“Flying is like something unmentionable in a lecture note handout – I haven’t always had all I wanted, but occasionally I’ve had all I could stand.”

Stephen Coonts
~ foreword ~

- The present notes serve as a support for in-class work, not the opposite! Refer to the introductory course notes for explanations.

- These notes are used as a succinct introduction to selected topics. They are *purposefully incomplete* and must not be used for real-life applications.
Feedback is always appreciated:

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8.1 A short review of Trim
Trim:

set the airplane in equilibrium
8.1.1 Trim with symmetrical airfoils
CG moving forward:
CG moving aft:
Optimum case: zero lift at the tail
8.1.2 Trim with asymmetrical airfoils
Best case: zero lift at the tail
This case defines *the most forward acceptable CG position*
8.2 Longitudinal stability
8.2.1 A first approach to stability
Stability:

Resistance to small disturbances
This is a stable configuration:
However, this is an *unstable* configuration:

Note that the aircraft is *still trimmed*!
To observe stability,

**tilt** the aircraft slightly.

Does it come back to its original position?
When the aircraft is tilted, the tail produces a restoring moment.
The wing also has a stabilizing effect.
CG aft: aircraft is less stable

The wing has a *destabilizing* effect
destabilizing
how much stable or unstable?
8.2.2 Quantifying stability
Stability is how “strongly” an aircraft tends to return to its original position.

→ how large is the restoring bending moment?
The bending moment around CG must vary with angle of attack

\[ \frac{d M_{CG}}{d \alpha} \]

Must be non-zero
Introducing coefficients (again): the \textit{pitch stiffness}

\[ C_{M, \alpha} \equiv \frac{d C_M}{d \alpha} \]

Measured in \text{deg}^{-1} \text{ (units per degree, u./°) }

Indicates how “strongly” the aircraft tends to return to initial position
A single criteria for an aircraft to be stable:

\[ C_{M,\alpha} < 0 \]

In practice, for human pilots to control with ease:

\[ -0.025 \text{ deg}^{-1} < C_{M,\alpha} < -0.008 \text{ deg}^{-1} \]
Different cases for stability

pitch-down disturbance

- statically stable
- statically neutral
- statically unstable
8.2.3 Quantifying stability on arbitrary aircraft

~ is my airplane stable enough? ~
Reminder: ensuring an aircraft is trimmed

\[ C_M = C_{M_{\text{wing}}} - \frac{l_{\text{wing}}}{\bar{C}} C_L - \bar{V} C_{F_{\text{tail}}} = 0 \]
Quantifying stability

\[ C_{M, \alpha} \equiv \frac{d C_M}{d \alpha} \]

\[ C_M = C_{M_{wing}} - \frac{l_{wing}}{\bar{c}} C_L - \bar{V} C_{F_{tail}} \]

\[ C_{M, \alpha} = - \frac{l_{wing}}{\bar{c}} \frac{d C_L}{d \alpha} - \bar{V} \frac{d C_{F_{tail}}}{d \alpha} \]
The lift coefficient slopes (properties of the aircraft)

For the entire aircraft:

\[ C_{L,\alpha} \equiv \frac{dC_L}{d\alpha} \]

For the tail:

\[ C_{Ftail,\alpha} \equiv \frac{dC_{Ftail}}{d\alpha} \]
One equation to quantify stability:

\[ C_{M, \alpha} = -\frac{l_{wing}}{\bar{C}} C_{L, \alpha} - \bar{V} C_{F_{tail}, \alpha} \]

The aircraft is stable if and only if this term (the pitch stiffness) is negative
A safe aircraft:

Can be trimmed at any point:

\[ C_M = 0 \]

Returns to initial position if disturbed:

\[ C_{M, \alpha} < 0 \]
Changing the CG position in flight:
Flight-testing stability performance in 747-8I prototype
A340 (?) prototype stability testing
8.2.3 A peek at dynamic stability
Dynamic stability:
How stable is the aircraft
*as it is rotating in pitch?*
Dynamic stability: overshooting the original point

pitch-down disturbance
Dynamic stability: overshooting the original point

- Statically stable, dynamically unstable
- Statically stable, dynamically damped
- Statically stable, dynamically overdamped
8.3 Canard aircraft
Canard aircraft:
replace (usually downwards-pushing) tail with (upwards-pushing) canards
but this configuration is unstable!
How can a canard aircraft be made stable?
Aft CG: even worse
Forward CG: can be stable

The wing has a stabilizing effect
On canard aircraft, the canard is *destabilizing*; it is the wing which stabilizes the aircraft.
ok – show me the math!
The same nomenclature applies

On canard aircraft, $b_{\text{tail}}$ will be negative
Just like any conventional design, a **safe** canard aircraft:

Can be trimmed at any point:

\[ C_M = 0 \]

Returns to initial position if disturbed:

\[ C_{M, \alpha} < 0 \]
Forward CG: risk of stalling canard during approach

This case sets the most forward acceptable CG position.
Beech Starship

Burt Rutan

Scaled Composites
Rutan Quickie
Project 8
Canards!
“We should get canards because:”

- “They are *eco-efficient*”
- “They look cool”
Project 8

- You are head of the trim and stability department at an aircraft manufacturer
- Your manager wishes to replace the tailplane with canards
- What is your opinion?