Design Report 02: Twin Sea Lion

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Contents

List of Figures

List of Tables

Nomenclature

AAA = Advanced Aircraft Analysis Program

AR_W = Aspect Ratio

b_W = Wing Span

$\bar{c}_W$ = Mean Geometric Chord

i_W = Incidence Angle

KTAS = Knots True Airspeed

l_f = Length of fuselage

MSL = Mean Sea Level Altitude

S_W = Wing Area

TWR = Thrust to weight ratio

ϵ_W = Wing Twist Angle

$\Lambda_{c/4w}[^\circ]$ = Wing Sweep Angle

λ_W = Taper Ratio

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

Γ_W = Dihedral

I. Introduction

The Twin Sea Lion is an upcoming cargo and personal transport aircraft meant for moving payloads over 1500 nautical miles quickly and efficiently. The aircraft is designed with challenging airports in mind, with planned takeoffs and landings from Aspen Airport, a 4000 foot runway at 7000 feet MSL. At lower altitudes, this equates to STOL performance. It has a takeoff weight of 37,689 pounds and a useful load of 16,682 pounds. Pratt and Whittney PW150A turboprop engines provide exceptional power and economy of operation. This report presents design considerations including the cockpit and cabin layouts, wing geometry and planform, flap configuration, and engine power calculations.

II. Addendum to Report 1

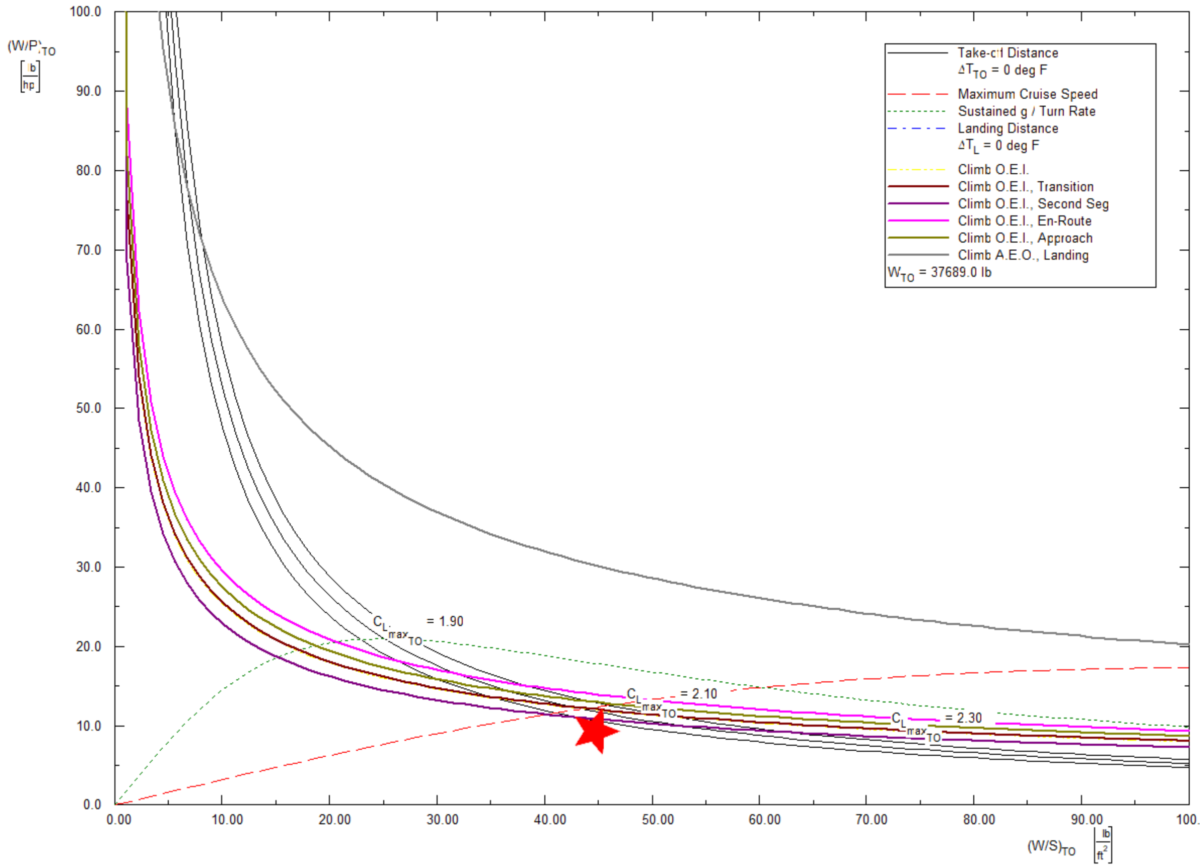

Fig. 1 Revised performance sizing plots

In Design Report 1, takeoff and maneuvering performance sizing plots were misinterpreted. Original performance sizing plots showed much lower lines for cruise and maneuvering performance constraints and a design point above these lines was chosen. This proved to be incorrect, however, as all example plots were given for a jet aircraft and the y-axis of the plot was thrust to weight (TWR). This plot shows power loading, so all the lines that the aircraft would need to be above, it now must be below. Cruise and maneuvering constraints were raised by decreasing the cruise speed from 0.8 to 0.6 Mach. Thankfully, this did not appreciably change the design point and wing loading was kept at roughly 45 pound per square foot and power loading at 8 pounds per horsepower, leading to a power requirement of 4711 total horsepower.

III. Configuration Selection

A. Selection of the Overall Configuration

A conventional configuration will provide the most reliable performance for the Twin Sea Lion. The Sea Lion needs large wings and engines to meet its STOL goal and thus large wings to produce lift and place engines. As the Sea Lion will be following a standard transport mission profile, there is no need for greater maneuverability as may be provided by a canard or Mach cone avoidance as provided by a Delta wing. A conventional wing provides high amounts of structural strength and space for the high-lift devices necessary for STOL. Though a conventional wing may not be at the forefront of all possible aerodynamics, this small disadvantage does not outweigh the advantages.

B. Wing Bracing and Position

The Sea Lion wings will be cantilevered. With a cruise Mach number of 0.6, the drag from wing struts would be extremely large.

A low mounted wing would reduce the gear length and weight and keep the wingbox out of the way. However, this decreases the possible size of the propellers. The powerful engines planned for the Twin Sea Lion will need comparably large propellers, so this point needs special attention. A mid mounted wing would allow more room for propellers but would require longer gears and puts the wing box in the middle of the plane. This would interfere with passenger comfort should the cargo to passenger proportion not allow for separation of cargo and passenger area with the wingbox. A high mounted wing would allow for the largest propellers but would require the gears to be in the fuselage to avoid extreme gear weight.

The British Aerospace ATP used a low mounted wing and large propellers by mounting the engines above the wings. Since the wing volume for our plane is much larger than needed for fuel with a relatively thin airfoil, the wing also makes the best position for the main landing gear. Therefore, the Twin Sea Lion will use a low mounted wing.

IV. Fuselage and Cockpit Layout Design

A. Fuselage and Cabin Layout Design

Fuselage width was determined from seat width, aisle width, and estimates for wall width. With 10 passengers, the Sea Lion needs 15 inches of aisle. Though an aisle width of 20 inches may be more suitable for embarking and disembarking, this narrow aisle will allow for wider seats and thus more comfort for sitting passengers, which will account for most of the flight. De Luxe Seats (Table 3.1, Pres 11) have 20 inches of cushion width and 2.75 inches for armrests. With two armrests a seat and two seats in a row across the fuselage, this is 51 inches for seats and 66 inches wide total in the interior. However, given considerations for headroom of the occupants, the inner diameter of the cabin was increased to 76 inches. Total exterior diameter is 8% larger than interior diameter, which puts exterior diameter at 82 inches.

Space between seat was determined by the femur length of a member of the design team, plus one inch for a $q1$ total of 25 inches. This gives a row width of 50.5 inches, including the existing 25.5 seat length.

The lavatory was chosen to match the dimensions of the lavatory in the Gulfstream I as in Table 3.6 of presentation 12 [**?**] since this plane was of comparable passenger number. No galley or wardrobe were deemed necessary for this trip length.

Necessary cargo dimensions were determined from assumptions of bag density of $12.5 lb/ft^3$ and packing efficiency of 85%. With 2400 pounds of cargo this equates to $225.88 ft^3$. With a removable aisle floor, some cargo can fit under the seat. The usable volume of this space was estimated as a trapezoid stretched below all passenger seats as depicted in figure 7. Thus the volume is $(20.5in \cdot 17.55in) + (22.63in \cdot 17.55in) = 181,663in^3 = 105.129ft^3$. The next most available space is across from the lavatory. This was also estimated as a trapezoid as in figure 7 stretched along the length of the lavatory. This volume is $(20.86in \cdot 17.01in) + (38.05in \cdot 20.86in) = 60,870in^3 = 35.23ft^3$. This leaves $115.523ft^3$ remaining. The final cargo space was assumed to take the entire interior fuselage cross sectional area ($A = \frac{1}{4}\pi(75.97/12ft)^2 = 31.478ft^2$) and had a length determined from $\frac{115.523ft^3}{31.478ft^2} = 3.67ft = 44.04in$. An inch was added to allow for a wall between this main cargo area and the passenger area.

Table 1 Characteristics of similar airplanes

Plane	l_f [ft]	d_f [ft]	W_E [lb]	W_E/l_f	l_f/d_f
DHC-6 Twin Otter	51.74	5.75	7,100	137.23	9.0
PC-24	55.12	5.6	10,957	198.79	9.8
DHC-4 Caribou	73.98	6.125	16,920	228.70	12.1
F-27 Friendship	77.30		27,964	361.78	
Dash 8 Q-400	107.74	8.25	36,520	338.96	13.1
Twin Sea Lion	47.58	6.875	37689	792.1	6.9

The fineness ratio was calculated as $\frac{l_f}{d_f} = \frac{180+391}{82.5} = 6.92$. This fineness ratio makes sense relative to that of the Twin Otter since sea lions are naturally fatter than otters. Though we are currently much less fine than any other aircraft, current dimensions neglect any tail length. Additional tail length will increase the fineness ratio.

An annotated layout of the fuselage design can be seen below in figure 7.

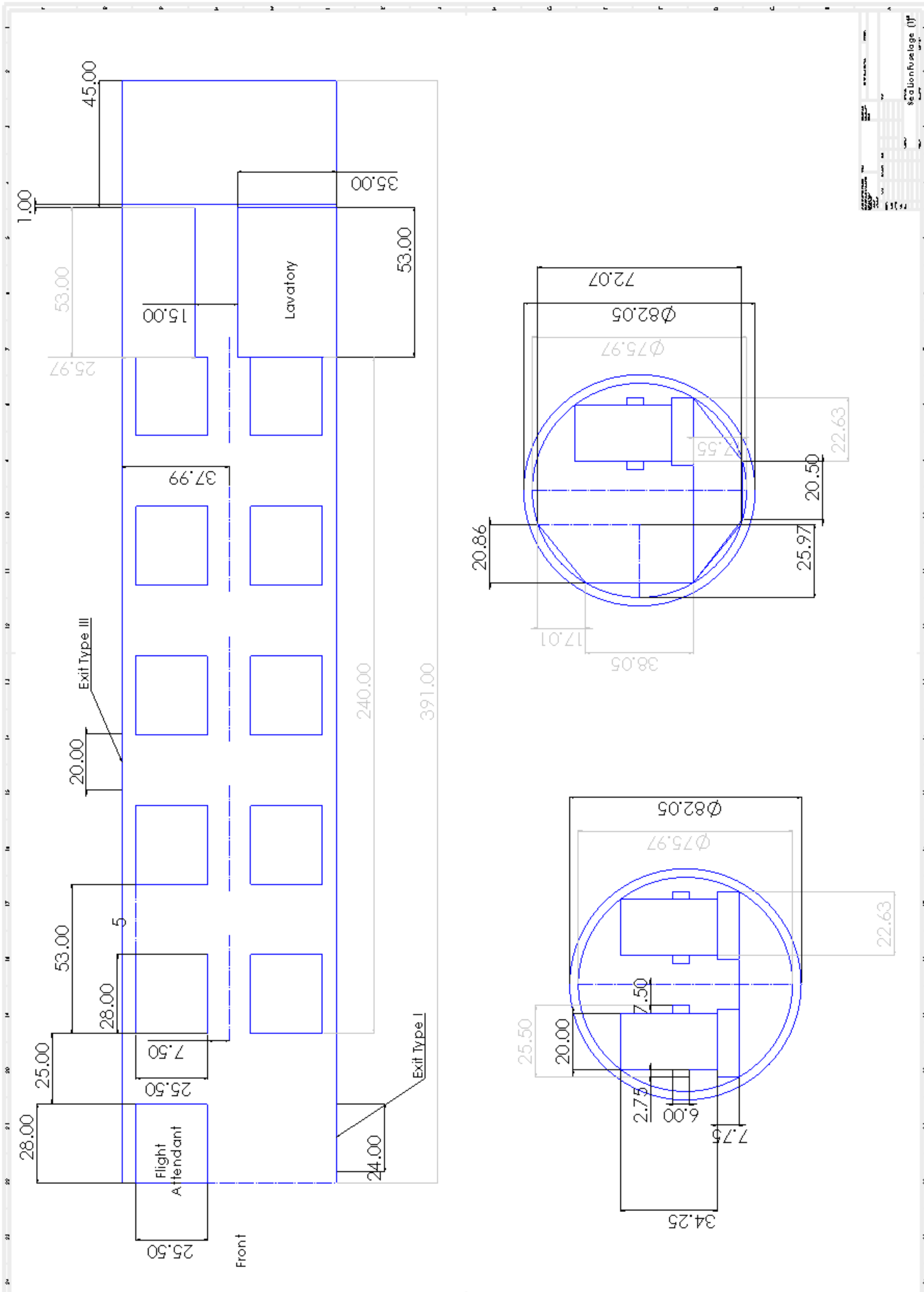

Fig. 2 Fuselage layout with measurements

B. Cockpit Layout Design

Cockpit design was modeled on existing aircraft with similar layouts, primarily the 1930s Lockheed Electra. The design is tightly integrated around the pilot, and he sits close to the windshield, with eyes only 22 inches away. Seat dimensions and control locations were based on presentation 13 [12] in class, which prescribes dimensions such as seat pan angle, rudder dimensions and deflections, and yoke travel requirements for a standard aircraft. The close position of the pilot was deemed necessary in order to accommodate the required vertical and horizontal fields of view in the available space for windows in the front of the Twin Sea Lion.

Controls are standard, with a yoke from the panel and conventional rudders and throttle placement between the pilots. The two pilot's seats are side by side. No accommodations are made for a flight engineer because modern avionics and engine controls negate the need for one.

An annotated cockpit layout can be seen below in figure 6 and an unannotated version can be seen in figure 5 on page 14.

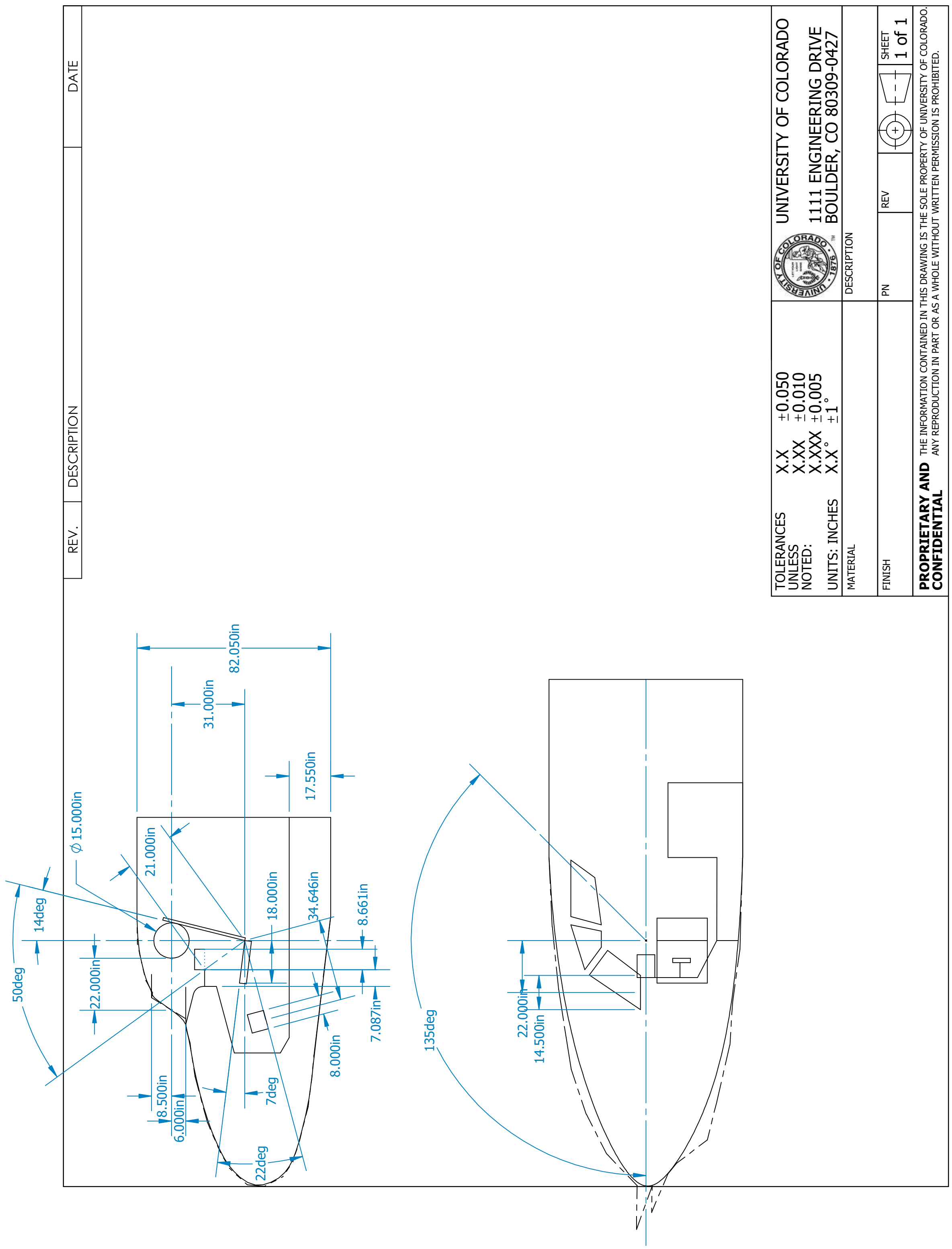

Fig. 3 Cockpit layout with measurements

V. Wing Layout Design

A. Airfoil Selection

Airfoil selection principally concerned finding an airfoil with the highest reasonable $C_{L_{max}}$ and the lowest possible cruise drag. The airfoils considered are tabulated in table 3 on page 23. The NACA 65(1)-412 airfoil was selected because it gives the highest lift of any airfoil found, low drag, and modest thickness at 12%. It also features a 'drag bucket', shown in figure 3 on page 12, which predictions show will align with the C_L required at cruise.

Using a predicted cruise altitude of 30,000 feet and a speed of 350 KTAS, equation 4 gives $\bar{q} = 155.4\ lbf/ft^2$. With S_w, the wing area from AAA as $837 ft^2$, equation 5 gives a predicted cruise $C_L = 0.259$ for the entire wing. Looking again at figure 3, this does indeed fall in the airfoil 'drag bucket' where $C_d = 0.004$, and should provide good cruise performance.

Again from figure 3, C_m stays nearly constant, as is desirable, at -0.8 for this airfoil.

B. Geometric Design

Since the wing is a straight tapered planform, the mean geometric chord can be calculated as follows.

$$\bar{c}_w = c_r \frac{1+\lambda}{2} \tag{1}$$

With c_r selected as 12.7 feet and $\lambda_W = 0.6$, $\bar{c}_W = 10.16$ feet.

Incidence angle was based on where the plain airfoil reaches the appropriate lift coefficient for cruise as calculated below.

$$W_C = W_{TO} - 0.4 W_F \tag{2}$$

$$C_L = \frac{W_C}{\bar{q} S} \tag{3}$$

In cruise conditions, $C_L = 0.259$, which is actually below the zero-lift angle of attack of 0.35, so it was decided to mount the wings at a $-1.5°$ angle of incidence so that the aircraft will cruise with the nose perfectly level. The airfoil still stays in the regime of minimum drag at this angle of attack.

As an alternative, the designers considered twisting the wingtips downwards to improve roll control during stall and reduce cruise C_L. However, this line of inquiry was dropped on the basis of geometric complexity and lack of access to the advanced aerodynamic modeling needed to determine the appropriate amount and distribution of twist needed to achieve these goals.

From Table 6.6 in [11] and tabulated in table 4 in the appendix, most regional airliners have no wing twist, solidifying the decision to keep the wingtips level. In addition, this data was used to make and educated guess at the appropriate dihedral angle Γ_W. The average dihedral angle of the selected aircraft is 4.67°. Thus, $\Gamma_W = 5°$ was selected as a reasonable value but if anything, this may have to be increased in the future to accommodate the anticipated ground clearance requirements of the propellers and the destabilizing effects of the low mounted wing. Most of the low wing aircraft in the aforementioned table have dihedral angles of 7°.

The final geometric design variables are tabulated below in table 4 and shown graphically in figure 18.

Table 2 Geometric design variables

S_W $[ft^2]$	b_w [ft]	AR_W	c_w[ft]	λ_W	$\Lambda_{c/4w}[°]$	$\Gamma_W[°]$	$i_W[°]$	$\epsilon_W[°]$
837	81.8	8	10.16	0.6	0	5	-1	0

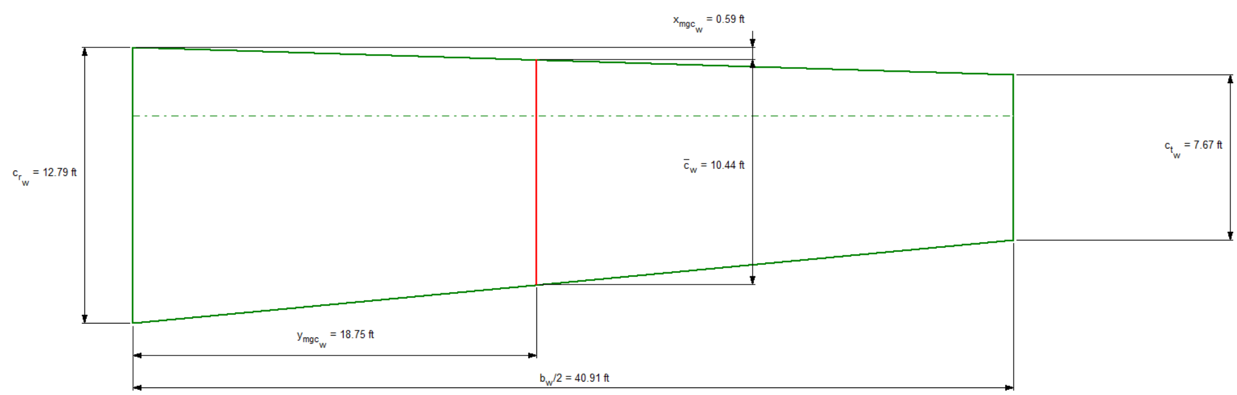

Fig. 4 Straight tapered wing geometry plot

C. Critical Mach Number Check

Based on the graph in figure 4 on page 13, the critical Mach number of the chosen NACA 65(1)-412 airfoil is $M = 0.75$, well above the intended cruise speed of the Twin Sea Lion. Our design point is circled at the very bottom left corner of the graph. No shocks are expected on the upper surface of the wing.

D. Fuel Volume of Wing

The surface is substantial, and AAA indicated a healthy margin for fuel as shown in figure 21. The Twin Sea Lion requires 10,679 pounds to achieve its 1500 nautical mile range and the wings have room for 20,559 pounds. Combined with more efficient than expected engines, no fuel issues are expected. Data from AAA can be seen in figure 21.

VI. Layout Design of the High Lift Devices

A. Sizing the High Lift Devices

The flap planform layout can be found in figure 16 below. Single slotted flaps were chosen for the Twin Sea Lion as they were found to fit the takeoff and landing performance requirements. Takeoff turned out to be the constraining limitation, at 20° deflection, the flaps needed to be 30% of the wing chord and span from 9% to 55.5% of the wing in order to achieve the improvement in C_L needed. Landing with a flap deflection of 30° was not a constraining factor. This makes intuitive sense with the adage that, "an airplane can land somewhere it can't take off from," referring to ground roll and obstacle clearance requirements. These numerical results can be seen in figure 17 on page 21.

Ailerons were sized to fit the remaining span of each wing, going from 60% to 98% of the half span, and taking up 25% of the wing chord.

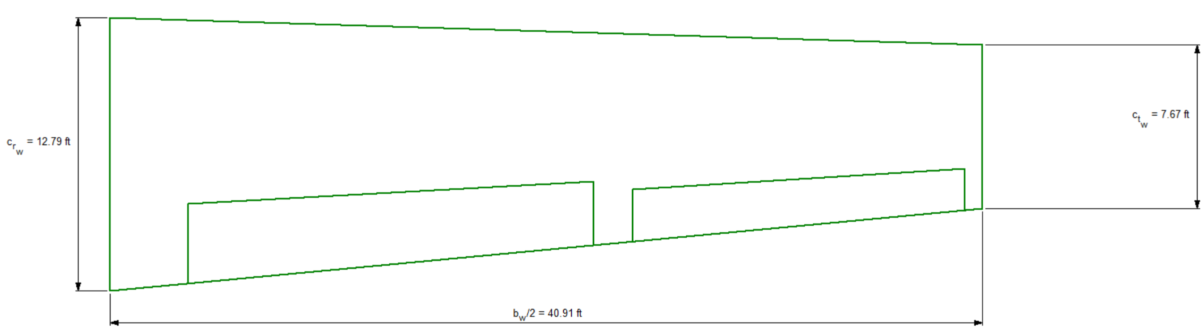

Fig. 5 High lift device sizing plot

B. Verifying the High Lift Devices

AAA gives an improvement in takeoff C_L of $\Delta C_{L_{w_{TO}}}$ = 0.4715, for a takeoff $C_{L_{max}}$ = 2.1215, beating the requirement of $C_{L_{TO}}$ = 2.1. Landing C_L was designed to be 2.2. With $\Delta C_{L_{w_L}}$ = 0.5765, for $C_{L_{max}}$ = 2.1965, which felt close enough to the predicted landing requirements given the lack of landing constraints. Should this prove to become a limiting factor in the future, plenty of room remains to enlarge the flaps, add more slots, or include leading edge devices such as slats and vortex generators.

VII. Selection and Integration of the Propulsion System

A. Selection of the Propulsion System

The engine was chosen in order to supply the high horsepower needed by the aircraft. The Sea Lion also needs a low c_p in order to maintain current weights. The Pratt and Whittney PW150A turboprop engine was chosen for its high power and very good efficiency. The PW150A can produce up to 5000 SHP and has a c_p of $0.433 lbs/hp \times hr$. This well exceeds our maximum power requirement of TBD and this engine's most common application, the Q-400, cruises only 5,000 feet lower at similar speeds. [8] Because the initially planned engine performance included a c_p of 0.6, the improved efficiency gives a comfortable margin over our intended range and provides improved capabilities.

B. Integration of the Propulsion System

The engines will be installed on the wings. Since this aircraft required multiple engines, placing them here provides symmetry. Additionally, the engine must be placed away from the fuselage by at least the radius of the propeller. The chosen Pratt and Whittney PW150A engine is 7.9 feet long, which fits onto our wing structure. However, propeller diameters will likely be quite large and necessitate mounting the engines above the wing slightly. Because the Sea Lion uses turboprops rather than turbojets, the presence of the engines will not reduce available flap area. The prop wash over the wing may, in fact, slightly increase the available lift.

C. Installed Thrust

A variety of accessories need to be run off engine power, including electrical, pneumatic, and hydraulic, systems. These all reduce the flying power available. Figures 9 through 13 in the appendix show the calculations. Mechanical systems, including all the pumps, take a total of 10.07 horsepower from each engine. Electrical systems extract 4 horsepower, and pneumatic systems 75 horsepower. After all the accessories are accounted for, the engines still transmit 4715 horsepower to the driveshaft.

The driveshaft connects to the gearbox and propeller, which each introduce their own losses. The gearbox is assumed to be 98% efficient and the propeller is 90% efficient. These reduce the effective power to 4,243 horsepower per engine, or 8,486 total horsepower. This remains well above the power requirements.

VIII. Conclusions and Recommendations

A. Conclusions

In summary, the Twin Sea Lion has begun to take shape for its mission. Despite the need to reduce planned cruising speed, initial results show that this aircraft can fit its mission requirements with room to spare. Passengers will have De Luxe sized seats, sitting one on each side of the aisle and five rows deep. While cargo storage solutions were forced to become innovative, everything required was fit into a compact fuselage and room for a lavatory was found. The selection of a low-wing will improve the stiffness of future landing gear. A NACA 65(1)-412 airfoil shows promise and modest flaps fit all takeoff and landing requirements. The overall wing design lacks complications such as twisted or curved leading and trailing edges. The wing also includes ample room for fuel. Coupled with highly efficient PW150A engines, range is no issue, even accounting for power lost to accessory drives. However, propeller choices will have to be made carefully in order to ensure continued high efficiency.

B. Recommendations

Future work for the Twin Sea Lion designers will delve into exact configurations and equipment balance. However, it may prove beneficial to review power and wing loading requirements. Current power loading is 4.4 pounds per horsepower. Based on the revised performance sizing chart shown in figure 1, this may afford a smaller wing - possibly even double the current wing loading. Currently, the constraining requirement on wing size is takeoff performance. A smaller wing, coupled with more aggressive flaps could result in higher cruise speed and better economy.

References

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[7] "Fokker F27 Friendship" Flugzeuginfo Info, http://www.flugzeuginfo.net/acdata_php/acdata_f27_en.php

[8] "Q-400 Fuel Burn?" Professional Pilot's Rumor Network, https://www.pprune.org/tech-log/353486-q400-fuel-burn.html#post4583597

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[10] Roskam, *Airplane Design* "Part II: Preliminary Configuration Design and Integration of the Propulsion System". University of Kansas. Lawrence, Kansas. 1989.

[11] Gerren, "Wing Geometry Tables", https://canvas.colorado.edu

[12] Gerren, "Presentation 12", https://canvas.colorado.edu

[13] Gerren, "Presentation 13", https://canvas.colorado.edu

Appendix

Equations

Dynamic Pressure

$$\bar{q} = \frac{1}{2}\rho V^2 \tag{4}$$

C_L of a wing

$$C_L = \frac{L}{\bar{q}S} \tag{5}$$

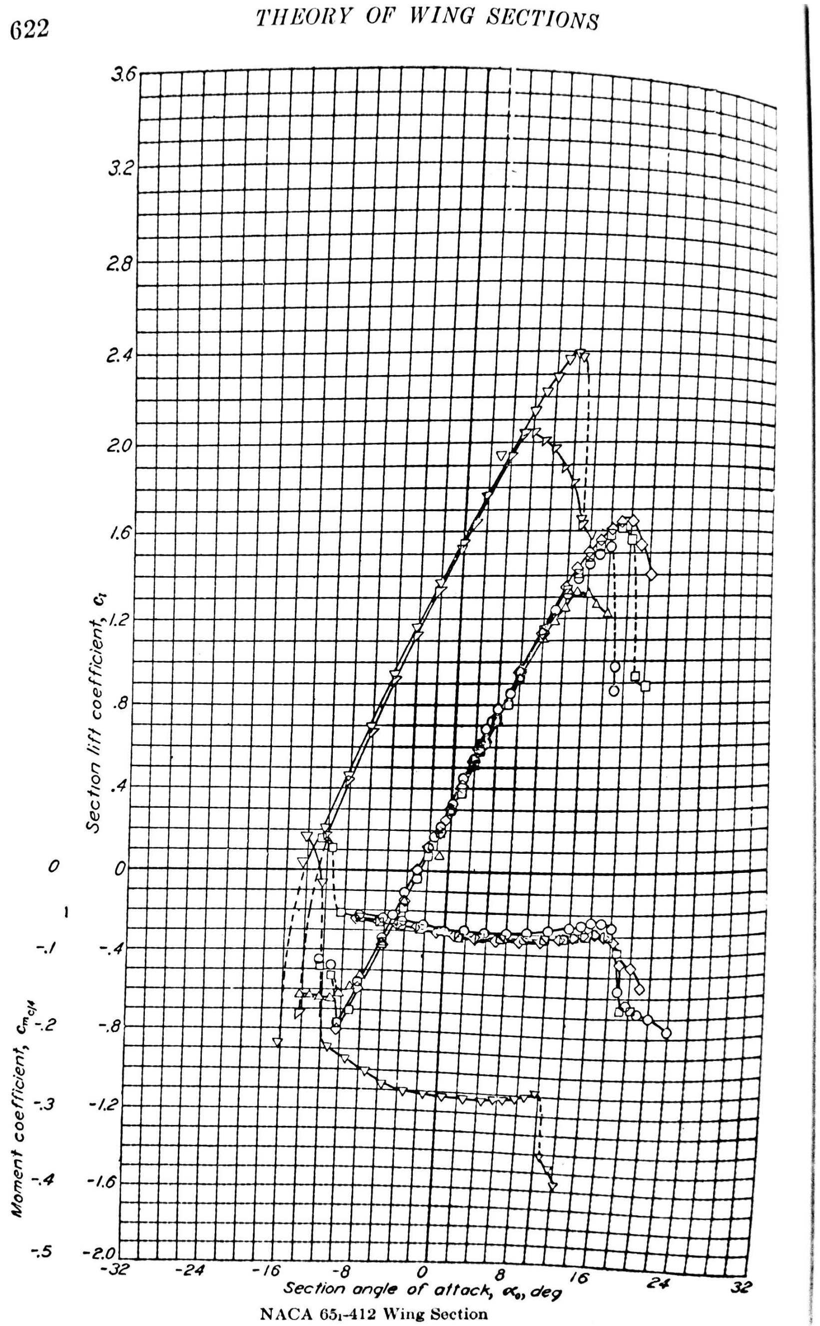
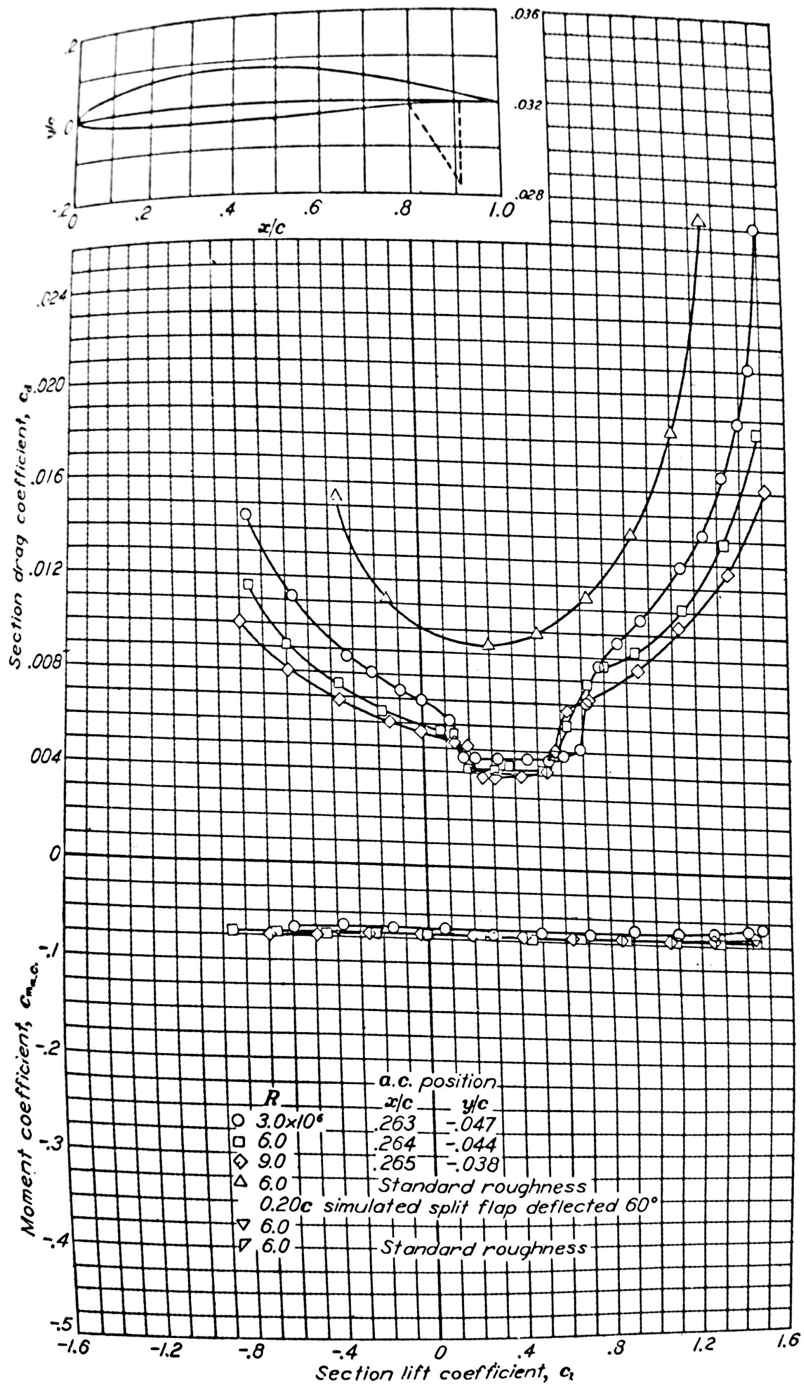


Fig. 6 NACA 65(1)-412 performance chart 1



NACA 65₁-412 Wing Section (*Continued*)

Fig. 7 NACA 65(1)-412 performance chart 2

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

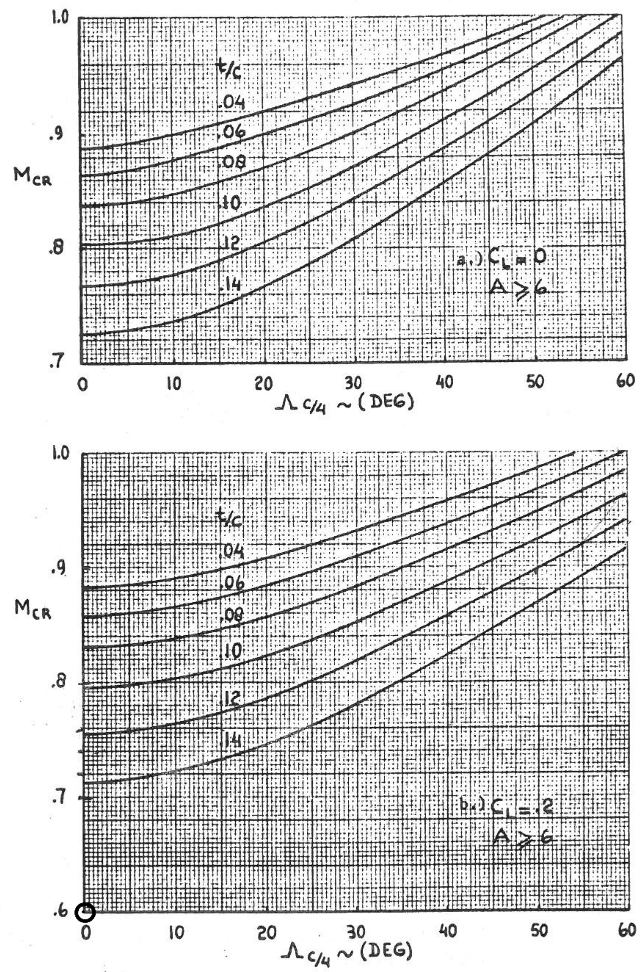


Figure 6.1a Effect of Thickness Ratio and Sweep Angle on Critical Mach Number

Part II Chapter 6 Page 150

Fig. 8 Critical mach number check

Cockpit and Fuselage Dimensions

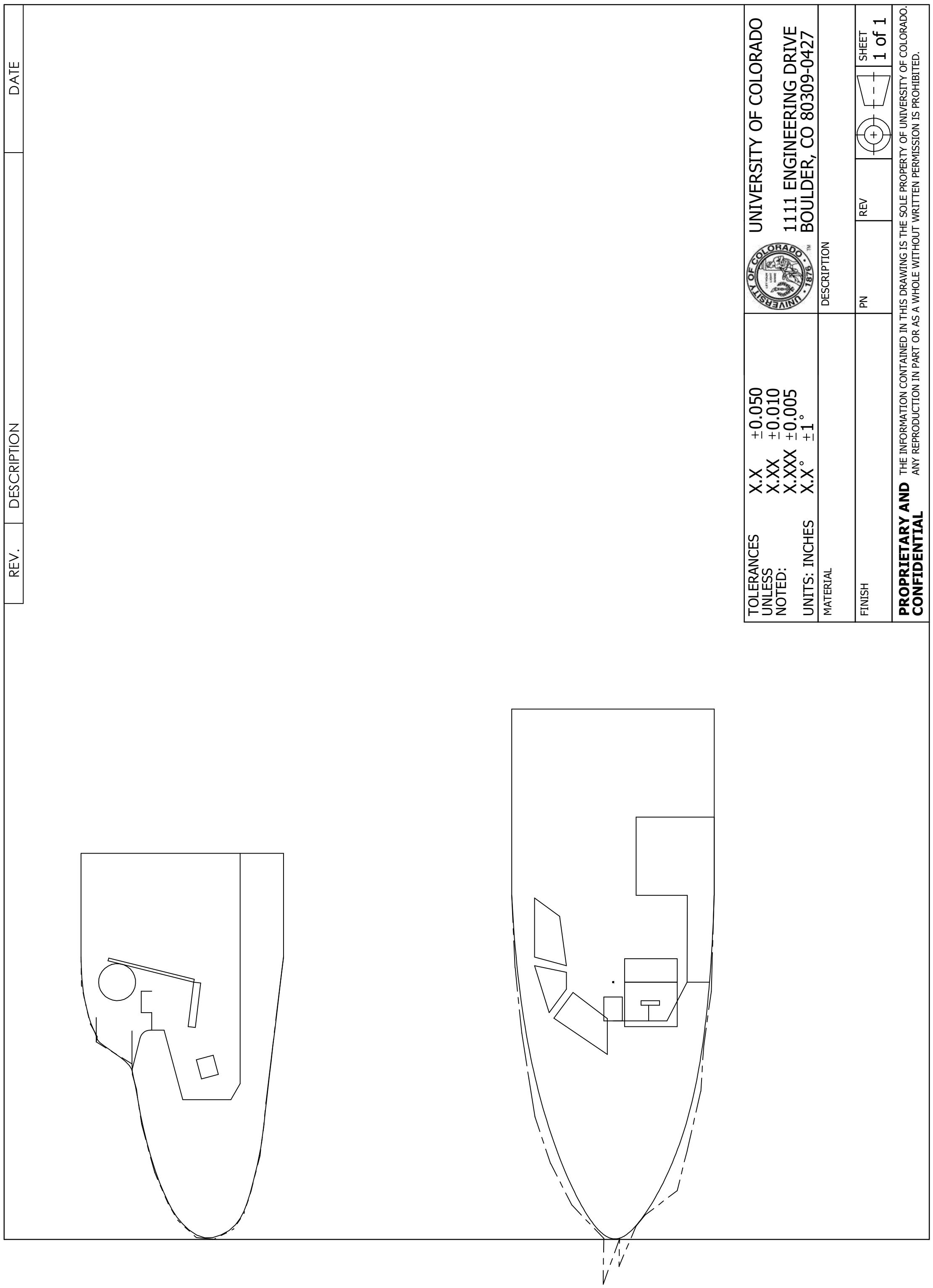


Fig. 9 Cockpit layout

Data from AAA

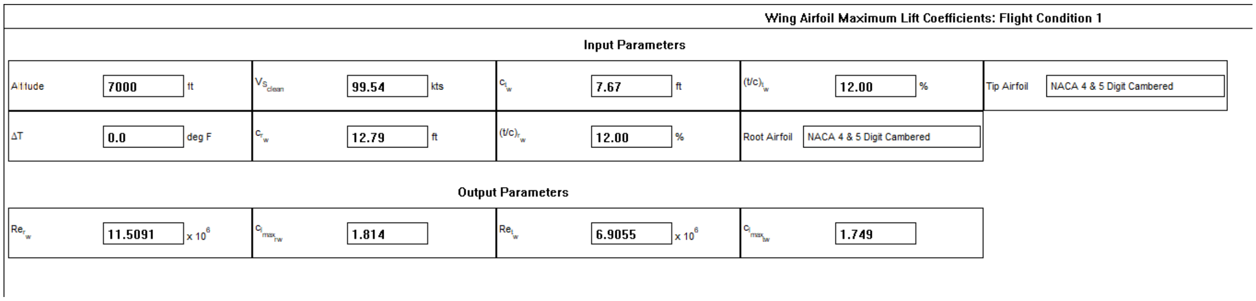


Fig. 10 Airfoil maximum lift coefficients

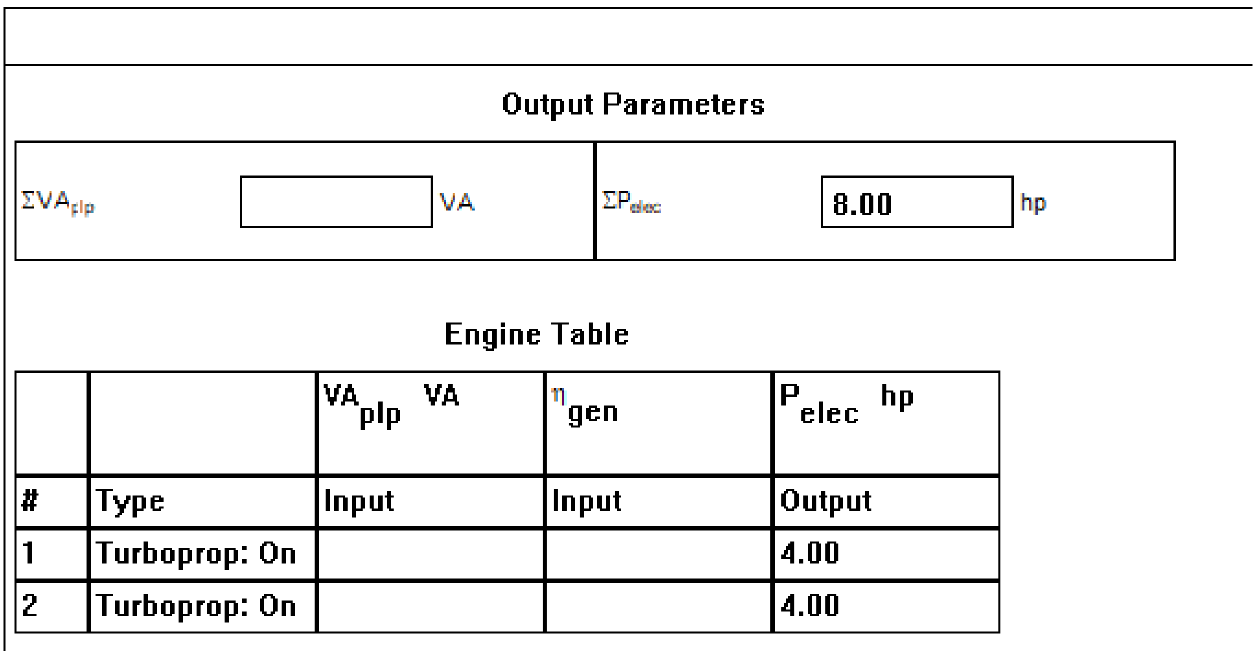


Fig. 11 Engine electrical power extraction

Input Parameters

Altitude	30000 ft	ΔT	0.0 deg F	U_1	350.00 kts

Output Parameters

M_1	0.594	ρ	0.00089 $\frac{slug}{ft^3}$

Inlet/Duct Table

			SHP_{set} hp	$\dot{m}_{gas}$ $\frac{slug}{s}$	$\dot{m}_{cool}$ $\frac{slug}{s}$	$\dot{m}_a$ $\frac{slug}{s}$	A_c ft^2	$\bar{A}_c$ ft^2
#	Inlet/Duct Attached to	In Nacelle	Input	Output	Output	Output	Output	Output
1	Turboprop #1: On	Yes	1555	1.40	0.07	1.47	2.79	2.79
2	Turboprop #2: On	Yes	1555	1.40	0.07	1.47	2.79	2.79

Fig. 12 Engine inlet area

Mechanical Power Extraction: Flight Condition 1

Output Parameters

$\Sigma P_{mech_{fp}}$	0.93 hp	$\Sigma P_{mech_{hydr}}$	19.20 hp	ΣP_{mech}	20.13 hp

Engine Table

		$P_{UnIns_{avail}}$ hp	c_p $\frac{lb/hr}{hp}$	η_{fp}	η_{hp}	ΔP_{hydr} $\frac{lb}{in^2}$	V_{hydr} gpm	$P_{mech_{other}}$ hp	$P_{mech_{fp}}$ hp	$P_{mech_{hydr}}$ hp	P_{mech} hp
#	Type	Input	Input	Input	Input	Input	Input	Input	Output	Output	Output
1	Turboprop: On	5000	0.43	0.65	0.75	3000.00	4.00	0.00	0.47	9.60	10.07
2	Turboprop: On	5000	0.43	0.65	0.75	3000.00	4.00	0.00	0.47	9.60	10.07

Fig. 13 Engine mechanical power extraction

Output Parameter

ΣP_{pneu} 150.00 hp

Engine Table

		$\dot{m}_b/\dot{m}_a$	$P_{avail_{shaft}}$ hp	P_{pneu} hp
#	Type	Input	Input	Output
1	Turboprop: On	0.015	4715	75.00
2	Turboprop: On	0.015	4715	75.00

Fig. 14 Engine pneumatic power extraction

Class I Total Power Extraction: Flight Condition 1

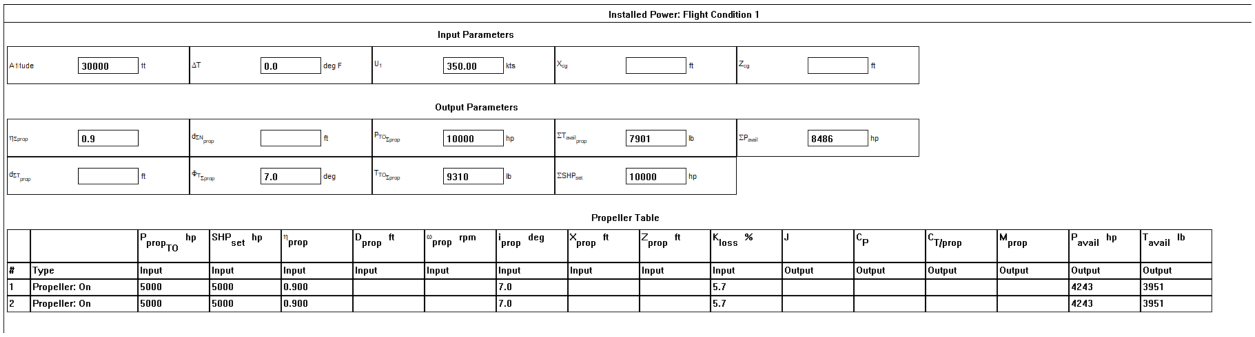
Output Parameters

ΣP_{mech} 20.13 hp | ΣP_{elec} 8.00 hp | ΣP_{pneu} 150.00 hp | ΣP_{extr} 178.13 hp

Engine Table

		P_{mech} hp	P_{elec} hp	P_{pneu} hp	P_{extr} hp
#	Type	Input	Input	Input	Output
1	Turboprop: On	10.07	4.00	75.00	89.07
2	Turboprop: On	10.07	4.00	75.00	89.07

Fig. 15 Engine total power extraction



Installed Power: Flight Condition 1

Input Parameters

Altitude	30000	ft
ΔT	0.0	deg F
U_1	350.00	kts
X_{cg}		ft
Z_{cg}		ft

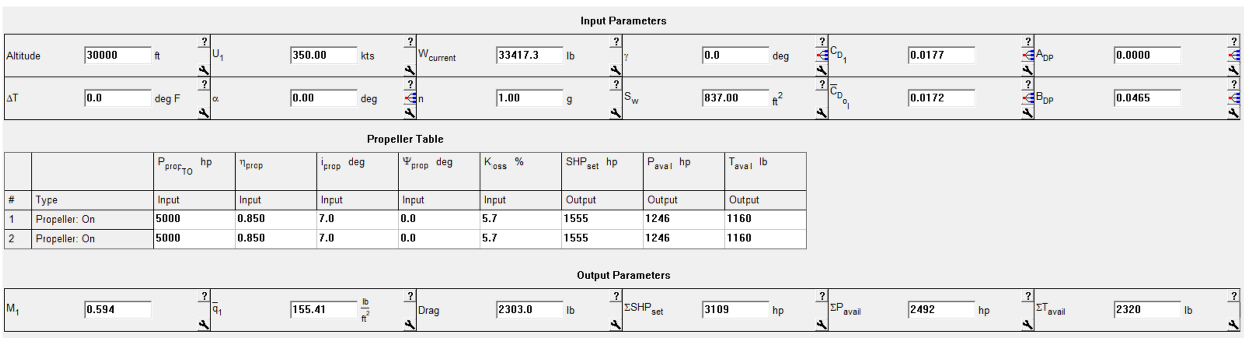
Output Parameters

$\eta_{\Sigma prop}$	0.9	
$d_{\Sigma N_{prop}}$		ft
$P_{TO_{\Sigma prop}}$	10000	hp
$\Sigma T_{avail_{prop}}$	7901	lb
ΣP_{avail}	8486	hp
$d_{\Sigma T_{prop}}$		ft
$\Phi_{T_{\Sigma prop}}$	7.0	deg
$T_{TO_{\Sigma prop}}$	9310	lb
ΣSHP_{set}	10000	hp

Propeller Table

#	Type	$P_{prop_{TO}}$ hp	SHP_{set} hp	η_{prop}	D_{prop} ft	ω_{prop} rpm	i_{prop} deg	X_{prop} ft	Z_{prop} ft	K_{loss} %	J	C_P	$C_{T/prop}$	M_{prop}	P_{avail} hp	T_{avail} lb
		Input	Input	Input	Input	Input	Input	Input	Input	Input	Output	Output	Output	Output	Output	Output
1	Propeller: On	5000	5000	0.900			7.0			5.7					4243	3951
2	Propeller: On	5000	5000	0.900			7.0			5.7					4243	3951

Fig. 16 Engine installed power



Input Parameters

Altitude	30000	ft
U_1	350.00	kts
$W_{current}$	33417.3	lb
γ	0.0	deg
C_{D_1}	0.0177	
A_{DP}	0.0000	
ΔT	0.0	deg F
α	0.00	deg
n	1.00	g
S_w	837.00	ft^2
$\overline{C}_{D_{o_1}}$	0.0172	
B_{DP}	0.0465	

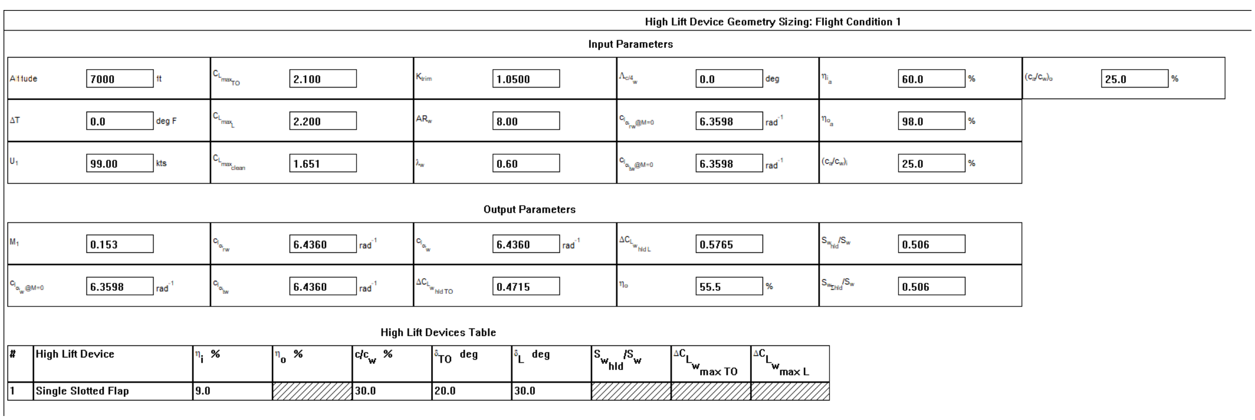
Propeller Table

#	Type	$P_{prop_{TO}}$ hp	η_{prop}	i_{prop} deg	Ψ_{prop} deg	K_{loss} %	SHP_{set} hp	P_{avail} hp	T_{avail} lb
		Input	Input	Input	Input	Input	Output	Output	Output
1	Propeller: On	5000	0.850	7.0	0.0	5.7	1555	1246	1160
2	Propeller: On	5000	0.850	7.0	0.0	5.7	1555	1246	1160

Output Parameters

M_1	0.594	
$\bar{q}_1$	155.41	lb/ft^2
Drag	2303.0	lb
ΣSHP_{set}	3109	hp
ΣP_{avail}	2492	hp
ΣT_{avail}	2320	lb

Fig. 17 Engine thrust from drag



High Lift Device Geometry Sizing: Flight Condition 1

Input Parameters

Altitude	7000	ft
$C_{L_{max_{TO}}}$	2.100	
K_{trim}	1.0500	
$\Lambda_{c/4_w}$	0.0	deg
η_{i_a}	60.0	%
$(c_a/c_w)_o$	25.0	%
ΔT	0.0	deg F
$C_{L_{max_L}}$	2.200	
AR_w	8.00	
$c_{l_{\alpha_{rw}}@M=0}$	6.3598	rad^{-1}
η_{o_a}	98.0	%
U_1	99.00	kts
$C_{L_{max_{clean}}}$	1.651	
λ_w	0.60	
$c_{l_{\alpha_{tw}}@M=0}$	6.3598	rad^{-1}
$(c_a/c_w)_i$	25.0	%

Output Parameters

M_1	0.153	
$c_{l_{\alpha_{rw}}}$	6.4360	rad^{-1}
$c_{l_{\alpha_w}}$	6.4360	rad^{-1}
$\Delta C_{L_{w_{hld\,L}}}$	0.5765	
$S_{w_{hld}}/S_w$	0.506	
$c_{l_{\alpha_w}@M=0}$	6.3598	rad^{-1}
$c_{l_{\alpha_{tw}}}$	6.4360	rad^{-1}
$\Delta C_{L_{w_{hld\,TO}}}$	0.4715	
η_o	55.5	%
$S_{w_{\Sigma hld}}/S_w$	0.506	

High Lift Devices Table

#	High Lift Device	η_i %	η_o %	c/c_w %	δ_{TO} deg	δ_L deg	$S_{w_{hld}}/S_w$	$\Delta C_{L_{w_{max\,TO}}}$	$\Delta C_{L_{w_{max\,L}}}$
1	Single Slotted Flap	9.0		30.0	20.0	30.0			

Fig. 18 High lift device sizing

Straight Tapered Wing Geometry: Flight Condition 1

Input Parameters

AR_w	8.00		S_w	837.00	ft^2	λ_w	0.60		$\Lambda_{c/4_w}$	0.0	deg	X_{apex_w}	0.00	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	Λ_{LE_w}	1.8	deg
c_{t_w}	7.67	ft	$\bar{c}_w$	10.44	ft	x_{mgc_w}	0.59	ft	Λ_{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	0.0000	1.2786	0.0000

Fig. 19 Straight tapered wing geometry

Thrust from Drag: Flight Condition 1

Input Parameters

Altitude	30000	ft	U_1	350.00	kts	$W_{current}$	33417.3	lb	γ	0.0	deg	C_{D_1}	0.0177		A_{DP}	0.0000	
ΔT	0.0	deg F	α	0.00	deg	n	1.00	g	S_w	837.00	ft^2	$\bar{C}_{D_{q_1}}$	0.0172		B_{DP}	0.0465	

Output Parameters

M_1	0.594		$\bar{q}_1$	155.41	$\frac{lb}{ft^2}$	Drag	2303.0	lb	ΣSHP_{set}	3109	hp	ΣP_{avail}	2492	hp	ΣT_{avail}	2320	lb

Propeller Table

		$P_{prop_{TO}}$ hp	η_{prop}	i_{prop} deg	Ψ_{prop} deg	K_{loss} %	SHP_{set} hp	P_{avail} hp	T_{avail} lb
#	Type	Input	Input	Input	Input	Input	Output	Output	Output
1	Propeller: On	5000	0.850	7.0	0.0	5.7	1555	1246	1160
2	Propeller: On	5000	0.850	7.0	0.0	5.7	1555	1246	1160

Fig. 20 Thrust from drag

Class I Wing Fuel Volume: Flight Condition 1

Input Parameters

AR_w	8.00		λ_w	0.60		$(t/c)_{r_w}$	12.00	%	$F_{F_{expansion}}$	4.0	%
S_w	837.00	ft^2	$(t/c)_{t_w}$	12.00	%	$W_{F_{max}}$	10679.3	lb	ρ_F	6.74	$\frac{lb}{gallon}$

Output Parameters

V_{F_w}	407.76	ft^3	$W_{F_{max_w}}$	20558.8	lb

Fig. 21 Wing fuel volume

Calculation of Wing Maximum Lift: Flight Condition 1

Input Parameters

$c_{l_{max_{rw}}}$	1.814		$\Lambda_{c/4_w}$	0.0	deg	c_{t_w}	7.67	ft	Root: NACA 4 & 5 Digit Cambered	$C_{L_{max_{clean}}}$	1.651	
$c_{l_{max_{tw}}}$	1.749		c_{r_w}	12.79	ft	f_{couple}	1.10		Tip: NACA 4 & 5 Digit Cambered	$\Delta C_{L_{w_{max_{hld}}}}$		

Output Parameters

λ_w	0.60	k_{λ_w}	0.927	$C_{L_{w_{max\,clean}}}$	1.651	$C_{L_{w_{max}}}$	1.651

Fig. 22 Wing maximum lift

Considered Airfoils and Similar Aircraft

Table 3 Airfoil options

Name	$C_{l_{max}}$	$C_{l_{\alpha=0}}$	$C_{d_{cruise}}$	In drag Bucket
NACA 64-110	1.4	0.1	0.004	yes
NACA 64-210	1.4	0.2	0.0045	yes
NACA 63A010	1.2	0.0	0.0055	no
NACA 63A210	1.45	0.1	0.004	yes
NACA 64A210	1.4	0.15	0.004	yes
NACA 64A410	1.6	0.35	0.005	no
NACA 65(1)-412	1.65	0.35	0.004	yes
NACA 64-110	1.4	0.1	0.004	yes
NACA 63A010	1.2	0.0	0.0055	no
Supercritical 2-0714	1.75	0.6	0.006	yes
Supercritical 2-0614	1.7	0.5	0.006	yes

Table 4 Selected regional turboprop wing geometries

Type	Γ_W (degrees)	i_w (degrees)	λ_W
Shorts 330	3	0	1
Shorts 360	3	0	1
Beech 1900	6	3.5/-1.1	0.42
Beech 99	7	4.8	0.5
Fokker F-27	2.5	3.5	0.41
DHC-6	0	0	0
DHC-7	4.5	3	0.44
DHC-8	2.5	0	0.45
EMB-110	7	3	0.5
EMB-120	6.5	2	0.5
BAE Jetstream 31	7	2	0.37
BAE 748	7	3	0.37