Stability and Control Evaluation of the Lancair 360 MKII

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2 Introduction

The Lancair 320/360 is an all composite homebuilt aircraft first introduced in the late 1980's. It is a two-seat side-by-side layout, low wing design with retractable landing gear. The design took advantage of the NLF(1)-0215F airfoil and good aerodynamics to achieve exceptional performance (~1.1 kt/hp). The design went through an evolutionary process during its production life. Two changes were made that had a significant impact on handling qualities: Lengthening of the engine mount and increasing both the area and aspect ratio of the horizontal stabilizer – designated as MKII. Numerous other changes primarily affected utility and construction of the aircraft and not necessarily performance or stability and control.

While not designed for aerobatics, the aircraft is known to be very responsive and have a light feel.

3 Objective and Test Approach

The goal was to evaluate the basic longitudinal stability and control of the Lancair 360 MKII. Examined were the stick free short and long period modes, as well as, speed stability. Four different configurations were tested: Two CG locations at 20% and 9% static margin in each of two flight configurations, cruise and landing.

Cruise configuration is defined as: Wide open throttle (WOT), 2480rpm, 7,500 ft pressure altitude, flaps and landing gear retracted.

Landing configuration is defined as: Full flaps, landing gear extended, 15" manifold pressure, 90 KIAS.

4 Test aircraft

The aircraft used in this study was a Lancair 360 MKII, N91CZ. The aircraft engine was a stock Lycoming O-360-A1A rated at 180 hp. 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 significantly affect the stability and control test results.

The aircraft had a two axis autopilot installed. The pitch axis was disabled during testing. 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.

5 Instrumentation

An airborne data acquisition system was installed in the aircraft. Data was recorded on an SD card via a stand-alone DATAQ DI-710 data logger. Engine speed, outside air temperature, fuel quantity and stick force were manually noted at each test point or series of test points. All other parameters were recorded at 20 Hz by the data logger.

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/Angle of Side Slip

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

5.4 Manifold Pressure

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 thermo couple (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 Evalutation of Cruise Flap Deflection on Total Aircraft Drag using the NLF(1)-0215F, 2013)

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 minimal lash or hysteresis. A 3 inch linear potentiometer, Panasonic PP1045SB, was used to measure elevator position by following the movements of one of the primary pushrods.

5.7 Flap Position

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

Prior to each test flight, the 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

Prior testing and analysis has confirmed the stick fixed neutral point in cruise to be 0.46. (Zavatson C. J., 2013) The same analytical model was used to determine the center of gravity locations for the static margins to be used for this evaluation, 0.20 and 0.09. The corresponding CG positions are 28.9” and 33.4” aft of the firewall. The aft CG location was achieved by use of sand bags secured in the rear of the baggage compartment behind the pilot/passengers seats.

Flight test data verified the stick fixed neutral of point 0.47 in the landing configuration. Figure 1 shows the neutral point derivation for both cruise and landing configurations from test data. The neutral point moved rearward approximately 0.5” in the landing configuration.

The lift curve slope decreases with flap deflection. Figure 2 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 3.

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. Table 1 summarizes the key parameters affected by the configuration change from cruise to landing.

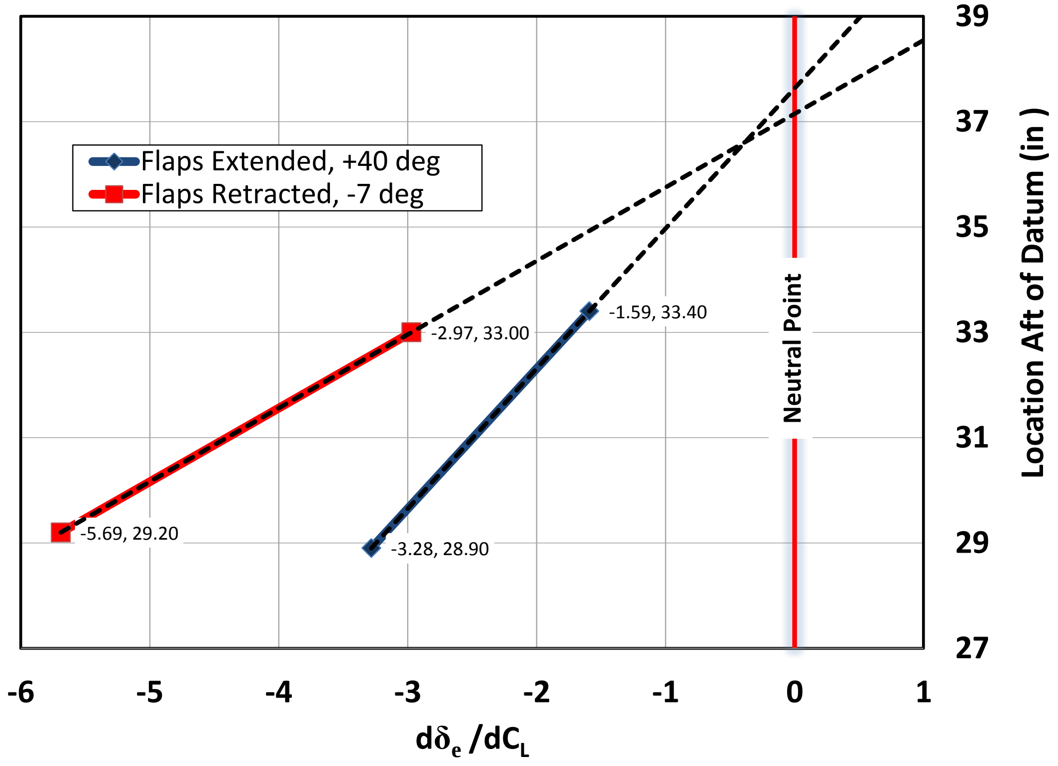

Figure 1, Configuration Neutral Points

Table 1, Parameters affected by Configuration Change

	$C_{L\alpha}$	$C_{m\alpha}$	$d\varepsilon/d\alpha$	hn
Cruise, WOT	0.096	-0.0321	0.40	0.46
Landing, 15" MP	0.068	-0.0250	0.52	0.47

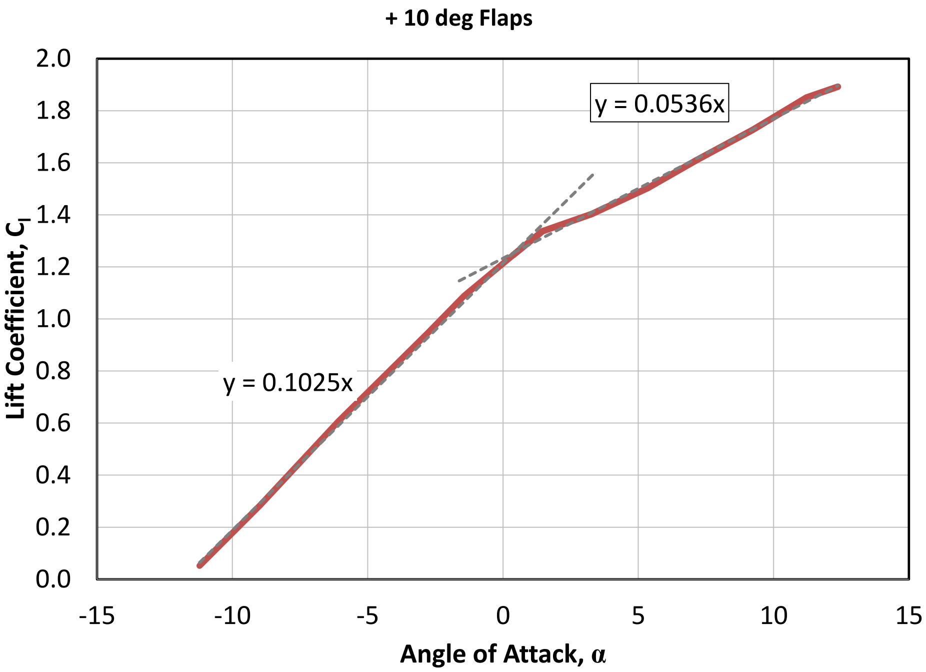

Figure 2, NLF(1)-0215F Section Lift Coefficient, Flaps +10 (Somers, 1981)

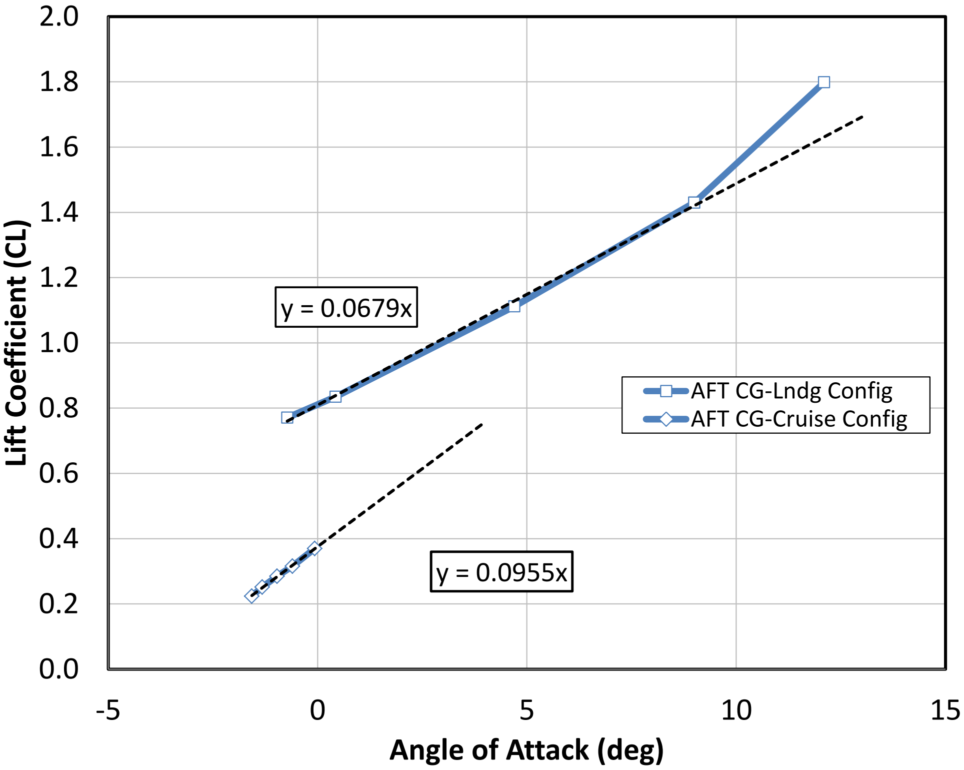

Figure 3, Lift Curve Slopes, Cruise, Landing Configurations

7 Results

7.1 Short and Long Period Modes

Dynamic response of both the short and long period modes were measured in all four aircraft configurations. Table 2 summarizes the period and damping ratios for all configurations. 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. Only a single cycle is obtained before the amplitude of the disturbance drops into the noise level of the signal. (Figure 4)

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. This provided a reasonable 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 of 61 KIAS. A pitch up to a 10 knot airspeed reduction was used to initiate the long period mode in the landing configuration.

All long period, as well as, short period tests exhibited stable behavior. 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 were only minimally affected by the configuration changes. In the landing configuration, the short period was slightly more damped than in cruise with forward CG while the phugoid was slightly more damped with an aft CG. The results show positive dynamic stability in all configurations tested.

Representative short and long period responses are shown in Figure 4 through Figure 6. Figure 4 is the short period response for the forward CG in cruise. The first two (large) peaks are driven by the doublet input. The next two peaks are the stick free response of the aircraft. Note that airspeed remains unchanged throughout the event.

Figure 5 shows the long period response for the cruise condition with forward CG and Figure 6 shows the long period response in the landing configuration with the aft CG.

Table 2, Period and Damping Ratio

	Cruise Confguration			
	Short Period		Phugoid	
	Period sec	ζ	Period sec	ζ
FWD CG	0.9	0.35	56	0.15
AFT CG	1.3	0.50	56	0.10

	Landing Configuration			
	Short Period		Phugoid	
	Period sec	ζ	Period sec	ζ
FWD CG	1.8	0.44	30	0.15
AFT CG	4.1	0.50	32	0.14

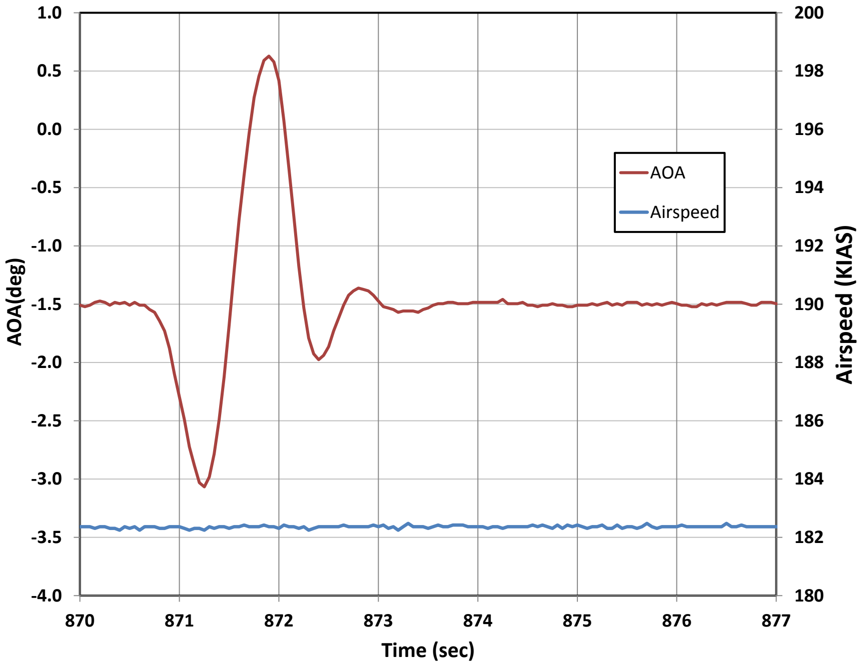

Figure 4, Short Period Mode, Cruise, FWD CG

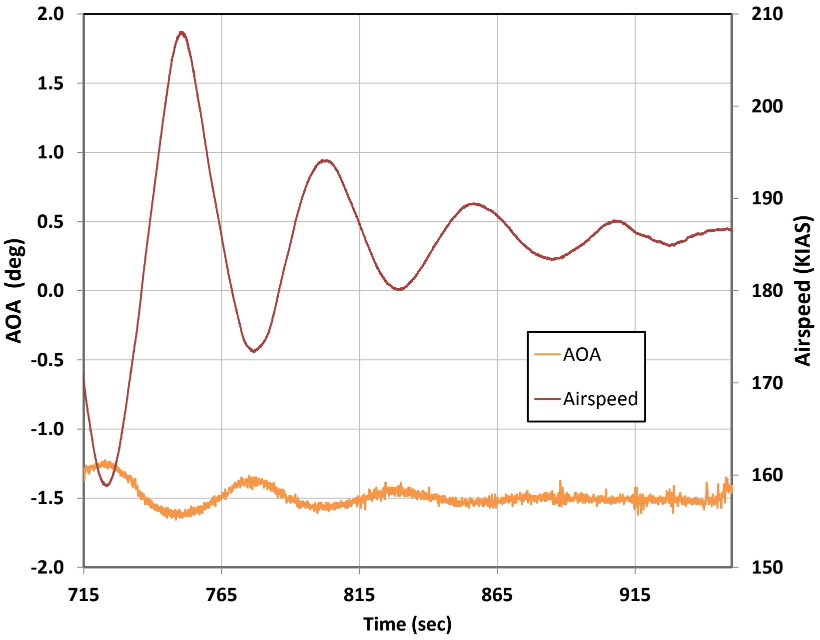

Figure 5, Phugoid, Cruise, FWD CG

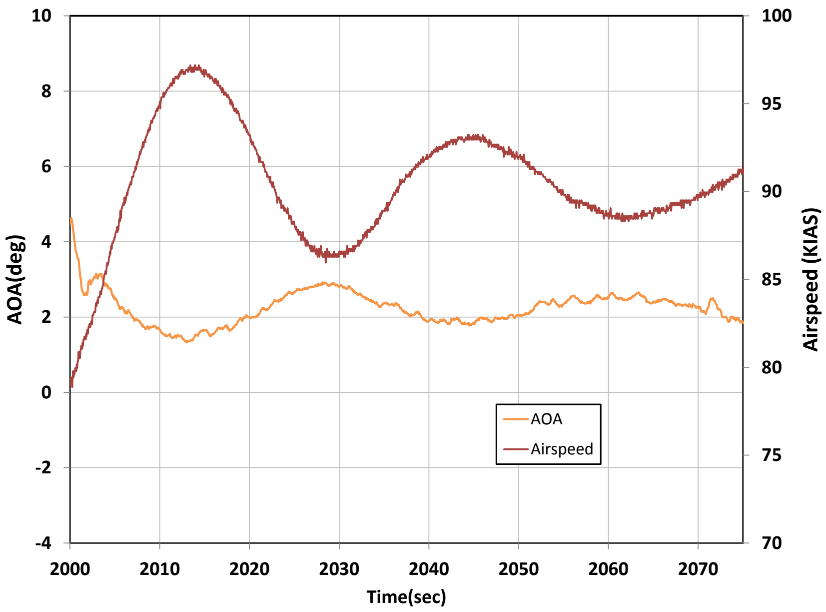

Figure 6, Phugoid, Landing, AFT CG

7.2 Stick Force Gradients and Control Effectiveness

In each of the four configurations, the airspeed deviation from trim speed for a given stick force input was recorded. The forward CG position was tested through a range of +/-500g (+/- 1.1 lb). The aft CG test was limited to +/-250g (0.55 lb) since the aircraft is more responsive with the aft CG position. Airspeed, elevator position and angle of attack were examined as a function of stick force, as well as, the relationship between elevator deflection and angle of attack.

Figure 7 and Figure 8 show the stick force gradients for the cruise and landing configurations respectively. In the cruise condition, the curves are nearly linear over the speed range tested. Figure 9 shows all four configurations together. Figure 11 shows elevator effectiveness or angle of attack for a given elevator input. Control effectiveness increases with the rearward CG movement.

In the landing configuration, the pitch response per unit force increases as airspeed reduces. The forward CG position produced a second order increase in angle of attack while the aft CG position produces a third order increase in angle of attack with respect to stick force (Figure 12). The increase is smooth through to stall speed and stability remains positive throughout. In the forward CG configuration, approximately 1 lb of stick force was required to reach the stall speed of 61 KIAS from a stabilized 90 KIAS.

With the aft CG, 0.5 lbs of force was required to reach stall speed – half that of the forward CG.

Total elevator (and stick movement) is very small in cruise, spanning no more than 0.5 degrees (Figure 10). These small deflections require minimal lash in the control system. In the landing configurations elevator movement is larger for the same force input, spanning nearly 3 degrees.

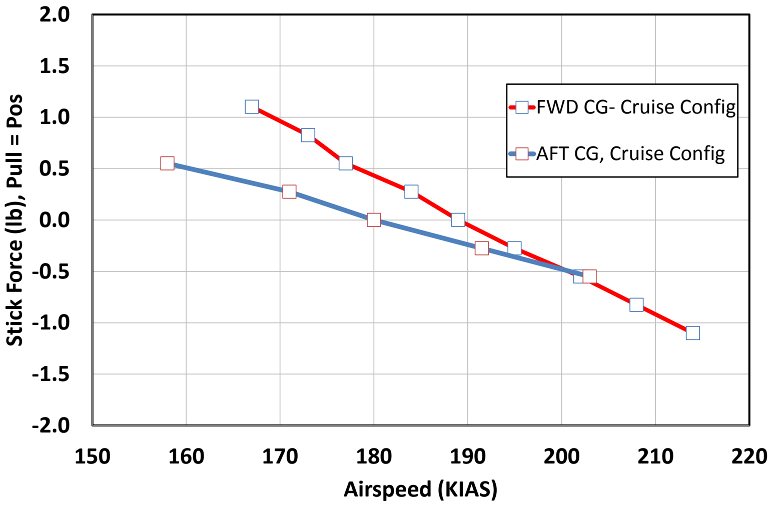

Figure 7, Stick Force Gradient, Cruise

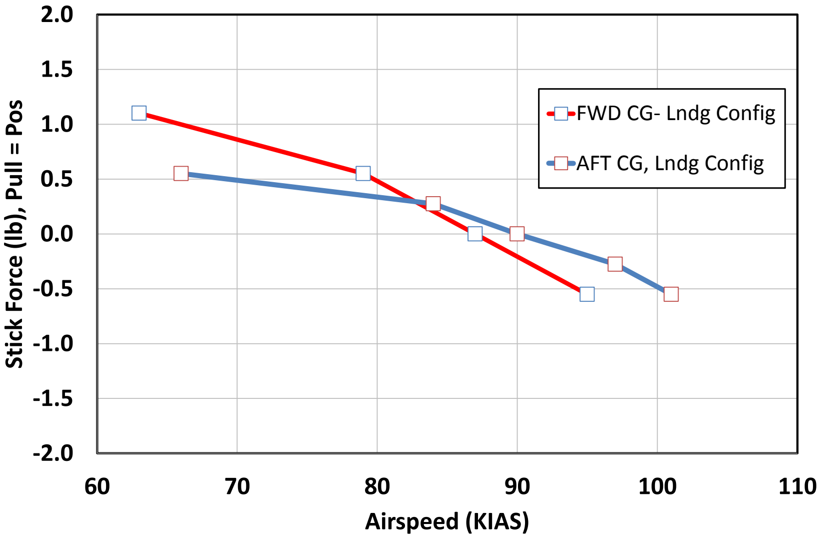

Figure 8, Stick Force Gradient, Landing Configuration

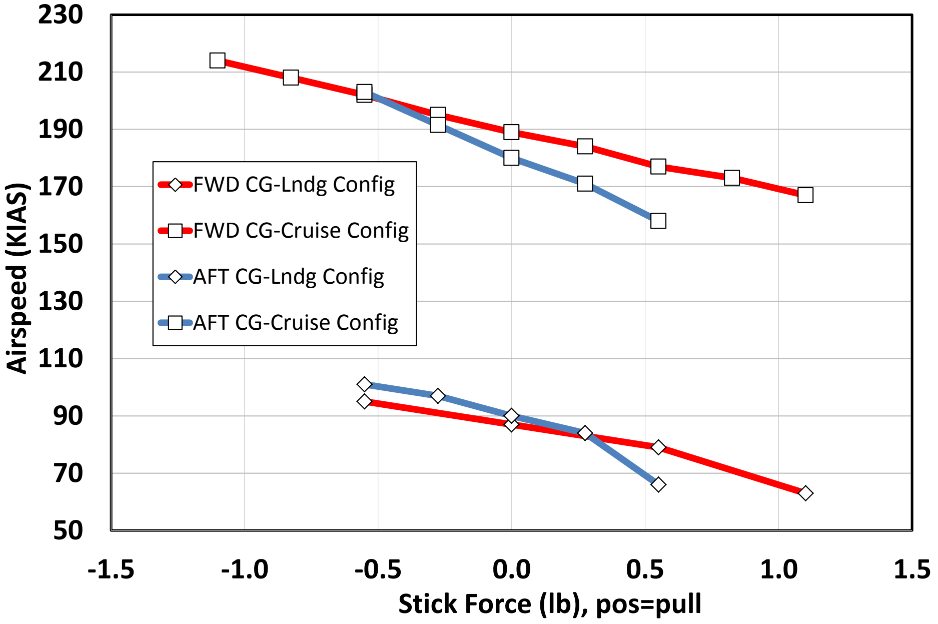

Figure 9, Airspeed Sensitivity to Stick Force

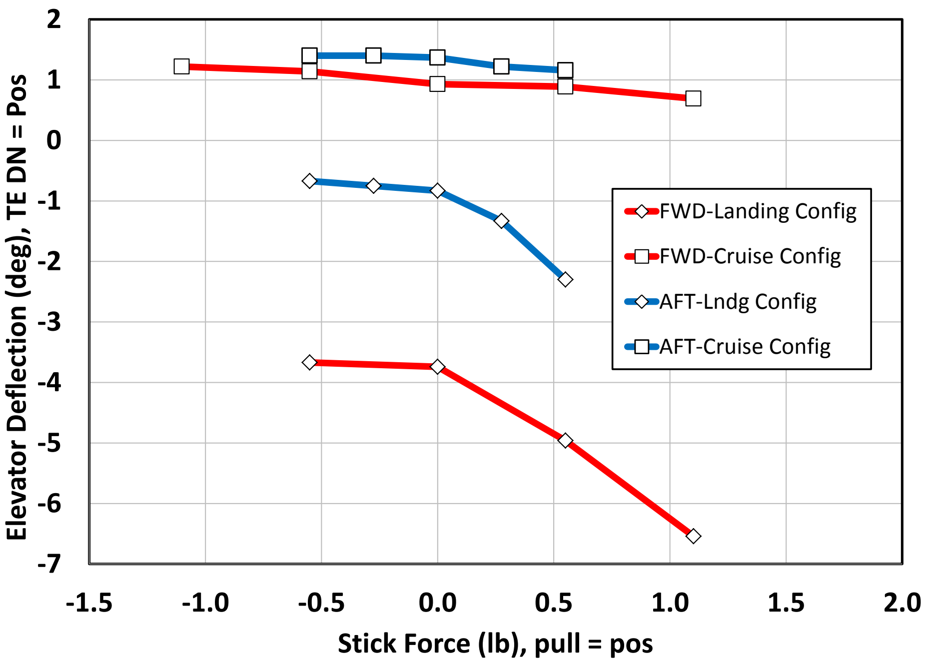

Figure 10, Elevator Deflection with Stick Force

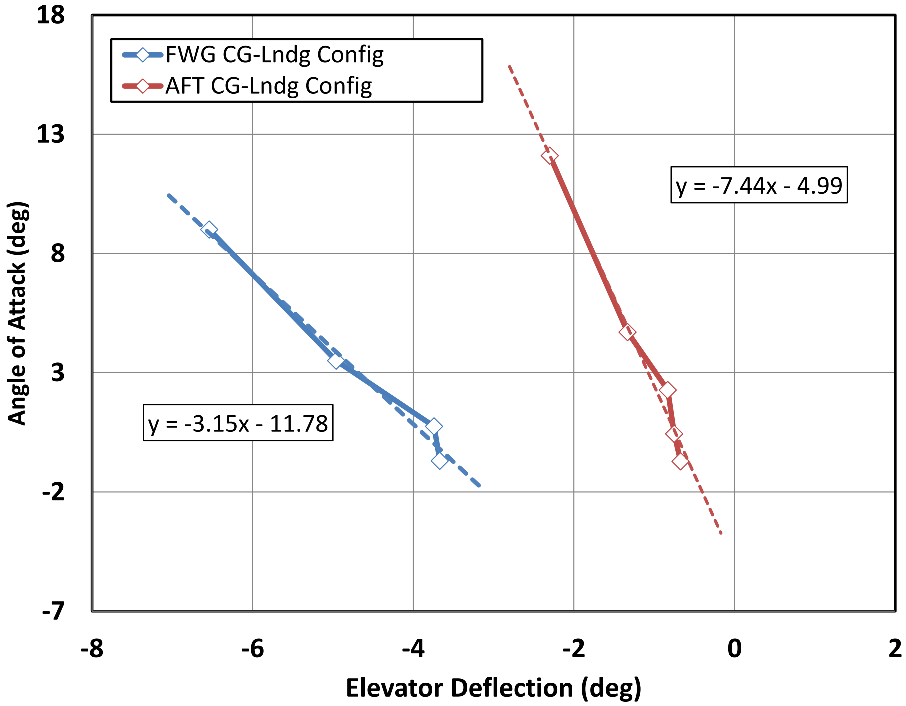

Figure 11, Elevator Effectiveness, Landing

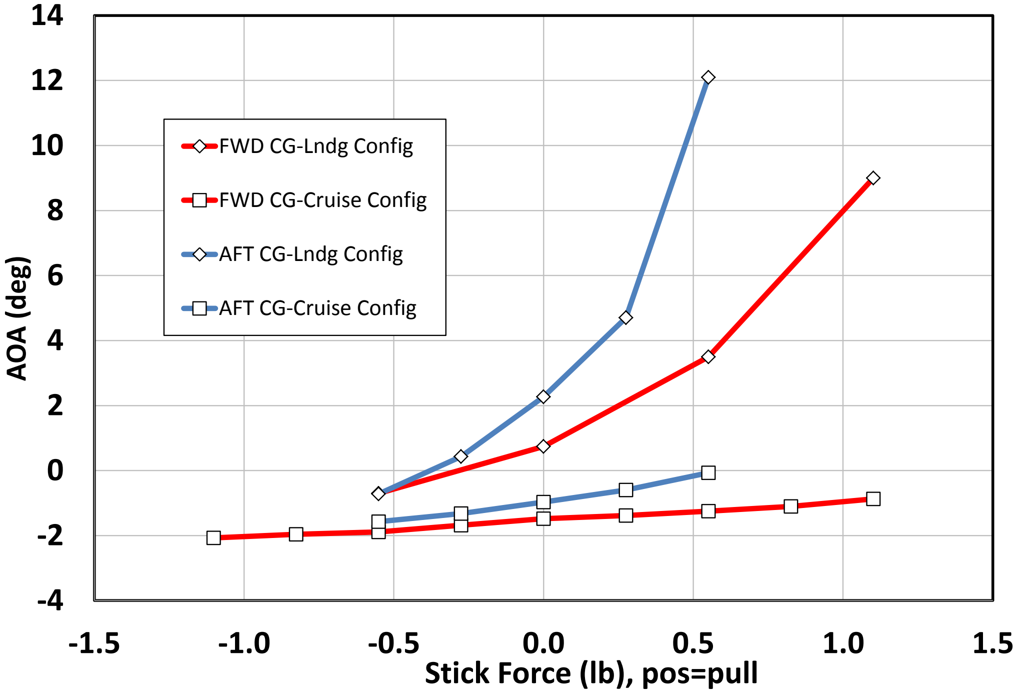

Figure 12, Angle of Attack Sensitivity to Stick Force

8 Handling Qualities

The pilot is an integral part of the aircraft flight control system and one with great variability in terms of training, skill and proficiency. The FAA is rather hands-off in setting quantitative standards for acceptable pitch sensitivity of GA aircraft and even less so in the experimental arena. 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 stability and handling qualities according to the mission at hand. High stick force gradients are a guard against inattention, distraction or inadvertently bumping the control stick (turbulence). Higher stick force gradients are also a guard against pilot induced oscillation (PIO). Studies have suggested ranges for stick force gradients suitable for GA. In addition, correlation between low stick force gradients and accident rates have been shown (Bromfield, 2012). Nonetheless, sub-categories of GA will desire lighter than average stick forces gradients, aerobatics for example. Light stick force gradients do however require a control system with low friction, low break-out forces (stiction) and low hysteresis. The Lancair 360 control system possesses these required attributes.

9 Conclusion

The aircraft exhibited positive static and dynamic stability in every configuration and in every flight condition tested. Control effectiveness was inversely proportional to static margin and no discontinuities or other undesirable characteristics were observed. Stick force gradients were light with a very predictable and consistent response.

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