To: Carleton University BWB UAV Project

Date: March 20th, 2025

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No. of Pages: 6

Subject: Peregrine 1 Elevon Linkage Loads

Details:

This technical memo outlines the method of determining the elevon linkage and elevon air loads on the Peregrine 1.

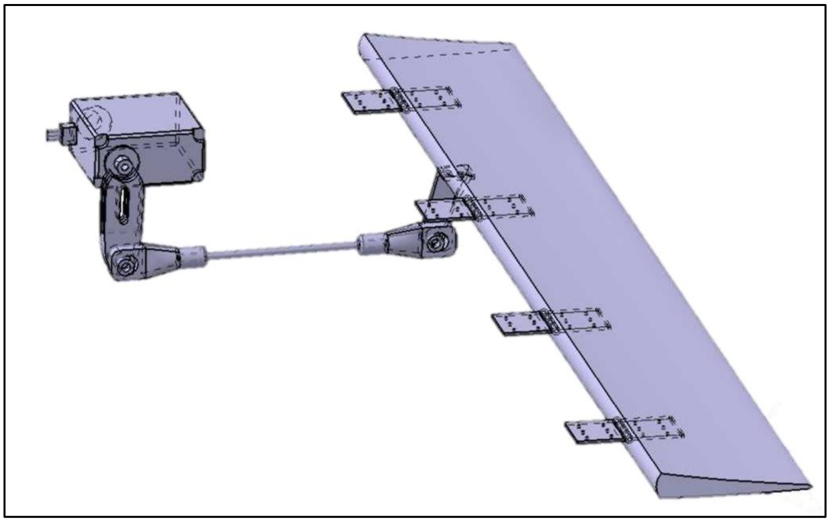

Figure 1: Elevon assembly model

Theory:

The loads experienced on a body from the fluid that passes around it are described by the drag force equation, shown in Equation 1.

$$F = \frac{1}{2} C_D \rho V^2 A \qquad (1)$$

The drag force equation relates the relative speed of the fluid with respect to a body immersed within it to the frontal area, A, as seen by the travelling fluid. ρ is the density of the fluid. The parameter C_D is the coefficient of drag, which is defined by Equation 1. It is a dimensionless quantity that defines the resistance of an object in a fluid.

C_D is affected by the bluntness, shape and proportions of a body, the velocity of the fluid, and surface roughness [1]. Values are in the range of 0.001 to 2.1, determined empirically, where the higher the drag coefficient, the more drag the body experiences from the fluid [2].

A study was performed in 2014 on the aerodynamics of a blended wing body [1]. It was shown that the coefficient of drag for their blended wing body ranged from near zero at a 0° angle of attack, to 1.2, 1.1, and 1 for speeds of 40 m/s, 35m/s and 25m/s, respectively, each at an angle of attack of 80 degrees. For the Peregrine 1, an angle of attack of 80 degrees is quite outside the operational limit, but the aerodynamics of the additively manufactured platform is likely less efficient than that of the blended wing body in the study.

Assumptions:

For this analysis, the maximum possible drag force the elevon would experience is desired to validate the strength of the elevon linkage and the elevon hinges.

From the presented information, the assumption was made that the maximum coefficient of drag that the peregrine 1 would experience is 1.3, at its highest operating angle of attack, with elevons deflected to their limit of 45 degrees. This is a generous estimate purposefully made higher than expected to account for worst case scenario.

Additionally, the cruise height of the Peregrine 1, being less than 300ft due to Canadian drone regulations, allows for the assumption that the density of air will be equal to 1.225 kg/m^3, which is the density of air at standard conditions.

For the static mechanics analysis, it was assumed that the elevon is rigid. Additionally, it is assumed that the torque produced from the load acting at the geometric center of the airfoil, which is laterally offset from the linkage connection point, is taken fully by the elevon hinges. This assumption allows the three-dimensional analysis to be conducted in two dimensions, in the plane of the linkage, shown in Figure 2.

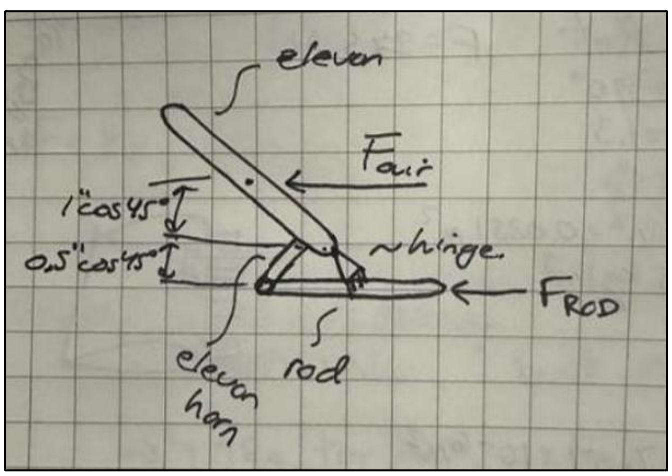

Figure 2: Sketch of FBD for store-bought linkage loads

The last assumption made was regarding the consideration of the hinge in the static loads problem. From the free body diagram shown in Figure 2, the hinge, which is modelled as a pin joint, is purely a reactionary force. There is a possibility that in the real application of the elevon, the force in the rod must overcome friction or resistance from the hinge. For this analysis, these effects will be neglected.

Calculations:

Air Loads

The frontal area of the elevon can be calculated as the length of the elevon multiplied by the vertical component of the depth of the elevon. From the model, the length and width of the elevon were measured as 18.52” and 2.0” respectively. At a 45 degree deflection, the vertical height of the computed with the sine of the angle.

$$Height_{vert} = Height * \sin(45°)$$

$$Height_{vert} = 2.0'' * \sin(45°)$$

$$Height_{vert} = 1.41''$$

The projected area of the elevon on the plane perpendicular to the freestream velocity is then computed with the area of a rectangle.

$$A_{projected} = 1.41*18.52$$

$$A_{projected} = 26.19\ [in^2]$$

The velocity of the freestream in cruise was received by the Performance Engineer as 34.3 [m/s].

The drag force is then calculated from Equation 1 as follows, where 1550 is a conversion factor:

$$F_D = \frac{1}{2}(1.3)\left(1.225\ \left[\frac{kg}{m^3}\right]\right) * \left(34.3\ \left[\frac{m}{s}\right]\right)^2 (26.91\ [in^2])\left(\frac{[m^2]}{1550[in^2]}\right)$$

$$F_D = 16.26\ [N]$$

This applied force acts at the geometric center of the elevon.

Stress in Linkage

Since the elevon horn is rigidly attached to the elevon, it is considered part of the same rigid body. In Figure 3, a section cut of the model can be considered passing through the linkage rod and everything to the left of this cut is kept. The problem reduces to reactionary horizontal and vertical forces at the hinge, a horizontal force to the left at the geometrical center of the elevon and a horizontal force within the linkage rod, to the left.

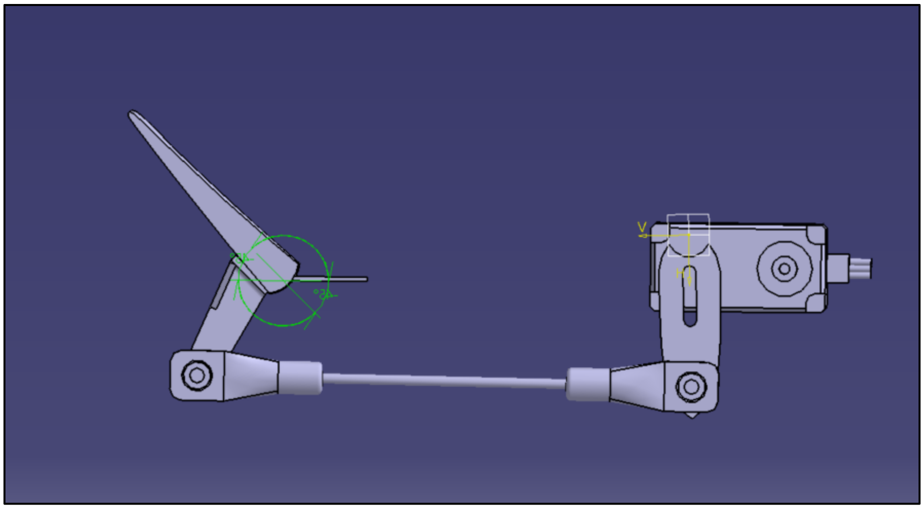

Figure 3: CAD Model of Elevon Linkage

The sum of the moments around the hinge can be taken to resolve the unknown force in the rod. The moment arm of the rod from the hinge is approximately 0.965”. Figure 2 displays the distance for the store-bought linkage.

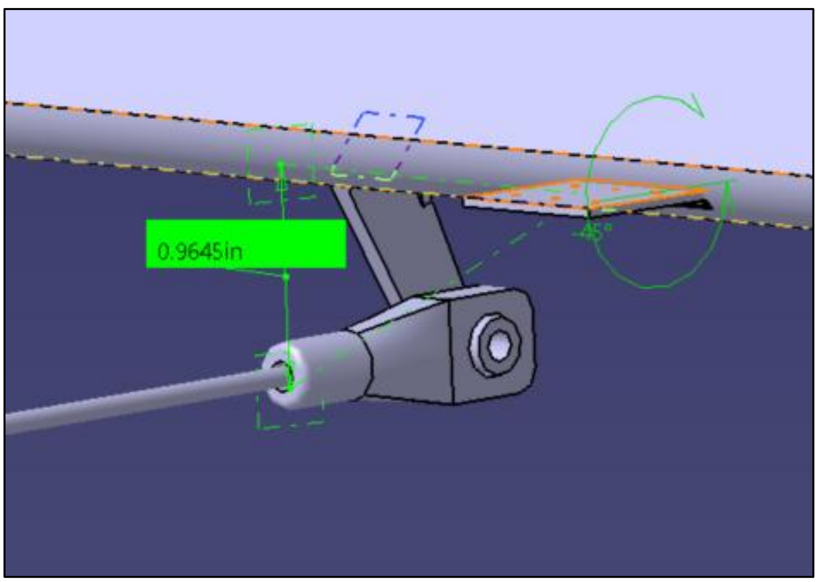

Figure 4: Manufactured linkage distance to rotational axis

The vertical distance to the combined air load force is found by taking the vertical component of the width of the elevon. This is the same distance made when resolving the air load force. The sum of the moment about the linkage is below.

$$\circlearrowleft + \Sigma M_{hinge} = F_D * D_{G.c.} - F_{rod} * D_{rod} = 0$$

$$16.26\ [N] * 1[in] * \sin{(45°)} + F_{rod} * 0.965[in] = 0$$

$$F_{rod} = \frac{16.26\ [N] * 1[in] * \sin{(45°)}}{0.965[in]}$$

$$F_{rod} = 11.9\ [N]$$

The stress experienced in the rod can be calculated using the area of the rod with the stress formula in Equation 2 below.

$$\sigma = \frac{F}{A} \qquad 2$$

The diameter of the aluminum 6061 rod is 3mm. The area of calculated below.

$$A_{rod} = \frac{\pi D^2}{4} = \frac{\pi(0.003[m]^2)}{4} = 7.0686 * 10^{-6}[m^2]$$

The stress is then calculated using Equation 2.

$$\sigma_{rod} = \frac{F_{rod}}{A_{rod}} = \frac{11.9[N]}{7.0686 * 10^{-6}\ [m^2]} = 1.6835\ [MPa]$$

Safety Factor:

The yield stress for aluminum 6061 is 110 [MPa] [2]. The safety factor is a term that represents how many multiples of an expected stress can be experienced before the failure mode is reached. For this analysis, the safety factor will be considered for the yielding stress, as opposed to the ultimate stress, because any deformation of the aluminum rod will alter the response of the control surfaces.

$$Safety\ Factor = \frac{Failure\ Stress}{Design\ Stress} = \frac{110[MPa]}{1.6835[MPa]} = 65.3$$

The resulting safety factor confirms there is no risk of deformation of the aluminum bar.

Recommendations:

There is an opportunity to size the diameter of the aluminum rod closer to the design load as a safety factor of 65 would be considered overkill for any component the author knows of on an aircraft. Small weight savings could be made in this avenue.

Additionally, bending stress within the elevon and servo horn should be considered in the analysis in the future. There may be a possibility in small weight savings in these components as well.

Lastly, the servo should be sized according to the determined air loads seen in this analysis. The selection should be proven empirically.

References:

[1] Glenn Research Center, "Factors That Affect Drag," NASA, Unknown. [Online]. Available: https://www.grc.nasa.gov/www/k-12/VirtualAero/BottleRocket/airplane/factord.html#:~:text=Drag%20depends%20directly%20on%20the,its%20viscosity%20and%20its%20compressibility.. [Accessed 10 04 2025].

[2] The Engineering Toolbox, "Drag Coefficient," engineeringtoolbox.com, 2025. [Online]. Available: https://www.engineeringtoolbox.com/drag-coefficient-d_627.html. [Accessed 8 10 2025].

[3] P. Mahamuni and A. Kulkarni, "Aerodynamic Study of Blended Wing Body," Intertional Jounral of Applied Engineering Research, vol. 9, no. 24, pp. 29247-29255, 2014.

[4] TheEngineeringToolbox, "Aluminum Alloys - Mechanical Properties," EngineeringToolBox.com, 2025. [Online]. Available: https://www.engineeringtoolbox.com/properties-aluminum-pipe-d_1340.html. [Accessed 05 04 2025].