Aircraft Design 1
Flying Qualities Criteria

Flying Qualities Criteria

- Criterion of the natural frequency and damping of the longitudinal motion:
  - Short Period
  - Phugoid
- Neal-Smith's frequency domain criterion
- Control Anticipation Parameter, CAP

Flying Qualities Criteria – cont.

- C* criterion
- Gibson Dropback Criterion for Pitch Angle Control
- Stick force criterion
- Simplified Roll-Rate response criterion
- Spiral stability criterion
- Dutch Roll stability criterion

Criterion of the natural frequency and damping of the longitudinal motion

eigenvalue problem:

$$\left[\mathrm{A} - \mathrm{I}\lambda\right]\mathrm{x} = 0$$

solution

general:

$$\lambda = \xi + \mathrm{i}\eta$$

period:

$$\mathrm{T} = \frac{2\pi}{\eta}$$

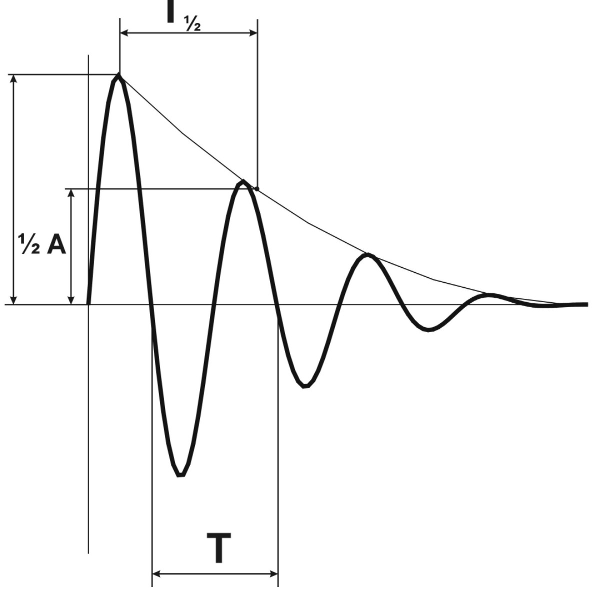
time to half amplitude (ξ<0):

$$\mathrm{T}_{\frac{1}{2}} = -\frac{\ln 2}{\xi}$$

time to doubled amplitude (ξ>0):

$$\mathrm{T}_2 = \frac{\ln 2}{\xi}$$

Criterion of the natural frequency and damping of the longitudinal motion



Criterion of the natural frequency and damping of the longitudinal motion

<u>Additional definitions (terms)</u>

the eigenvalue has the form:

$$\lambda = \xi + i\eta$$

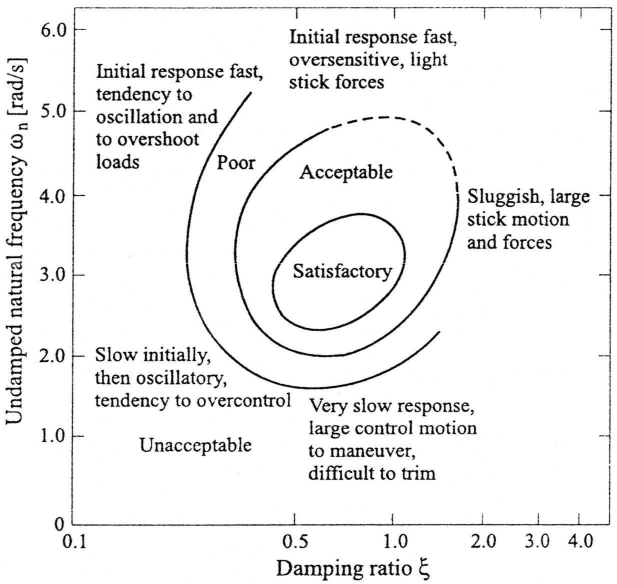
undamped natural frequency is defined as:

$$\omega_n = \sqrt{\xi^2 + \eta^2}$$

and damping ratio:

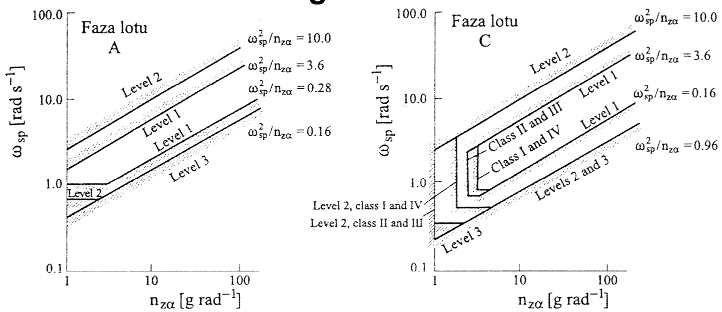
$$\zeta_d = -\frac{\xi}{\sqrt{\xi^2 + \eta^2}}$$

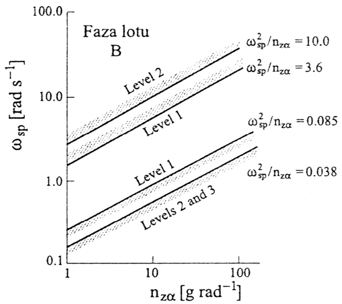
Criterion of the natural frequency and damping of the longitudinal motion



Influence of the undamped natural frequency ω_n and damping ratio ξ, of Short period oscillations on handling qualities rating: *Satisfactory (recommended), Acceptable and Poor (unacceptable)*

Criterion of the natural frequency and damping of the longitudinal motion





gradient definition: $n_{z\alpha} = \frac{\partial n_z}{\partial \alpha}$

Scoring of the flying qualities acceptance level as the relation between short period oscillations ω_n and derivative $n_{z\alpha}$; (Level 1, 2, 3)

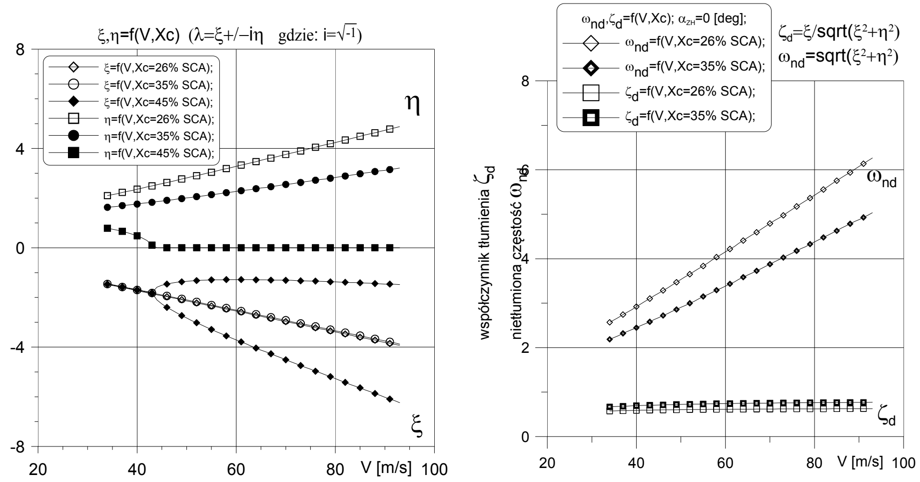
Recommended values for damping coefficients

Description		Acceptance Level					
		1		2		3	
Motion type	Flight phase	Dimensionless damping coefficient					
		Min.	Max.	Min.	Max.	Min.	Max.
Short Period	Class A	0.35	1.30	0.25	2.00	0.10	-
Short Period	Class B	0.30	2.00	0.20	2.00	0.10	-
Short Period	Class C	0.50	-	0.35	2.00	0.25	-
Phugoid	All	0.04	-	0.00	-	(N)	-

Remarks:

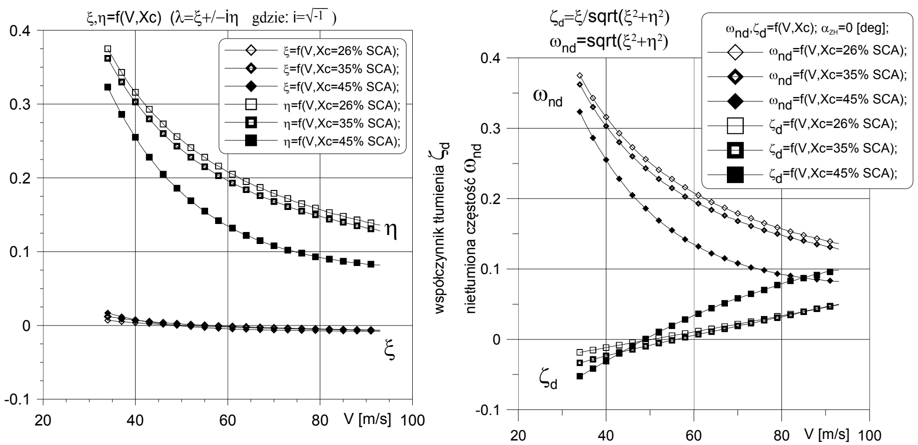
- For level 3 unstable phugoid is acceptable (N), however period has to be greater than 55 s.
- Requirements are defined in case the frequency of the short period oscillations is at least 10 times greater than frequency of the phugoid oscillations

Examples of undamped frequency and damping ratio



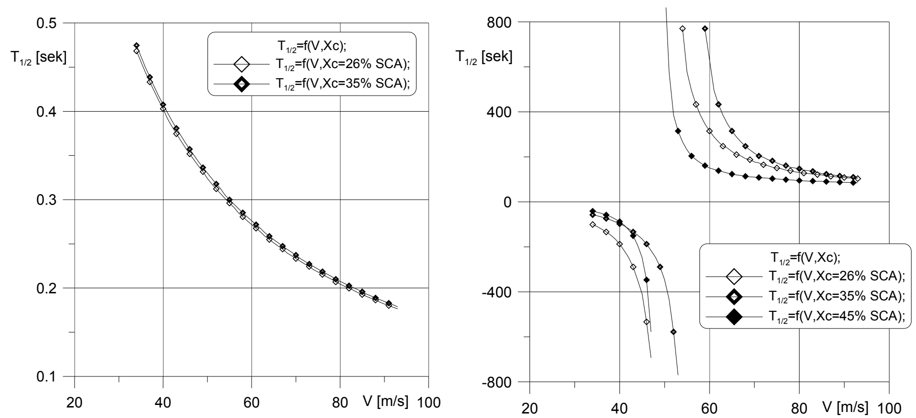
EM-11 Orka – short period oscillations

Examples of undamped frequency and damping ratio



EM-11 Orka – phugoid oscillations

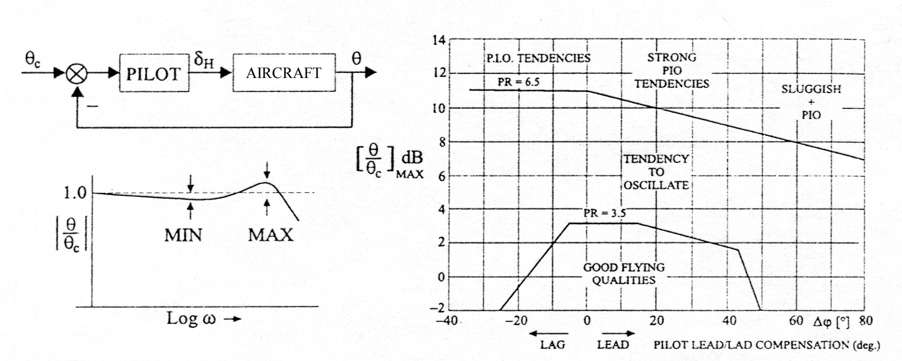
Time to half amplitude



short period oscillations – EM-11 Orka – phugoid oscillations

Acceptance levels according to the Neal-Smith's criterion

$$G_p(s) = k_p \, e^{-\tau s} \frac{T_D s + 1}{(T_N s + 1)(T_I s + 1)}$$



(PIO – Pilot Induced Oscillations)

Control Anticipation Parameter criterion

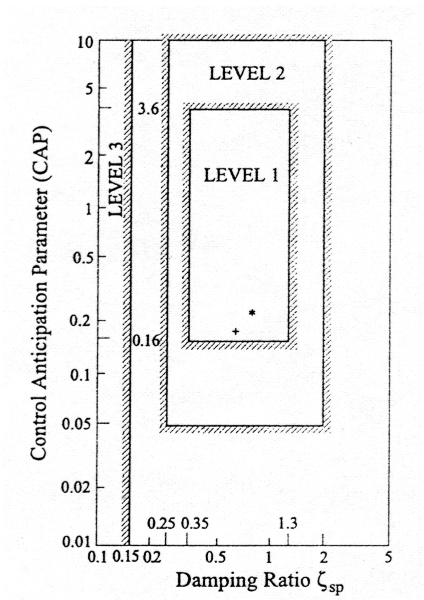
CAP – Control Anticipation Parameter

$$CAP = \frac{q(t = 0^+)}{\Delta n_z (t \to \infty)} [rd / s \cdot g]$$

for short period approximation:

$$CAP \cong \frac{\omega_{sp}^2}{n_{z\alpha}}$$

Control Anticipation Parameter criterion



CAP criterion for flight phase C

Control Anticipation Parameter criterion

Flight phase	Acceptance level					
	1		2		3	
	Control Anticipation Parameter CAP					
	min.	max	min.	max	min.	max
A	0.28[1]	3.6	0.16[3]	10.0	0.16	-
B	0.085	3.6	0.038	10.0	0.038	-
C	0.16[2]	3.6	0.096[4]	10.0	0.096	-

[1] for $\omega_{sp} > 1.0$, [2] for $\omega_{sp} > 0.6$, [3] for $\omega_{sp} > 0.7$, [4] for $\omega_{sp} > 0.4$.

Norm MIL-STD-1797A accepts minimum value of CAP = 0.05 for the second acceptance level In flight chase C.

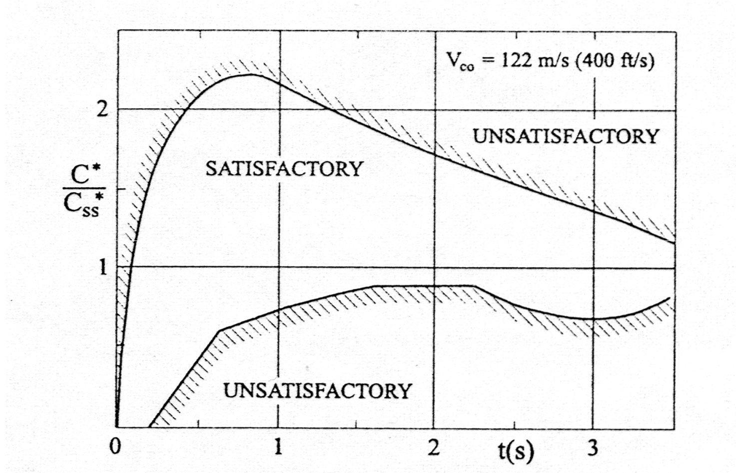
C* criterion

Criterion C* is used to score the phase just after stick (in pitch channel) was deflected

$$C^*(t) = \Delta n_{zp}(t) + \frac{U_c}{g} q(t); \qquad \Delta n_{zp}(t) = \Delta n_z + l_p \dot{q}(t)$$

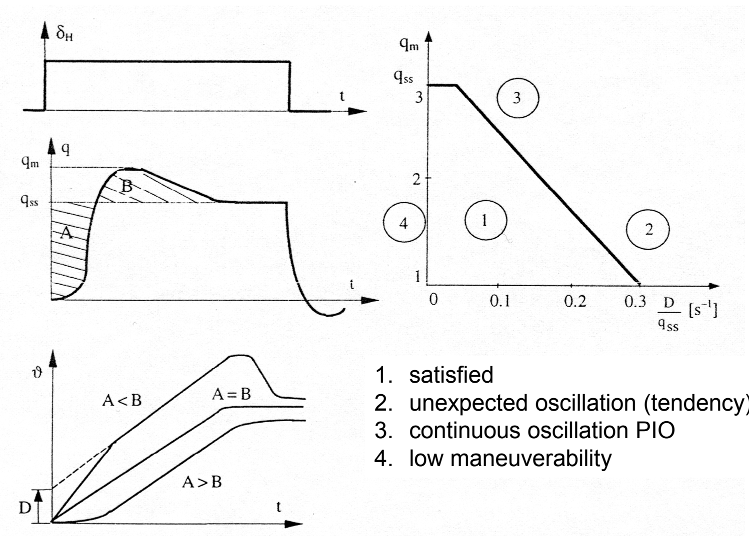
where: Δn_{zp} – load factor increment filled by pilot
Δn_z – load factor increment of CG
l_p - distance between CG and pilot seat,
$l_p > 0$ when CG is behind the pilot

C* criterion



Recommended area for normed C* factor

Gibson Dropback Criterion for Pitch Angle Control



1. satisfied
2. unexpected oscillation (tendency)
3. continuous oscillation PIO
4. low maneuverability

Flight parameters after step control (elevator deflection) and recommended range according to the Gibson criterion

Stick force criterion

$$\delta_H^{n_z} = \frac{\partial P_H}{\partial n_{zss}} [N/g]$$

MIL-F8587C recommends the gradient value from the range:

$$\delta_H^{n_z} = \frac{A}{(n_{z\max} - 1)} [N/g]$$

where: $n_{z\,max}$ max. feasible load factor
A – parameter depending on control type:
- for stick A_{min}=93, A_{max}=250
- for wheel A_{min}=133, A_{max}=370