# Design Report 03: Twin Sea Lion

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# Nomenclature

$AAA$ Advanced Aircraft Analysis Program

$AR_W$ Wing Aspect Ratio

$b_W$ Wing Span [ft]

$b_h$ Horizontal Stabilizer Span [ft]

$b_v$ Vertical Stabilizer Span [ft]

$b_e$ Elevator Span [ft]

$b_r$ Rudder Span [ft]

$\bar{c}$ Mean Aerodynamic Chord [ft]

$\bar{c}_W$ Mean Geometric Chord [ft]

$CG$ Center of Gravity

$c_h$ Horizontal Stabilizer Chord [ft]

$c_v$ Vertical Stabilizer Chord [ft]

$c_a$ Aileron Chord [ft]

$c_e$ Elevator Chord [ft]

$c_r$ Rudder Chord [ft]

$ft$ Feet [ft]

$K_{lav}$ Lavatory Sizing Coefficient

$K_p$ Propeller Sizing Coefficient

$lbs$ Pounds Mass [lbs]

$M$ Mach Number

$NACA$ National Advisory Committee for Aeronautics

$N_{pax}$ Number of Passengers

$S_W$ Wing Area [$ft^2$]

$S_h$ Horizontal Stabilizer Area [$ft^2$]

$S_v$ Vertical Stabilizer Area [$ft^2$]

$S_e$ Elevator Area [$ft^2$]

$S_r$ Rudder Area [$ft^2$]

$TWR$ Thrust to Weight Ratio [lbf/lbm]

$V_h$ Horizontal Tail Volume Ratio

$V_v$ Vertical Tail Volume Ratio

$W_{lav}$ Lavatory Weight [lbm]

$x_{cg}$ X Location of the Center of Gravity [ft]

$y_{cg}$ Y Location of the Center of Gravity [ft]

$z_{cg}$ Z Location of the Center of Gravity [ft]

$\eta_{a_i}$ Aileron Inboard Station as Fraction of Half-Span

$\eta_{a_o}$ Aileron Outboard Station as Fraction of Half-Span

$\eta_{e_i}$ Elevator Inboard Station as Fraction of Half-Span

$\eta_{e_o}$ Elevator Outboard Station as Fraction of Half-Span

$\Gamma_W$ Dihedral [deg]

$\Lambda_{c/4w}$ Wing Sweep Angle [deg]

$\lambda_W$ Wing Taper Ratio

$\lambda_h$ Horizontal Stabilizer Taper Ratio

$\lambda_v$ Vertical Stabilizer Taper Ratio

$\lambda_{c/4w}$ Quarter-chord Sweep Angle

# I. Introduction

The Twin Sea Lion is being developed as a combination cargo and passenger turboprop. The large wings resulting from intended STOL performance give the Sea Lion high structure and powerplant weights. These large powerplants will require weight to be shifted from other components to allow more powerplant weight. This report details the weight and CG of each major component defined in order to develop a loading order for both passengers and cargo that will not tip over the plane. Defining the plane's CG also allows stability characterization and empennage design based on control needs.

# II. Preliminary Weight and Balance Analysis

### A. Preliminary Weight Breakdown

The very nose of the plane defines x axis zero, the plane of symmetry of the plane defines y axis zero with the right wing going in the positive y direction, and the bottom of the wing defines z axis zero with positive z going upwards.

Propeller diameter was determined from the Gerren equation as included below[1]. Above 4 blades, $K_p$ is not explicitly defined, so $K_p = 1.1$ was assumed to account for the 8 blades used. Engine power was determined to be 5000 hp in the second design report[**?** ]. This results in $D = 1.1(5000)^{1/4} = 9.25$ ft.

$$D = K_p\left(\frac{Power}{Engine}\right)^{1/4} \;\; where \;\; \begin{cases} Blades & K_p \\ 2 & 1.7 \\ 3 & 1.6 \\ 4+ & 1.5 \end{cases}$$

From AAA Figure 8, propellers with a 9.25 foot diameter will weigh about 1800 lbs. The engines themselves weigh 3000 lbs and about 700 lbs of extra power plant weight was added to account for additional powerplant needs. This number was reduced from normal extra engine weight by the use of electronic actuators. Total powerplant weight is about 5500 lbs. The initial weight breakdown in Figure 9 gave 4627.2 lbs for powerplant, so some extra weight for the engines had to be found by downsizing other components.

Figure 10 shows the final weight breakdown obtained by moving the initial weight fractions obtained from similar airplanes to a single custom airplane shown in Figure 7 and basing the new estimate solely on that custom airplane. The wing weight fraction was reduced from 0.107 to 0.095, which will be done through the use of composite materials. This same method will allow the reduction of empennage weight fraction from 0.027 to 0.020.

These changes allowed an increase in powerplant weight fraction from 0.127 to 0.157 and also allowed an increase in gear weight fraction from 0.042 to 0.046. Powerplant weight budget increased to 5596.2 lbs, which is now sufficient to account for engines, propellers, and extra powerplant weight.

These final weights were used to obtain an empty weight breakdown as in Table 1.

**Table 1 Empty weight breakdown of the Sea Lion.**

| | Fuselage | Wing | Empennage | Landing Gear | Nacelle | Powerplant | Fixed Equipment |
|---|---|---|---|---|---|---|---|
| [lbm] | 4455.5 | 3386.2 | 712.9 | 1639.6 | 855.5 | 5596.2 | 5275.4 |

The structural weight breakdown shown in Table 2 is based on the empty weight breakdown but separates empennage into vertical and horizontal tails and gear into nose and main gear. Vertical tail weight was assumed to be 3/8 of allotted tail weight to approximately conform to Beech 1900 tail area proportions as in table 8.6 of the technical documentation[3]. So the vertical tail weighs $\frac{3}{8}712.9 = 267.3$ lbs and the horizontal tail weighs $712.9 - 267.3 = 445.6$ lbs.

Nose gear was assumed to be 15%[2] of the gear weight at $0.15 \cdot 1639.6 = 245.9$ lbs with the main gear taking the remaining weight of $1639.6 - 245.9 = 1399.7$.

**Table 2 Structural weight breakdown.**

| | Wing | Fuselage | Horizontal Tail | Vertical Tail | Nose Gear | Main Gear |
|---|---|---|---|---|---|---|
| [lbm] | 3386.2 | 4455.6 | 445.6 | 267.3 | 245.9 | 1399.7 |

Power plant weight as shown in Table 3 was determined by dividing the allowed weight in two and subtracting the 901.8 allotted for each side of propeller.

**Table 3 Powerplant weight breakdown.**

| | Engine 1 | Engine 2 | Propeller 1 | Propeller 2 |
|---|---|---|---|---|
| [lbm] | 1896.3 | 1896.3 | 901.8 | 901.8 |

Weight of the lavatory is determined as follows $W_{lav} = K_{lav}(N_{pax})^1.33 = 3.9(10^{1.33}) = 83.38$lbs[2]. $K_{lav}$ of a business jet was chosen to account for this equation's tendency to underestimate the weight of the lavatory. The lavatory was the only fixed equipment large enough to separate out for the fixed equipment weight breakdown in Table 4.

**Table 4 Fixed equipment CG**

| | Lavatory | Other |
|---|---|---|
| [lbm] | 83.4 | 5192.0 |

The CG breakdown shown in Table 5 is concerned with the CGs of wing, fuselage, horizontal tail, vertical tail, nose gear, and main gear. With the wing apex at 21 feet, the $x_{cg}$ was places two feet behind the apex. Since the wing is symmetric across the y axis, $y_{cg} = 0$. With a 12% thick airfoil and a root chord of 12.79 ft, the maximum thickness of the wing will be 1.53 feet. Half this width plus a little more than a foot from the bottom of the airplane to the bottom of the wing gives $z_{cg} = 2$ feet.

Fuselage $x_{cg}$ was approximated at 0.45 of length[2] to be $0.45 \cdot 47.58 = 21.41$ ft.

Approximate landing gear dimensions from table 9.1 of the landing gear technical documentation [3] gives a main gear tire width of 9 inches and a nose gear tire diameter of 23.4 inches. The z direction offset will be 4.5 inches for the main gear and 11.7 inches for the nose gear. These correspond to 0.98 ft in the z direction for the nose gear and $2 + \frac{4.5}{12} = 2.38$ ft for the main gear. All structural components are symmetric about the y axis.

**Table 5 Structural CG breakdown.**

| | $x_{cg}$ [ft] | $y_{cg}$ [ft] | $z_{cg}$ [ft] |
|---|---|---|---|
| Wing | 23 | 0 | 2 |
| Fuselage | 21.41 | 0 | 3.5 |
| Horizontal Tail | 62 | 0 | 6 |
| Vertical Tail | 62 | 0 | 16 |
| Nose Gear | 8 | 0 | 0.98 |
| Main Gear | 30 | 0 | 2.38 |

Table 6 shows the CG breakdown of the components of the powerplant group. The engines are 7.9 feet long and so suggest about 10 foot long nacelles. A suggested value of 0.4 the length of the nacelle [2] puts the $x_{cg}$ of the engine 4 feet behind the beginning of the nacelle. Assuming the nacelle begins 1 ft ahead of the wing, the engine cg will be 3 ft behind the beginning of wing. Due to all the wing shifting that occurred in the stability adjustment, the engine CG ended up only 2 ft behind the beginning of the wing at 23 ft.

The nacelles were assumed to be placed about 1 ft above the wing, making $z_{cg} = 3$. The propeller and fuselage radii require the engine to be 9 feet along the y axis to account for room taken up and some space in between: $\frac{82.5}{2 \cdot 12} + \frac{9.25}{2} = 8.06$. One engine will be along the positive axis and the other the negative axis.

Propeller $x_{cg}$ will be about 1 ft ahead of the apex of the wing at 20 ft and will be at the same points in the y and z axes.

**Table 6 Powerplant CG breakdown.**

| | $x_{cg}$ [ft] | $y_{cg}$ [ft] | $z_{cg}$ [ft] |
|---|---|---|---|
| Engine 1 | 23 | 9 | 3 |
| Engine 2 | 23 | -9 | 3 |
| Propeller 1 | 20 | 9 | 3 |
| Propeller 2 | 20 | -9 | 3 |

Assuming the lavatory to be a rectangular prism of constant density, the SolidWorks model developed for the second report[**?** ] can be used to find the CG in any direction. The distance from the front of the plane to the middle of the lavatory is 499.5 inches. The distance from the centerline of the plane to the middle of the lavatory is 23.5 in. The distance from the bottommost part of the fuselage to the middle of the lavatory is 50.5 in. Table 7 shows the CG breakdown of the fixed equipment.

**Table 7 Fixed equipment CG breakdown.**

| | $x_{cg}$ [ft] | $y_{cg}$ [ft] | $z_{cg}$ [ft] |
|---|---|---|---|
| Lavatory | 41.63 | 1.96 | 4.21 |
| Other | 21.41 | 0 | 3.5 |

### B. Preliminary Weight and Balance Calculation

Loaded weights come from the mission specifications describes in the first report[**?** ]. The crew CG comes from summing moments from the positions of the pilot, copilot, and flight attendant considered as point masses. Trapped fuel and oil CG was assumed to be the same as the CG of the fuselage and fuel CG was assumed to be the same as the wing CG. Here $x_{cg}$ ended up slightly behind that of the wing because the wing got moved and the fuel got left behind. Passenger group CG was found by the the positions of each passenger. Cargo was again the sum of moments of the different masses under the row, across from the lavatory, and at the end of the plane. All loaded weights are symmetric across the y axis except for the crew and cargo being on the negative portion of the y axis. Table 8 shows the weight and CG of these loaded components. 0

**Table 8 Fully-loaded weight and CG breakdown.**

| | Weight [lbm] | $x_{cg}$ [ft] | $y_{cg}$ [ft] | $z_{cg}$ [ft] |
|---|---|---|---|---|
| Crew | 525 | 12.05 | -0.56 | 5 |
| Trapped Fuel and Oil | 188.4 | 21.41 | 0 | 3.5 |
| Mission Fuel Group 1 | 10679.3 | 22 | 0 | 2 |
| Passenger Group 1 | 1750 | 28.92 | 0 | 5 |
| Baggage | 605 | 28.92 | 0 | 3 |
| Cargo | 2020 | 33 | -2 | 0 |

Table 9 shows the loading order of all plane components and Figure 17 shows the resulting changes in CG. Empty weight is automatically first loaded and last unloaded since it is a permanent fixture. Trapped fuel and oil are next to be loaded and next to last to be unloaded since it can never truly be removed. This shift in weight over time causes a shift in CG as loading goes on. The loading order is then crew, fuel, cargo, passengers, and baggage. This arrangement allows preparation of the plane with minimal passenger inconvenience. Unloaded begins with fuel since it is leaving the airplane as the mission goes. The remaining unloading order is passengers, baggage, cargo, and crew. This once again minimizes passenger time onboard.

**Table 9 CG excursion ordering.**

| | Weight | $x_{cg}$ [ft] | Load | Unload |
|---|---|---|---|---|
| Empty Weight | 21921.3 | 23.96 | 1 | 13 |
| Crew | 525.0 | 12.05 | 3 | 5 |
| Trapped Fuel and Oil | 188.4 | 21.41 | 2 | 12 |
| Mission Fuel Group 1 | 10679.3 | 22 | 4 | 1 |
| Passenger Group 1 | 1750.0 | 28.92 | 6 | 2 |
| Baggage | 605.0 | 29.92 | 7 | 3 |
| Cargo | 2020.0 | 33.0 | 5 | 4 |

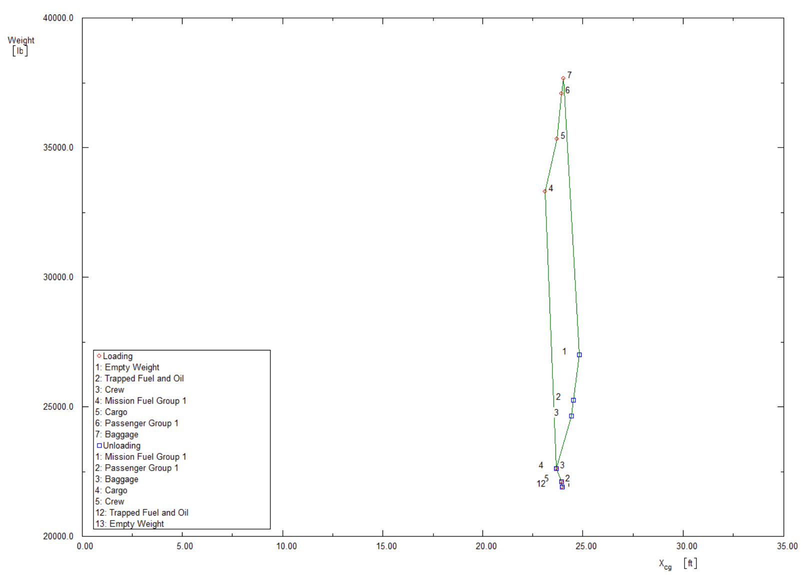


**Fig. 1 Plot of CG excursion**

The most forward CG is 23.67 ft and the most aft cg is 24.78 ft as can be seen in Figures 19 and 18. The total shift is 1.11 ft or 13.31 inches. The mean aerodynamic chord is 10.4 ft as follows in Equation 1[6]. The shift in CG as a portion of aerodynamic chord is $\frac{1.11\ ft}{10.4\ ft} = 0.106$. From technical documentation, [5] regional turboprops exhibit a typical $\Delta CG = [12, 20]$ with a proportion of mean aerodynamic chord of $\frac{\Delta CG}{\bar{c}} = [0.14, 0.27]$. The Twin Sea Lion falls in the range of $\Delta CG$ and below the range of $\frac{\Delta CG}{\bar{c}}$. This indicates that our change in $CG$ is in the range of typical even though our wing is larger relative to this change than typical.

$$\bar{c} = \frac{2c_r}{3}\frac{1+\lambda+\lambda^2}{1+\lambda} = \frac{2(12.79\ ft)}{3}\frac{1+0.6+0.6^2}{1+0.6} = 10.4\ ft \tag{1}$$

## III. Empennage Layout Design

A conventional tail layout was selected in the interest of simplicity and separating design concerns for the horizontal and vertical surfaces. The tail and empennage serves only aerodynamic stability and control, so no special features were required.

### A. Sizing the Horizontal Stabilizer

The horizontal stabilizer was designed principally for ensuring that the horizontal tail volume coefficient, $V_h$, lay between 0.7 and 1.1, as seen in [3], as well as keeping the static margin, fuselage length, and horizontal tail area to reasonable limits. This effort was only a partial success, as while $V_h$ was eventually tuned to be around 0.8, a suitable static margin has not yet been found. Currently, it lies around 44.7%, whereas it should be at most 15%.

The surface area of the horizontal tail is 190 square feet with an aspect ratio of 7. It is 36.47 feet in span, with a taper ratio, $\lambda$, of 1. For simplicity, it has no dihedral, and no sweep. Although this group neglected to actually input a control surface airfoil into AAA, the airfoil selected for the tail is a NACA 0012 for its simple construction and symmetrical aerodynamic properties which allow it to be used for both horizontal and vertical control surfaces.

By inspecting Figure 22, the cruise speed of $M = 0.6$ is too low for any shock formation. If cruise speed was higher, then a thinner control surface airfoil might be required. However, in this case the thickness of the horizontal stabilizer could safely be increased to just about any reasonable amount without worrying about the formation of shocks.

NOTE: FOR SUPERCRITICAL AIRFOILS USE $\Delta M_{CR} = 0.05$

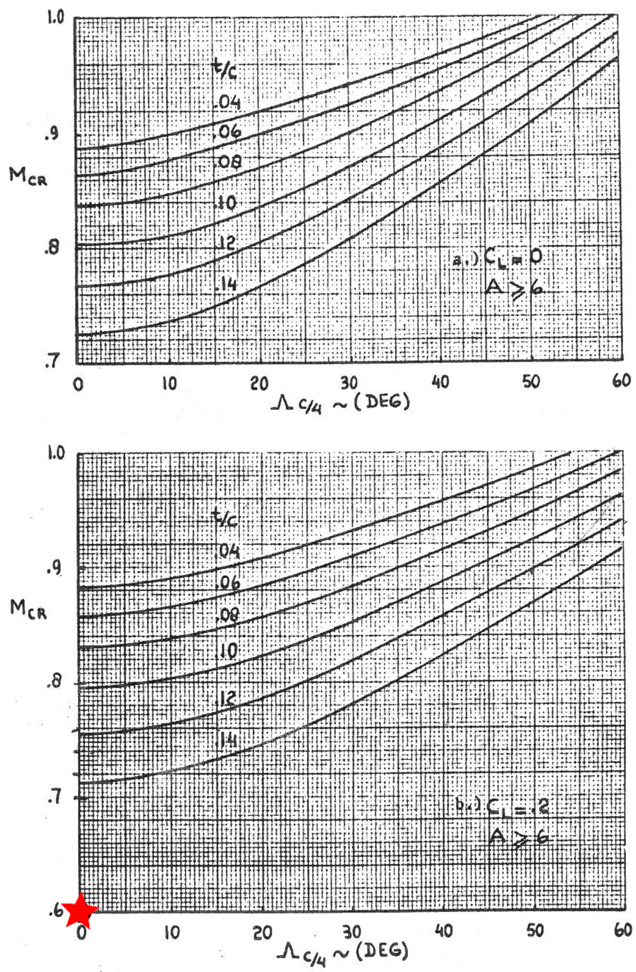


Figure 6.1a Effect of Thickness Ratio and Sweep Angle on Critical Mach Number

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**Fig. 2 Critical Mach number checks for shockwave formation on an airfoil. The Twin Sea Lion's location is marked with a red star[? ].**

The end results are shown below, in table 10. They are derived from the sizing charts in AAA, shown in figures 24 and 23. Note that because $\lambda_h = 1$, $c_{r_h} = c_{t_h}$.

**Table 10 Horizontal stabilizer dimensions**

| $AR_h$ | $S_h$ $[ft^2]$ | $b_h$ $[ft]$ | $\Gamma_{c/4}$ $[deg]$ | $\lambda_h$ | $\Lambda_{c/4_h}$ $[deg]$ | $X_{apex_h}$ $[ft]$ | $\bar{c}_h$ $[ft]$ | $V_h$ |
|---|---|---|---|---|---|---|---|---|
| 7.0 | 190.0 | 36.47 | 0 | 1.0 | 0.0 | 61.30 | 5.21 | 0.8104 |

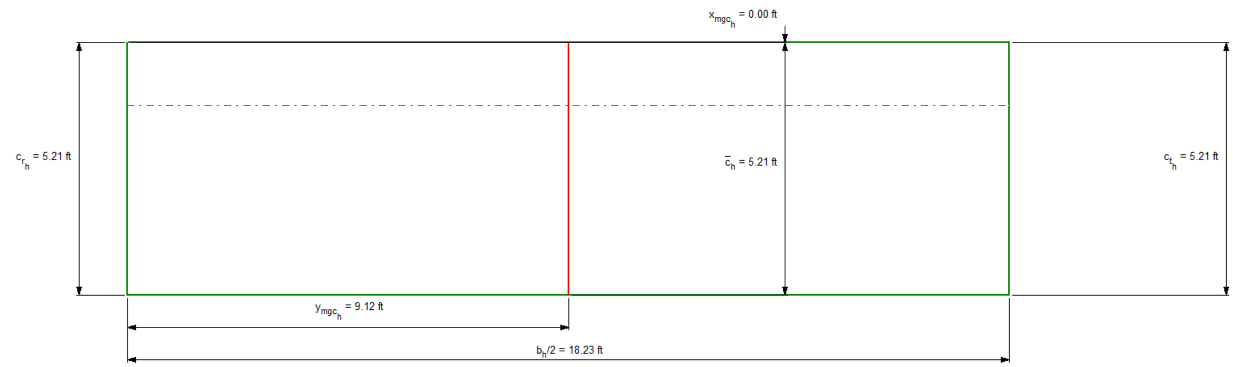


**Fig. 3 Horizontal stabilizer layout**

## B. Sizing the Vertical Stabilizer

Like the horizontal stabilizer, vertical stabilizer sizing and placement was driven primarily by the vertical tail volume ratio, $V_v$. In table 8.6b of [3], all the volume ratios are between 0.065 and 0.120. A volume ratio of 0.0774 was eventually settled on, with the rest of the parameters in Table 11 balanced between placement on the aircraft and control surface size. These results are from figures 25 and 26. Like the horizontal stabilizer, the vertical stabilizer uses a NACA 0012 airfoil.

**Table 11 Vertical stabilizer dimensions**

| $AR_v$ | $t/c$ | $S_v$ $[ft^2]$ | $b_v$ $[ft]$ | $\lambda_v$ | $\Lambda_{c/4_v}$ $[deg]$ | $X_{apex_v}$ $[ft]$ | $\bar{c}_v$ $[ft]$ | $c_{r_v}$ $[ft]$ | $c_{t_v}$ $[ft]$ | $V_v$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 3.0 | 12% | 137.0 | 20.27 | 0.80 | 5.0 | 60.00 | 6.79 | 7.51 | 6.01 | 0.0774 |

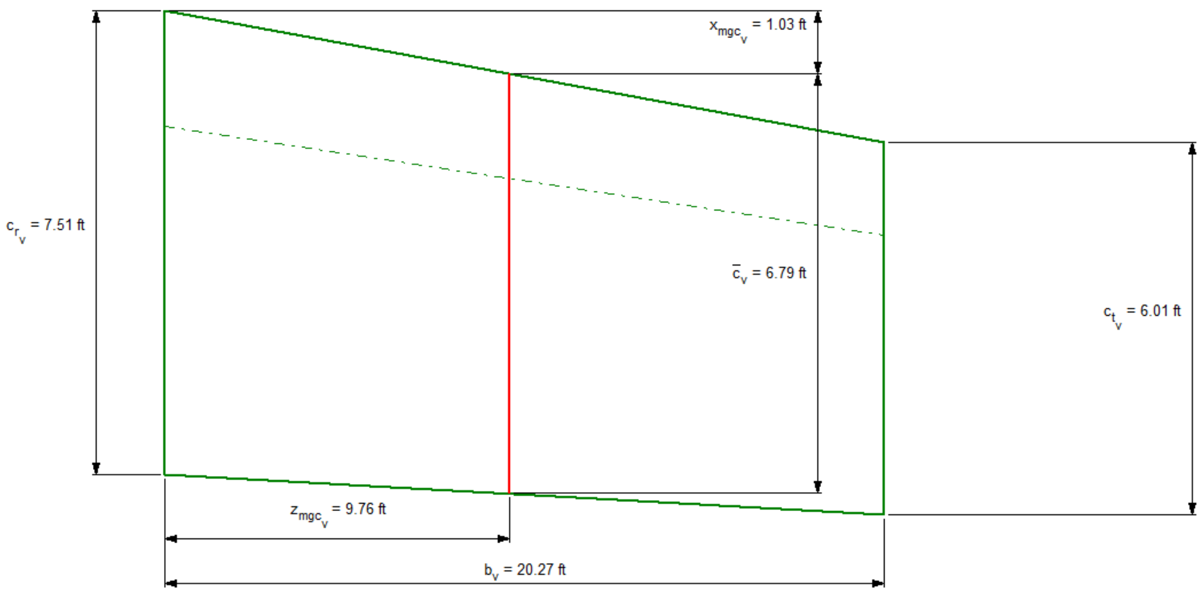


**Fig. 4 Vertical stabilizer layout**

# IV. Control Surface Layout Design

## A. Sizing the Lateral Control Surfaces

The aileron was sized to take up the remaining room on the wing, given the practical constraints that some room should be left between it and the flap for possible hinges and some space should also be left at the wingtip for navigation lights and strobes. The resulting numerical dimensions are shown in Figure 28 in the Appendix and Figure 3 below, as well as being tabulated in Table 12. The aileron maintains a constant chord ratio ($c_a/c_w$) throughout.

**Table 12 Aileron dimensions**

| $c_a/c_w$ | $\eta_{a_i}$ | $\eta_{a_o}$ | $S_a/S_w$ |
|---|---|---|---|
| 25.0% | 60.0% | 98.0% | 0.039 |

Given an aileron area, $S_a$ of 32.29 square feet from Figure 28, $S_a/S_w$ is calculated to be 0.039. Referencing [3], there is a large variability in aileron area vs wing area for other regional airliners. Notable, the DHC-6 Beaver has an $S_a/S_w$ of 0.079 while the DHC-8 (also known as the Q-400) has an $S_a/S_w$ of 0.31. The Fairchild F-27 has an $S_a/S_w$ of 0.050. With these values for comparison, the Twin Sea Lion is in a reasonable place with regards to aileron sizing.

However, if more roll authority is determined to be necessary, it could be accomplished by using up the last bit of space on the trailing edge of the wing, currently separating the flaps and ailerons.

Of these aircraft, only the DHC-6 has larger control surfaces. This makes sense because it is a bush plane which needs very good roll authority at low speed. While such large control surfaces are admirable, their necessity is not proven in the case of the Twin Sea Lion. The aircraft's wingspan both gives the ailerons a comparatively large moment arm for roll authority and limits the number of airstrips where nimble roll control might be required.

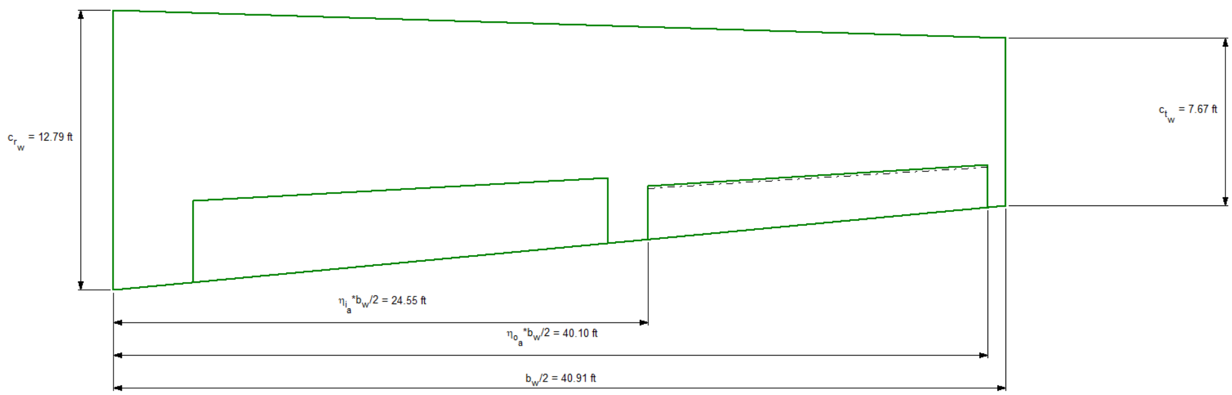


**Fig. 5 Aileron layout on the Twin Sea Lion**

### B. Sizing the Longitudinal Control Surfaces

As seen in Figure 29, elevator design was kept as simple as possible. $c_e/c_h$ was kept at 30% for the entire length of the elevator, which runs from 5% to 95% of the horizontal stabilizer half span. The elevator area, $S_e$, is 48.74 square feet of the 190 square feet of the entire horizontal stabilizer, $S_h$.

**Table 13 Elevator dimensions**

| $c_e/c_h$ | $\eta_{e_i}$ | $\eta_{e_o}$ | $S_e/S_h$ |
|---|---|---|---|
| 30.0% | 5% | 95.0% | 0.256 |

Based on the substantial control surfaces, a properly balanced aircraft would be easily controllable with this tail configuration. Because the Twin Sea Lion has such a large static margin, this elevator may still be undersized. In either case, the area ratios and chord ratios of the elevator and horizontal stabilizer are in the range of values noted in [3], which range between 0.28 and 1 for $S_e/S_h$ and 0.29 to 0.50 for $c_e/c_h$.

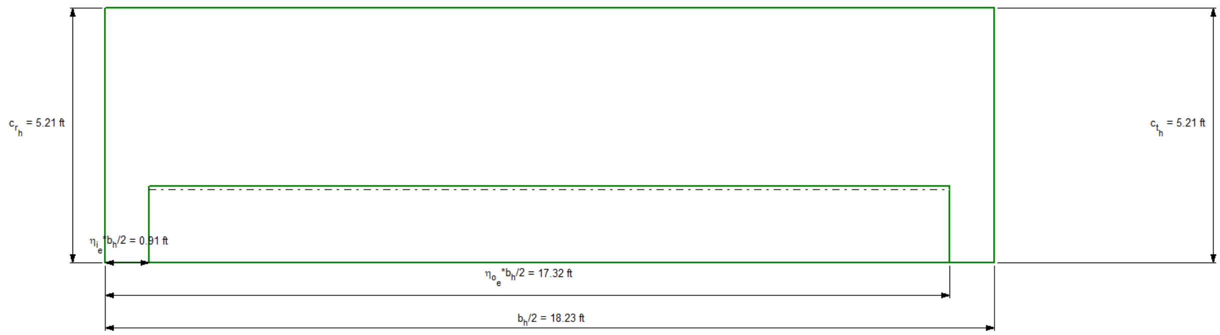


**Fig. 6 Elevator layout on the Twin Sea Lion**

### C. Sizing the Directional Control Surfaces

The rudder was sized according to Figure 30. Its dimensions are very similar to those of the elevators. The geometry is summarized in Table 14 below. The total rudder area, $S_r$, is 35.14 square feet, making $S_r/S_v$ equal to 0.256. Looking at [3] again, most regional turboprop aircraft have rudders between 0.26 and 0.41 of the total vertical surface area. This means that some issues with rudder authority might appear. This could be a limiting factor on the crosswind capabilities and spin recovery of the Twin Sea Lion.

**Table 14 Rudder dimensions**

| $c_r/c_v$ | $\eta_{r_i}$ | $\eta_{r_o}$ | $S_r/S_v$ |
|---|---|---|---|
| 30.0% | 5% | 95.0% | 0.256 |

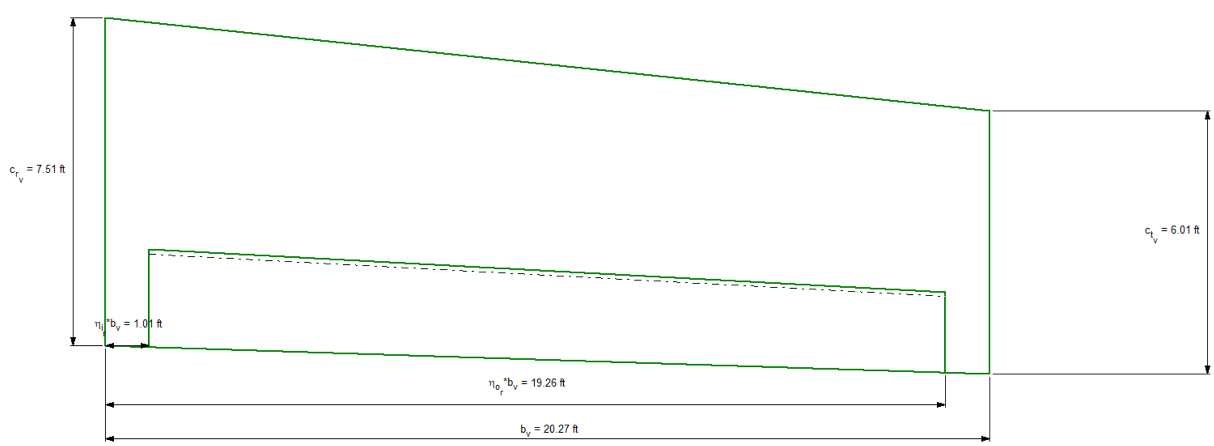


**Fig. 7 Rudder control surface layout**

# V. Conclusions and Recommendations

## A. Conclusions

The Twin Sea Lion has had a full weight analysis and breakdown, and the aircraft is balanced and expected to be controllable. However, the static margin is still very high at around 44%, though accommodations for shifting fuel tank locations could improve this. Of the aircraft elements, propellers wound up weighing an unexpected amount, bringing the total weight of the powerplant system. Composite construction materials will be required to compensate for this increase. Wing placement was driven by CG and static margin requirements. CG is only expected to shift around a foot through the mission profile, with $x_{cg}$ ranging from 23.67 feet to 24.78 feet. The horizontal stabilizer turned out to be the most difficult aerodynamic surface to size properly, as shown by the current static margin. In the future it could be moved farther rearwards for better authority with a smaller surface. In comparison, the vertical stabilizer proved easier. Both surface have volume ratios that are similar to other aircraft in this class. Fortunately, large aerodynamic surfaces mean that the control surfaces can be similarly large. The area of all the control surfaces in proportion to their parent surfaces lie in the range of values that are normal for this class. However, in each case, the Twin Sea Lion has room to grain even more control authority if it is needed in the future.

## B. Recommendations

The first item the Twin Sea Lion needs to address moving forwards is the excessively high static margin. The second item is the excessive propeller weight. While AAA most likely makes these calculations based on aluminum propellers, large composite propellers should be investigated in the future. Reducing weight from the propellers would have the dual benefit of moving the CG farther backwards in order to reduce static margin as well as saving weight from the large powerplants. The static margin may be improved by correcting the CG of the wing fuel tanks in the future. Finally, if extending the empennage is feasible, it may be reasonable to do so in order to reduce the size of the tail surfaces and increase control authority.

# References


[1] Etkin and Reid, *Dynamics of Flight* "Stability and Control, Third Edition." 1996,John Wiley & Sons, Inc.

[2] Gerren, "Presentation 18", `https://canvas.colorado.edu`

[3] Gerren, "Presentation 19", `https://canvas.colorado.edu`

[4] Junker and Killelea, "Design Report 01: Twin Sea Lion."

[5] Junker and Killelea, "Design Report 02: Twin Sea Lion."

[6] Roskam, "Center of Gravity Ranges", Table 10.3, `https://canvas.colorado.edu`

[7] Roskam, "Landing Gear Sizing", `https://canvas.colorado.edu`

[8] Roskam, "Mcr check - CL = 0 & CL = 0.2", `https://canvas.colorado.edu`

[9] Roskam, "Tail and Control Surface Info", `https://canvas.colorado.edu`

# VI. Appendix

## A. AAA: Preliminary Weight Analysis

**Class I Empty Weight Breakdown: Flight Condition 1**

**Output Parameters**

| | | | |
|---|---|---|---|
| $W_{structure}$ 11049.7 lb | $X_{cg_{structure}}$ ft | $Y_{cg_{structure}}$ ft | $Z_{cg_{structure}}$ ft |
| $W_E$ 21921.3 lb | $X_{cg_E}$ ft | $Y_{cg_E}$ ft | $Z_{cg_E}$ ft |

**Empty Weight Table**

| Component | Weight lb | $X_{cg}$ ft | $Y_{cg}$ ft | $Z_{cg}$ ft |
|---|---|---|---|---|
| Fuselage Group | 4455.5 | | | |
| Wing Group | 3386.2 | | | |
| Empennage Group | 712.9 | | | |
| Landing Gear Group | 1639.6 | | | |
| Nacelle Group | 855.5 | | | |
| Powerplant Group | 5596.2 | | | |
| Fixed Equipment Group | 5275.4 | | | |

**Fig. 8 Structural component weight breakdown**

**Component Weight Fractions: Flight Condition 1**

**Input Parameter**

Number 1

**Weight Fraction Table**

| # | Airplane Name | $F_{W_{gross}}$ | $F_{W_{structure}}$ | $F_{W_{pp}}$ | $F_{W_{fix}}$ | $F_{W_E}$ | $F_{W_w}$ | $F_{W_{emp}}$ | $F_{W_f}$ | $F_{W_n}$ | $F_{W_{gear}}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Adjuster | 1.000 | 0.310 | 0.157 | 0.148 | 0.615 | 0.095 | 0.020 | 0.125 | 0.024 | 0.046 |

**Fig. 9 A custom airplane model used for weight allocation in AAA**

### Propeller Weight Estimation: Flight Condition 1

**Output Parameters**

| | | | |
|---|---|---|---|
| $P_{TC_{\Sigma srcp}}$ 10000 hp | $W_{\Sigma prop_{Torenb}}$ 1803.6 lb | $W_{\Sigma prop_{GD}}$ 1803.6 lb | Propeller Data: Defined |

**Propeller Table**

| | | $P_{prop_{TO}}$ hp | $N_{blades_p}$ | $D_{prop}$ ft | $W_{prop_{Torenb}}$ lb | $W_{prop_{GD}}$ lb |
|---|---|---|---|---|---|---|
| # | Type | Input | Input | Input | Output | Output |
| 1 | Propeller: On | 5000 | 5 | 9.25 | 901.8 | 901.8 |
| 2 | Propeller: On | 5000 | 5 | 9.25 | 901.8 | 901.8 |

**Fig. 10 Propeller weights estimates**

### Component Weights: Flight Condition 1

**Input Parameters**

| | | |
|---|---|---|
| $W_{TO}$ 37689.0 lb | $W_E$ 21921.3 lb | $F_{W_{gross}}$ 1.000 |

**Output Parameter**

$W_{gross}$ 37689.0 lb

**Component Weight Table**

| Component | $F_W$ | $W_{estimate}$ lb | $\Delta W$ lb | Weight lb |
|---|---|---|---|---|
| Fuselage | 0.125 | 4700.4 | -146.2 | 4554.1 |
| Wing | 0.107 | 4048.9 | -125.9 | 3922.9 |
| Empennage | 0.027 | 1028.4 | -32.0 | 996.4 |
| Landing Gear | 0.042 | 1599.1 | -49.7 | 1549.3 |
| Nacelle | 0.024 | 910.8 | -28.3 | 882.5 |
| Structure | 0.323 | 12287.5 | -382.2 | 11905.3 |
| Powerplant | 0.127 | 4775.7 | -148.6 | 4627.2 |
| Fixed Equipment | 0.148 | 5561.8 | -173.0 | 5388.8 |
| Empty Weight | 0.615 | 22625.0 | -703.8 | 21921.3 |

**Fig. 11 Initial structural weight fractions**

**Component Weights: Flight Condition 1**

**Input Parameters**

| | | |
|---|---|---|
| $W_{TO}$ 37689.0 b | $W_E$ 21921.3 lb | $F_{W_{gross}}$ 1.000 |

**Output Parameter**

| |
|---|
| $W_{gross}$ 37689.0 lb |

**Component Weight Table**

| Component | $F_W$ | $W_{estimate}$ lb | ΔW lb | Weight lb |
|---|---|---|---|---|
| Fuselage | 0.125 | 4711.1 | -255.6 | 4455.5 |
| Wing | 0.095 | 3580.5 | -194.2 | 3386.2 |
| Empennage | 0.020 | 753.8 | -40.9 | 712.9 |
| Landing Gear | 0.046 | 1733.7 | -94.1 | 1639.6 |
| Nacelle | 0.024 | 904.5 | -49.1 | 855.5 |
| Structure | 0.310 | 11683.6 | -633.8 | 11049.7 |
| Powerplant | 0.157 | 5917.2 | -321.0 | 5596.2 |
| Fixed Equipment | 0.148 | 5578.0 | -302.6 | 5275.4 |
| Empty Weight | 0.615 | 23178.7 | -1257.4 | 21921.3 |

**Fig. 12 Finalized structural weight fractions**

## B. AAA: Preliminary Balance Analysis

**Empty Weight Center of Gravity: Flight Condition 1**

**Input Parameters**

| | | | | | |
|---|---|---|---|---|---|
| $W_{structure}$ 11049.7 lb | $W_{fix}$ 5275.4 lb | $X_{cg_{pp}}$ 22.58 ft | $Y_{cg_{structure}}$ 0.00 ft | $Y_{cg_{fix}}$ 0.03 ft | $Z_{cg_{pp}}$ 3.80 ft |
| $W_{pp}$ 5596.2 lb | $X_{cg_{structure}}$ 25.73 ft | $X_{cg_{fix}}$ 21.73 ft | $Y_{cg_{pp}}$ 0.00 ft | $Z_{cg_{structure}}$ 3.28 ft | $Z_{cg_{fix}}$ 3.51 ft |

**Output Parameters**

| | | | |
|---|---|---|---|
| $W_E$ 21921.3 lb | $X_{cg_E}$ 23.96 ft | $Y_{cg_E}$ 0.01 ft | $Z_{cg_E}$ 3.47 ft |

**Fig. 13 Detailed breakdown of CG components of the empty aircraft**

Class I Breakdown for Fixed Equipment Weight Component: Flight Condition 1

Output Parameters

| | | | |
|---|---|---|---|
| $W_{fix}$ 5275.4 b | $X_{cg_{fix}}$ 21.73 ft | $Y_{cg_{fix}}$ 0.03 ft | $Z_{cg_{fix}}$ 3.51 ft |

Fixed Equipment Weight Table

| Component | Weight lb | $X_{cg}$ ft | $Y_{cg}$ ft | $Z_{cg}$ ft |
|---|---|---|---|---|
| Flight Control System | | | | |
| Hydraulic & Pneumatic System | | | | |
| Electrical System | | | | |
| Instruments/Avionics/Electronics | | | | |
| Air Condition & Pressurizing | | | | |
| Anti-icing & De-icing System | | | | |
| Oxygen System | | | | |
| Auxiliary Power Unit | | | | |
| Furnishings | 83.4 | 41.63 | 1.96 | 4.21 |
| Cargo Handling Equipment | | | | |
| Operational Items | | | | |
| Armaments | | | | |
| Guns Launchers & Weapon System | | | | |
| Flight Test Instruments | | | | |
| Auxiliary Gear | | | | |
| Ballast | | | | |
| Paint | | | | |
| Others Group 1 | 5192.0 | 21.41 | 0.00 | 3.50 |
| Others Group 2 | | | | |

**Fig. 14 Detailed breakdown of CG and weight of the fixed equipment**

Class I Breakdown for Powerplant Weight Component: Flight Condition 1

Output Parameters

| | | | | | |
|---|---|---|---|---|---|
| $W_{eng}$ 3792.6 b | $W_{pp}$ 5596.2 lb | $X_{cg_{prop}}$ 20.00 ft | $Y_{cg_{eng}}$ 0.00 ft | $Y_{cg_{pp}}$ 0.00 ft | $Z_{cg_{prop}}$ 3.80 ft |
| $W_{prop}$ 1803.6 lb | $X_{cg_{eng}}$ 23.80 ft | $X_{cg_{pp}}$ 22.58 ft | $Y_{cg_{prop}}$ 0.00 ft | $Z_{cg_{eng}}$ 3.80 ft | $Z_{cg_{pp}}$ 3.80 ft |

Powerplant Weight Table

| Component | Weight lb | $X_{cg}$ ft | $Y_{cg}$ ft | $Z_{cg}$ ft |
|---|---|---|---|---|
| Engine No. 1 | 1896.3 | 23.80 | 9.00 | 3.80 |
| Engine No. 2 | 1896.3 | 23.80 | -9.00 | 3.80 |
| Engine No. 3 | | | | |
| Engine No. 4 | | | | |
| Propeller No. 1 | 901.8 | 20.00 | 9.00 | 3.80 |
| Propeller No. 2 | 901.8 | 20.00 | -9.00 | 3.80 |
| Propeller No. 3 | | | | |
| Propeller No. 4 | | | | |
| Fuel System | | | | |
| Air Induction System | | | | |
| Propulsion System | | | | |

**Fig. 15 Powerplant CG breakdown**

Class I Breakdown for Structural Weight Component: Flight Condition 1

Output Parameters

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $W_{emp}$ | 712.9 | lb | $W_{structure}$ | 11049.7 | lb | $X_{cg_{gear}}$ | 26.70 | ft | $Y_{cg_{emp}}$ | 0.00 | ft | $Y_{cg_{structure}}$ | 0.00 | ft | $Z_{cg_{gear}}$ | 2.17 | ft |
| $W_{gear}$ | 1639.6 | lb | $X_{cg_{emp}}$ | 62.00 | ft | $X_{cg_{structure}}$ | 25.73 | ft | $Y_{cg_{gear}}$ | 0.00 | ft | $Z_{cg_{emp}}$ | 9.75 | ft | $Z_{cg_{structure}}$ | 3.28 | ft |

Structural Weight Table

| Component | Weight lb | $X_{cg}$ ft | $Y_{cg}$ ft | $Z_{cg}$ ft |
|---|---|---|---|---|
| Wing | 3386.2 | 23.00 | 0.00 | 2.00 |
| Fuselage | 4455.6 | 21.41 | 0.00 | 3.50 |
| Horizontal Tail | 445.6 | 62.00 | 0.00 | 6.00 |
| Vertical Tail | 267.3 | 62.00 | 0.00 | 16.00 |
| Nose Gear | 245.9 | 8.00 | 0.00 | 0.98 |
| Main Gear | 1393.7 | 30.00 | 0.00 | 2.38 |

**Fig. 16 Structure CG breakdown**

Class I Empty Weight Breakdown: Flight Condition 1

Output Parameters

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $W_{structure}$ | 11049.7 | lb | $X_{cg_{structure}}$ | 25.73 | ft | $Y_{cg_{structure}}$ | 0.00 | ft | $Z_{cg_{structure}}$ | 3.28 | ft |
| $W_E$ | 21921.3 | lb | $X_{cg_E}$ | 23.96 | ft | $Y_{cg_E}$ | 0.01 | ft | $Z_{cg_E}$ | 3.47 | ft |

Empty Weight Table

| Component | Weight lb | $X_{cg}$ ft | $Y_{cg}$ ft | $Z_{cg}$ ft |
|---|---|---|---|---|
| Fuselage Group | 4455.6 | 21.41 | 0.00 | 3.50 |
| Wing Group | 3386.2 | 23.00 | 0.00 | 2.00 |
| Empennage Group | 712.9 | 62.00 | 0.00 | 9.75 |
| Landing Gear Group | 1639.6 | 26.70 | 0.00 | 2.17 |
| Nacelle Group | 855.5 | 27.00 | 0.00 | 4.00 |
| Powerplant Group | 5596.2 | 22.58 | 0.00 | 3.80 |
| Fixed Equipment Group | 5275.4 | 21.73 | 0.03 | 3.51 |

**Fig. 17 Equipment group CG breakdown**

Weight & Balance C.G. Excursion: Flight Condition 1

Input Parameters

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $W_{FL}$ | 4550.0 | lb | $W_{PL_{exp}}$ | 0.0 | lb | $X_{cg_{mg}}$ | | ft | $X_{apex_w}$ | 21.00 | ft | $x_{mgc_w}$ | 0.59 | ft | $\bar{c}_w$ | 10.44 | ft |

Output Parameters

| | | | | | |
|---|---|---|---|---|---|
| $W_{current}$ | 37689.0 | lb | $X_{cg}$ | 24.02 | ft |

C.G. Excursion Table

| Component | Weight lb | $X_{cg}$ ft | Load (1-13) | Unload (1-13) |
|---|---|---|---|---|
| Empty Weight | 21921.3 | 23.96 | 1 | 13 |
| Crew | 525.0 | 12.05 | 3 | 5 |
| Trapped Fuel and Oil | 188.4 | 21.41 | 2 | 12 |
| Mission Fuel Group 1 | 10679.3 | 22.00 | 4 | 1 |
| Mission Fuel Group 2 | 0.0 | 0.00 | | |
| Passenger Group 1 | 1750.0 | 28.92 | 6 | 2 |
| Passenger Group 2 | 0.0 | 0.00 | | |
| Passenger Group 3 | 0.0 | 0.00 | | |
| Passenger Group 4 | 0.0 | 0.00 | | |
| Baggage | 605.0 | 28.92 | 7 | 3 |
| Cargo | 2020.0 | 33.00 | 5 | 4 |
| Military Load Group 1 | 0.0 | 0.00 | | |
| Military Load Group 2 | 0.0 | 0.00 | | |

**Fig. 18 CG excursion ordering**

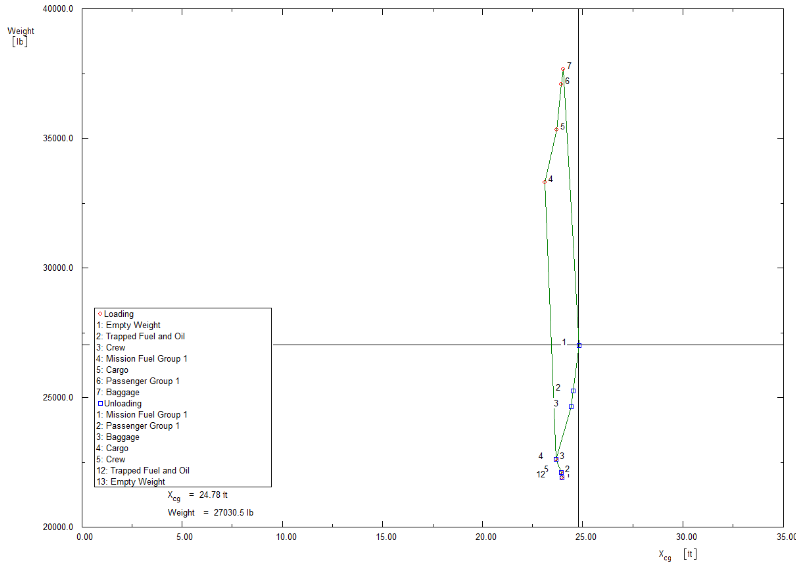


**Fig. 19 Plot of CG excursion with most aft point marked**

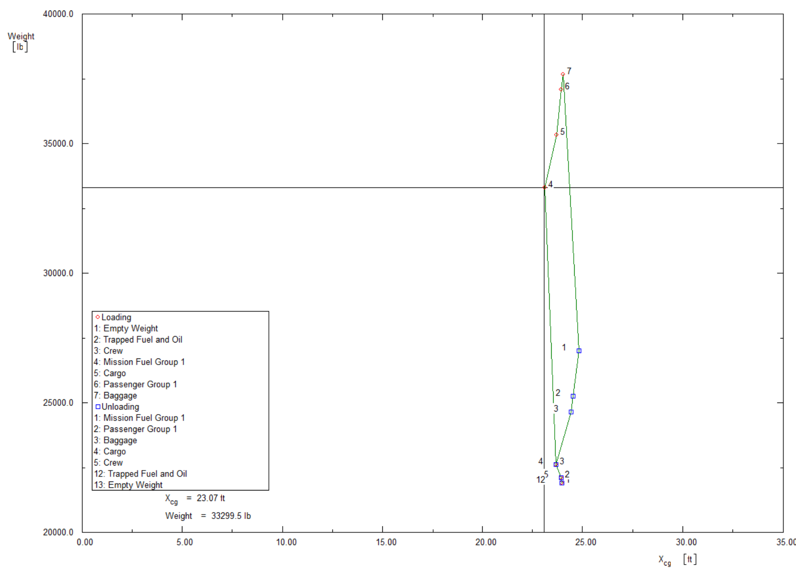


**Fig. 20 Plot of CG excursion with most forward point marked**

**Class I: Total Aircraft Center of Gravity: Flight Condition 1**

**Input Parameters**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $W_E$ | 21921.3 | lb | $X_{cg_E}$ | 23.96 | ft | $Y_{cg_E}$ | 0.01 | ft | $Z_{cg_E}$ | 3.47 | ft |

**Output Parameters**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $W_{current}$ | 37689.0 | lb | $X_{cg}$ | 24.02 | ft | $Y_{cg}$ | -0.11 | ft | $Z_{cg}$ | 2.95 | ft |

**Loading Table**

| Component | Weight lb | $X_{cg}$ ft | $Y_{cg}$ ft | $Z_{cg}$ ft |
|---|---|---|---|---|
| Crew | 525.0 | 12.05 | -0.56 | 5.00 |
| Trapped Fuel and Oil | 188.4 | 21.41 | 0.00 | 3.50 |
| Mission Fuel Group 1 | 10679.3 | 22.00 | 0.00 | 2.00 |
| Mission Fuel Group 2 | 0.0 | 0.00 | 0.00 | |
| Passenger Group 1 | 1750.0 | 28.92 | 0.00 | 5.00 |
| Passenger Group 2 | 0.0 | 0.00 | 0.00 | |
| Passenger Group 3 | 0.0 | 0.00 | 0.00 | |
| Passenger Group 4 | 0.0 | 0.00 | 0.00 | |
| Baggage | 605.0 | 28.92 | 0.00 | 3.00 |
| Cargo | 2020.0 | 33.00 | -2.00 | 0.00 |
| Military Load Group 1 | 0.0 | 0.00 | 0.00 | |
| Military Load Group 2 | 0.0 | 0.00 | 0.00 | |

**Fig. 21 Fully loaded aircraft CG breakdown**

## C. AAA: Empennage Layout Design

**Straight Tapered Wing Geometry: Flight Condition 1**

**Input Parameters**

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $AR_w$ | 8.00 | | $S_w$ | 837.00 | $ft^2$ | $\lambda_w$ | 0.60 | | $\Lambda_{c/4_w}$ | 0.0 | deg | $X_{apex_w}$ | 21.00 | ft | $Y_{offset_w}$ | 0.00 | ft |

**Output Parameters**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $c_{r_w}$ | 12.79 | ft | $b_w$ | 81.83 | ft | $y_{mgc_w}$ | 18.75 | ft | $\Lambda_{LE_w}$ | 1.8 | deg |
| $c_{t_w}$ | 7.67 | ft | $\bar{c}_w$ | 10.44 | ft | $x_{mgc_w}$ | 0.59 | ft | $\Lambda_{TE_w}$ | -5.4 | deg |

**Straight Tapered Wing Geometry: Output Parameters**

| Panel | $c_r$ ft | $c_t$ ft | $X_r$ ft | $X_t$ ft | $Y_r$ ft |
|---|---|---|---|---|---|
| 1 | 12.7858 | 7.6715 | 21.0000 | 22.2786 | 0.0000 |

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**Fig. 22 Wing layout, with adjusted apex location**

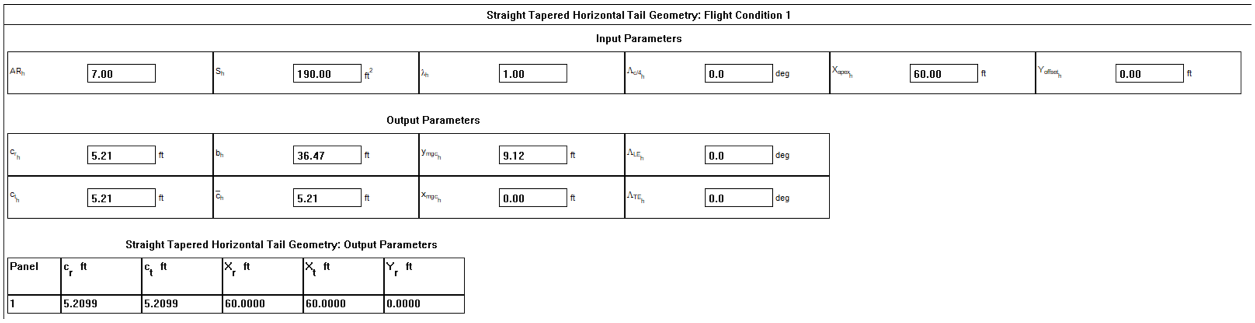



**Fig. 23 Horizontal stabilizer sizing**

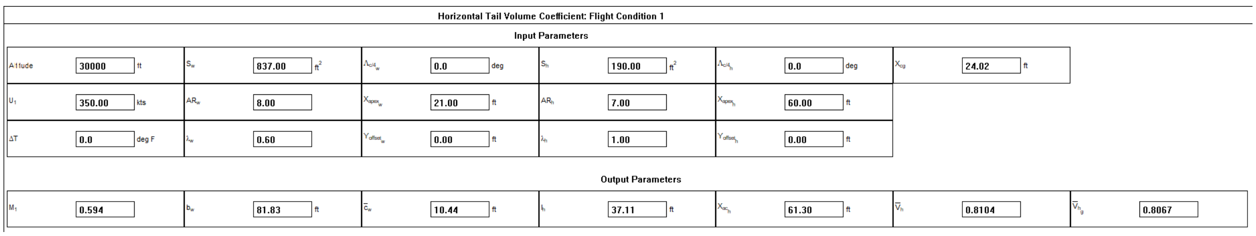



**Fig. 24 Horizontal tail volume coefficient calculations**

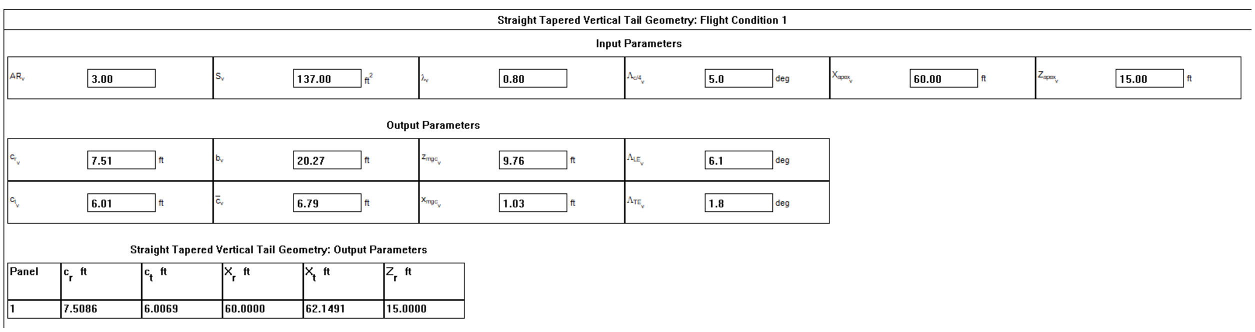



**Fig. 25 Vertical stabilizer sizing**

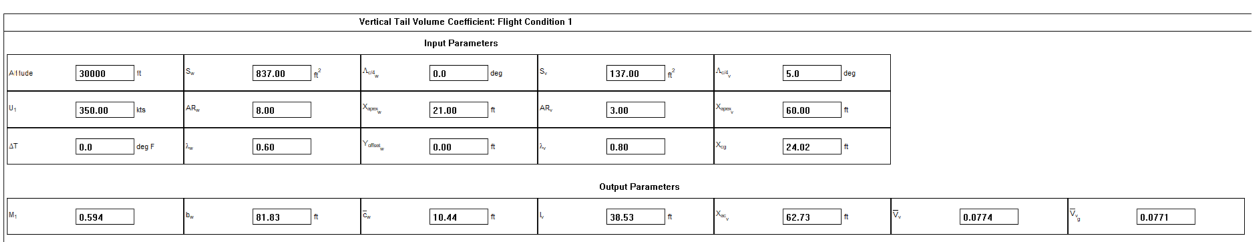



**Fig. 26 Vertical stabilizer volume ratio calculation**

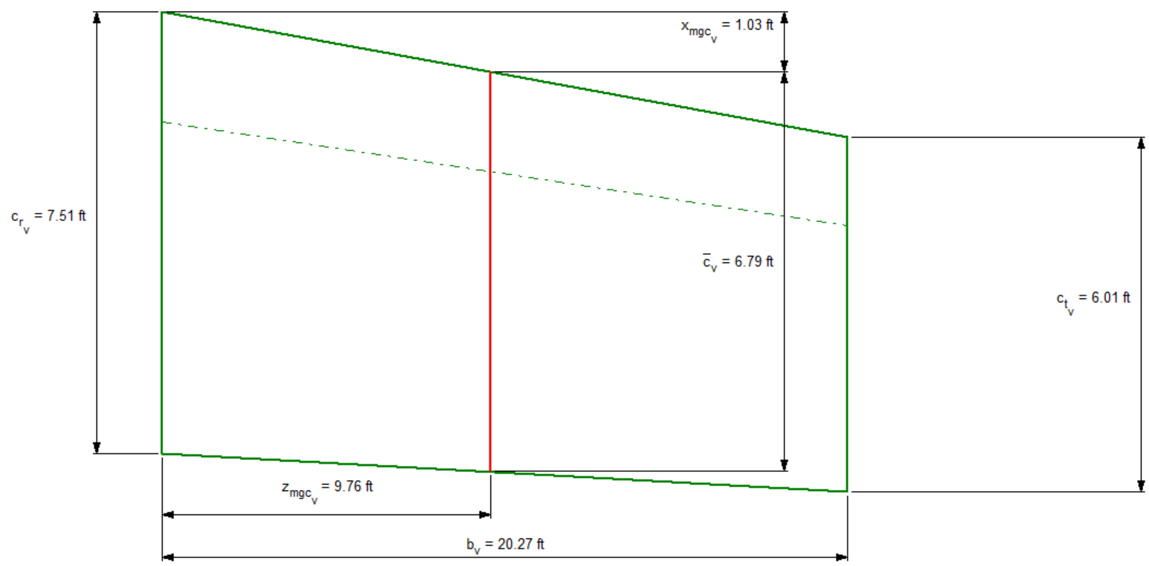
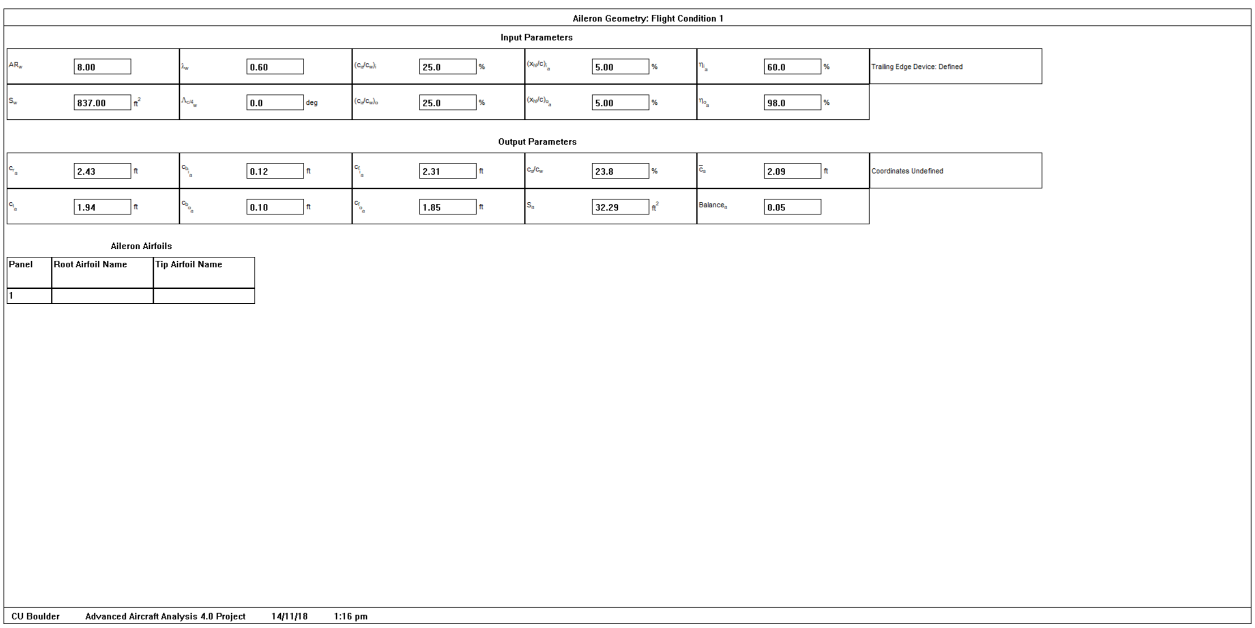



**Fig. 27 Vertical stabilizer with aerodynamic center shown**



Aileron Geometry: Flight Condition 1

Input Parameters

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $AR_w$ | 8.00 | $\lambda_w$ | 0.60 | $(c_a/c_w)_i$ | 25.0 % | $(x_H/c)_{i_a}$ | 5.00 % | $\eta_{i_a}$ | 60.0 % | Trailing Edge Device: Defined |
| $S_w$ | 837.00 ft$^2$ | $\Lambda_{c/4_w}$ | 0.0 deg | $(c_a/c_w)_o$ | 25.0 % | $(x_H/c)_{o_a}$ | 5.00 % | $\eta_{o_a}$ | 98.0 % | |

Output Parameters

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $c_{r_a}$ | 2.43 ft | $c_{b_{i_a}}$ | 0.12 ft | $c_{f_{i_a}}$ | 2.31 ft | $c_a/c_w$ | 23.8 % | $\bar{c}_a$ | 2.09 ft | Coordinates Undefined |
| $c_{t_a}$ | 1.94 ft | $c_{b_{o_a}}$ | 0.10 ft | $c_{f_{o_a}}$ | 1.85 ft | $S_a$ | 32.29 ft$^2$ | $Balance_a$ | 0.05 | |

Aileron Airfoils

| Panel | Root Airfoil Name | Tip Airfoil Name |
|---|---|---|
| 1 | | |

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**Fig. 28 Aileron layout**

## D. AAA: Control Surface Layout Design

**Elevator Geometry: Flight Condition 1**

**Input Parameters**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $AR_h$ | 7.00 | | $\lambda_h$ | 1.00 | | $(c_e/c_h)_i$ | 30.0 | % | $(x_H/c)_{i_e}$ | 5.00 | % | $\eta_{i_e}$ | 5.0 | % |
| $S_h$ | 190.00 | $ft^2$ | $\Lambda_{c/4_h}$ | 0.0 | deg | $(c_e/c_h)_o$ | 30.0 | % | $(x_H/c)_{o_e}$ | 5.00 | % | $\eta_{o_e}$ | 95.0 | % |

**Output Parameters**

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $c_{r_e}$ | 1.56 | ft | $c_{b_{i_e}}$ | 0.08 | ft | $c_{f_{i_e}}$ | 1.48 | ft | $c_e/c_h$ | 28.5 | % | $\bar{c}_e$ | 1.48 | ft | Coordinates Undefined |
| $c_{t_e}$ | 1.56 | ft | $c_{b_{o_e}}$ | 0.08 | ft | $c_{f_{o_e}}$ | 1.48 | ft | $S_e$ | 48.74 | $ft^2$ | $Balance_e$ | 0.05 | | |

**Elevator Airfoils**

| Panel | Root Airfoil Name | Tip Airfoil Name |
|---|---|---|
| 1 | | |

**Fig. 29 Elevator control surface sizing**

**Rudder Geometry: Flight Condition 1**

**Input Parameters**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $AR_v$ | 3.00 | | $\lambda_v$ | 0.80 | | $(c_r/c_v)_i$ | 30.0 | % | $(x_H/c)_{i_r}$ | 5.00 | % | $\eta_{i_r}$ | 5.0 | % |
| $S_v$ | 137.00 | $ft^2$ | $\Lambda_{c/4_v}$ | 5.0 | deg | $(c_r/c_v)_o$ | 30.0 | % | $(x_H/c)_{o_r}$ | 5.00 | % | $\eta_{o_r}$ | 95.0 | % |

**Output Parameters**

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $c_{r_r}$ | 2.23 | ft | $c_{b_{i_r}}$ | 0.11 | ft | $c_{f_{i_r}}$ | 2.12 | ft | $c_r/c_v$ | 28.5 | % | $\bar{c}_r$ | 1.94 | ft | Coordinates Undefined |
| $c_{t_r}$ | 1.82 | ft | $c_{b_{o_r}}$ | 0.09 | ft | $c_{f_{o_r}}$ | 1.73 | ft | $S_r$ | 35.14 | $ft^2$ | $Balance_r$ | 0.05 | | |

**Rudder Airfoils**

| Panel | Root Airfoil Name | Tip Airfoil Name |
|---|---|---|
| 1 | | |

**Fig. 30 Rudder sizing**

## E. AAA: Stability Derivatives

**Angle of Attack Related Derivatives: Lift: Flight Condition 1**

**Input Parameters**

| | | | | | | |
|---|---|---|---|---|---|---|
| Altitude 30000 ft | $f_{gap_w}$ 0.93 | $i_w$ -1.0 deg | $Z_{c_r/4_w}$ 2.00 ft | $X_{apex_h}$ 60.00 ft | $\Gamma_h$ 0.0 deg | $w_{f_h}$ 2.00 ft |
| $\Delta T$ 0.0 deg F | $S_w$ 837.00 $ft^2$ | $X_{apex_w}$ 21.00 ft | $S_h$ 190.00 $ft^2$ | $Y_{offset_h}$ 0.00 ft | $\eta_{h_{p.off}}$ 1.000 | $D_{f_{max_w}}$ 6.83 ft |
| $U_1$ 350.00 kts | $AR_w$ 8.00 | $Y_{offset_w}$ 0.00 ft | $AR_h$ 7.00 | $(t/c)_{r_h}$ 12.0 % | $c_{l_{\alpha_{rh}}}@M=0$ 6.2504 $rad^{-1}$ | |
| $c_{l_{\alpha_{rw}}}@M=0$ 6.3598 $rad^{-1}$ | $\lambda_w$ 0.60 | $(t/c)_{r_w}$ 12.00 % | $\lambda_h$ 1.00 | $(t/c)_{t_h}$ 12.0 % | $c_{l_{\alpha_{th}}}@M=0$ 6.2504 $rad^{-1}$ | |
| $c_{l_{\alpha_{tw}}}@M=0$ 6.3598 $rad^{-1}$ | $\Lambda_{c/4_w}$ 0.0 deg | $(t/c)_{t_w}$ 12.00 % | $\Lambda_{c/4_h}$ 0.0 deg | $Z_{c_r/4_h}$ 6.00 ft | $f_{gap_h}$ 1.00 | |

**Output Parameters**

| | | | | | | |
|---|---|---|---|---|---|---|
| $M_1$ 0.594 | $c_{l_{\alpha_w}}$ 7.9041 $rad^{-1}$ | $C_{L_{\alpha_{wf}}}$ 5.3724 $rad^{-1}$ | $c_{l_{\alpha_h}}$ 7.7681 $rad^{-1}$ | $d\varepsilon_h/d\alpha$ 0.3848 | $C_{L_{\alpha_{no\ empen}}}$ 5.3724 $rad^{-1}$ | $C_{L_\alpha}$ 6.1694 $rad^{-1}$ |
| $\bar{q}_1$ 155.41 $lb/ft^2$ | $C_{L_{w_{\alpha\ clean}}}$ 5.3706 $rad^{-1}$ | $K_{wf}$ 1.0003 | $Z_{ac_h}$ 6.00 ft | $C_{L_{h_\alpha}}$ 5.7070 $rad^{-1}$ | $C_{L_{\alpha_{clean\ p.off}}}$ 6.1694 $rad^{-1}$ | |
| $c_{l_{\alpha_{rw}}}$ 7.9041 $rad^{-1}$ | $C_{L_{\alpha_{wf\ clean}}}$ 5.3724 $rad^{-1}$ | $c_{l_{\alpha_{rh}}}$ 7.7681 $rad^{-1}$ | $d\varepsilon_h/d\alpha_{clean}$ 0.3848 | $C_{L_{\alpha_h}}$ 0.7970 $rad^{-1}$ | $C_{L_{\alpha\ p.off}}$ 6.1694 $rad^{-1}$ | |
| $c_{l_{\alpha_{tw}}}$ 7.9041 $rad^{-1}$ | $C_{L_{w_\alpha}}$ 5.3706 $rad^{-1}$ | $c_{l_{\alpha_{th}}}$ 7.7681 $rad^{-1}$ | $(d\varepsilon_h/d\alpha)_{p.off}$ 0.3848 | $C_{L_{\alpha_{no\ emp\ clean}}}$ 5.3724 $rad^{-1}$ | $C_{L_{\alpha_{clean}}}$ 6.1694 $rad^{-1}$ | |

**High Lift Devices Table**

| # | High Lift Device | $\eta_i$ % | $\eta_o$ % | $c/c_w$ % | $\delta$ deg |
|---|---|---|---|---|---|
| 1 | Single Slotted Flap | 9.0 | 55.5 | 30.0 | 0.0 |

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**Fig. 31 Calculations of derivatives of $C_L$**

**Angle of Attack Related Derivatives: Pitching Moment: Flight Condition 1**

**Input Parameters**

| | | | | | | |
|---|---|---|---|---|---|---|
| Altitude 30000 ft | $f_{gap_w}$ 0.93 | $X_{apex_w}$ 23.00 ft | $S_h$ 190.00 $ft^2$ | $Y_{offset_h}$ 0.00 ft | $\eta_{h_{p.off}}$ 1.000 | $D_{f_{max_w}}$ 6.83 ft |
| $\Delta T$ 0.0 deg F | $S_w$ 837.00 $ft^2$ | $Y_{offset_w}$ 0.00 ft | $AR_h$ 7.00 | $(t/c)_{r_h}$ 12.0 % | $c_{l_{\alpha_{rh}}}@M=0$ 6.2504 $rad^{-1}$ | $\Delta\bar{x}_{ac_f}$ -0.0451 |
| $U_1$ 350.00 kts | $AR_w$ 8.00 | $(t/c)_{r_w}$ 12.00 % | $\lambda_h$ 1.00 | $(t/c)_{t_h}$ 12.0 % | $c_{l_{\alpha_{th}}}@M=0$ 6.2504 $rad^{-1}$ | $X_{cg}$ 24.06 ft |
| $c_{l_{\alpha_{rw}}}@M=0$ 6.3598 $rad^{-1}$ | $\lambda_w$ 0.60 | $(t/c)_{t_w}$ 12.00 % | $\Lambda_{c/4_h}$ 0.0 deg | $Z_{c_r/4_h}$ 6.00 ft | $f_{gap_h}$ 1.00 | |
| $c_{l_{\alpha_{tw}}}@M=0$ 6.3598 $rad^{-1}$ | $\Lambda_{c/4_w}$ 0.0 deg | $Z_{c_r/4_w}$ 2.00 ft | $X_{apex_h}$ 60.00 ft | $\Gamma_h$ 0.0 deg | $w_{f_h}$ 2.00 ft | |

**Output Parameters**

| | | | | | | |
|---|---|---|---|---|---|---|
| $M_1$ 0.594 | $c_{l_{\alpha_{rw}}}$ 7.9041 $rad^{-1}$ | $C_{L_{w_\alpha}}$ 5.3706 $rad^{-1}$ | $\bar{x}_{ac_{wf\ p.off}}$ 0.2049 | $\bar{x}_{ac_h}$ 3.6121 | $d\varepsilon_h/d\alpha$ 0.3931 | SM 59.40 % |
| $\bar{q}_1$ 155.41 $lb/ft^2$ | $c_{l_{\alpha_{tw}}}$ 7.9041 $rad^{-1}$ | $C_{L_{\alpha_{wf}}}$ 5.3724 $rad^{-1}$ | $c_{l_{\alpha_{rh}}}$ 7.7681 $rad^{-1}$ | $C_{L_{h_\alpha}}$ 5.7070 $rad^{-1}$ | $\bar{V}_h$ 0.8095 | $C_{L_{\alpha\ p.off}}$ 6.1586 $rad^{-1}$ |
| $\bar{x}_{cg}$ 0.0459 | $c_{l_{\alpha_w}}$ 7.9041 $rad^{-1}$ | $X_{ac_w}$ 26.20 ft | $c_{l_{\alpha_{th}}}$ 7.7681 $rad^{-1}$ | $C_{L_{\alpha_h}}$ 0.7862 $rad^{-1}$ | $X_{ac}$ 30.27 ft | $C_{L_\alpha}$ 6.1586 $rad^{-1}$ |
| $\bar{c}_w$ 10.44 ft | $C_{L_{w_{\alpha\ clean}}}$ 5.3706 $rad^{-1}$ | $\bar{x}_{ac_w}$ 0.2500 | $c_{l_{\alpha_h}}$ 7.7681 $rad^{-1}$ | $Z_{ac_h}$ 6.00 ft | $\bar{x}_{ac_{p.off}}$ 0.6399 | $C_{m_{\alpha\ p.off}}$ -3.6582 $rad^{-1}$ |
| $x_{mgc_w}$ 0.59 ft | $C_{L_{\alpha_{wf\ clean}}}$ 5.3724 $rad^{-1}$ | $X_{ac_{wf\ p.off}}$ 25.73 ft | $X_{ac_h}$ 61.30 ft | $(d\varepsilon_h/d\alpha)_{p.off}$ 0.3931 | $\bar{x}_{ac}$ 0.6399 | $C_{m_\alpha}$ -3.6582 $rad^{-1}$ |

**High Lift Devices Table**

| # | High Lift Device | $\eta_i$ % | $\eta_o$ % | $c/c_w$ % | $\delta$ deg |
|---|---|---|---|---|---|
| 1 | Single Slotted Flap | 9.0 | 55.5 | 30.0 | 0.0 |

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**Fig. 32 Initial static margin calculation**

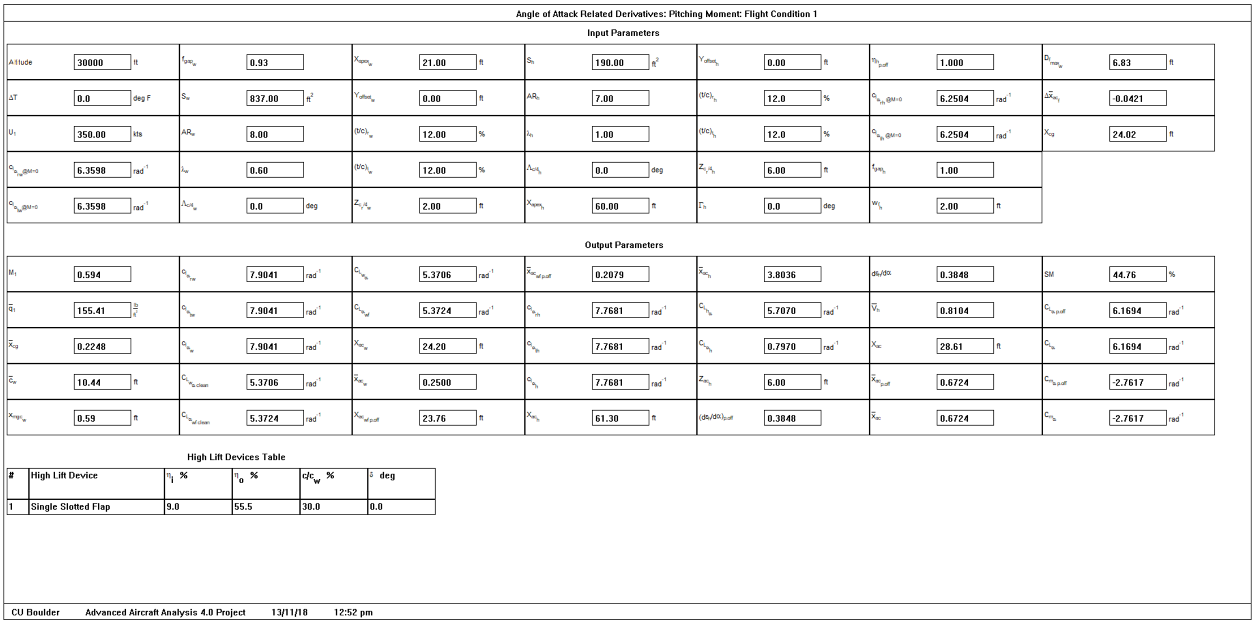


**Fig. 33 Revised static margin calculation**

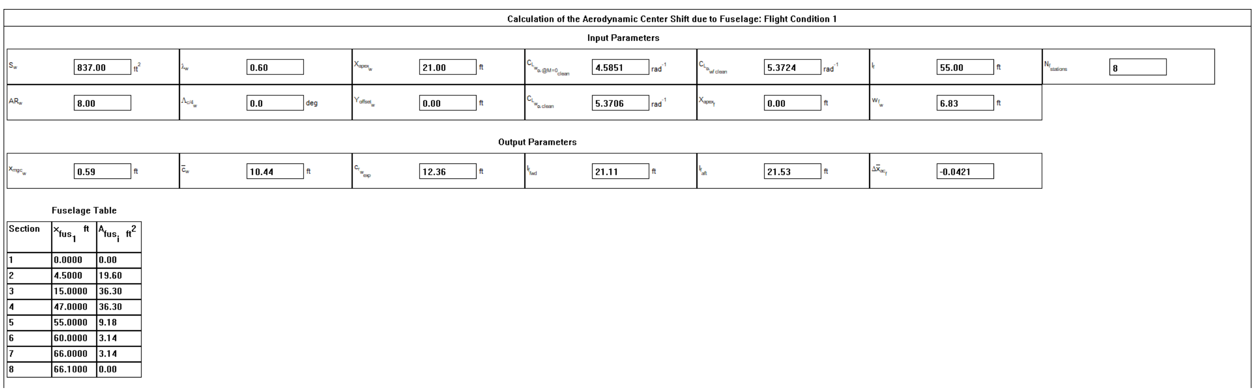


**Fig. 34 Change in aerodynamic center due to fuselage influence**