Design Report 01: Twin Sea Lion

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I. Nomenclature

c_p = Specific Fuel Consumption [lbs/hp/hr]

CGR = Climb Gradient

η_p = Propeller Efficiency coefficient

L/D = Lift to Drag Ratio

M = Mach Number

MFF = Mission Fuel Fraction

$MTOW$ = Maximum Takeoff Weight [lbs]

R/C = Climb Rate

$STOL$ = Short Takeoff and Landing

W_{TO} = Takeoff Weight [lbs]

W_{PL} = Payload Weight [lbs]

W_E = Empty Weight [lbs]

W_{tfo} = Weight of trapped fuel and oil [lbs]

W/S = Wing loading [lbs/sq.ft]

II. Introduction

The Twin Sea Lion is a combination cargo and transport plane designed to transport a small number of passengers and a reasonably large amount of cargo around the continental United States. The Twin Sea Lion features high cruise speeds and good takeoff and landing performance. Its maximum gross weight is 40,240.9 lbs and its useful load is 16,682.3 lbs.

III. Mission Specifications, Mission Profile, and Descriptions of Similar Airplanes

A. Mission Specifications and Mission Profile

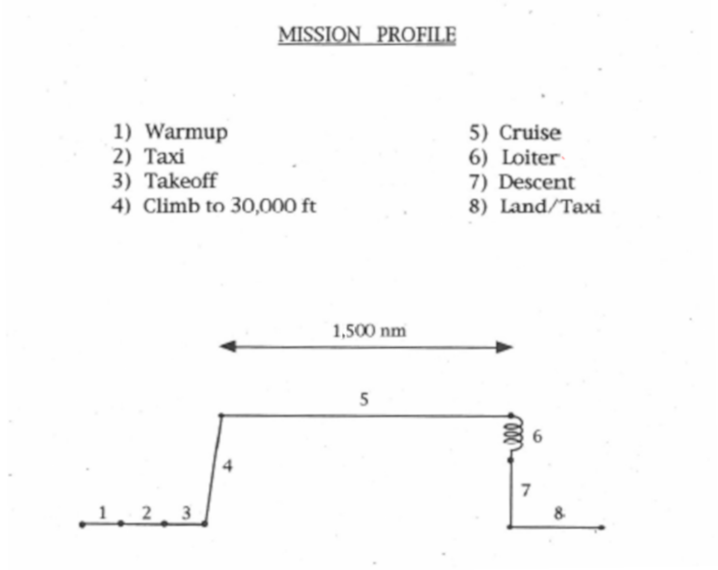

Fig. 1 The planned mission profile [1]

The Twin Sea Lion is meant to transport 10 passengers and a cargo load of 2500 pounds between many airfields in North America. The plane features Short Takeoff and Landing (STOL) Performance and a 1500 nautical mile range. Coupled with high cruise speeds ($M = 0.8$) and altitudes of up to 30,000 feet, the Twin Sea Lion can place half of the continent within the range of a single flight.

The mission profile of a typical flight would involve a short time in warm-up and taxi, followed by takeoff from from a short runway. We expect to use roughly 4000 feet for ground roll at a field elevation of 7000 feet. After rotation, the Twin Sea Lion will establish initial climb at 3000 feet per minute (FPM). After leveling off at 30,000 feet, the aircraft will cruise up to 1500 nautical miles at $M = 0.8$ before beginning descent. Accounting for a 45 minute loiter at 250 knots, the aircraft will then be able to land on a comparable runway surface to that it which took off from.

B. Descriptions of Similar Airplanes

1. De Havilland Canada DHC-6 Twin Otter

Fig. 2 A DHC-6 in its natural habitat - Vancouver Harbor

The Twin Otter is a twin turboprop bushplane most often used on floats in British Columbia and the Pacific Northwest, though it has found a use wherever a rugged cargo plane is required and a paved runway might not be available. It is a 19 passenger STOL utility aircraft. It has a wingspan of 65 feet, a Maximum Takeoff Weight (MTOW) of 12,500 lbs, and a maximum range of 800 nautical miles.

2. Pilatus PC-24

Fig. 3 Pilatus refers to the PC-24 as entirely new class of aircraft - the Super Versatile Jet

The PC-24 is a business jet with Pilatus' unique touches. It's capable of landing on unimproved surfaces and has a large cargo door, making it useful for more than just golfing trips. It has a seats for six, a range of 1,836 nautical miles, and a maximum weight of 17,968 lbs.

3. De Havilland Canada DHC-4 Caribou

Fig. 4 A DHC-4 in flight

The Caribou, also known to the US Army as the C-7A, is a twin radial engine STOL cargo aircraft. It has a maximum range of 1,280 miles, a maximum weight of 28,500 lbs, and a takeoff distance of 910 feet. However, it cannot achieve all of these at the same time. Fully loaded with cargo or up to 36 soldiers, its range drops to 240 miles.

4. Fairchild/Fokker F-27 Friendship

Fig. 5 The F-27 may have the best name of all time.

The wonderfully named Friendship has a MTOW of 45,000 lbs. A range of 1,197 miles and room for up to 56 passengers makes it an effective airliner. It is powered by Rolls-Royce Dart turboprop engines, which were first run in 1946.

5. Bombardier Dash 8 (Q-400)

Fig. 6 The Q-400 is a common sight throughout the world.

Originally the De Havilland Canada DHC-8, the Q-400 is the latest version of the enduring regional airliner. Holding up to 90 passengers, MTOW is 60,198 lbs. Cruise is up to 360 knots, and the range is up to 1,100 nautical miles. Takeoff distance at max gross is 4,675 feet under sea level ISA conditions.

Plane	Takeoff Distance (feet)	Landing Distance (feet)	W_{TO} [lb]	W_E [lb]
DHC-6 Twin Otter	1200	1,050	12,500	7,100
PC-24	2,810	2,335	17,968 [6]	10,957 [7]
DHC-4 Caribou	1,100	750	28,500	16,920
F-27 Friendship	3,570	3,290	45,000	27,964
Dash 8 Q-400	4,675	4,230	60,198	36,520

Table 1 Characteristics of similar airplanes.

IV. Mission Weight Estimates

A. Determination of the Payload Weight and Crew Weight

Each person onboard was assumed to weigh 175 lbs. This is an increase from the FAA assumption of 170 lbs to account for the increasing size of passengers. This is the same standard that US Airways uses[1]. We assumed 50 lbs of baggage for the 10 passengers and 35 lbs of baggage for the three crew members. This amounts to 525 lbs of crew and 105 lbs of crew baggage and $W_{pax} = 2250$. Upon entering this weight into AAA, 425 lbs was mistakenly entered. This may be accounted for in the future by shifting 100 lbs from payload to crew weight. In addition to passengers, we chose to also include 2500 lbs of additional cargo to reach our objective as a high-cargo capacity passenger plane. This weight allowed us to nearly match the passenger and baggage associated weight for a total of $W_{PL} = 4855$ lbs.

B. Determination of the Fuel Weight, Trapped Fuel and Oil Weight, Empty Weight, and Takeoff Weight

The weight of the fuel is the sum of the required fuel for the mission and reserve fuel for safety. For a civilian plane, the reserve fuel is the fuel used for loiter, which we assumed to be 45 minutes. Thus the weight of the fuel may be determined from the takeoff weight and mission fuel fraction by $W_F = (1 - M_{ff})W_{TO}$. The M_{ff} for the entire mission is the product of the M_{ff} for each leg of the mission as can be seen in Figure 14. The majority of mission segments had fuel fractions chosen from historical data for regional turboprops. Climb, cruise, and loiter required further performance specification as shown in Figures 15 through 17. Climb fuel fraction depended on change in height, rate of climb, climb L/D, c_p, η_p, and velocity. Cruise depended on range, c_p, η_p, and cruise L/D. Loiter depended on endurance, c_p, η_p, and velocity. Since we cruise at $M = 0.8$, our cruise velocity is 470 knots. Our loiter velocity is lower at 250 knots.
Weight of trapped fuel and oil was calculated according to standard assumptions $W_{tfo} = 0.005W_{TO}$ [2]. When attempted to determine empty weight, classifying the plane as a regional turboprop was insufficient to achieve a weight solution. We had to do a regression analysis with our similar airplanes in order to determine weights. Fortunately, our airplanes had a significantly linear relationship with $A = 0.2414$ and $B = 0.9988$ as seen in Figure 19. This suggests that this regression is a suitable method for determining weights. Takeoff weight is the sum of all included weights: $W_{TO} = W_E + W_F + W_{tfo} + W_{PL} + W_{crew}$. Beside payload and crew, all determined weights are related to W_{TO}. This is what allows AAA to use the regression of weights of similar airplanes to solve for a solution for W_E and W_{TO}. The Twin Sea Lion ended up with $W_E = 23357.3$ lbs and $W_{TO} = 40240.9$ lbs.

M_{ff}	W_F	W_{tfo}	W_{PL}	W_E	W_{useful}	W_{TO}
0.7166	11402.3 lb	201.2 lb	4855.0 lb	23357.3 lb	16682.3 lb	40240.9

Table 2 Summary of resulting data as in Figure 20

V. Determination and Interpretation of Takeoff Weight Sensitivities

A. Sensitivity of Takeoff Weight to Payload Weight and Empty Weight

AAA automatically generates weight sensitivity data for us, which is shown in Figure 22. Based on our similar aircraft and mission profile. Two of the most important numbers are the sensitivity of takeoff weight (W_{TO}) to payload weight (W_{PL}) and empty weight (W_E). This is based on the assumption that W_{TO} is a function of many different variables, including the payload and empty weights. By taking a partial differential of W_{TO} with respect to W_{PL} and W_E, we can see how small changes in the design point of the plane affect the final weight of the aircraft.

In this case, $\partial W_{TO}/\partial W_{PL} = 7.66$. This means that for every pound of cargo or passenger we add to plan, we end up adding 6.66 *extra* pounds in supporting material. This is extra structure, fuel, and consumables needed for that pound of passenger or cargo.

In addition, $\partial W_{TO}/\partial W_E = 1.72$. Every pound we add to the empty weight of the aircraft adds 1.72 pounds to the takeoff weight. This is likely to mostly be fuel needed to carry extra structure, but it also means that larger engines might be needed, more hydraulic fluid and wiring is required, and even small things like paint and corrosion proof coatings all add weight to the aircraft.

B. Sensitivity of Takeoff Weight to Range, Endurance, Specific Fuel Consumption, Propeller Efficiency, and Lift-To-Drag Ratio

Mission Profile	$\frac{\partial W_{TO}}{\partial c_p}(hp \times hr)$	$\frac{\partial W_{TO}}{\partial R}(\frac{lb}{nm})$	$\frac{\partial W_{TO}}{\partial L/D}(lb)$	$\frac{\partial W_{TO}}{\partial E}(\frac{lb}{hr})$	$\frac{\partial W_{TO}}{\partial \eta_p}(lb)$
Climb	5207.2		-217.0	15621.5	-3063.0
Cruise	92041.3	36.8	-4248.1		-64970.4
Loiter	11505.2		-531.0	9204.1	-8121.3
Total	108753.7	36.8	-4996.1	24825.7	-76154.7

Table 3 Weight Sensitivies Throughout the Mission Profile

These sensitivities reveal more important characteristics of our aircraft. $\partial W_{TO}/\partial c_p$ relates the variable c_p, which is the propeller-engine specific fuel consumption, in $lbs/hp/hr$, to takeoff weight. To make some sense of c_p, a value of 1 would mean that it would take 1 lb of fuel per hour to produce a continuous 1 horsepower. During climb, a value of 5,207.2 means that increasing c_p by 1 would increase our takeoff weight by 5,207.2 lbs. During cruise, a value of 92,041.3 means that increasing c_p by 1 would add more than two additional fully loaded Sea Lions to the takeoff weight. During loiter a value of 11,505.2 also shows a good sensitvity to this variable.

$\partial W_{TO}/\partial R$ is, in this case, 36.8 lbs per nautical mile. That is to say, for every extra nautical mile we add to design range, the aircraft design weight increases by 36.8 lbs. Were we to add another 100 nautical miles to our range, we'd need to add 3,680 lbs of extra fuel. Conversely, removing 100 nautical miles from the range would free up the same amount.

$\partial W_{TO}/\partial(L/D)$ is one of two sets of numbers that are negative. Improvements in our L/D ratio mean a better performing wing. We'd get more lift for less drag. With less drag, we can reduce the power to the engines and save fairly dramatically on fuel. In the climb phase, increasing L/D by 1 means we could carry 217 fewer pounds of fuel. In cruise, an improvement of 1 means we could carry 4248.1 fewer pounds of fuel, a substantial improvement. While in loiter, the same improvement means we could carry 531 fewer pounds. The order of magnitude difference between the improvements in cruise versus climb and loiter can be explained by the very high aircraft speed and the duration of this part of the flight profile. Because we would design our wing to perform best in cruise, this is where we would see the lowest induced drag. In comparison, during climb, we'll be milking our aerodynamics and engines for all they're worth.

We might have flaps or other high lift devices increasing drag anyway, and we'll be trying to get up to altitude and out of this configuration as quickly as possible anyway. During loiter, we'll be moving at a lower speed with more induced drag on the wings, but less from the fuselage. In addition, the engines will likely be at a lower power setting and the overall flight phase does not last as long.

$\partial W_{TO}/\partial E$ relates time spent in each phase of flight to the amount of fuel needed. During climb, the engines operate continuously at full power, trying to convert as much fuel into altitude as possible, as quickly as possible. Therefore we see that each hour spent in climb conditions burns 15,621.5 pounds of fuel. This is a tremendous amount. However, this phase of flight is typically over as quickly as possible. Good safety practice usually calls for a fast climb to an initial altitude, since staying low and slow would limit options in an emergency such as an engine failure. During cruise, endurance isn't a considered parameter. Instead, we looked at the range the aircraft would fly. Finally, by increasing loiter by an hour this aircraft would take off 9,204.1 pounds heavier. This is due to the assumption that loiter is at a lower altitude where the fuel burn rate of a turbine engine is higher and the carry on effect of needing fuel in order to carry the extra loitering fuel.

$\partial W_{TO}/\partial \eta_p$ relates propeller efficiency to takeoff weight. It is the second set of negative numbers. During climb, this number is relatively close to zero at -3063. Considering that changes to η_p will at best be in the range of 0.1, this is relatively little effect. However, during cruise, 0.1 increase in η_p would reduce takeoff weight by about 6,500 pounds, a substantial improvement. Again, during loiter, the number is a good deal smaller than in cruise.

Our two most sensitive values, $\partial W_{TO}/\partial \eta_P$ and $\partial W_{TO}/\partial c_P$ are both during cruise and depend on our engine and propeller performance. Selecting efficient props and engines will be vital to the success of this aircraft since weight could be drastically reduced or increased by even small changes in performance.

VI. Performance Constraint Analysis

A. Calculation of Performance Constraints

An aircraft has several crucial points in flight where it must be able to perform. These inform our performance constraints, which then restrict the design space.

1. Drag Polar Estimation

Drag polars are plots that relate the C_L of an aircraft to C_D. In general the equation for any drag polar is:

$$C_D = C_{D0} + \frac{C_L^2}{\pi A R e} + \Delta C_{D0} \tag{1}$$

Here C_D is the total aircraft drag, C_{D0} is the parasitic drag caused by the aircraft body and skin, C_L is the coefficient of lift of the wings, AR is the wing aspect ratio, e is the span efficiency factor of the wing, which is always less than or equal to one, and ΔC_{D0} is additional drag caused items such as flaps, gear, or any large antennas that stick out of the aircraft during flight.

While C_{D0} and AR are fixed, e and ΔC_{D0} will change based on aircraft configuration (flaps and/or gear). In particular, takeoff flaps would add roughly 0.015 to ΔC_{D0}. Gear would add another 0.02 or so. This means that each part of the flight segment will have its own drag polar. For each segment, we either computed or made educated guesses with respect to these two values based on historical data. These inputs may be seen in Figures 23 through 29. The results are tabulated and shown in Table 4 and Figure 7 below.

Configuration	$C_D = \bar{C}_{D_{0,conf}} + B_{DP_{conf}} C_L^2$
Takeoff, gear down	$C_D = 0.0517 + 0.0517 C_L^2$
Takeoff, gear up	$C_D = 0.0317 + 0.0517 C_L^2$
Landing, gear down	$C_D = 0.1067 + 0.0545 C_L^2$
Landing, gear up	$C_D = 0.0867 + 0.0545 C_L^2$
Clean	$C_D = 0.0167 + 0.0468 C_L^2$
OEI	$C_D = 0.0217 + 0.0497 C_L^2$

Table 4 Drag polar equations for all configurations.

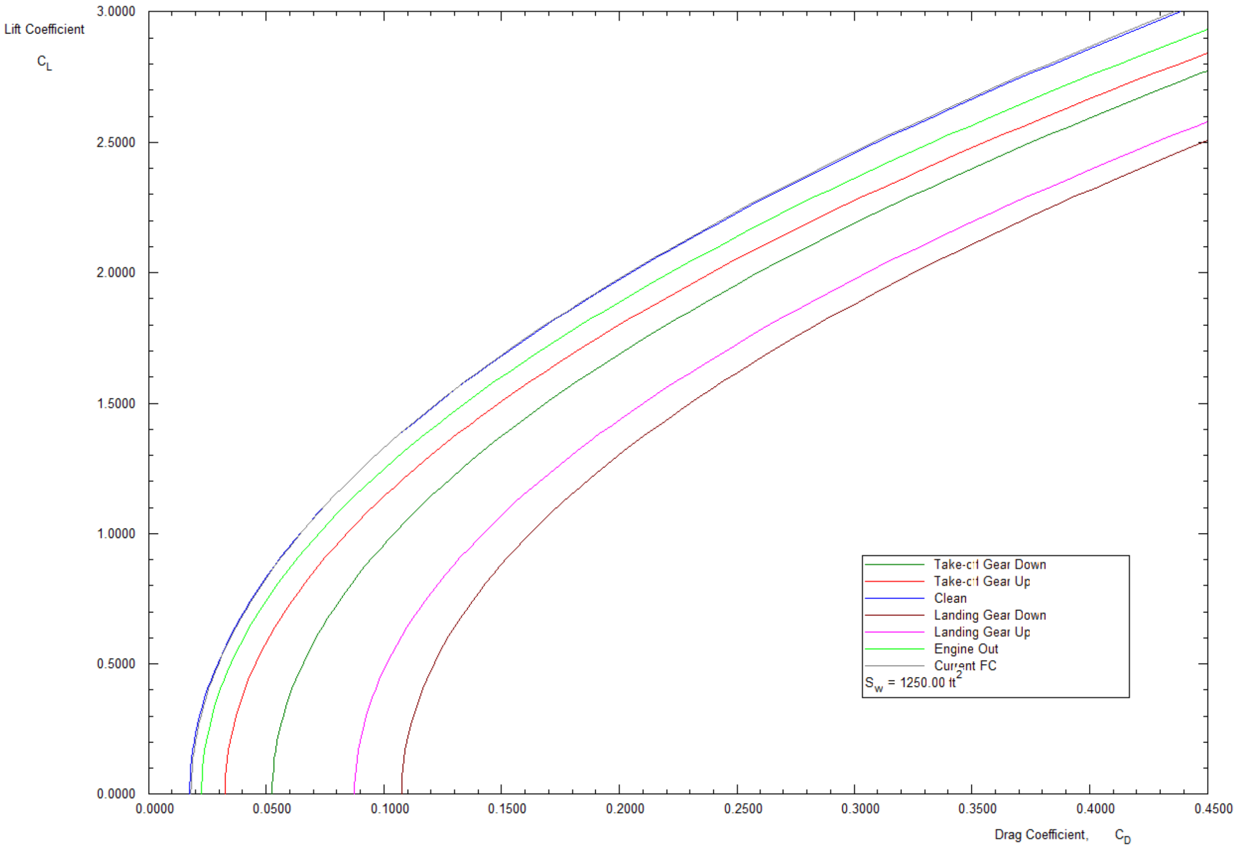

Fig. 7 Drag polars for all configurations.

2. Takeoff Distance Constraints

We selected demanding takeoff and landing requirements for this aircraft. We calculated our take off at an altitude of 7,000 feet, like in Aspen. We decided to only use 4,000 feet of runway, despite more being available at Aspen. All performance data was calculated assuming ISA conditions.

The resulting weight-to-power ratio vs. wing loading plot is shown in Figure 8. Since the Sea Lion is a prop plane, the performance of the airplane is determined by the weight-to-power ratio rather than the more common thrust-to-weight ratio of jets. Thus the acceptable area for design is under the takeoff constraint rather than above.

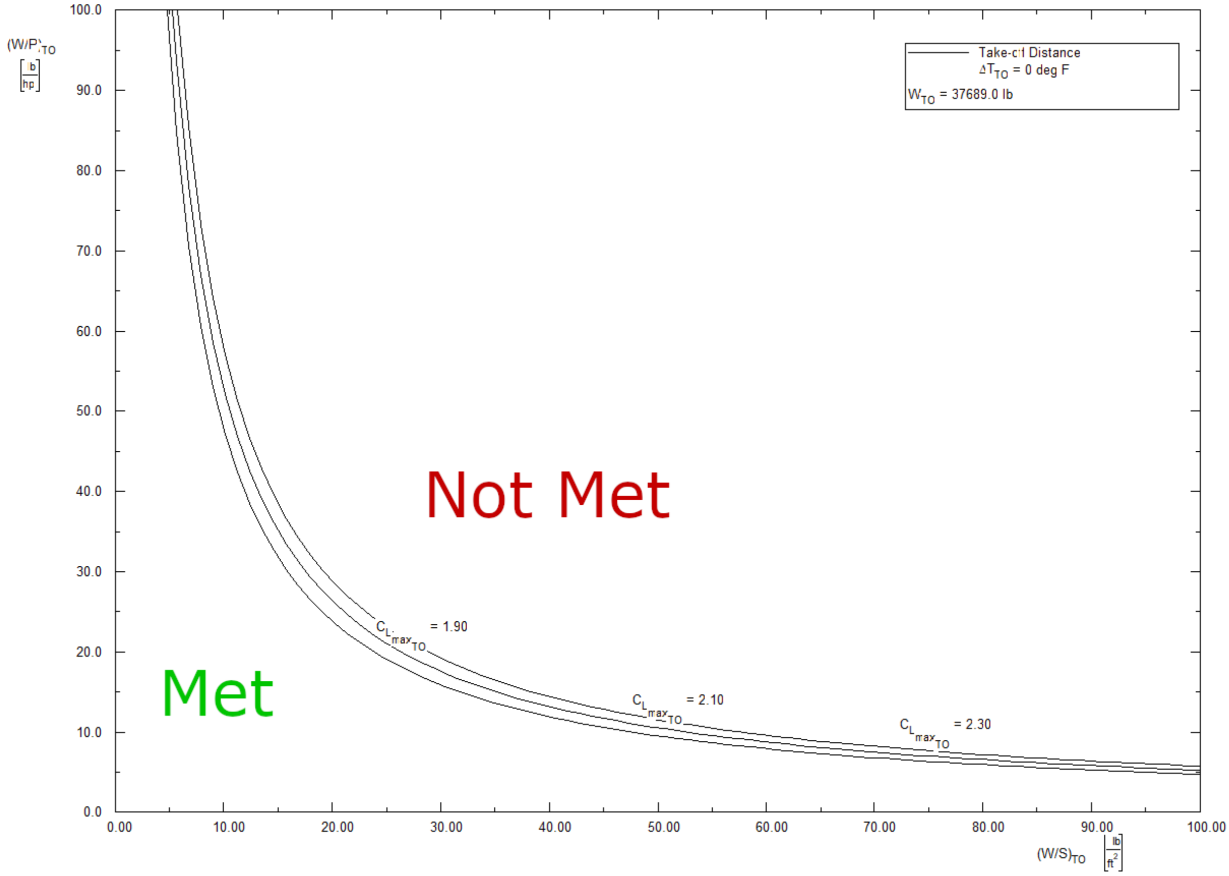

Fig. 8 Performance plot for takeoff.

3. Landing Distance Constraints

Landing was again calculated at 7,000 feet altitude on a standard day, with 4,000 feet of used field length. As a FAR 25 aircraft, we have no legal landing speed minimums. With a planned $C_{L_{max_L}} = 3.3$ at a landing weight which is $0.72 W_{TO}$, AAA gives us a maximum wing loading of $(W/S)_L = 165.41$ pounds per square foot at landing. This number is independent of the power loading (in pounds per horsepower) of the aircraft and met at any lower wing loading. FAR 25 now limits us to operations at fields at least $S_L/0.6$, or 6,667 feet in length.

Since the maximum wing loading resulting from our landing requirements is larger than AAA would allow for a plotting range of the x-axis in Figure 9, the performance plot for landing ends up very boring. All visible area is acceptable design space for this requirement, with the theoretical restricting vertical line being off the scale to the right.

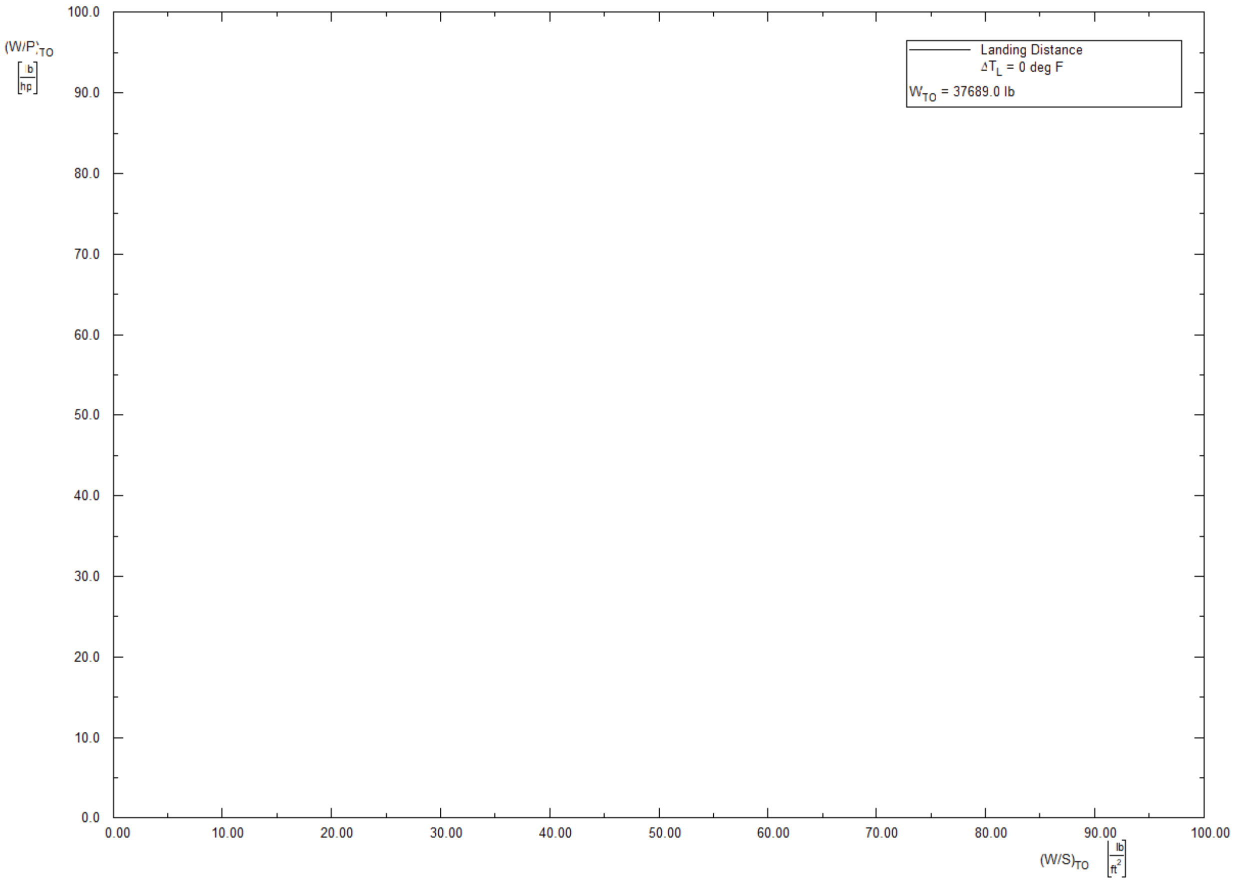

Fig. 9 Performance plot for landing.

4. Climb Constraints

Climb is one of the only times we can't assume that lift equals weight and thrust equals drag. In the climb, the aircraft has its flight path above the horizon and therefore lift acts at a different angle from weight. Calling this flight path angle θ, The new equations of flight are as follows.

$$T = D + W sin\theta \tag{2}$$

$$L = W cos\theta \tag{3}$$

$$TV_\infty = D_\infty + WV_\infty sin\theta \tag{4}$$

$$(R/C) = V_\infty sin\theta \tag{5}$$

Here R/C is the climb rate, or vertical velocity of the aircraft. FAR 25 specified climb performance in terms of the minimum climb gradient (CGR), which is a ratio of R/C to forward speed, $V_\infty cos\theta$.

The wind loading and weight-to-power ratio requirements vary on the climb conditions as seen in Figure 10. As expected, all engines operating results in the least constrictive requirement and one engine inoperative results in more constrictive requirements.

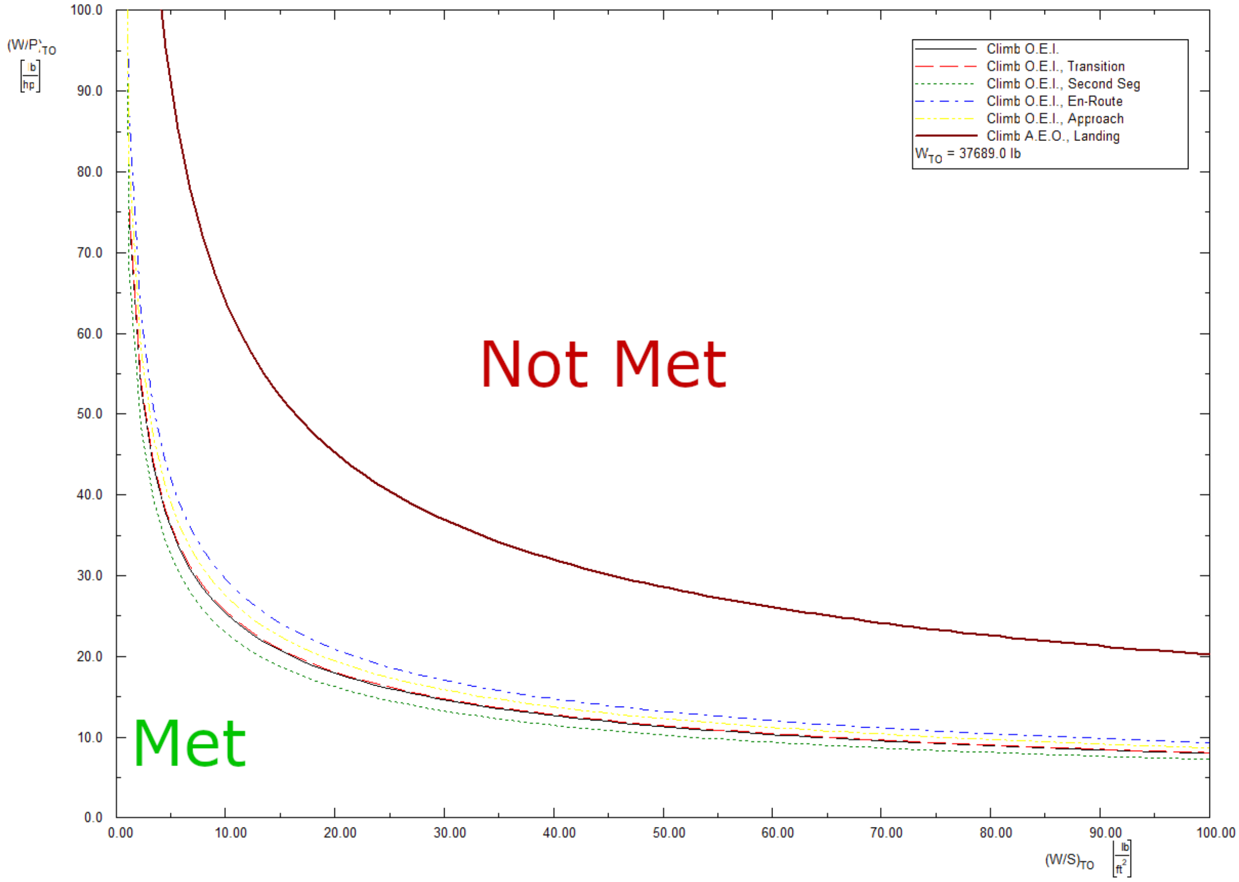

Fig. 10 Performance plot for climb.

5. Maneuvering Constraints

Our maneuvering constraint requires the aircraft to make a standard rate turn with one engine inoperative (OEI). In this case, lift is also not aligned weight because the aircraft is banked. Instead, $Lcos\phi = W$, where ϕ is the bank angle. Rearranged, $L/W = 1/cos\phi = n$, where n is called the *load factor* and is equal to 1.01. Note, our lift is only a few percent higher than it would be in level flight. Figure 11 shows the design constraints from the maneuver requirements. Unlike previous constraints, this one is met for a design point above the line.

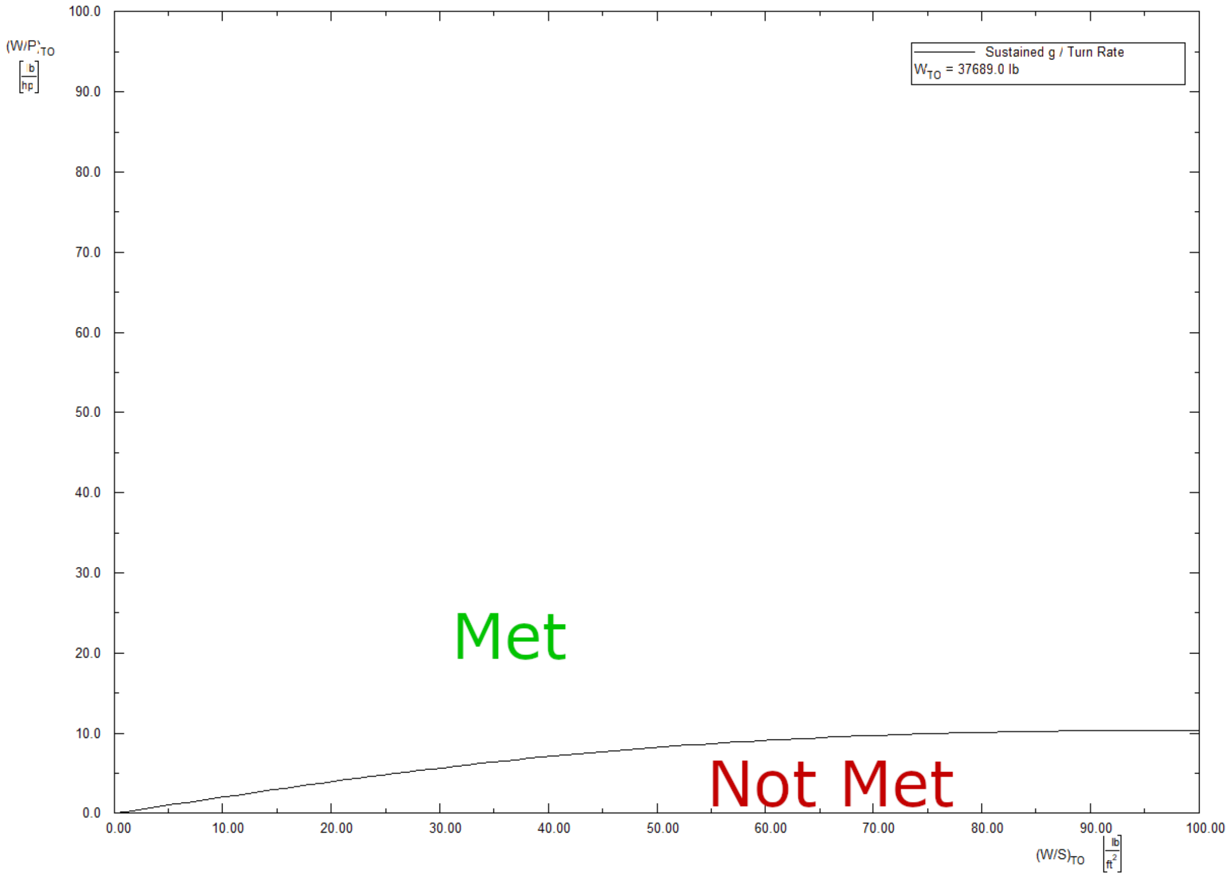

Fig. 11 Performance plot for maneuvering.

6. Speed Constraints

As a FAR 25 certified aircraft, we are not subject to any legal speed constraints, aside from a prohibition of supersonic flight which is beyond aspirational for this turboprop. Our desired cruise speed is M=0.8 or about 470 kts at 30,000 ft. As seen in Figure 32, we assume that the propellers are running at full power in cruise as propellers typically run at full power for most of a mission and that these propellers are relatively efficient.

Figure 12 shows the cruise constraint on design space. Again, the requirement is met above the curve.

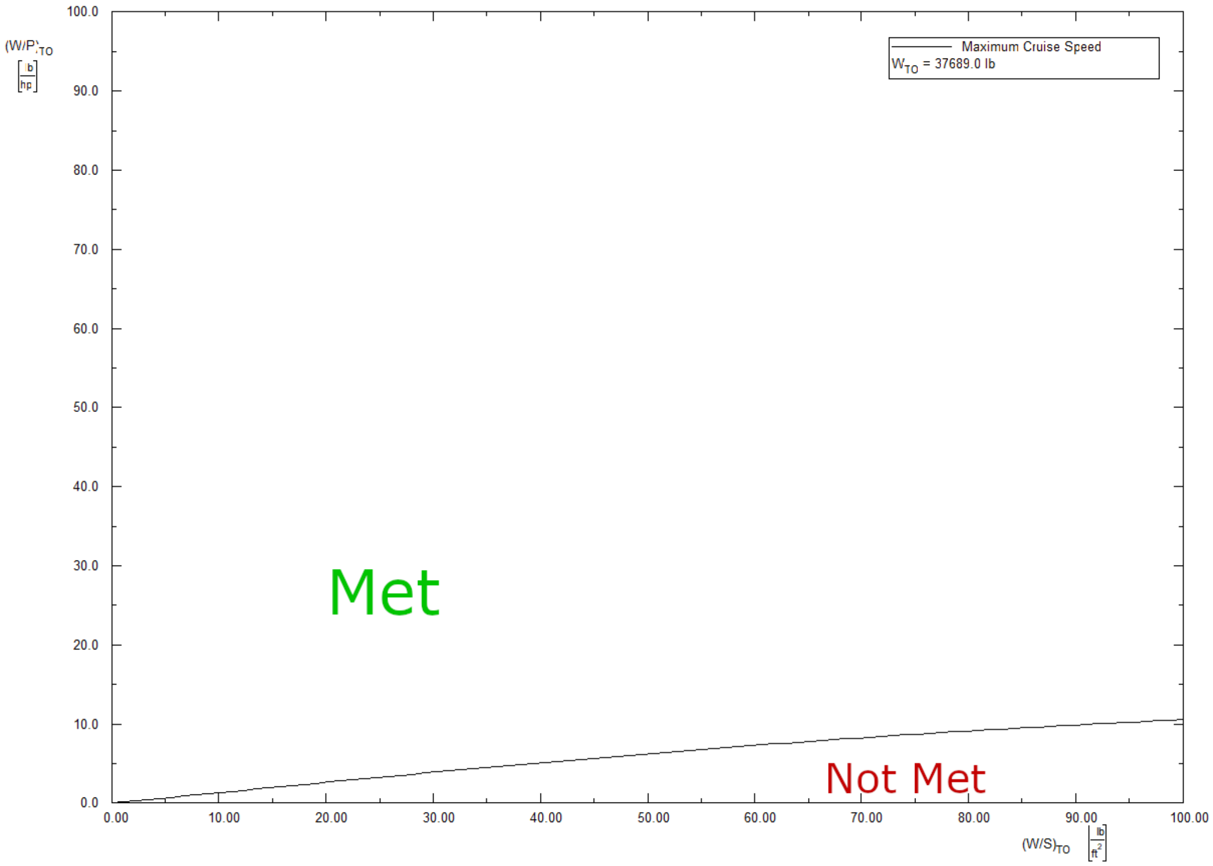

Fig. 12 Performance plot for cruise.

B. Determination of Takeoff Thrust-To-Weight Ratio (or Weight-To-Power Ratio), Takeoff Wing Loading, Takeoff Thrust (or Power) and Wing Area

With all the flight regimes designed for, we can look at the final sizing plot for the aircraft. This is shown in Figre 13.

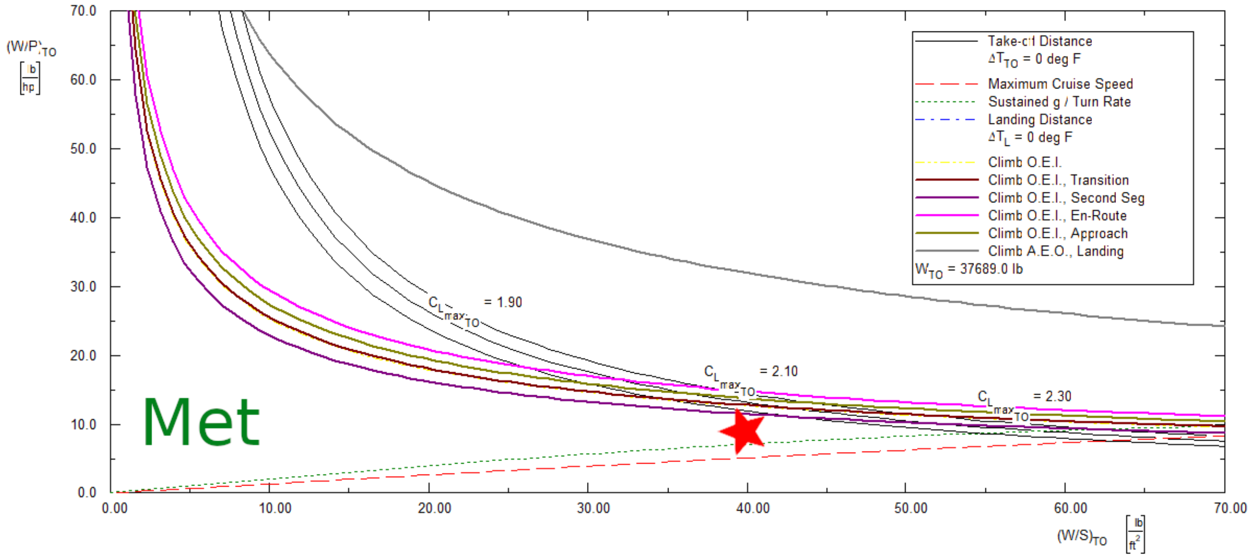

Fig. 13 All performance plots

We chose three different wing loadings to examine. They were 50, 40, and 30 pounds per square foot and are tabulated below.

Takeoff Wing Loading (lb/ft^2)	Wing Area (ft^2)	Maximum Power Loading (lb/hp)	Minimum Power Loading (lb/hp)
30	1,341	14	7
40	1,006	11	8
50	804.8	10	10

Table 5 Selected Wing Loadings

All of these points lie between the DHC-6 and PC-24 in terms of wing loading. However, we will need to have engine powers between 2,874 and 5,749 horsepower total. We selected a wing loading of 40 pounds per square foot as a final design point and marked it with a star on the chart. This will give us a wing area of about 1,000 feet and total engine power 5,030 and 3,658 horsepower. This feels like a 'sweet spot' because we will need large fuel tanks and large flaps in order to meet our range and landing distance goals, as well as larger engines for the high cruise speed.

Plane	Takeoff Wing Loading (lb/ft^2)	Maximum Power (hp)
DHC-6 Twin Otter	29.76	1500 [11]
PC-24	54.01	7,200 (lbf thrust) [12]
DHC-4 Caribou	31.25	2,900 [13]
F-27 Friendship	60.00	2,500 [14]
Dash 8 Q-400	87.37	4,800 [15]

Table 6 Horsepower and Wing Loading of the Similar Aircraft

In comparison with our previous aircraft, we're beginning to look like an enlarged DHC-4 or DHC-6, which fits well with our original intentions.

VII. Conclusions and Recommendations

At this point in time, we a looking at creating a plane which is unlikely to be economical to operate in commercial service. However, as a capable, fast, mid-range transport for high value items, we fit a particular niche which may provide good success. Few aircraft in the Twin Sea Lion's weight group combine such strong performance with access to small airfields. Our sensitivity analysis showed that we need to pay particular attention to powerplant choice, picking something that will give us both good power and good efficiency will be a very high priority. We need to meet or exceed our predicted c_p and η_p values. Second, we will need to find a way to sell this aircraft. Potential customers will probably only pick us if they really need the range and speed that aircraft provies, and cannot use a jet instead.

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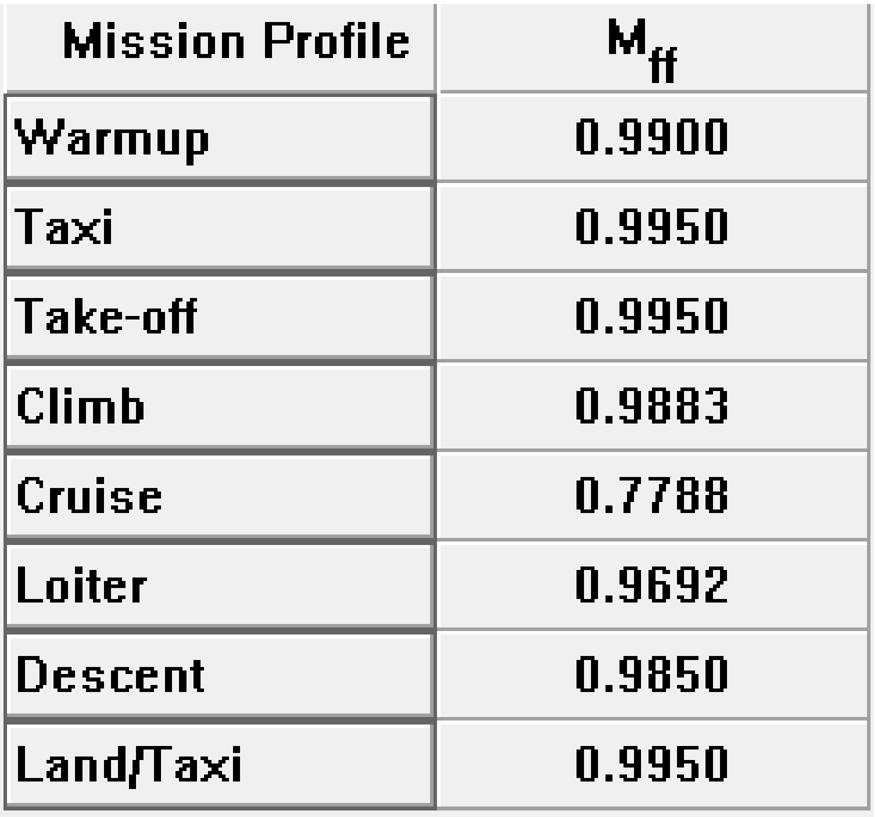
VIII. Appendices

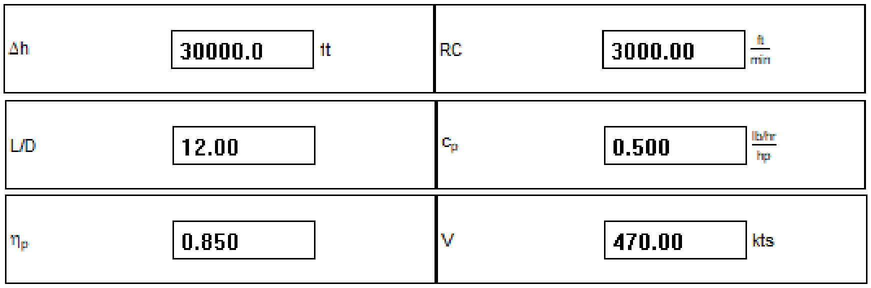
A. Aircraft Weight

1. Mission Fuel Fraction



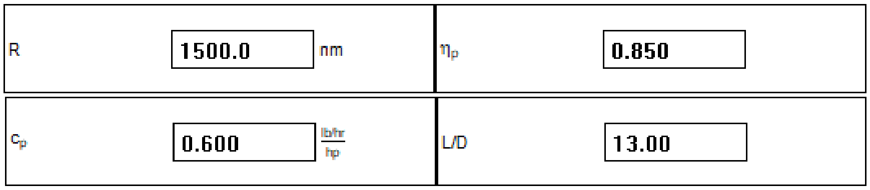
Mission Profile	M_{ff}
Warmup	0.9900
Taxi	0.9950
Take-off	0.9950
Climb	0.9883
Cruise	0.7788
Loiter	0.9692
Descent	0.9850
Land/Taxi	0.9950

Fig. 14 Resulting Sea Lion mission fuel fractions.



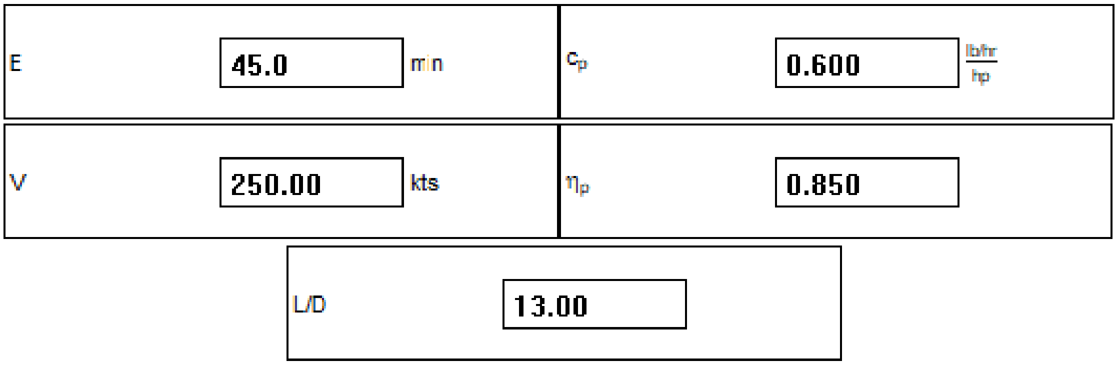
Δh	30000.0	ft	RC	3000.00	$\frac{ft}{min}$
L/D	12.00		c_p	0.500	$\frac{lb/hr}{hp}$
η_p	0.850		V	470.00	kts

Fig. 15 Input for climb mission fuel fraction.



R	1500.0	nm	η_p	0.850	
c_p	0.600	$\frac{lb/hr}{hp}$	L/D	13.00	

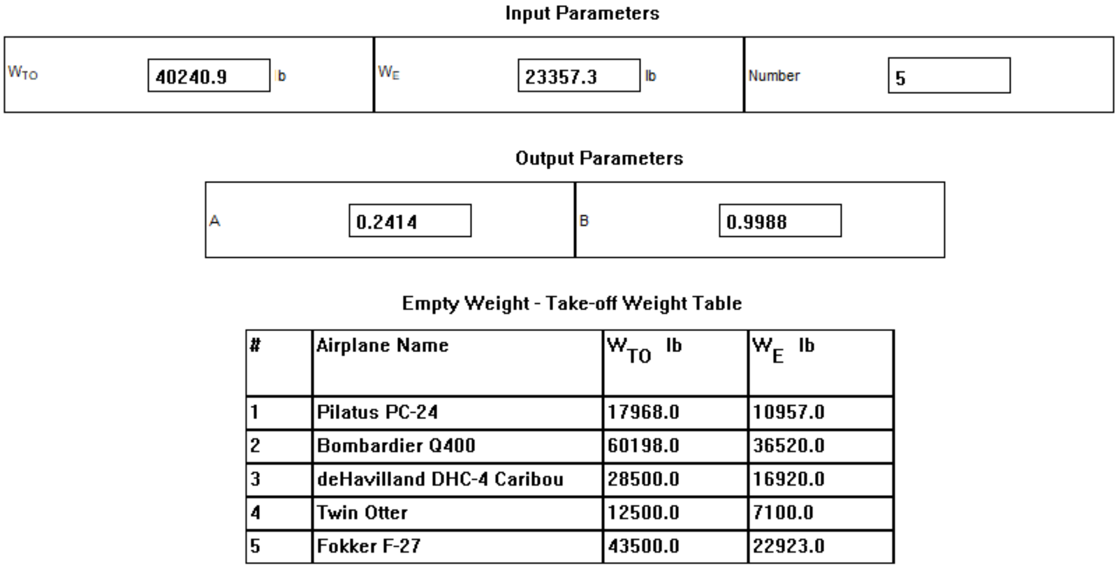
Fig. 16 Input for cruise mission fuel fraction.



E	45.0	min	c_p	0.600	$\frac{lb/hr}{hp}$
V	250.00	kts	η_p	0.850	
L/D	13.00				

Fig. 17 Input for loiter mission fuel fraction.

2. *Takeoff Weight*



Input Parameters

W_{TO}	40240.9	b	W_E	23357.3	lb	Number	5

Output Parameters

A	0.2414	B	0.9988

Empty Weight - Take-off Weight Table

#	Airplane Name	W_{TO} lb	W_E lb
1	Pilatus PC-24	17968.0	10957.0
2	Bombardier Q400	60198.0	36520.0
3	deHavilland DHC-4 Caribou	28500.0	16920.0
4	Twin Otter	12500.0	7100.0
5	Fokker F-27	43500.0	22923.0

Fig. 18 Input for similar plane weights.

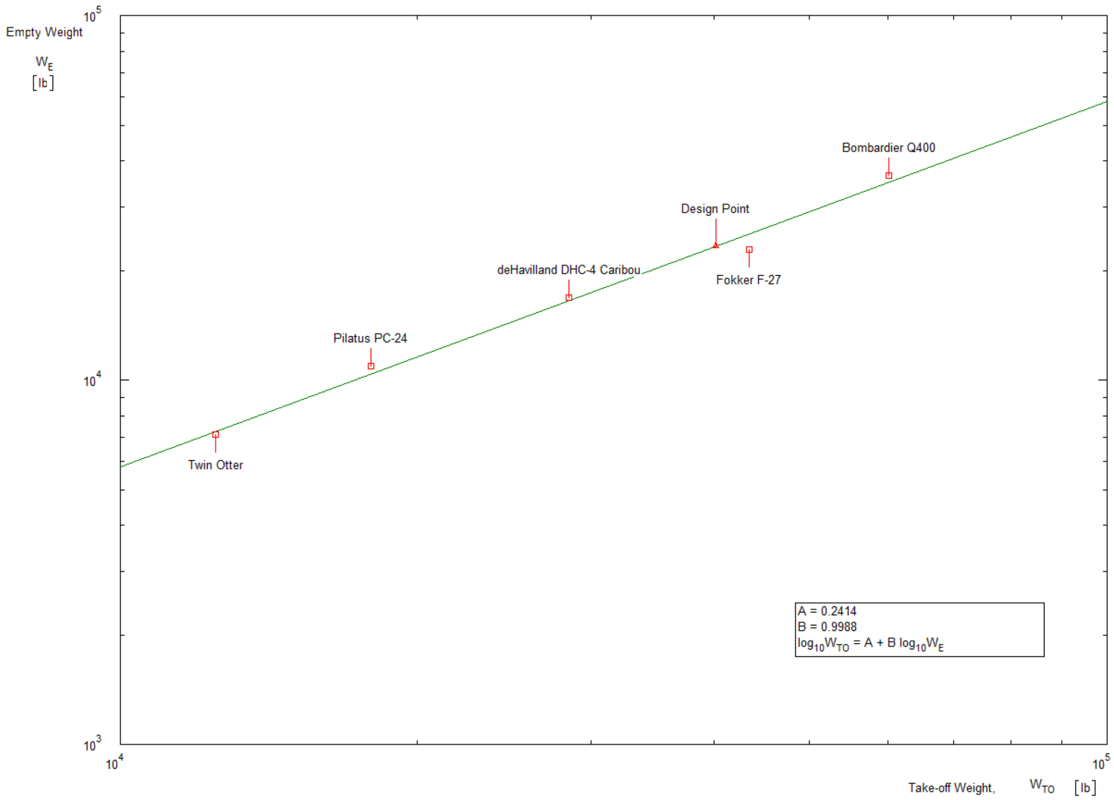
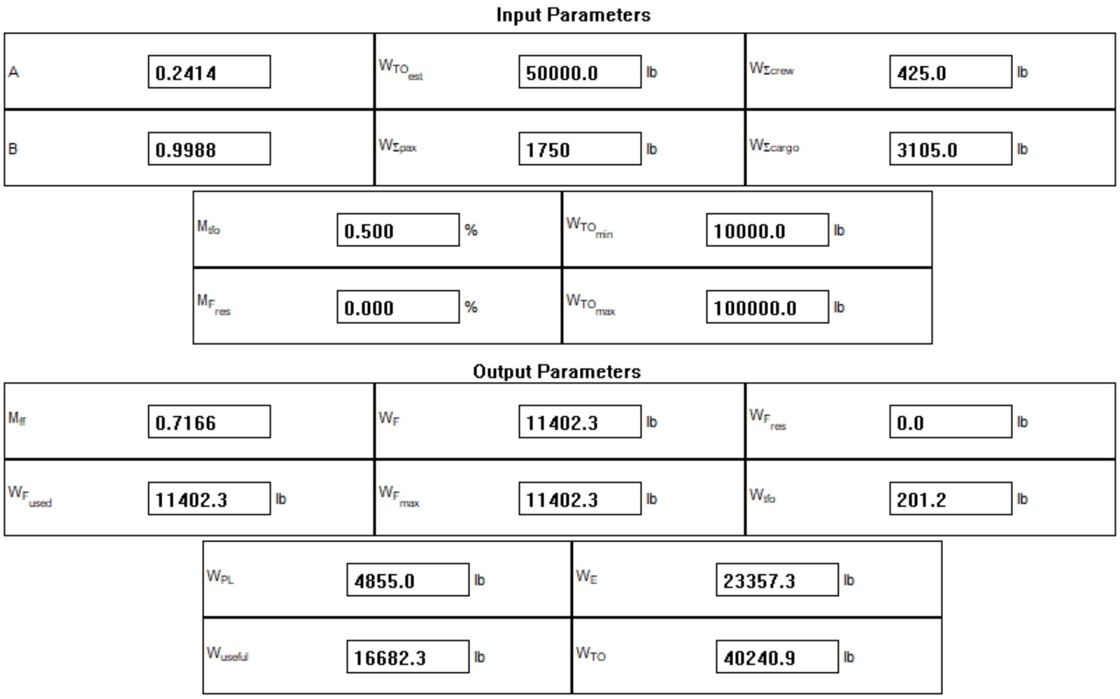


Fig. 19 Plot of similar plane weights.



Input Parameters

A	0.2414		$W_{TO_{est}}$	50000.0	lb	$W_{\Sigma crew}$	425.0	lb
B	0.9988		$W_{\Sigma pax}$	1750	lb	$W_{\Sigma cargo}$	3105.0	lb

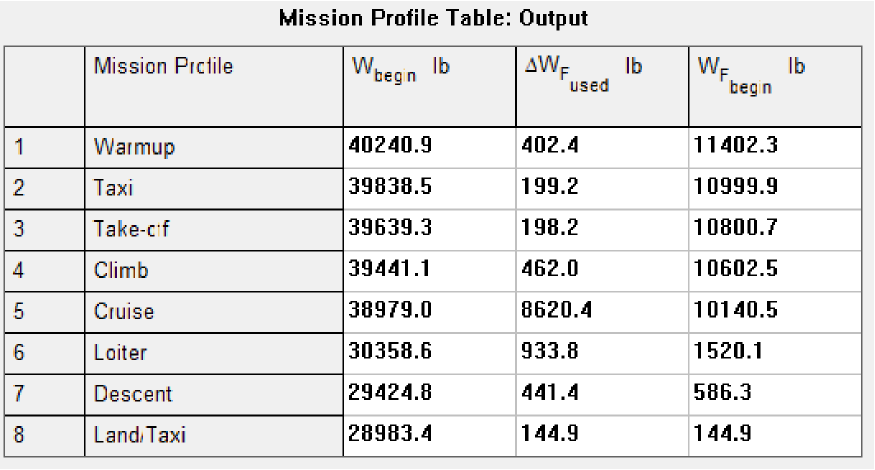
M_{tfo}	0.500	%	$W_{TO_{min}}$	10000.0	lb
$M_{F_{res}}$	0.000	%	$W_{TO_{max}}$	100000.0	lb

Output Parameters

M_{ff}	0.7166		W_F	11402.3	lb	$W_{F_{res}}$	0.0	lb
$W_{F_{used}}$	11402.3	lb	$W_{F_{max}}$	11402.3	lb	W_{tfo}	201.2	lb

W_{PL}	4855.0	lb	W_E	23357.3	lb
W_{useful}	16682.3	lb	W_{TO}	40240.9	lb

Fig. 20 Input and output for takeoff weight determination.

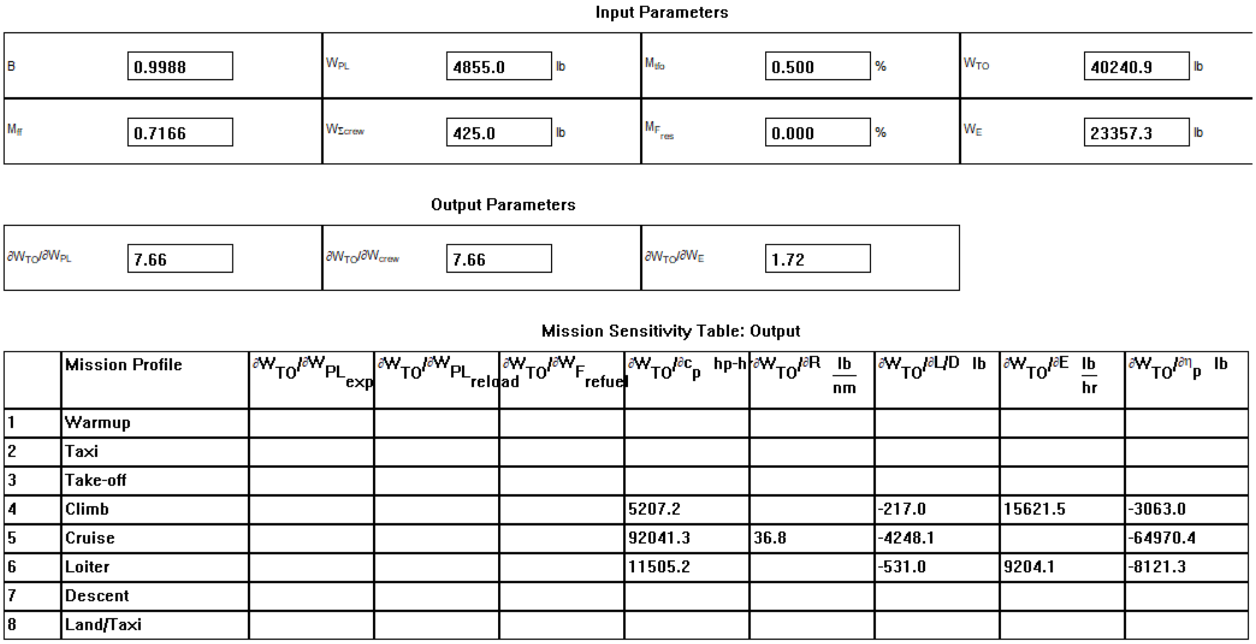


Mission Profile Table: Output

	Mission Profile	W_{begin} lb	$\Delta W_{F_{used}}$ lb	$W_{F_{begin}}$ lb
1	Warmup	40240.9	402.4	11402.3
2	Taxi	39838.5	199.2	10999.9
3	Take-off	39639.3	198.2	10800.7
4	Climb	39441.1	462.0	10602.5
5	Cruise	38979.0	8620.4	10140.5
6	Loiter	30358.6	933.8	1520.1
7	Descent	29424.8	441.4	586.3
8	Land/Taxi	28983.4	144.9	144.9

Fig. 21 Weights at different points throughout mission

3. Sensitivity



Input Parameters

B 0.9988
W_{PL} 4855.0 lb
M_{tfo} 0.500 %
W_{TO} 40240.9 lb
M_{ff} 0.7166
$W_{\Sigma crew}$ 425.0 lb
$M_{F_{res}}$ 0.000 %
W_E 23357.3 lb

Output Parameters

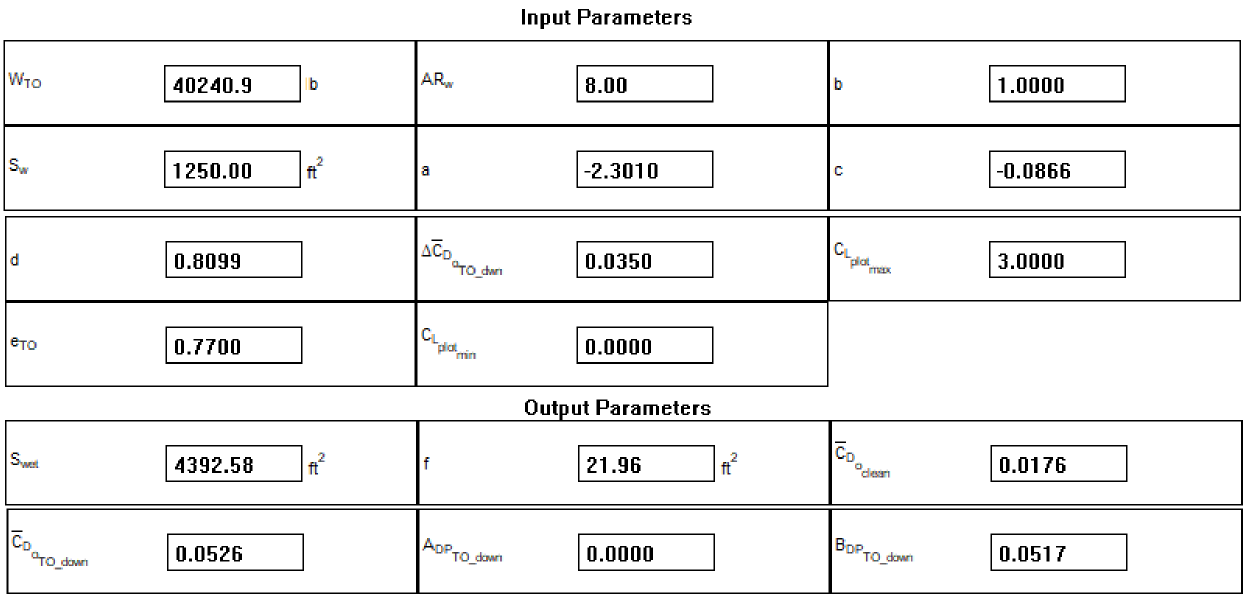
$\partial W_{TO}/\partial W_{PL}$ 7.66
$\partial W_{TO}/\partial W_{crew}$ 7.66
$\partial W_{TO}/\partial W_E$ 1.72

Mission Sensitivity Table: Output

	Mission Profile	$\partial W_{TO}/\partial W_{PL_{exp}}$	$\partial W_{TO}/\partial W_{PL_{reload}}$	$\partial W_{TO}/\partial W_{F_{refuel}}$	$\partial W_{TO}/\partial c_p$ hp-h	$\partial W_{TO}/\partial R$ lb/nm	$\partial W_{TO}/\partial L/D$ lb	$\partial W_{TO}/\partial E$ lb/hr	$\partial W_{TO}/\partial \eta_p$ lb
1	Warmup								
2	Taxi								
3	Take-off								
4	Climb				5207.2		-217.0	15621.5	-3063.0
5	Cruise				92041.3	36.8	-4248.1		-64970.4
6	Loiter				11505.2		-531.0	9204.1	-8121.3
7	Descent								
8	Land/Taxi								

Fig. 22 Sensitivity of aircraft weight to various parameters.

B. Drag Polars



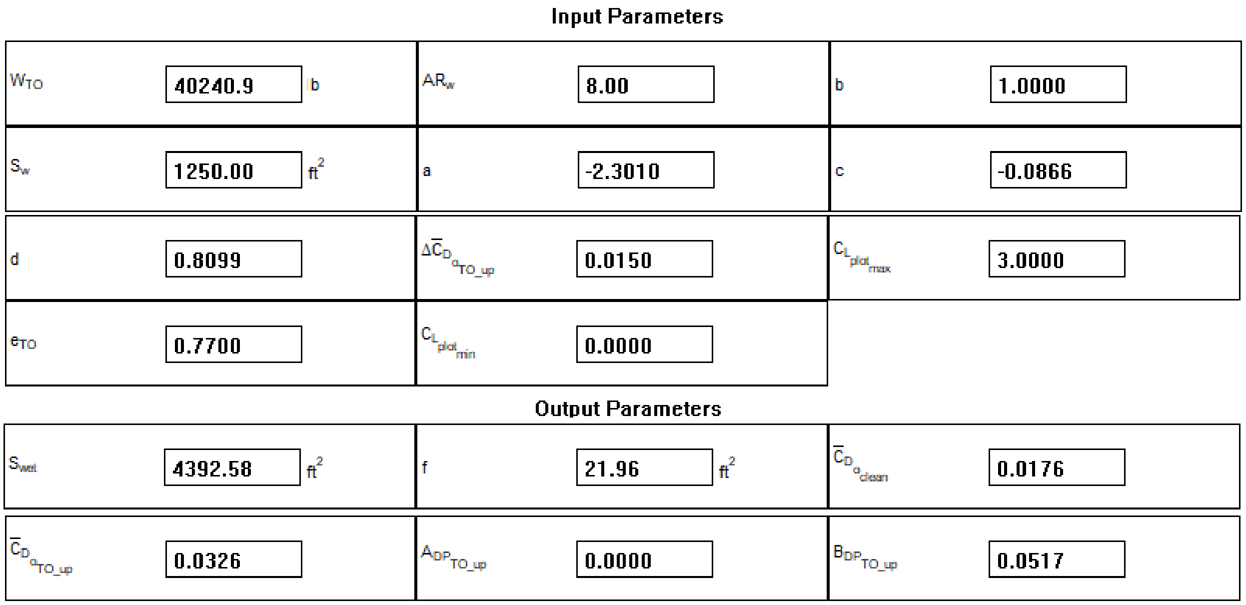
Input Parameters

W_{TO}	40240.9	lb	AR_w	8.00		b	1.0000
S_w	1250.00	ft^2	a	-2.3010		c	-0.0866
d	0.8099		$\Delta\bar{C}_{D_{o_{TO\_dwn}}}$	0.0350		$C_{L_{plot_{max}}}$	3.0000
e_{TO}	0.7700		$C_{L_{plot_{min}}}$	0.0000			

Output Parameters

S_{wet}	4392.58	ft^2	f	21.96	ft^2	$\bar{C}_{D_{o_{clean}}}$	0.0176
$\bar{C}_{D_{o_{TO\_down}}}$	0.0526		$A_{DP_{TO\_down}}$	0.0000		$B_{DP_{TO\_down}}$	0.0517

Fig. 23 Drag polar inputs takeoff, gear down.



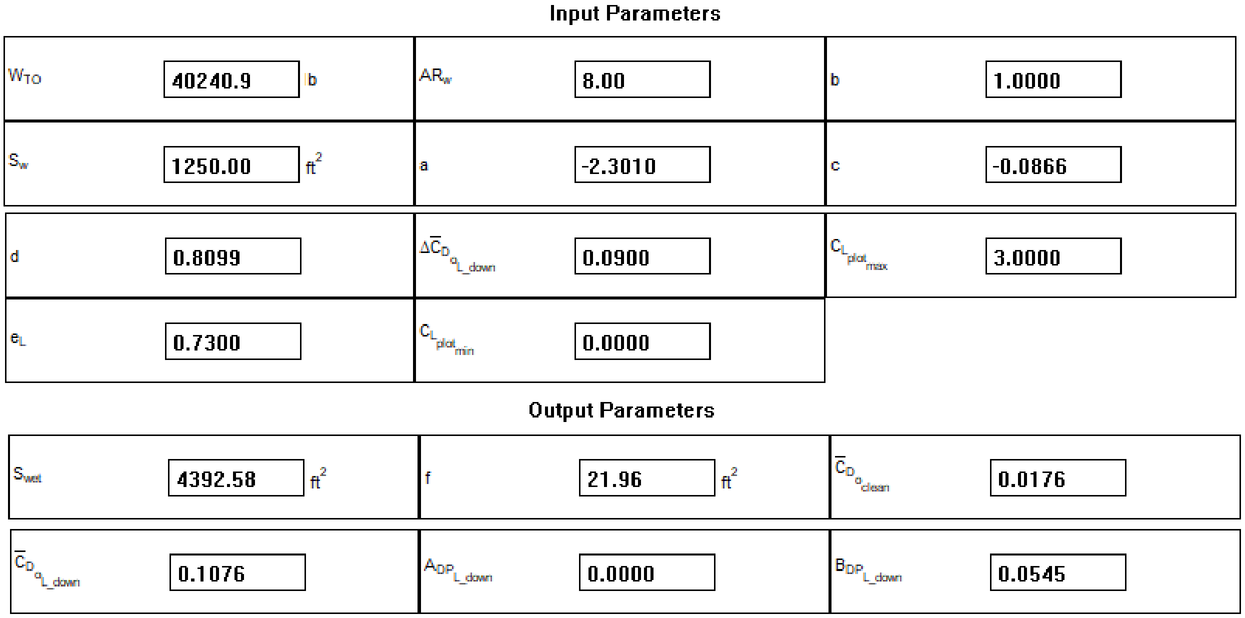
Input Parameters

W_{TO}	40240.9	lb	AR_w	8.00		b	1.0000
S_w	1250.00	ft^2	a	-2.3010		c	-0.0866
d	0.8099		$\Delta\bar{C}_{D_{o_{TO\_up}}}$	0.0150		$C_{L_{plot_{max}}}$	3.0000
e_{TO}	0.7700		$C_{L_{plot_{min}}}$	0.0000			

Output Parameters

S_{wet}	4392.58	ft^2	f	21.96	ft^2	$\bar{C}_{D_{o_{clean}}}$	0.0176
$\bar{C}_{D_{o_{TO\_up}}}$	0.0326		$A_{DP_{TO\_up}}$	0.0000		$B_{DP_{TO\_up}}$	0.0517

Fig. 24 Drag polar inputs takeoff, gear up.



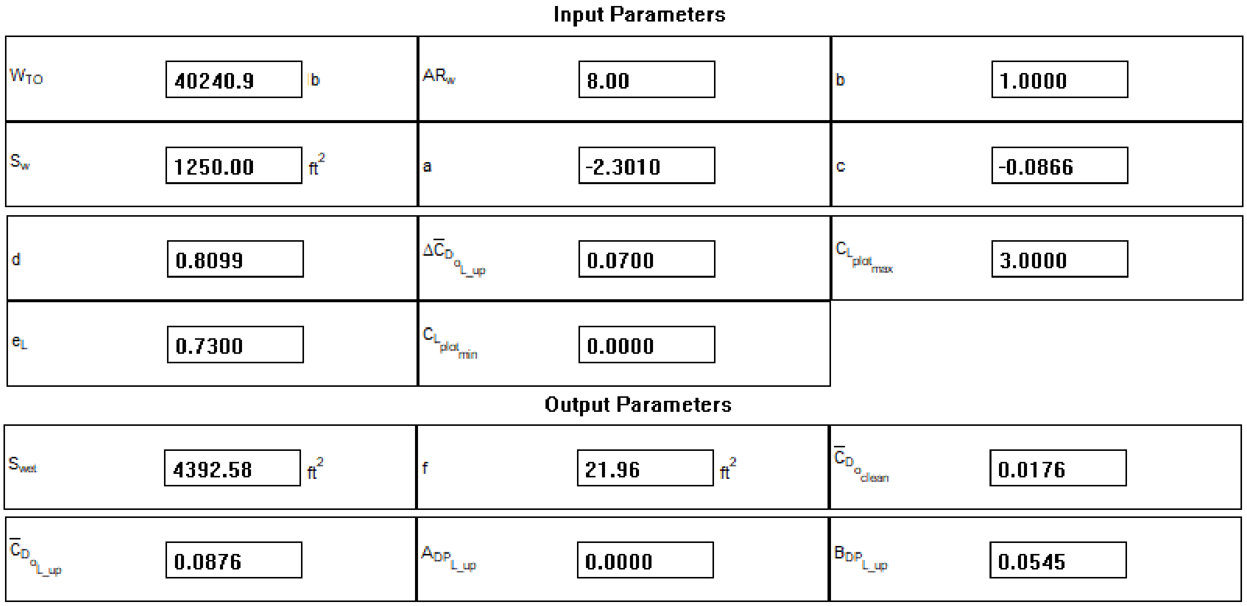
Input Parameters

W_{TO}	40240.9 lb	AR_w	8.00	b	1.0000
S_w	1250.00 ft^2	a	-2.3010	c	-0.0866
d	0.8099	$\Delta\bar{C}_{D_{0_{L\_down}}}$	0.0900	$C_{L_{plot_{max}}}$	3.0000
e_L	0.7300	$C_{L_{plot_{min}}}$	0.0000		

Output Parameters

S_{wet}	4392.58 ft^2	f	21.96 ft^2	$\bar{C}_{D_{0_{clean}}}$	0.0176
$\bar{C}_{D_{0_{L\_down}}}$	0.1076	$A_{DP_{L\_down}}$	0.0000	$B_{DP_{L\_down}}$	0.0545

Fig. 25 Drag polar inputs landing, gear down.



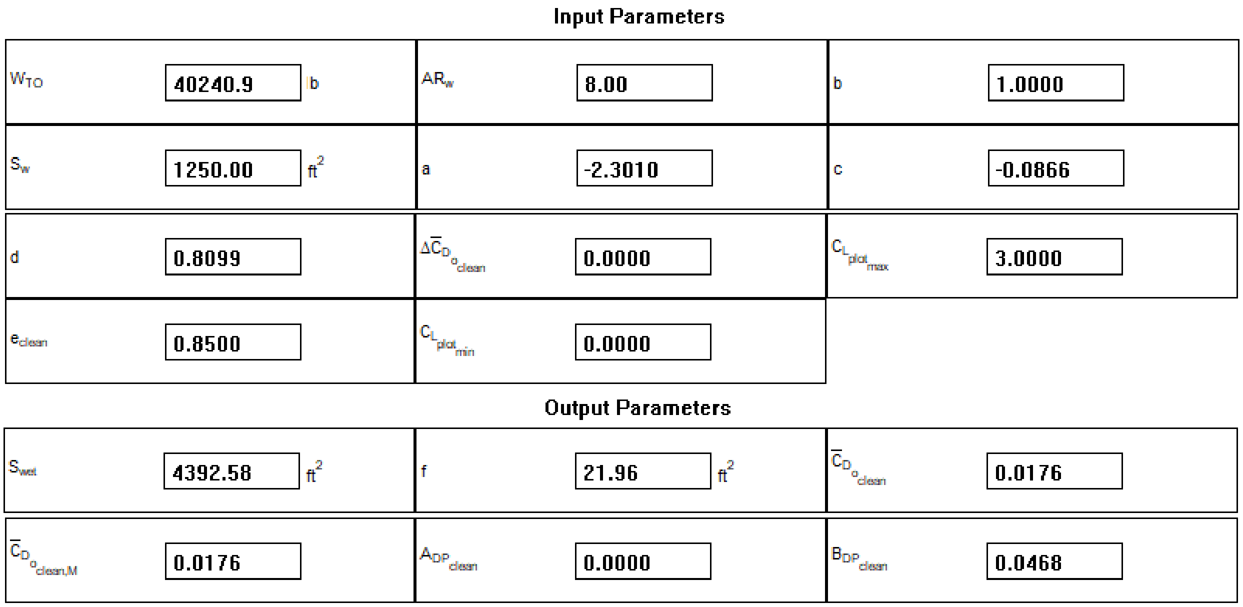
Input Parameters

W_{TO}	40240.9 lb	AR_w	8.00	b	1.0000
S_w	1250.00 ft^2	a	-2.3010	c	-0.0866
d	0.8099	$\Delta\bar{C}_{D_{0_{L\_up}}}$	0.0700	$C_{L_{plot_{max}}}$	3.0000
e_L	0.7300	$C_{L_{plot_{min}}}$	0.0000		

Output Parameters

S_{wet}	4392.58 ft^2	f	21.96 ft^2	$\bar{C}_{D_{0_{clean}}}$	0.0176
$\bar{C}_{D_{0_{L\_up}}}$	0.0876	$A_{DP_{L\_up}}$	0.0000	$B_{DP_{L\_up}}$	0.0545

Fig. 26 Drag polar inputs landing, gear up.



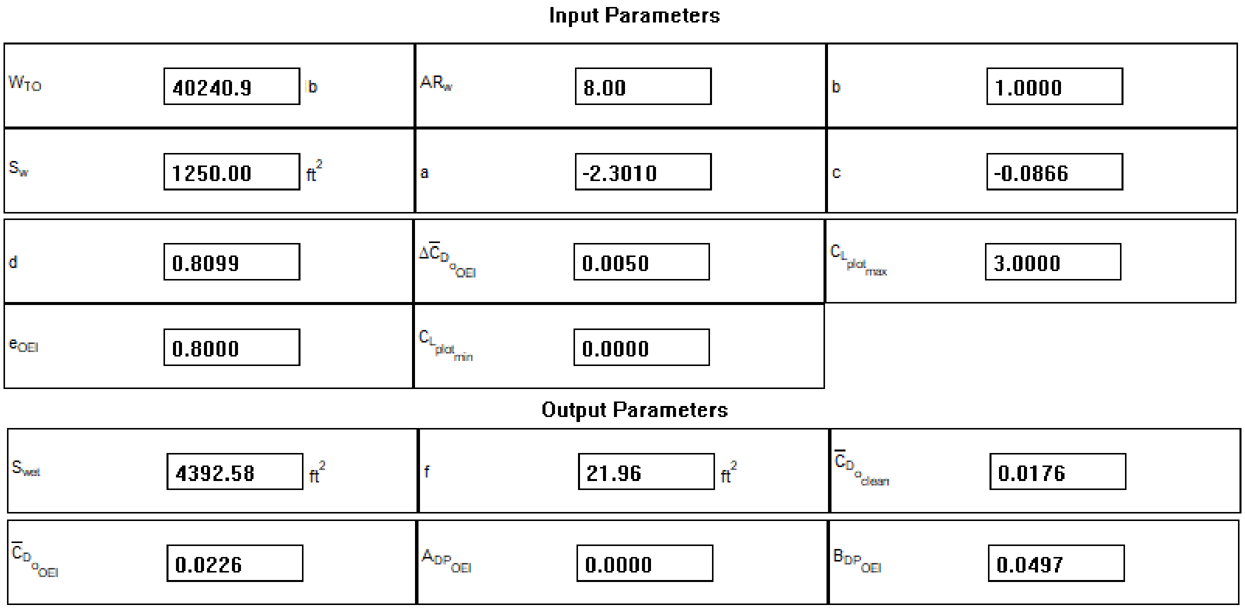
Input Parameters

W_{TO}	40240.9 lb	AR_w	8.00	b	1.0000
S_w	1250.00 ft^2	a	-2.3010	c	-0.0866
d	0.8099	$\Delta\bar{C}_{D_{o_{clean}}}$	0.0000	$C_{L_{plot_{max}}}$	3.0000
e_{clean}	0.8500	$C_{L_{plot_{min}}}$	0.0000		

Output Parameters

S_{wet}	4392.58 ft^2	f	21.96 ft^2	$\bar{C}_{D_{o_{clean}}}$	0.0176
$\bar{C}_{D_{o_{clean,M}}}$	0.0176	$A_{DP_{clean}}$	0.0000	$B_{DP_{clean}}$	0.0468

Fig. 27 Drag polar clean.



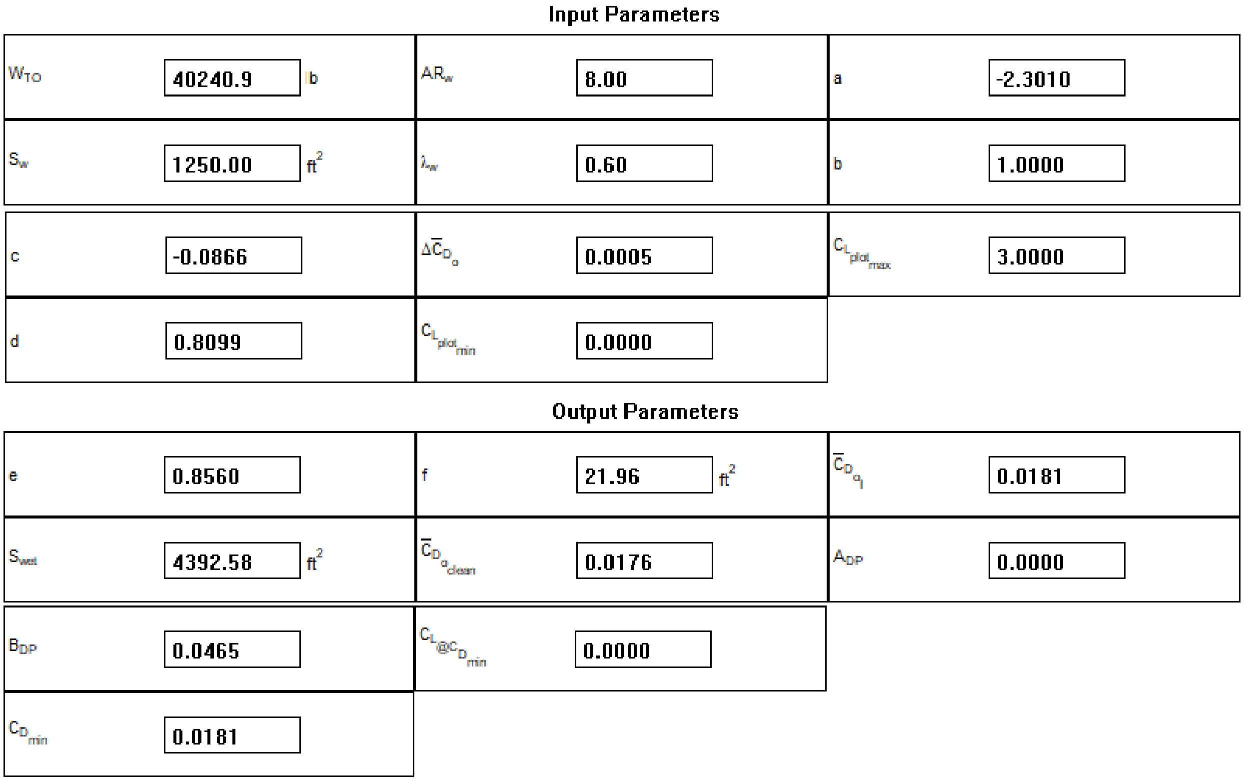
Input Parameters

W_{TO}	40240.9 lb	AR_w	8.00	b	1.0000
S_w	1250.00 ft^2	a	-2.3010	c	-0.0866
d	0.8099	$\Delta\bar{C}_{D_{o_{OEI}}}$	0.0050	$C_{L_{plot_{max}}}$	3.0000
e_{OEI}	0.8000	$C_{L_{plot_{min}}}$	0.0000		

Output Parameters

S_{wet}	4392.58 ft^2	f	21.96 ft^2	$\bar{C}_{D_{o_{clean}}}$	0.0176
$\bar{C}_{D_{o_{OEI}}}$	0.0226	$A_{DP_{OEI}}$	0.0000	$B_{DP_{OEI}}$	0.0497

Fig. 28 Drag polar OEI.



Input Parameters

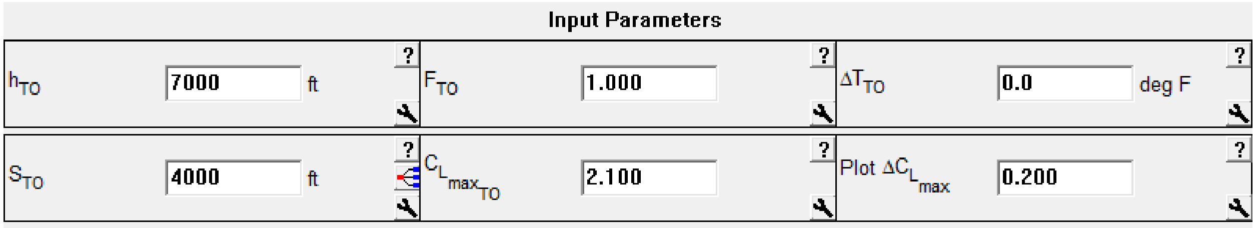
W_{TO}	40240.9 lb	AR_w	8.00	a	-2.3010
S_w	1250.00 ft^2	λ_w	0.60	b	1.0000
c	-0.0866	$\Delta\bar{C}_{D_o}$	0.0005	$C_{L_{plot_{max}}}$	3.0000
d	0.8099	$C_{L_{plot_{min}}}$	0.0000		

Output Parameters

e	0.8560	f	21.96 ft^2	$\bar{C}_{D_{o_i}}$	0.0181
S_{wet}	4392.58 ft^2	$\bar{C}_{D_{o_{clean}}}$	0.0176	A_{DP}	0.0000
B_{DP}	0.0465	$C_{L_{@C_{D_{min}}}}$	0.0000		
$C_{D_{min}}$	0.0181				

Fig. 29 Drag polar current.

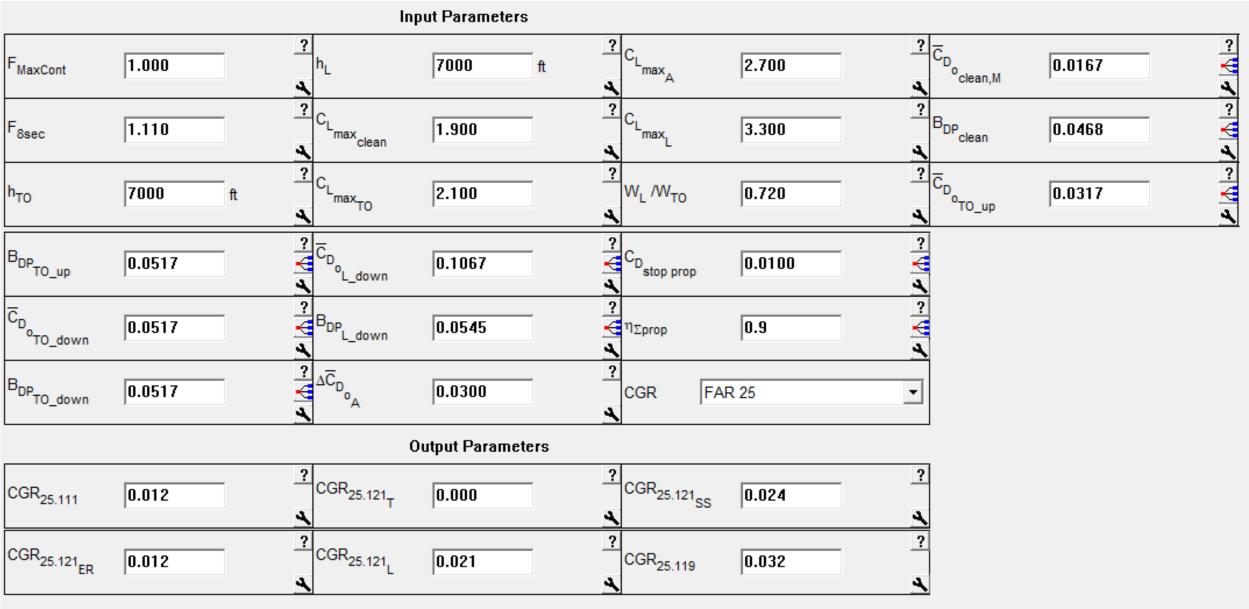
C. Performance



Input Parameters

h_{TO}	7000 ft	F_{TO}	1.000	ΔT_{TO}	0.0 deg F
S_{TO}	4000 ft	$C_{L_{max_{TO}}}$	2.100	Plot $\Delta C_{L_{max}}$	0.200

Fig. 30 Performance sizing for takeoff.



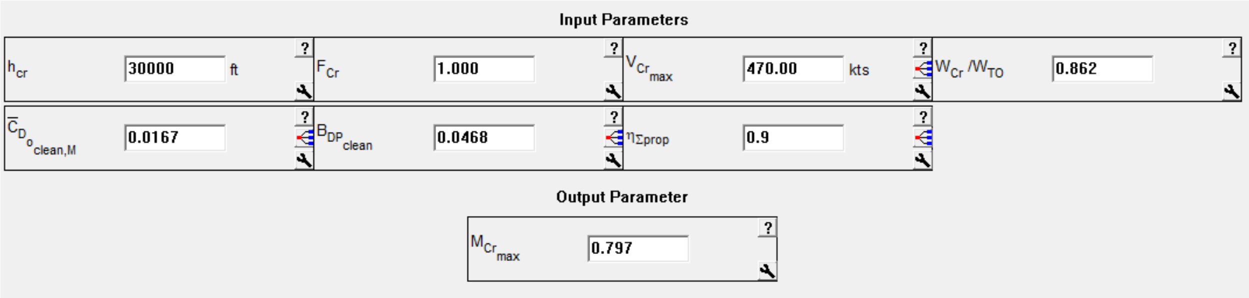
Input Parameters

$F_{MaxCont}$	1.000	h_L	7000 ft	$C_{L_{max_A}}$	2.700	$\bar{C}_{D_{o_{clean,M}}}$	0.0167
F_{8sec}	1.110	$C_{L_{max_{clean}}}$	1.900	$C_{L_{max_L}}$	3.300	$B_{DP_{clean}}$	0.0468
h_{TO}	7000 ft	$C_{L_{max_{TO}}}$	2.100	W_L/W_{TO}	0.720	$\bar{C}_{D_{o_{TO\_up}}}$	0.0317
$B_{DP_{TO\_up}}$	0.0517	$\bar{C}_{D_{o_{L\_down}}}$	0.1067	$C_{D_{stop\ prop}}$	0.0100		
$\bar{C}_{D_{o_{TO\_down}}}$	0.0517	$B_{DP_{L\_down}}$	0.0545	$\eta_{\Sigma prop}$	0.9		
$B_{DP_{TO\_down}}$	0.0517	$\Delta\bar{C}_{D_{o_A}}$	0.0300	CGR	FAR 25		

Output Parameters

$CGR_{25.111}$	0.012	$CGR_{25.121_T}$	0.000	$CGR_{25.121_{SS}}$	0.024
$CGR_{25.121_{ER}}$	0.012	$CGR_{25.121_L}$	0.021	$CGR_{25.119}$	0.032

Fig. 31 Performance sizing for climb.



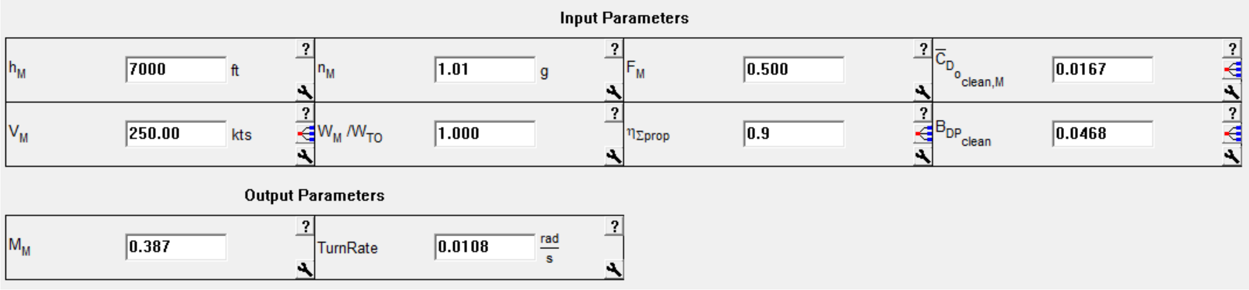
Input Parameters

h_{cr}	30000 ft	F_{Cr}	1.000	$V_{Cr_{max}}$	470.00 kts	W_{Cr}/W_{TO}	0.862
$\bar{C}_{D_{o_{clean,M}}}$	0.0167	$B_{DP_{clean}}$	0.0468	$\eta_{\Sigma prop}$	0.9		

Output Parameter

$M_{Cr_{max}}$	0.797

Fig. 32 Performance sizing for cruise.



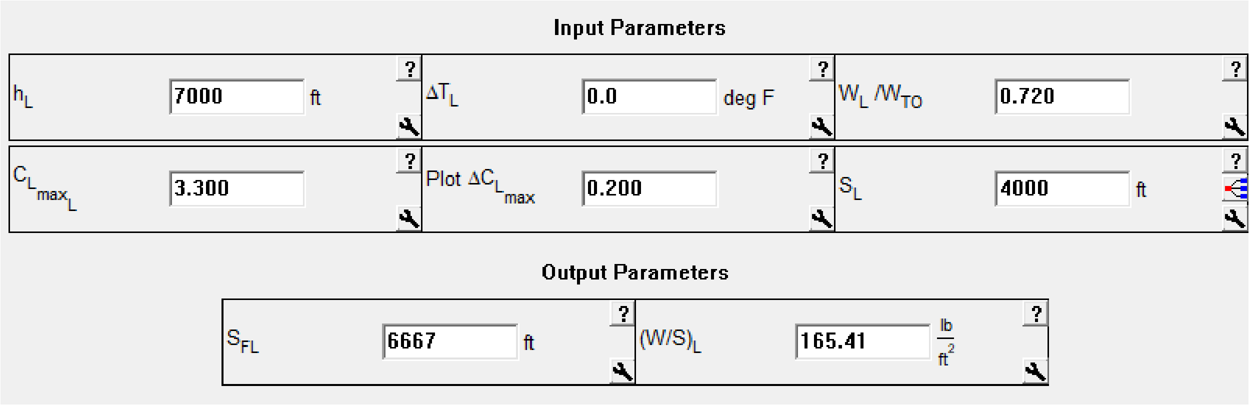
Input Parameters

h_M	7000 ft	n_M	1.01 g	F_M	0.500	$\bar{C}_{D_{o_{clean,M}}}$	0.0167
V_M	250.00 kts	W_M/W_{TO}	1.000	$\eta_{\Sigma prop}$	0.9	$B_{DP_{clean}}$	0.0468

Output Parameters

M_M	0.387	TurnRate	0.0108 $\frac{rad}{s}$

Fig. 33 Performance sizing for maneuver.



Input Parameters

h_L 7000 ft

ΔT_L 0.0 deg F

W_L / W_{TO} 0.720

$C_{L_{max_L}}$ 3.300

Plot $\Delta C_{L_{max}}$ 0.200

S_L 4000 ft

Output Parameters

S_{FL} 6667 ft

$(W/S)_L$ 165.41 $\frac{lb}{ft^2}$

Fig. 34 Performance sizing for landing.