AITN 001 PJM.

A

PJM 22 June 2012

ESTIMATION OF AIRBRAKE PERFORMANCE. $M = 1.0$

ASSUMPTION DRAG RISE BETWEEN M0.8 & M1.0 IS DUE TO WAVE DRAG.

FOR BLUE FLAME = 0.57 − 0.26 = 0.31

FOR BM. 0.69 − 0.46 = 0.23

BLUE FLAME LOOKS CLOSER TO AI. SHAPE.

FROM SLENDER BODY THEORY

$$C_{D\,wave} = \frac{9\pi^2}{8}\left(\frac{1}{\left(\frac{L}{D_{max}}\right)^2}\right)$$ AS CAR IS MORE COMPLEX

replace the formula with a constant K.

$$\therefore C_{D\,wave} = K\left(\frac{1}{\left(\frac{L}{D_{max}}\right)^2}\right)$$ as it is the ratio $\left(\frac{L}{D_{max}}\right)^2$ we are interested in

D_{max} equivalent base on AI max area = $1.7\,m^2$.

$$D_{max} = \sqrt{\frac{4 \times 1.7}{\pi}} = 1.47\,m$$

$$C_{D\,wave} = \left(\frac{1}{\left(\frac{12}{1.47}\right)^2}\right)K = 0.015K$$ where $L = 12\,m$*

* estimated length of car to max Area point

Area with air brakes.
= base + total effective airbrake frontal area

$= 1.7 + 2 \times 0.44 \times 0.65 \sin 60$

$= 1.7 + 0.495 = 2.195\,m^2$

$$\text{Equivalent } D_{max} = \sqrt{\frac{4 \times 2.195}{\pi}} = 1.672\,m$$

$$C_{D\,wave} \text{ with airbrakes} = \frac{1}{\left(\frac{12}{1.672}\right)^2}K = 0.0194K$$

$$\Delta C_{D\,wave} = (0.0194 - 0.015)K = 0.00441K$$

find K.

$$0.015K = 0.31 \quad \therefore \quad K = \frac{0.31}{0.015} = 20.67$$

Estimation of airbrake performance $M = 1.0$ cont

From graph. (Pg Q).

Drag clean (airbrakes stowed)

$D = C_D \, \frac{1}{2} \rho V^2 S$

$q = \frac{1}{2} \rho V^2$ or $\frac{1}{2} \gamma M_\infty^2 P$.

$P = 101325$ Pa. & $\gamma = 1.4$

$q = 0.5 \times 1.4 \times 1^2 \times 101325 = 70927$ Pa

$D = 0.57 \times 70927 \times 1.7 = 68728$ N.

Drag airbrakes deployed

$0.00442 K = 20.67 \times 0.00442 = 0.091 = C_{D\,airbrake}$.

Drag $= (0.57 + 0.091)\, 0.5 \times 1.4 \times 1^2 \times 101325 (1.7 + 0.495)$

$= 102908$ N

$A = 102908 - 68728 = 34180$ N. ← Force no end plates

C_D of airbrake base or plan area $(2 \times 0.44 \times 0.65)$.

$= \frac{34180}{q A} = \frac{34180}{70927 \times (2 \times 0.44 \times 0.65)}$

$= 0.842$.

$C_{D\,@\,90^\circ} = \frac{0.842}{\sin 60} = 0.972$

C.
22 June 2014

Do a similar calculation for BH to check against CFD results.

Assume BH max area is $1.93\ m^2$

So $D_{max\,eq} = \sqrt{\frac{1.93 \times 4}{\pi}} \quad 1.568\ m$

$$C_{D\,wave} = K\left(\frac{1}{\left(\frac{L}{D_{max}}\right)^2}\right) = \left(\frac{1}{\left(\frac{12}{1.568}\right)^2}\right)K$$

$$= 0.017K$$

Airbrake Door Area $= 0.787\ m^2$

corrected for projection Area $= 0.787 \sin 60$
$= 0.681\ m^2$

Total projected area $= 1.93 + 0.681 = 2.61\ m^2$

Equivalent $D_{max} = \sqrt{\frac{4 \times 2.61}{\pi}} = 1.823\ m$

$$C_{D\,wave} = K\left(\frac{1}{\left(\frac{L}{D_{max\,eq}}\right)^2}\right) = \left(\frac{1}{\left(\frac{12}{1.823}\right)^2}\right)K = 0.0231K$$

$\Delta C_{D\,wave} = (0.023 - 0.017)K = 0.0061K$

$K = 0.017K = 0.23 \quad \therefore K = \frac{0.23}{0.017} = 13.53$

Drag clean. M1.0

$= 0.69 \times 0.5 \times 1.4 \times 101325 \times 1^2 \times 1.93 = 94454\ N$

Drag airbrakes deployed

$= (0.69 + (0.0061 \times 13.53))\ \frac{1}{2}\ 1.4 \times 1^2 \times 101325 \times (2.61)$

$= 143011\ N$

$\Delta = 143011 - 94454 = 48557\ N$

$$C_D = \frac{48557}{70927 \times 0.787} = \underline{\underline{0.87}}$$

From Solid Dow CFD. $\frac{D}{q}\ (m^{-2}) = 0.966 \approx 0.8$

$\frac{D}{q}$ $0.966 \times 0.787 = 0.76$

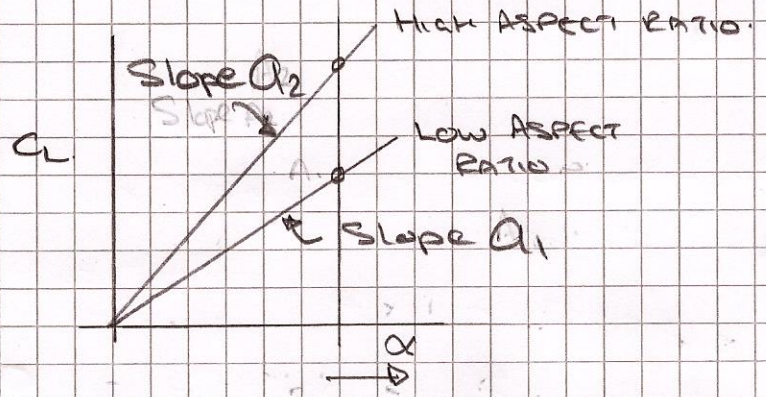
Compressibility correction $\simeq 15\%$ $0.76 \times 1.15 = 0.874$

close enough!

$AR_{BH} = \frac{1.05^2}{0.787} = \underline{\underline{1.41}}$ $\quad C_{L/\infty} = 0.03$

CALCULATING THE EFFECT OF THE ENDPLATE.

INCORPORATING ENDPLATES HAS THE EFFECT OF INCREASING THE ASPECT RATIO OF THE WING / PLATE



AS THE DEFLECTED OR DEPLOYMENT ANGLE IS FIXED (60°) FOR THE SAME AREA THE HIGHER ASPECT RATIO WING IS MORE EFFICIENT. THIS RESULTS IN A HIGHER C_L.

BECAUSE THE ANGLE OF ATTACK IS FIXED THE LIFT AT ANY SPEED WILL ALSO BE HIGHER SO THE INDUCED DRAG WILL BE HIGHER.

$$D_i = \frac{L^2}{q S \pi e AR}$$

THUS THE HYPOTHESIS IS; INCORPORATING THE ENDPLATES TO CHANGE THE EFFECTIVE ASPECT RATIO IS ANALOGOUS TO REPLACING THE AREA OF THE AIRBRAKE WITH AN EQUIVALENT AREA THAT IS PROPORTIONAL TO THE RATIO OF LIFT CURVE SLOPES $\frac{a_2}{a_1}$.

Aspect ratio of base airbrake $= \frac{0.44}{0.65} = 0.677$

using Hoerner empirical formula.

$$AR_{eff} = AR\left(1 + 1.9\left(\frac{h}{b}\right)\right)$$

h = height of endplate
b = span of panel

$$= 0.677\left(1 + 1.9\left(\frac{0.1b}{0.44}\right)\right) = 1.145$$

Having endplates on one side only is usually not as good as equispaced though flow on suction surface will be minimal due to body interferences. assume 10% loss so $AR_{eff} = 1.03$.

lift curve slope for base airbrake without endplates

AR = 0.677

Using DATCOM formula, $a_0 = 0.018$ / degree 1.03 / Rad

For AR_{eff} 1.03 (160mm endplate). $a_0 = 0.026$ / degree 1.52 / Rad.

(Ref only BM AR = 1.075. $a_0 = 0.027$ / degree)

FACTOR IN COMPRESSIBILITY.

$$a_{0\,comp} = \frac{a_0}{\sqrt{\underbrace{1 - M_\infty^2}_{0}} + \left(\frac{a_0}{\pi AR}\right)^2 + \frac{a_0}{\pi AR}}$$ Hemhold 1942.

at $M_\infty = 1$.

Reduces to:

$$a_{0\,comp} \quad \frac{a_0}{\left(\frac{a_0}{\pi AR}\right)^2 + \frac{a_0}{\pi AR}}$$

for base

$$a_{0\,comp} = \frac{1.03}{\left(\frac{1.03}{\pi\, 0.677}\right)^2 + \frac{1.03}{\pi\, 0.677}} = \frac{1.03}{0.2345 + 0.4843}$$

$a_0 = 1.433$ / Rad.
0.025 / deg

for airbrake + endplates (160mm)

$$a_{0\,comp} = \frac{1.52}{\left(\frac{1.52}{\pi\, 1.03}\right)^2 + \frac{1.52}{\pi\, 1.03}} \qquad \frac{1.52}{0.2206 + 0.4697}$$

$a_0 = 2.2$ / Rad
$a_0 = 0.038$ / deg.

$$\text{Area Ratio} = \frac{2.2}{1.433} = 1.536.$$

New frontal airbrake area

$2 \times 0.44 \times 0.65 \times 1.536 \times \sin 60 = 0.761\ m^2$.

new vehicle frontal $= 1.7 + 0.761 = 2.46\ m^2$

$$D_{equivalent} = \sqrt{\frac{4 \times 2.46}{\pi}} = 1.77\ m.$$

$$C_{D_{wave}} = K\left(\frac{1}{\left(\frac{L}{D_{eqv}}\right)^2}\right) = K\left(\frac{1}{\left(\frac{12}{1.77}\right)^2}\right) = K\,0.0218$$

$$\Delta C_{D_{wave}} = (0.0218 - 0.015)K \quad \text{+ pg. A}$$

$$= 6.76 \cdot 10^{-3} K \Rightarrow 6.76 \cdot 10^{-3} \times 20.67 = 0.1398$$

Drag with brakes deployed =

$$\left((0.57 + 0.1398)\,0.5 \times 1.4 \times 1^2 \times 101325 \times 2.46\right)$$

$$= 123839\ N.$$

$$\Delta drag = 123839 - 68728 = 55111\ N.$$ Force with 160mm end plates

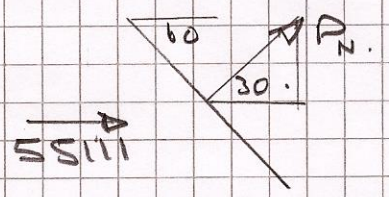
C_D Based on plan area of airbrake =

$$\frac{55111}{qA} = \frac{55111}{70927 \times (2 \times 0.44 \times 0.65)} = \underline{\underline{1.36}}.$$ 60% improvement

$0.572\,m^2$

Equivalent Pressure on Plate. $P_N = \dfrac{55111}{0.572 \times \cos 30}$

$$= \underline{\underline{111253\ Pa.}}$$



Similar calculations for 320 mm endplates.

$$AR_{eff} = AR\left(1 + 1.9\left(\frac{h}{b}\right)\right)$$

$$= 0.677\left(1 + 1.9\left(\frac{320}{440}\right)\right) = 0.677 \times 2.38 = 1.612$$

allow 10% losses = 1.451

$a_0 = 2.02$ / Radian $= 0.035$ / degree.

factor in compressibility.

$$a_{0_{comp}} = \frac{a_0}{\left(\frac{a_0}{\pi AR}\right)^2 + \frac{a_0}{\pi AR}} \qquad @ M = 1.0.$$

$$= \frac{2.02}{\left(\frac{2.02}{\pi 1.451}\right)^2 + \frac{2.02}{\pi 1.451}} = \frac{2.02}{0.19647 + 0.4431}$$

$= 3.159$ / Rad

$= 0.055$ / deg.

lift curve slope ratio $= \frac{3.159}{1.433} = 2.20$.

New Frontal airbrake area =

$2 \times 0.44 \times 0.65 \times 2.2 \times \sin 60 = 1.09\ m^2$

New vehicle Frontal area $1.7 + 1.09 = 2.79\ m^2$.

Equivalent $D_{max} = \sqrt{\frac{4 \times 2.79}{\pi}} = 1.885\ m$.

C_D wave with brakes deployed $= \frac{K}{\left(\frac{12}{1.885}\right)^2} = 0.025K$

$C_{D\,wave} = 0.025 \times 20.67 = 0.51$

$\Delta C_D = (0.025 - 0.015)20.67 = 0.2067$ (say 0.21).

Drag airbrakes deployed

$= (0.57 + 0.21)0.5 \times 1.4 \times 1^2 \times 101325 \times 2.79$

$= 153699\ N$.

$\Delta = 153699 - 68728 = 84971\ N$.

C_D of airbrake based on plan area $(2 \times 0.44 \times 0.65 = 0.572\ m^2)$

$$= \frac{84971}{qA} = \frac{84971}{70927 \times 0.572} = 2.09 \leftarrow \text{Too thick}$$

$$C_{D\,90} = \frac{2.09}{\sin 60} = 2.42$$

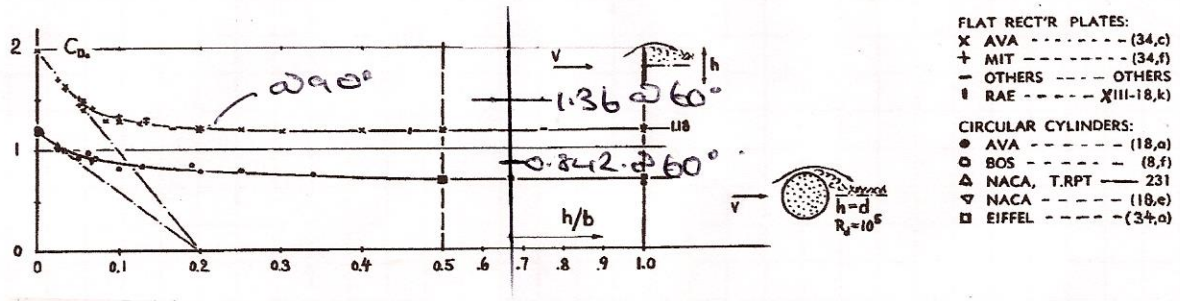


Figure 28. Drag coefficients of rectangular plates and circular cylinders as a function of their height (or diameter) to span ratio.

From the above graph the maximum C_D attainable is for 2D flow $\simeq 2$. $\therefore$ $2 \sin 60 = \sqrt{3} = 1.732$

1.732 is the maximum C_D attainable so any endplate that give higher than this is in effect capped & the excess is just drag when stowed

At 160 mm C_D @ 60 = 1.36 $\Rightarrow \frac{1.36}{\sin 60} = 1.57$

if the relationship is assumed linear

then the maximum useful endplate height is determined thru iteration start with 190 mm

<u>check</u> $AR_{eff} = AR\left(1 + 1.9\left(\frac{190}{440}\right)\right) 0.9 = AR\ 1.64$

$= 1.11$

a_0 @ M = 0 1.62 / Rad 0.028 / deg.

a_0 comp

$$\frac{1.62}{\left(\frac{1.62}{\pi 1.11}\right)^2 + \left(\frac{1.62}{\pi 1.11}\right)} = \frac{1.62}{0.216 + 0.465} = 2.38$$

area ratio $= \frac{2.38}{1.433} = 1.66$

new frontal airbrake area

$2 \times 0.44 \times 0.65 \times 1.66 \times \sin 60 = 0.822\ m^2$.

Now vehicle frontal area = 1.7 + 0.822 = 2.522 m²

$$D_{eq} = \sqrt{\frac{4 \times 2.522}{\pi}} = 1.792 \text{ m}$$

$$C_{D\,wave} = \frac{K}{\left(\frac{12}{1.792}\right)^2} = 0.0223K$$

$K = 20.67$

$$\Delta C_{D\,wave} = (0.0223 - 0.015)K$$
$$= 0.151$$

Drag with airbrake deployed

$$(0.57 + 0.151)\,0.5 \times 1.4 \times 1^2 \times 101325 \times 2.522$$
$$= 128869 \text{ N}$$

$$\Delta drag = 128869 - 68728 = 60141 \text{ N}$$ ← 190mm envelope.

CD based on plan area of airbrake

$$\frac{60141}{qA} = \frac{60141}{70927 \times 0.572} = 1.48$$

$$\frac{1.48}{\sin 60} = 1.711$$ too low

Run the numbers for an endplate height of 270mm.

$$\text{Aspect Ratio}_{eff} = 0.677\left(1 + 1.9\left(\frac{270}{440}^{*}\right)\right)0.9 = 1.32$$

* Hoerners theory limits are $\frac{h}{b} = 0.4$ $\quad \frac{270}{440} = \underline{0.61}$ caution!

lift curve slope $a_0 = 1.87$ / Radian. $\quad$ (0.033/deg).

$$a_0\ \text{corr} = \frac{1.87}{\left(\frac{1.87}{\pi 1.32}\right)^2 + \frac{1.87}{\pi 1.32}} = \frac{1.87}{0.2033 + 0.4509} = 2.858/\text{Rad.}$$

$$\text{Area Ratio} = \frac{2.858}{1.433} = 1.995$$

New frontal airbrake area

$$2 \times 0.44 \times 0.65 \times 1.995 \sin 60 = 0.998\ m^2$$

$$\text{New Vehicle frontal} = 1.7 + 0.998 = 2.69\ m^2$$

$$D_{eq} = \sqrt{\frac{4 \times 2.69}{\pi}} = 1.85\ m.$$

$$C_{D\,wave} = \frac{K}{\left(\frac{12}{1.85}\right)^2} = 0.0238\,K.$$

$$\Delta C_{D\,wave} = (0.0238 - 0.015)K = 0.181$$

Drag with brakes deployed =

$$(0.57 + 0.181)0.5 \times 1.4 \times 1^2 \times 101325 \times 2.69 = 143330\ N$$

$$\Delta_{drag} = 143330 - 68728 = 74602\ N$$

C_D based on plan area of airbrake

$$= \frac{74602}{qA} = \frac{74602}{70927 \times 0.572} = 1.84$$

$$C_D\ @\ 90 = \frac{1.84}{\sin 60} = 2.1 \quad \text{Still a little high}$$

K.

Run the numbers for a height of 240 mm.

$$\text{aspect Ratio}_{eff} = 0.677\left(1 + 1.9\left(\frac{240}{440}\right)\right)0.9 = 1.24$$

lift curve slope 1.78 / Rad 0.031 / deg.

$$a_{0\,comp} = \frac{1.78}{\left(\frac{1.78}{\pi 1.24}\right)^2 + \left(\frac{1.78}{\pi 1.24}\right)} = 2.674 \text{ / Rad}$$

$$\text{area Ratio} = \frac{2.674}{1.433} = 1.866$$

New frontal area of airbrake

$= 2 \times 0.44 \times 0.65 \times 1.866 \sin 60 = 0.924\ m^2$

New Vehicle frontal $= 1.7 + 0.924 = 2.624\ m^2$

$$D_{eq} = \sqrt{4 \times \frac{2.624}{\pi}} = 1.828\ m.$$

$$C_{DWave} = \frac{K}{\left(\frac{12}{1.828}\right)^2} = 0.0234K$$

$\Delta C_{DWave} = (0.0234 - 0.015)K = 0.1696K = 0.174$

Drag with brakes deployed.

$(0.57 + 0.169)\ 0.5 \times 1.4 \times 1^2 \times 101325 \times 2.624 = 137645\ N$

$\Delta drag = 137645 - 68728 = 68917\ N$

$$C_D = \frac{68917}{70927 \times 0.572} = 1.699 \text{ base on airbrake area.}$$

$$C_{DW90} = \frac{1.699}{\sin 60} = 1.96$$

$$P_N = \frac{68917}{0.572 \cos 30} = 139123\ Pa.$$

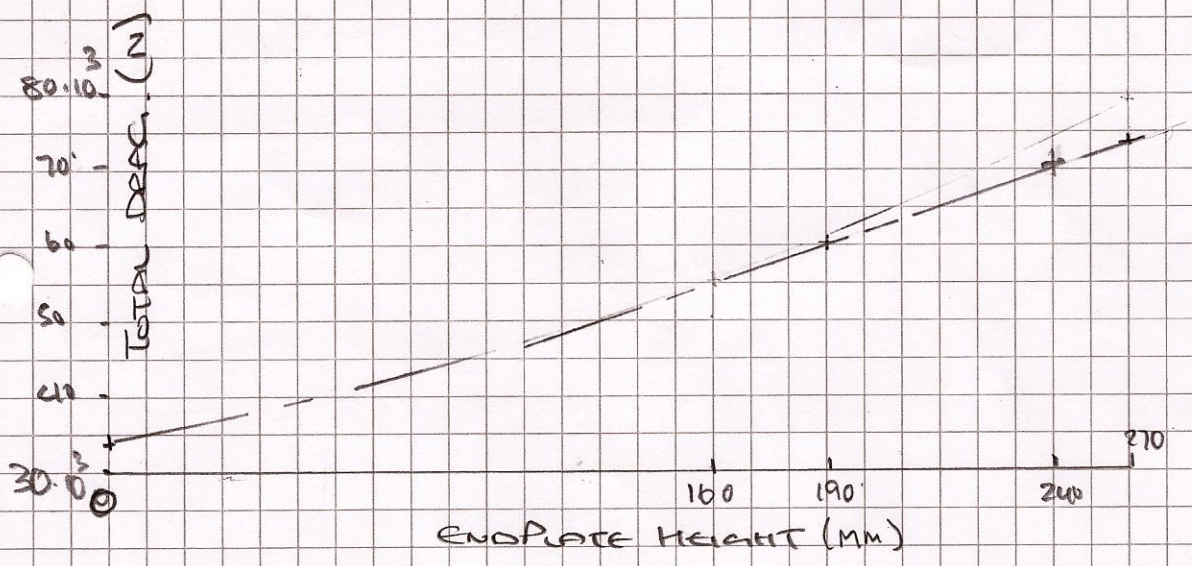
L

TALLY M1.0 RESULTS

ENDPLATE HEIGHT (MM)	* DRAG (N)	P_N (Pa)
0	34180	69000
160	55111	111253.
190	60141	121400
240	68917	139123.
270 **	74602	

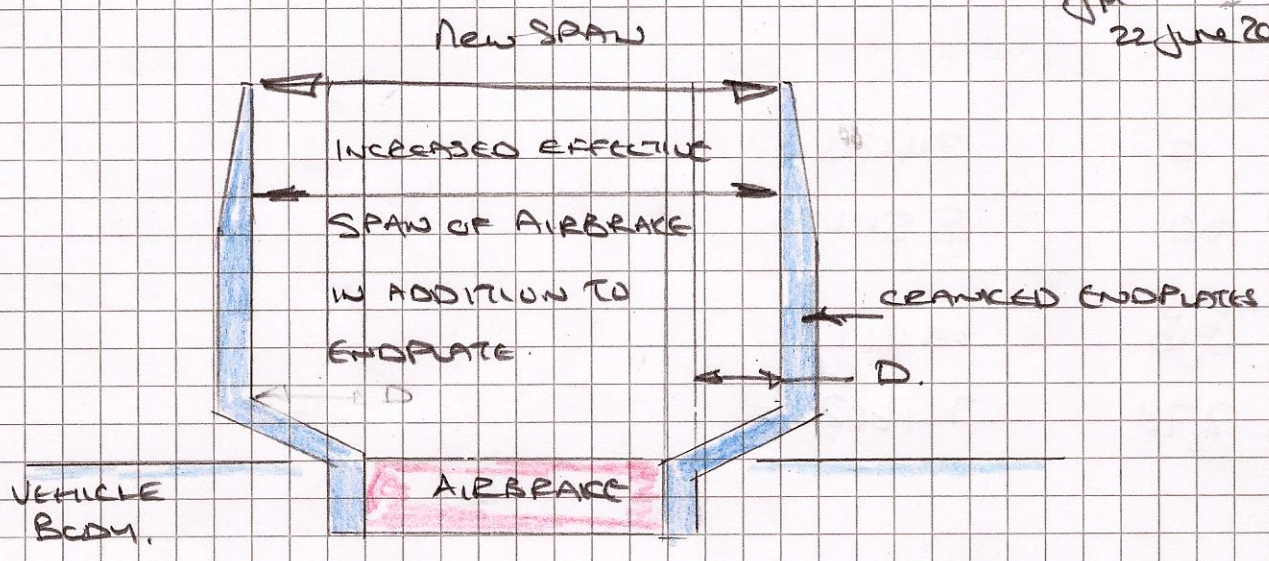
Total for both airbrakes

** MAX. Probably 70.10^3 N



M

GM
22 June 2014



HAVING CRANKED ENDPLATES WOULD INCREASE CAPTURE AREA IF MORE DRAG WAS REQUIRED

Sizing with offset endplates

Assume endplate height is 80mm. to keep within boundary layer.

For Maximum performance total frontal area need to be $2.624\,m^2$ (based on 240 mm endplates).

So effective area of endplates = $2.624 - 1.7 = 0.924\,m^2$

Made up from aspect ratio effect of endplates + increase in span due to $2 \times D$.

$$\text{Aspect Ratio}_{eff} = 0.677\left(1 + 1.9\left(\frac{80}{440}\right)\right)0.9 = 0.819$$

$C_{L\alpha} = 1.23$ /Rad 0.022/deg.

$$a_{0\,comp} = \frac{1.23}{\left(\frac{1.23}{\pi\, 0.819}\right)^2 + \frac{1.23}{\pi\, 0.819}} = 1.741 \text{ /Rad}$$

Area ratio effect due to endplate aspect ratio change

$$= \frac{1.741}{1.433} = 1.215.$$

& $2 \times 0.44 \times 0.65 \times 1.215 \times \sin 60 = 0.602\,m^2$.

$0.924 - 0.602 = 0.322\,m^2$ required by span increase

$0.322 = 0.65 \times 4D \times \sin 60$ $D = 0.143$.

2 outboards

So new span $= 0.44 + 2(0.143) = 0.726\,m$.

Sizing with offset endplates.

Assume endplate height is 160 mm.

As before area to find is 0.924 m^2.

From previous calculations pg E

$a_{0\,comp} = 2.2/Rad$.

aspect ratio = 1.536.

Airbrake frontal area = 0.761 m^2.

to find with extra width = 0.924 − 0.761 = 0.163.

$0.163 = 0.65 \times 4D \times \sin 60$

$D = 0.072\,m$.

So new span = 0.44 + 2(0.072) = 0.58 m.

An interesting conclusion.

The endplate height + the offset (D) when summed approximates to the optimum condition of 240 mm. Conventional endplate design of wings recommends that is space is not an issue then go for tip extensions over endplates or winglets.

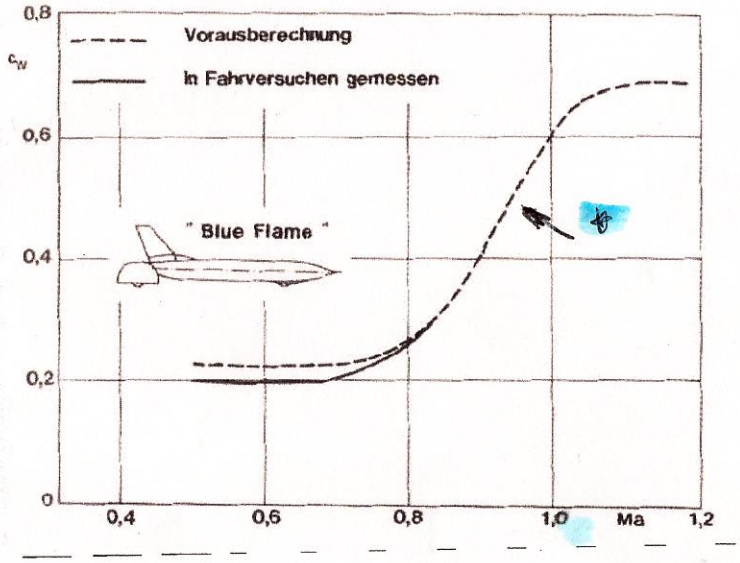
Given a choice between 240mm endplates & 160 with offset if the offset is contained within the boundary displacement thickness (≃ 18mm) then this will be a lower drag solution when stowed.

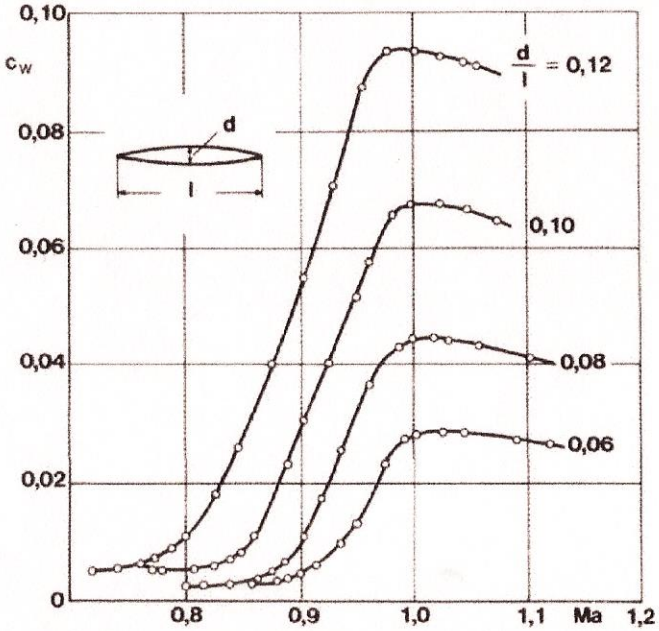
Transonic speeds

$$\frac{T_0}{T} = 1 + \frac{1}{2}(\gamma - 1)\mathrm{Ma}^2$$

$$\frac{\rho_0}{\rho} = \left(1 + \frac{1}{2}(\gamma - 1)\mathrm{Ma}^2\right)^{\frac{1}{\gamma-1}}$$

- Compressibility
- Displacement of the force application point
- Strong increase of the drag coefficient

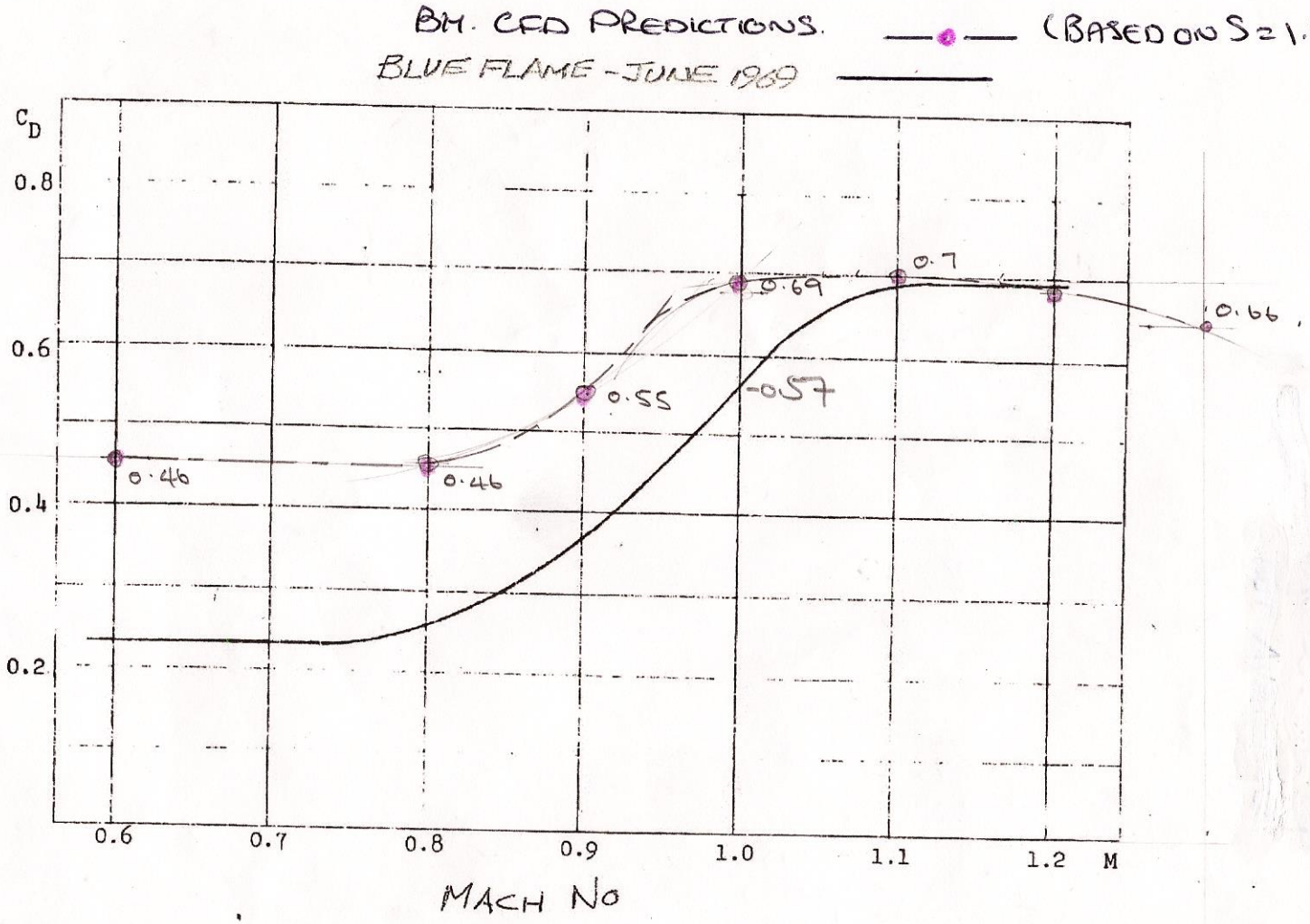




Lift has been avoided for all speeds
But, during sound transmission the negative pressure under the vehicle becomes positive.
Subsonic: acceleration → underpressure
Supersonic: oblique shock →overpressure
Can lead to instability

* CAUTION. THIS GRAPH ISNT THE SAME AS SHOWN ON PAGE 'Q'. A CHANGE IN THE BASELINE CD @ MI.0 WILL CHANGE THE EFFECTIVENESS OF THE BRAKES. AS CD OF CAR INCREASES WAVE DRAG EFFECT OF BRAKES REDUCES. A CASE OF GIGO!

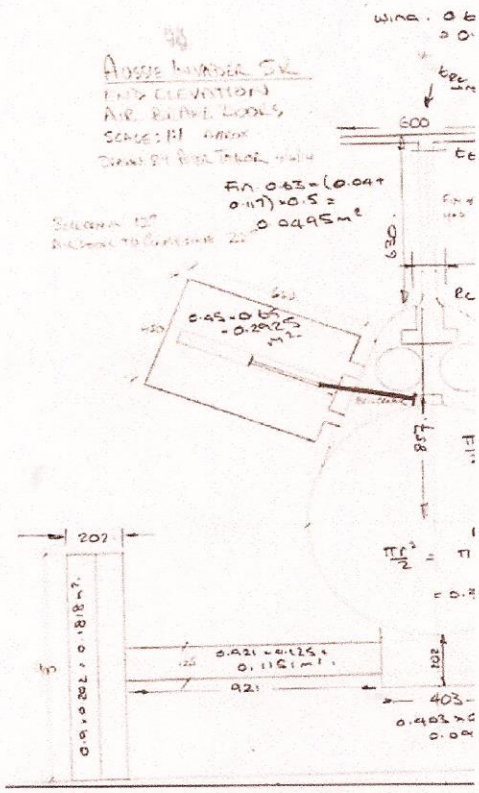
ESTIMATED DRAG COEFFICIENT

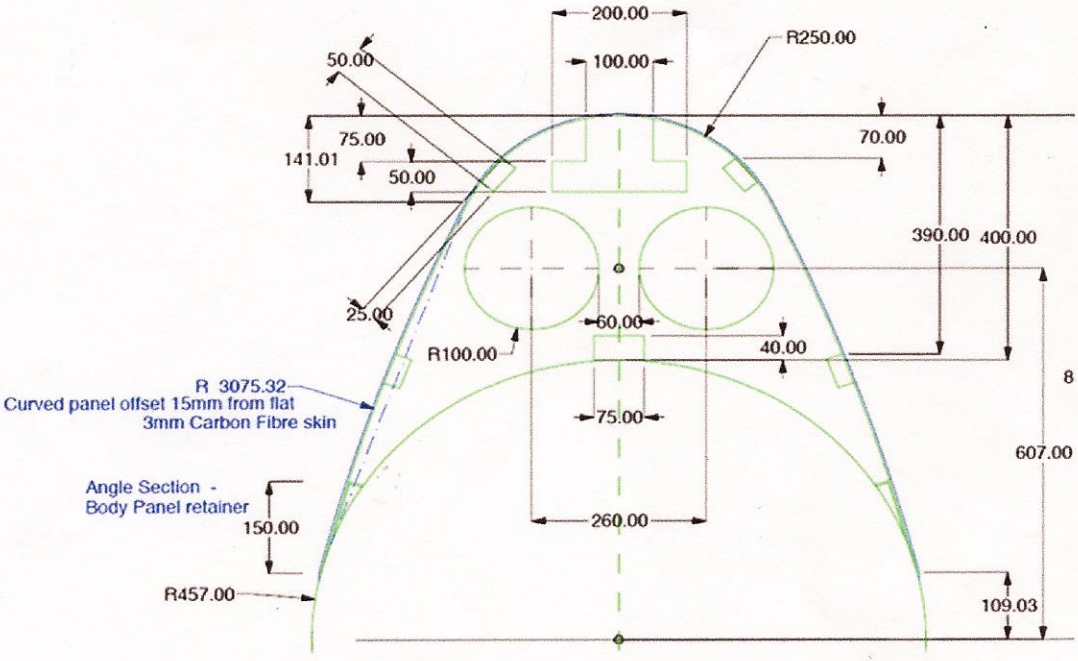


R

Approximation of areas

REGION		m^2
LHS wheel		0.1818
RHS wheel		0.1818
LHS suspension		0.1151
RHS suspension		0.1151
Underbody		0.0921
Lower half of chassis		0.328
Upper half of chassis		0.6152
Vertical fin		0.0495
T Tail		0.0135
	Total	**1.6921**
LHS Airbrake.		0.2925
RHS Airbrake.		0.2925
	Total	**0.585**



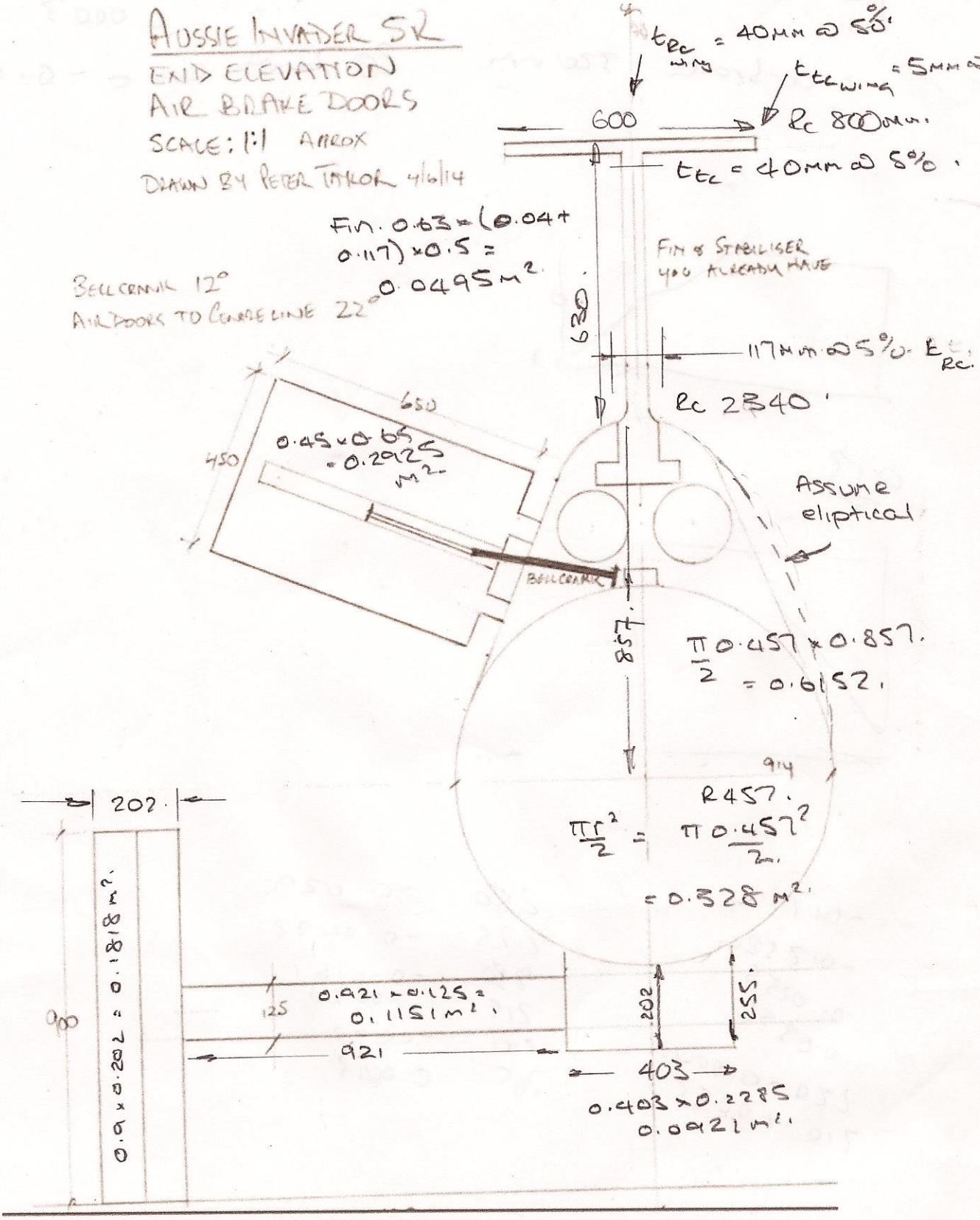


S

Wing. 0.6 (0.04 + 0.005) 0.5
= 0.0135 M2

AUSSIE INVADER SR

END ELEVATION
AIR BRAKE DOORS
SCALE: 1:1 APROX
DRAWN BY PETER TAYLOR 4/6/14



CSA = 1.7M2

13.44 / MO.
SCALE