University of BRISTOL

Aerospace Vehicle Design And System Integration 3
AENG30013

Stability Analysis using XFLR5

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Volcán de Fuego, Guatemala
University of Bristol, March 2019

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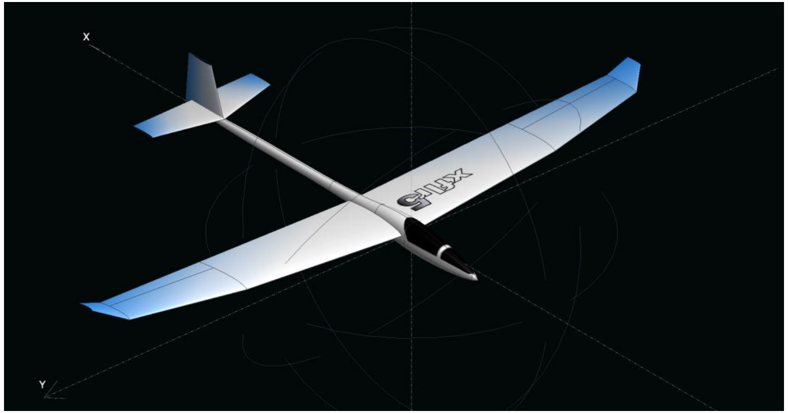
3. Lab Exercise

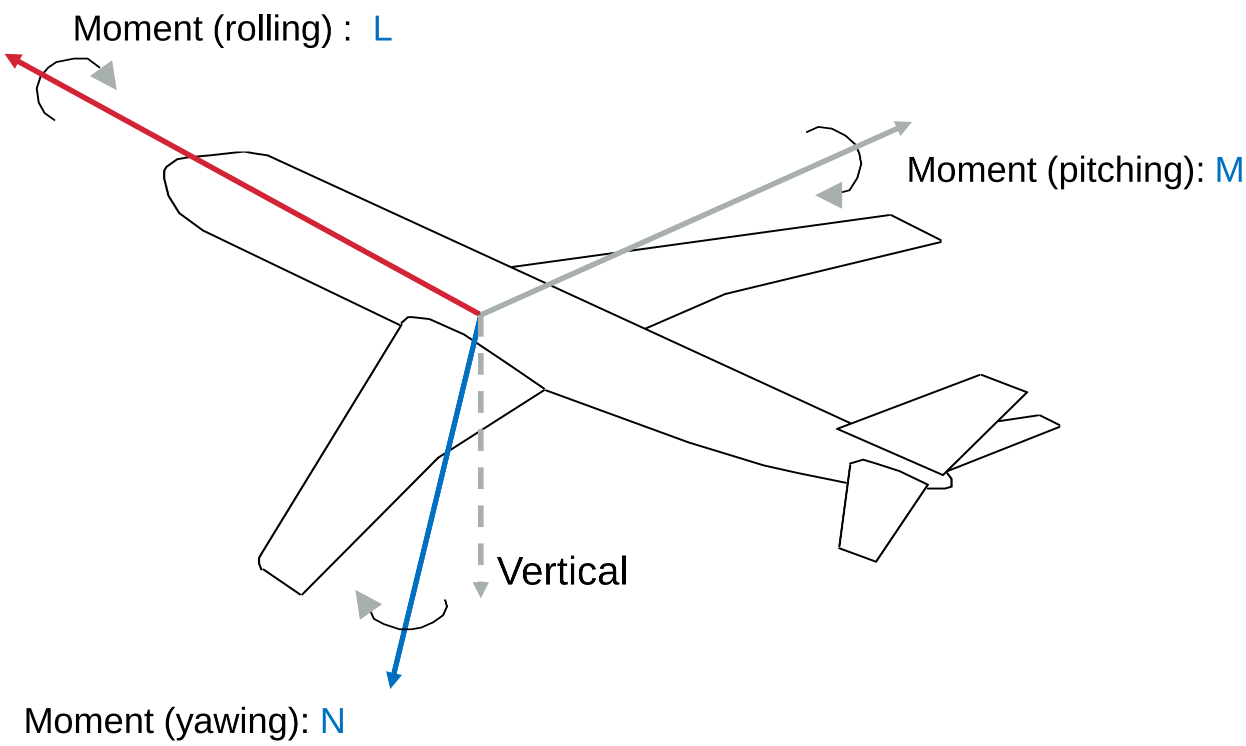
Manam Volcano Vent, Papua New Guinea
University of Bristol, May 2019



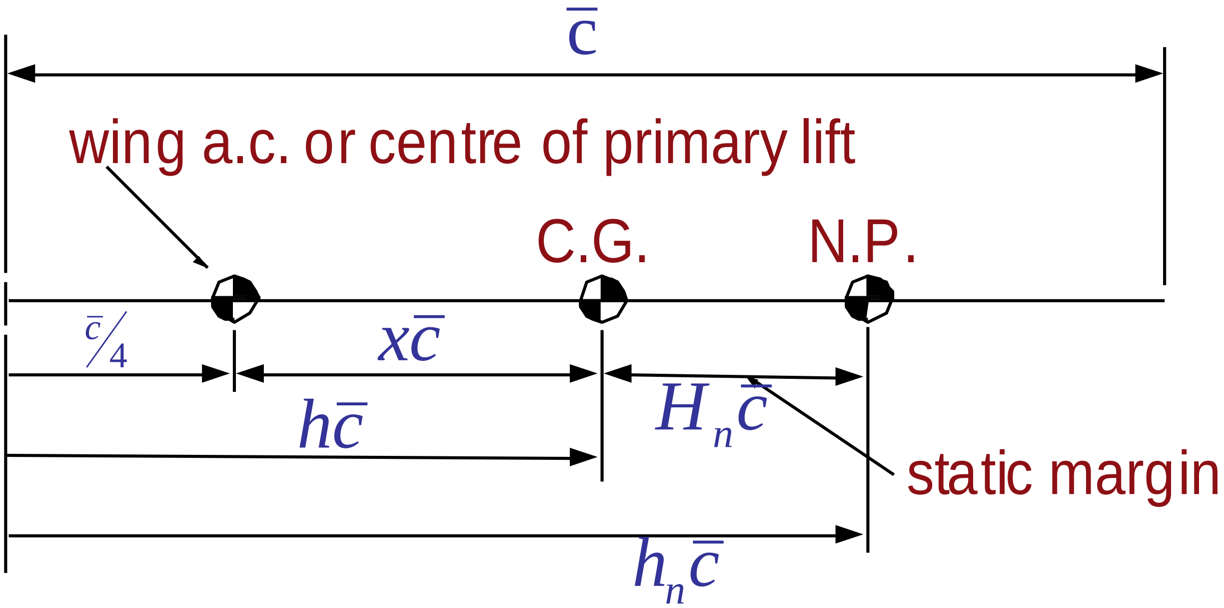
Static & Dynamic Stability Analysis
XFLR5

http://www.xflr5.com/xflr5.htm
https://sourceforge.net/projects/xflr5/files/
(latest version) Sample_Project.zip
http://www.xflr5.com/docs/XFLR5_and_Stability_analysis.pdf
http://www.xflr5.com/docs/XFLR5_Mode_Measurements.pdf

Body Axes Notation and Sign Conventions



The Neutral Point and Static Margin



The **neutral point** is the rearmost position of the c.g. before an unstable condition occurs.

Static Stability

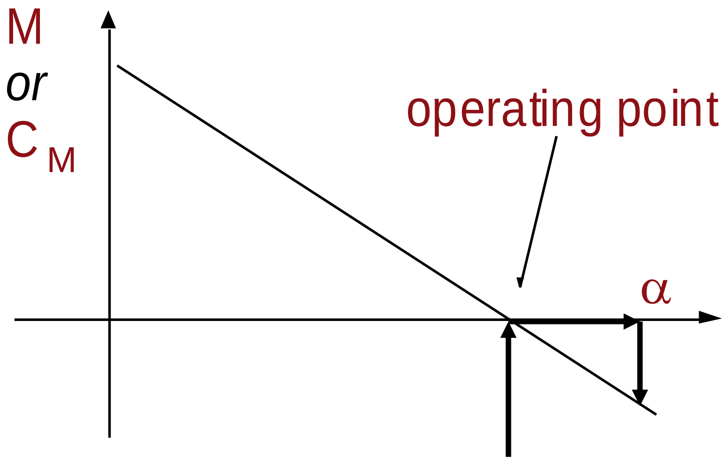
- Consider a perturbation $\Delta\alpha$ away from a trimmed, straight and level operating point? +ve or –ve slope desirable?

- This implies that whichever sign there is for $\Delta\alpha$ away from the equilibrium flight angle α, the pitching moment caused by $\Delta\alpha$ will be of such a sign as to counteract $\Delta\alpha$ and restore the flight to its equilibrium incidence.

The slope given by $\partial M / \partial \alpha$ must therefore be negative for stability.

Static Stability

- The "system" is the pitch response of an aircraft; the "input" is a pitch displacement $\Delta\alpha$ and the "output" is the consequent pitching moment ΔM.
- For stable flight we need $\Delta M < 0$ for $\Delta\alpha > 0$ so that there will be a restoring action.

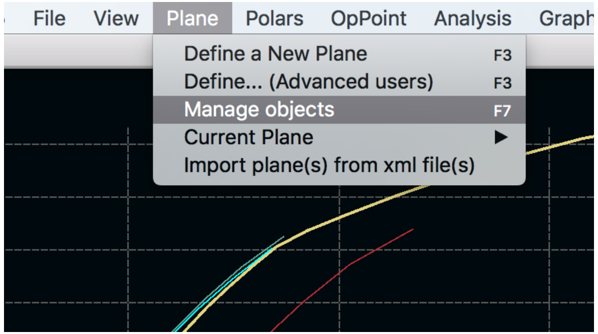


Static Stability

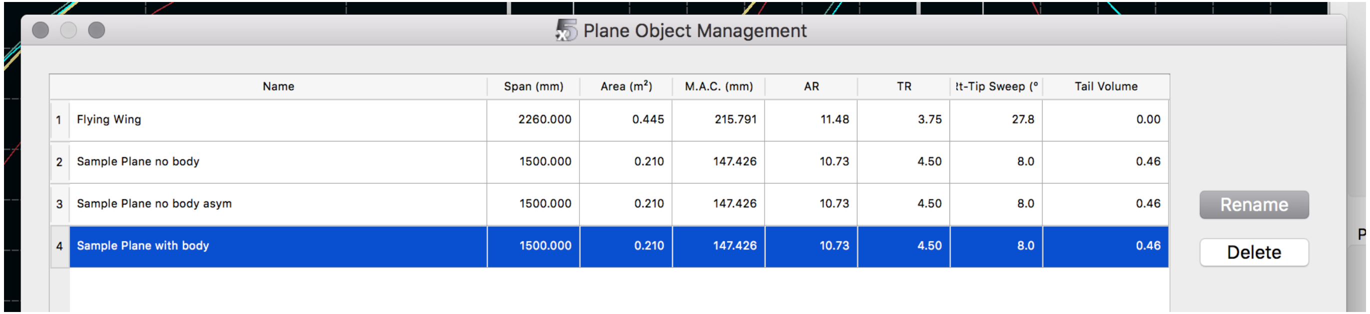
and thus in general

$$\frac{1}{a_1}\frac{\partial C_M}{\partial \alpha} \text{ or } \frac{\partial C_M}{\partial C_L} \begin{array}{ll} > 0 & \text{unstable} \\ = 0 & \text{neutrally stable} \\ < 0 & \text{stable} \end{array}$$

XFLR5 Example

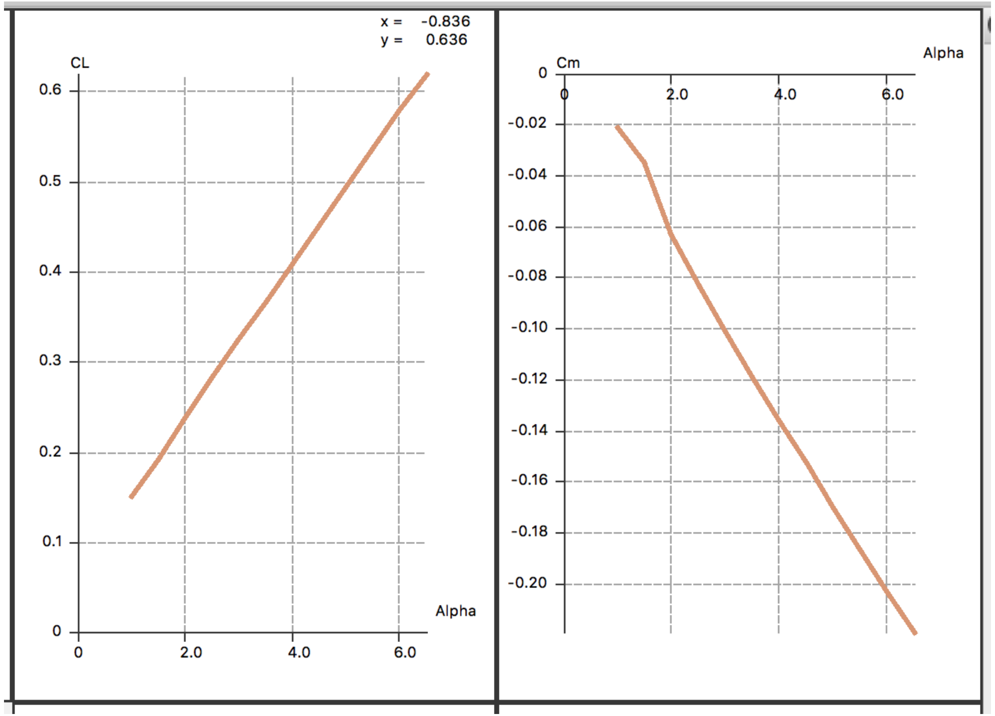


- Remove additional 'objects' – keeping 'Sample Plane'
- *Note: examples given in this lecture are exaggerated*



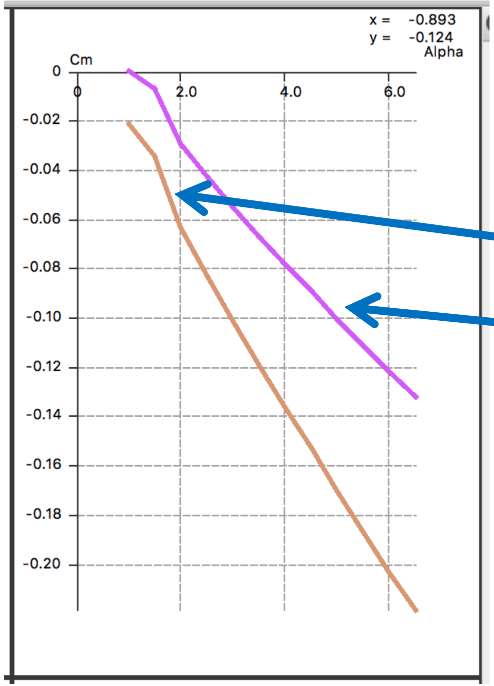
	Name	Span (mm)	Area (m²)	M.A.C. (mm)	AR	TR	ɫt-Tip Sweep (°	Tail Volume
1	Flying Wing	2260.000	0.445	215.791	11.48	3.75	27.8	0.00
2	Sample Plane no body	1500.000	0.210	147.426	10.73	4.50	8.0	0.46
3	Sample Plane no body asym	1500.000	0.210	147.426	10.73	4.50	8.0	0.46
4	Sample Plane with body	1500.000	0.210	147.426	10.73	4.50	8.0	0.46

XFLR5 Example



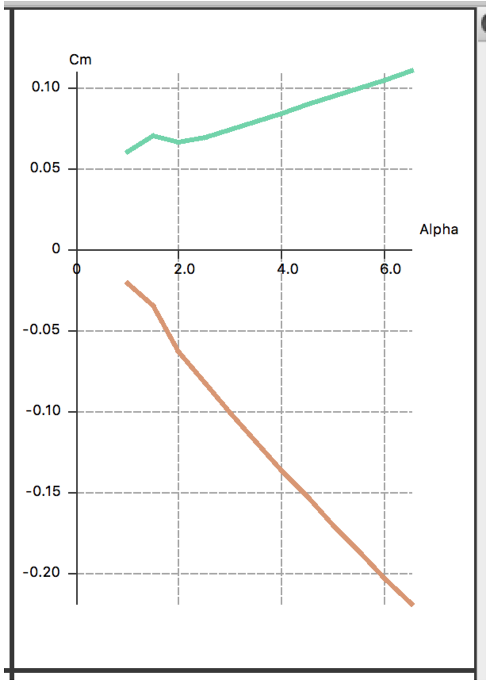
- C_m vs α with CoG.x = 58.44 mm

XFLR5 Example



- C_m vs α with
- CoG.x = 58.44 mm &
- CoG.x = 80.00 mm

XFLR5 Example



- C_m vs α with
- CoG.x = 58.44 mm &
- CoG.x = 140.00 mm

Derivatives of the Pitching Moment Equation

- The pitching moment expression which we obtained was:

$$C_M = C_{M_0} - \bar{V} a_{1_T} i_T - C_{L_{WFP}} \left[\bar{V} \frac{a_{1_T}}{a_1} (1-k) - x \right] - \bar{V} a_{2_T} \eta$$

For trimmed flight $C_M = 0$

$$\bar{V} = \frac{S_T l_T}{S \bar{c}}$$

- Now consider a disturbance in pitch ($\Delta\alpha$), perhaps caused by an upward gust, and this $\Delta\alpha$ leads to an associated disturbance $\Delta C_L > 0$.

Static Stability

- Thus for the case where the elevator is locked and η = constant (but not necessarily zero), we have for static stability

$$\frac{1}{a_1}\frac{\partial C_M}{\partial \alpha} = \frac{\partial C_M}{\partial C_L} = -\left[\bar{V}\frac{a_{1_T}}{a_1}(1-k) - x\right] < 0$$

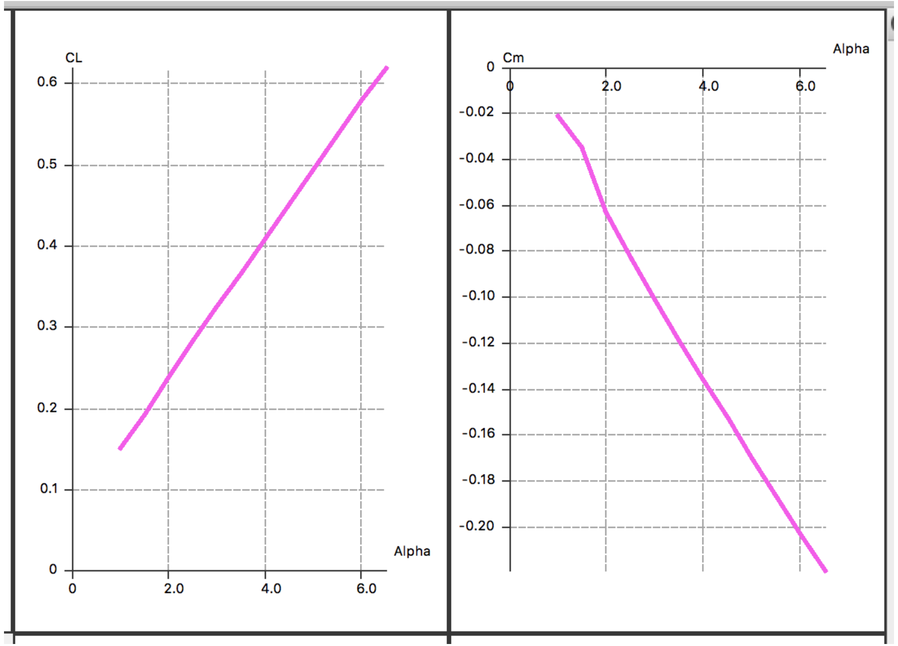
and the factor in the square brackets must therefore be positive for a stable aircraft.

Elevator-Angle-to-Trim – *For Reference*

- *and thus the elevator angle required to obtain this trim is:*

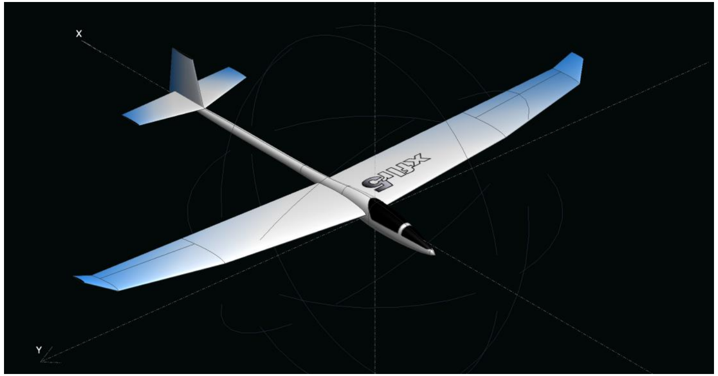
$$\eta_{trim} = \frac{1}{\bar{V} a_{2_T}} \left\{ C_{M_0} - \bar{V} a_{1_T} i_T - C_{L_{WFP}} \left[\bar{V} \frac{a_{1_T}}{a_1} (1-k) - x \right] \right\}$$

XFLR5 Example

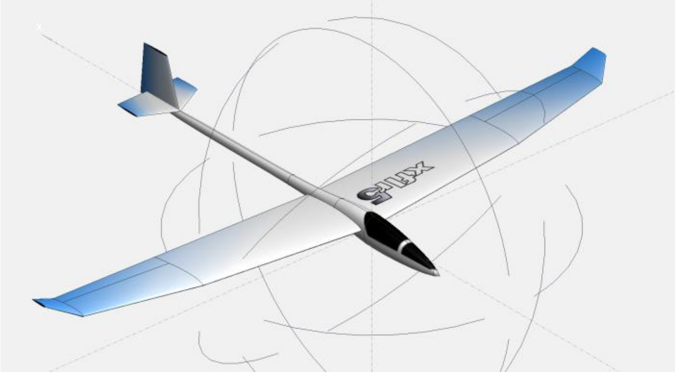


- C_m vs α with CoG.x = 58.44 mm

XFLR5 Example

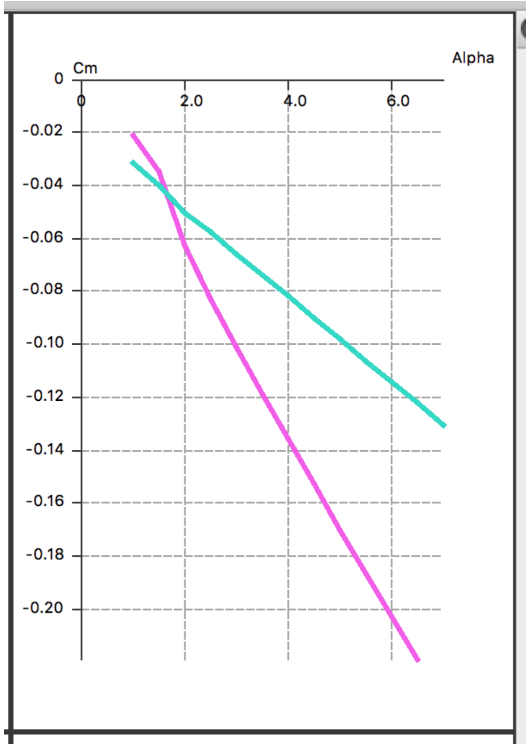


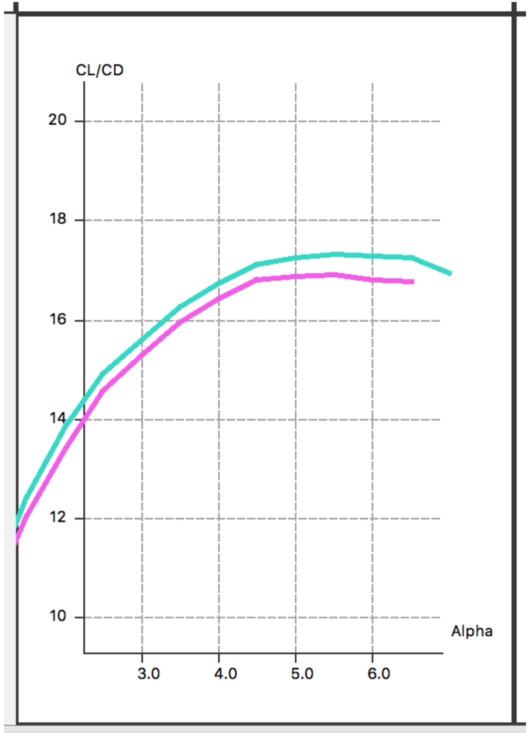
160 mm elevator semi-span



80 mm elevator semi-span

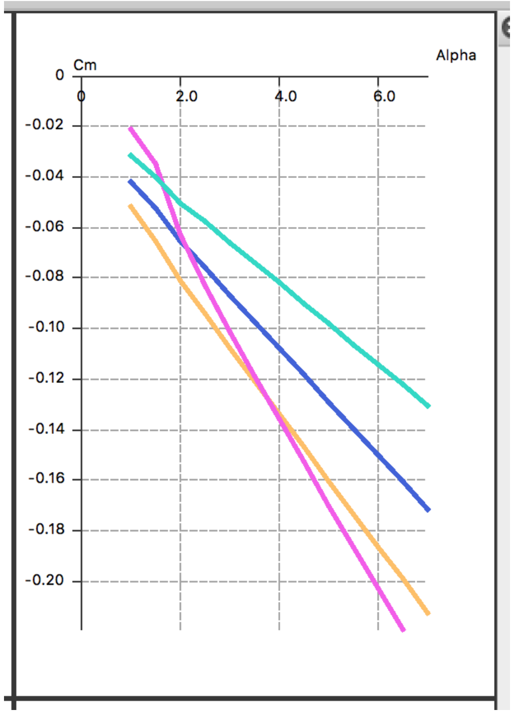
XFLR5 Example





- Reduced tail size vs original

XFLR5 Example



- Reduced tail size vs original
- New tail size with C.of.G. at 48.44mm and 38.44 mm
- Effect on static stability & static margin?
- Trim requirement?
- Control requirement?

Aircraft Modes

Aircraft Modes

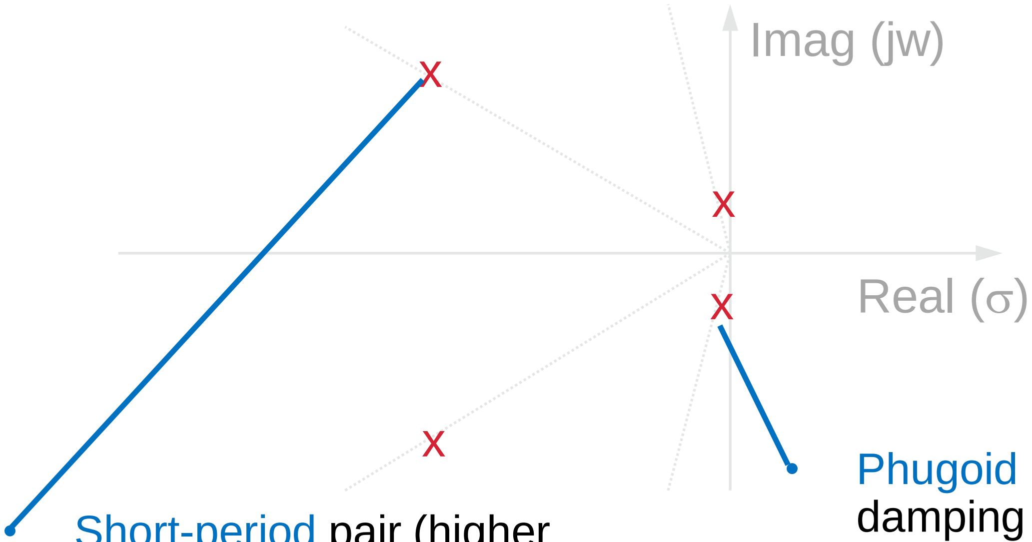
- Short Period
- Phugoid
- Roll Subsidence
- Spiral
- Dutch Roll

Longitudinal

Lateral

Typical Longitudinal Responses

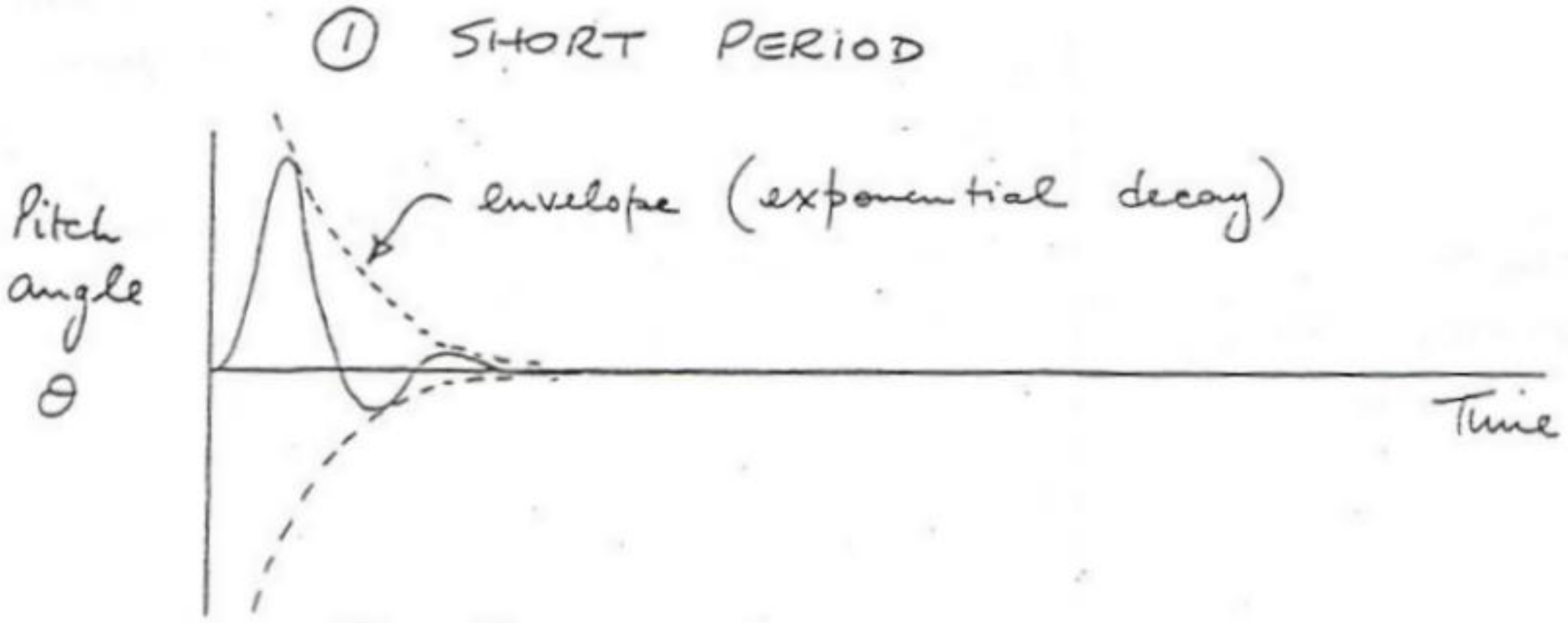
- For a conventional aircraft configuration, the characteristic roots will normally occur in two complex pairs, as shown below.



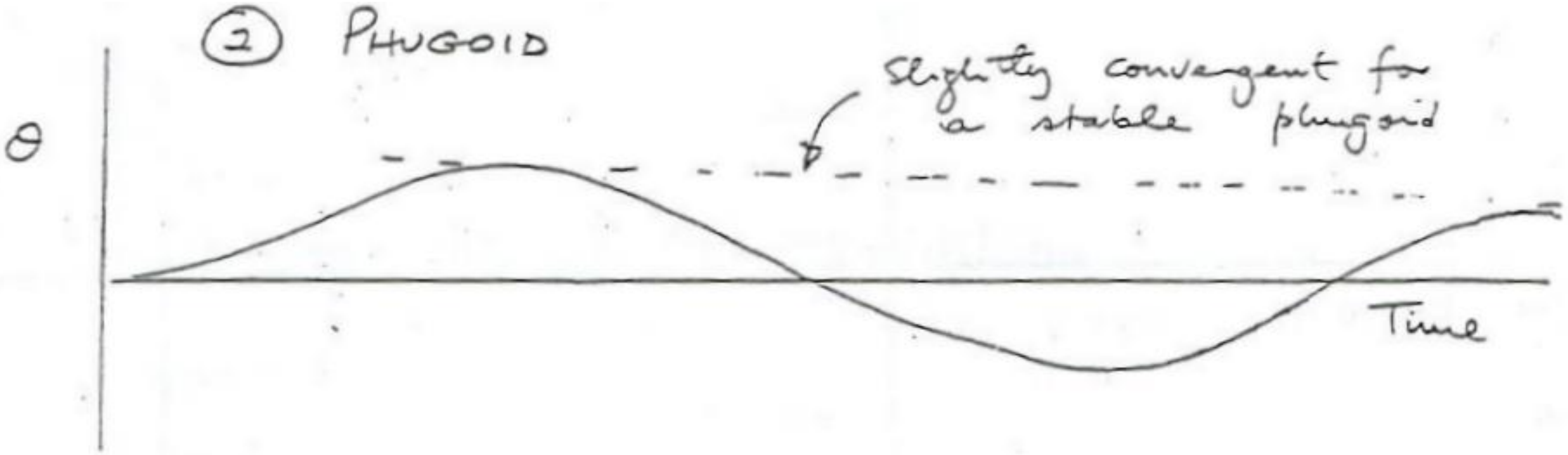
Short-period pair (higher frequency and more heavily damped) σ is much more negative

Phugoid pair (low frequency and low damping ratio) i.e. σ is not large and can even be positive for some flight conditions.

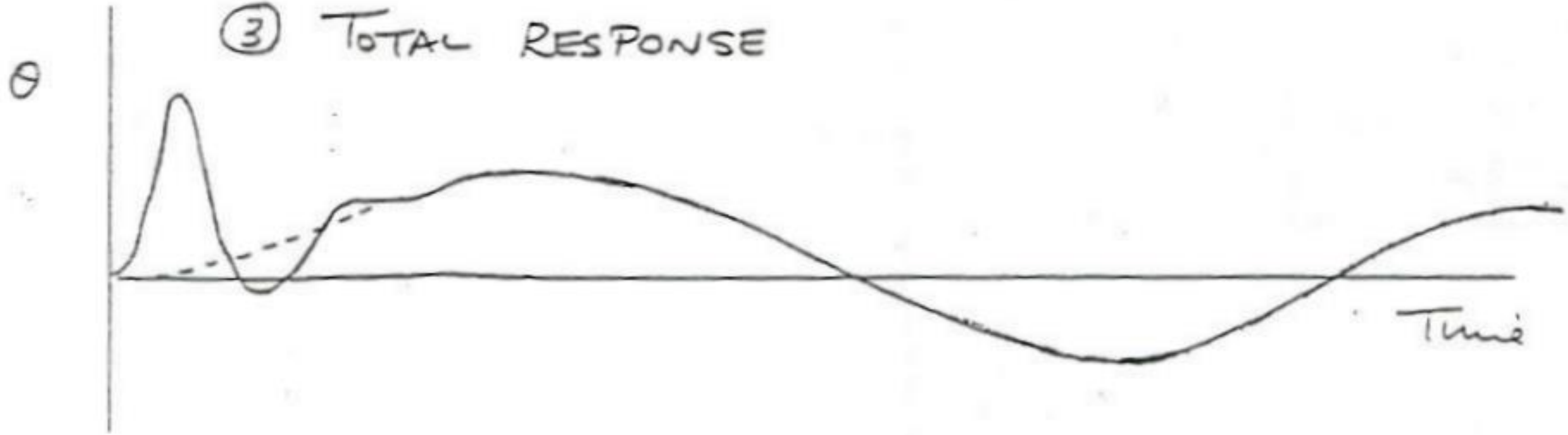
Typical Aircraft Response



Typical Aircraft Response



Typical Aircraft Response



Root locus as CG is shifted aft

- h is the CG position relative to the leading edge; values shown on the loci are for static margin H_n.
- Instability occurs when H_n=0, i.e. starting when the first root crosses into the right half plane.
- As this occurs here at the origin it corresponds to static instability.
- The CG position affects the derivative M_w fairly significantly, although other derivatives may also vary.

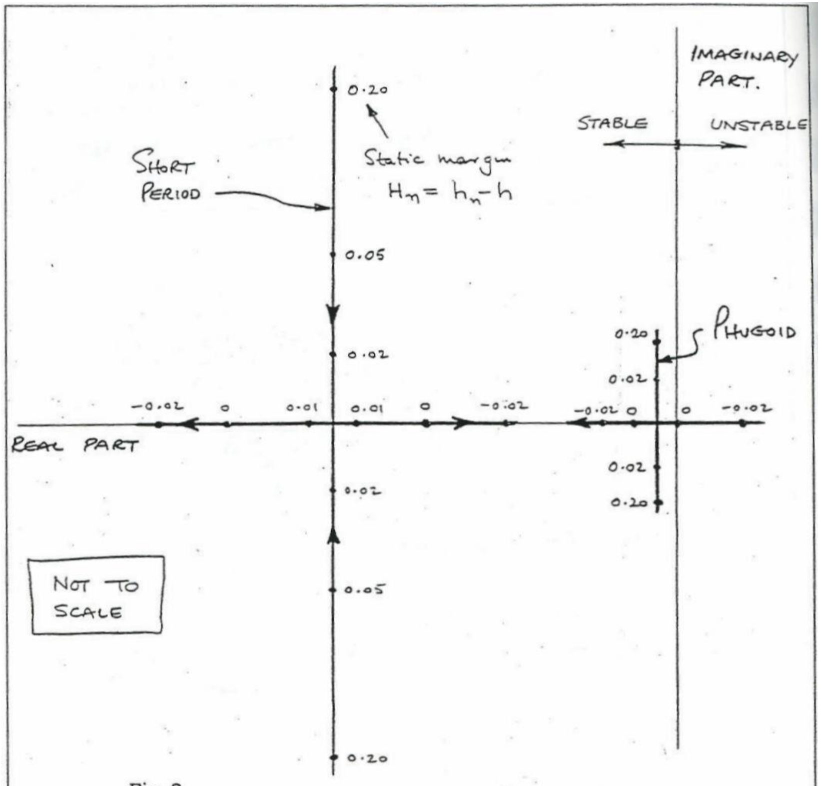
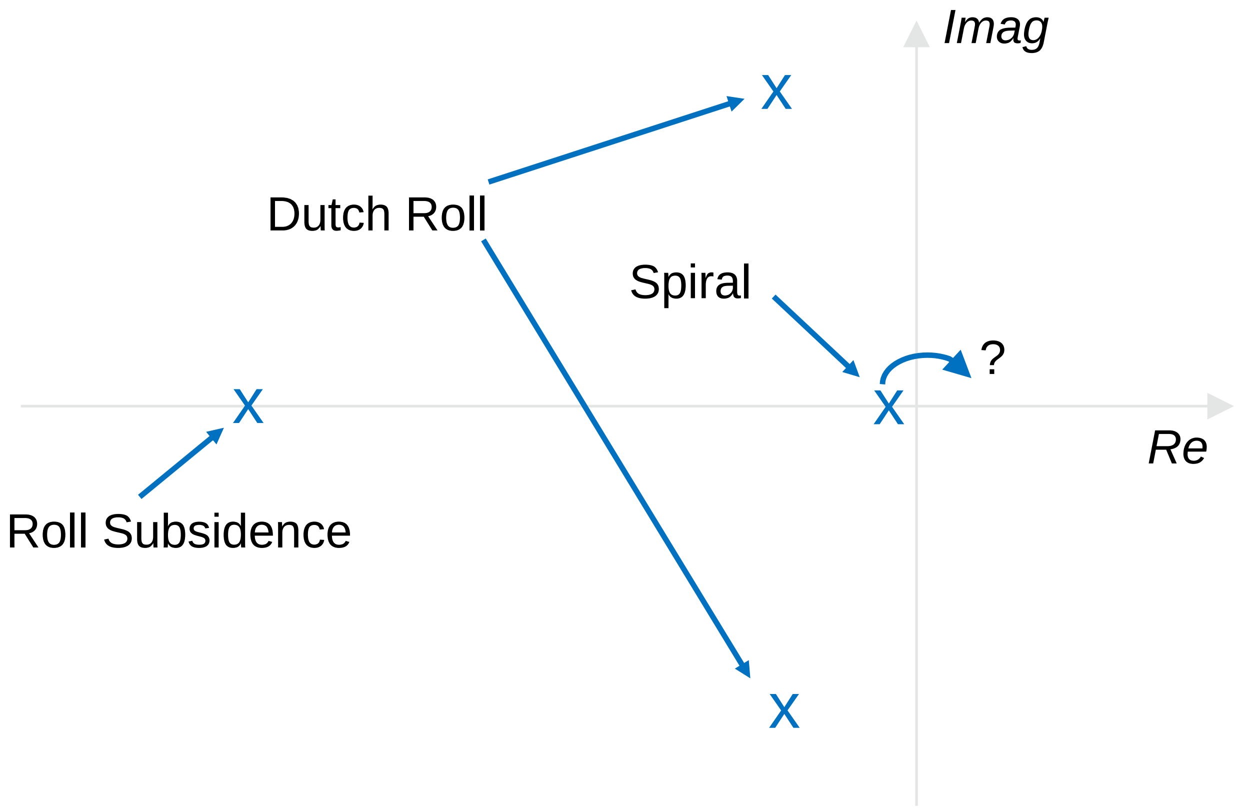


Fig. 3

Lateral Roots



Lateral Modes

1. Large negative real root - the **roll convergence** (***or roll subsidence***).

   This implies almost pure rolling motion and of course cannot last long in reality.

   A more realistic attitude suggests that if a roll "pulse" hits the aircraft (e.g. a brief up-gust on one wing), the consequent response in roll would be heavily damped.

Lateral Modes

2. Small real root, of either sign - the **spiral mode**.

   This would be, for an unstable case, a slow divergence in yaw (say nose to starboard) while a roll angle built up (rolling to starboard) and thus also a sideslip would develop.

   The later stage would be a tightening spiral dive with all three motion variables involved.

   In practice, a pilot can control an unstable spiral mode (*slow!*).

Lateral Modes

3. The complex pair - **Dutch Roll**.

   Strictly speaking, all freedoms are active here, in an oscillatory sense, and out of phase with each other.

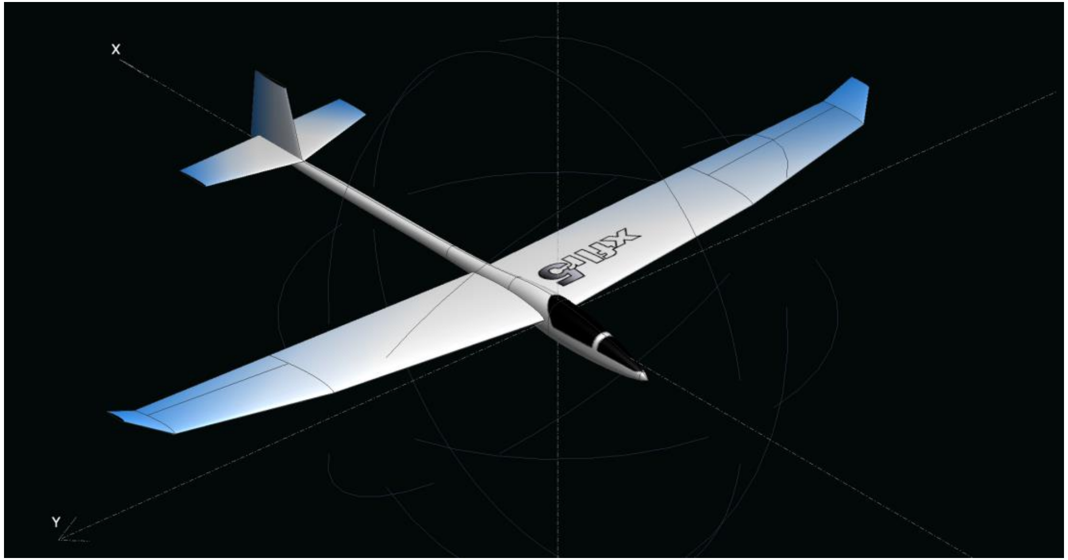
   This mode can be badly (though positively) damped and will affect Handling Qualities. The frequency is probably lower (the period a bit longer) than the longitudinal short period mode.

   Can be unpleasant if poorly damped! (nausea)

   Often poorly damped on swept wing aircraft

   Yaw damper

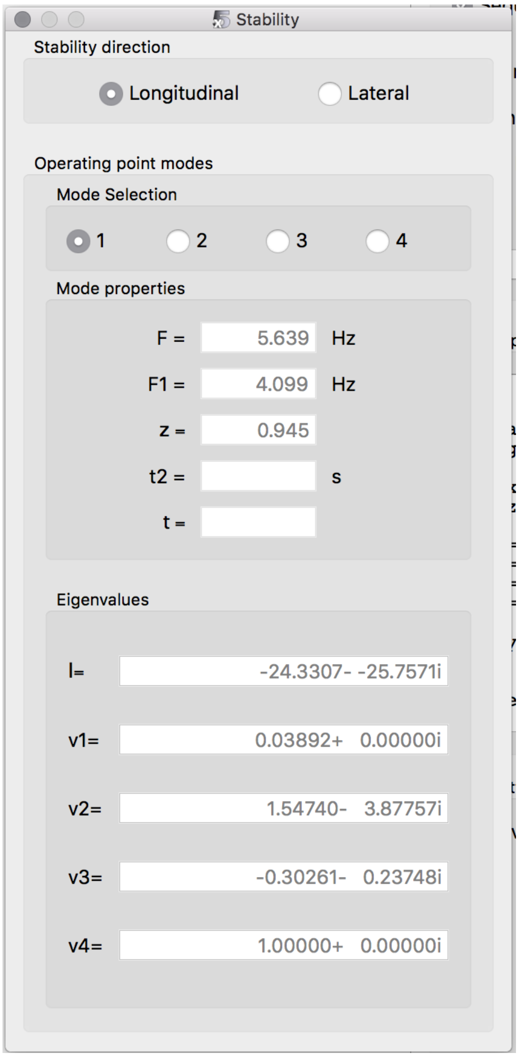
XFLR example



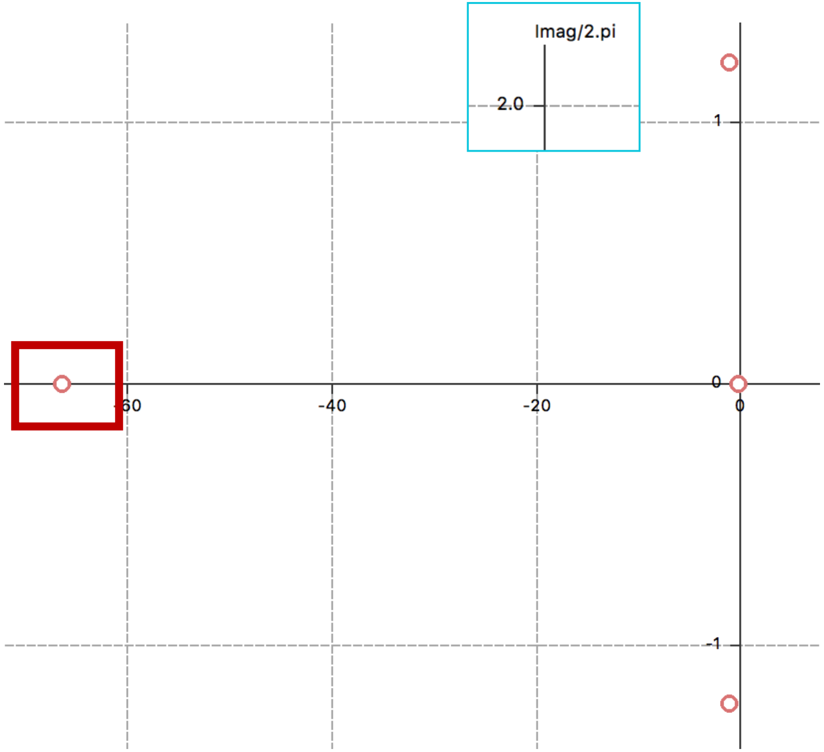
(Using the baseline configuration)

XFLR example

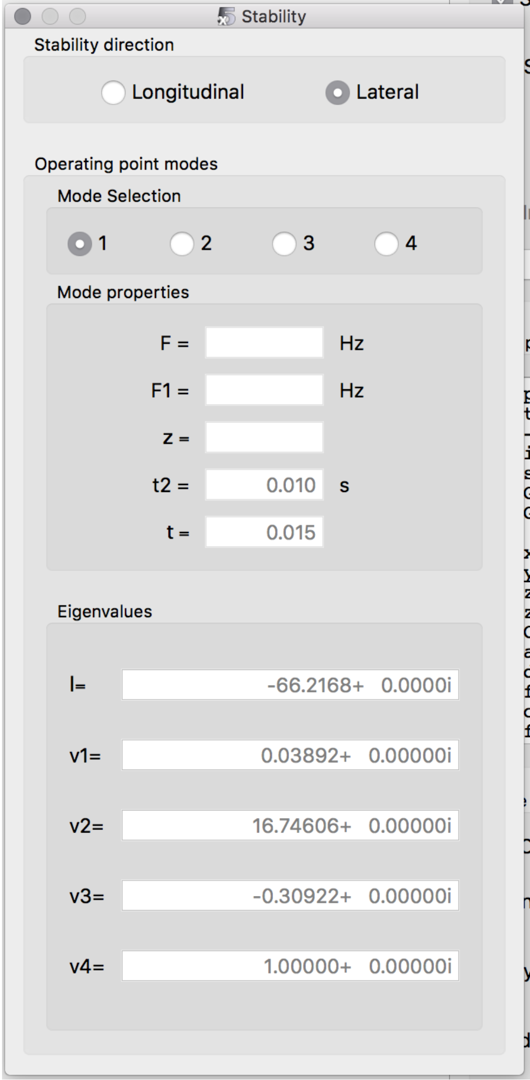
Longitudinal modes



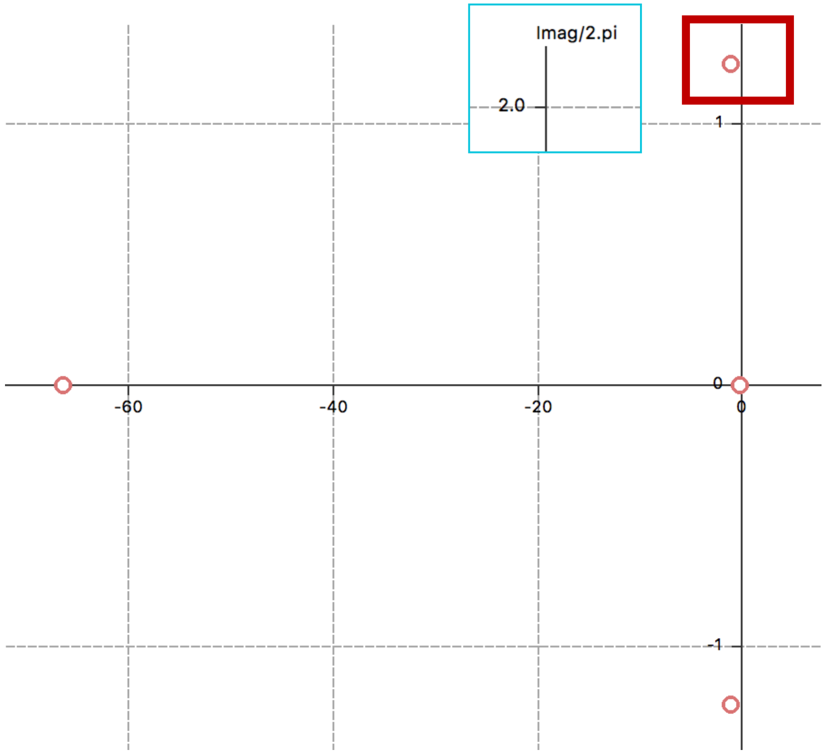
XFLR example



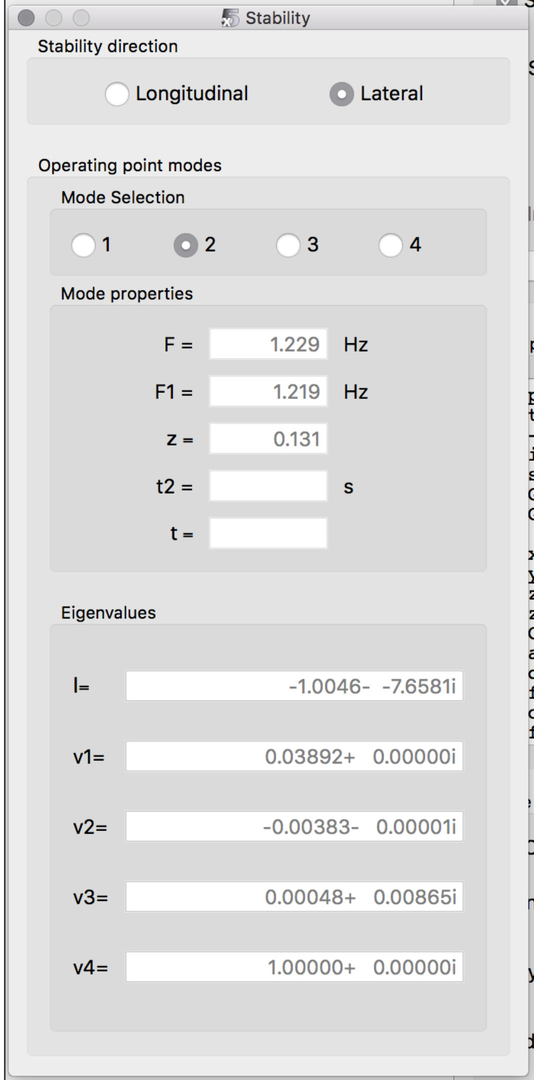
Lateral modes



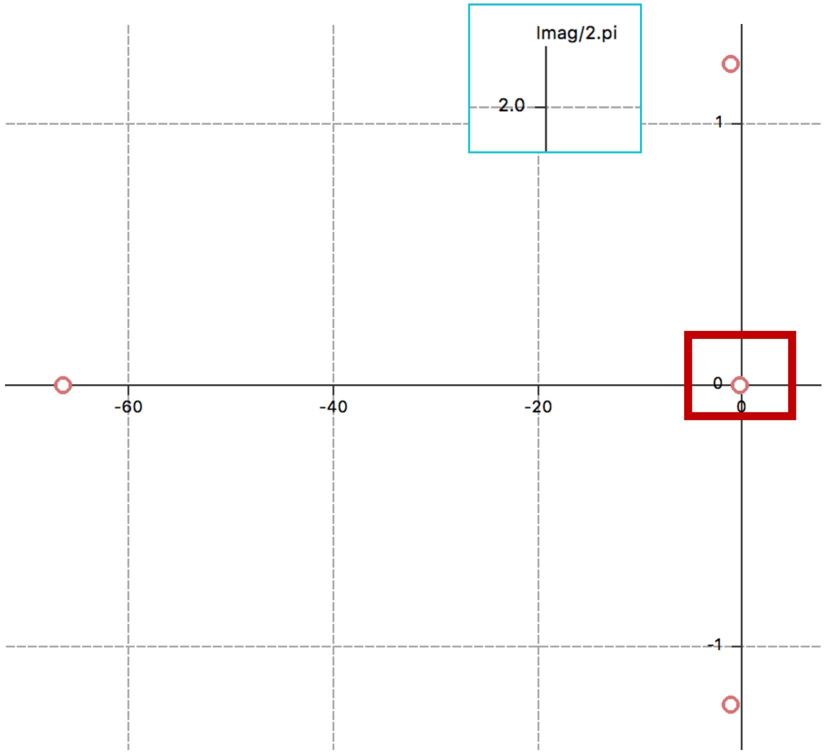
XFLR example



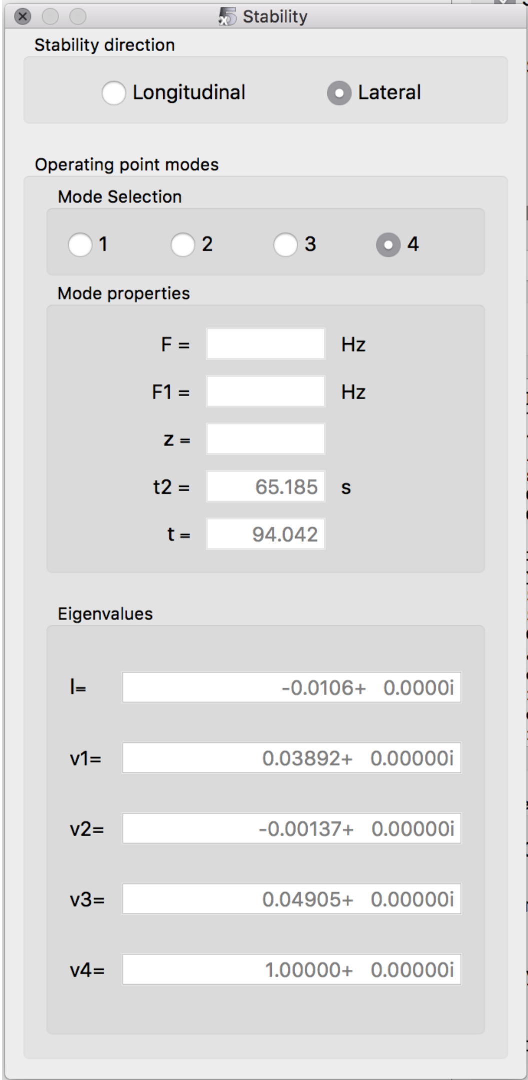
Lateral modes



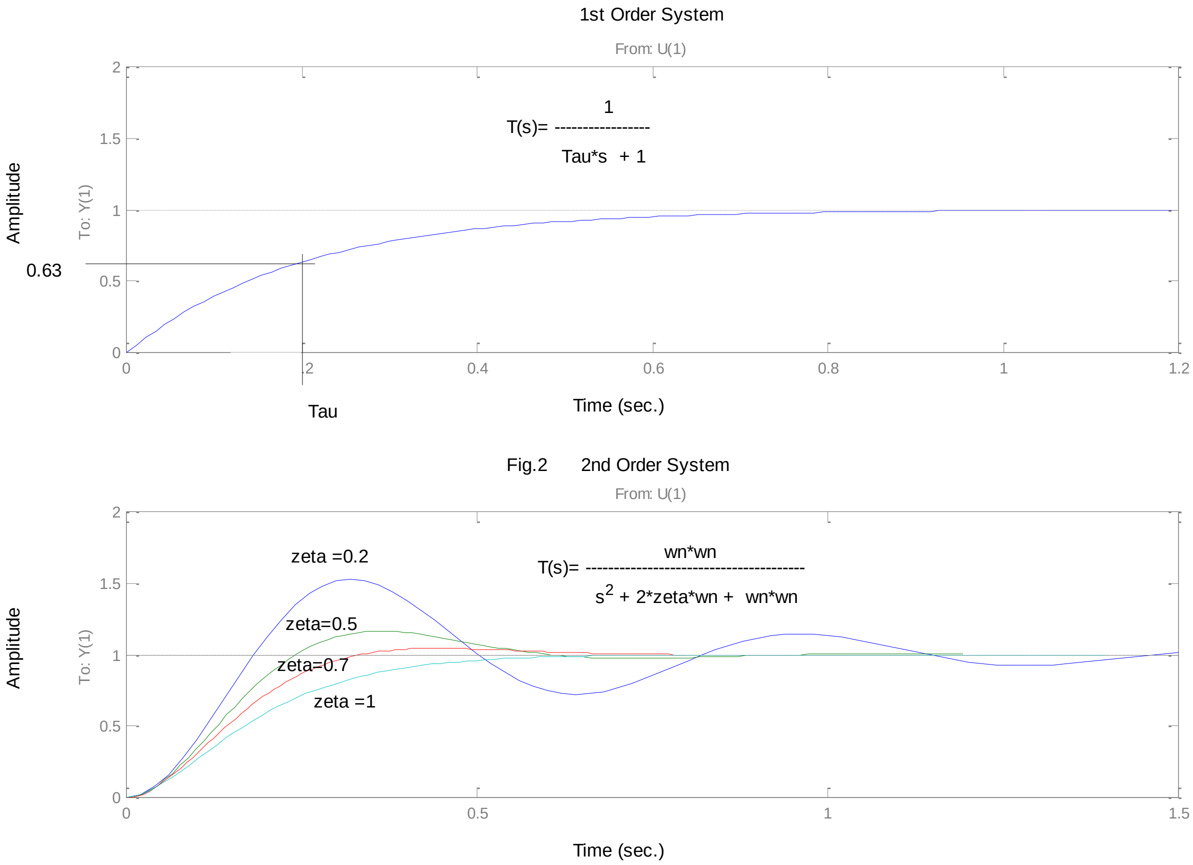
XFLR example



Lateral modes

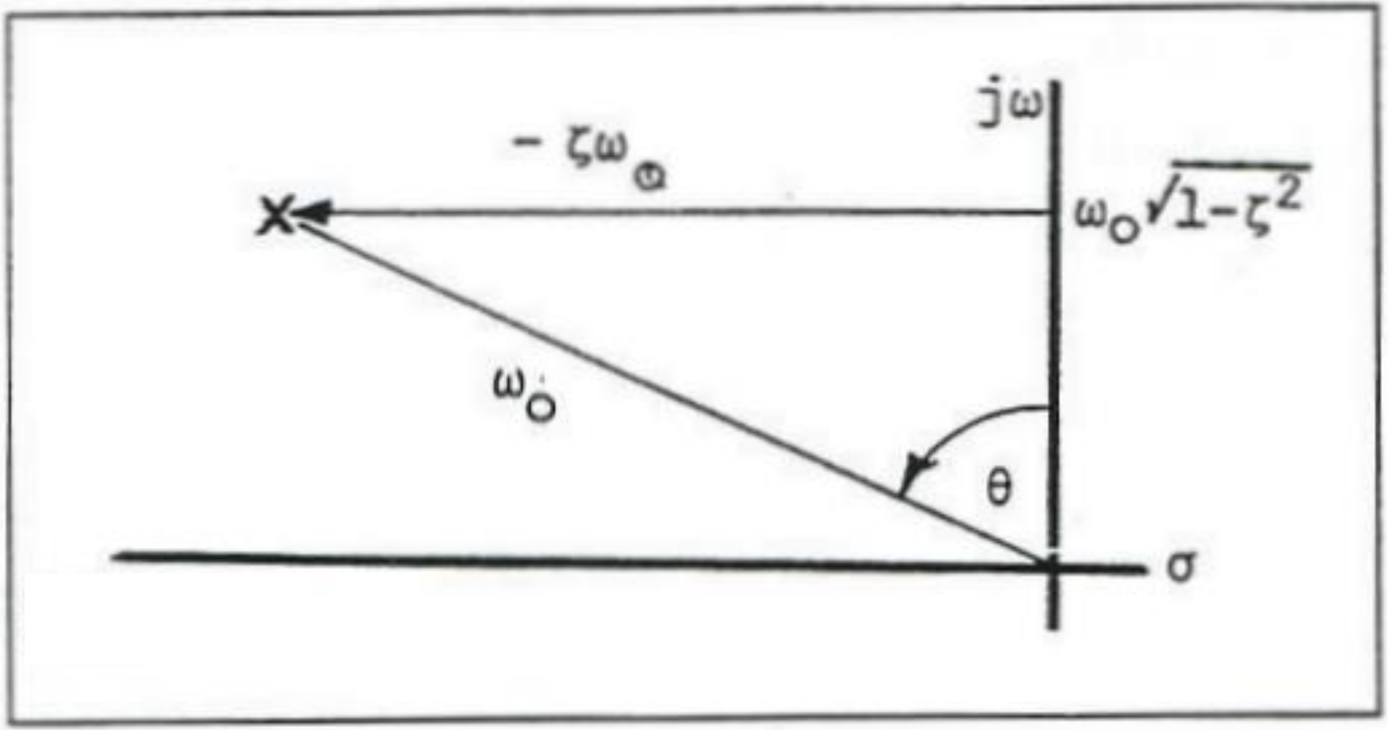


System Stability



Constant Damping Ratio ζ

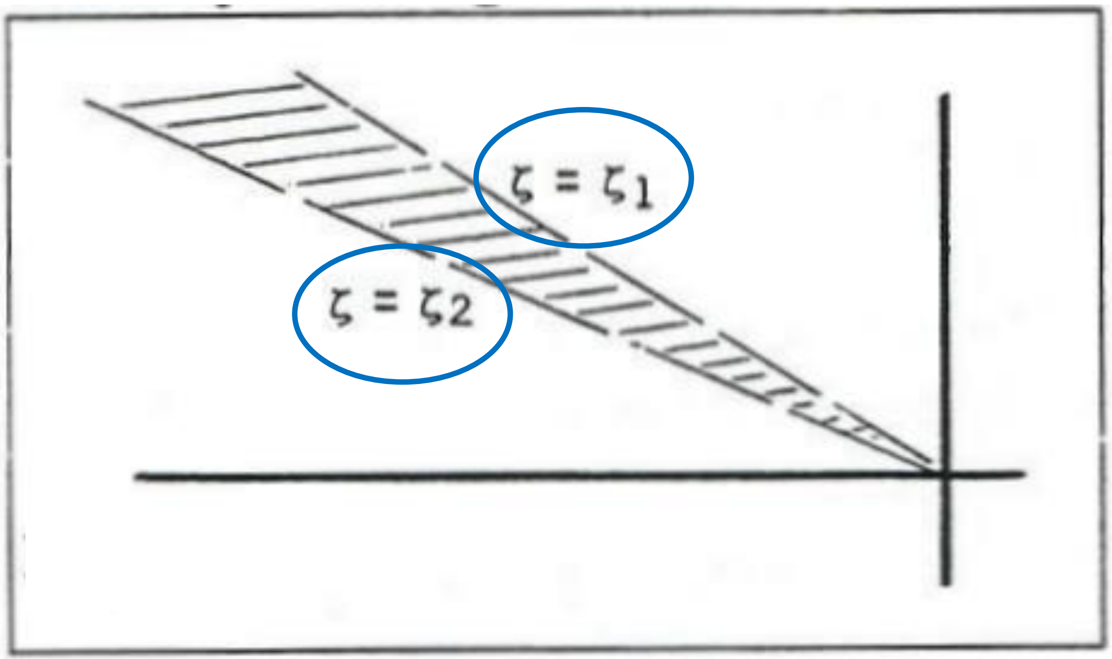
- Where $\lambda = \sigma \pm j\omega$



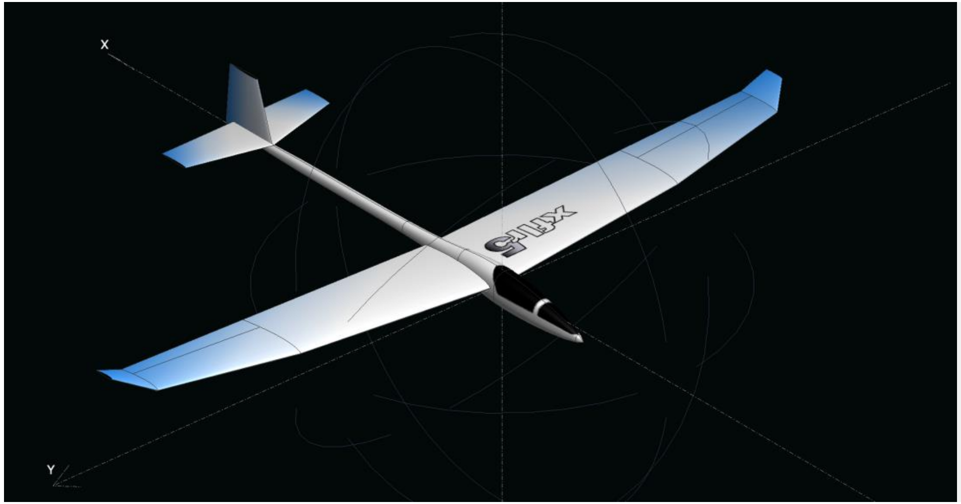
Constant Damping Ratio ζ

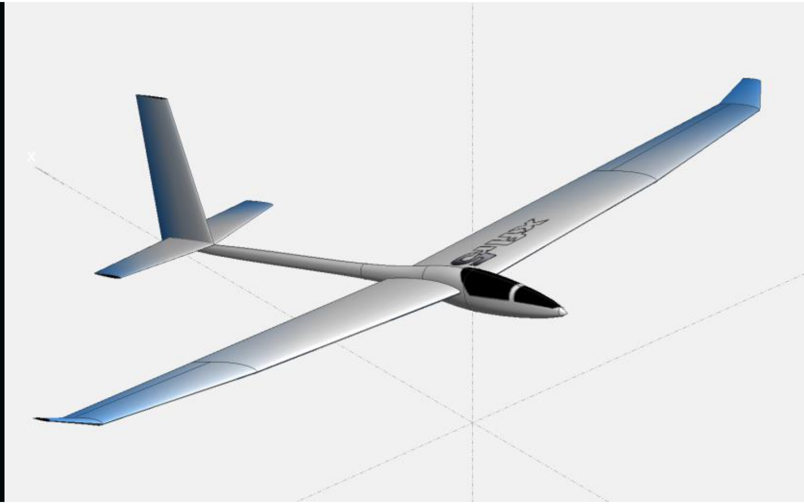
- We can show that:

$$\zeta = \sin\theta$$

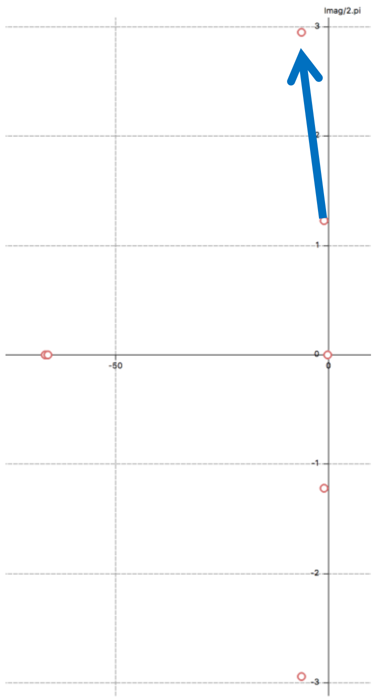


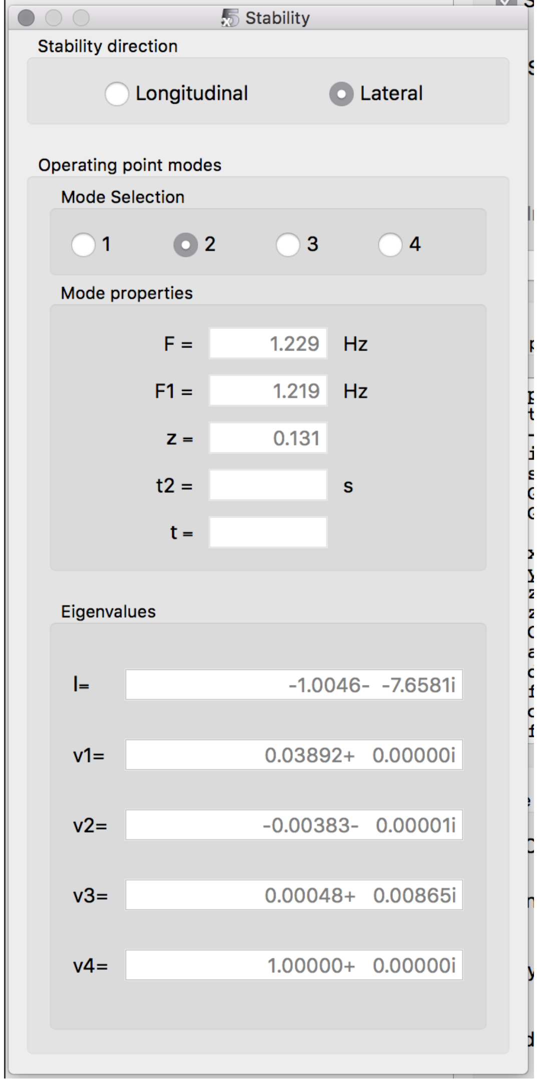
XFLR example

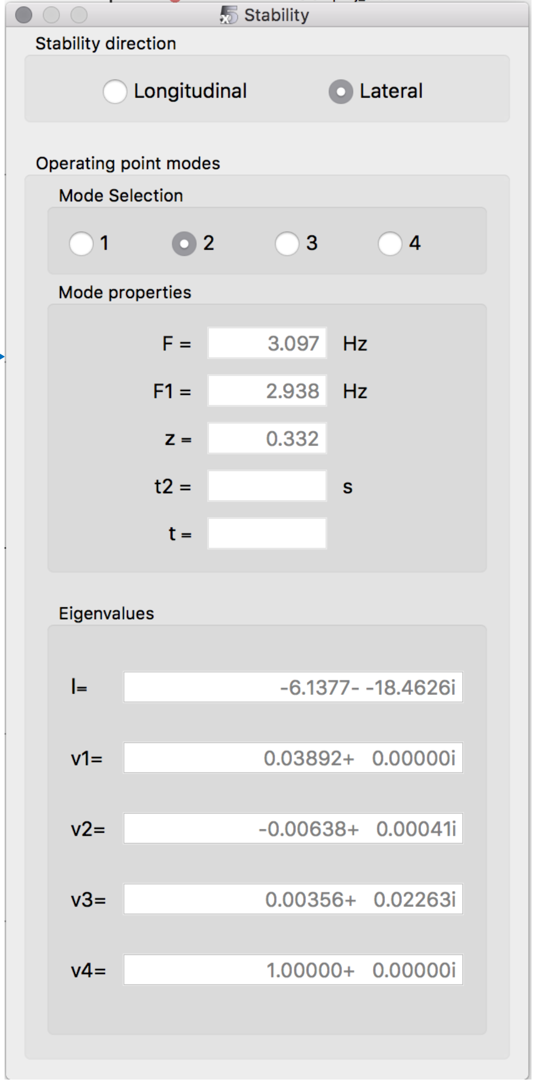




XFLR example







Lateral modes

Coursework

- 2 Flight Mechanics Design
- The stretch variant of the aircraft developed in part 1 (Aerodynamic Design) requires a horizontal and a vertical new tail, which you need to design and assess their effects on the aircraft trim and stability.
  - 2.1 Tail sizing and trim
  - 2.2 Static stability
  - 2.3 Dynamic stability
- *Clear plots*
- *Physical explanations*

Any Questions?