SparrowHawk Tail Boom Load Calculations Report

Thomas Greenhill 12.20.2019

Using AVL and XFoil for validation, the tail boom tension-compression loads associated with pithing and yawing control inputs for the SparrowHawk were calculated. All load calculations were performed neglecting fuselage lift for simplicity. The wing and tail .avl file named "SH_With_Tail_Final_1.AVL" can be found here. The run case files can be found here. Unless otherwise specified, the presented lift coefficients are referenced to the geometry of their respective surfaces and not to the geometry of the entire aircraft.

Contents

Load Case Description & Procedure

I. Pitch Tension-Compression:

1. Looping flight at VA at stall CL (CL 1.4) to determine whether required elevator deflection to perform a such maneuver is physically possible.
2. Straight and level flight when full up elevator deflection is applied at VA.
3. Looping flight with full up elevator deflection at VA.
4. Straight and level flight when full down elevator deflection is applied at VA.
5. Looping flight with full down elevator deflection at VA.
6. Full down elevator deflection applied at α found in (3).
7. Full up elevator deflection applied at α found in (5).
8. +5.48G pull from level flight (max loading as prescribed by flight manual) at VNE.
9. -4.0G push from level flight (min loading as prescribed by flight manual) at VNE.

II. Yaw Tension-Compression

10. Max rudder deflection in no sideslip flight at VA.
11. Max left rudder applied when in max right sideslip condition at VA.

Constants:

Air Properties: (STP)

$\rho = 1.225\ kg/m^3$

$\upsilon = \ 1.5111 * 10^{-5} \frac{m^2}{s}$

$\mu = 1.81 * 10^{-5} Pa * s$

Speeds & Re: (Ma numbers calculated at STP)

VA = 80 kn = 41.156 m/s = 0.119987 Mach

VNE = 123 kn = 63.3 m/s = 0.184548 Mach

$Re_{wing,VA} = 2{,}033{,}000$

$Re_{wing,VNE} = 3{,}127{,}000$

Mach numbers for VA & VNE are below 0.3, flow is said to be incompressible.

Geometry:

Wing chord CRef or CMAC = 0.73 m

Surface area SRef = 6.5 m^2

Wingspan BRef = 11.0 m

H Stab Surface Area S_{HStab} = 0.59 m^2

V Stab Surface Area S_{VStab} = 0.61 m^2

Wing Airfoil   Horizontal Stab Airfoil   Vertical Stab Airfoil   Fuselage

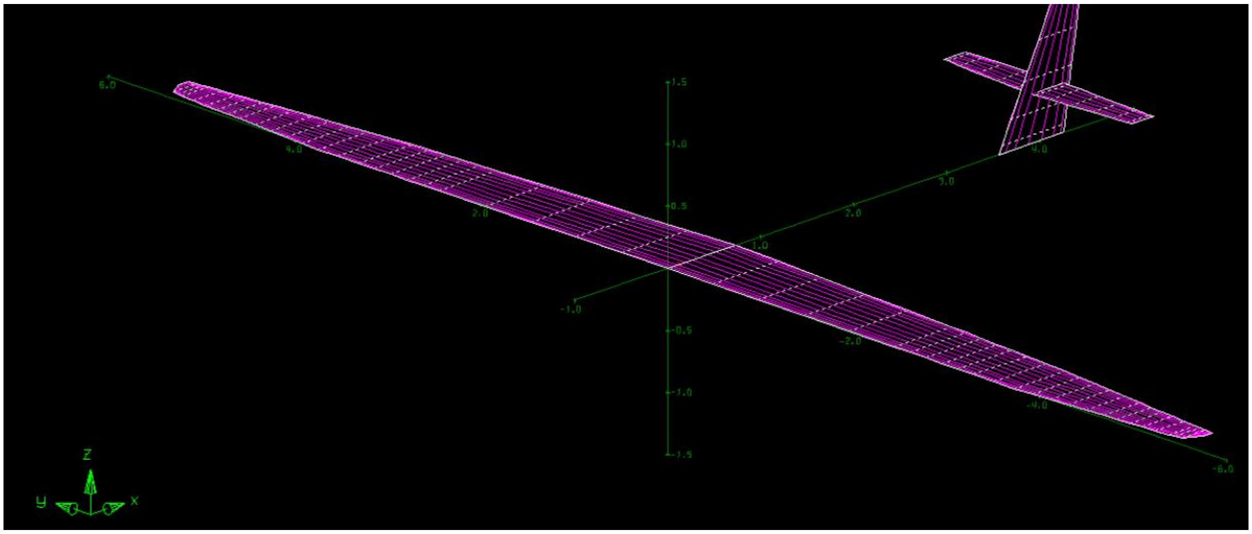
A detailed spreadsheet of SH geometry can be found here.

Inertial Properties: (Max gross at fore CG limit)

Mass = 484 lb. = 219.5 kg

X_{CG} = 15% MAC = 4.613 in = 0.117 m (from flight manual: measured towards tail from wing LE with MAC = 25.341 in and distance from wing LE to MAC LE = 0.812 in)

All directions are in accordance with the +x,y,z directions shown in the following figure with (0,0,0) at the LE of the wing at root.



Execution

I. Pitch Tension-Compression

1. Looping flight at VA at stall CL

This case is examined to determine whether the airframe is limited by stall or full up elevator deflection (FUED) at VA. This provides insight to the physical feasibility of certain load cases.

CL_{stall} = 1.4 See *XFoil Documentation.docx*

Wing pitching moment determined by XFoil analysis for α = 0:1:21. Results of the analysis is shown in the table below. Complete results of the analysis are available here.

alpha	*CL*	*CD*	*CDp*	*CM*	*Top_Xtr*	*Bot_Xtr*
0.000	*0.3067*	*0.00712*	*0.00133*	*-0.0576*	*0.6257*	*0.0520*
0.000	*0.3067*	*0.00712*	*0.00133*	*-0.0576*	*0.6257*	*0.0520*
1.000	*0.3363*	*0.00525*	*0.00112*	*-0.0401*	*0.6134*	*0.6193*
2.000	*0.3876*	*0.00470*	*0.00124*	*-0.0264*	*0.5943*	*0.8555*
3.000	*0.4811*	*0.00483*	*0.00139*	*-0.0224*	*0.5646*	*0.8920*
5.000	*0.7389*	*0.00730*	*0.00293*	*-0.0334*	*0.3103*	*0.9453*
6.000	*0.8311*	*0.00892*	*0.00406*	*-0.0311*	*0.2018*	*0.9676*
7.000	*0.9051*	*0.01048*	*0.00538*	*-0.0247*	*0.1466*	*0.9864*
8.000	*1.0198*	*0.01167*	*0.00643*	*-0.0278*	*0.1171*	*0.9920*
9.000	*1.0967*	*0.01487*	*0.00907*	*-0.0257*	*0.0283*	*0.9987*
10.000	*1.1667*	*0.01676*	*0.01101*	*-0.0209*	*0.0208*	*1.0000*
11.000	*1.2174*	*0.01904*	*0.01340*	*-0.0129*	*0.0193*	*1.0000*
12.000	*1.2658*	*0.02185*	*0.01634*	*-0.0057*	*0.0179*	*1.0000*
13.000	*1.3043*	*0.02555*	*0.02026*	*0.0017*	*0.0158*	*1.0000*
14.000	*1.3328*	*0.03033*	*0.02529*	*0.0088*	*0.0144*	*1.0000*
15.000	*1.3648*	*0.03518*	*0.03030*	*0.0143*	*0.0140*	*1.0000*
16.000	*1.3821*	*0.04161*	*0.03699*	*0.0197*	*0.0136*	*1.0000*
17.000	*1.3966*	*0.04888*	*0.04449*	*0.0237*	*0.0130*	*1.0000*
18.000	*1.3943*	*0.05892*	*0.05482*	*0.0258*	*0.0126*	*1.0000*
19.000	*1.3966*	*0.06967*	*0.06580*	*0.0255*	*0.0118*	*1.0000*
20.000	*1.3898*	*0.08244*	*0.07880*	*0.0231*	*0.0111*	*1.0000*
21.000	*1.3563*	*0.09959*	*0.09627*	*0.0180*	*0.0104*	*1.0000*
22.000	*1.2978*	*0.12165*	*0.11871*	*0.0091*	*0.0101*	*1.0000*
23.000	*1.2346*	*0.14531*	*0.14273*	*-0.0023*	*0.0097*	*1.0000*

From the highlighted values, the pitching moment coefficient during looping flight will be somewhere between 0 and 0.025.

First Cm pitchmom = 0.000 is set in AVL.

For this case, the angle of attack is found to be α = 14.15 deg and the necessary elevator deflection is found to be 38.95 deg.

Next, Cm pitchmom = 0.025 is set in AVL.

For this case, the angle of attack is found to be α = 14.21 deg and the necessary elevator deflection is found to be 40.41 deg.

Since the maximum elevator deflection is 22 degrees and the elevator deflection required to stall the wing is around 40 degrees, the airframe is clearly limited by elevator deflection and not stall.

2. **Straight and level flight when full up elevator deflection (FUED) is applied**

This case is used to determine the surface forces with FUED at VA starting in straight and level flight (CL = 0.319). These results are also checked using XFoil with the horizontal stabilizer airfoil (NACA 1315) at FUED.

Results from AVL:

Horizontal stabilizer lift coefficient $\boldsymbol{CL_{HStab}}$ **= -0.65**

Horizontal stabilizer total force: $\boldsymbol{L_{HStab}}$ **= -396.37 N**

α = 3.33

Results from XFoil:

Horizontal stabilizer lift coefficient $\boldsymbol{CL_{HStab}}$ **= -0.73**

Horizontal stabilizer total force: $\boldsymbol{L_{HStab}}$ **= -447.1 N**

3. Looping flight with FUED

This case is used to check for reasonable-ness and will later be used to calculate what I expect to be the maximum upwards pitch load: applying full down elevator deflection after reaching equilibrium angle of attack with full up elevator deflection.

Results: α = 10.11 deg, CL_{Wing} = 1.0669, CL_{HStab} = -0.1068

Reasonable-ness check:

In looping flight at VA, total airframe lift $L_{aiframe}$ = 6773 N which give a load factor of approximately 3.15G. Note that this value is less than the maximum load factor of 5.48G as prescribed in the flight manual. <u>This seems reasonable</u>.

4. Straight and level flight when full down elevator deflection (FDED) is applied.

This case is used to determine the surface forces with FDED at VA starting in straight and level flight (CL = 0.319). These results are also checked using XFoil with the horizontal stabilizer airfoil at FDED.

Results from AVL:

Horizontal stabilizer lift coefficient $\boldsymbol{CL_{HStab}}$ **= 1.04**

Horizontal stabilizer total force: $\boldsymbol{L_{HStab}}$ **= 636.90 N**

α = 1.63

Results from XFoil:

Horizontal stabilizer lift coefficient $\boldsymbol{CL_{HStab}}$ **= 1.1629**

Horizontal stabilizer total force: $\boldsymbol{L_{HStab}}$ **= 712.16 N**

5. Looping flight with FDED

This case is used to check for reasonable-ness and will later be used to calculate what I expect to be the maximum downwards pitch load: applying full up elevator deflection after reaching equilibrium angle of attack with full down elevator deflection.

Results: α = -13.85 deg, CL_{Wing} = -1.272, CL_{HStab} = 0.0587

Reasonable-ness check:

In outside-looping flight at VA, total airframe lift $L_{aiframe}$ = -8116.38 N which give a load factor of approximately -3.77. Note that the absolute value of this load factor is less than the absolute value of the minimum load factor of -4.0G as prescribed in the flight manual. This seems reasonable.

6. FDED with α = 10.11 as found in (3)

This is expected to be the maximum upwards pitch load. Results are calculated in AVL and checked with XFoil.

Results from AVL:

Horizontal stabilizer lift coefficient $\boldsymbol{CL_{HStab}}$ **= 1.52**

Horizontal stabilizer total force: $\boldsymbol{L_{HStab}}$ **= 930.85 N**

Results from XFoil:

Horizontal stabilizer lift coefficient $\boldsymbol{CL_{HStab}}$ **= 1.87**

Horizontal stabilizer total force: $\boldsymbol{L_{HStab}}$ **= 1141.94 N**

7. FUED with α = -13.85 as found in (5)

This is expected to be the maximum downwards pitch load. Results are calculated in AVL and checked with XFoil.

Results from AVL:

Horizontal stabilizer lift coefficient CL_{HStab} **= -1.65**

Horizontal stabilizer total force: L_{HStab} **= -1010.46 N**

Results from XFoil:

Horizontal stabilizer lift coefficient CL_{HStab} **= -1.96**

Horizontal stabilizer total force: L_{HStab} **= -1199.88 N**

Note that for sections 8 & 9 V = VNE = 63.3m/s is used whereas sections 1-7 use V = VA = 41.166 m/s. We are still assuming incompressible conditions since $Ma_{VNE} < 0.3$

8. +5.48G pull (max loading as prescribed by flight manual) at VNE.

In this section, the loads associated with a +5.48G pull at VNE from level flight are considered.

The lift coefficient associated with a +5.48G pull is found to be CL = 0.74.

Using this value for CL, the associated angle of attack and elevator deflection for looping flight are calculated: $\alpha = 7.06$, $\varphi = -20.0469$ deg.

This elevator deflection is then input, initially at CL = 0.1349 (straight and level flight).

Results:

Horizontal stabilizer lift coefficient CL_{HStab} **= -0.6915**

Horizontal stabilizer total force: L_{HStab} **= -1001.28 N**

9. -4.0G push (min loading as prescribed by flight manual) at VNE.

In this section, the loads associated with a -4.0G push at VNE from level flight are considered.

The lift coefficient associated with a -4.0G push is found to be CL = -0.54.

Using this value for CL, the associated angle of attack and elevator deflection for looping flight are calculated: $\alpha = -6.54$, $\varphi = 9.90$ deg.

This elevator deflection is then input, initially at CL = 0.1349 (straight and level flight).

Results:

Horizontal stabilizer lift coefficient CL_{HStab} **= 0.43**

Horizontal stabilizer total force: L_{HStab} **= 629.01 N**

II. Yaw Tension-Compression

10. Max rudder deflection in no sideslip flight at VA.

Results from AVL:

Vertical stabilizer lift coefficient CL_{VStab} **= 0.53**

Vertical stabilizer total force: L_{VStab} **= 336.21 N**

Equilibrium sideslip angle found to be **β = 10.4 deg.**

Results from XFoil:

Vertical stabilizer lift coefficient CL_{VStab} **= 0.89**

Vertical stabilizer total force: L_{VStab} **= 563.5 N**

11. Max left rudder applied when in max right sideslip condition.

Using $\beta = 10.4$ deg from (10) and applying full left rudder (-17 deg):

Results from AVL:

Vertical stabilizer lift coefficient CL_{VStab} **= -1.04**

Vertical stabilizer total force: L_{VStab} **= -659.75 N**

Results from XFoil:

Vertical stabilizer lift coefficient $\boldsymbol{CL_{VStab}}$ **= -1.75**

Vertical stabilizer total force: $\boldsymbol{L_{VStab}}$ **= -1108.03 N**

Summary of Results

The tabulated results are shown in the table below.

Load Case	Using	LHstab (N)	LVstab (N)
2	AVL	-396.37	N/A
2	XFoil	-447.10	N/A
4	AVL	636.90	N/A
4	XFoil	712.16	N/A
6	AVL	930.85	N/A
6	XFoil	1141.94	N/A
7	AVL	-1010.46	N/A
7	XFoil	-1199.88	N/A
8	AVL	-1001.28	N/A
9	AVL	629.01	N/A
10	AVL	N/A	336.21
10	XFoil	N/A	563.5
11	AVL	N/A	-659.75
11	XFoil	N/A	-1108.03

The dominating load cases are 6 (up) and 7 (down) for pitch tension-compression and load case 11 for yaw tension-compression. The question now is whether we can interpret the flight manual as allowing a maneuver as detailed in cases 6, 7 and 11 and whether we trust XFoil over AVL or vice-versa.

It appears that on average, XFoil is around 10-15% more conservative than AVL except for the vertical stabilizer loads which exhibit a greater difference.

Pranay and Damon, have you noticed this trend in the past? Which of the two programs has proven itself to be more representative of reality?