ASD2 DBT Wing Refined Checks - Calcs Illustration

Note Title — JRF 10.11.2014 — 22/10/2012

0 — 10.11.2014

These notes are complimentary to and continuous from the Wing Initial Checks

CONTENTS:

- PART MODELS
- SECTION MODELS
  - $0 \leq x = 250$ } Areas
  - $250 \leq x \leq 1500$ } Stresses
- STIFFNESS CHECKS
  - Tip Deflection
  - Tip Rotation
- STRENGTH CHECKS
- STABILITY CHECKS

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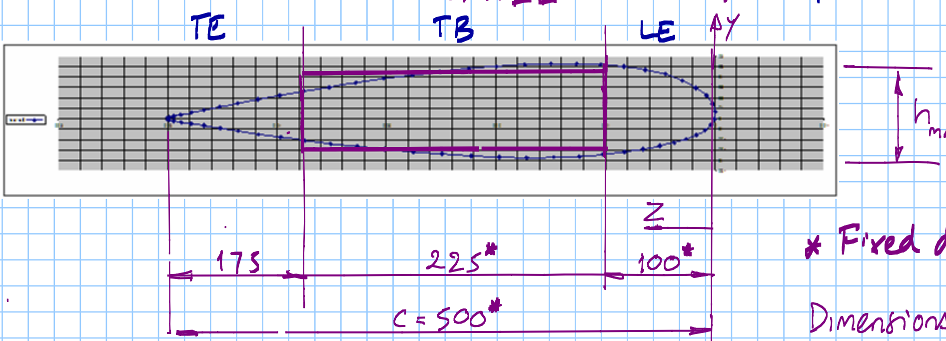
TRIAL AEROFOIL SCHEME

Naca xxx## → ##% h/c



$h_{MAX} = \# \times 500 = \#$ mm

* Fixed dimensions

Dimensions: mm

$h_{max} = \#$ mm for 500 mm chord

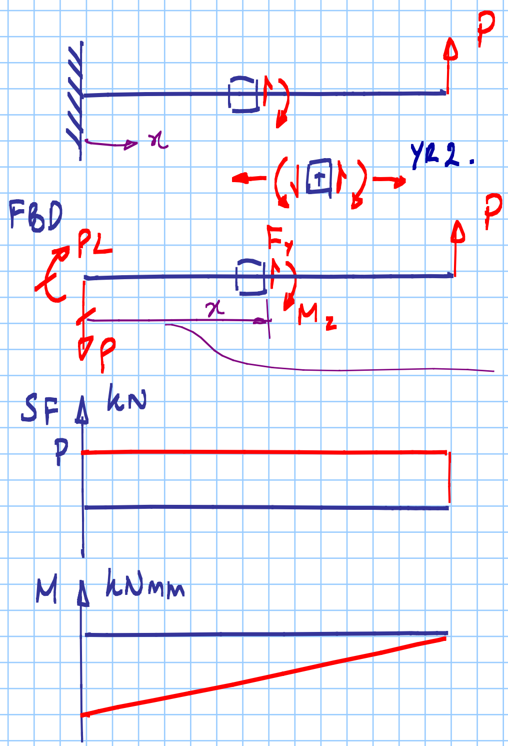
Naca co-ords → h, ave height over TB ie over 100–325 mm chord

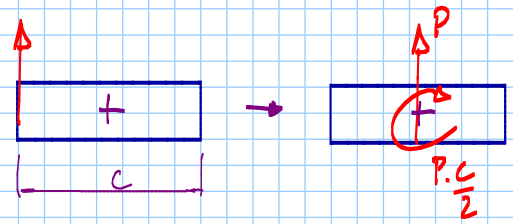
$$h = \sqrt{\Sigma h_i^2 / n} = \# \text{ mm}$$

12.4.2013
JRP ②

PART MODEL Cantilever beam with offset tip load

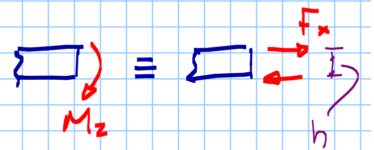
Internal Loads and Moments:





$P_{ULT} = \# \times 1.5 = \#\ kN$

Note couple approximation



LHS FBD: 0 to x $\qquad M_z = F_x . h$

$\Sigma \uparrow = 0$: $\rightarrow F_y = \#$ N constant

$\Sigma \circlearrowright_x = 0$: $\rightarrow M = \#$

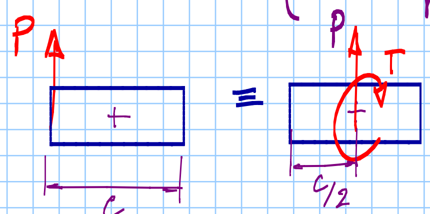
@ $x = 0$, $M_z = \#$ $\rightarrow F_x = \#$

@ $x = 250$, $M_z = \#$ $\rightarrow F_x = \#$

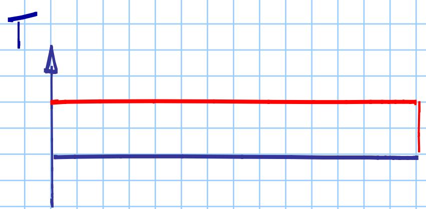
③
10.11.2014

Transverse shear + torsion

(due to offset of load from box shear centre)

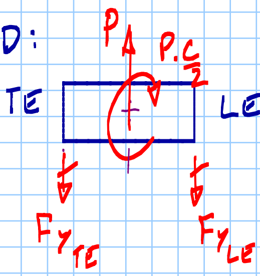


$T = \frac{P.c}{2}$ Assuming SC @ ℄.



- At the root, $x=0$, we must consider the joint arrangement and equilib'm to assess the loads. Considering the upr and lwr LE joints as a single reaction

FBD:



I.e. ignoring the moment reaction generated between the LE upr and lwr joints

$$\Sigma \overset{+}{\circlearrowleft} LE = 0: \quad F_{Y_{TE}} \cdot c - P\frac{c}{2} - P\frac{c}{2} = 0 \rightarrow \underline{F_{Y_{TE}} = P}$$

$$\Sigma \overset{+}{\circlearrowleft} TE = 0: \quad P.\frac{c}{2} - P\frac{c}{2} - F_{Y_{LE}} \cdot c = 0 \rightarrow \underline{F_{Y_{LE}} = 0}$$

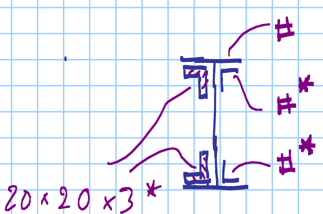
So, at the root ($x=0$): TE carries all shear and LE carries only bending

- at $x \geq 250$ we can reasonably assume that all the box section skins are are reacting shear and torsion so that shear flows due to transverse shear load and torsion can be calculated accounting for the appropriate active skins and added separately by superposition.

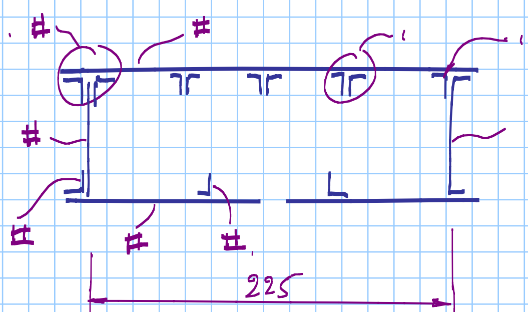
SECTION MODEL and Trial Scheme

Assumed effective torque box section:

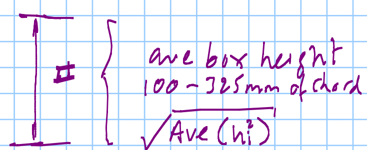
@ X=0



@ X=250



Light angles 12×12mm



* Note, final design
↳ pairs of 3mm angles for LE root joint

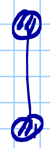
TB Rib pitch $L_R =$ # mm

Spar web stiffener pitch $a =$ # mm

Idealised section @ $0 < x \leq 250$

Assuming all bending load must be transferred through an effective I-section at the root due to the wing root fixing configuration.

Simplifying to boom + web areas:



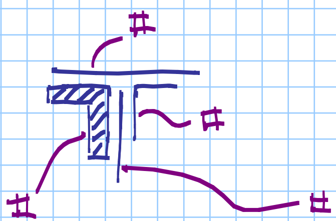
Neglecting non symmetry about fwd TB spar line. etc.

Note use of 20×20×3 mm angle in fwd TB spar in root region to provide reinforcement for offloading to this region and transfer at the root joint.

Effective areas @ $x = 0$

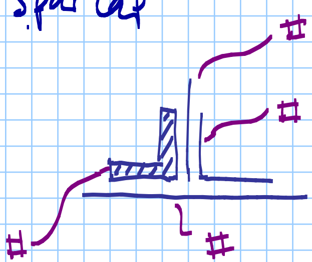
Equivalent boom areas @ box outer skin line

- Upr fwd TB spar cap



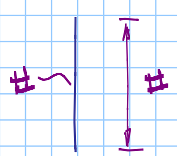
$A_{SPR_{U_{LE}}} = \#$ mm^2

- Lwr fwd TB spar cap

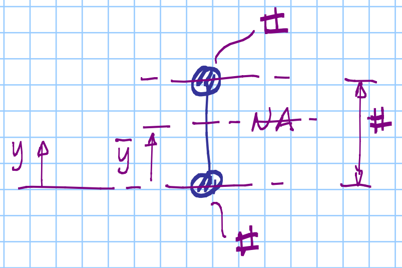


$A_{SPR_L} = \#$ mm^2

- Fwd TB spar web



$A_w = \#$ mm^2



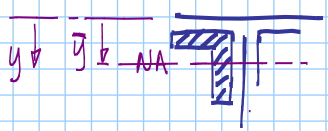
$\bar{y}$ = # mm

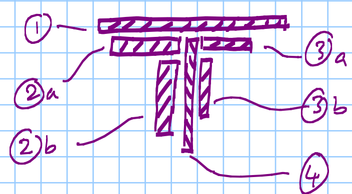
Note ~ symm top & btm

↳ I_{NA_z} = # mm^4

Areas ctd.:

Also calc 'I' for upr spr boom for use in column buckling check: = I_{NA} = I_{NA_z}





(Note, no "0.95" offset reduction since <u>not</u> converting to outer box point area).

	A	y_i	$A_i y_i$	$bd^3/12$	y_i^2	$A_* y_i^2$
1						
2a						
2b						
3a						
3b						
4						
Σ	#		#	#		#

ie: defining convenient areas

$\bar{y}$ = # mm

I_{zz} = # mm^4

I_{NA_z} = # mm^4

Stresses @ $x = 0$

- Direct stress: LE spar "beam"

Upr booms: $\sigma_x = \frac{F_x}{\Sigma A_u} = \frac{\#}{\#} = \#$ N/mm²

Lwr booms: $\sigma_x = \frac{F_x}{\Sigma A_L} = \frac{\#}{\#} = \#$ N/mm²

Check

Upr: $\sigma_x = \frac{M_z Y}{I} = \#$

$I = I_{NA_z}$

Lwr: $\sigma_x = \frac{M_z Y}{I} = \#$

Agrees according to use of point + line area approximation

- Shear Stress: TE spar web / lwr cover skin.

At the root, according to the joint configuration and the internal forces and moments previously estimated we can assume that all the transverse shear load is carried by the rear spar.

Shear flow: $q = \frac{F_Y}{h_{TE}}$, assuming torque is reacted around the box section simply add by superposition, ie. $+ \frac{T}{2A.t}$

where h_{TE} refers to TE web height only

ie $$q = \frac{F_Y}{h_{TE}} + \frac{T}{2A}$$

$$\hookrightarrow \quad = \frac{\#}{\#} + \frac{\#}{2 \times \#} = \# \text{ N/mm}$$

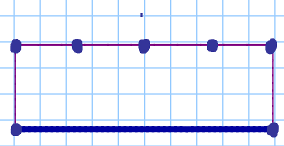
Lower depth @ rear spar!

Shear stresses: $\tau = \frac{q}{t} = \frac{\#}{\#} = \#$ N/mm² (web) $= \frac{\#}{\#} = \#$ N/mm² (lwr skin)

Idealised section @ $x \geq 250$ mm

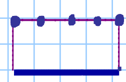
Assuming full section active according to boom + line areas:

Simplifying to boom, smeared line and web skin areas:

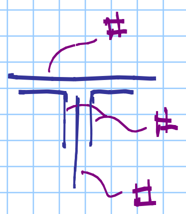


Effective areas: @ $x \geq 250$

Equivalent boom/line areas @ box outer skin line

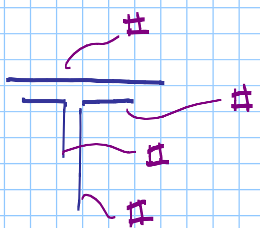


- Upr fwd TB spar cap



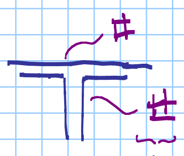
$A_{SPR_{U_{LE}}} = \#$ mm^2

- Upr aft TB spar cap.



$A_{SPR_{U_{TE}}} = \#$ mm^2

- Upr str boom*



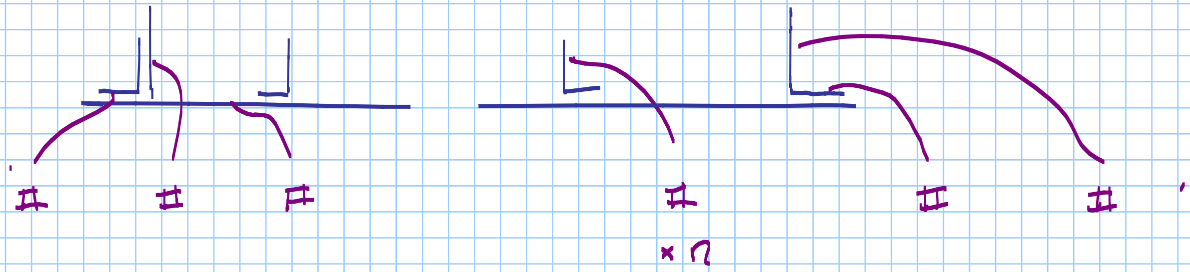
Allowance for offset from box outer skin line.

$A_{STR_U} = \#$ mm^2 $\times n$

↳ $\sum A_{UPR} = \#$ mm^2

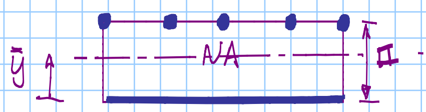
- Lwr Smeared area:

(14)



↳ $\Sigma A_{LWR} = \underline{\underline{\#}}\ mm^2$

- Box N/A ie $\bar{y}$

For 

$\Sigma A_U = \#$

$\Sigma A_L = \#$

$\} \ \bar{y} = \# \ mm$

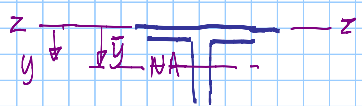
↳ $I_{NA_Z} = \# \ mm^4$

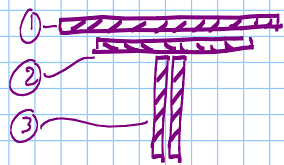
Areas ctd.:

(15)

*Also calc I for upr str boom for use in column buckling check:

ie: defining convenient areas





(Note, no "0.95" offset reduction since <u>not</u> converting to outer box point areas)

	A	y_i	$A_i y_i$	$bd^3/12$	y_i^2	$A_x y_i^2$
①						
②						
③						
Σ	#		#	#		#

↖ Full area (ie no offset allowance)

$\bar{y} = \# \ mm$

$I_{zz} = \# \ mm^4$

$I_{NA_z} = I_{zz} - A\bar{y}^2 = \# \ mm^4$

Stresses @ $x \geq 250$

- Direct stress

Upr booms: $\sigma_x = \dfrac{F_x}{\Sigma A_u} = \dfrac{\#}{\#} = \#$ N/mm^2

Lwr cover: $\sigma_x = \dfrac{F_x}{\Sigma A_L} = \dfrac{\#}{\#} = \#$ N/mm^2

check

Upr $\sigma_x = \dfrac{M_z Y}{I} = \#$

Lwr: $\sigma_x = \dfrac{M_z Y}{I} = \#$

Agrees since use of point and line approximation.

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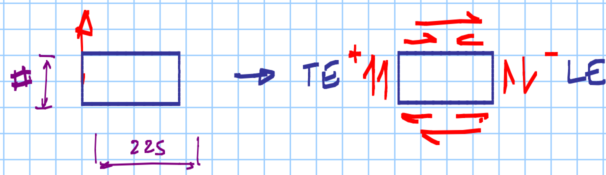
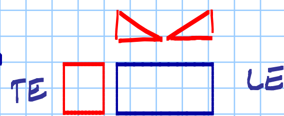
- Shear stress:



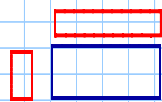
Start with shear flow in spar web

- Due to trans shear load $\quad q_{F_y} = \dfrac{F_y}{2 \times b_w} = \dfrac{\#}{2 \times \#} = \#$ N/mm

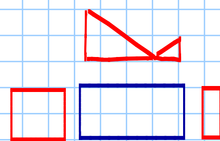


Then shear flow in box

- Due to torsion $\quad q_T = \dfrac{T}{2A} = \dfrac{\#}{2 \times \#} = \#$ N/mm



- Adding @ TE spar web, TE upr/lwr skin $\quad q_{TE} = q_{F_y} + q_T = \# + \# = \#$ N/mm

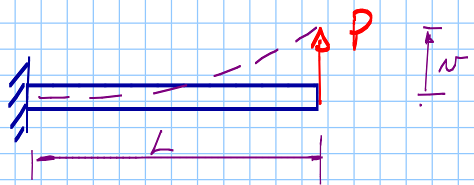


↳ Shear stresses: $\tau_{TE} = \dfrac{q}{t} = \dfrac{\#}{\#} = \#$ N/mm^2 (web t) $\Big\}$ $= \dfrac{\#}{\#} = \#$ N/mm^2 (lwr skin t)

- Subtracting @ LE web, LE upr/lwr skin $\quad q_{LE} = q_{F_y} - q_T = \# - \# = \#$ N/mm

↳ Shear stresses: $\tau_{LE} = \dfrac{q}{t} = \dfrac{\#}{\#} = \#$ N/mm^2 (web) $\Big\}$ $= \dfrac{\#}{\#} = \#$ N/mm^2 (lwr skin)

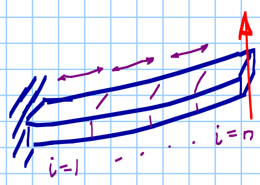
STIFFNESS CHECKS



- **Tip Deflection**

Account for Non-prismatic beam section

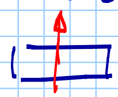
i.e. significant changes in the effective beam section such as changes in skin and stiffener gauges represented as incremental cantilever model



Bending + Shear deflection. $v = v_b + v_s$

Skin + boom idealisations area approximations as for initial sizing

Assume symmetric loading



Neglect Fixed LE+TE contribution

See APM notes

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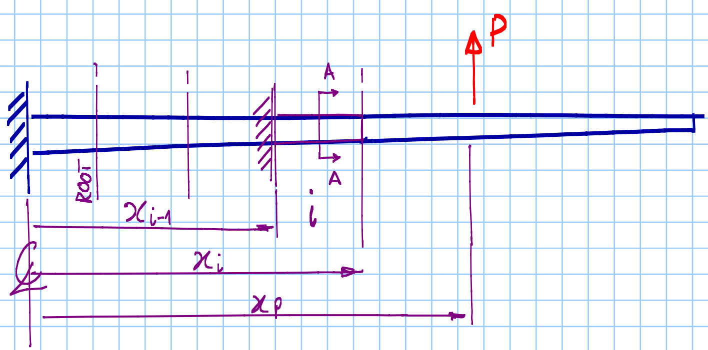
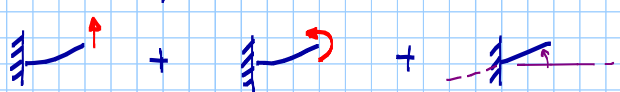
Eg. Superposition model for non prismatic cantilever beam

Consider beam as a system of connected cantilevers with end load and moment



Sum the tip deflections for each cantilever due to tip load, tip moment + tip rotation

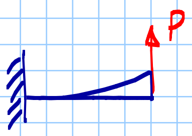


$$v = \sum_{i=1}^{n} \left(v_{P_i} + v_{m_i} + v_{\theta_i} \right)$$

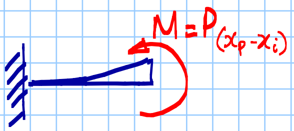
Cantilever deflections

element "i"

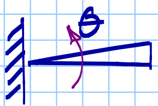
	Deflection	Rotation (rad)

Tip load : 

$$v_P = \frac{PL_i^3}{3EI_i}, \quad \theta_P = \frac{PL_i^2}{2EI_i}$$

Tip moment: 

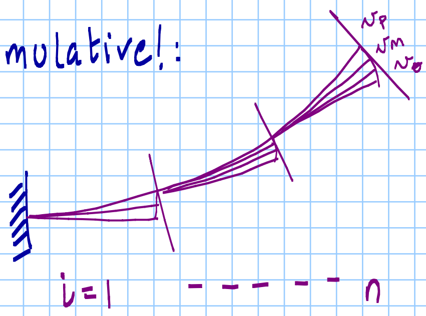
$$v_M = \frac{ML_i^2}{2EI_i}, \quad \theta_M = \frac{ML_i}{EI_i}$$

Tip rotation: 

$$v_\theta = \theta \cdot L_i, \quad \theta_i = \sum_{i=1}^{i-1} \theta_{P_i} + \theta_{M_i}$$

* cumulative from root to inboard element.

Cumulative!:



Shear deflection can also be added element by element by simple superposition.

$$v_s = k_s \frac{P_i L_i}{GA_{s_i}}$$

E.g. Considering two spanwise increments: $0 < x \le 250$, $250 < x \le 1500$

Using previous idealised sections:

$0 < x \le 250$:

$$v_P = \frac{1}{3}\frac{PL^3}{EI} = \frac{1}{3} \times \frac{\# \times \#^3}{\# \times \#} = \# \text{ mm}$$

↑6082-T6

$$\theta_P = \frac{1}{2}\frac{PL^2}{EI} = \frac{1}{2} \times \frac{\# \times \#^2}{\# \times \#} = \# \text{ rad}$$

$$v_M = \frac{1}{2}\frac{ML^2}{EI} = \frac{1}{2} \times \frac{\# \times \#^2}{\# \times \#} = \# \text{ mm}$$

$$\theta_M = \frac{ML}{EI} = \frac{\# \times \#}{\# \times \#} = \# \text{ rad}$$

$$\Sigma v = \# + \# = \# \text{ mm}$$

$$\Sigma \theta = \# + \# = \# \text{ rad}$$

$250 < x \le 1500$: $v_p = \frac{1}{3}\frac{PL^3}{EI} = \frac{1}{3} \times \frac{\# \times \#^3}{\# \times \#} = \#$ mm

↑ 2014a-T3

$v_\theta = \theta \cdot L = \# \times \# = \#$ mm

$\Sigma v = \# + \# + \# = \#$ mm

Shear deflection can also be added element by element by simple superposition.

$G = \frac{\#}{2(1+\#)} = \#$ N/mm²

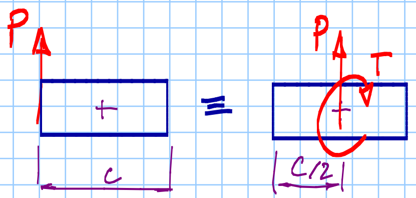
$$v_s = \Sigma K_s \frac{P_i L_i}{G A_{s_i}} = \frac{\# \times \# \times \#}{\# \times \# \times \#} + \frac{\# \times \# \times \#}{\# \times \# \times \#}$$

↖ $x < 250$ TE only ↖ $x > 250$ LE + TE

$= \# + \# = \underline{\underline{\#}}$ mm

↳ $\Sigma v = \# + \#$ mm $= \underline{\underline{\#}}$ mm

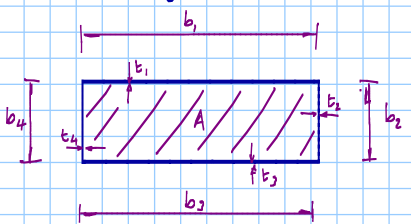
- **Tip Rotation** $\theta = \frac{TL}{GJ}$



$T = P \cdot \frac{c}{2}$

For J use enclosed section formed by the upper and lower skins and the webs approximated as effective rectangular box as for initial sizing.

where $J = \frac{4A^2}{\Sigma(b_i/t_i)}$



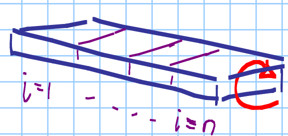
here: $b_1 = b_3 = c$, $b_2 = b_4 = h$

$$J = \frac{4 \times (70 \times 225)^2}{2 \times \frac{70}{0.6} + \frac{225}{0.4} + \frac{225}{0.6}} = 847 \times 10^3 \text{ mm}^4$$

Account for changes in skin gauges. Neglect open sections, eg. stiffeners.

Neglect the fixed LE+TE contribution. Neglect droop + flap.

Simply add the twist of each beam element. θ_i



$$\theta = \Sigma \theta_i = \sum_{i=1}^{n} \frac{T L_i}{G J_i} = \frac{\# \times \# \times \# \times \#}{\# \times \#} = \# \text{ rad} = \#^\circ$$

Check results against initial estimates!

STRENGTH CHECKS

- CHECK: lwr LE spar cap boom tension @ root, $x = 0$

$\sigma^{*}_{ULT} = \#$ c/w $\sigma_x = \#$: $\boxed{RF = \#}$

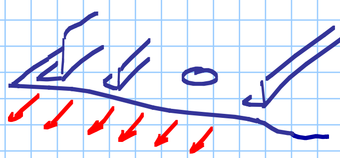
Bending only (no shear) @ LE root according to DBT joint config.

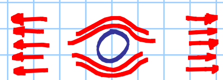
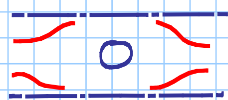
- CHECK: TE spar web @ root, $x = 0$

$\tau^{*} = \#$ N/mm^2 c/w $\tau = \#$ N/mm^2 : $\boxed{RF = \#}$

Shear only (no bending) @ TE root according to DBT joint config.

- CHECK: lwr surface tension material failure @ $x = 250$



At inspection hole :  

(Neglecting shear flow @ mid chord).

As an initial estimate we can consider the magnified stress due to a stress concentration factor $K_T = 3$ and an offload to adjacent stringers reducing the average stress calculated for the lower surface smeared area by a factor of 2. This is of course only a rough check but further refined checks here would typically involve FE modelling which is outside the scope.

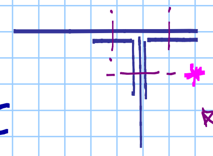
$$\hookrightarrow \quad \sigma = \frac{\sigma_x}{2} \times K_T = \frac{\#}{2} \times 3 = \# \quad N/mm^2$$

c/w: $\sigma^{*}_{ULT} = \#$ N/mm^2 $\longrightarrow$ $\boxed{RF = \#}$

(24)

- **CHECK** TE Spar – cover joint @ $x=0$ where TE carries all transverse shear

For ϕ # mm rivets.



@ root (requested) : q = # N/mm due to $F_y + T$ @ TE

Based on 'ave' web shear flow approximation

Note single rivet between web and spar cap flanges is most critical in illustration

Rivet pitch p = # mm : Force per rivet $P_r = p \cdot q$ = # × # = # N

But note double shear

- Check rivet shear : Rivet single shear strength = # kN

  ↳ $RF = \frac{\#}{\# / 2}$: $\boxed{RF = \#}$

- Check: Plate bearing : Allowable $\sigma_{br}^* = 1.5 \times \#$ = # N/mm²

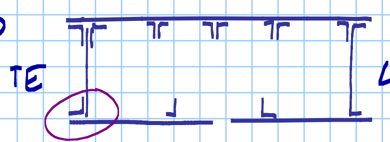
  Applied $\sigma = \frac{P}{dt} = \frac{\#}{\# \cdot \#}$ = # N/mm²

  ↳ $RF = \frac{\#}{\#}$: $\boxed{RF = \#}$

Referring to thinnest most critical element.

(25)

- **CHECK:** lwr TE cover/spar cap flange @ $x = 250$



Check combined stress material failure

Direct stress σ_x = # N/mm² – Average direct stress in btm surface

Shear flow: $q_{TE} = q_{F_y} + q_T$ = # N/mm – accounting for transverse + torsional shear @ TE

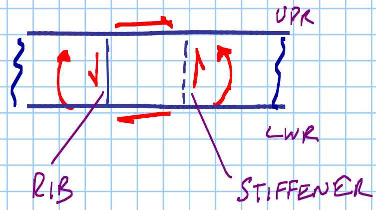
Shear stress $\tau = \frac{q}{t} = \frac{\#}{\#^*}$ = N/mm² – Peak shear stress at box corner based on thinnest element* (lwr skin)

Using EoD criteria:

$$\left(\frac{\sigma_x}{\sigma_0}\right)^2 + 3\left(\frac{\tau_{xy}}{\sigma_0}\right)^2 = FI \quad , \quad RF = \frac{1}{\sqrt{FI}}$$

$$\left(\frac{\#}{\#}\right)^2 + 3\left(\frac{\#}{\#}\right)^2 = \# \quad : \quad RF = \frac{1}{\sqrt{\#}} \quad : \quad \boxed{RF = \#}$$

- **CHECK:** LE Spar web @ $x = 250$ 26



Bending stress σ_x = # N/mm^2 – Higher on lwr web

Shear stress τ = # N/mm^2

Combined stress failure:

$$\left(\frac{\sigma_x}{\sigma_0}\right)^2 + 3\left(\frac{\tau_{xy}}{\sigma_0}\right)^2 = FI \quad , \quad RF = \frac{1}{\sqrt{FI}}$$

$$= \left(\frac{\#}{\#}\right)^2 + 3\left(\frac{\#}{\#}\right)^2 = \# \quad , \quad RF = \frac{1}{\sqrt{\#}} \quad : \quad \boxed{RF = \#}$$

27

STABILITY CHECKS

COLUMN BUCKLING

Using: $\frac{\sigma_{CR}^*}{2} = \frac{P_{CRIT}}{A} = \frac{k\pi^2 EI}{L^2} \Big/ A$

Where E = Youngs modulus
⇒ "Elastic buckling"

I = Boom 2nd mmt of area I_{NA_z}

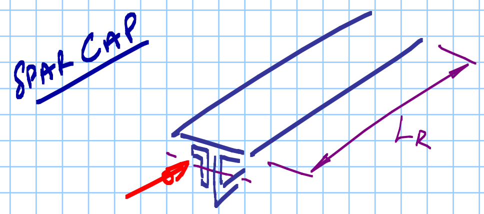
A = Boom area.

L = effective length of boom
e.g. pitch between ribs if cleated.

$k = 1$ assuming no mom't reaction at ends

Note $\frac{\sigma_{CR}^*}{2}$ represents the uncorrected elastic buckling strength

• <u>CHECK</u>: Upr Spar Cap boom column buckling @ root, $x=0$ (28)



$$\frac{\sigma_{CR}^*}{2} = \frac{P_{CRIT}}{A} = \frac{k\pi^2 EI}{L^2} \Big/ A$$

(continuous web ⇒ conservative)

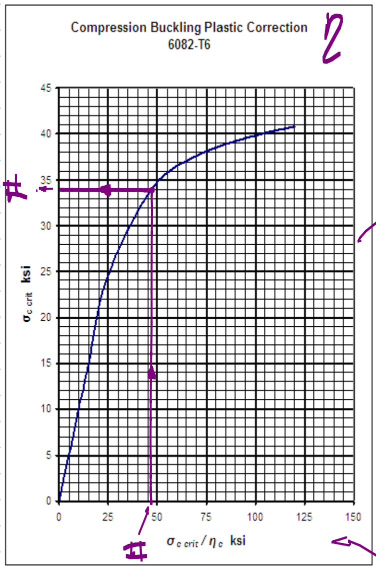
Dominated by 6082 T6 Ally angle so refer to 6082-T6 data:

$$\frac{\sigma_{CR}^*}{2} = \frac{\# \times \pi^2 \times \# \times \#}{\#^2} \Big/ \# = \# \ \text{N/mm}^2$$

$> \sigma_p^* = \#$? reject / correct, eg.:

$\# \ \text{N/mm}^2 \xrightarrow{\div 6.895} \# \ \text{ksi} \xrightarrow{2} \# \ \text{ksi} \xrightarrow{\times 6.895} \# \ \text{N/mm}^2$

Aero/Wb



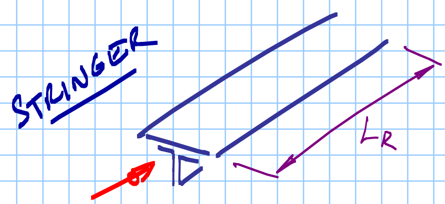
c/w $\sigma_x = \#$ N/mm²:

↳ $RF = \frac{\#}{\#}$: $\boxed{RF = \#}$

Note further charts in Niu + Bruhn refs: see extracts.

Note $\frac{\sigma_{CR}}{2}$ represents uncorrected elastic buckling strength

• <u>CHECK</u> UPR stringer boom column buckling @ $x = 250$ (29)



$$\frac{\sigma_{CR}^*}{2} = \frac{P_{CRIT}}{A} = \frac{k\pi^2 EI}{L^2} \Big/ A$$

$$\frac{\sigma_{CR}^*}{2} = \frac{\# \times \pi^2 \times \# \times \#}{\#^2} \Big/ \# = \# \ \text{N/mm}^2$$

$< \sigma_p^*$? accept / reject ...

c/w $\sigma_x = \#$ N/mm²: $\boxed{RF = \#}$

Cladding correction!

Niu extract.

(C) CLADDING EFFECT

Cladding will reduce the plate buckling stress (F_{cr}) of an aluminum clad material. A simple method for accounting the presence of the cladding is to use bare material properties and reduce the material thickness used in Eq. 11.2.3 and Eq. 11.2.4. The actual thickness used to calculate buckling stress is indicated in Fig. 11.2.6 by the cladding reduction factor (λ).

Material	Cladding	Plate thickness (in.)	Reduction facotr (λ)
→ 2014	6053	t < 0.04	0.8
		t > 0.04	0.9
2024	1230	t < 0.064	0.9
		t > 0.064	0.95
7075	7072	All thickness	0.92

Fig. 11.2.6 Cladding Reduction Factor (λ) for Aluminum Clad Materials (Ref. 11.7)

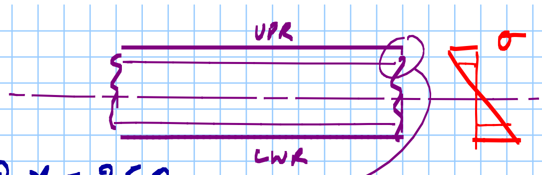
Cladding reduction factor

⇒ reduced effective area properties and increased stress level } But currently neglected in the above calcs *

Note, plastic correction charts may inherently account for clad thickness.

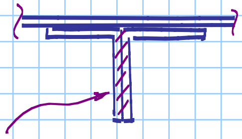
(30)

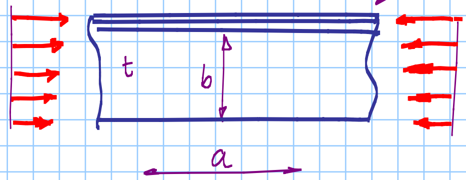
PANEL BUCKLING.



• CHECK: Upper stringer blade panel buckling @ $x = 250$

Check $\sigma < \sigma^{*}_{c_{CRIT}}$





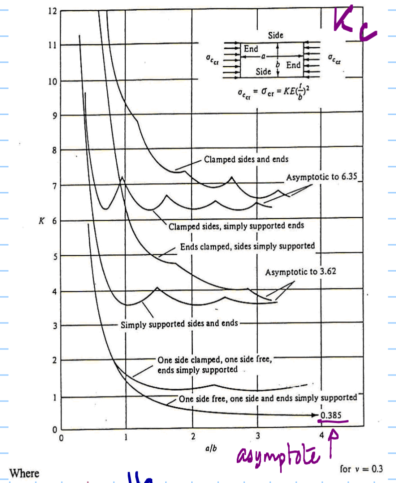
Assuming constant stress over blade at peak value (neglecting 2ndary bending and shear)

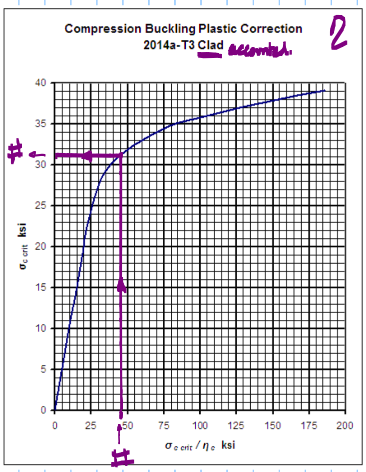
Claiming combined blades as single thickness. $t = 2 \times \# = \#\ mm$

Assuming simple supported / free edge, $a/b > 4$

$\underset{2}{\underline{\sigma_{c_{CRIT}}}} = K_c E \left(\frac{t}{b}\right)^2$

$a/b \rightarrow$ asymptote on K_c chart.





$\underset{2}{\underline{\sigma_{c_{CRIT}}}} = \# \times \# \left(\frac{\#}{\#}\right)^2 = \#\ N/mm^2 > \sigma_p\ ?$

eg. $N/mm^2 \xrightarrow{\div 6.895} \#\ ksi \xrightarrow{2} \#\ ksi \xrightarrow{\times 6.895} \#\ N/mm^2$

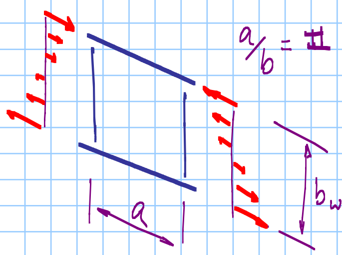
c/w $\sigma_{x_c} = \#\ N/mm^2$

$\hookrightarrow$ $RF = \frac{\#}{\#}$: $\boxed{RF =\quad}$

Aero h/b

(31)

• CHECK: LE Spar web panel buckling @ $x = 0$



$a/b = \#$

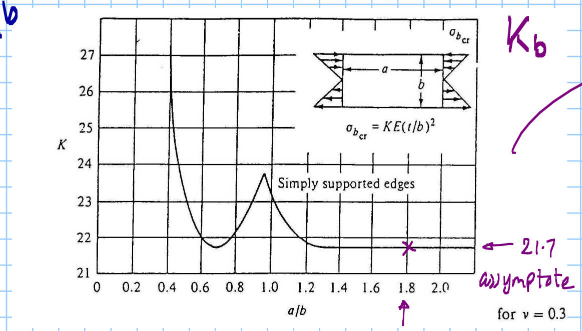
Note, bending only @ LE root due to joint arrangement.

$\sigma^{*}_{b_{CRIT}} = K_b E \left(\frac{t}{b}\right)^2$

$= \# \times \# \times \left(\frac{\#}{\#}\right)^2 = \#\ N/mm^2$

$< \sigma_p$? ...

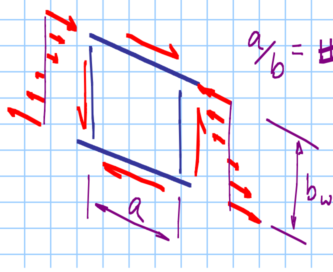
Aero h/b



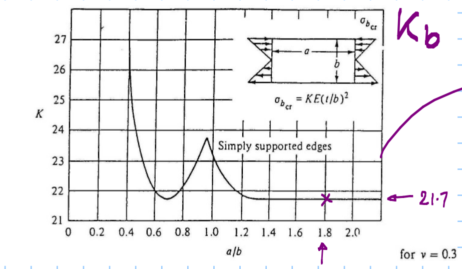
c/w $\sigma_{x_c} = \#\ N/mm^2$: $\boxed{RF = \#}$

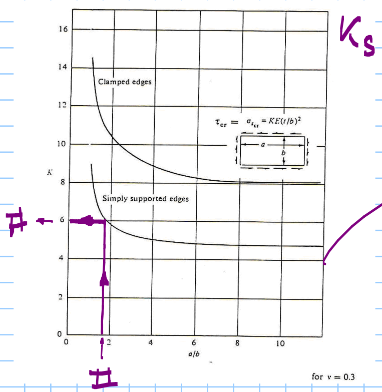
web height conservative?

- **CHECK**: LE Spar web panel buckling @ $x = 250$



Aero h/b:





Combined bending and shear @ $x = 250$
Assuming all edges simply supported

Bending:

$$\frac{\sigma^*_{b_{CRIT}}}{2} = K_b E \left(\frac{t}{b}\right)^2$$

$$= \# \times \# \times \left(\frac{\#}{\#}\right)^2 = \# \ N/mm^2$$

correction?

c/w $\sigma_{x_c} = \#$ N/mm² ; $RF = \frac{\#}{\#}$ $\boxed{RF = \#}$

Shear:

$$\frac{\tau^*_{crit}}{2} = K_s E \left(\frac{t}{b}\right)^2$$

$$= \# \times \# \left(\frac{\#}{\#}\right)^2 = \# \ N/mm^2$$

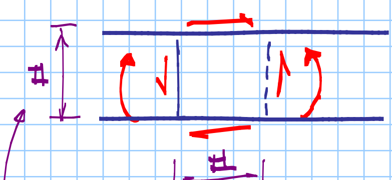
correction?

c/w $\tau = \#$ N/mm²: $RF = \frac{\#}{\#}$: $\boxed{RF = \#}$

Considering combined stress buckling:

i.e: combined bending + shear

assuming no end compression



Conservative due to flange support?

i.e.: $$\cancel{\left(\frac{\sigma_c}{\sigma_{c_{cr}}}\right)} + \left(\frac{\sigma_b}{\sigma_{b_{cr}}}\right)^2 + \left(\frac{\tau}{\tau_{cr}}\right)^2 = FI$$

and $$RF = \frac{1}{\sqrt{FI}}$$

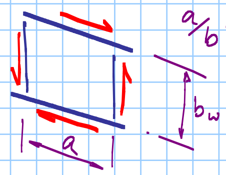
Applied stresses: $\sigma_c = \#$ N/mm² $\tau = \#$ N/mm²

Critical buckling strengths: $\sigma^*_{c_{CRIT}} = \#$ N/mm² $\tau^*_{CRIT} = \#$ N/mm²

$$\hookrightarrow \left(\frac{\#}{\#}\right)^2 + \left(\frac{\#}{\#}\right)^2 = \# \ :$$

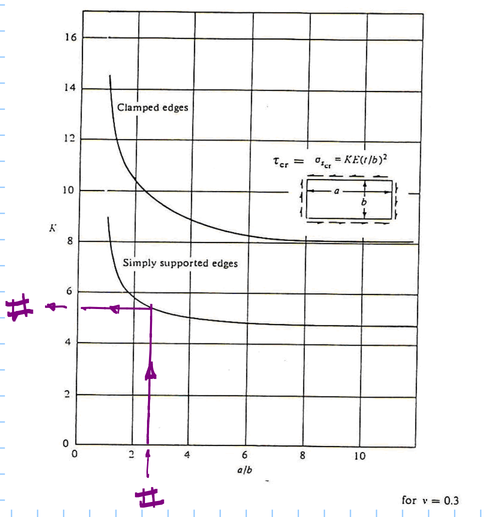
$$\hookrightarrow RF = \frac{1}{\sqrt{\#}} \ : \ \boxed{RF = \#}$$

• CHECK: TE Spar web panel buckling @ $x=0$



Note, shear only @ TE root due to joint arrangement.

Use actual rear spar height.



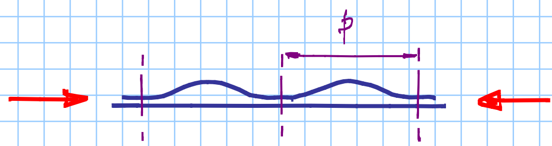
$$\frac{\tau^*_{crit}}{2} = K_s E \left(\frac{t}{b}\right)^2$$

$$= \# \times \# \left(\frac{\#}{\#}\right)^2 = \# \quad N/mm^2$$

correction?

c/w $\tau = \#$ N/mm²: RF = $\frac{\#}{\#}$: $\boxed{RF = \#}$

• CHECK: Inter rivet buckling @ LE root, $x = 0$ and $x = 250$



Assuming outer flange buckling

$$\sigma_{ir\,crit} = 2\,KE\left(\frac{t}{p}\right)^2$$

where $k = \frac{\pi^2}{12(1-\nu^2)} \cdot c$ $= 0.9c$

Using $c = 1$ for pop rivets! : $k = 0.9$

$$\hookrightarrow \frac{\sigma_{ir_{CRIT}}}{2} = \# \times \# \left(\frac{\#}{\#}\right)^2 = \# \quad N/mm^2$$

correction?

@ $x = 0$: c/w $\sigma_{x_c} = \#$ N/mm²

$\hookrightarrow$ RF = $\frac{\#}{\#}$: $\boxed{RF = \#}$

But note: two 19×19×3 mm angles @ root → lower stress

@ $x = 250$: c/w $\sigma_{x_c} = \#$ N/mm²

$\hookrightarrow$ RF = $\frac{\#}{\#}$: $\boxed{RF = \#}$