventional Control Surfaces – Ailerons

Ailerons

- Generally, a small spanwise portion of the trailing edge.
- Relatively far out from the aircraft centre-line to give a good moment arm for roll control.
- Some aircraft have split ailerons.
- The deflection angle is ξ [ksi], positive when the starboard trailing-edge is down (and the port t.e. is up) – *checks!*

Control Surfaces – Ailerons



- View is from aft
- A positive aileron deflection is shown which causes a negative rolling moment following the sign convention which we use
- Note: full span ailerons are sometimes used for aerobatic aircraft

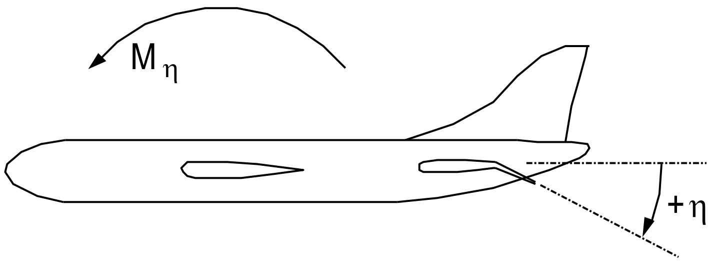
Control Surfaces – Ailerons

https://www.extraaircraft.com/

Northrop Grumman B-2A Spirit
Gary Chambers, https://www.airliners.net/

Control Surfaces – Elevator

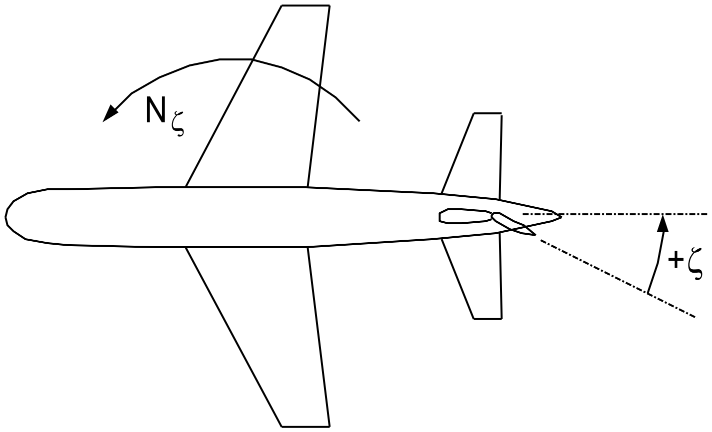
- This can occupy the whole of the spanwise extent of the trailing-edge of the horizontal tailplane but is usually smaller.
- The tip area is often used for "balance".
- The deflection angle is η [eta], positive for trailing edge down.



- the moment shown is due to positive elevator but is negative, following the sign convention for pitching moment.

Control Surfaces – Rudder

- Generally, this will be a large portion of the fin trailing-edge.
- The deflection angle is ζ [zeta], positive when the t.e. is to port.



- the moment shown is due to positive rudder but is negative, following the sign convention for yawing moment.

Primary Control Actions

- All of these controls are essentially designed to provide strong moments about the flight axes while providing relatively small direct forces.
- Note: *each positive control surface rotation follows the **right-hand rule about its own nominal axis**.*

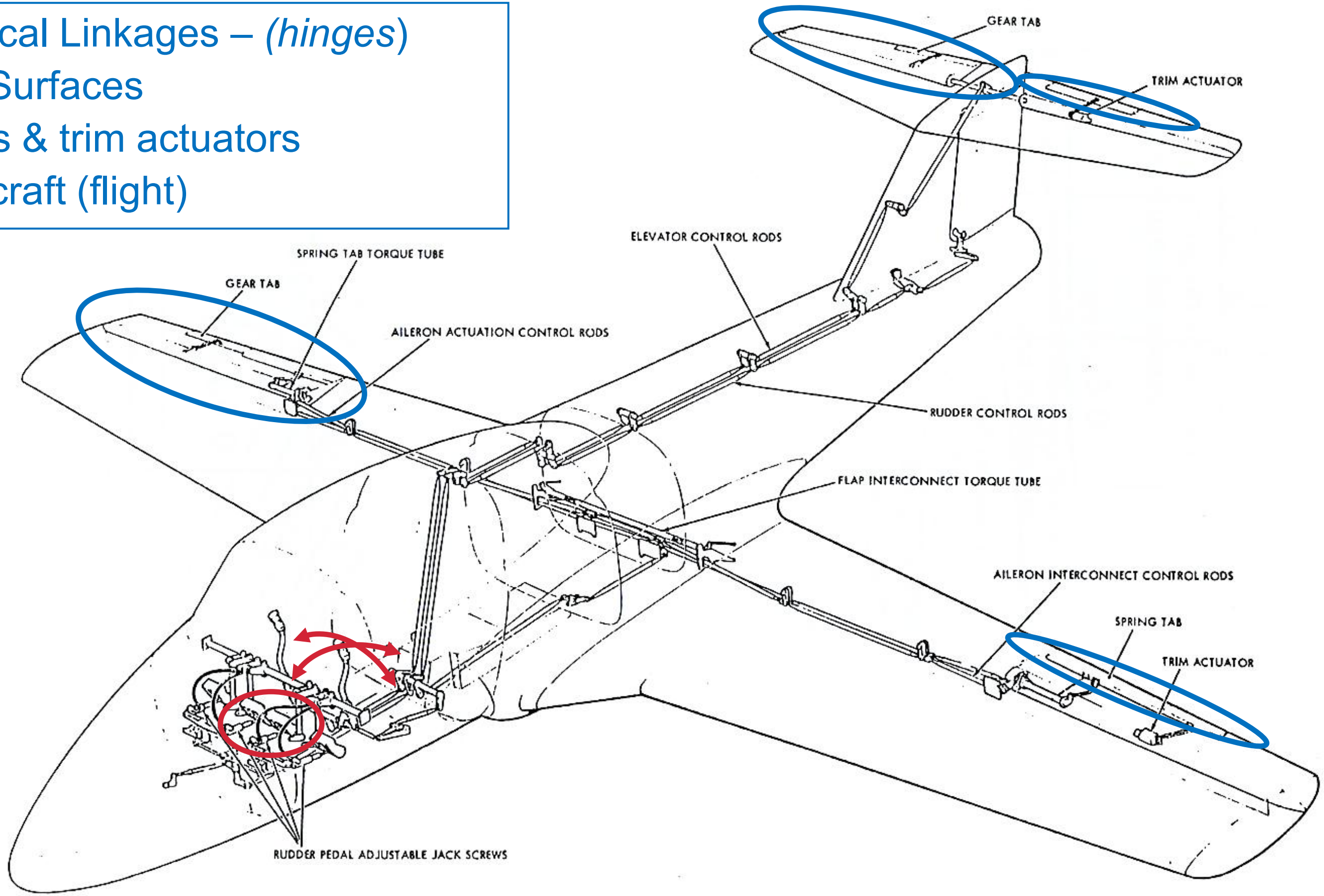
Control Surfaces

Each positive control deflection produces a negative moment:

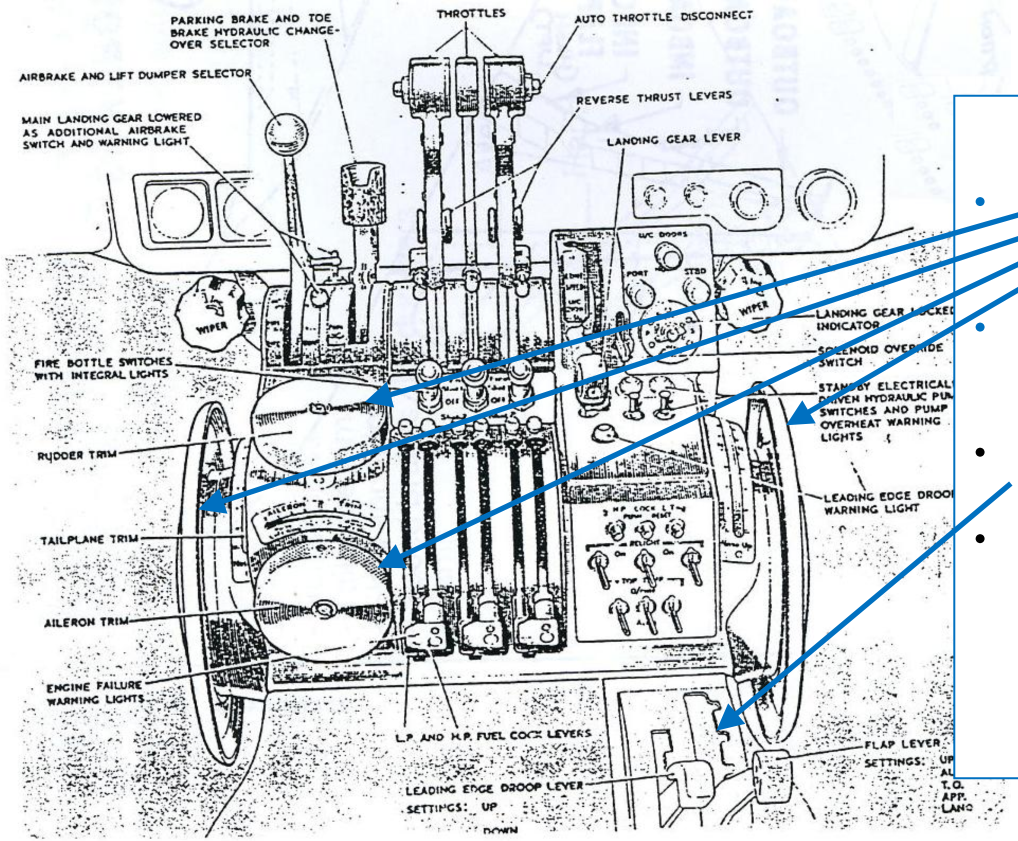
- positive ξ [ksi] produces negative L (rolling moment)
- positive η [eta] produces negative M (pitching moment)
- positive ζ [zeta] produces negative N (yawing moment)

Note: American terminology often defines positive notation which results in a positive moment

- Mechanical Linkages – (*hinges*)
- Control Surfaces
- Trim tabs & trim actuators
- Light aircraft (flight)



Classical Design -Trident Cockpit

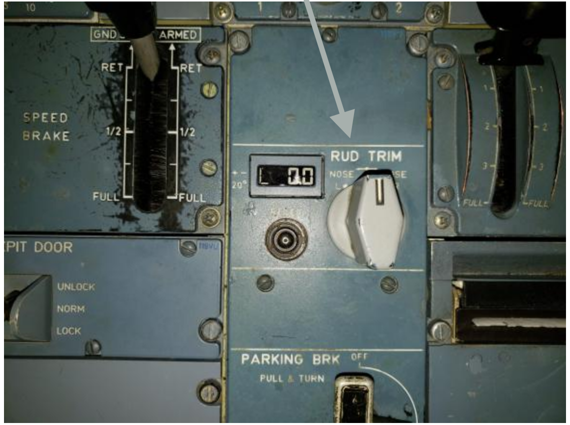


Note

- Trim wheels – rotate in the direction in which they have an effect.
- Tactile recognition – different shapes and sizes.
- Limited number of flap settings.
- Auto-throttle disconnects quickly.

Trim – A320

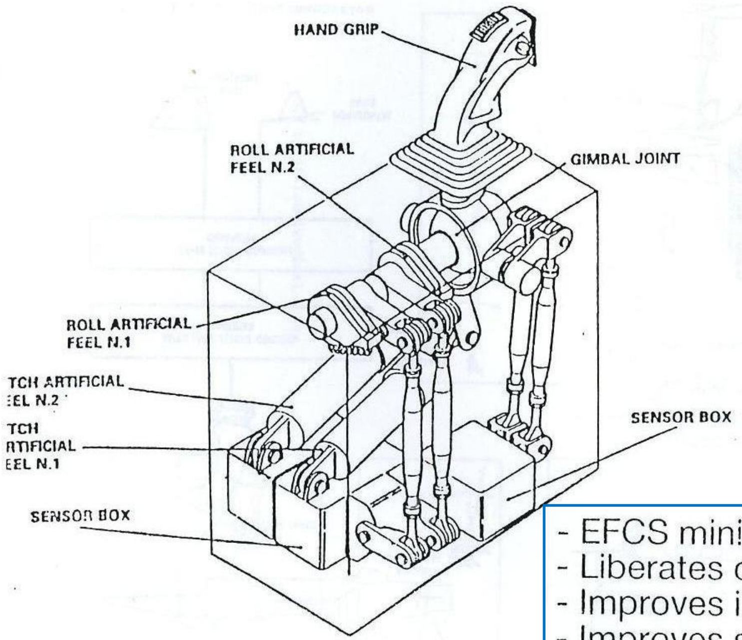
- Pitch trim wheels
- Rudder trim rotary selector

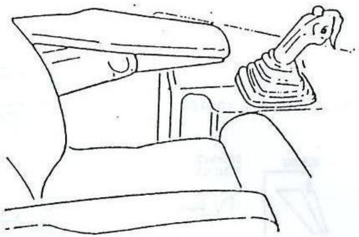


https://blog.thea320insider.com/2021/07/16/how-do-the-facs-control-rudder-trim-in-the-a320/

https://www.airbus.com/en/products-services/commercial-aircraft/cockpits

A320 Side stick controller





The side stick controller is constructed as shown and can be regarded as a "plug in L.R.U."

It is installed in the side console and the associated arm-rest is mounted on the pilots seat

- EFCS minimises forces so large controller not needed.
- Liberates cockpit design.
- Improves instrument panel design and view.
- Improves seat access
- Makes a work table possible.

Alternative Control Inceptor

Trim – A380 and A350

The A380 and the A350 do not have traditional trim wheels situated on the throttle quadrant.

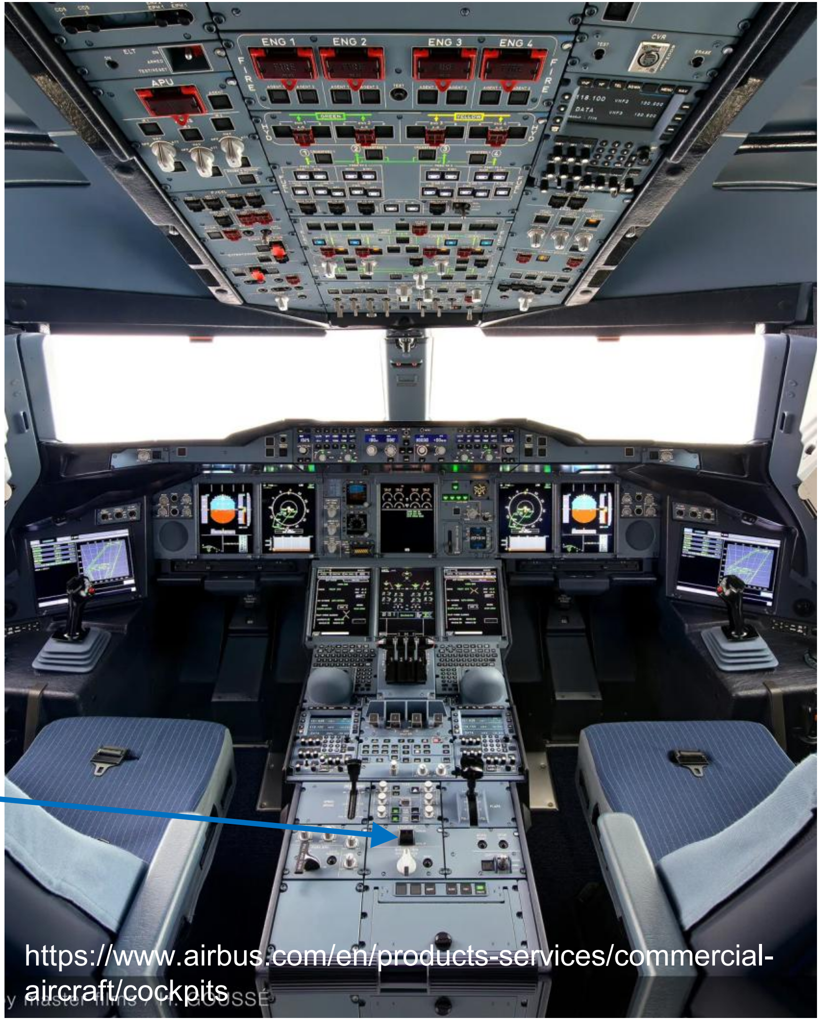
In normal operation, trim wheels are usually used only when setting takeoff trim – which can be automated.

Thus fly-by-wire control systems eliminate the need for a traditional trim wheel. The aircraft's **computer automatically adjusts the trim to maintain the desired flight attitude**.

This allows for greater precision and stability, and eliminates the potential for human error in the trimming process. It also provides greater protection against overspeed, stall and other potential hazards.

In the A380 and the A350, pilots can manually adjust the trim using the alternate **pitch trim control rocker** behind the flap lever.

aeropeep.com/why-dont-the-a380-and-a350-have-trim-wheels/



https://www.airbus.com/en/products-services/commercial-aircraft/cockpits

Additional Control Surfaces

Tony Hisgett: https://commons.wikimedia.org/

Additional Control Surfaces – Spoilers

- These can be operated on only one side at a time, in flight, to augment the ailerons for **roll control** but obviously this produces a loss of overall lift at the same time.

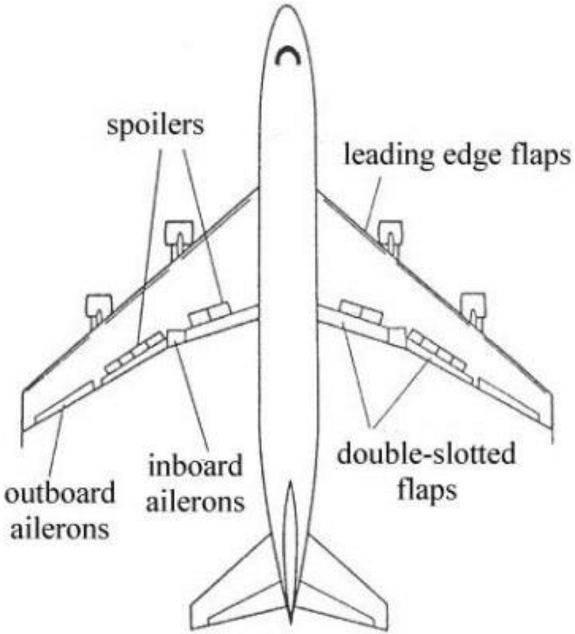
- Used simultaneously on the ground, these are referred to as ***lift-dumpers*** and, when deployed, will ensure that the aircraft weight is rapidly transferred to the wheels for effective braking; they also serve as ***air brakes*** because they produce a lot of drag.

Additional Control Surfaces – Spoilers

- Normally hinged to the upper surface of wings at a point that is further forward than the hinge-line for conventional trailing-edge devices – i.e. hinged at about $x/c = 0.6\text{-}0.7^{+}$.

- The Boeing 747 figure on the following slide shows the lateral distribution of spoilers and also shows their hinge-lines well forward of the flap hinges.

Additional Control Surfaces – Spoilers



Boeing 747

Images from
http://people.clarkson.edu/~pmarzocc/AE430/AE-430-5.pdf

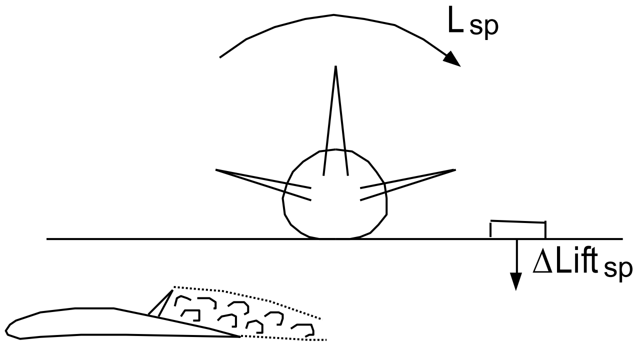
Airbus A319

Boeing 777

Additional Control Surfaces – Spoilers

Sketch shows view from aft.

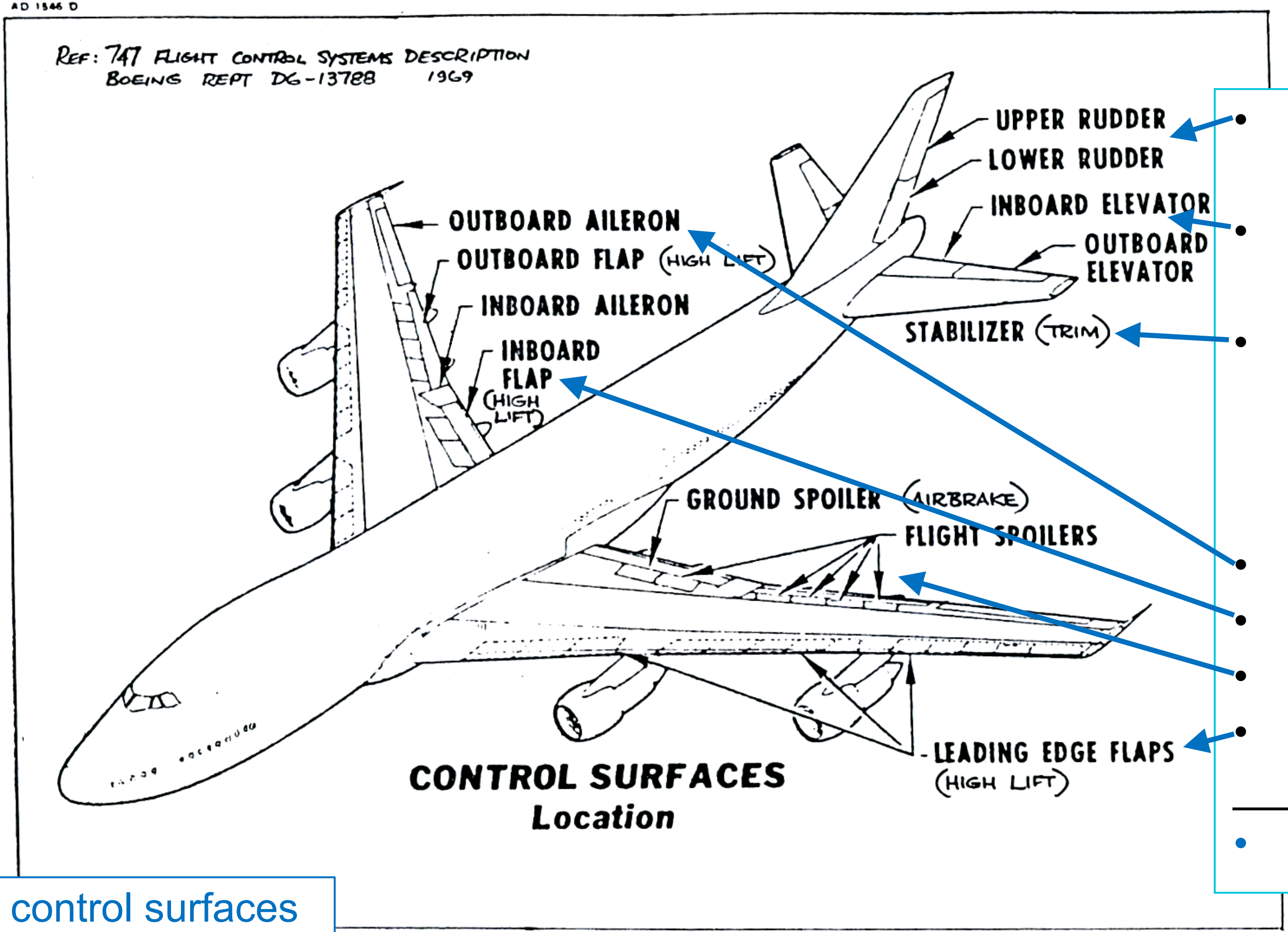
Spoiler deflected on only one side



Stopping a Large Passenger Aircraft?

- Cut throttle.
- Apply spoilers – after firm contact with the ground.
- Reverse thrust.
- Brakes – relatively small contribution.

How many control surfaces are there on a 747?

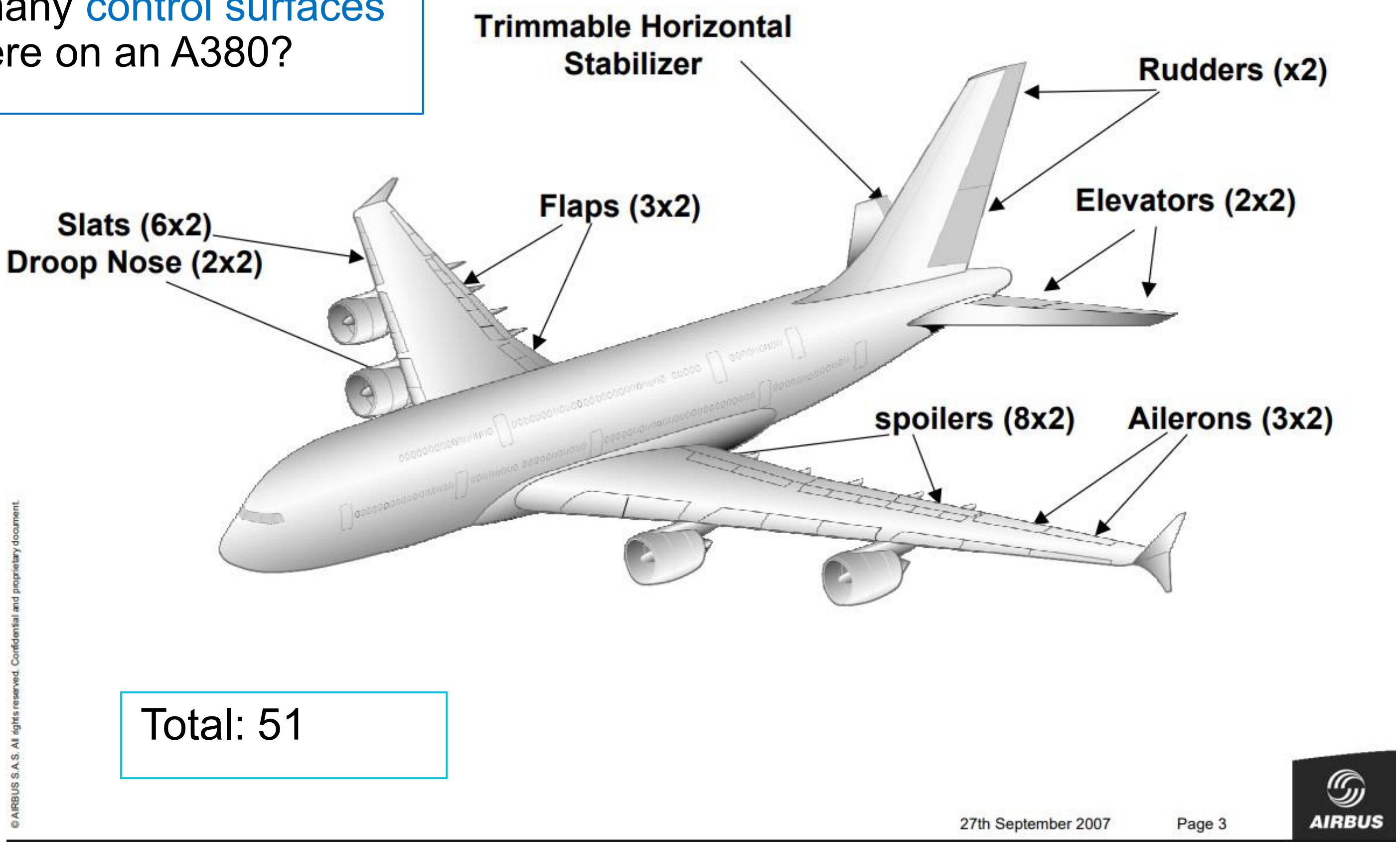


- 2
- 4
- 1
- 4
- 4
- 12
- 26

- **53**

How many control surfaces are there on a 747?

How many control surfaces are there on an A380?



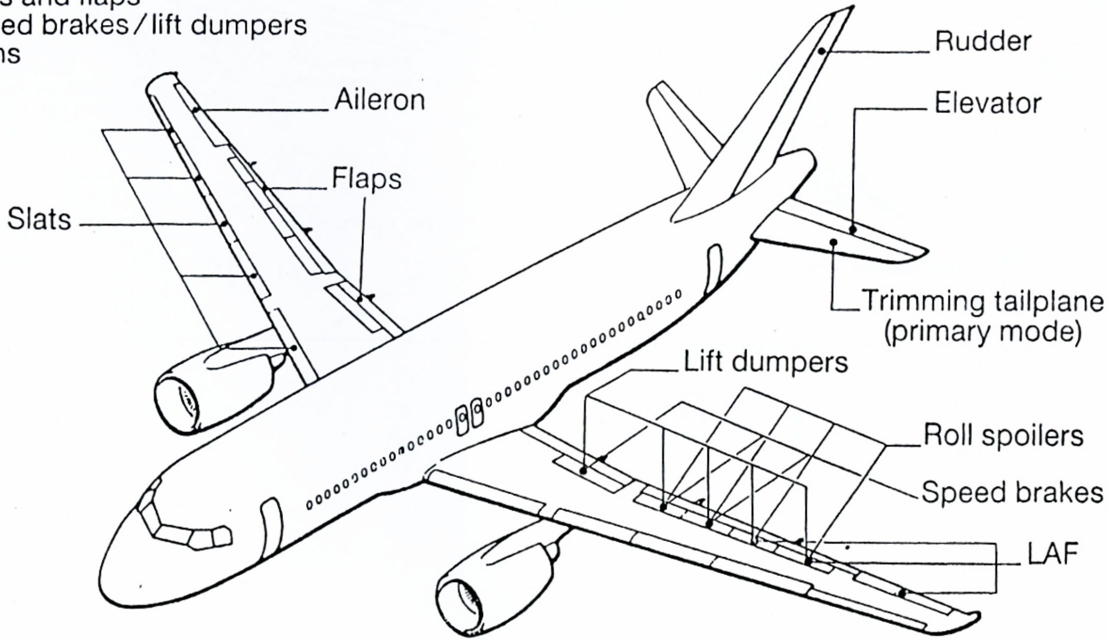
Total: 51

A320 Flight control surfaces

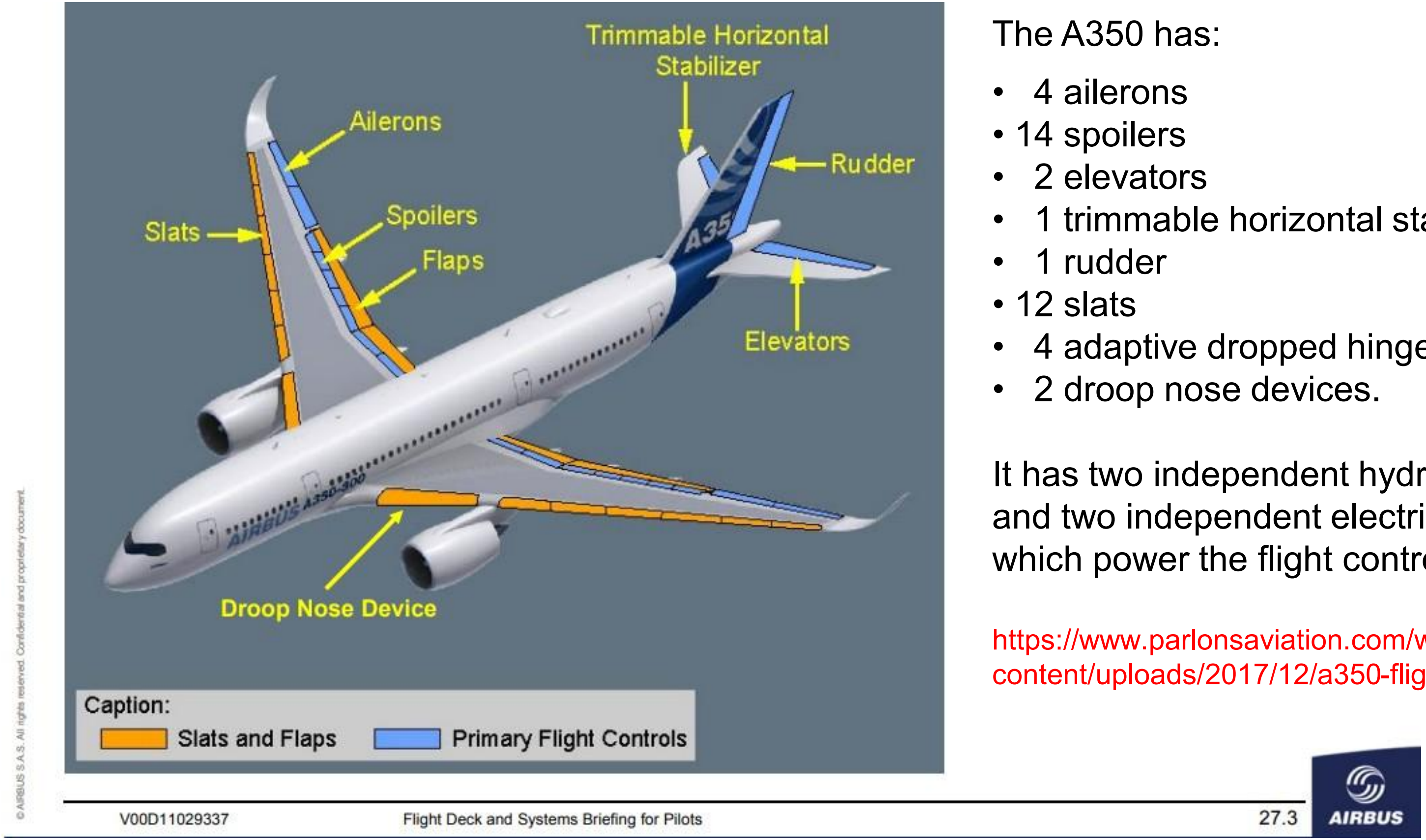
- Hydraulic actuation of all surfaces

- Electrical control
  - Elevators
  - Ailerons
  - Roll spoilers
  - Tailplane trim
  - Slats and flaps
  - Speed brakes / lift dumpers
  - Trims

- Mechanical control
  - Rudder
  - Tailplane trim (Reversionary mode)



A350 flight control surfaces



The A350 has:

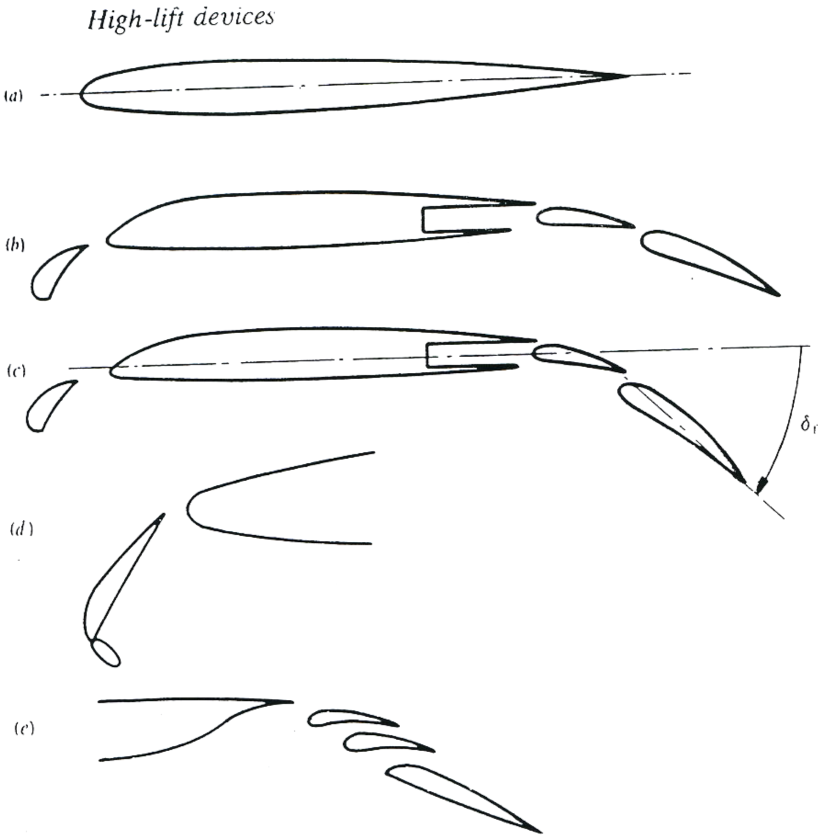
- 4 ailerons
- 14 spoilers
- 2 elevators
- 1 trimmable horizontal stabiliser (THS)
- 1 rudder
- 12 slats
- 4 adaptive dropped hinge flaps
- 2 droop nose devices.

It has two independent hydraulic circuits and two independent electrical circuits which power the flight controls surfaces.

https://www.parlonsaviation.com/wp-content/uploads/2017/12/a350-flight-controls.pdf

High-lift devices

Boeing 747 (see approach video in lecture)



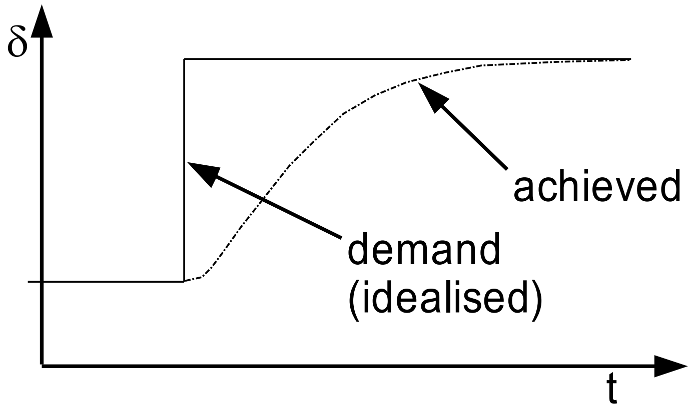
Boeing 747

Note the large deflection of trailing-edge flaps

Adrian Pingstone, https://en.wikipedia.org/

Response to a Pilot Input

- In modern systems the response time of a control surface to a pilot demand (*e.g. aileron or rudder*) is relatively fast, with typical response times in the region of a fraction of a second.



- The first-order time-constant would be of order 0.1s but the demand issued by a pilot would not normally be as sharp as the step shown here; it is more likely to be a ramp input over 0.5s or more.

Alternative Control Surfaces

Tony Hisgett: https://commons.wikimedia.org/

Links:

- F35B – First vertical take-off
  - https://www.youtube.com/watch?v=zW28Mb1YvwY
- Harrier
  - https://www.youtube.com/watch?v=BjZ2T2blUJE
- Kestrel Hovering
  - https://www.youtube.com/watch?v=7j6OsP7zL6w
- Su-35
  - https://www.youtube.com/watch?v=woQsWq4aDWo

All moving tailplane

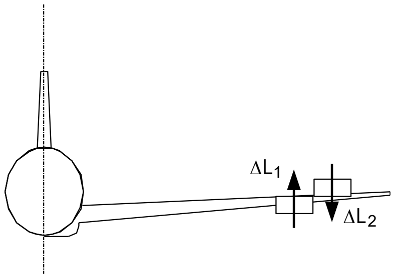
- Control is effected by α variation rather than effective camber change.
- Most supersonic fighters also use differential movement of opposite sides to improve roll rate (known as tailerons).
- Typically incurs a mass penalty due to large actuation mechanisms.

https://en.wikipedia.org/

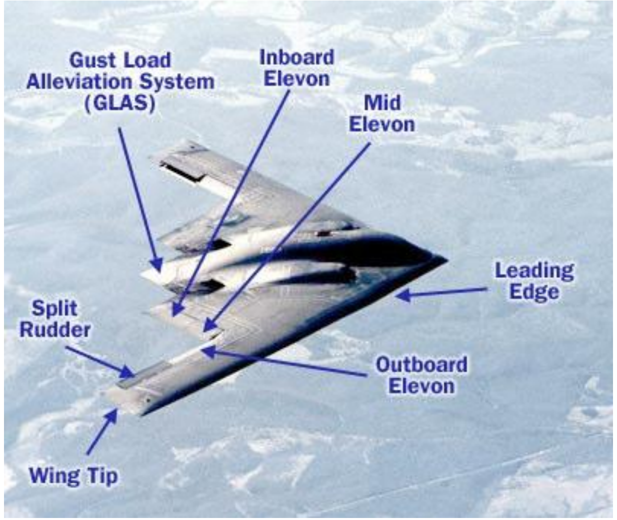
Other Methods for Developing Control Forces

Several other possible means of creating aerodynamic or thrust-control deserve some attention, some of these being simply unconventional uses of conventional surfaces, e.g.:

- symmetric aileron deflection, which will alter wing lift directly without producing a rolling moment.
- split-ailerons (each side has two parts: one deflected up while the other goes down) generate drag without generating additional lift or rolling moment. See also 'split rudder' on B2. ⇨



- anti-symmetric deflection of the two sides of an all-moving tailplane, which will augment normal aileron action for roll-control.



B2 control surfaces

http://people.clarkson.edu/~pmarzocc/AE430/AE-430-5.pdf

Thrust vectoring – e.g. Harrier

https://en.m.wikipedia.org/

F-15B ACTIVE with Thrust Vectoring

- The aircraft is highly modified and is not representative of production F-15 aircraft. It served as the research testbed for the ACTIVE programme (Advanced Control Technology for Integrated Vehicles) from 1993 to 1999, and later in the Intelligent Flight Control System programmes from 1999 to 2008) because of the flexibility of its unique quad-redundant, digital-fly-by-wire, flight and propulsion control system.

- The twin-engine F-15 is equipped with Pratt & Whitney nozzles that can turn up to 20 degrees in any direction, giving the aircraft thrust control in the pitch (up and down) and yaw (left and right) directions.

- NASA flight testing started in 1996, using thrust-vectoring to improve aircraft performance and control.

F-15B ACTIVE with thrust vectoring

The F-15 ACTIVE in flight
over the Mojave desert

https://commons.wikimedia.org/

Other research aircraft with thrust vectoring

F18 HARV (High Angle-of-attack Research Vehicle)

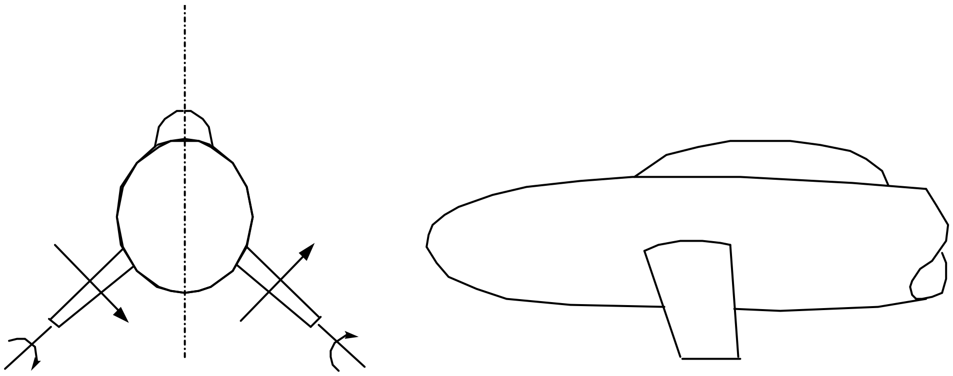
X-31

F16 MATV (Multi-Axis Thrust Vectoring)

https://military-history.fandom.com/wiki/General_Dynamics_F-16_VISTA?file=3_three_thrust-vectoring_aircraft.jpg

F22 – pitch thrust vectoring

Other Methods for Developing Control Forces



Canards which are intended only for pitch control purposes (not a significant augmenting of lift) are often not horizontal and thus a differential (or anti-symmetric) deflection can produce a rolling moment and a side-force.

Other Methods for Developing Control Forces

Short-coupled canards ⬂

Long-coupled canards ⇨

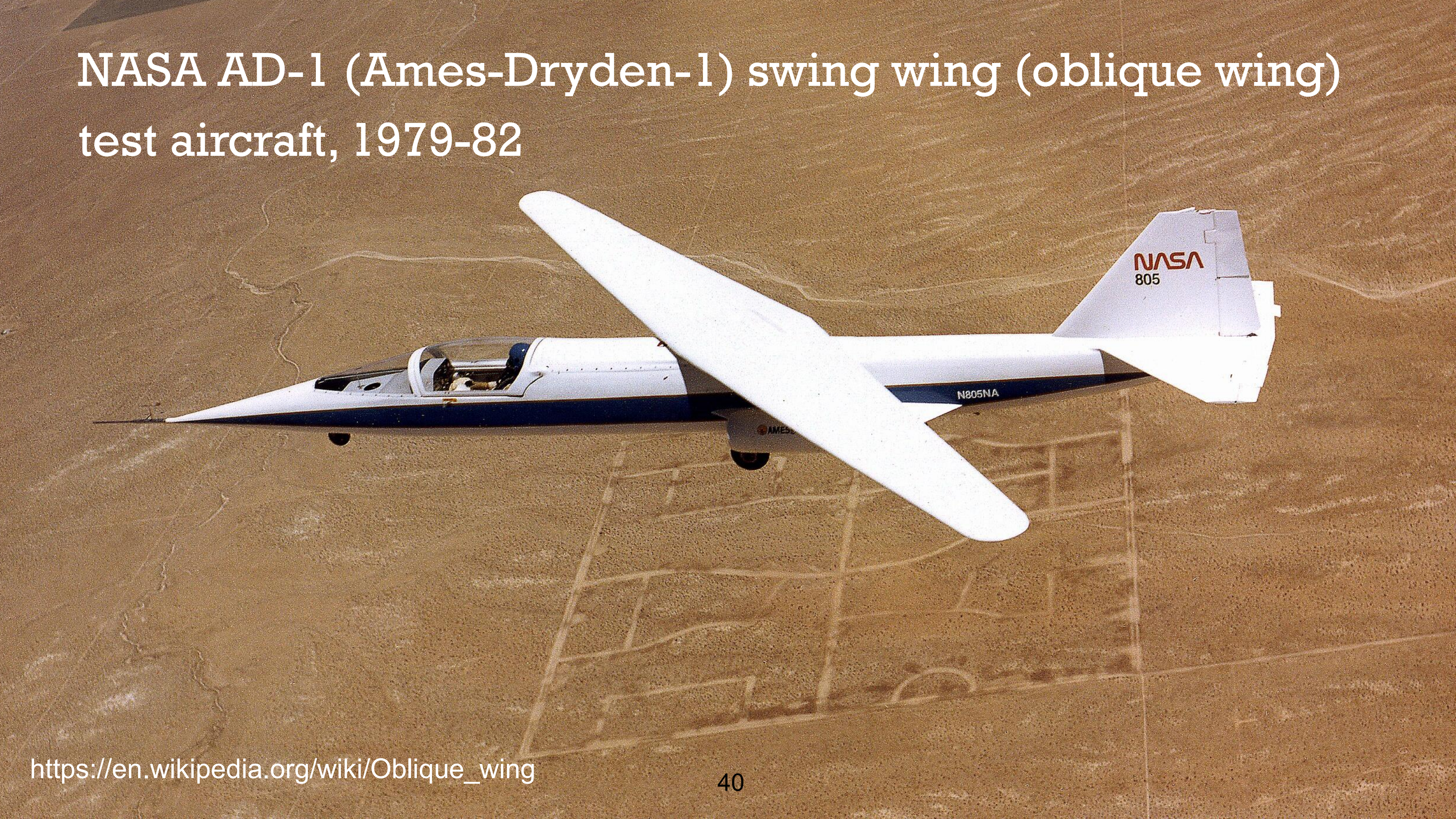
Rockwell B-70 Valkyrie

Saab Gripen

Eurofighter Typhoon

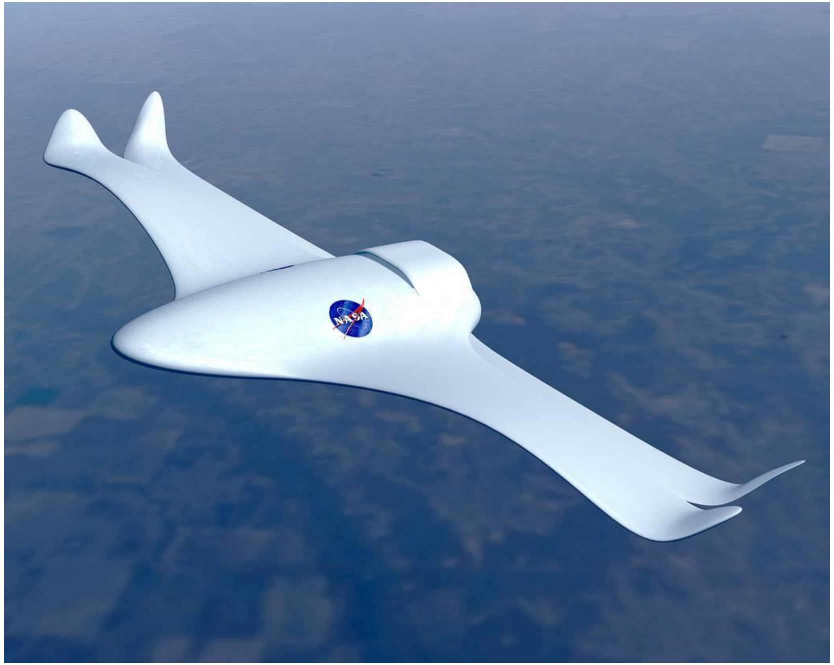
http://people.clarkson.edu/~pmarzocc/AE430/AE-430-5.pdf

NASA AD-1 (Ames-Dryden-1) swing wing (oblique wing) test aircraft, 1979-82



https://en.wikipedia.org/wiki/Oblique_wing

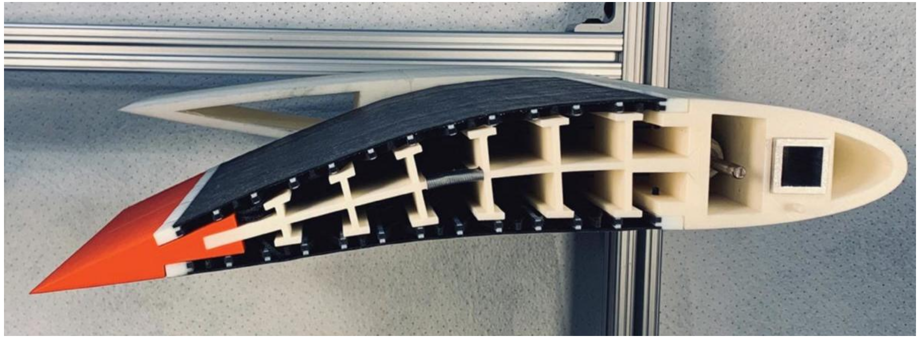
Other Methods for Developing Control Forces



https://www.nasa.gov/image-article/21st-century-aerospace-vehicle/

Professor Ben Woods

- Bristol Composites Institute
- Fish Bone Active Camber Morphing Concept
- https://research-information.bris.ac.uk/en/persons/ben-k-s-woods

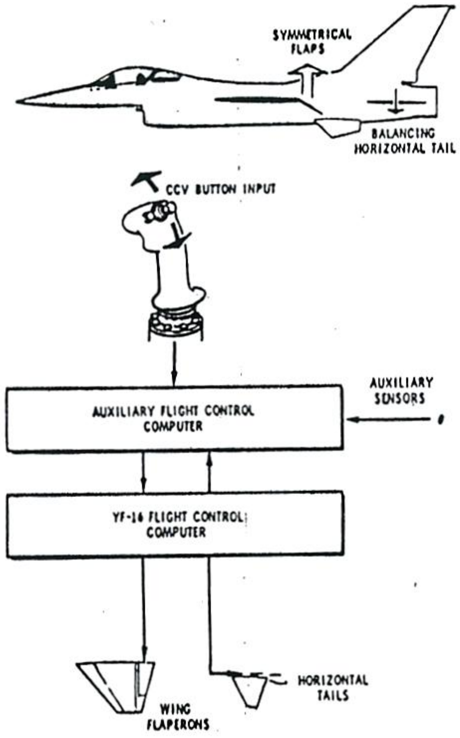


https://flyer.co.uk/feature/microlights/

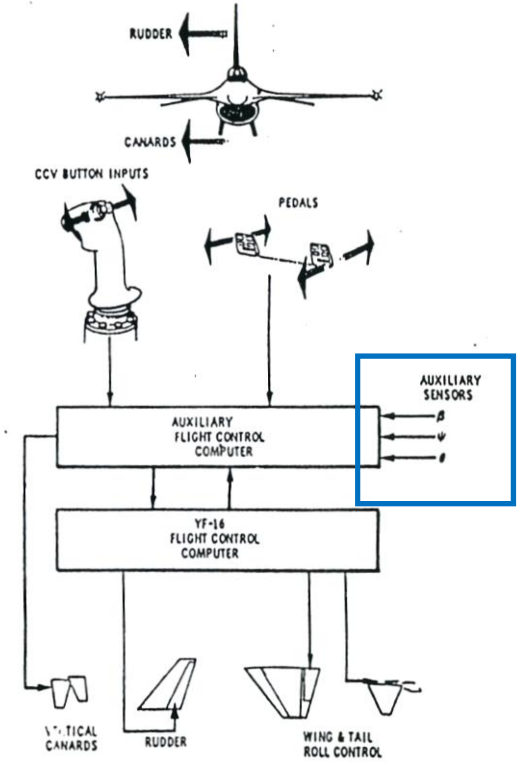
‘Control Configured Vehicle’

Tony Hisgett: https://commons.wikimedia.org/

CCV: Control-configured Vehicles

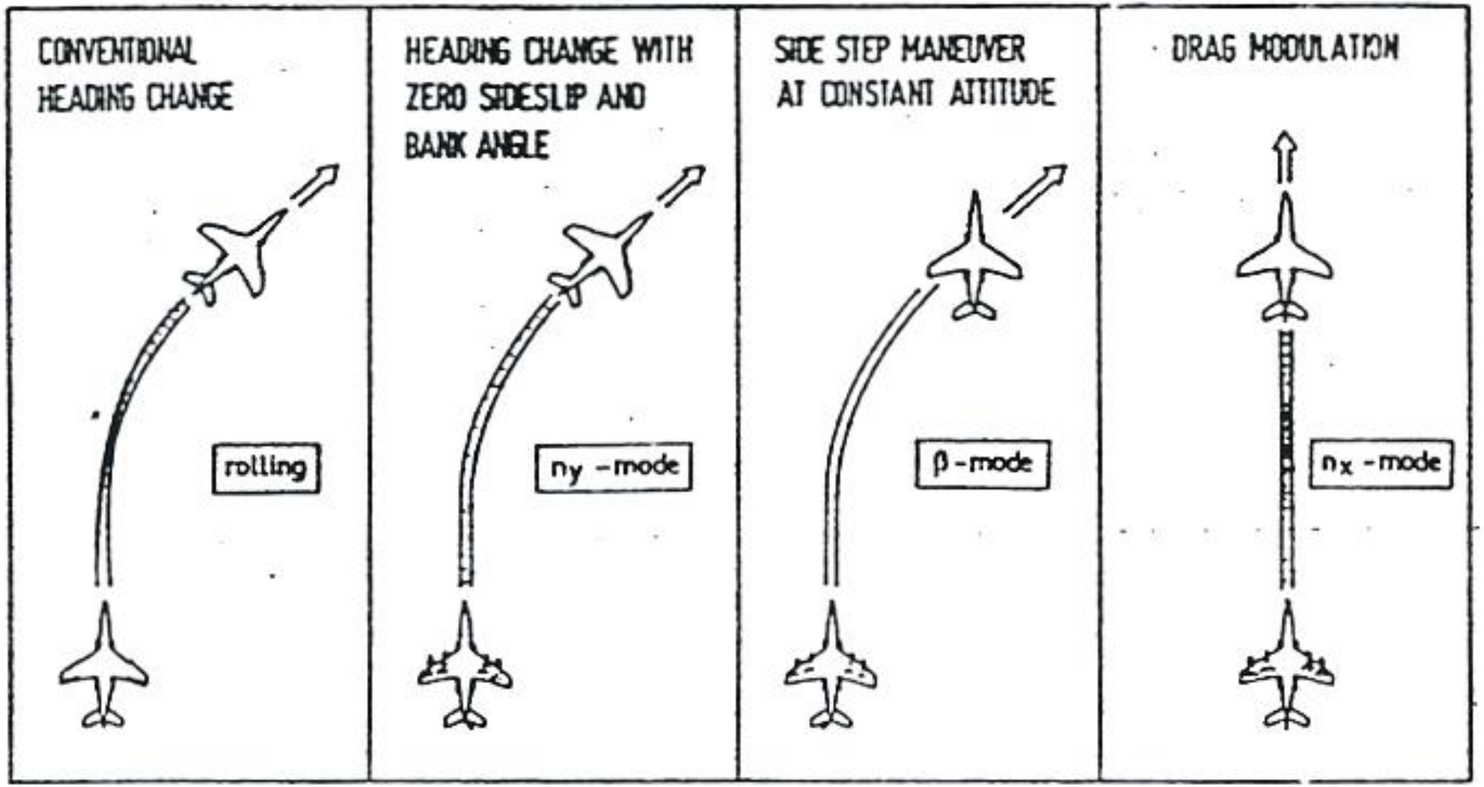


Direct Lift Implementation



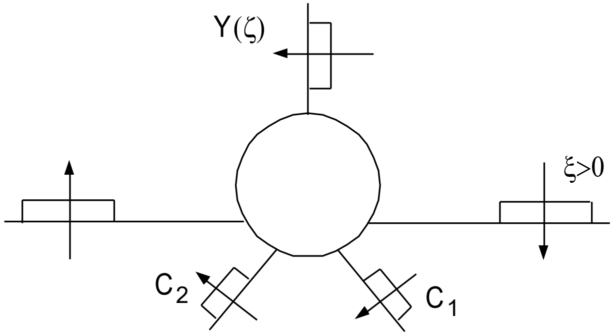
Direct Sideforce Implementation

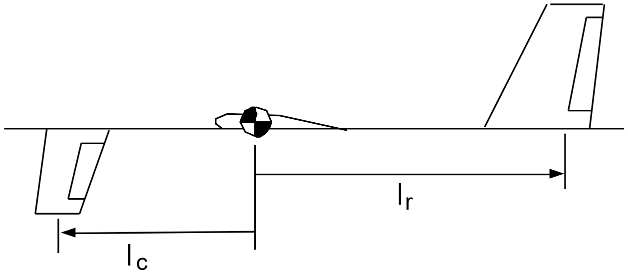
CCV: Control-configured Vehicles



QinetiQ VAAC Harrier

Other Methods for Developing Control Forces





- Exercise: consider how this configuration might be used to create:
  - pure lateral motion
  - pure vertical motion
- Balancing forces and moments.

Note: As soon as the vehicle does start to move laterally, additional aerodynamic forces will be developed over the vehicle, and these will alter any existing balance – hence a need for active control.

Summary:

Primary control surfaces + nomenclature for a conventional aircraft:

- positive ξ [ksi] produces negative L (rolling moment)
- positive η [eta] produces negative M (pitching moment)
- positive ζ [zeta] produces negative N (yawing moment)

Additional control surfaces + purpose

Existence of alternative control strategies + examples.

Next Session
Strip Theory 1

https://www.redbull.com/

University of BRISTOL

EQUATIONS OF MOTION 4

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