Longitudinal Stability of the Lancair 320/360 with Original and MKII Horizontal Stabilizers

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4-23-2014, Rev B

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2 Introduction

The Lancair 320/360 was introduced in the late 1980's. It is an all-composite, low-wing aircraft with two seats side-by-side. The Lancair was known to be responsive in pitch with light stick forces. Controversy soon developed with regard to the handling characteristics of the design, in particular after mishaps were attributed to stability issues. A number of aviation authorities will not grant airworthiness certificates to Lancair 320/360 aircraft with the original stabilizers citing stability concerns, among them Australia and the United Kingdom (UK). While claiming the horizontal stabilizer was adequately sized, Lancair soon afterward introduced the larger MKII horizontal stabilizer. The elevator trim system was changed from a spring-bias system on the elevator push rod to an electrically driven trim tab built in to one of the elevators. The original 'small' tail is still flown around the world and has a loyal following.

This study seeks to quantitatively compare key stability and handling quality parameters for the two different stabilizer configurations.

2.1 Stability

Stability of an aircraft is the study of its response to disturbance from equilibrium. It can be broken down into two areas, static and dynamic.

- An aircraft is statically stable, if when disturbed, it initially tries to return to its equilibrium condition.
- An aircraft is dynamically stable if it eventually does return to its equilibrium condition.

Static and dynamic stability can either be positive, negative or neutral. Positive stability reduces the workload on the pilot. Small disturbance are corrected naturally. The aircraft will fly hands-free to a state of equilibrium. A neutrally stable aircraft will not return to its original flight attitude if disturbed and will require more attention by the pilot. Finally, an unstable aircraft will require input from the pilot to stop the flight path from diverging. The degree of instability will determine how much time the pilot has to make a correction, before loss of control. Figure 1 depicts stable and unstable responses to a disturbance.

The FAA and other aviation oversight organizations mandate the level of stability required for different types of aircraft. Transport category requirements are more stringent than general aviation (GA) requirements. Experimental aircraft have no mandated standard in the United States.

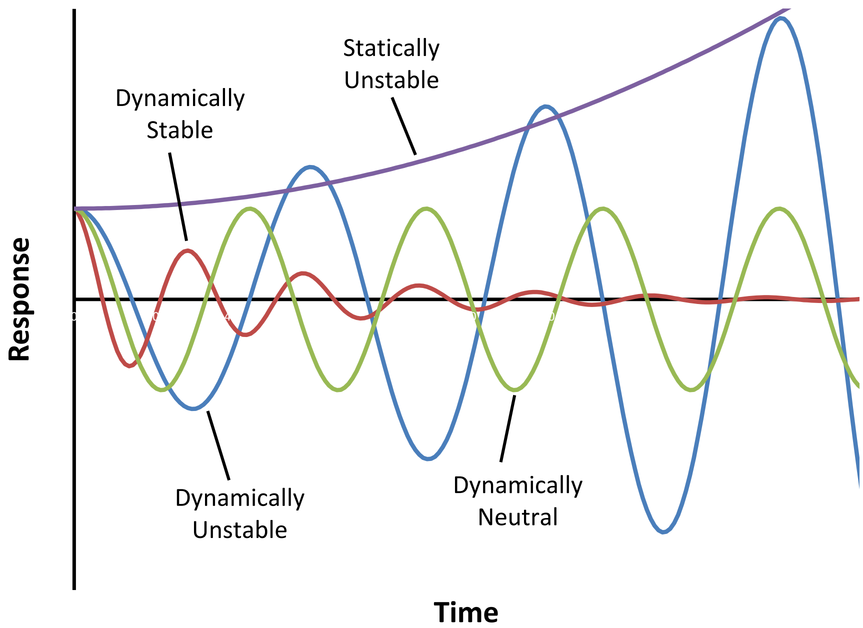

Figure 1, Stability

3 Objective and Test Approach

The goal was to evaluate and compare basic longitudinal stability of the Lancair 320/360 with both the original and MKII horizontal stabilizer. Examined were the stick free short and long period modes, stick fixed longitudinal stability, stick force gradients, and speed stability. With each stabilizer design, four different flight configurations were tested: A fore and aft CG location in both cruise and landing configurations. The neutral point for each aircraft configuration was determined analytically and then verified by flight test.

4 Test Aircraft

The two aircraft used in this study were a Lancair 360 MKII, N91CZ and a Lancair 320, N230EZ. N91CZ had a stock Lycoming O-360-A1A rated at 180 hp and the long engine mount. An extended engine mount was introduced along with the MKII tail. The aircraft also has the larger main gear known as the “Outback Gear”. External modifications to this aircraft include changes to the cowling inlets to accept a plenum type cooling system and a change to the landing gear doors. These modifications have previously shown to substantially reduce aircraft drag (Zavatson C. J., Cooling Drag, 2007), but were not expected to affect the stability and control test results.

N230EZ has a Lycoming O-320-D1A rated at 160 hp. It has the shorter original engine mount, the original landing gear and the original horizontal stabilizer configuration.

Both aircraft have an autopilot installed. The autopilot was used in the roll axis to maintain wings-level for all test points. Using the autopilot for lateral control avoided any unintended stick inputs in the pitch axis.

Figure 2 shows the planform of the original and MKII horizontal stabilizers superimposed. The new stabilizer added 22% in area, but more importantly, increased the aspect ratio from 3.3 to 4.1.

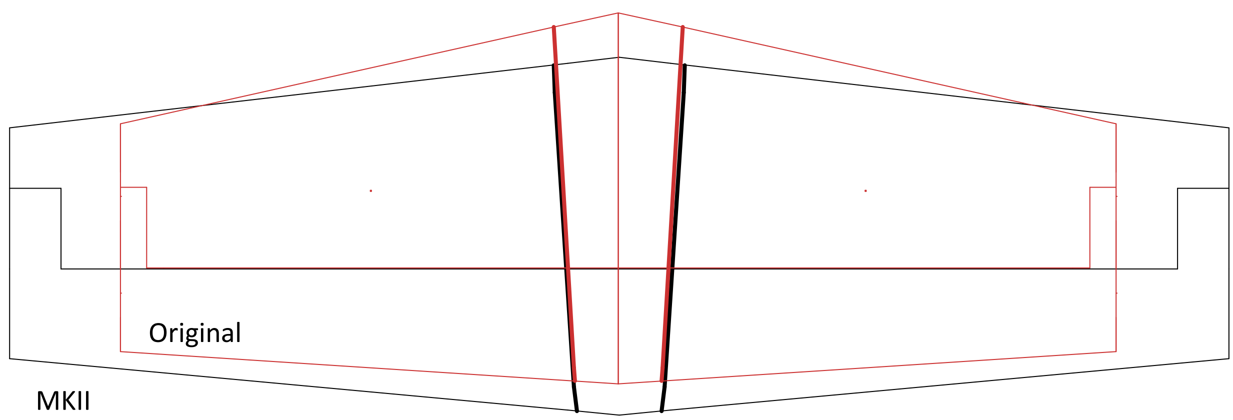

Figure 2, Horizontal Stabilizer Comparison

5 Instrumentation

Key data required were recorded at 20 Hz with an airborne data acquisition system installed in the aircraft. This included a DATAQ DI-710 data logger along with calibrated transducers. Engine speed, outside air temperature, fuel quantity and stick force were manually noted at each test point or series of test points. N91CZ had additional parameters recorded via data logger that were not utilized for this test.

The following parameters were recorded during test flights:

1. Dynamic Pressure (Airspeed)
2. Static Pressure (Altitude)
3. Angle of Attack
4. Angle of Side Slip
5. Elevator Position
6. Control Stick Input Force

7. Flap Position
8. Outside Air Temperature
9. Manifold Pressure
10. Engine Speed
11. Fuel Quantity

5.1 Airspeed

A +/-1 psi differential pressure transducer, Omega part # PX139-001D4V, was used to capture dynamic pressure. The unit was calibrated using a manometer. The low range of the transducer provides excellent resolution to a fraction of a knot.

5.2 Pressure Altitude

Pressure altitude was measured using a 15 psia pressure transducer, Omega part # PX139-015A4V. This unit was also calibrated via manometer to 14,000’.

5.3 Angle of Attack (both)/Angle of Side Slip (N91CZ only)

Angle of attack and side slip were measured using an “alpha/beta” probe mounted to the left wing of the aircraft. Non-contact sensors AS5162 by AMS captured angular position of the vanes to 12-bit resolution.

5.4 Manifold Pressure (N91CZ only)

Manifold pressure was measured with a 15 psia pressure transducer Omega part # PX139-015A4V. This transducer was also calibrated via manometer.

5.5 OAT

OAT was captured by a thermocouple (TC) probe behind the rear spar of the wing. Previous testing identified this location to be very accurate in capturing stagnation temperature across the entire speed envelope of the aircraft. (Zavatson C. J., Experimental Evaluation of Cruise Flap Deflection on Total Aircraft Drag using the NLF(1)-0215F, 2013). N230EZ used a TC probe on the underside of the wing behind the main wheel well.

5.6 Elevator Position

Elevator control from the pilot control stick to the elevator is via pushrods and rod-end bearings. This results in a very solid and responsive control system with negligible lash or hysteresis. N91CZ used a 3 inch linear potentiometer, Panasonic PP1045SB to capture elevator position by following the movements of the elevator pushrod. N230EZ used a 4 inch potentiometer ALPS RSA0N11S9A0K.

5.7 Flap Position (N91CZ only)

The flap is operated via an electric linear actuator. It is capable of continuous travel between full up and full down positions. The flap can be stopped at any intermediate position. There are no detents. A 100 mm linear potentiometer, ALPS RSA0N11S9A0K, was used to measure flap position by mounting an arm to the flap torque tube.

5.8 Aircraft Weight and Center of Gravity

Each aircraft was measured to obtain precise planform data for the wing, stabilizer and landing gear positions. Also measured were firewall location and fuselage contour. The moment arms for both pilot and fuel were determined by loading and unloading the aircraft. Prior to each test flight, the actual weight and CG were verified by weighing the ready-to-fly aircraft at each wheel position. The pilot was weighed just prior to entering the aircraft. A calibrated fuel flow transducer and totalizer tracked fuel burn throughout the flight. This information is used to determine aircraft weight and CG at each test point.

5.9 Stick Force

Stick force was applied to the control stick using a spring scale.

6 CG Locations and Neutral Points

The published CG limits are the same for both aircraft. The limits reference the firewall as a datum, whereas the format of the weight and balance worksheets established by Lancair reference the backside of the spinner as a datum. All weight and balance calculations are thus done using the spinner datum and the results are then translated to the firewall datum for comparison with the allowable CG envelope. Reporting values using this firewall reference introduces some potential error when comparing different aircraft. After mapping out the geometry of both test aircraft, it was determined that firewall is not precisely in the same longitudinal position relative to the wing. There was a 0.6” difference. One aircraft was a ‘standard’ kit while the other was a ‘fast-build’ kit. This must be considered when evaluating stability results against the published CG range. It does not, however factor into the comparison of stability calculations and results that reference the mean aerodynamic chord (MAC).

Evaluated CG locations for the MKII tail were driven by analysis. The published aft CG limit was considered too conservative. Prior testing had confirmed the stick fixed neutral point in cruise to be 0.46. (Zavatson C. J., 2013) The forward CG used was the most forward practical CG position while the aft CG was set at a reasonable static margin of 0.09. The corresponding CG positions are 28.9” and 33.4” aft of the firewall. For the original tail, the aft CG limit was held precisely at the published limit of 30.3”. The aft CG location was achieved by use of sand bags secured in the rear of the baggage compartment.

Table 1, Aft Center of Gravity Test Configurations

	Original Stabilizer			MKII Stabilizer		
	CG	h_n	static margin	CG	h_n	static margin
AFT CG	0.31 (30.3")*	0.36	0.05	0.37 (33.4")	0.46	0.09
FWD CG	0.25 (27.6")		0.11	0.26 (28.9")		0.20

* 30.3" is the published aft CG limit

Flight test data with the MKII stabilizer verified the stick fixed neutral point in the cruise configuration at 0.46 and in the landing configuration at 0.47. Figure 3 shows the neutral point derivation for both cruise and landing configurations from test data.

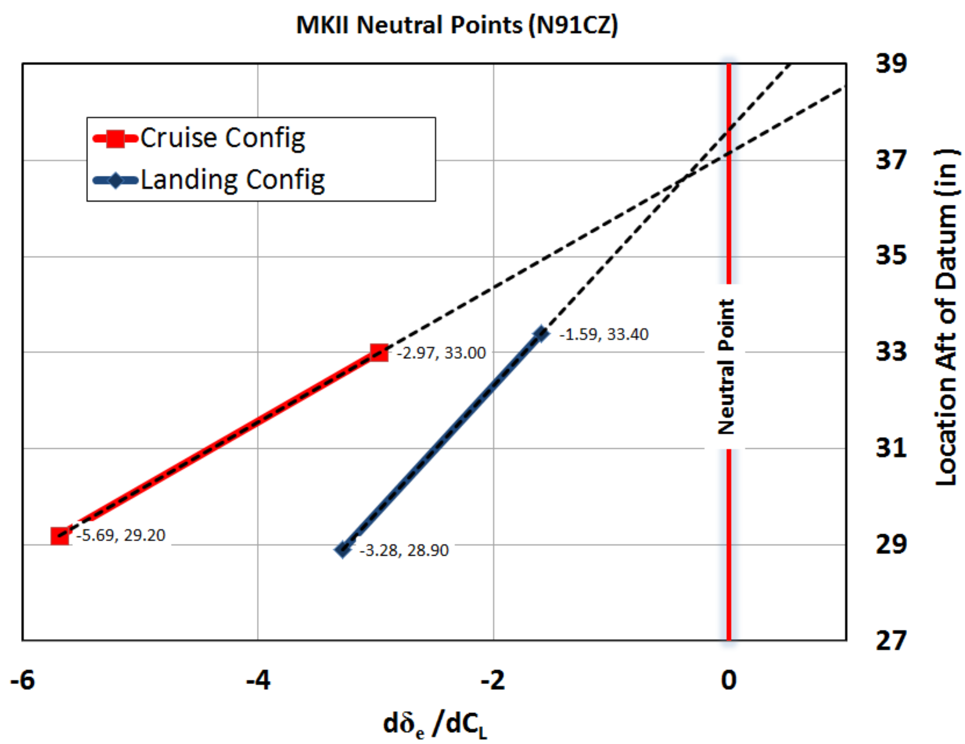

Figure 3, MKII Stabilizer Neutral Point

The lift curve slope decreases with flap deflection. Figure 4 is adapted from NASA TP-1865 and shows the reduction in the two dimensional $C_{l\alpha}$ curve once flow separation occurs on the upper surface of the simple flap. Full flap deflection will produce flow separation at all angles of attack and therefore a reduction of the lift curve slope for the flapped region of the wing. The net lift curve slope for both cruise and landing configurations were extracted from test data and are presented in Figure 5. Full flap deflection also yields an increase in downwash derivative, dε/dα, which is effectively balanced by the reduced lift curve slope of the wing thus leaving the neutral point virtually unchanged

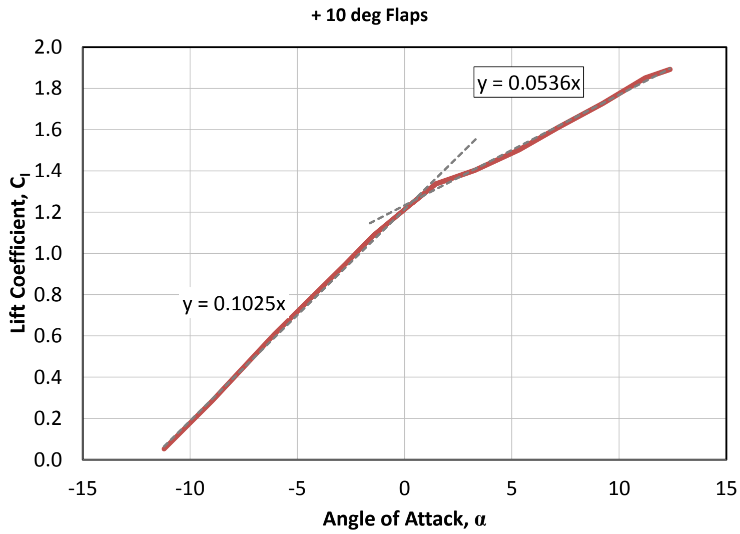

Figure 4, NLF(1)-0215F Section Lift Coefficient, Flaps +10 (Somers, 1981)

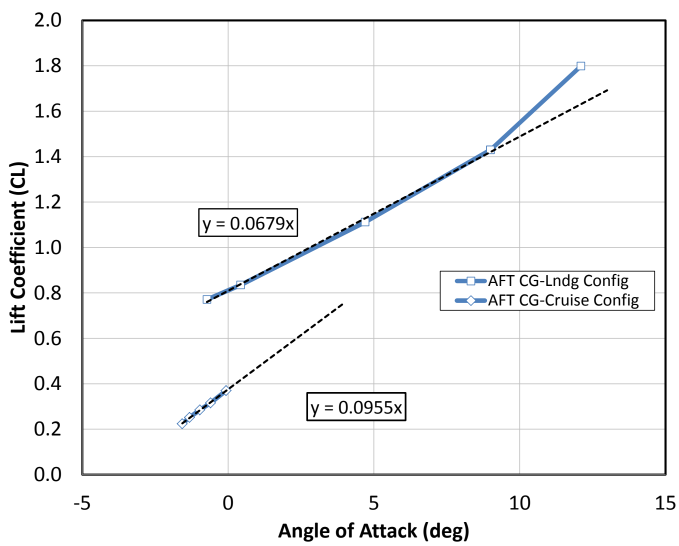

Figure 5, Lift Curve Slopes, Cruise, Landing Configurations

The neutral point was also determined for N230EZ both through analysis and flight test. The aft CG condition tested was at the published limit of 30.3”. A precise geometric mapping of the aircraft was done to assure good weight and balance information. The neutral point results are shown in Figure 6. Interpolating two test points when one is unstable may not yield the precise neutral point, but it is clearly reduced. The aircraft exhibited unstable divergent characteristics in the landing configuration and the neutral point is indeed shown to be ahead of the CG. A stick force reversal was encountered. Maintaining a lower speed required a more forward stick position indicating negative stability margin. This trend was consistent throughout the Aft CG landing configuration neutral point test. Appendix A shows all plots of elevator deflections for both cruise and landing configurations for the MKII and original stabilizers. For positive stability in a simple reversible control system, the slopes should all be negative. Figure 18 shows a positive slope in the landing configuration of the original stabilizer.

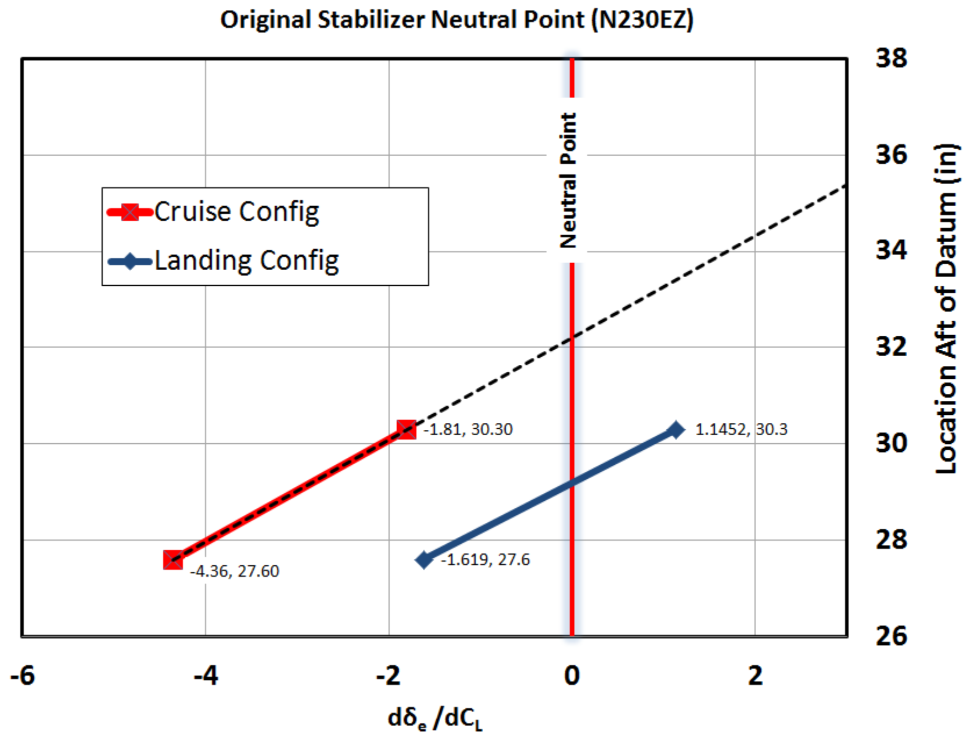

Figure 6, Original Stabilizer Neutral Point

7 Results

7.1 Short and Long Period Modes

For all short period tests, doublet pulses were input by the pilot both in push-pull and pull-push directions. Angle of attack was used to evaluate the period and damping ratio. Airspeed was used to evaluate period and damping ratio for the long period or phugoid. In the cruise configuration, a pitch up to roughly a 30 knot speed delta was used to initiate the maneuver. This provides a good margin to V_{ne} on the first descending cycle. In the landing configuration, speeds were bounded by the maximum full flap extension speed of

100 KIAS and stall speed. A pitch up to a 10-15 knot airspeed reduction was used to initiate the long period mode in the landing configuration.

Table 2 summarizes the period and damping ratios for all flight configurations for the MKII stabilizer. All long period, as well as, short period tests exhibited stable behavior. The short period response is highly damped. Only a single cycle is obtained before the amplitude of the disturbance drops into the noise level of the signal (Figure 7). The aft CG increased the duration of the short period mode for both landing and cruise configurations. In the landing configuration, the long period was nearly half of that in cruise, 30/32 vs. 56 seconds. Damping ratios (ζ) were only minimally affected by the configuration changes. The results show positive dynamic stability in all configurations tested.

Table 2, Period and Damping Ratio, MKII Stabilizer

MKII Stabilizer	Cruise Configuration				Landing Configuration			
	Short Period		Phugoid		Short Period		Phugoid	
	Period sec	ζ	Period sec	ζ	Period sec	ζ	Period sec	ζ
FWD CG	0.9	0.35	56	0.15	1.8	0.44	30	0.15
AFT CG	1.3	0.50	56	0.10	4.1	0.50	32	0.14

Table 3 shows the response of the original tail. The results indicated a much reduced stability and in four areas unstable divergent behavior was encountered. In the cruise configuration, the duration of the short period response was more than twice that of the MKII stabilizer (Figure 8). The doublet input also triggered a small, but noticeable phugoid (Figure 9). The long period response shown in Figure 11 for the forward CG cruise configuration, had only minimal damping with a damping ratio of 0.03. It also exhibits a relatively high change in angle of attack during the maneuver. In the aft CG configuration, the long period response was slowly divergent with aggressive pitch-overs near zero g's and pull-outs exceeding two g's (Figure 12). G-levels were extracted from the Dynon PFD memory. In the landing configuration, only the forward CG short period response could be obtained. All other tests showed unstable, divergent behavior.

Table 3, Period and Damping Ratio, Original Stabilizer

Original Stabilizer	Cruise Configuration				Landing Configuration			
	Short Period		Phugoid		Short Period		Phugoid	
	Period sec	ζ	Period sec	ζ	Period sec	ζ	Period sec	ζ
FWD CG	2.0	0.57	33	0.03	4.0	0.37	divergent	
AFT CG	3.0	0.50	divergent		divergent		divergent	

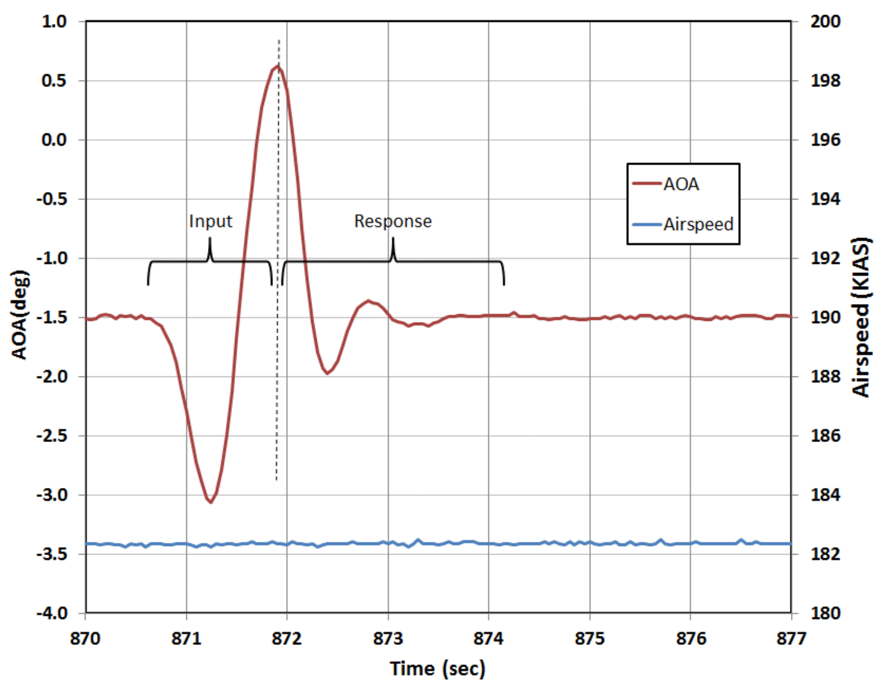

Figure 7, MKII Stabilizer, Short Period, Cruise, FWD CG

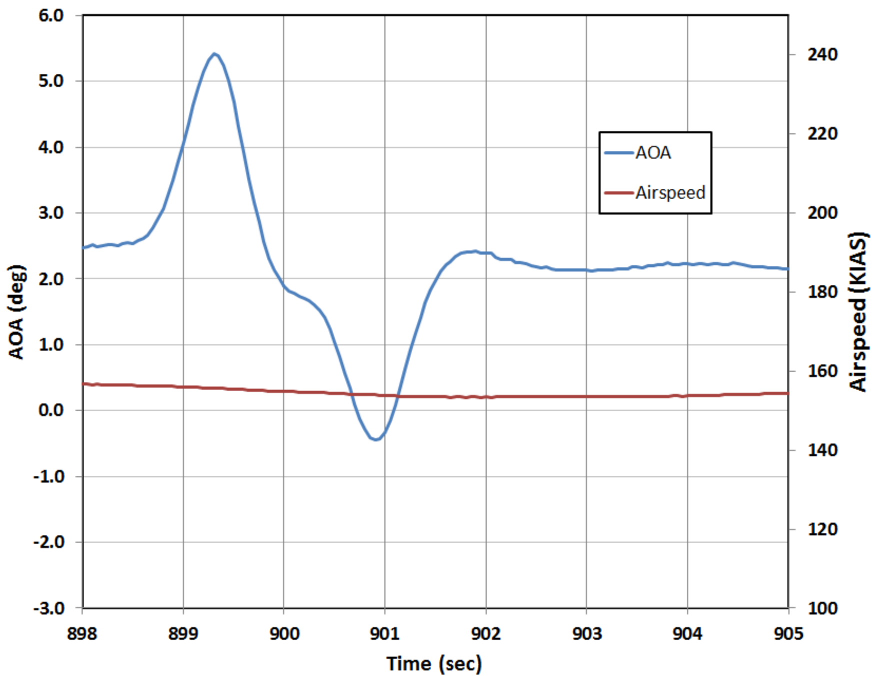

Figure 8, Original Stabilizer, Short Period, Cruise, FWD CG

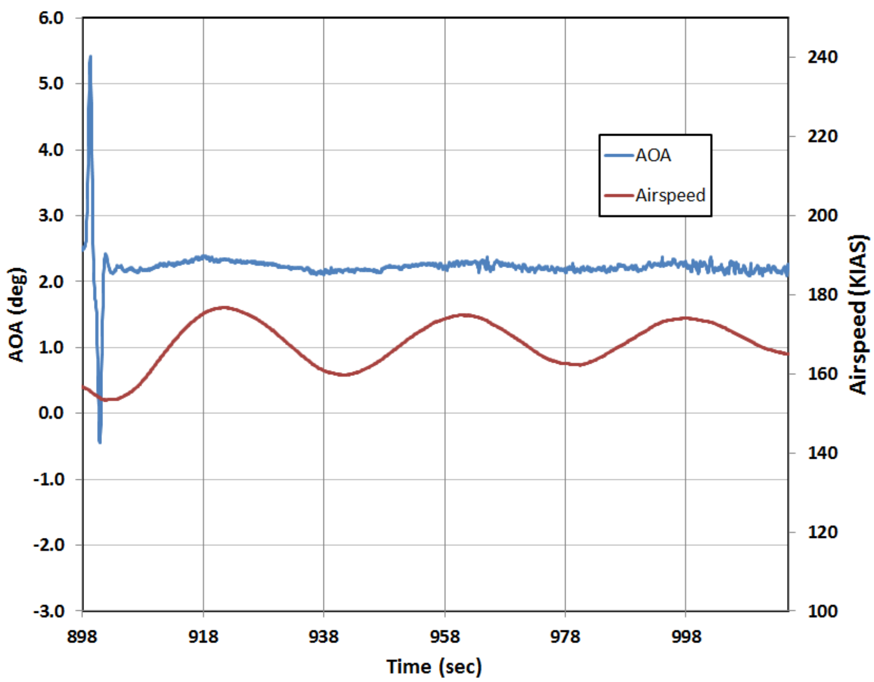

Figure 9, Original Stabilizer, Phugoid triggered by Doublet

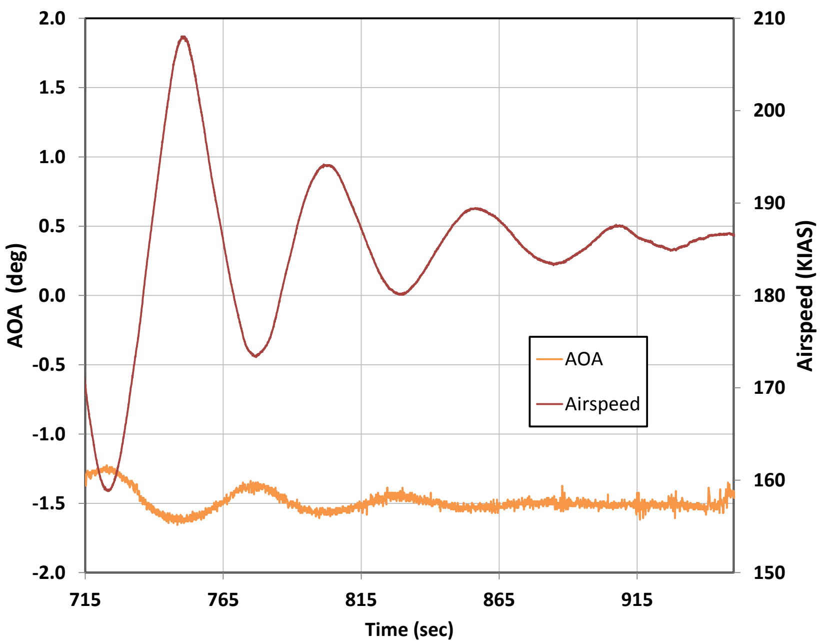

Figure 10, MKII Stabilizer, Phugoid, Cruise, FWD CG

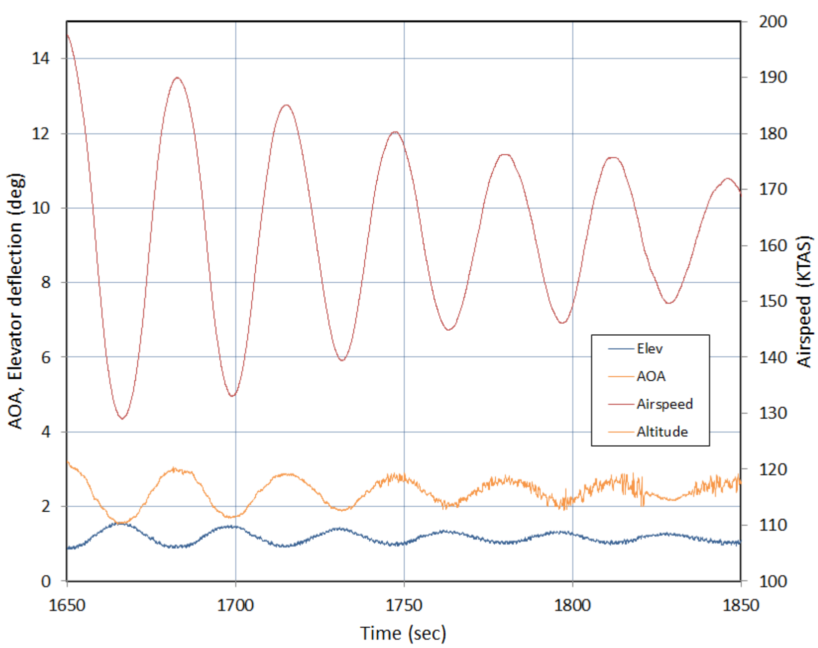

Figure 11, Original Stabilizer, Phugoid, Cruise, FWD CG

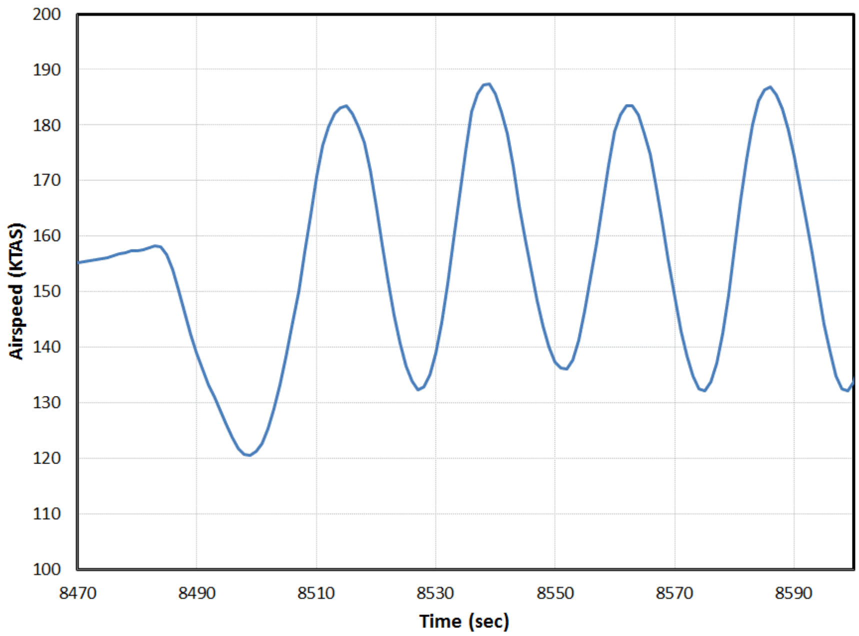

Figure 12, Original Stabilizer, Phugoid, Cruise, AFT CG

7.2 Stick Force Gradients

The stick force gradient is obtained by applying a given stick force to the trimmed aircraft. A stable aircraft will settle into a new equilibrium of speed, angle of attack and elevator deflection. Table 4 summarizes the results in cruise.

Table 4, Stick Force Gradients, Cruise

	Speed Stability			
	Original Stabilizer		MKII Stabilizer	
	CG	kts/lb	CG	kts/lb
Aft CG	30.3"*	29.5	33.4"	40.1
FWD CG	27.6"	25.9	28.9"	21.7

* 30.3" is the published aft CG limit

Figure 13 shows the stick force gradients for the cruise and landing configurations for the MKII stabilizer. In the cruise condition, the curves are nearly linear over the speed range tested. The slope is negative for all cases indicating proper feedback. At low speeds, reduced hinge moments result in greater control surface deflection. Figure 15 shows the corresponding angle of attack for a given stick force. All curves are smooth and continuous providing good feedback.

The original tail produced a shallow negative slope in the forward CG configuration (Figure 14). In the aft CG configuration, however, the slope is virtually flat indicating nearly neutral behavior. In the landing configuration, both forward and aft CG conditions produced divergent behavior. No restoring force was generated to counter the stick input force and thus no data is presented for these two cases.

In the cruise configuration, the stick force gradient for the original stabilizer exhibited a dramatic reduction in hinge moment at low airspeed. Figure 14 and Figure 16 show a sharp increase in angle of attack and elevator deflection at the higher stick force input near two pounds.

In the landing configuration, once trimmed for 90 KIAS, the application of any stick force resulted in divergent behavior. This is consistent with the results obtained in long and short period testing.

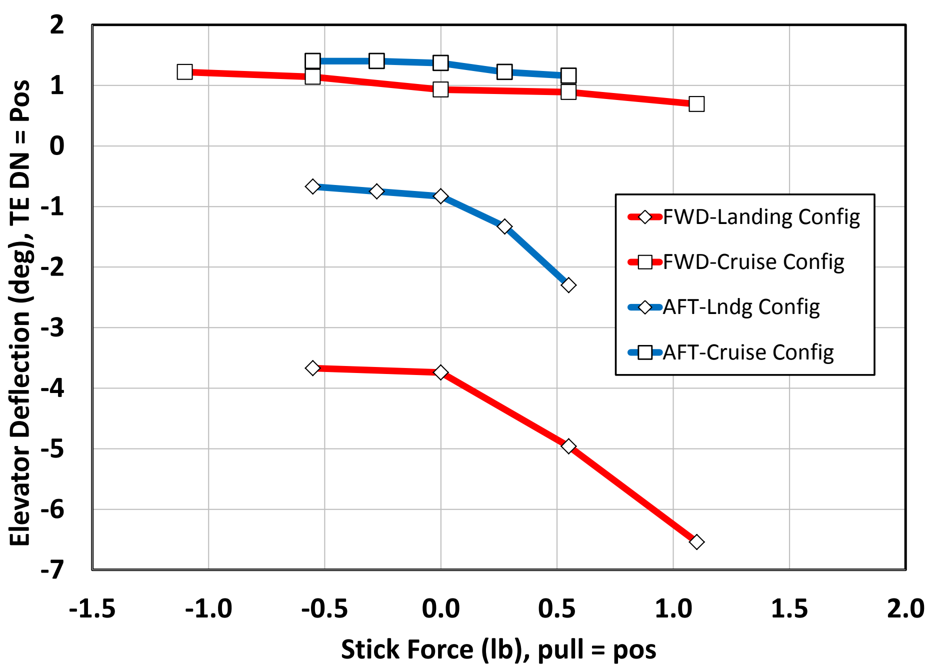

Figure 13, MKII Stabilizer Elevator Deflection with Stick Force

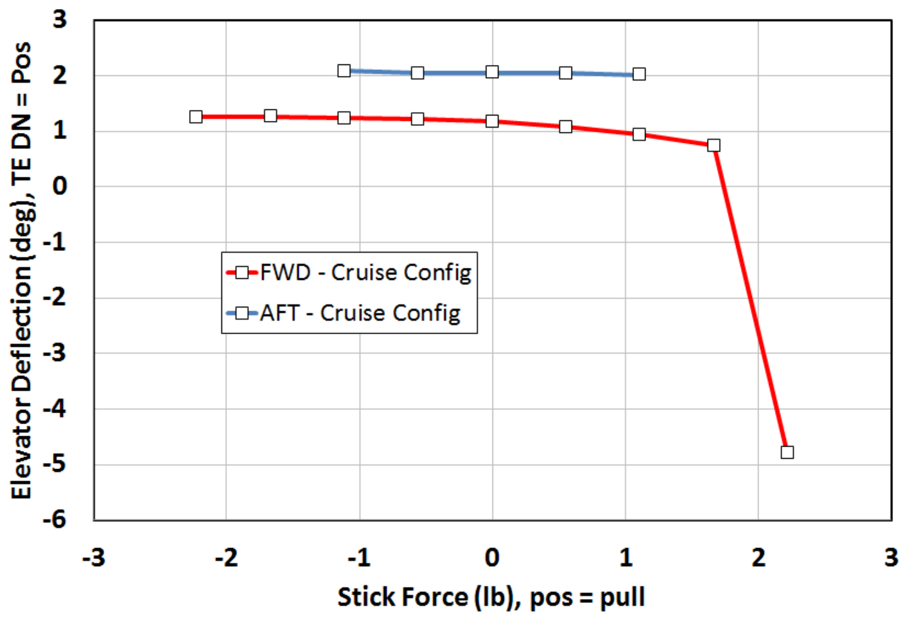

Figure 14, Original Stabilizer, Elevator Deflection with Stick Force

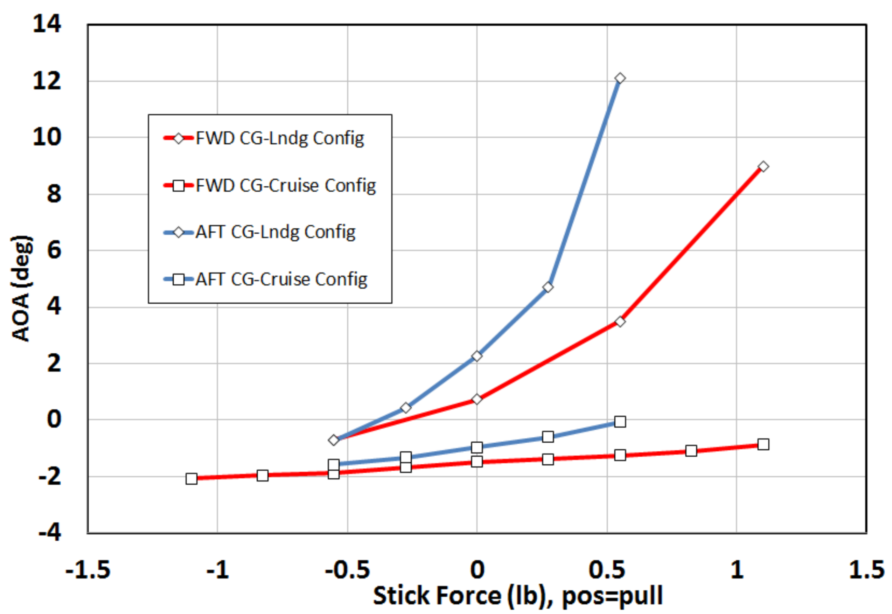

Figure 15, MKII Stabilizer, Angle of Attack Sensitivity to Stick Force

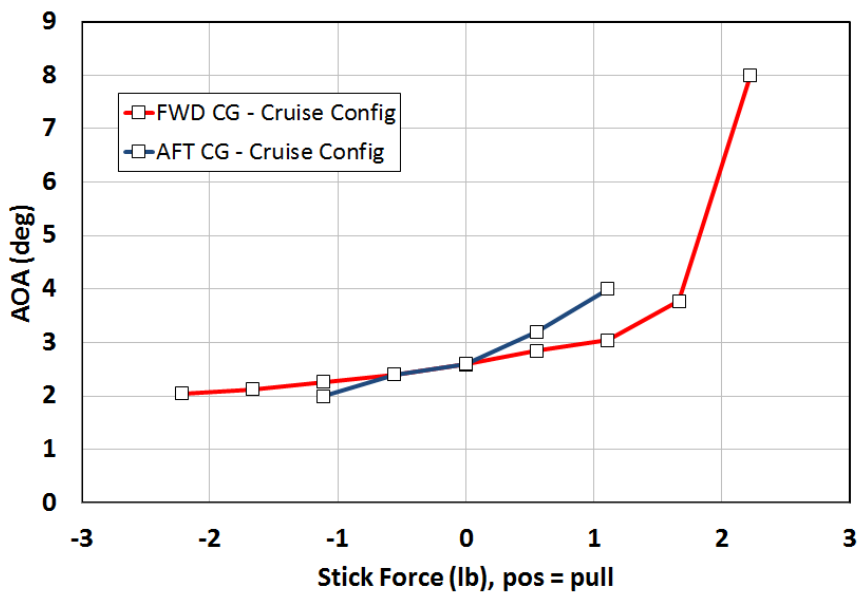

Figure 16, Original Stabilizer, Angle of Attack Sensitivity to Stick Force

7.3 Handling Qualities

Experimental aircraft are not bound by FAA regulation in terms of stability and handling qualities. It is useful, however, to review a few guidelines outlined in FAR 23.175 applicable to the results obtained during testing. FAR 23.175 is presented in its entirety in Appendix B.

Design guidelines call for stable and predictable behavior in all phases of flight, specifically within specified ranges of various trimmed flight conditions. The stick force gradient must always be stable and upon relaxing of stick forces, the aircraft is to return to its originally trimmed speed within a margin to allow for friction in the control system. The MKII stabilizer meets these design guidelines. The original tail falls short in the landing configuration. Specifically, the aircraft diverged once disturbed from its trim condition instead of returning to the trim speed.

Stick force gradients are very shallow for both stabilizers. The FAA is rather hands-off in setting quantitative standards for acceptable pitch sensitivity of GA aircraft. From FAR-23: "any substantial speed change results in a stick force clearly perceptible to the pilot." This leaves room for interpretation, but it also provides the freedom to increase or reduce stick forces according to the mission at hand.

8 Further Study

8.1 Trim system

The spring bias trim system used with the original stabilizer design may be aggravating the stick free instability as the aircraft moves farther from trim speed. The rapid change in hinge moments observed at speed less than 100 KIAS may be adversely combining with fixed trim forces from the spring system. A few aircraft with the original stabilizer have been modified with electrically driven trim tabs. Re-testing points that showed divergent behavior on such a modified aircraft may provide insight into the contribution, if any, of the trim system.

8.2 Strakes

The lift curve slope is dramatically reduced by the low aspect ratio of the original horizontal stabilizer. The use of strakes may improve its effectiveness at lower air speeds and higher angles of attack where instabilities were observed.

9 Conclusion

While both stabilizers have light stick forces, the flight characteristics produced by the original and MKII stabilizers were found to be markedly different. The MKII stabilizer exhibited stable behavior throughout the flight envelope in all configurations and CG positions. Stick force feedback and stability followed criteria generally expected in good aircraft design.

The original stabilizer showed instabilities and divergent behavior, most notably in slower regions of the flight envelope. These characteristics require more vigilance and active input by the pilot. Stick force reversals eliminate the typically expected force feedback to the pilot. This necessitates use of flight instruments and other visual cues to determine the proper control inputs. The instabilities are more pronounced at the aft CG limit.

The MKII stabilizer greatly increases the usable CG range of the aircraft. This permits a significantly broader range of loading conditions.

10 Acknowledgements

I would like to extend my gratitude to Dan Meyer who volunteered the use of his Lancair 320 for this testing of the original stabilizer. Dan offered his assistance in instrumenting the aircraft and also served as test pilot for all flights in N230EZ.

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Appendix A Neutral Point Determination

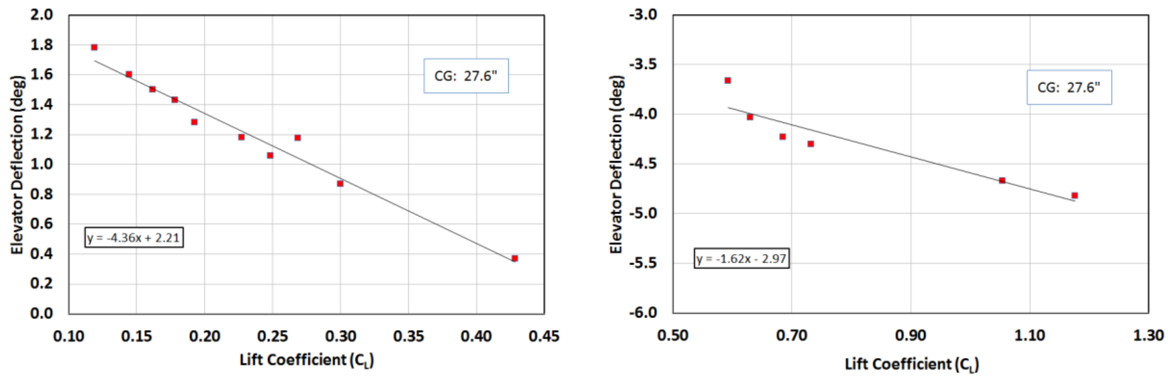

Figure 17, Original Stabilizer Neutral Point Testing in Cruise Configuration

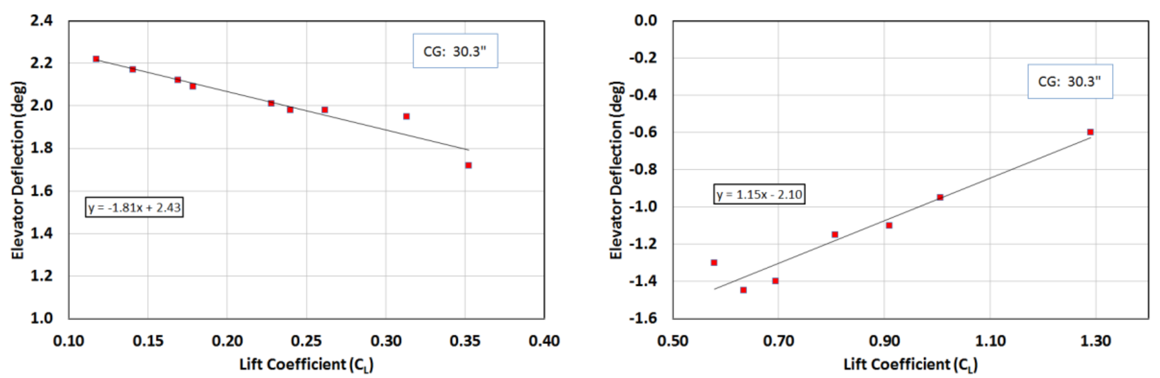

Figure 18, Original Stabilizer Neutral Point Testing in Landing Configuration

The neutral point can be determined experimentally with minimal instrumentation. For a given trimmed flight condition and CG location there is a nearly linear relationship between change in elevator position and change in lift coefficient. This relationship can be exploited to find the neutral point in flight.

The process involves conducting at least two flight tests with the aircraft loaded to two different CG positions, preferably near both ends of the envelope. During each test flight the aircraft is trimmed for hands-free level flight. Then, without re-trimming, the aircraft is manually held off trim speed long enough to capture steady state data for airspeed and elevator position. The altitude must remain in a reasonable band for each test point. A 1,000’ window is sufficient. It is convenient to alternate one point above the trim speed and one point below to keep the data points at nearly the same altitude.

Appendix B FAR Part 23.175

Sec. 23.175 Demonstration of static longitudinal stability.

Static longitudinal stability must be shown as follows:

(a) Climb. The stick force curve must have a stable slope at speeds between 85 and 115 percent of the trim speed, with--

(1) Flaps retracted;

(2) Landing gear retracted;

(3) Maximum continuous power; and

(4) The airplane trimmed at the speed used in determining the climb performance required by Sec. 23.69(a).

(b) Cruise. With flaps and landing gear retracted and the airplane in trim with power for level flight at representative cruising speeds at high and low altitudes, including speeds up to VNO or VMO/MMO, as appropriate, except that the speed need not exceed VH--

(1) For normal, utility, and acrobatic category airplanes, the stick force curve must have a stable slope at all speeds within a range that is the greater of 15 percent of the trim speed plus the resulting free return speed range, or 40 knots plus the resulting free return speed range, above and below the trim speed, except that the slope need not be stable--

(i) At speeds less than 1.3 VS1; or

(ii) For airplanes with VNE established under Sec. 23.1505(a), at speeds greater than VNE; or

(iii) For airplanes with VMO/MMO established under Sec. 23.1505(c), at speeds greater than VFC/MFC.

(2) For commuter category airplanes, the stick force curve must have a stable slope at all speeds within a range of 50 knots plus the resulting free return speed range, above and below the trim speed, except that the slope need not be stable--

(i) At speeds less than 1.4 VS1; or

(ii) At speeds greater than VFC/MFC; or

(iii) At speeds that require a stick force greater than 50 pounds.

(c) Landing. The stick force curve must have a stable slope at speeds between 1.1 VS1 and 1.8 VS1 with--

(1) Flaps in the landing position;

(2) Landing gear extended; and

(3) The airplane trimmed at--

(i) VREF, or the minimum trim speed if higher, with power off; and

(ii) VREF with enough power to maintain a 3 degree angle of descent.