SM302 - A/C Structures

Flight Loads *Flight Mechanics - Regulation - Failures*

Aerodynamics - Surface Loads
Inertial Flight Loads - Flexible Structures

Sym. / Asym Manoeuvre. Turbulence / Gusts
Pressure, Gyroscopic & Thermal Loads

Ground Loads *Landing Loads - Ground Roll Loads*

Certification of Civil A/C | MTOW $\geq$ 5700 kg

Quality Process : Design, Compute, Test, Service

Fulfill JAR Part25 ($\approx$FAR25) & Obtain Type Certificate

Limit Load $\equiv$ Max. in Service

Ultimate Load $\equiv$ LL* Regulation Coeff

RC $\equiv$ 1.5 if no other specification

RC is JAR-Statutory, depending : Load Nature (hydr.= 2)
Occurence Probability

NB : Fatigue is specific (SL<LL, A/C lives)

Safety Goal ~10^{-7} /Fl.Hour (~10^{-9} /FH/Pax)

Two Aerodynamical Orthonormed Direct G-Bases defined by 2 Plans

Aircraft Ref. $x_{A/C}$ ≡ Held by A/C Longi.Axe Fwd (see sheet 5)

$x_{A/C}z_{A/C}$ ≡ A/C Sym.Plan ($z_{A/C}$Down)

Aerodyn.Ref. X ≡ Held by Relative Speed A/C-Air (Fwd)

XY ≡ Plan $\perp x_{A/C}z_{A/C}$ (Y RH)

3 A/C Rates	*Roll Rate*	p ≡ A/C Angular Speed around $x_{A/C}$
	Pitch Rate	q ≡ " " " " $y_{A/C}$
	Yaw Rate	r ≡ " " " " $z_{A/C}$
2 Aero Angles	***Attack***	α ≡ angle $(X;x_{A/C})$ proj.on $x_{A/C}z_{A/C}$
	Sideslip	β ≡ angle $(x_{A/C};X)$ proj.on XY

Aerodynamic Efforts Definitions

Moments on Aircraft

Roll (around $x_{A/C}$)
Pitch (around $y_{A/C}$)
Yaw (around $z_{A/C}$)

$$\begin{cases} L \equiv \overline{q}\mathcal{S}_{ref}\ell_{ref}C_l \\ M \equiv \overline{q}\mathcal{S}_{ref}\ell_{ref}C_m \\ N \equiv \overline{q}\mathcal{S}_{ref}\ell_{ref}C_n \end{cases}$$

Aerodynamic Resultants

Drag (on -X)
Lateral (on Y)
Lift (on -Z)

$$\begin{cases} R_X \equiv -\overline{q}\mathcal{S}_{ref}C_X \\ R_Y \equiv \overline{q}\mathcal{S}_{ref}C_Y \\ R_Z \equiv -\overline{q}\mathcal{S}_{ref}C_Z \end{cases}$$

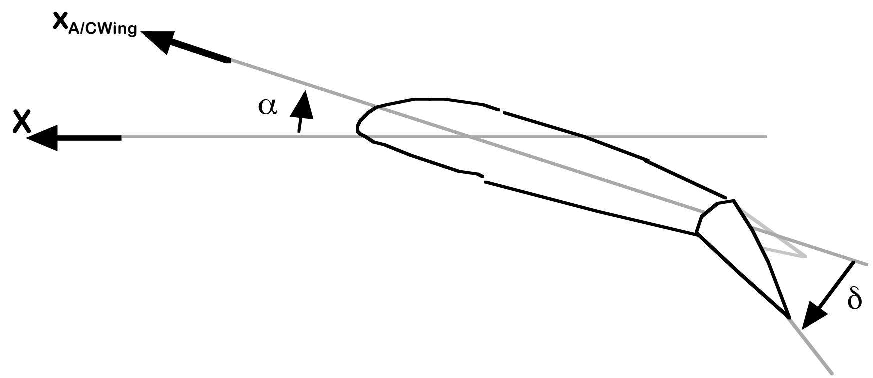
With : $\overline{q}$ ≡ Bernoulli Kinetik Pressure $\equiv \frac{1}{2}\rho V^2 \equiv \frac{1}{2}\rho_0 V^2_{equiv0} \quad \left(\rho_0 \equiv 1.225\ \mathrm{kg/m^3}\right)$

$\mathcal{S}_{ref}$ ≡ A/C Reference Aero Area (= Wing Conventional Surface)

ℓ_{ref} ≡ A/C Reference Aero Distance (= Wing Conventional Cord)

Aerodynamic Wing Profile (2D) Pitch Model

Possible Convention **Zero Lift $\Leftrightarrow \alpha \equiv 0$**
($\Rightarrow$ precise definition of $x_{A/C}$ axe)



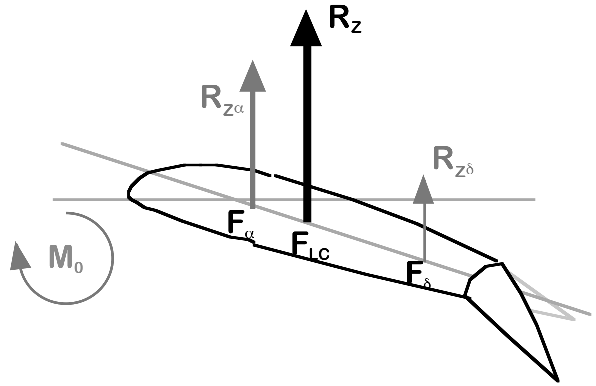
Control : No effect on profile $\Leftrightarrow \delta \equiv 0$

The Flow induces the constant pure moment $M_0 \equiv \overline{q}\mathcal{S}_{ref}\ell_{ref}C_{m0}$ <u>and</u> the Resultant Lift

$$R_Z \equiv \underbrace{R_{Z\alpha}}_{\substack{\text{lift induced by } \alpha \\ \text{and applied at } F_\alpha}} + \underbrace{R_{Z\delta}}_{\substack{\text{lift induced by } \delta \\ \text{and applied at } F_\delta}} \quad \left(\text{in linear model : } C_Z \equiv \frac{\partial C_Z}{\partial \alpha}\alpha + \frac{\partial C_Z}{\partial \delta}\delta \equiv A\alpha + D\delta\right)$$

$F_\alpha \equiv$ Main Aerodyn.Center (classically 25% of Cord) ; $F_\beta \equiv$ Secondary Aerodyn.Center

The Lift Center F_{LC} is the Point where $M \equiv 0$



Inertial Loads

Angular Acceler. $\begin{pmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{pmatrix}$ NB : Generally p>>q,r

Linear Acceler. $\begin{pmatrix} a_{xA/C} \equiv -g_0 n_x + g_{xA/C} \\ a_{yA/C} \equiv -g_0 n_y + g_{yA/C} \\ a_{zA/C} \equiv -g_0 n_z + g_{zA/C} \end{pmatrix}$ NB : Generally $g_{zA/C} >> g_{xA/C}$, $g_{yA/C}$

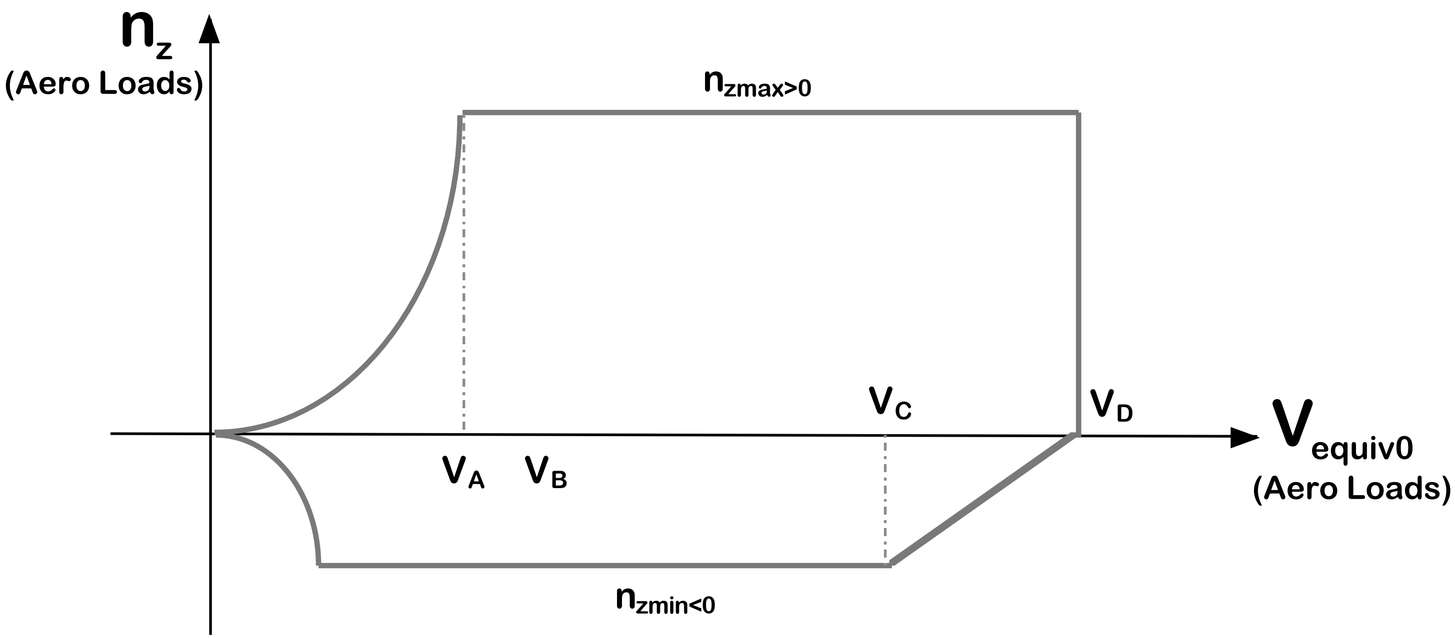
NB : $g_0 \equiv 9.80665\, m/s^2$ (conventional), whereas g is the local gravity

Flexible A/C

Quasi-Static Modification of Shape

Dynamic Coupling Transcient and Vibration

JAR Part 25-333b Flight Limit Domain



Inertia *(JAR §25.337) :* $n_{z\,min/max} \Leftrightarrow$ ***Extremal Continuous Loads*** *(3 sec) :*

$$n_{z\,min<0} \overset{JAR}{\equiv} -1 \;;\; n_{z\,max>0} \overset{JAR}{\in} \left[\,2.5_{(Large\,A/C)}\;;\;3.8_{(Middle\,A/C)}\right] \quad \left(n_{z\,max>0} \overset{JAR}{=} 2.1 + \frac{10886}{MTOW(kg)+4536}\right)$$

Aerodynamics *(JAR §25.103&333)*

2 Min and 2 Max Equivalent Ground Design Velocities

$V_A \overset{JAR}{\equiv}$ **Min V for Continuous Stable Flight with Maneuvers** $= V_{S1G} \cdot \sqrt{n_{z\,max>0}}$

where $V_{S1G} \equiv$ **Stall Velocity at $n_z = 1G$, MTOW, Flaps Retracted**

$V_C \overset{JAR}{\equiv}$ **Max Cruise V with Full Engine** (in Horizontal Flight)

V_C **must be significantly** (~ twice) **Higher than V_B , where**

$V_B \overset{JAR}{\equiv}$ Simil. V_A but with additional 17m/s **Cruise Gust** $= V_{S1G} \cdot \sqrt{n_{z\,max\ with\ Gust}}$

$V_D \overset{JAR}{\equiv}$ **Never Exceed V Engine+Dive** $\approx 1.25 V_{NE}$

Flight Manoeuvres

Symmetrical Pitch

Antisymmetrical Roll

Asymmetrical Yaw Command

Turbulence & Gusts

Commands :	**p (Roll)**	**Ailerons**
	q (Pitch)	**Elevator**
	r (Yaw)	**Rudder**

n_z dominant $\Rightarrow$ Pitch (& Roll) are critical for operation (joystick)

Symmetrical Steady Ressource

Resultant : $n_z M g_0 \equiv \overline{q}\, \mathcal{S}_{ref} C_z \quad \left(\equiv \frac{1}{2}\rho V^2 \mathcal{S}_{ref} \frac{\partial C_z}{\partial \alpha}\alpha \right)$

Pitch Rate :

$$\left.\begin{array}{r} \text{Accel. at low point } \gamma_z = g_0(n_z - 1) \equiv \dfrac{V^2}{R} \\ \text{Stabilised Pitch Rate } q \equiv \dfrac{V}{R} \end{array}\right\} \Rightarrow q_{ressour.} = \frac{g_0(n_z - 1)}{V}$$

NB : In Stabilised Turn $q_{turn} = \dfrac{g_0\left(n_z - \dfrac{1}{n_z}\right)}{V}$

Angles of Attack : **General :** $\alpha = q\dfrac{d_F}{V}$ d_F being $x_{A/C}$ distance G to F (A/C main center)

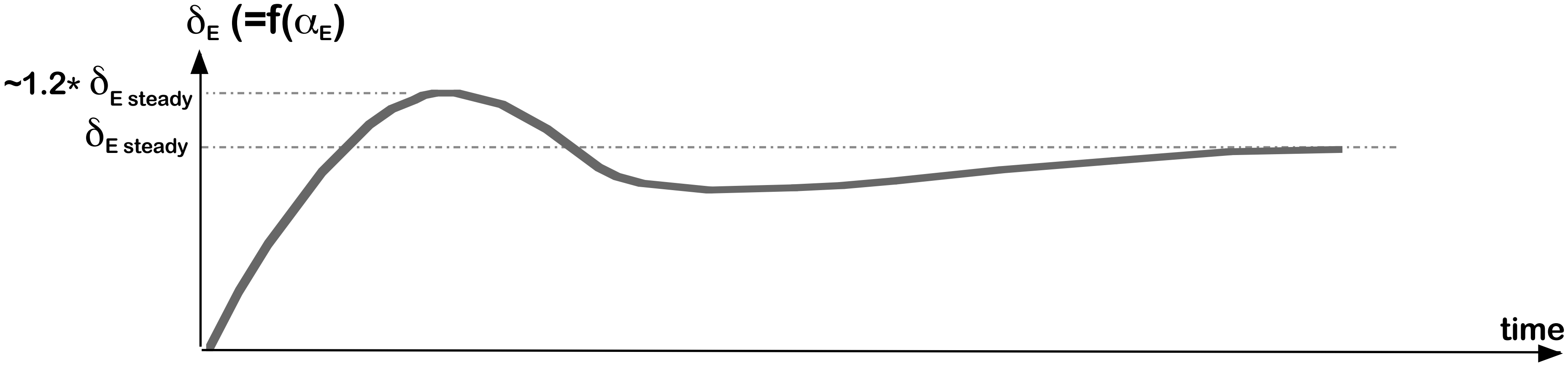
Average Horiz.Empennage : $\alpha_E = \alpha_{Etrim} + (\alpha - \varepsilon_{defl.}) + q\dfrac{d_E}{V}$

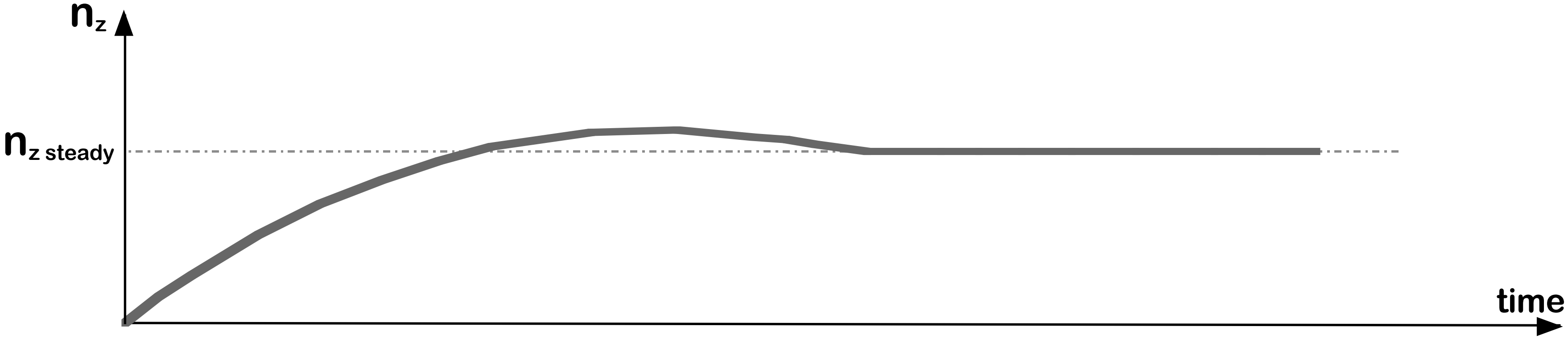
$\alpha_{Etrim} \equiv$ **Adjusted Incidence of Horiz.Empen. / $x_{A/C}$**

$\varepsilon_{defl.} \equiv$ **Aero Deflection made by Wing, possibly linearised** $\left(= \varepsilon_{defl.0} + \dfrac{\partial \varepsilon_{defl.}}{\partial \alpha}\alpha \right)$

d_E $x_{A/C}$ distance G to F_E (empennage main center)

Transcient Ressource State *(JAR §25.331)*





- **Inertial Rotation Loads and Structure Flexion**
- **α_E max at V_A , Pilot Control for other Speeds**

Steady Roll Manoeuvre

Rigid A/C Equation-Type : $\alpha_{\text{induced by p at y distance}} \equiv \dfrac{py}{V}$

$$I_x \dot{p} \equiv \bar{q}\, S_{ref} \ell_{ref} \left(\frac{\partial C_{\ell_{ref}}}{\partial \delta_{\ell_{ref}}} \delta_{\ell ref} - \frac{\partial C_{\ell_{ref}}}{\partial \frac{p\ell_{ref}}{V}} \frac{p\ell_{ref}}{V} \right) \quad (\equiv \text{driving} - \text{resisting})$$ *steady if* $p \equiv 0$ *dynamic if* $\dot{p}$ *max*

NB : All parameters being unsymmetrical and non-constants, are equivalent coefficients

Rolling Certification Conditions *(JAR §25.349)* :

- **At any** $n_z \in [\, 0 \, ; \, \dfrac{2\, n_{z\max > 0}}{3} \,]$
- **At V_A with $\delta_{\ell\max}$ aileron maximal deflection** ($p_A \equiv$ induced roll rate)

  At V_C with δ_ℓ inducing the same p_A

  At V_D with δ_ℓ inducing no less than $p_A / 3$

NB : Aileron Efficiency $\eta_{aileron} \equiv \dfrac{p_{\text{rigid A/C}}}{p_{\text{flexibl A/C}}}$ **must remain significant** in spite of wing torsion