Bugatti 100P Neutral Point and Longitudinal Trim – Rev A

Neutral Point Location

Stick-fixed static longitudinal stability (neutral point) and longitudinal moment trim (elevator deflection vs. airspeed) were computed for the Bugatti 100P flap up and flap extended configurations over a range of proposed center of gravity positions. The aircraft neutral point was estimated using the wing-tail vortex lattice model (VLM) shown in Figure 1. The destabilizing effect of the body on neutral point location was estimated using Royal Aeronautical Society Data Sheet 08.01.01. from Appendix B of Etkin's *Dynamics of Flight, Stability & Control.* The reference wing planform used for the VLM model is shown in Figure 2 with the mean aerodynamic chord location identified. This mean aerodynamic chord definition was not reconciled with previous 100P definitions. Wing incidence in the VLM model was 1.5° (Rev A change) and tail incidence 0°.

The Bugatti 100P stick-fixed neutral point was estimated to be at 26%c of the mean aerodynamic chord for the power-off condition. High-power at low airspeeds will cause a further forward shift in neutral point. This destabilizing effect due to power has yet to be estimated. For center of gravity (CG) loadings forward of 26%c, the aircraft will possess positive longitudinal stability. Longitudinal moment trim was investigated for CG positions of 10%c, 15%c & 20%c, nominally forward, mid and aft CG. These positions were chosen arbitrarily for this analysis. Figure 3 shows that the main wheel ground contact point is located at 10.9%c. This would represent the forward CG limit for ground handling (keeping the aircraft on the tail wheel).

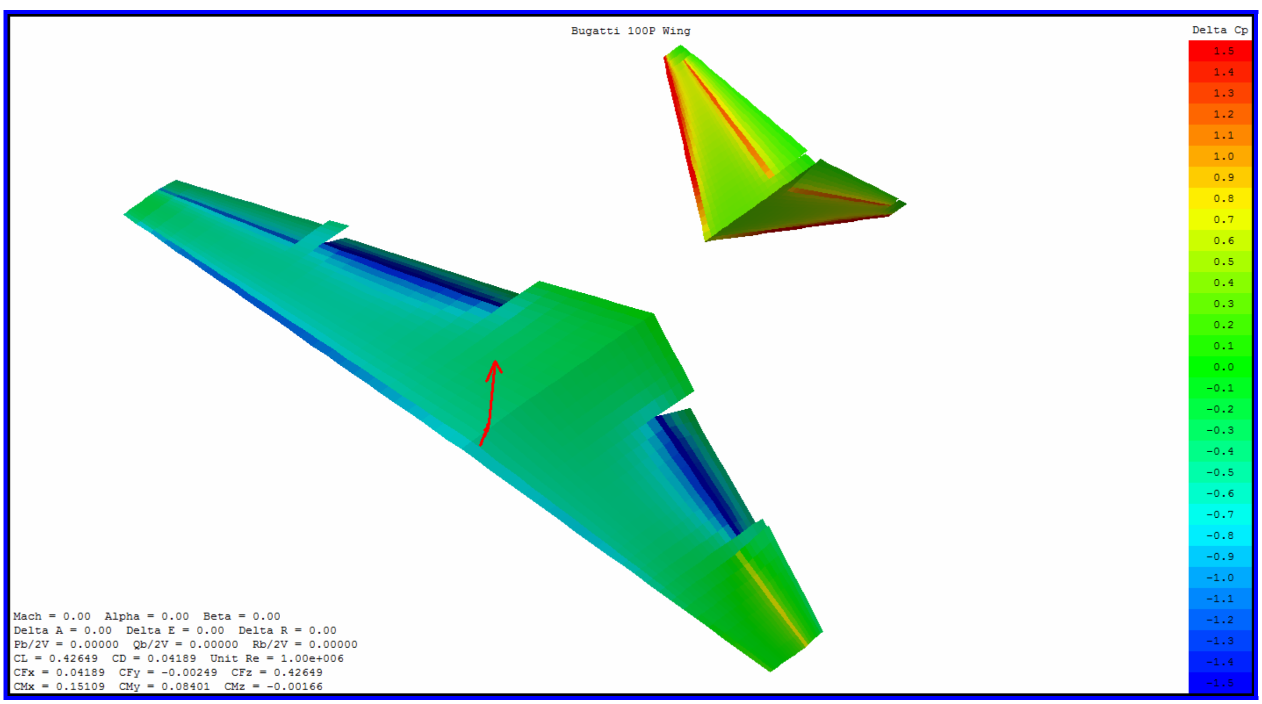


Figure 1. Bugatti 100P Wing-Tail Vortex Lattice Model

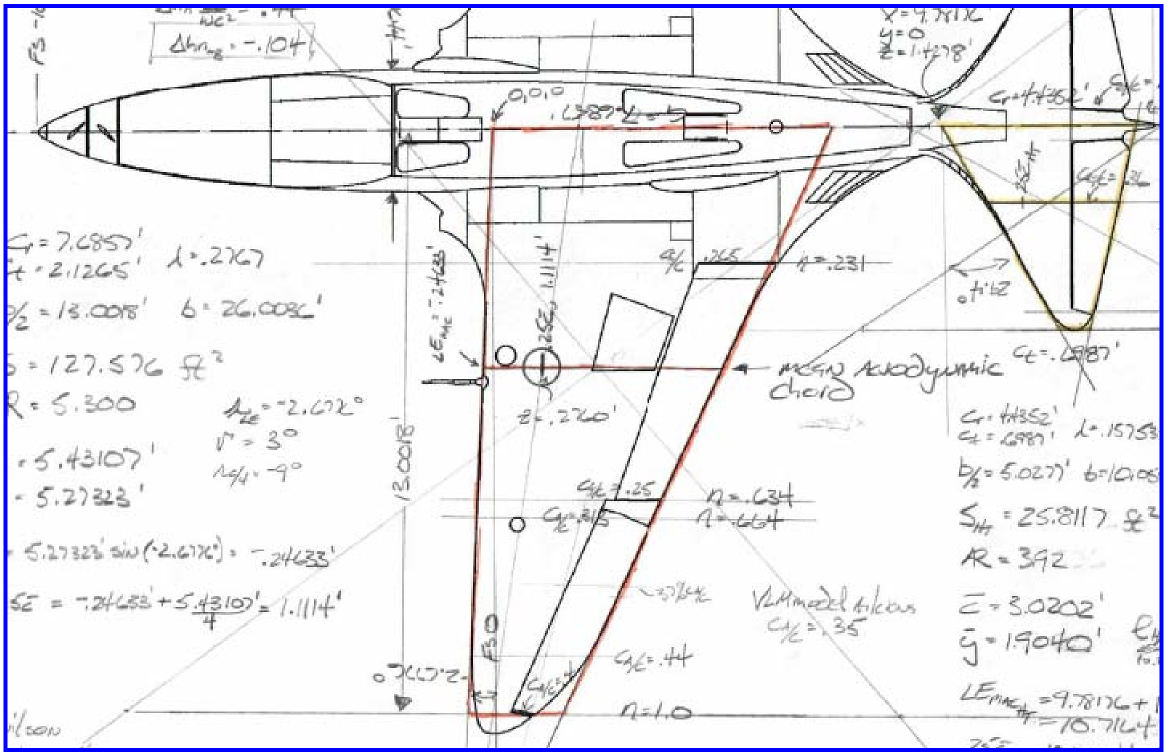


Figure 2. Wing and Tail Reference Planform Definitions (Highlighted)

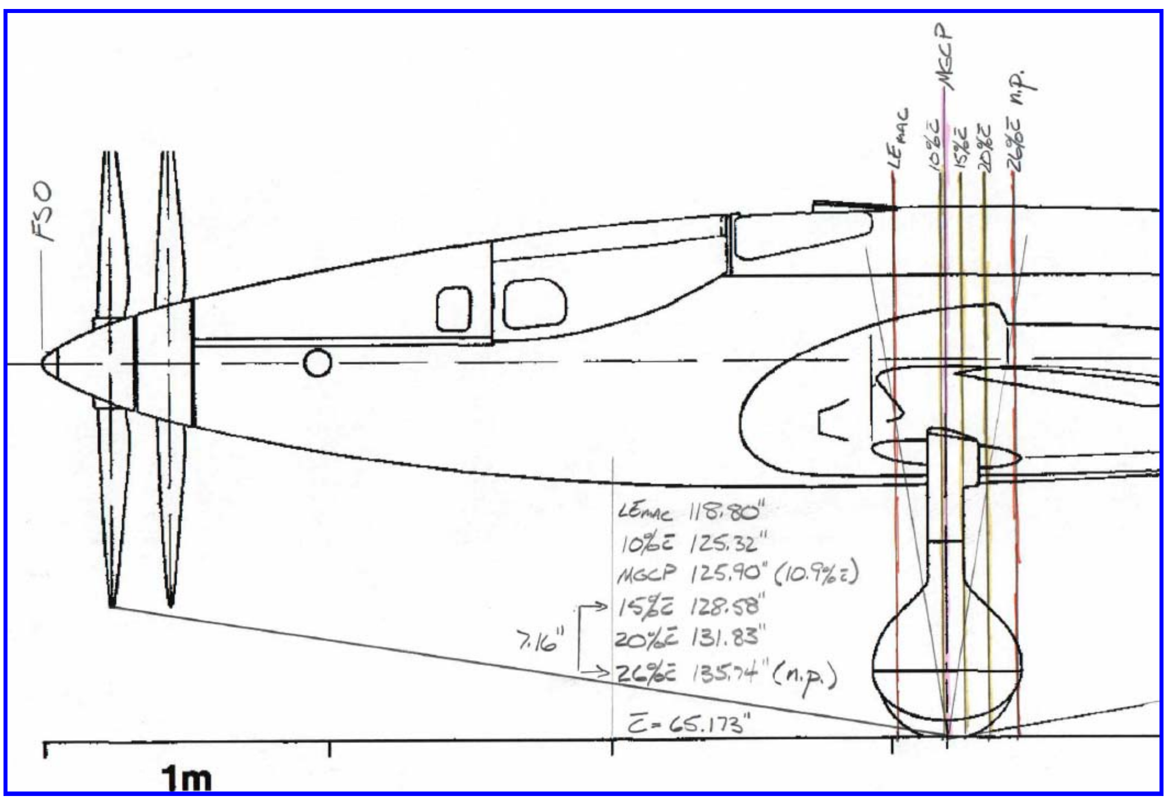


Figure 3. Center of Gravity Envelope Analyzed

Elevator Deflections Required

Elevator deflection to trim versus airspeed curves are plotted in Figure 4 for the flap up, flap 12.5° and flap 25° deflections at forward, mid and aft CG. The 100P plain flap geometry is given in Figure 5. Full deflection for landing is 25° and a mid deflection of 12.5° was assumed for takeoff. Note that plain flap deflections for landing are generally much higher than 25°. Maximum flap extended speeds (V_{FE}) of 113 kts and 111 kts for the 12.5° and 25° positions were calculated based on the FAR 23 1.8 x Vso definition. The flap up V_{NE} speed identified on the plot is arbitrary and likely would be set by other considerations like flutter.

The curves in Figure 4 show that the elevator will be trailing edge up throughout much of the 100P's flight envelope. Flaps up at mid CG (15%c), there will be a natural trim point at 190 knots (elevator deflection = 0). The curves also show that there will not be much of a trim change with flap deflection. At a forward CG of 10%c, the aircraft will be elevator limited in stall. An aerodynamic stall at fwd CG will not be possible because elevator deflections exceed the surface travel limit of -25° TEU. The deflections will also likely exceed the elevator's aerodynamic effectiveness limits. Slightly aft of 10%c, the aircraft will be capable of reaching an aerodynamic wing stall.

Note that the elevator deflection curves plotted in Figure 4 are for a 2650 lbs aircraft.

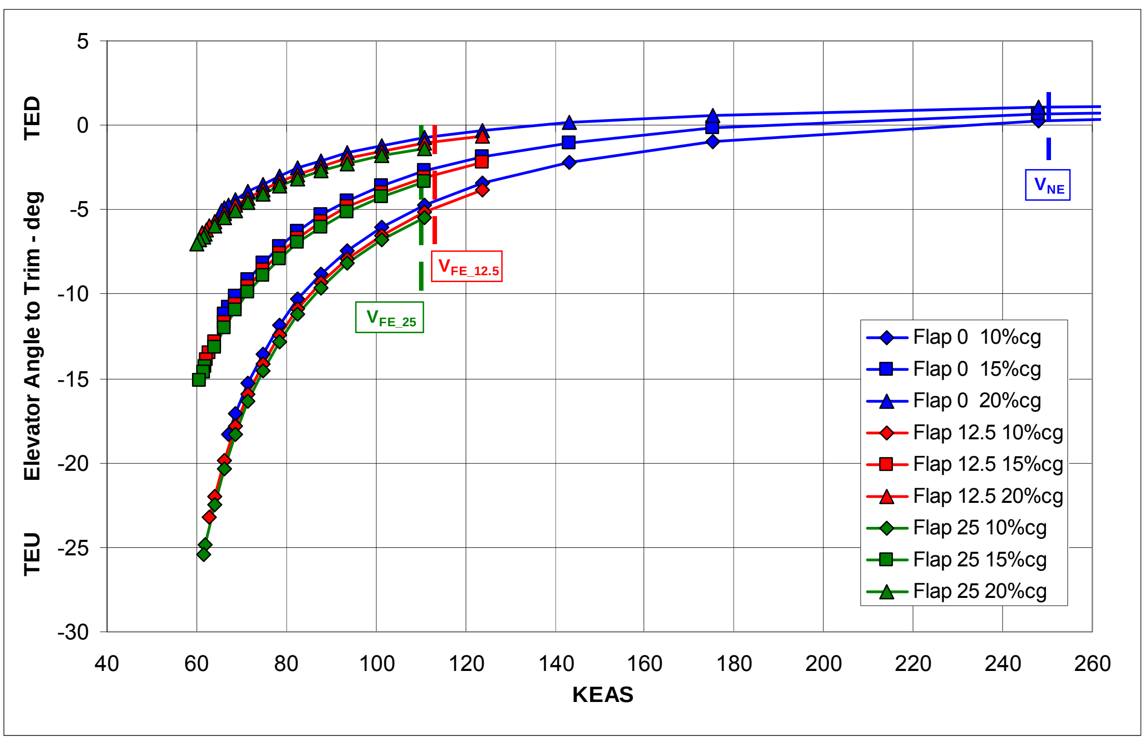


Figure 4. Elevator Deflections for a Given Airspeed and CG Location
(2650 lbs Aircraft Weight)

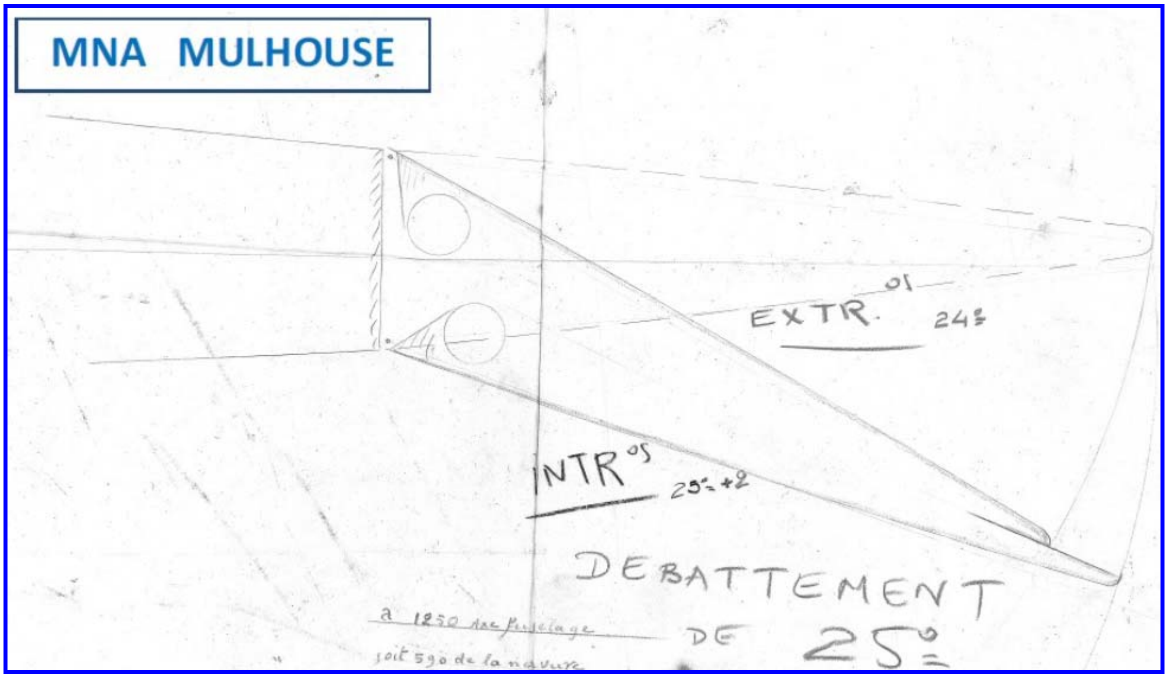


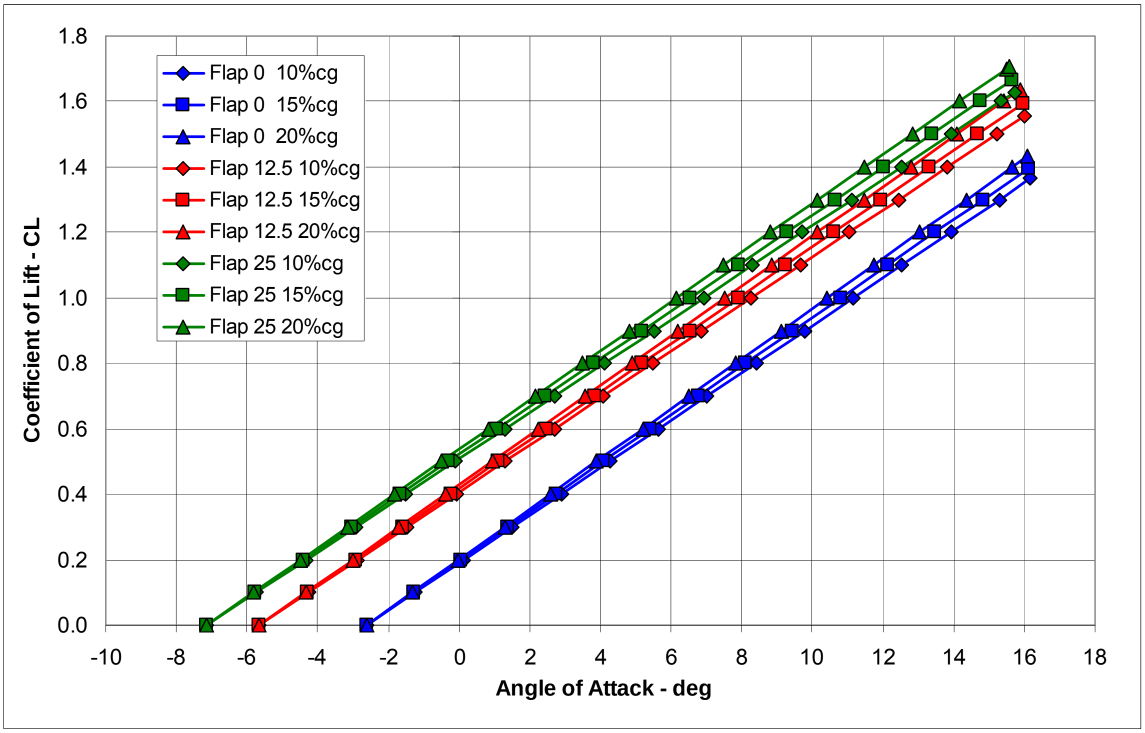
Figure 5. 100P Plain Flap Geometry

Trimmed Lift Curves and Stall Speeds

Trimmed lift curves for all three reference flap positions at fwd, mid and aft CG are plotted in Figure 6. Trimmed refers to the elevator being deflected at the position required to bring all pitching moments to zero about the aircraft's center of gravity, i.e. the elevator deflection curves plotted in Figure 4. The lift curves are plotted as linear up to stall. Generally, there is 2°~3° of non-linear lift curve before maximum lift coefficient is reached. This non-linear portion of the lift curve could not be predicted and was therefore not included. Actual stall angles of attack should be slightly higher than those shown in Figure 6.

The lift curve characteristics such as lift curve slope ($C_{L\alpha}$), lift coefficient at zero angle of attack (C_{Lo}), zero-lift angle of attack (α_{OL}) and maximum lift coefficient (C_{Lmax}) are listed in the Tables below Figure 6. The 1g stall speeds for a 2650 lbs aircraft are also listed in the Tables. Normal load factor generally drops below 1.0 at stall. So, the minimum speed observed during the stall should be 1 or 2 knots slower than those listed.

Cruise (flap up) C_L for a 2500 lbs aircraft at 200 knots is 0.14. Body attitude at that speed would be about -0.7° in level flight. Lift coefficient for a flap up approach speed of 1.3Vs (V_{ref} = 84 kts) would be 0.83 with a body attitude of 5.5° in a -3° approach. With landing flaps, body attitude at 1.3Vs (V_{ref} = 76 kts) would be 3.4° (C_L 1.0) in a -3° approach. More speed may need to be added to V_{ref} in order to get a reasonable look over the nose during approach.



Flaps Up Aircraft Trimmed Lift Curves

	CLα	CLo	α_OL	CLmax	Vs @ 2650 lbs
	/deg		deg		kts
0.10c fwd	0.0725	0.191	-2.63	1.364	67.1
0.15c mid	0.0745	0.196	-2.63	1.397	66.3
0.20c aft	0.0766	0.201	-2.63	1.432	65.5
untrimmed	0.0792	0.197	-2.49	-	-

Flaps 12.5 Aircraft Trimmed Lift Curves

	CLα	CLo	α_OL	CLmax	Vs @ 2650 lbs
	/deg		deg		kts
0.10c fwd	0.0719	0.406	-5.65	1.556	62.8
0.15c mid	0.0739	0.417	-5.65	1.595	62.1
0.20c aft	0.0759	0.429	-5.65	1.635	61.3
untrimmed	0.0785	0.435	-5.54	-	-

Flaps 25 Aircraft Trimmed Lift Curves

	CLα	CLo	α_OL	CLmax	Vs @ 2650 lbs
	/deg		deg		kts
0.10c fwd	0.0711	0.508	-7.15	1.626	61.5
0.15c mid	0.0730	0.522	-7.15	1.666	60.7
0.20c aft	0.0751	0.537	-7.15	1.708	60.0
untrimmed	0.0776	0.548	-7.07	-	-

Figure 6. Trimmed Lift Curves for All Three Reference Flap Positions at Forward, Mid and Aft Center of Gravity

Stall Characteristics

Some gage of the aircraft's stall characteristics can be gleaned from the wing spanwise lift distribution. Figure 7a shows the spanwise lift distribution on the flap up wing at stall angle of attack. An airfoil two-dimensional maximum lift coefficient line is plotted for reference. When the local wing C_l reaches the airfoil C_{lmax}, the wing is said to be stalled (or stalling). The Figure shows that the stall occurs out towards the tip at 70% to 80% span. This characteristic would likely mean a tip stall leading to wing drop and roll off.

Spanwise lift distributions on the wing for the flap 12.5° and flap 25° configurations are given in Figures 7b & 7c, respectively. Again, a two-dimensional airfoil maximum lift coefficient line is plotted. As expected, the flapped portion of the wing has a higher 2-D C_{lmax}. The Figures show the wing stalling outboard of the flap. The flap induces higher local angles of attack that raise the lift coefficients of the outboard (unflapped) portion of the wing. Using the drooped aileron would raise the local sectional C_{lmax} outboard and help load the wing to higher lift coefficients before stalling. The result would be a higher aircraft C_{Lmax} and thus lower stall speeds. Stall location would be more inboard, about 50% to 60% span. Flap extended roll offs at stall would likely be less severe than flap up. Note that aileron effectiveness plays a role in the severity of the roll offs at stall, but that is difficult to predict with these methods.

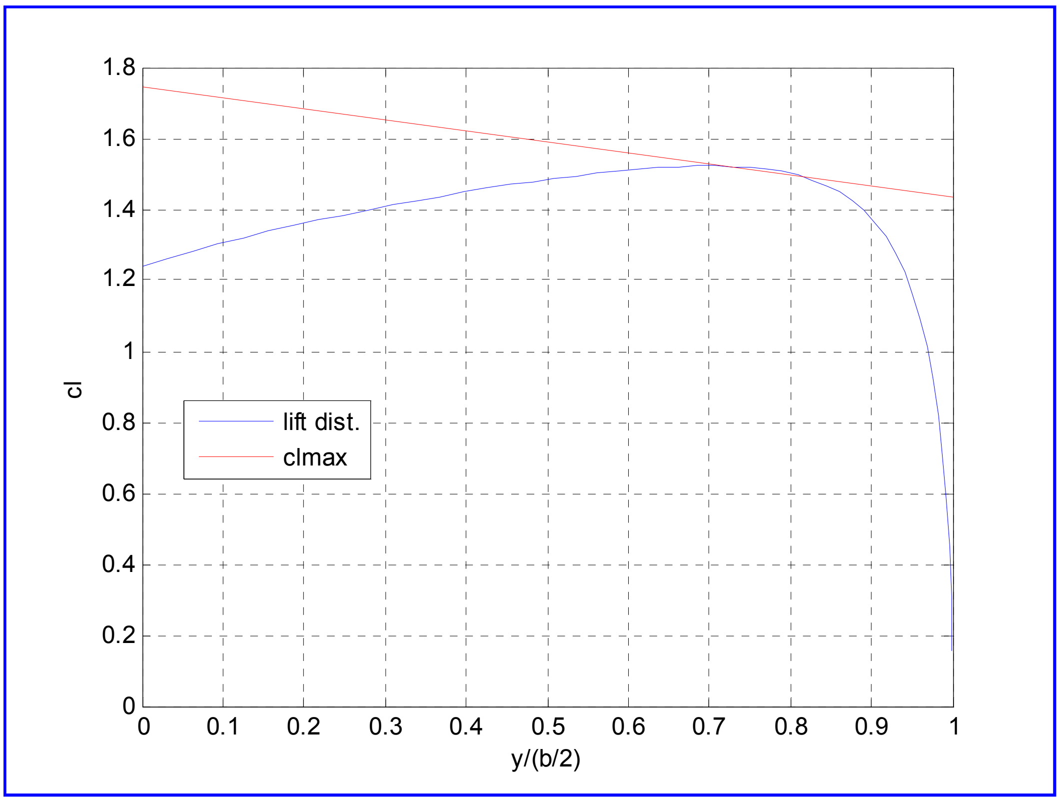


Figure 7a. 100P Flap Up Spanwise Lift Distribution on the Wing at Stall

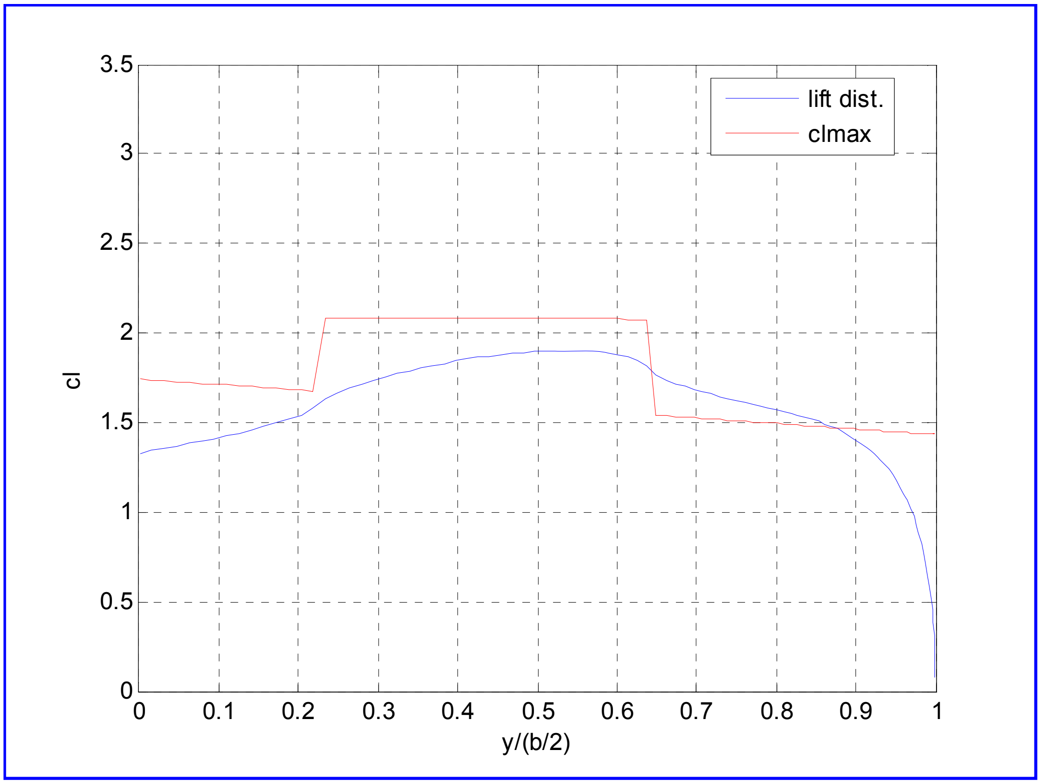


Figure 7b. 100P Flap 12.5° Spanwise Lift Distribution on the Wing at Stall

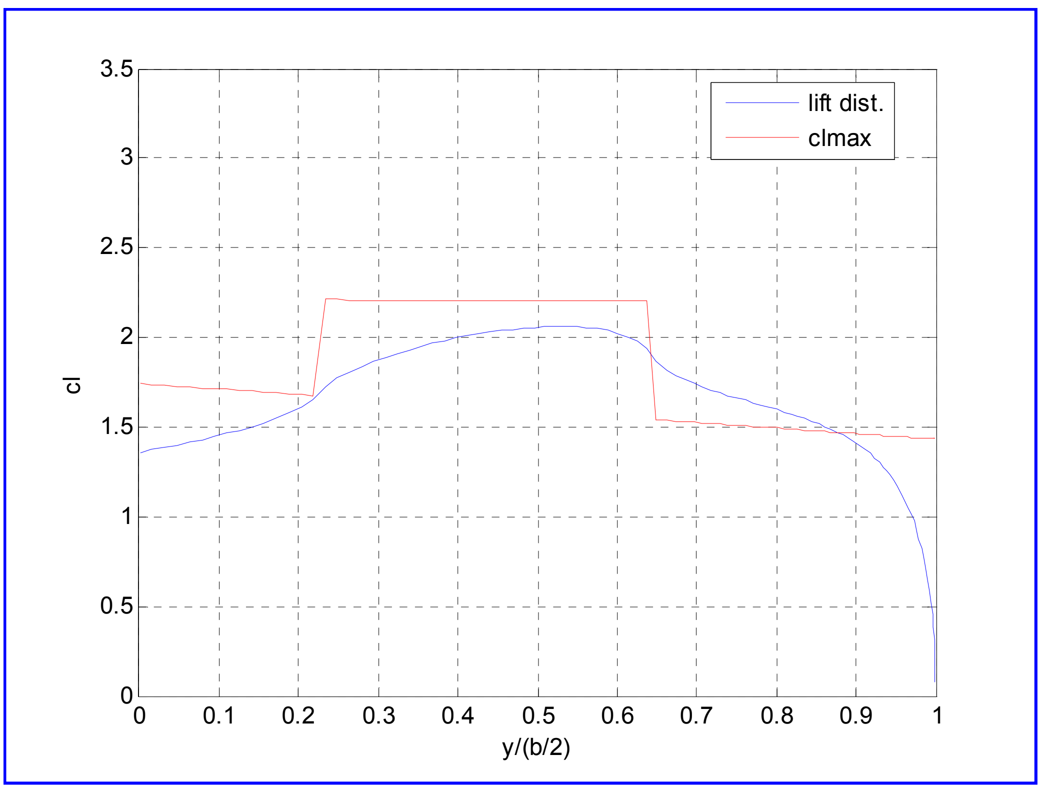


Figure 7c. 100P Flap 25° Spanwise Lift Distribution on the Wing at Stall

Horizontal Tail Lift Coefficient

The average downwash angle at the horizontal tail is plotted in Figure 8 versus aircraft angle of attack. The close-coupled tail on the 100P leads to a rather large downwash gradient ($\partial\varepsilon/\partial\alpha$) of about 0.50. Using these estimated downwash gradients, tail lift coefficients were computed for the three reference flap positions at forward, mid and aft center of gravity. These tail C_Ls are plotted against aircraft C_L in Figure 9. The Figure shows that the minimum tail lift coefficient is just -0.40 for the flap 25° configuration at forward CG. Flaps up minimum tail C_L is on the order of -0.15. In all conditions, the horizontal tail is not highly loaded.

There is some concern as to the aerodynamic effectiveness of the 100P's horizontal stabilizer with the leading edge inlets installed. A horizontal stabilizer with a large 45 minute ice shape on the leading edge could be considered an analogous situation in terms of flow disturbance over the tail. The 45 minute ice shape generally has two forward protruding "horns" which can be as tall as the tail's maximum thickness. This effectively makes the horizontal tail leading edge square (or blunt). Ice shapes of this size have been found to reduce tail C_{Lmin} (less negative) but not change tail lift curve slope. Note that C_{Lmin} would be C_{Lmax} for a downloaded tail. By not changing tail lift curve slope, the tail's contribution to longitudinal stability would be unchanged. The concern then becomes tail stall.

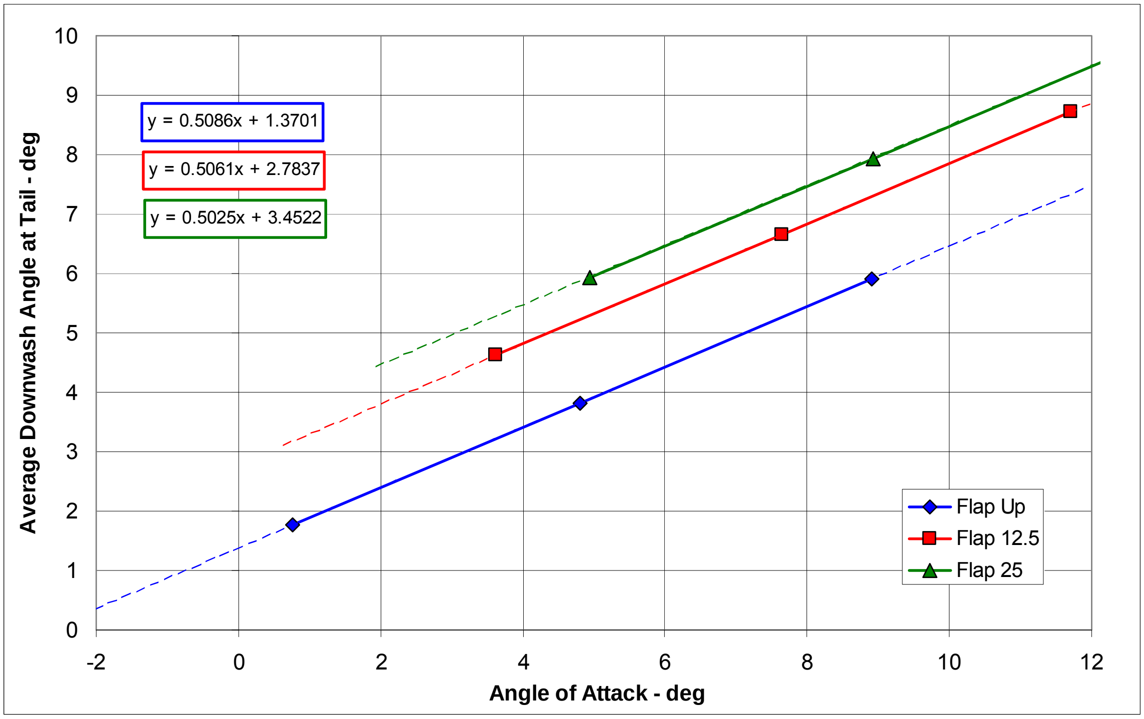


Figure 8. Average Downwash Angle at the Horizontal Tail

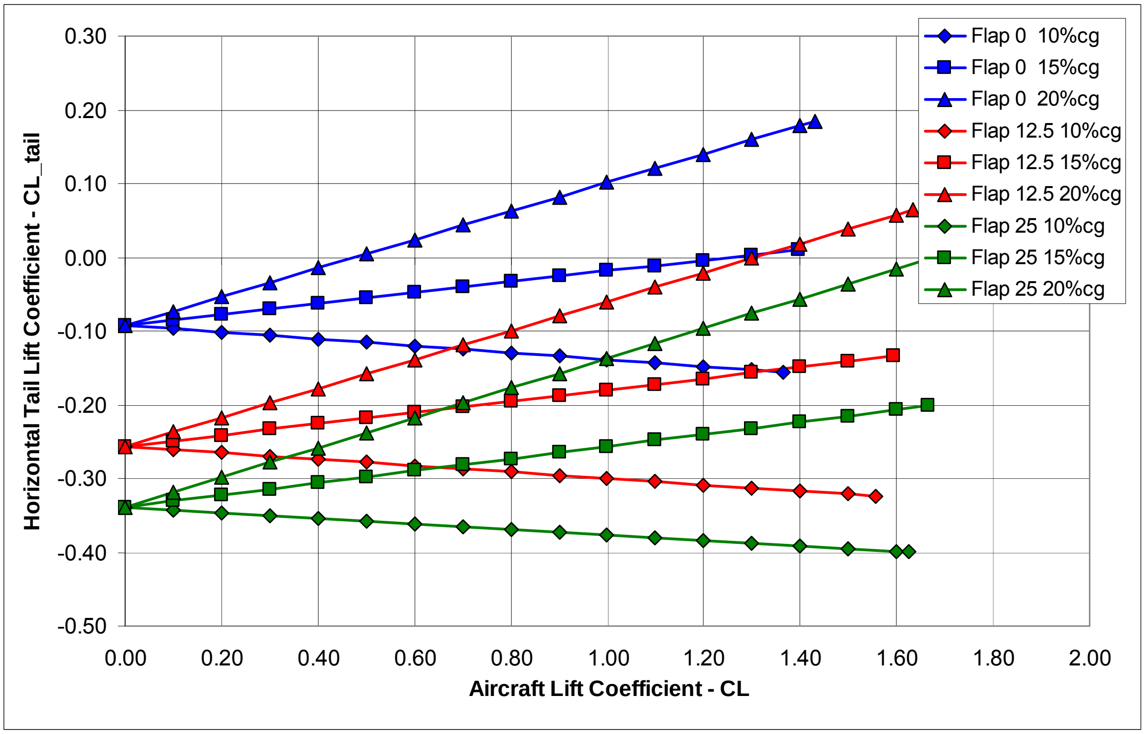


Figure 9. 100P Horizontal Tail Lift Coefficient Range

The two wind tunnel test examples I could find for a horizontal tail with a 45 minute ice shape showed a C_{Lmin} drop from -1.10 to -0.63 for a twin-engine jet and a -0.90 to -0.74 C_{Lmin} drop for a single-engine jet. Another wind tunnel example with 36-grit sandpaper on the horizontal tail showed a tail C_{Lmin} drop from -0.79 down to -0.69. All three examples lowered tail C_{Lmin} down to a value in the neighborhood of that of a flat plate. Assuming a flat plate like value of -0.60 for the 100P tail C_{Lmin} shows that there would still be margin to tail stall based on the horizontal tail loadings given in Figure 9.

Summary:

- The 100P's stick-fixed neutral point is predicted to be at 26%c (135.74" from nose)
- Elevator deflection curves show that the aircraft should not be elevator deflection limited in stalls if the CG is positioned aft of 10%c.
- Flaps up stall speed for a 2650 lbs aircraft is predicted to be 66 ~ 67 knots.
- The flaps up spanwise lift distribution indicates tip stall.
- The horizontal stabilizer is lightly loaded which should mitigate some of the concern with the leading edge inlets.

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