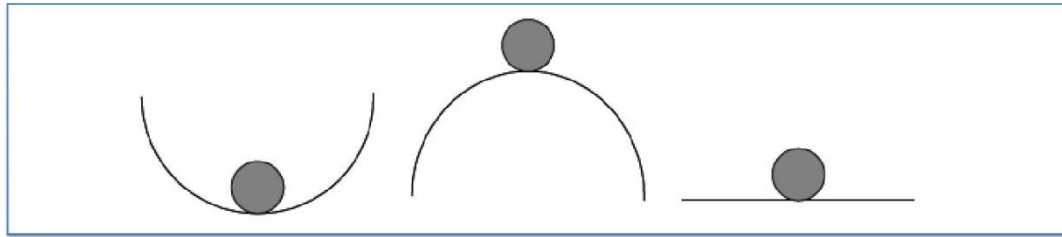




# ESTABILIDAD DEL AVIÓN

## Estados de Equilibrio

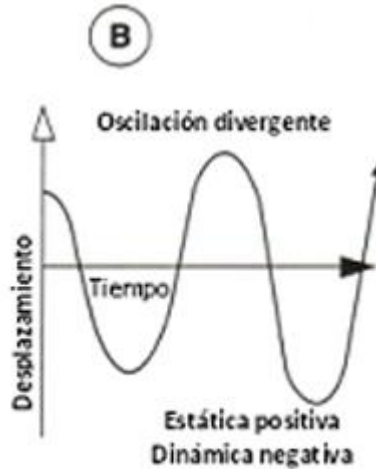
Al aplicar un fuerza a la esfera que la hace moverse de su posición de equilibrio por su propio peso puede suceder:



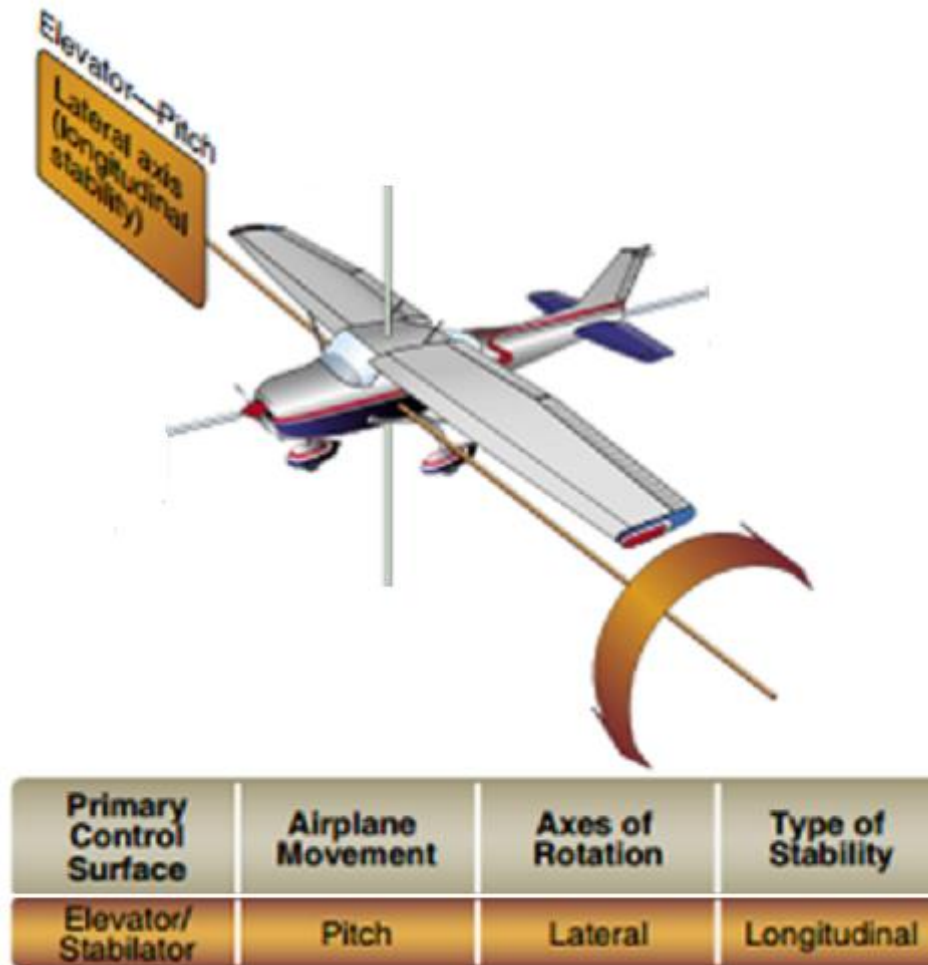
Equilibrio ESTABLE:  
La esfera vuelve a su posición original

Equilibrio INESTABLE  
La esfera se aleja de su posición de origen

Equilibrio NEUTRO O INDIFERENTE  
La esfera no se mueve por sí misma luego de retirada la fuerza



# ESTABILIDAD ESTÁTICA LONGITUDINAL



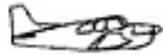
# ESTABILIDAD ESTÁTICA LONGITUDINAL

Sustentación = peso

Empuje = Resistencia

Momento resultante = 0

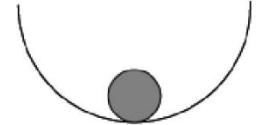
Avión en equilibrio



Avión perturbado

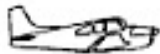


Avión vuelve a su posición de equilibrio



**Equilibrio estático estable**

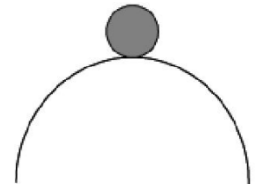
Avión en equilibrio



Avión, después de perturbado, se aleja de su posición de equilibrio

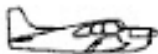


Avión continúa alejándose de su posición de equilibrio



**Equilibrio estático inestable**

Avión en equilibrio



Avión perturbado

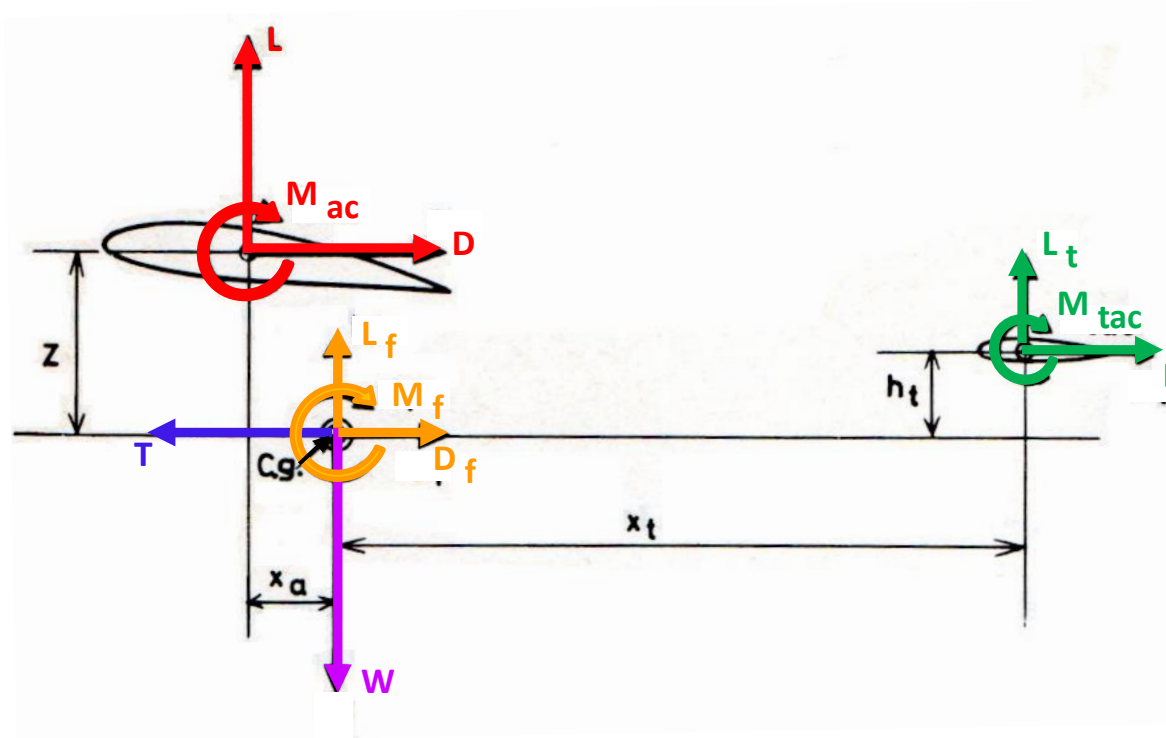


Avión perturbado mantiene la nueva posición de equilibrio



**Equilibrio estático indiferente**

## ESTABILIDAD ESTÁTICA LONGITUDINAL



$$+ \leftarrow \Sigma F_x = 0$$

$$\Sigma F_x = T - D - D_f - D_t = 0$$

$$+ \uparrow \Sigma F_z = 0$$

$$\Sigma F_z = L + L_f + L_t - W = 0$$

$$+ \text{C} \Sigma M_{cg} = 0$$

$$\Sigma M_{cg} = M_{ac} + L \cdot x_a + D \cdot z + M_f + M_{tac} - L_t \cdot x_t + D_t \cdot h_t = 0$$

## ESTABILIDAD ESTÁTICA LONGITUDINAL

$$M_{cg} = M_{ac} + L \cdot x_a + D \cdot z + M_f + \cancel{M_{ac}} - L_t \cdot x_t + \cancel{D_t} h_t = 0$$

$$M_{cg} = M_{ac} + L \cdot x_a + D \cdot z + M_f - L_t \cdot x_t = 0$$

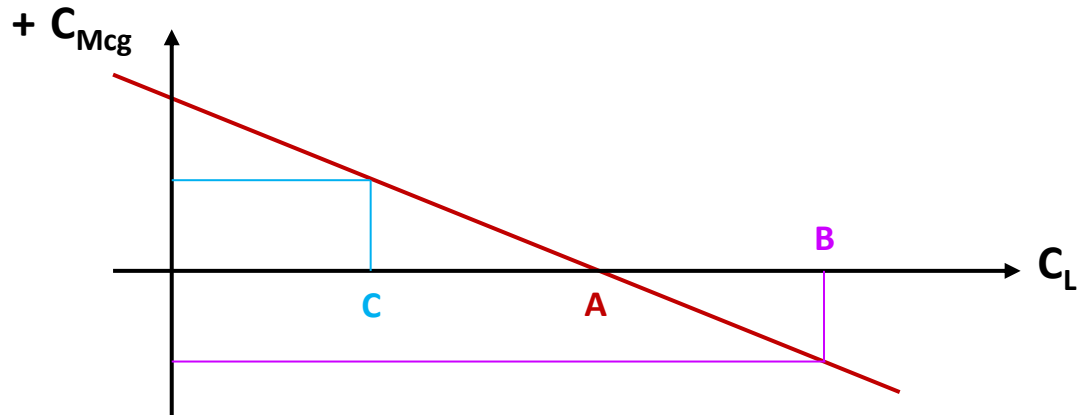
$$M_{cg} = C_{Mac} \cdot q \cdot S \cdot c + C_L \cdot q \cdot S \cdot x_a + C_D \cdot q \cdot S \cdot z + C_{Mf} \cdot q \cdot S \cdot c - C_{Lt} \cdot q_t \cdot S_t \cdot x_t = 0$$

Dividiendo miembro a miembro por  $q \cdot S \cdot c$

$$C_{Mcg} = C_{Mac} + C_L \cdot \frac{x_a}{c} + C_D \cdot \frac{z}{c} + C_{Mf} - C_{Lt} \cdot \frac{q_t}{q} \cdot \frac{S_t \cdot x_t}{S \cdot c} = 0$$

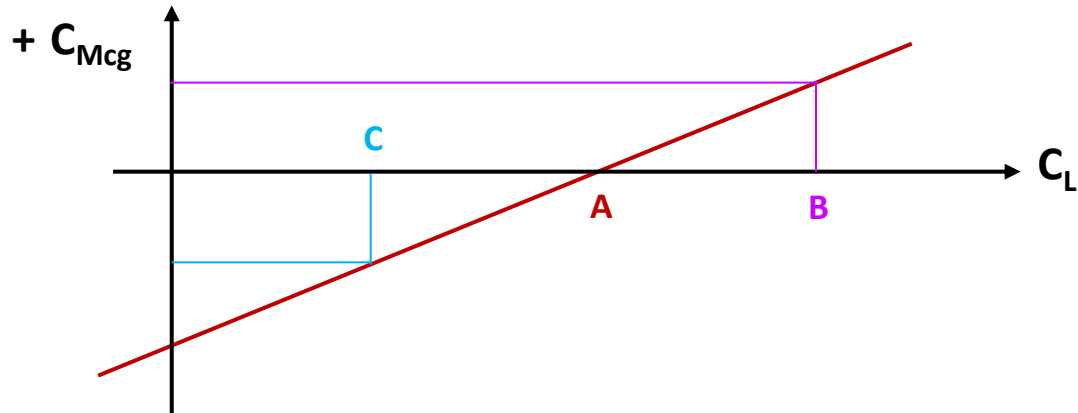
$$C_{Mcg} = C_{Mac} + C_L \cdot \frac{x_a}{c} + C_D \cdot \frac{z}{c} + C_{Mf} - C_{Lt} \cdot \eta_t \cdot \bar{V} = 0$$

# ESTABILIDAD ESTÁTICA LONGITUDINAL



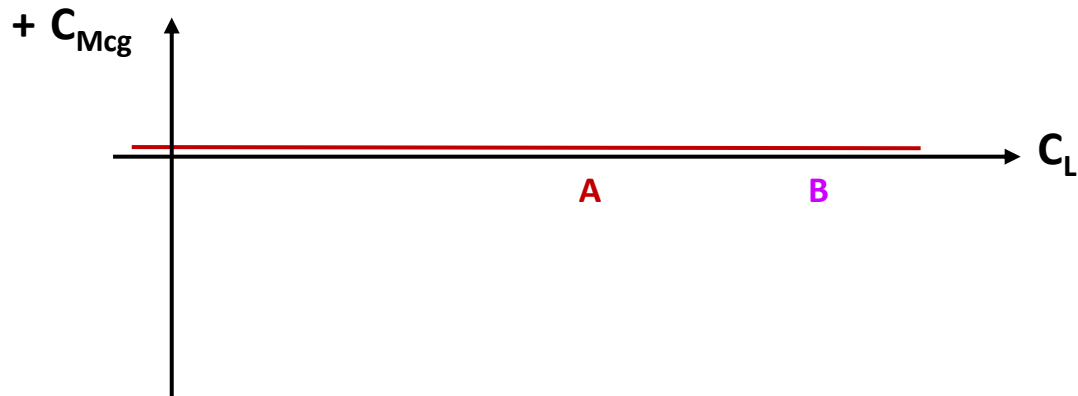
$$\frac{dC_{Mcg}}{dC_L} < 0$$

**ESTABLE**



$$\frac{dC_{Mcg}}{dC_L} > 0$$

**INESTABLE**



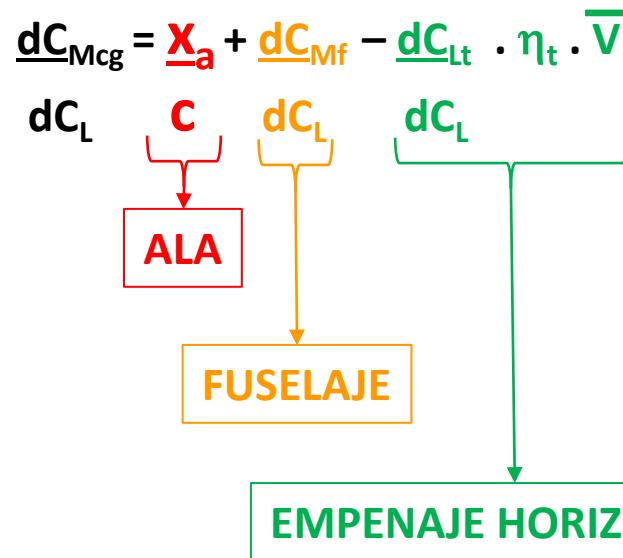
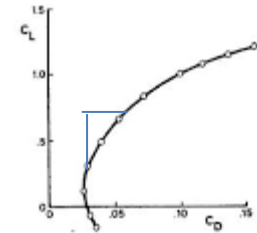
$$\frac{dC_{Mcg}}{dC_L} = 0$$

**NEUTRO**

# ESTABILIDAD ESTÁTICA LONGITUDINAL

$$C_{Mcg} = C_{Mac} + C_L \cdot \frac{x_a}{c} + C_D \cdot \frac{z}{c} + C_{Mf} - C_{Lt} \cdot \eta_t \cdot \bar{V} = 0$$

$$\frac{dC_{Mcg}}{dC_L} = \frac{dC_{Mac}}{dC_L} + \frac{dC_L}{dC_L} \cdot \frac{x_a}{c} + \frac{dC_D}{dC_L} \cdot \frac{z}{c} + \frac{dC_{Mf}}{dC_L} - \frac{dC_{Lt}}{dC_L} \cdot \eta_t \cdot \bar{V}$$

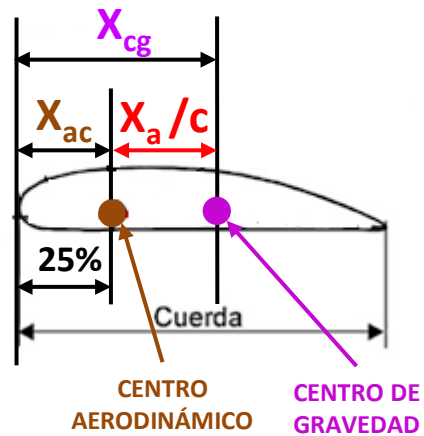




## CONTRIBUCIÓN DEL ALA

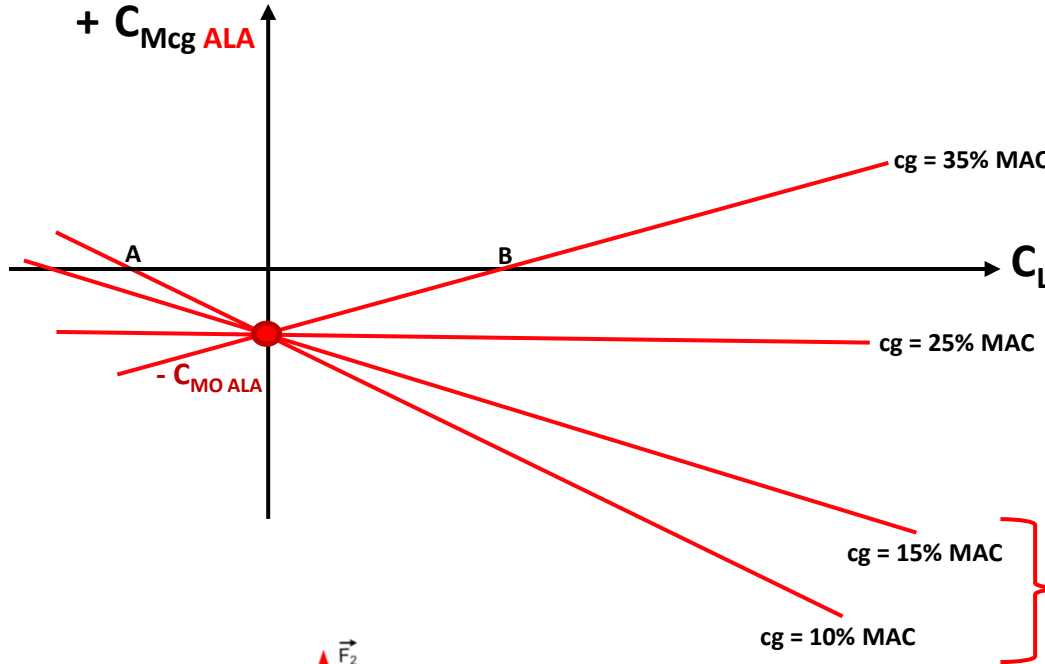
$$\left[ \frac{dC_{M_{cg}}}{dC_L} \right]_{\text{ALA}} = \frac{X_a}{c} = X_{cg} - X_{ac}$$

**> 0 INESTABLE**  
**< 0 ESTABLE**  
**= 0 NEUTRO**



# CONTRIBUCIÓN DEL ALA

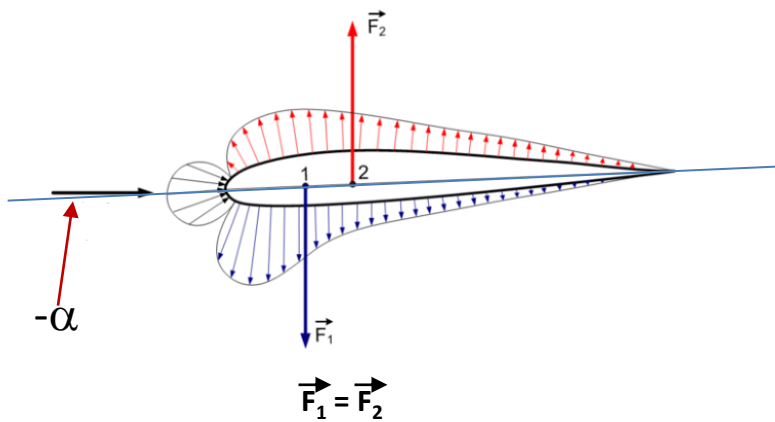
$$\left[ \frac{dC_{Mcg}}{dC_L} \right]_{ALA} = \frac{X_a}{c} = X_{cg} - X_{ac}$$



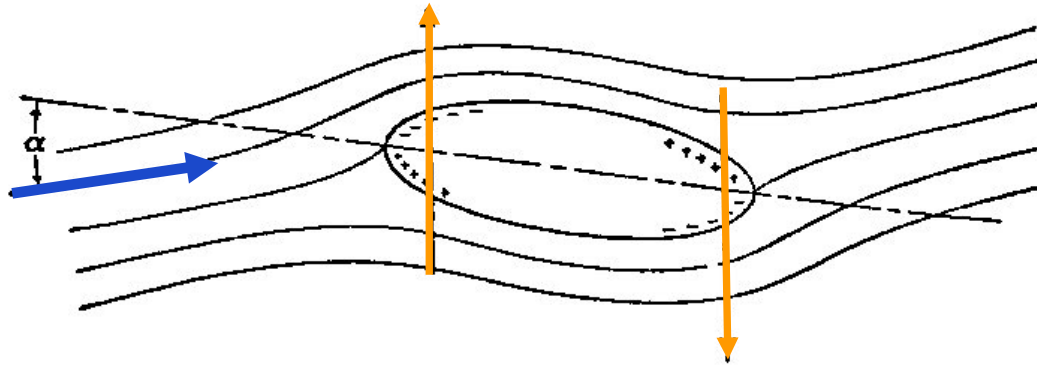
$$\frac{dC_{Mcg}}{dC_L} = X_{cg} - X_{ac} > 0 \text{ INESTABLE}$$

$$\frac{dC_{Mcg}}{dC_L} = X_{cg} - X_{ac} = 0 \text{ NEUTRO}$$

$$\frac{dC_{Mcg}}{dC_L} = X_{cg} - X_{ac} < 0 \text{ ESTABLE}$$

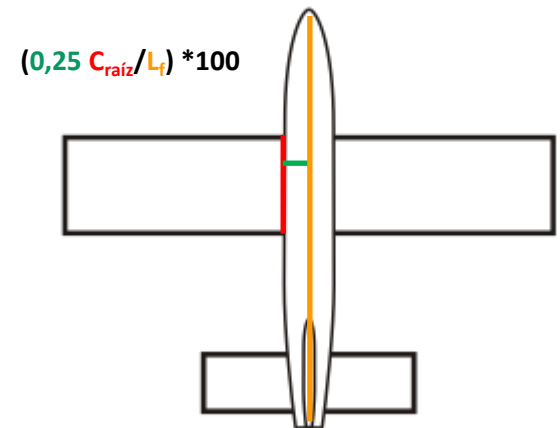
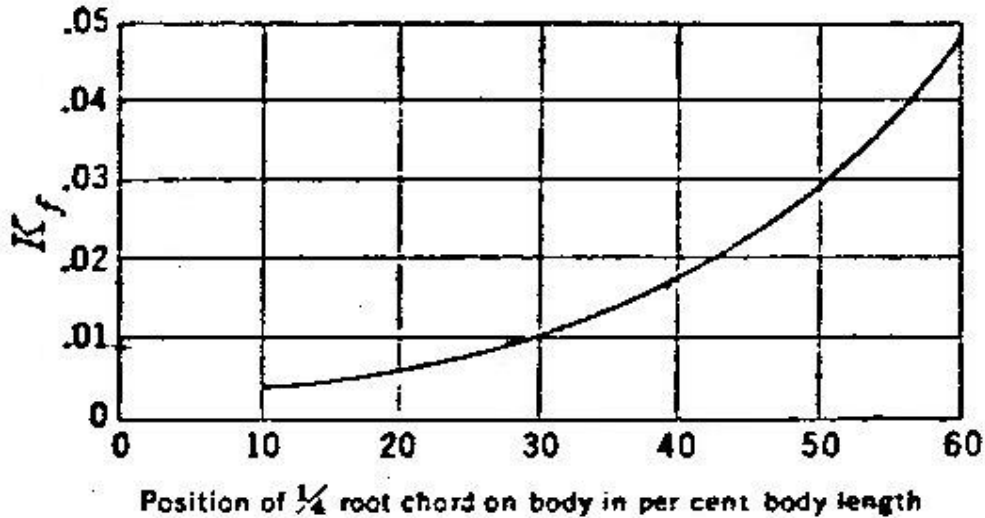


# CONTRIBUCIÓN DEL FUSELAJE

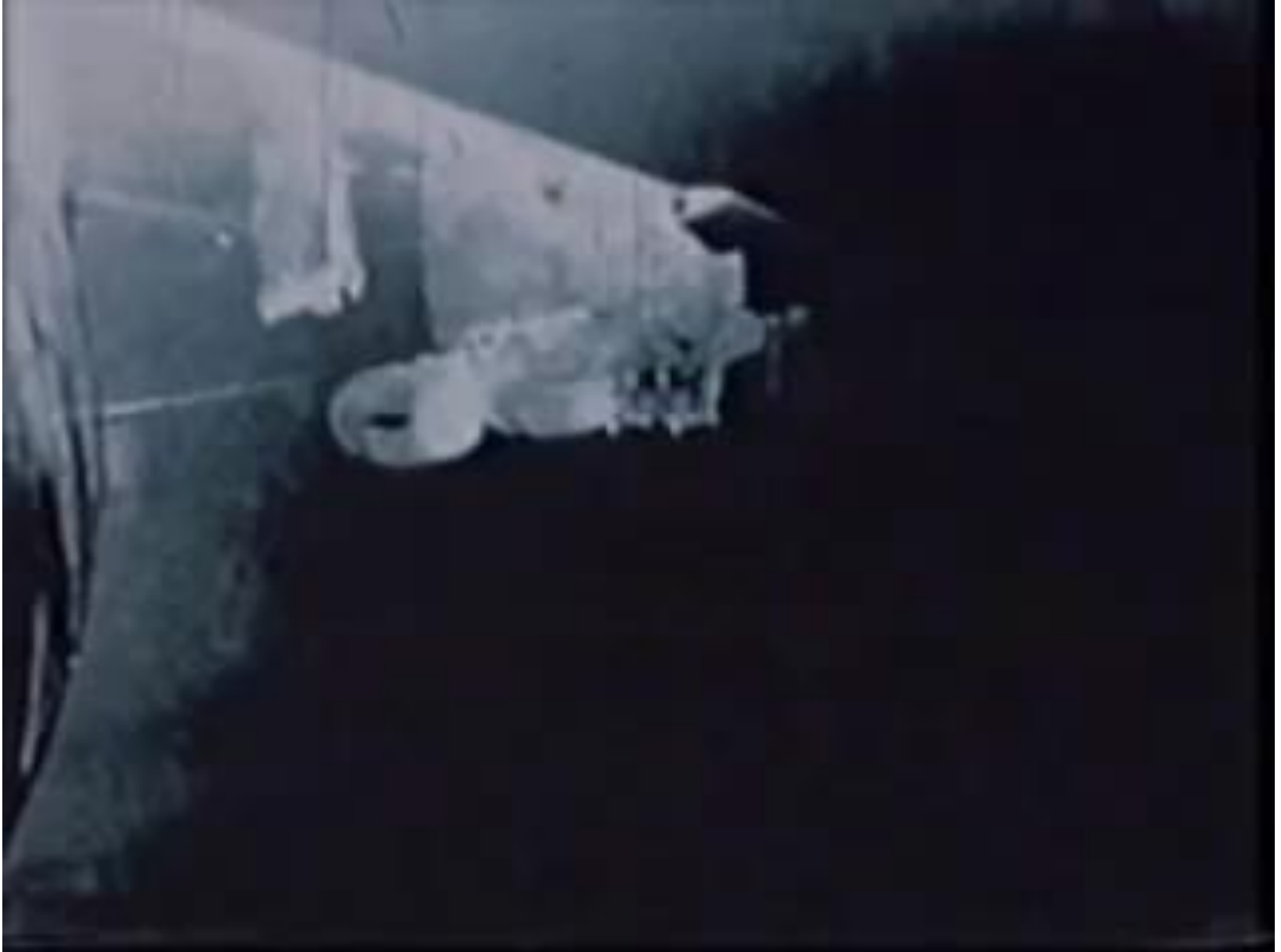


$$\left[ \frac{dC_{Mcg}}{dC_L} \right]_{FUS} = \frac{K_f \cdot w_f^2 \cdot L_f}{S_w \cdot c \cdot a_w}$$

> 0 INESTABLE

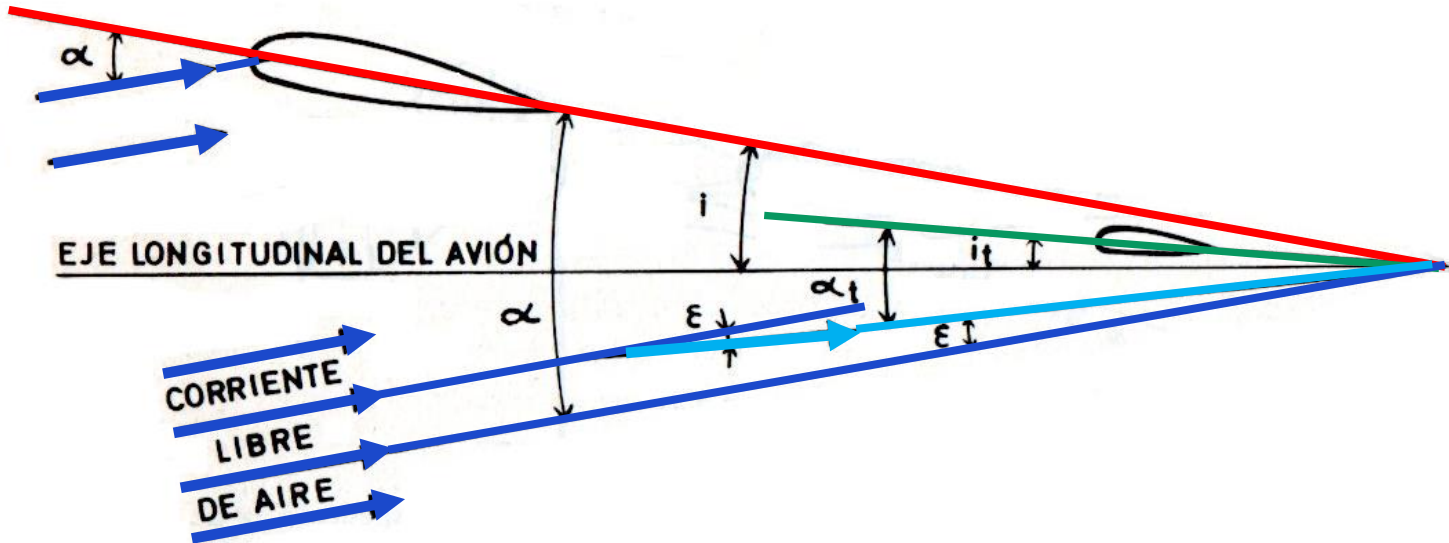


## CONTRIBUCIÓN DEL FUSELAJE



## CONTRIBUCIÓN DEL EMPENAJE HORIZONTAL

$$\left[ \begin{array}{c} \frac{dC_{Mcg}}{dC_L} \end{array} \right]_{EH} = - \frac{dC_{Lt}}{dC_L} \cdot \eta_t \cdot \bar{V}$$



$$\alpha_t = \alpha - i + i_t - \epsilon$$

## ESTABILIDAD ESTÁTICA LONGITUDINAL



## ESTABILIDAD ESTÁTICA LONGITUDINAL



## CONTRIBUCIÓN DEL EMPENAJE HORIZONTAL

$$\left[ \frac{dC_{Mcg}}{dC_L} \right]_{EH} = - \frac{dC_{Lt}}{dC_L} \cdot \eta_t \cdot \bar{V}$$

$$\alpha_t = \alpha - i + i_t - \varepsilon$$

$$C_{Lt} = a_t \cdot \alpha_t = a_t \cdot (\alpha - i + i_t - \varepsilon)$$

$$\frac{dC_{Lt}}{dC_L} = a_t \cdot \left[ \frac{d\alpha}{dC_L} - \frac{d\varepsilon}{dC_L} \right]$$

$$\frac{dC_{Lt}}{dC_L} = \frac{a_t}{a} \cdot \left[ 1 - \frac{d\varepsilon}{d\alpha} \right]$$

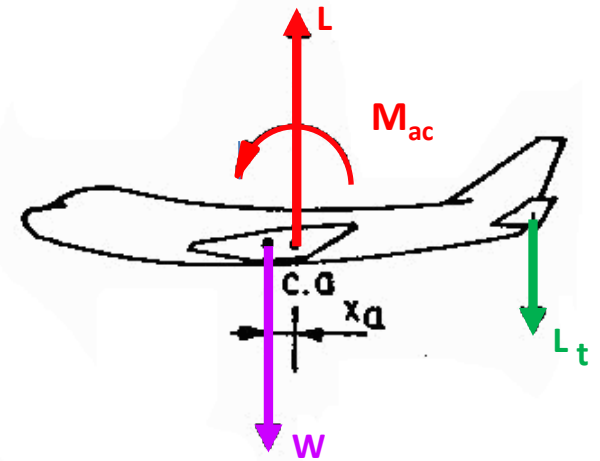
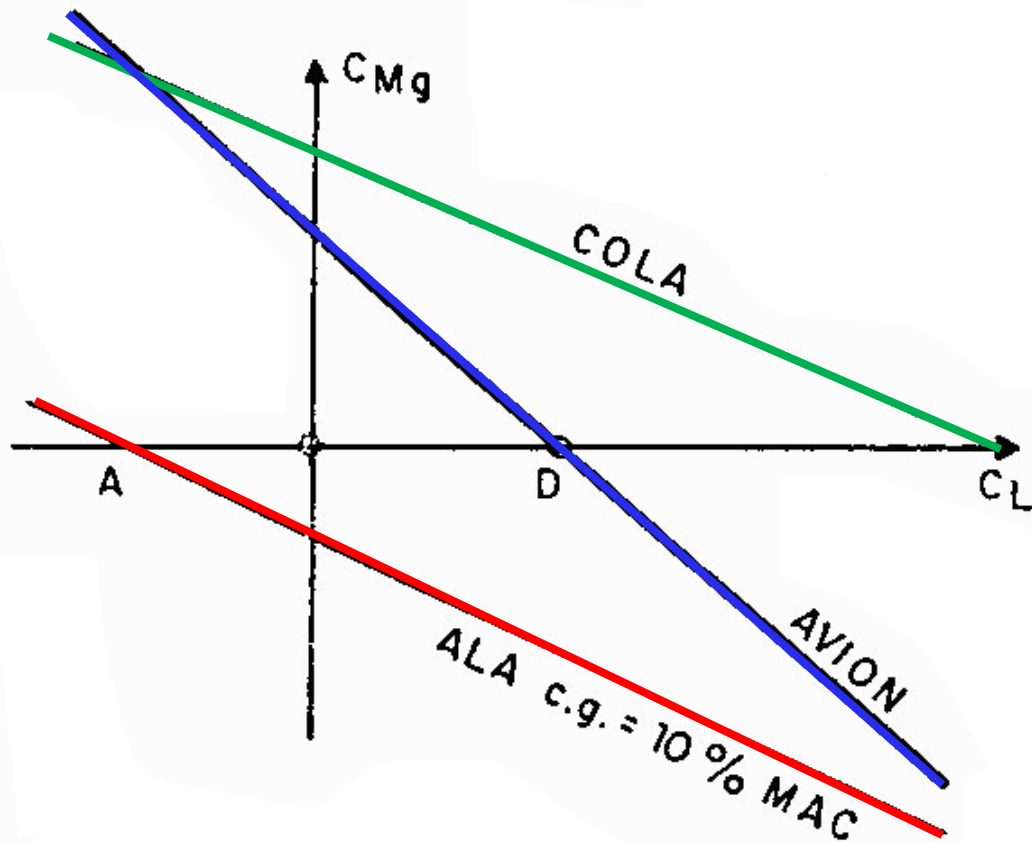
$$dC_L = a \cdot d\alpha$$

$$d\alpha = \frac{dC_L}{a}$$

$$\left[ \frac{dC_{Mcg}}{dC_L} \right]_{EH} = - \frac{a_t}{a} \cdot \left[ 1 - \frac{d\varepsilon}{d\alpha} \right] \cdot \eta_t \cdot \bar{V}$$

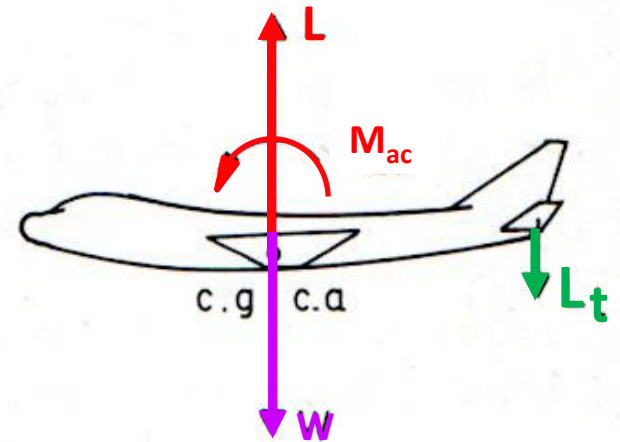
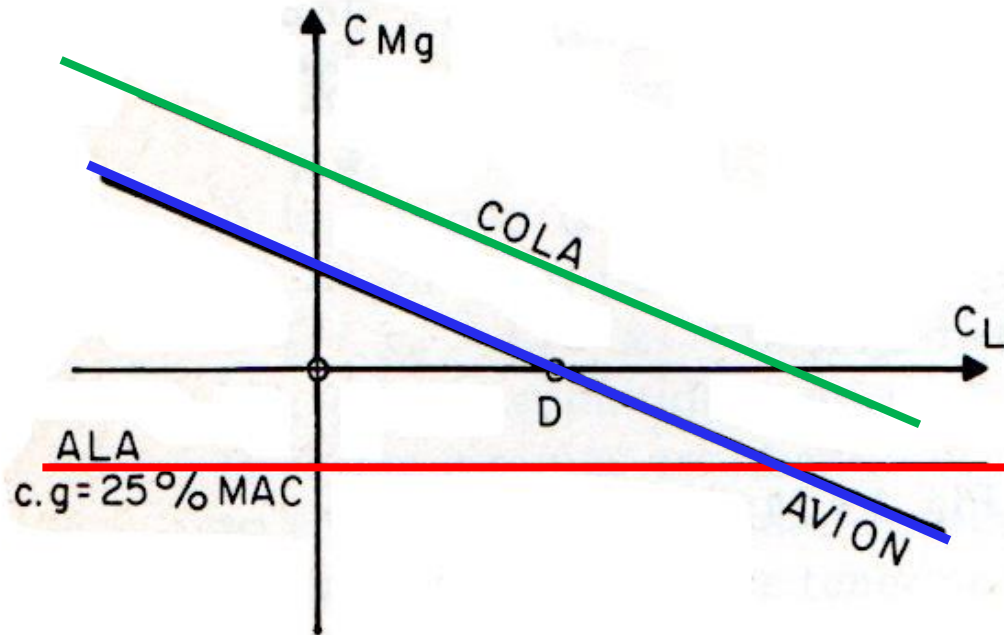


# ESTABILIDAD ESTÁTICA DEL AVIÓN



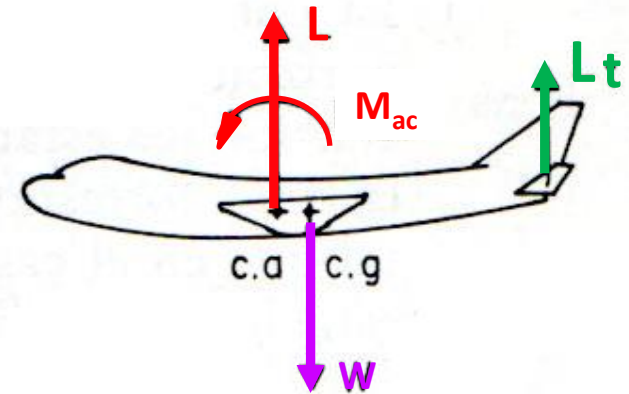
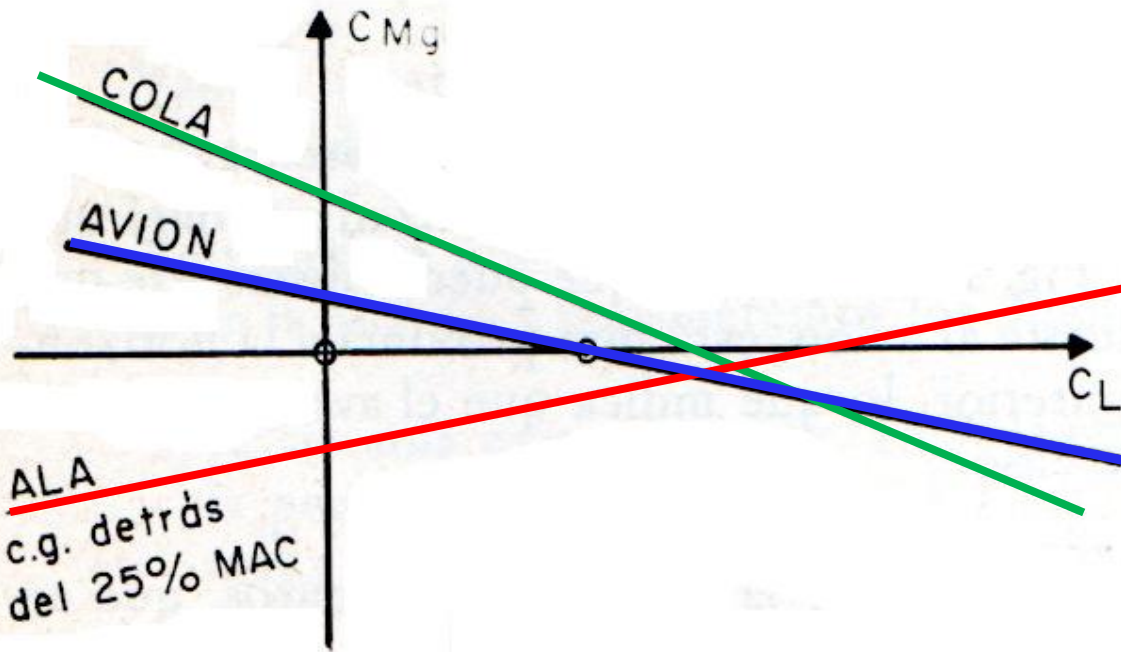
$$\Sigma M_{cg} = -M_{ac} - L \cdot x_a + L_t \cdot x_t = 0$$

# ESTABILIDAD ESTÁTICA DEL AVIÓN



$$\Sigma M_{cg} = -M_{ac} - L x_a + L_t \cdot x_t = 0$$

# ESTABILIDAD ESTÁTICA DEL AVIÓN



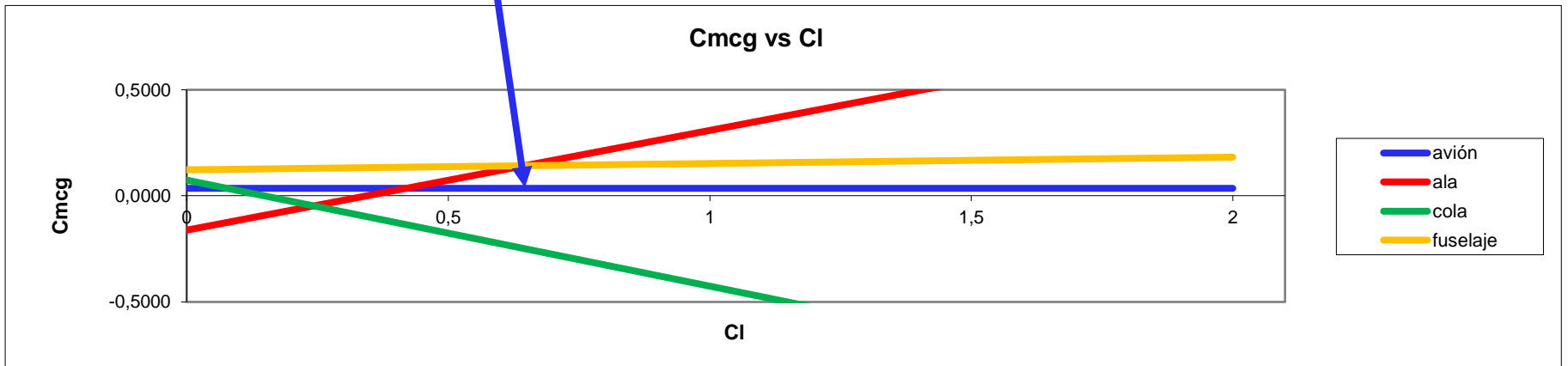
$$\Sigma M_{cg} = -M_{ac} + L \cdot x_a - L_t \cdot x_t = 0$$

# PUNTO NEUTRO CON MANDOS FIJOS

$$\frac{dC_{Mcg}}{dC_L} = \underbrace{X_a + \frac{dC_{Mf}}{dC_L}}_c - \frac{dC_{Lt}}{dC_L} \cdot \eta_t \cdot \bar{V}$$

$$\frac{dC_{Mcg}}{dC_L} = X_{cg} - X_{ac} + \frac{dC_{Mf}}{dC_L} - \frac{dC_{Lt}}{dC_L} \cdot \eta_t \cdot \bar{V}$$

$$0 = N_o - X_{ac} + \frac{dC_{Mf}}{dC_L} - \frac{dC_{Lt}}{dC_L} \cdot \eta_t \cdot \bar{V}$$



$$\frac{dC_{Mcg}}{dC_L} = X_{cg} - N_o$$

AVIÓN

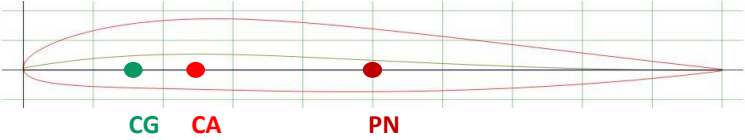
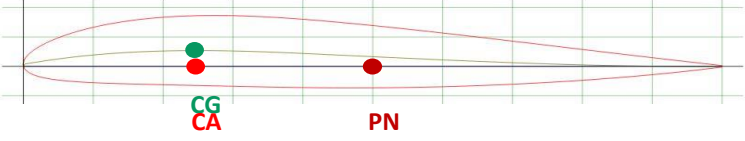
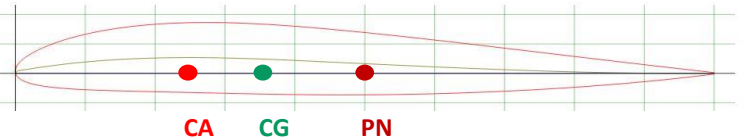
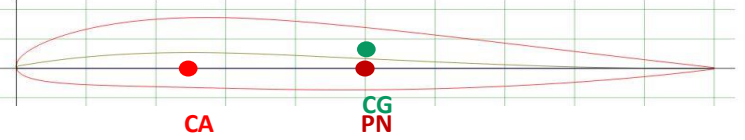
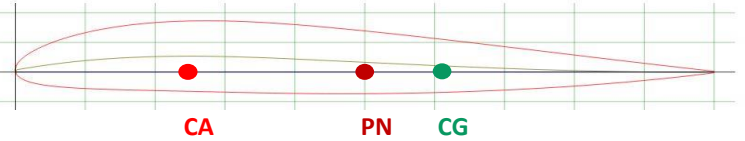
< 0 ESTABLE

= 0 NEUTRO

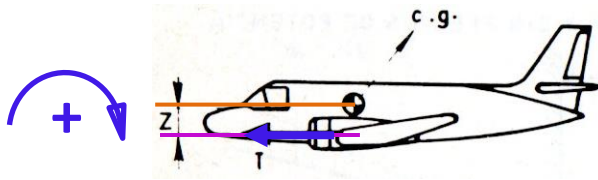
> 0 INESTABLE

# CONTRIBUCIÓN DEL ALA Y ESTABILIDAD DEL AVIÓN

## CONTRIBUCIÓN DE ALA ESTABILIDAD AVIÓN

	<b>ESTABLE O POSITIVA</b>	<b>ESTABLE O POSITIVA</b>
	<b>INDIFERENTE O NEUTRA</b>	<b>ESTABLE O POSITIVA</b>
	<b>INESTABLE O NEGATIVA</b>	<b>ESTABLE O POSITIVA</b>
	<b>INESTABLE O NEGATIVA</b>	<b>INDIFERENTE O NEUTRA</b>
	<b>INESTABLE O NEGATIVA</b>	<b>INESTABLE O NEGATIVA</b>

# CONTRIBUCIÓN DE LA TRACCIÓN / EMPUJE

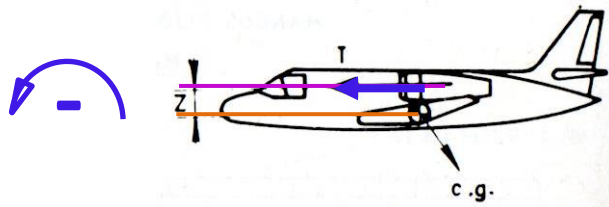


$$T \cdot Z = C_{Mcg} \cdot q \cdot S \cdot C$$

$$C_{Mcg} = \frac{T \cdot Z}{q \cdot S \cdot c} \quad W = q \cdot S \cdot C_L$$

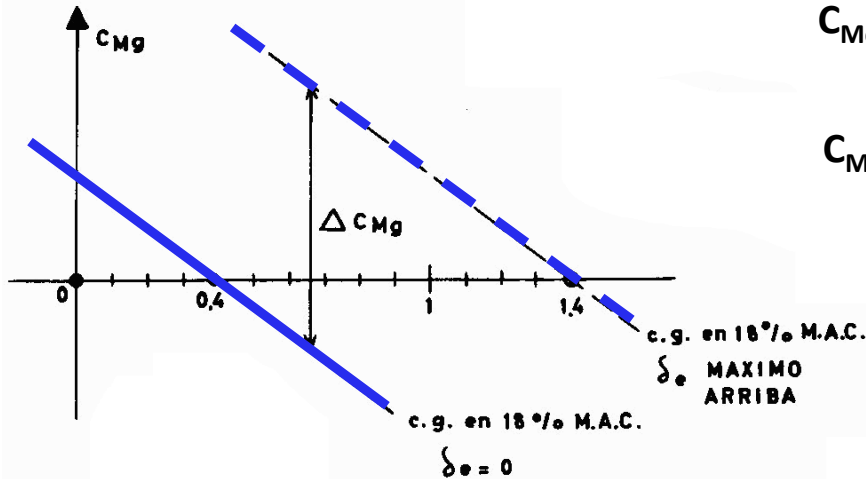
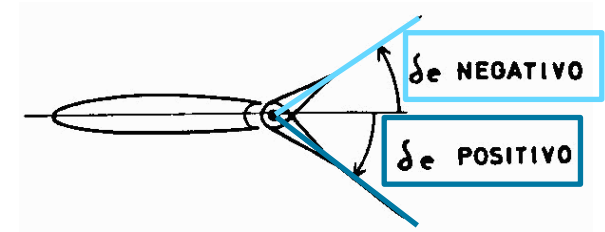
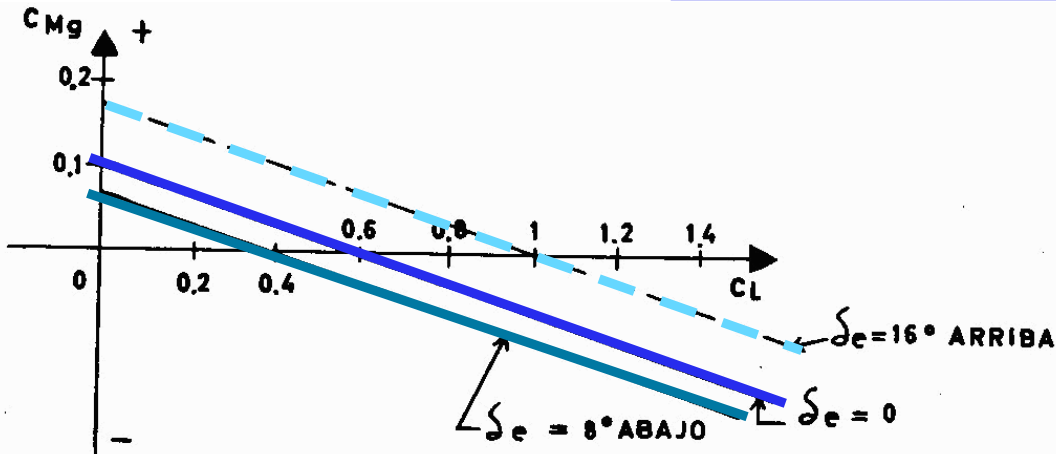
$$C_{Mcg} = \frac{T \cdot Z \cdot C_L}{W \cdot c}$$

$$\left[ \frac{dC_{Mcg}}{dC_L} \right]_T = \frac{T \cdot Z}{W \cdot C} > 0 \text{ INESTABLE}$$



$$\left[ \frac{dC_{Mcg}}{dC_L} \right]_T = - \frac{T \cdot Z}{W \cdot C} < 0 \text{ ESTABLE}$$

# CONTROL LONGITUDINAL



$$C_{Mcg} = C_{Mac} + C_L \cdot \frac{x_a}{c} + C_{Mf} - C_{Lt} \cdot \eta_t \cdot \bar{V} = 0$$

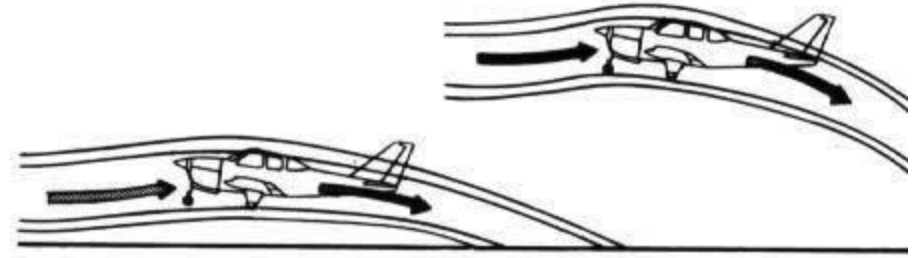
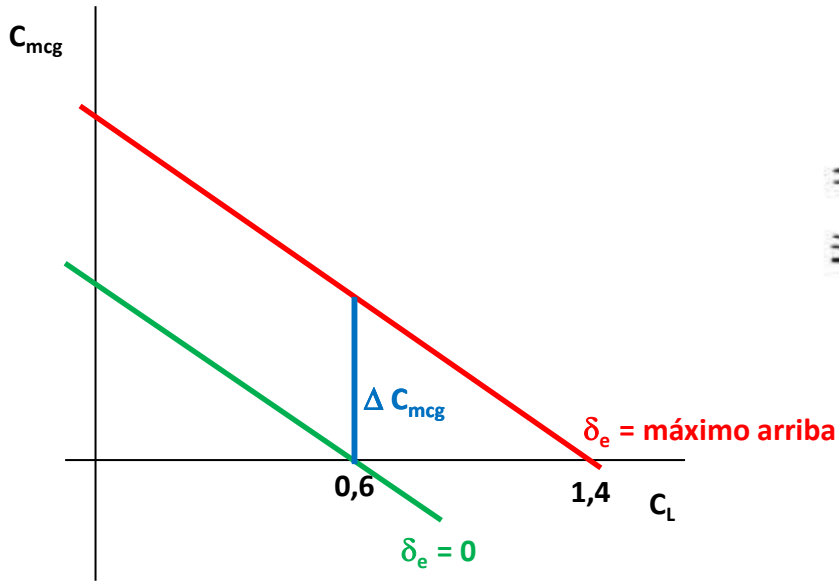
$$C_{Mcg} = C_{Mac} + C_L \cdot \frac{x_a}{c} + C_{Mf} - a_t \cdot (\alpha - i + i_t - \varepsilon + \tau \cdot \delta_e) \cdot \eta_t \cdot \bar{V}$$

$$\tau = \frac{d \alpha_t}{d \delta_e} = \text{EFECTIVIDAD DEL TIMÓN}$$

Límites posición delantera C.G.:

- 1) La deflexión total disponible del timón de profundidad.
- 2) La capacidad de aterrizar con efecto suelo.
- 3) La capacidad de maniobra en la configuración de aterrizaje.

# CONTROL LONGITUDINAL



$\varepsilon_{\text{Suelo}} < \varepsilon_{\text{Vuelo}}$   
 $a_{\text{Suelo}} > a_{\text{Vuelo}}$   
 $a_t \text{ Suelo} > a_t \text{ Vuelo}$

$$\left[ \frac{dC_{M_{cg}}}{dC_L} \right]_{EH} = - \frac{a_t}{a} \cdot \left[ 1 - \frac{d\varepsilon}{d\alpha} \right] \cdot \eta_t \cdot \bar{V}$$

$$\left[ \frac{dC_{M_{cg}}}{dC_L} \right]_{EH \text{ Suelo}} > \left[ \frac{dC_{M_{cg}}}{dC_L} \right]_{EH \text{ Vuelo}}$$

