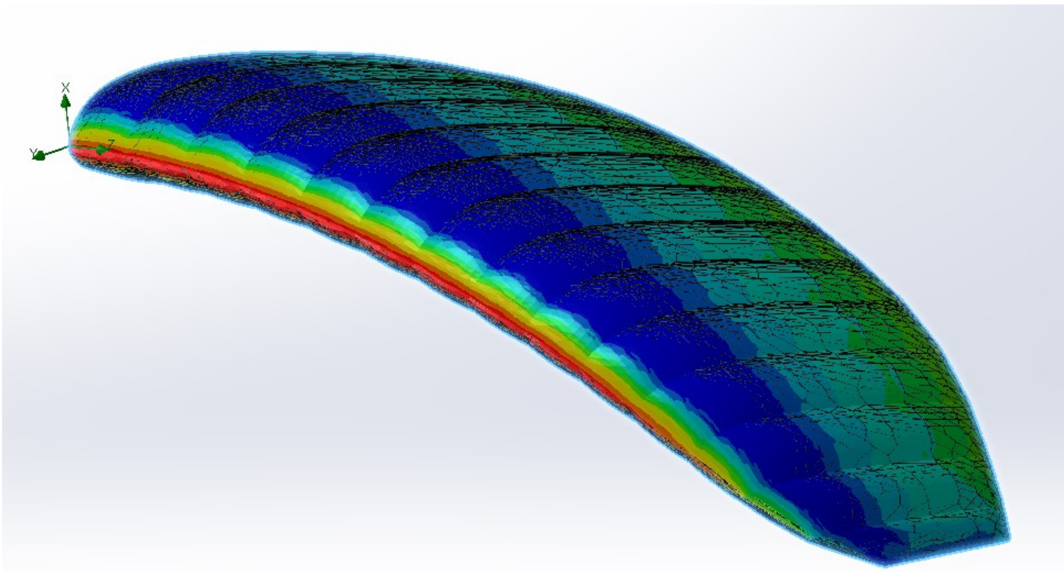


Aerodynamic results for Hegela wing and determination of inital pilot position.

JF de Villiers 18/08/2022

Rev 1 - 10/06/2020 - Initial report - Trim GR 7 - Very basic line drag
Rev 2 - 20/06/2020 - Improved line drag calculations - Added Appendix C for stitched lines. Line choice 2 and 1.5 mm - Trim GR 6.2
Rev 3 - Improved line drag calculations - Added Appendix D for spliced lines - Small improvement on GR due to upper cascade line choice of 1.5 to 1.2 mm - Trim GR 6.4
Rev 4 - Increasing pilot drag,extra wing drag and adding results of xflr5 and equilibrium calculations for determining pilot position - Trim GR 5.7

Appendix

A - Initial line and pilot drag
B - Line drag and Re nr effect
C - Stitched line result - calc in excel using RE effect
D - Spliced lines result - calc in excel using RE effect
E - Equilibrium calculation for determining pilot position

Introduction

This report provides the cfd results of the wing and estimates of the pilot and line drag and resulting glide ratio for a wing built by Eric Fontaine using the LE Paragliding program. The wing was also analysed in Xflr5 and an equlibrium calculation was setup to determine the pilot position

Assumptions

- Trim speed is 12.7 m/sec at AOA of 9.45 degrees
- Max speed at is 13.89 m/sec at A0A of 5.45 degrees
- Vents of the wing are analysed closed, drag will increase when vents are opened
- No deformation of the wing is calculated, wing is rigid
- The billow tensioning is included in the CFD analyses.
- The LE Paraglding program provides an STL file of the wing and small kinks in the wing exist due to AOA quickly changing near the wing tip.
- Some small smoothening were done between the interface of the vent and where the cells starts billowing.
-No pilot or lines are included in the cfd but used for glide ratio and inflight balance calculation at trim speed in the report

Definition of paramaters

$\mathbf{V} := 12.7 \cdot \frac{\mathbf{m}}{\mathbf{sec}}$ $\quad \mathbf{V} = 45.72 \cdot \frac{\mathbf{km}}{\mathbf{hr}}$ $\quad \rho := 1.225 \cdot \frac{\mathbf{kg}}{\mathbf{m}^3}$ $\quad \mathbf{A} := 14.5 \cdot \mathbf{m}^2$ $\quad \alpha := 9.45 \cdot \mathbf{deg}$

$\mathbf{F} := \frac{1}{2} \cdot \rho \cdot \mathbf{V}^2 \cdot \mathbf{A}$ $\quad \mathbf{F} = 1432.5\,\mathbf{N}$

CFD results and L/D calcs

The calc in the cfd was done at 13.89 m/sec so the load and drag values are scaled. There will be very little Re effect between 12.7 and 13.89 m/sec

$$\mathbf{f} := \frac{\mathbf{V}^2}{\left(13.89 \cdot \frac{\mathbf{m}}{\mathbf{sec}}\right)^2} \qquad \mathbf{f} = 0.836$$

From CFD for half wing $\quad \mathbf{L_h} := \mathbf{447.5697564} \cdot \mathbf{N}$ $\quad \mathbf{D_h} := \mathbf{43.5779294119807} \cdot \mathbf{N}$

$\mathbf{L} := 2 \cdot \mathbf{L_h} \cdot \mathbf{f}$ $\quad \mathbf{L} = 748.331\,\mathbf{N}$ .....lift along the glide path

$\mathbf{D_w} := 2 \cdot \mathbf{D_h} \cdot \mathbf{f}$ $\quad \mathbf{D_w} = 72.862\,\mathbf{N}$ .....drag along the glide path with AOA of 9.45 deg

$\mathbf{D_p} := 26 \cdot \mathbf{N}$ ......drag of pilot - see calcs in appendix

$\mathbf{D_L} := 11.2 \cdot \mathbf{N} \cdot 2$ ......drag of lines - See Appendix D

$\mathbf{D_f} := 6.7085 \cdot 2 \cdot \mathbf{N}$ .....friction drag .....from cfd results

$\mathbf{D_{we}} := 12.3 \cdot \mathbf{N}$ ...extra drag due to vents/cell openings

$\mathbf{D_i} := \mathbf{D_w} - \mathbf{D_f}$ .....induced plus pressure drag

$\mathbf{D} := \mathbf{D_w} + \mathbf{D_{we}} + \mathbf{D_p} + \mathbf{D_L}$ $\quad \mathbf{D} = 133.562\,\mathbf{N}$.....total drag along the glide path

$$\begin{pmatrix} D_p \\ D_L \\ D_f \\ D_i \\ D_w + D_{we} \end{pmatrix} \cdot \frac{100}{D} = \begin{pmatrix} 19.467 \\ 16.771 \\ 10.046 \\ 44.507 \\ 63.762 \end{pmatrix}$$

Pilot drag
Line drag
Friction drag
Induced + Pressure drag
Wing (Friction +induced+ pressure)

$$d_t := \begin{pmatrix} D_p \\ D_L \\ D_f \\ D_i \\ D_w \end{pmatrix} \cdot \frac{100}{D}$$

....drag percentages

$C_l := \frac{L}{F}$ $\quad C_l = 0.522$ ....lift coefficient $\quad CL1 := C_l$

$C_d := \frac{D}{F}$ $\quad C_d = 0.093$ ....drag coefficient $\quad CD1 := C_d$

$C_{dw} := \frac{D_w}{F}$ $\quad C_{dw} = 0.051$ $\quad \frac{C_l}{C_{dw}} = 10.271$ $\quad \frac{C_l}{C_d} = 5.603$

$\gamma := \text{atan}\left(\frac{C_d}{C_l}\right)$ $\quad \gamma = 10.12 \cdot \text{deg}$ ....glide angle

$GR := \frac{C_l}{C_d}$ $\quad GR = 5.603$ ....glide ratio in still air

$W := 0.5 \cdot A \cdot V^2 \cdot \rho \cdot \sqrt{C_d^2 + C_l^2}$ $\quad W = 760.156\,N$

$W := \frac{C_d \cdot \frac{1}{2} \cdot \rho \cdot V^2 \cdot A}{\sin(\gamma)}$ $\quad W = 760.156\,N$ .....checks

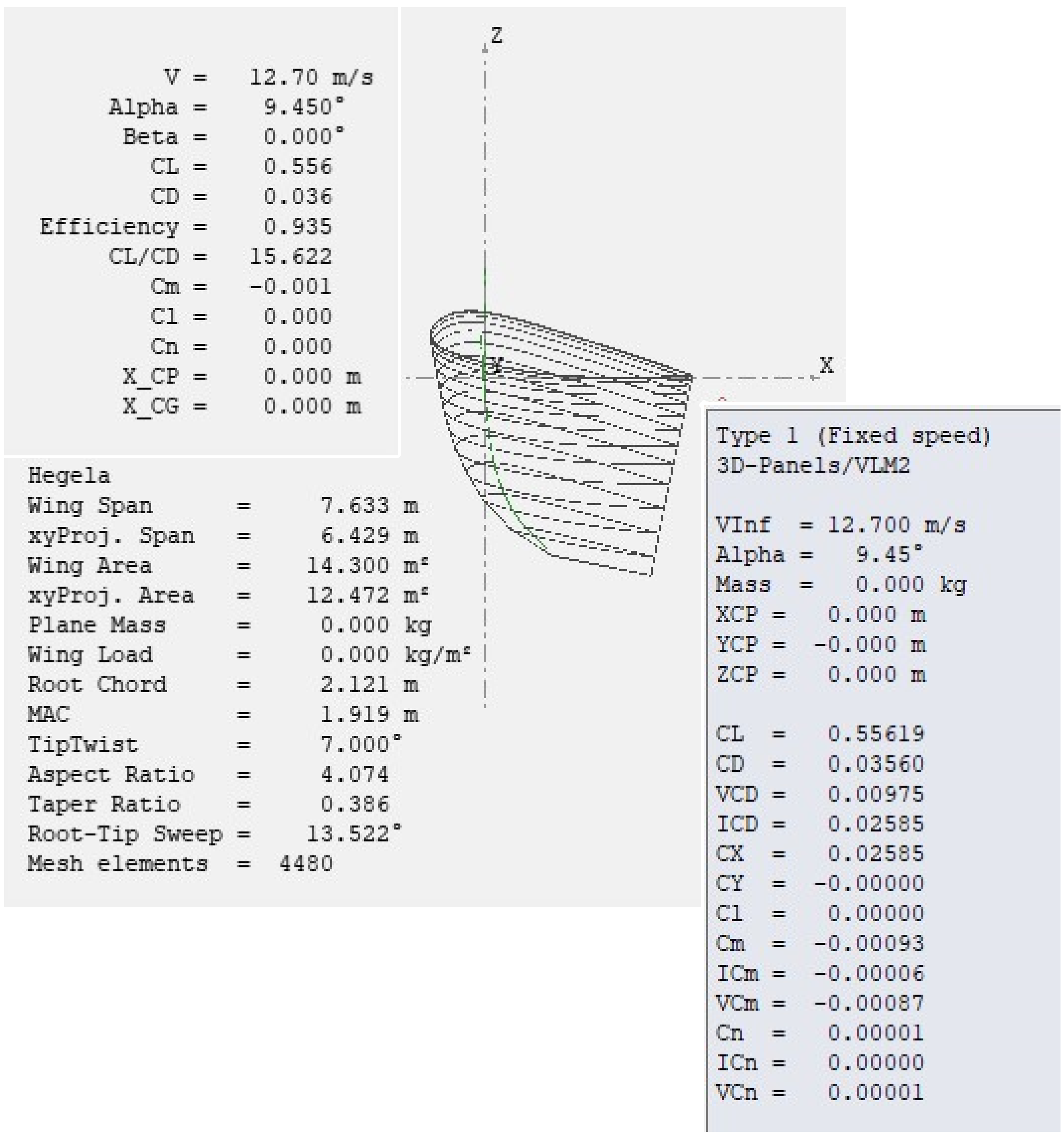
$W := \frac{C_l \cdot \frac{1}{2} \cdot \rho \cdot V^2 \cdot A}{\cos(\gamma)}$ $\quad W = 760.156\,N$ ....checks

$h_{dot} := V \cdot \sin(\gamma)$ $\quad h_{dot} = 2.231 \frac{m}{s}$ ....sink rate (vertical velocity)

$r_{dot} := V \cdot \cos(\gamma)$ $\quad r_{dot} = 12.502 \frac{m}{s}$ ....horisontal velocity

$\frac{r_{dot}}{h_{dot}} = 5.6$ ....checks

The wing is also analysed in xflr5 without pilot and lines. Currently in Xflr5 the wing does not have billowing and the vent/cell openings are not modeled. Since the wing is smooth the lift and drag will be better than the CFD. The axis is moved until it coincides with the center of pressure determined by xflr5. Note that due to the billowing and the vents the center of pressure will be at a different position but ignored for the moment. Due to the profile used the cm < 0.001 and assumed zero when determining the pilot placement for trim conditions. (hands up and no brakes) A value of of Cm <0.001 have an effect of less than a mm movement for pilot position. An estimation is made for the drag due to billowing.



From xflr5 with the VLM2 calculation and nr of mesh elements of 80 along the chord and 2 per cell spanwise

See Appendix E for calculation of pilot position due to all the forces acting on the wing.
The inputs and outputs are shown below

Outputs

$Calage_p = 28.7656$

$cp_{lepP} = 31.414$

$X_{cpP} = 23.055$

$Z_{cpP} = 14.097$

$M_{total} = 70.985$

$\theta = 10.125 \cdot deg$

$\delta = 0.675 \cdot deg$

$GR_w = 15.623$

$L = 685.288$

$D_w = 43.863$

$D_{we} = 30.101$

$D_{pilot} = 26.004$

$D_{line} = 22.406$

$cd_{we} = 0.024$

$cp_{lep} \cdot 1000 = 666.2879301$

$$\frac{Calage_p}{100} \cdot chord_{center} \cdot 1000 = 610.11743$$

Inputs

$GR \equiv 5.6$

$cd_{line} \equiv 1$

$A_{line} \equiv 0.2268$

$A_p \equiv 0.4387$

$cd_p \equiv 0.6$

$M_{wing} \equiv 5 \cdot kg$

$z_{pilot} \equiv 4.770 \cdot m$

Inputs from xflr5

$$V \equiv 12.7 \frac{m}{sec}$$

$\alpha \equiv 9.45 \cdot deg$

$C_l \equiv 0.55619$

$C_d \equiv 0.03560$

$X_{cp} \equiv 489 \cdot mm$

$Z_{cp} \equiv 299 \cdot mm$

$chord_{mac} \equiv 1.919 \cdot m$

$chord_{center} \equiv 2.121 \cdot m$

$A \equiv 12.472 \cdot m^2$

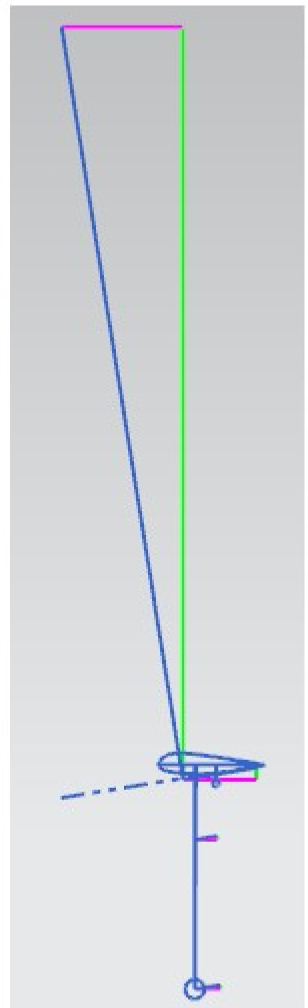
$z_{w\_cog} \equiv 0.361 \cdot m$

$x_{w\_cog} \equiv 1.142 \cdot m$

$$\frac{L}{D_w} = 15.623$$

$$\frac{L}{D_w + D_{we}} = 9.265$$

$$\frac{L}{D_w + D_{we} + D_{pilot} + D_{line}} = 5.6$$



Sketch representing lift and drag forces for GR 5.6 and center of pressure of xcp of 489 mm along the chord line from the leading edge

Discussion of the CFD and xflr5 results

Basically the Xflr5 results were tuned to the calculated GR of 5.7 from initial CFD wing results and extra wing drag due cell openings.

CFD

$\mathbf{L} = 748.331\,\mathbf{N}$

$\mathbf{D_w} = 72.862\,\mathbf{N}$

$$\frac{\mathbf{L}}{\mathbf{D_w}} = 10.271$$

$\mathbf{D_{we}} = 12.3\,\mathbf{N}$ ...vents estimate

To be verified by later cfd results when vents are included

$$\frac{\mathbf{L}}{\mathbf{D_w} + \mathbf{D_{we}}} = 8.787$$

$$\frac{\mathbf{L}}{\mathbf{D_w} + \mathbf{D_{we}} + \mathbf{D_p} + \mathbf{D_L}} = 5.603$$

$\mathbf{D_p} = 26\,\mathbf{N}$

$\mathbf{D_L} = 22.4\,\mathbf{N}$

Xflr5

$\mathbf{L} = 685.288$ .....

$\mathbf{D_w} = 52.726$

$$\frac{\mathbf{L}}{\mathbf{D_w}} = 15.623$$

$\mathbf{D_{we}} = 30.1$ ....vents+billowing estimate

To be verified by extra billow analyses in Xflr5. The LE program makes an estimation of billowing and this can be analysed by xflr5 but not yet implimented in LEP for analyses by xflr5

$$\frac{\mathbf{L}}{\mathbf{D_w} + \mathbf{D_{we}}} = 9.265$$

$$\frac{\mathbf{L}}{\mathbf{D_w} + \mathbf{D_{we}} + \mathbf{D_p} + \mathbf{D_{line}}} = 5.6$$

$\mathbf{D_p} = 26 \cdot \mathbf{N}$ same pilot drag

$\mathbf{D_{line}} = 22.4 \cdot \mathbf{N}$ same line drag

Uncertanty in xcp due to billowing and cell openings/vent

There are a difference between the xcp and zcp calculated by CFD and XFLR5. See below. The cfd includes billowing without the opening and xflr5 does not have either. CFD further does not have the reduced effect of billowing due to the miniribs and there were some kinks/folds from the LEP stl output. It is possile to vary the xcp and see effect of longitudinal balance. Assuming that cm effect is small.

CFD	**Xflr5**
Xcp = 27.8%	**Xcp =** 23%
Zcp = 16%	**Zcp =** 14.1%

The effect of moving xcp 100 mm back from 23 % to 27.8 % inline with the cfd result moves the Calage to 34 % at trim condition. Feedback from Eric that is currently testing the risers is that the CalageP was moved to 35 % on the inititial flight. Now awaiting more results

Outputs

$Calage_p = 33.8441$

$cp_{lepP} = 36.492$

$X_{cpP} = 27.77$

$Z_{cpP} = 14.097$

$M_{total} = 70.985$

$\theta = 10.125 \cdot deg$

$\delta = 0.675 \cdot deg$

$GR_w = 15.623$

$L = 685.288$

$D_w = 43.863$

$D_{we} = 30.101$

$D_{pilot} = 26.004$

$D_{line} = 22.406$

$cd_{we} = 0.024$

$cp_{lep} \cdot 1000 = 774.003386$

$\frac{Calage_p}{100} \cdot chord_{center} \cdot 1000 = 717.83289$

Inputs

$GR \equiv 5.6$

$cd_{line} \equiv 1$

$A_{line} \equiv 0.2268$

$A_p \equiv 0.4387$

$cd_p \equiv 0.6$

$M_{wing} \equiv 5 \cdot kg$

$z_{pilot} \equiv 4.770 \cdot m$

Inputs from xflr5

$V \equiv 12.7 \frac{m}{sec}$

$\alpha \equiv 9.45 \cdot deg$

$C_l \equiv 0.55619$

$C_d \equiv 0.03560$

$X_{cp} \equiv 589 \cdot mm$

$Z_{cp} \equiv 299 \cdot mm$

$chord_{mac} \equiv 1.919 \cdot m$

$chord_{center} \equiv 2.121 \cdot m$

$A \equiv 12.472 \cdot m^2$

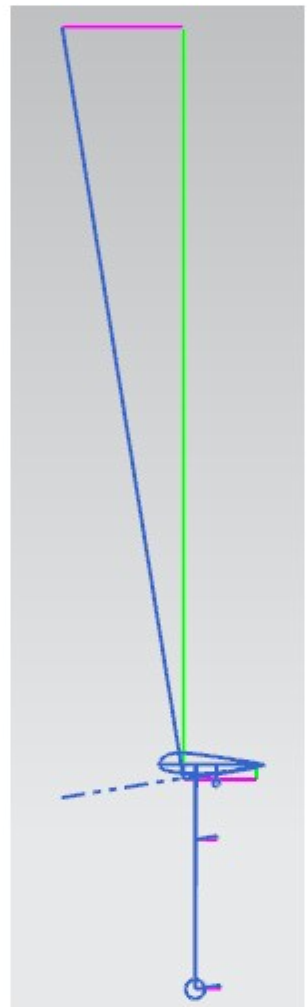
$z_{w\_cog} \equiv 0.361 \cdot m$

$x_{w\_cog} \equiv 1.142 \cdot m$

$\frac{L}{D_w} = 15.623$

$\frac{L}{D_w + D_{we}} = 9.265$

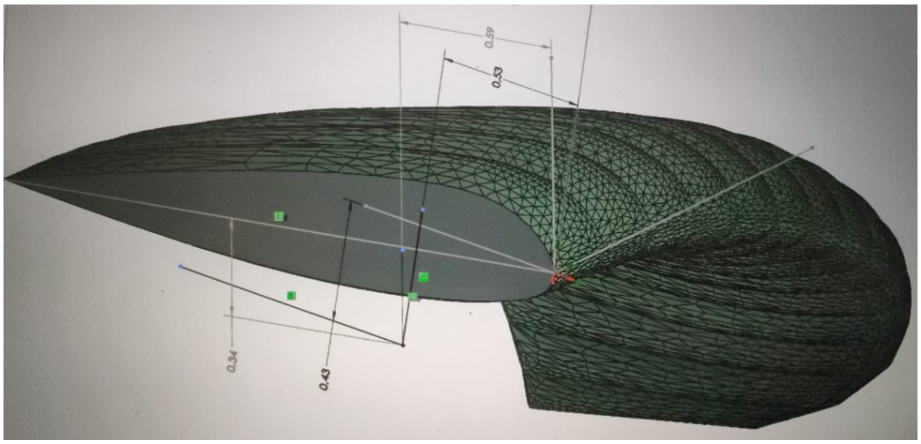
$\frac{L}{D_w + D_{we} + D_{pilot} + D_{line}} = 5.6$



Sketch representing lift and drag forces for GR 5.7 and center of pressure of xcp of 489 mm along the chord line from the leading edge

CFD Aerodynamic Center - where drag and lift act and where moments are zero

The aerodynamic center was calculated and the coordinated system then moved to the point and integration of forces redone to check if moments went to zero.
The resulting Cp at different AOA are shown below.



Calculated load action point - where moment is zero

AOA - 9.45 degrees

Profile orientation - Coordinate System at leading edge of center cell

Along the chordline - 0.59 m - 27.8 %
Below the chord line - 0.34 m - 16 %

AOA - 5.45 degrees

Profile orientation - Coordinate System at leading edge of center cell

Along the chordline - 0.571 m - 26.9 %   **xflr5**
Below the chord line - 0.36 m - 17 %

about 1 % movement with 4
degrees angle of attack

Conclusion

The results are interesting so far and I am starting to get a feel for how sensitive the glide ratio is for small changes in drag and all the important parameters.

Next steps are:

- Study papers referenced by BGD papers and checking their assumptions (G. Iosilevskii) - Francois
- To improve the calculations in Xflr5 by incorporating billowing and miniribs for reduced billowing and update this report.
- to include miniribs in the STL for further cfd analyses. I feel it is a waste of time to continue with cfd without the correct input.
- to calculate wing in steady state condition in flight by assuming a fixed pilot postition and calculating AOA and GR as a function of pilot input. Initial analyses with no brake input as answer should match inititial longitudinal balance at trim speed. (Mathcad - Francois)
- As above with speedbar (without and with input)
- to calculate wing in steady state condition on ground (Tow point) by assuming a fixed pilot postition and calculating AOA and GR as a function of pilot input (Mathcad)
- Dynamic Analysis to simulate in flight (smiliaras per BGD paper)
- To complete CFD on Hegela including cell openings and effect of miniribs

Special note

Special thanks to Pere currently building the Aerodynamic calculations into LEP and also for providing the part that writes out the required information for Xflr5 wing analyses. Looking forward to work with LEP many more hours and looking forward to LEP upgrades in the future to make analysing wings easier.

APPENDIX A

Pilot and line drag for 3.19
and Hegela

First run of hegela cfd was set 13.88 m/sec but the carry force was 92 kg so scaled with velocity to 12.7 m/sec to have same carrying force as 3.19 so we can compare apples with apples

$$A_p := 0.44 \cdot m^2 \quad cd := 0.5 \qquad VV := \begin{pmatrix} 11 \\ 12.7 \\ 13.89 \end{pmatrix} \cdot \frac{m}{sec} \quad VV = \begin{pmatrix} 39.6 \\ 45.72 \\ 50.004 \end{pmatrix} \cdot \frac{km}{hr}$$

$$Drag_{pilot}(V, A) := cd \cdot \frac{1}{2} \cdot \rho \cdot V^2 \cdot A$$

$$Drag_{pilot}(VV, A_p) = \begin{pmatrix} 16.305 \\ 21.734 \\ 25.998 \end{pmatrix} N$$

3.19
helega
helega at speed

Line drag $\quad cd_{line} := 1.3 \qquad A_l := .28 \cdot m^2 \qquad f := \frac{147}{407}$ line length ratio assuming same ratio of thin and thick lines

$$Drag_{line}(V, A) := cd_{line} \cdot \frac{1}{2} \cdot \rho \cdot V^2 \cdot A \qquad A_l \cdot f = 0.101\, m^2$$

$$Drag_{line}(VV_0, A_l) = 26.977\, N$$ drag of 3.19

$$Drag_{line}(VV_1, A_l \cdot f) = 12.988\, N$$ drag of hegela (big assumption in factor)

$$Drag_{line}(VV_2, A_l \cdot f) = 15.536\, N$$ drag of hegela at speed (big assumption in factor)

$$Drag_{pilot}(VV_0, A_p) + Drag_{line}(VV_0, A_l) = 43.282\, N$$ drag for 3.19

$$Drag_{pilot}(VV_1, A_p) + Drag_{line}(VV_1, A_l \cdot f) = 34.722\, N$$ drag for hegela

$$Drag_{pilot}(VV_2, A_p) + Drag_{line}(VV_2, A_l \cdot f) = 41.533\, N$$ drag for hegela

Conclusion without proper calc on hegela drag: The higher pilot drag due to faster hegela wing is offset by the lower drag of the line length.

APPENDIX B

Drag around cylinder for determining the drag on paraglider lines — **JF de Villiers**, **13/06/2022**

Introduction

This calc to determine the drag for paraglider lines including the effect of reynolds nr. The final aim is also to calculate the drag of lines in various lines thickness and line orientations. When creating a loop the resulting stitched line can either be two cylinders aligned with the flow or next to one another perpendicular and crossed with the flow and well as a few multiple line connections. Below the calc for a single lines only

Ref 1

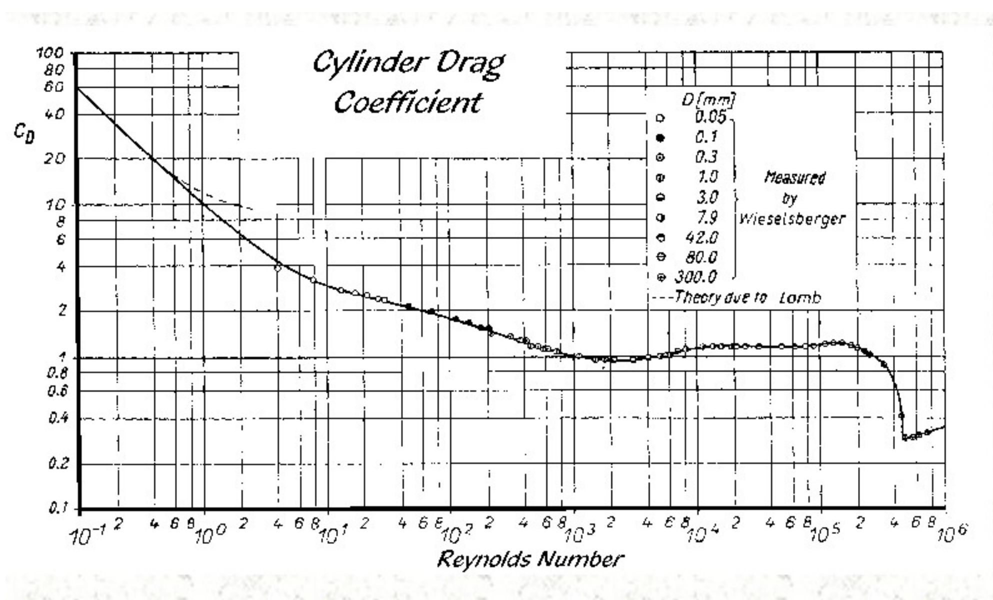


Fig 1: Ref Measured by Wieseisberger

Ref 2

White (1991)	Fit to single-cylinder experimental data $C_D = 1 + 10.0\mathrm{R}_d^{-2/3}$

[a]The pseudofluid model has an S term, but this is omitted here. For $S \leq 1/100$, differences to estimated C_D value are within $\pm 1\%$.

[b]$C_{D\mathrm{White}}$ refers to the White (1991) function.

Digitised from the graph above the X and Y values
for only part of the graph we are interested

$$\mathbf{X} := \begin{pmatrix} \mathbf{10} \\ \mathbf{22.6324} \\ \mathbf{54.937} \\ \mathbf{115.928} \\ \mathbf{256.321} \\ \mathbf{470.216} \\ \mathbf{992.251} \\ \mathbf{1778.28} \\ \mathbf{2971.48} \\ \mathbf{6125.79} \\ \mathbf{9769.33} \end{pmatrix} \qquad \mathbf{Y} := \begin{pmatrix} \mathbf{2.90999} \\ \mathbf{2.40799} \\ \mathbf{2.02985} \\ \mathbf{1.71174} \\ \mathbf{1.41654} \\ \mathbf{1.17284} \\ \mathbf{1.00772} \\ \mathbf{0.93356} \\ \mathbf{0.914978} \\ \mathbf{1.06067} \\ \mathbf{1.1205} \end{pmatrix}$$

Using linear interpolation and testing

$$\mathbf{cd}(\mathbf{x}) := \mathbf{linterp}(\mathbf{X}, \mathbf{Y}, \mathbf{x})$$

$\mathbf{cd}(115.928) = 1.712$ ....test

$\mathbf{cd}(992.251) = 1.008$ ...test

Typical conditions at sea level

$$\mathbf{P} := 101.3 \cdot \mathbf{kPa} \qquad \mathbf{R} := 287 \cdot \frac{\mathbf{joule}}{\mathbf{kg} \cdot \mathbf{K}} \qquad \mathbf{T} := 293 \cdot \mathbf{K} \qquad \mu := 1.81 \cdot 10^{-5} \cdot \mathbf{Pa} \cdot \mathbf{sec}$$

$$\rho := \frac{\mathbf{P}}{\mathbf{R} \cdot \mathbf{T}} \qquad \rho = 1.205 \frac{\mathbf{kg}}{\mathbf{m}^3} \qquad \mathbf{Re}(\mathbf{d}, \mathbf{V}) := \frac{\rho \cdot \mathbf{d} \cdot \mathbf{V}}{\mu}$$

$\mathbf{V} := 39 \cdot \frac{\mathbf{km}}{\mathbf{hr}}$ ....typical trim speed of paraglider

Wieselsberger

$$\mathbf{D} := \begin{pmatrix} 0.015 \\ 0.5 \\ 1 \\ 1.5 \\ 2 \end{pmatrix} \cdot \mathbf{mm} \quad \mathbf{Re}(\mathbf{D}, \mathbf{V}) = \begin{pmatrix} 11 \\ 361 \\ 721 \\ 1082 \\ 1442 \end{pmatrix} \qquad \mathbf{cd}(\mathbf{Re}(\mathbf{D}, \mathbf{V})) = \begin{pmatrix} 2.878 \\ 1.298 \\ 1.094 \\ 0.999 \\ 0.965 \end{pmatrix}$$

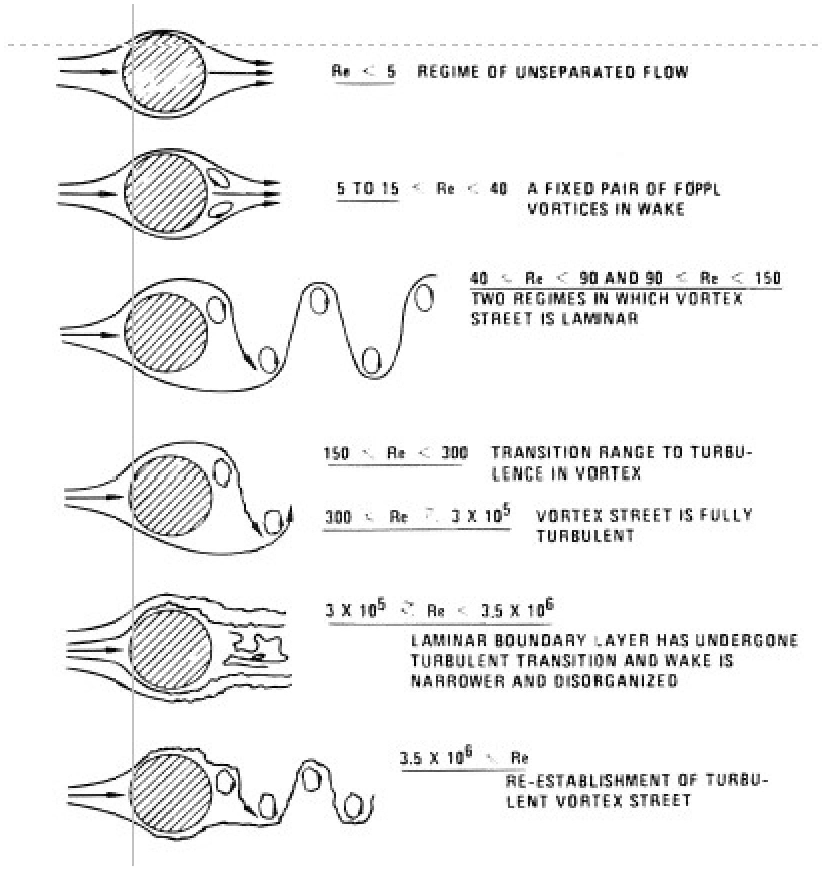
1082

The variation of reynolds number on a paraglider varies between 7 and 2500

$$\mathbf{Re}\left(\mathbf{D}, 25 \cdot \frac{\mathbf{km}}{\mathbf{hr}}\right) = \begin{pmatrix} 7 \\ 231 \\ 462 \\ 693 \\ 924 \end{pmatrix} \qquad \mathbf{Re}\left(\mathbf{D}, 65 \cdot \frac{\mathbf{km}}{\mathbf{hr}}\right) = \begin{pmatrix} 18 \\ 601 \\ 1202 \\ 1803 \\ 2403 \end{pmatrix}$$

Reference from white seems close to Weisener and its a simple equation

$$\mathbf{cd_w}(\mathbf{d},\mathbf{V}) := \left(10\cdot\mathbf{Re}(\mathbf{d},\mathbf{V})^{\frac{-2}{3}} + 1\right)$$ White for single cylinder $$\overrightarrow{\mathbf{cd_w}(\mathbf{D},\mathbf{V})} = \begin{pmatrix} 3.045 \\ 1.197 \\ 1.124 \\ 1.095 \\ 1.078 \end{pmatrix}$$



1

2

3

4

5

6

From Blevins, R. D. (1990), Flow Induced Vibration, 2nd Edn., Van Nostrand Reinhold Co.

The flow regimes for paraglider lines falls between 2 and 4 above

Since the drag force is so small per meter the calc below is shown per 100 m

$$\mathbf{L} := 100\cdot\mathbf{m}$$

$$\mathbf{F_{weis}}(\mathbf{d},\mathbf{V}) := \mathbf{cd}(\mathbf{Re}(\mathbf{d},\mathbf{V}))\cdot\frac{1}{2}\cdot\rho\cdot\mathbf{V}^2\cdot\mathbf{d}\cdot\mathbf{L} \qquad \mathbf{F_{white}}(\mathbf{d},\mathbf{V}) := \mathbf{cd_w}(\mathbf{d},\mathbf{V})\cdot\frac{1}{2}\cdot\rho\cdot\mathbf{V}^2\cdot\mathbf{d}\cdot\mathbf{L}$$

$$\frac{\mathbf{D}}{\mathbf{mm}} = \begin{pmatrix} 0.015 \\ 0.5 \\ 1 \\ 1.5 \\ 2 \end{pmatrix} \qquad \overset{\textbf{Trim}}{\overrightarrow{\mathbf{F_{weis}}\left(\mathbf{D}, 39\cdot\frac{\mathbf{km}}{\mathbf{hr}}\right)} = \begin{pmatrix} 0.305 \\ 4.587 \\ 7.73 \\ 10.596 \\ 13.647 \end{pmatrix}\cdot\mathbf{N}} \qquad \overset{\textbf{Max}}{\overrightarrow{\mathbf{F_{weis}}\left(\mathbf{D}, 55\cdot\frac{\mathbf{km}}{\mathbf{hr}}\right)} = \begin{pmatrix} 0.57 \\ 8.159 \\ 14.135 \\ 20.191 \\ 26.138 \end{pmatrix}\mathbf{N}}$$

To make comparison between white and weisner at trim speed

$\mathbf{f} := 4.6$ ....factor to scale values to line drag of gnu A6

$$\mathbf{F_{weis\_t}} := \mathbf{f}\cdot\left[0.2\cdot\overrightarrow{\mathbf{F_{weis}}\left(\mathbf{D}, 39\cdot\frac{\mathbf{km}}{\mathbf{hr}}\right)}_4 + 0.2\cdot\overrightarrow{\mathbf{F_{weis}}\left(\mathbf{D}, 39\cdot\frac{\mathbf{km}}{\mathbf{hr}}\right)}_3 + 0.6\cdot\left(0.2\cdot\overrightarrow{\mathbf{F_{weis}}\left(\mathbf{D}, 39\cdot\frac{\mathbf{km}}{\mathbf{hr}}\right)}_2\right)\right.$$

$\mathbf{F_{weis\_t}} = 26.571\,\mathbf{N}$ ...typical value of gnu A6

20 % 2 mm 20 % 1.5 mm 60 % 1 mm

$$\mathbf{F_{white\_t}} := \mathbf{f}\cdot\left[0.2\cdot\overrightarrow{\mathbf{F_{white}}\left(\mathbf{D}, 39\cdot\frac{\mathbf{km}}{\mathbf{hr}}\right)}_4 + 0.2\cdot\overrightarrow{\mathbf{F_{white}}\left(\mathbf{D}, 39\cdot\frac{\mathbf{km}}{\mathbf{hr}}\right)}_3 + 0.6\cdot\left(0.2\cdot\overrightarrow{\mathbf{F_{white}}\left(\mathbf{D}, 39\cdot\frac{\mathbf{km}}{\mathbf{hr}}\right)}_2\right.\right.$$

$\mathbf{F_{white\_t}} = 29.094\,\mathbf{N}$ ....for comparison $\qquad \dfrac{\mathbf{F_{white\_t}} - \mathbf{F_{weis\_t}}}{\mathbf{F_{white\_t}}}\cdot 100 = 8.674$

Conclusion

Reynolds numbers have effect on thin lines between 0.5 and 2 mm where the cd varies between 1.3 to 0.965 from the references above The cd of 1.3 was used in the first calc of gnu A6 and will be corrected. There are some variation of cd factors in the literature and this is not the final result. The difference between 2 references above is already 8 % so its important to get accurate info and this is only for single lines. Other arrangments that needs to be considered and calculated by CFD are

1. Lines in tandem like in stitch format for a loop
2. Lines parallel to flow directions - as above in 1 but turned 90 degrees
3. Various lines in close proximity and making connections 1-1,1-2,1-3,1-4 etc
4. Single line comparision with White's equation
5. Effect of roughness of lines

The turbulence from lines ahead and in close proximity will also effect the cd factor. Its important to notice that the line drag will alway be a statistical value due to various possible arrangments during flight at each loop. The amount of variation can be determined once all the cd factors are determined.

Appendix C

The initial drag calculated for Helega was was based on a line factor from the line length ratio between Helega and gnu A6. Shown again below.

Line drag $cd_{line} := 1.3$ $\quad A_L := .28\cdot m^2$ $\quad f := \frac{147}{407}$ line length ratio assuming same ratio of thin and thick lines

$$Drag_{line}(V, A) := cd_{line}\cdot\frac{1}{2}\cdot\rho\cdot V^2\cdot A \qquad A_l\cdot f = 0.101\,m^2 \qquad f = 0.361$$

$$Drag_{line}\left(VV_1, A_l\cdot f\right) = 12.772\,N$$ drag of hegela (big assumption in factor)

More detail analyses were done in Excel (Hegelaline.xcl) for the line drag of Hegala at the two speeds and for various line thicknesses. The assumtion that a factor could be used turned out not to be true since thicker lines will be used on the Hegela according to Eric. The drag is twice that of the initital value and using thicker lines makes a huge difference. See below for a half wing

For half wing										
	13.89	m/sec								
		Lower	Upper Lines		Avg Dr	Min D	Max I	GR (avg drag)		
		[mm]	[mm]		[N]	[N]	[N]			
Hegala Line Force		2	1		12.0	11.0	13.1	5.7		
Hegala Line Force		1	0.5		6.8	6.2	7.4	6.3		
Hegala Line Force		2	0.5		8.8	8.1	9.5	6		
Hegala Line Force		2	2		18.2	16.6	19.9	5		
Hegala Line Force		2	1.5		15.2	13.8	16.5	5.3		
12.7	m/sec	Lower Lines	Upper Lines		Avg Drag	Min Drag	Max Drag	GR	GR	GR
		[mm]	[mm]		[N]	[N]	[N]	avg drag	min drag	max drag
Hegala Line Force		2	1		10.2	9.4	11.1	6.5	6.6	6.4
Hegala Line Force		1	0.5		5.9	5.3	6.4	7.0		
Hegala Line Force		2	0.5		7.5	6.9	8.2	6.8		
Hegala Line Force		2	2		15.3	14.0	16.7	6.0		
Hegala Line Force		2	1.5		12.8	11.7	14.0	6.2		

Conclusion It makes a 1 point on GR difference between choosing lines upper/lower of 2/2 and 1/0.5 with resulting GR of 6 to 7. The orientation of the loops relative to flow direction only makes a difference of 0.1 on GR

Appendix D

According to Eric he splices all his lines. The loops are twice the diameter of the initial diameter. Find the drag below as a resulting splicing. For 2/1.5 line cascade the drag is the same for both stitching and splicing methods. Eric thinks he might be using 2 and 1.2 mm which is 22.4 N line drag at trim speed

For half wing						
	13.89	m/sec				
		Lower	Upper Lines			Min Drag
		[mm]	[mm]			[N]
Hegala Line Force		2	2			18.2
Hegala Line Force		2	1.5			15.2
Hegala Line Force		2	1.2			13.3
Hegala Line Force		1.5	0.5			7.8
	12.7 m/sec	Lower Lines	Upper Lines		Avg Drag	
		[mm]	[mm]		[N]	
Hegala Line Force		2	2			15.3
Hegala Line Force		2	1.5			12.8
Hegala Line Force		2	1.2			11.2
Hegala Line Force		1.5	0.5			6.7

Appendix E 12/08/2022

This worksheet uses a solve block to calculate the wingposition of a pilot under a paraglider wing given input parameters from the LEP program and XFLR5. The input and output paramaters are at then end of the worksheet and uses global variables.

$\rho := 1.225 \cdot \frac{kg}{m^3}$ ...design density

Initial conditions for the solve block

$L := 1000$ $D_w := 50$ $D_{we} := D_w$ $D_{line} := 20$ $D_{pilot} := 40$ $cd_{we} := 1$

$cp_{lep} := 1$ $x_{lh} := 1$ $z_{hv} := 1$ $x_{pilot} := 1.5$ $X_{wing} := 1$ $M_{pilot} := 100$

$M_{total} := 100$ $Calage := 1$ $cp_{lepP} := 1$ $Calage_p := 100$ $GR_w := 1$ $\theta := 15 \cdot deg$

$x_{pilot2} := 1$ $z_{vp} := 1$ $X_{cpP} := 1$ $Z_{cpP} := 1$ $\delta := 10 \cdot deg$ $c_m := 0$

Making variable defined at the end of the worksheet dimensionless

$z_{pilot} := \frac{z_{pilot}}{m}$ $chord_{mac} := \frac{chord_{mac}}{m}$ $M_{wing} := \frac{M_{wing}}{kg}$ $chord_{center} := \frac{chord_{center}}{m}$

$x_{w\_cog} := \frac{x_{w\_cog}}{m}$ $z_{w\_cog} := \frac{z_{w\_cog}}{m}$ $Z_{cp} := \frac{Z_{cp}}{m}$ $X_{cp} := \frac{X_{cp}}{m}$

$\rho := \frac{\rho}{\frac{kg}{m^3}}$ $V := \frac{V}{\frac{m}{sec}}$ $A := \frac{A}{m^2}$ $g := \frac{g}{\frac{m}{sec^2}}$

Solve block

Given

$$L = C_l \cdot \frac{1}{2} \cdot \rho \cdot V^2 \cdot A$$

$$D_w = C_d \cdot \frac{1}{2} \cdot \rho \cdot V^2 \cdot A$$

$$D_{pilot} = cd_p \cdot \frac{1}{2} \cdot \rho \cdot V^2 \cdot A_p$$

$$D_{line} = cd_{line} \cdot \left(\frac{1}{2} \cdot \rho \cdot V^2\right) \cdot A_{line}$$

$$D_{we} = cd_{we} \cdot \left(\frac{1}{2} \cdot \rho \cdot V^2 \cdot A\right)$$

$$X_{wing} = \left(x_{w\_cog} + z_{w\_cog} \cdot \tan(\theta - \alpha)\right) \cdot \cos(\theta - \alpha)$$

$$z_{hv} = \frac{Z_{cp}}{\cos(\theta-\alpha)} - x_{lh}\cdot\tan(\theta-\alpha)$$

$$x_{lh} = \left(Z_{cp}\cdot\tan(\theta-\alpha) + X_{cp}\right)\cdot\cos(\theta-\alpha)$$

$$x_{pilot2} = cp_{lep}\cdot\cos(\theta-\alpha) - \left(Z_{cp}\cdot\tan(\theta-\alpha) + X_{cp}\right)\cdot\cos(\theta-\alpha)$$

$$z_{vp} = \frac{z_{pilot}}{\cos(\theta-\alpha)} - cp_{lep}\cdot\sin(\theta-\alpha) - z_{hv}$$

$$L\cdot\cos(\theta) + \left(D_w + D_{we}\right)\cdot\sin(\theta) + D_{pilot}\cdot\sin(\theta) + D_{line}\cdot\sin(\theta) - M_{pilot}\cdot g - M_{wing}\cdot g = 0$$

$$L\cdot\sin(\theta) - \left(D_w + D_{we}\right)\cdot\cos(\theta) - D_{pilot}\cdot\cos(\theta) - D_{line}\cdot\cos(\theta) = 0$$

$$\left(D_{line}\cdot\sin(\theta) + D_{pilot}\cdot\sin(\theta) - M_{pilot}\cdot g\right)\cdot x_{pilot2} - M_{wing}\cdot g\cdot\left(X_{wing} - x_{lh}\right) + D_{line}\cdot\cos(\theta)\cdot\left(\frac{1}{3}\right.$$

$$M_{total} = M_{pilot} + M_{wing}$$

$$GR_w = \frac{C_l}{C_d}$$

$$cp_{lepP} = \frac{cp_{lep}}{chord_{center}}\cdot 100$$

$$\theta = \operatorname{atan}\left(\frac{1}{GR}\right)$$

$$\delta = \theta - \alpha$$

$$Calage_p = 100\cdot\frac{cp_{lep} - z_{pilot}\cdot\tan\left(\operatorname{atan}\left(\frac{1}{GR}\right) - \alpha\right)}{chord_{center}}$$

$$X_{cpP} = \frac{X_{cp}}{chord_{center}}\cdot 100 \qquad Z_{cpP} = \frac{Z_{cp}}{chord_{center}}\cdot 100$$

$$\begin{pmatrix} cp_{lep} \\ D_{pilot} \\ M_{pilot} \\ x_{lh} \\ z_{hv} \\ X_{wing} \\ x_{pilot2} \\ z_{vp} \\ D_{line} \\ L \\ D_{w} \\ D_{we} \\ M_{total} \\ Calage_{p} \\ \theta \\ GR_{w} \\ cd_{we} \\ \delta \\ cp_{lepP} \\ X_{cpP} \\ Z_{cpP} \end{pmatrix} := \mathrm{Find}\left(cp_{lep}, D_{pilot}, M_{pilot}, x_{lh}, z_{hv}, X_{wing}, x_{pilot2}, z_{vp}, D_{line}, L, D_{w}, D_{we}, M\right.$$

Test

$$L\cdot\cos(\theta) + \left(D_{w} + D_{we}\right)\cdot\sin(\theta) + D_{pilot}\cdot\sin(\theta) + D_{line}\cdot\sin(\theta) - M_{pilot}\cdot g - M_{wing}\cdot g =$$

$$L\cdot\sin(\theta) - \left(D_{w} + D_{we}\right)\cdot\cos(\theta) - D_{pilot}\cdot\cos(\theta) - D_{line}\cdot\cos(\theta) =$$

$$\left(D_{line}\cdot\sin(\theta) + D_{pilot}\cdot\sin(\theta) - M_{pilot}\cdot g\right)\cdot x_{pilot2} - M_{wing}\cdot g\cdot\left(X_{wing} - x_{lh}\right) + D_{line}\cdot\cos(\theta)\cdot\left(\frac{1}{3}\cdot z\right.$$

Outputs

$Calage_p = 28.7656$

$cp_{lepP} = 31.414$

$X_{cpP} = 23.055$

$Z_{cpP} = 14.097$

$M_{total} = 70.985$

$\theta = 10.125 \cdot deg$

$\delta = 0.675 \cdot deg$

$GR_w = 15.623$

$L = 685.288$

$D_w = 43.863$

$D_{we} = 30.101$

$D_{pilot} = 26.004$

$D_{line} = 22.406$

$cd_{we} = 0.024$

$cp_{lep} \cdot 1000 = 666.2879301$

$\frac{Calage_p}{100} \cdot chord_{center} \cdot 1000 = 610.11743$

Inputs

$GR \equiv 5.6$

$cd_{line} \equiv 1$

$A_{line} \equiv 0.2268$

$A_p \equiv 0.4387$

$cd_p \equiv 0.6$

$M_{wing} \equiv 5 \cdot kg$

$z_{pilot} \equiv 4.770 \cdot m$

Inputs from xflr5

$V \equiv 12.7 \frac{m}{sec}$

$\alpha \equiv 9.45 \cdot deg$

$C_l \equiv 0.55619$

$C_d \equiv 0.03560$

$X_{cp} \equiv 489 \cdot mm$

$Z_{cp} \equiv 299 \cdot mm$

$chord_{mac} \equiv 1.919 \cdot m$

$chord_{center} \equiv 2.121 \cdot m$

$A \equiv 12.472 \cdot m^2$

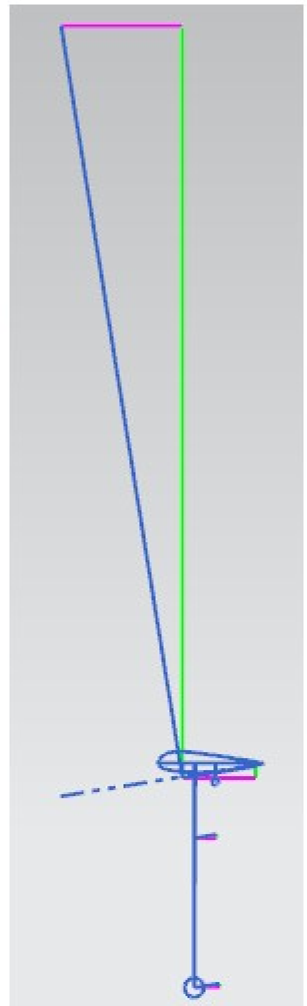
$z_{w\_cog} \equiv 0.361 \cdot m$

$x_{w\_cog} \equiv 1.142 \cdot m$

$\frac{L}{D_w} = 15.623$

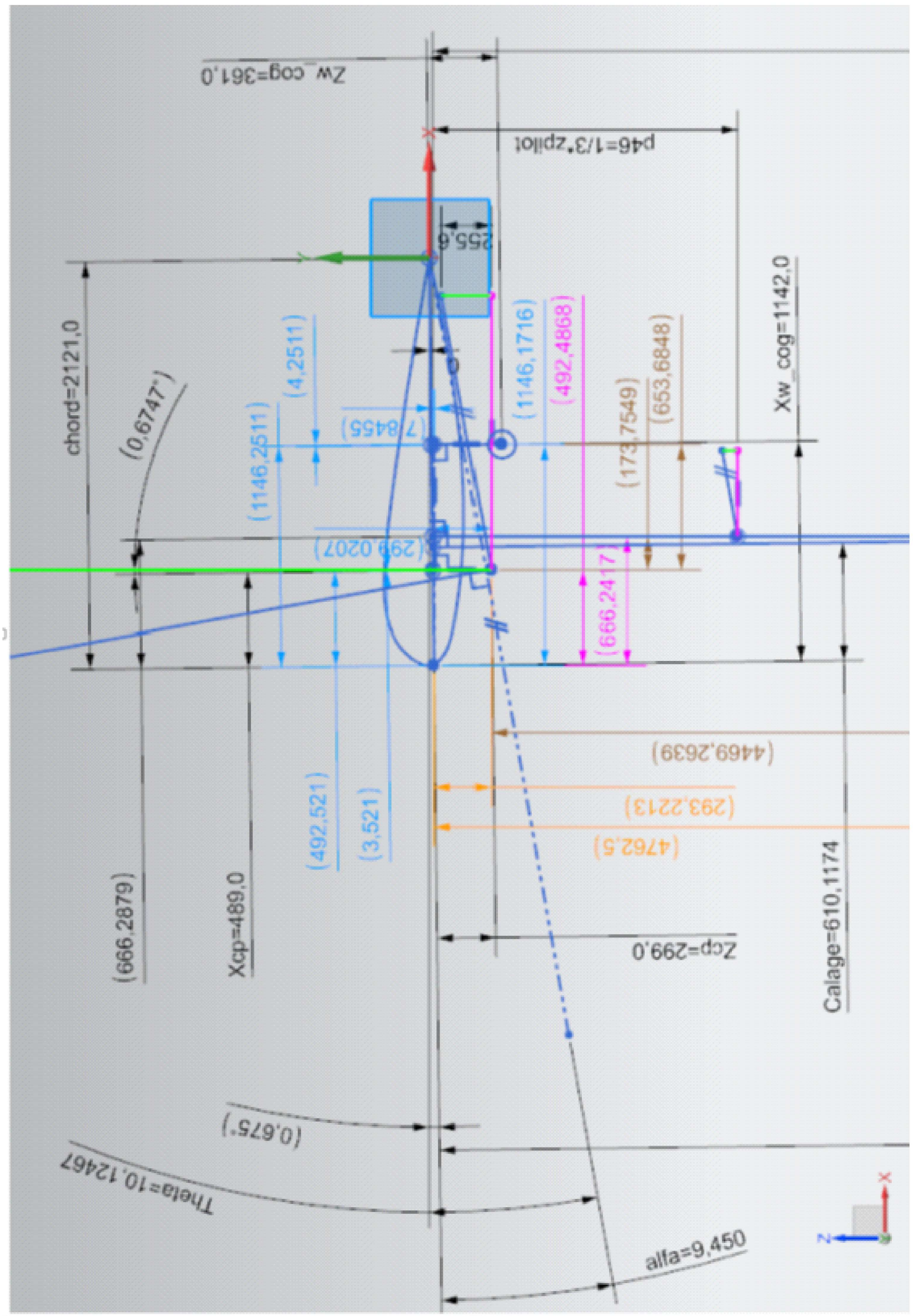
$\frac{L}{D_w + D_{we}} = 9.265$

$\frac{L}{D_w + D_{we} + D_{pilot} + D_{line}} = 5.6$



Sketch representing lift and drag forces for GR 5.7 and center of pressure of xcp of 489 mm along the chord line from the leading edge

Trim speed, no brakes



Parametric cad model matching Mathcad 100 %

$$\cdot z_{pilot} - z_{hv}\Big) + D_{pilot} \cdot \cos(\theta) \cdot z_{vp} + c_m \cdot \left(\frac{1}{2} \cdot \rho \cdot V^2 \cdot A\right) \cdot chord_{mac} = 0$$

$\mathbf{total}, \mathbf{Calage_p}, \theta, \mathbf{GR_w}, \mathbf{cd_{we}}, \delta, \mathbf{cp_{lepP}}, \mathbf{X_{cpP}}, \mathbf{Z_{cpP}}\Big) =$

$\mathbf{pilot} - \mathbf{z_{hv}}\Big) + \mathbf{D_{pilot}} \cdot \cos(\theta) \cdot \mathbf{z_{vp}} + \mathbf{c_m} \cdot \left(\frac{1}{2} \cdot \rho \cdot \mathbf{V}^2 \cdot \mathbf{A}\right) \cdot \mathbf{chord_{mac}} =$