Longitudinal Static Stability of the Lancair 360

C. Zavatson, 5/15/2013, rev D

The longitudinal stability of the Lancair 360 has been a topic of discussion for a long time. The evolution of the design was at least partially influenced by longitudinal stability. The Lancair 360 has two horizontal tail configurations: The original “small” tail and the MKII tail. Much has been debated qualitatively regarding the handling qualities of each variant. The intent here is to present quantitative results from both analysis and flight tests that show the differences between the two configurations. Two approaches were used to determine the longitudinal static stability of N91CZ, a Lancair 360 with the MKII tail. First was a conventional analytical approach. The second was through flight test. The results are in excellent agreement. Some background is provided for each.

Longitudinal Static Stability is a measure of the reaction of the aircraft when pitch is disturbed. More technically, it describes the rate of change of pitching moment in response to a change in angle of attack. If for example the nose is raised by some means, increasing the lift coefficient, is there a natural tendency for the aircraft to lower the nose and return its initial condition. ….and if so, with how much assertiveness?

Mean Aerodynamic Center and Mean Aerodynamic Chord

The mean aerodynamic chord is a length parameter that is the mathematical equivalent of the entire wing planform reduced to a single chord length, longitudinal position and angle of attack. The entire wing is essentially replaced by the mean aerodynamic chord for all calculations pertaining to stability. The mean aerodynamic center describes a point on the wing where the pitching moment is no longer a function of angle of attack. For a subsonic airfoil, this point is located at 25% of the chord. The ability to treat both the mean aerodynamic center and the pitching moment coefficient as constants makes subsequent calculation much easier.

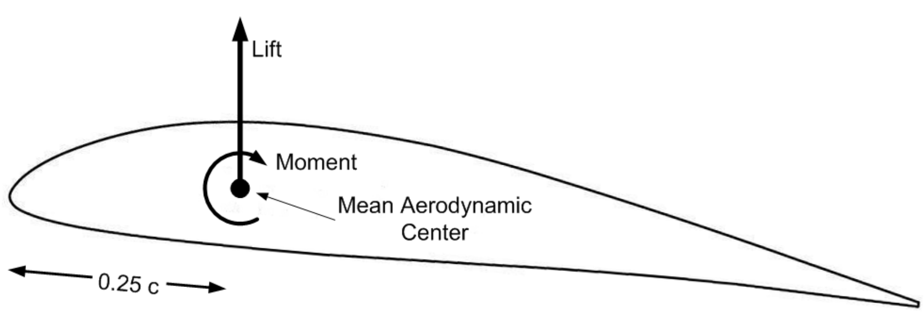

Figure 1, Mean Aerodynamic Center of an Airfoil

For a complete aircraft, the mean aerodynamic center moves aft by the addition of the horizontal stabilizer. This new location is also known as the aircraft aerodynamic center or neutral point. In order to satisfy the criteria for natural stability the aircraft CG must remain ahead of the neutral point. The distance between the neutral point and the aircraft CG is referred to as the static margin and is presented as a percentage of the mean aerodynamic chord. Figure 2 shows the final summation of lift and moments acting on an aircraft.

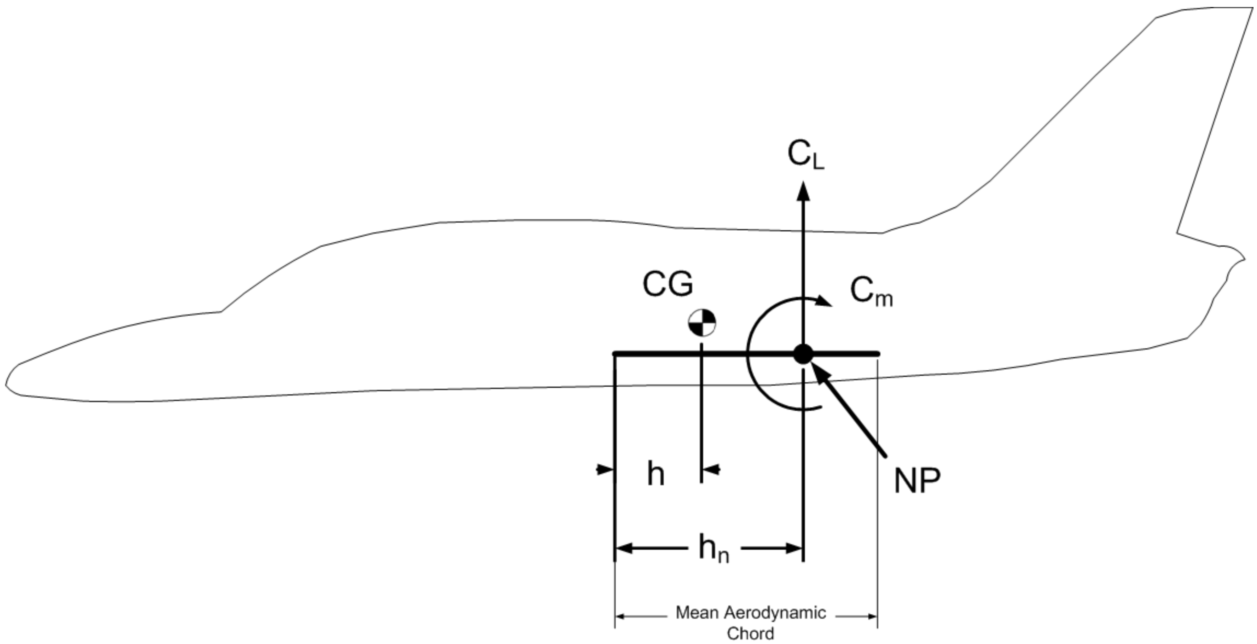

Figure 2, Total Lift and Moment acting on aircraft

h = CG location as percentage of mean aerodynamic chord
h_n = neutral point location as percentage of mean aerodynamic chord
NP = neutral point
C_L = total lift coefficient, CL = $\frac{2\,W}{S\rho v^2}$
C_m = Total Moment
Static Margin = $h_n - h$

For aircraft without any artificial stability augmentation, static margin is a measure of how much stability a particular aircraft possess. Training aircraft will be quite high: 20%, aerobatic aircraft might approach zero. 10% is a conservative number to use if some degree of pilot skill can be assumed. i.e. not a primary trainer. Table 1 shows the static margin of an assortment of aircraft.

Table 1, Static Margin of various Aircraft

Aircraft Type	Static Margin
Cessna 172	0.19
Learjet 35	0.13
North American P-51 Mustang	0.05
General Dynamics F-16C	0.01

*Source R.Cummings, CalPoly, San Luis Obispo, CA

Longitudinal Stability

An aircraft is considered statically stable if a disturbance from equilibrium generates a restoring force that tries to return it to equilibrium. An aircraft is considered dynamically stable is it actually does return to equilibrium. A wing by itself is naturally unstable.   In fact, both the wing and the fuselage have negative, or destabilizing, moment coefficients. It is the tail that provides a stabilizing component. In the normal flight regime, these values are constant, or nearly so.   The total curve is a summation of all the contributing components, fuselage, tail, nacelle, etc .   The final curve of pitching moment with respect to lift coefficient must have a negative slope to possess natural stability. The slope of this curve is what the pilot perceives as the stability of the aircraft. A steep slope is felt as very stable, a flatter slope is perceived as a less stable aircraft. (Figure 4). Note that in general this should not be confused with responsiveness to control inputs. Stability refers to the natural response of an aircraft when disturbed from equilibrium. While it certainly requires less force to maneuver a less stable aircraft, controls can be made to be more or less effective through other design aspects.

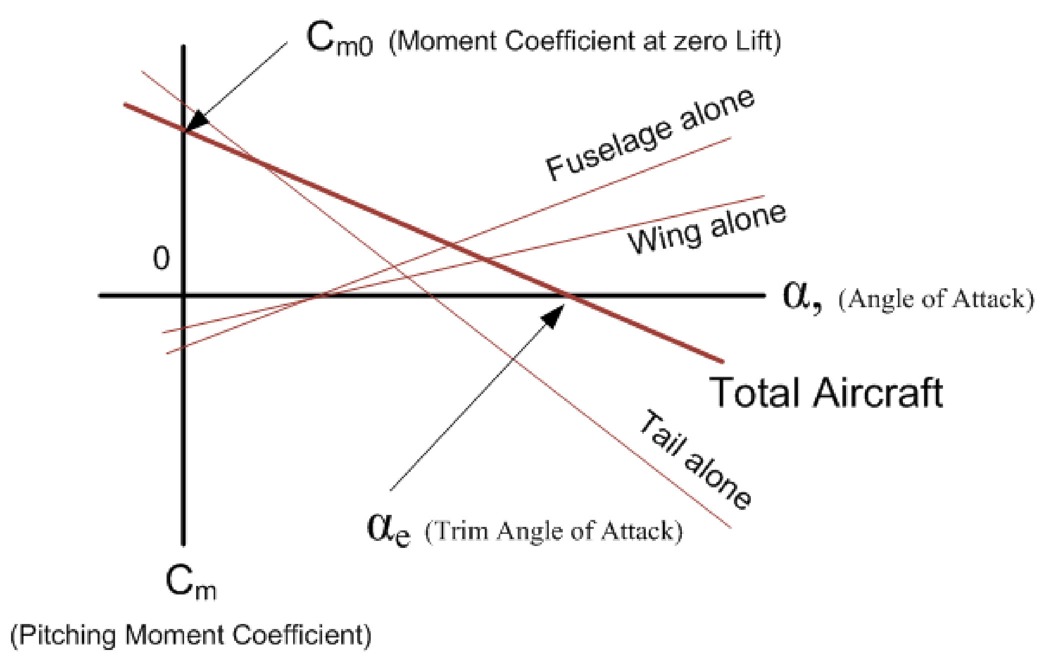

Figure 3, Longitudinal Stability Contributions

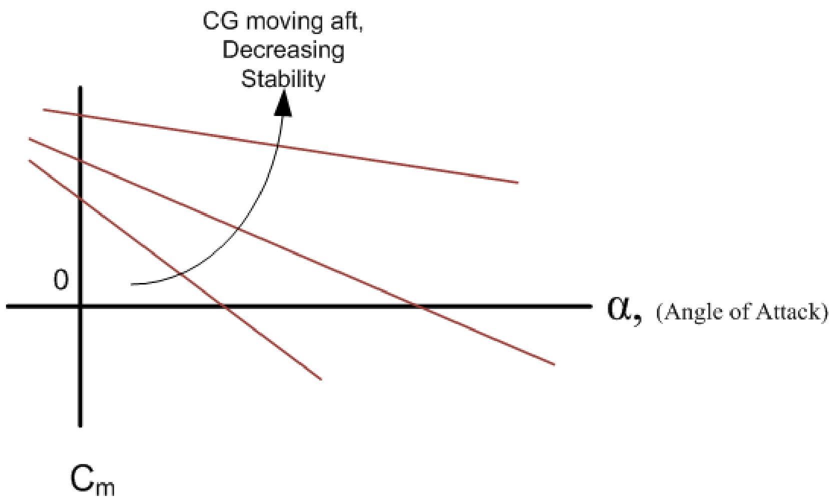

Figure 4, Pitching Moment Slope and Stability

The Trim Condition

A second condition must be met in conjunction with stability for straight and level flight – the trim condition. To this end the aircraft must have a positive moment (nose up) at zero lift coefficient. Combined with a negative pitching moment slope, the aircraft will seek equilibrium at a positive lift coefficient. The trim condition is a summation of the pitching moments produced by the wing, fuselage tail, engine and CG etc. when the net moment goes to zero.

The pilot has a few options for changing the trim condition. Most convenient and common is the elevator. This changes the tail contribution. The flaps can also be used. Flaps change the camber of the wing and thus its pitching moment at any given angle of attack. The CG can be moved, although this is not easily achieved on demand in most small aircraft. Fuel burn does change the contribution of CG and thus moves the trim point. Figure 6 shows how elevator deflection shifts the total $C_{m\alpha}$ curve vertically. The aircraft then finds a new angle of attack and a new trim air speed.

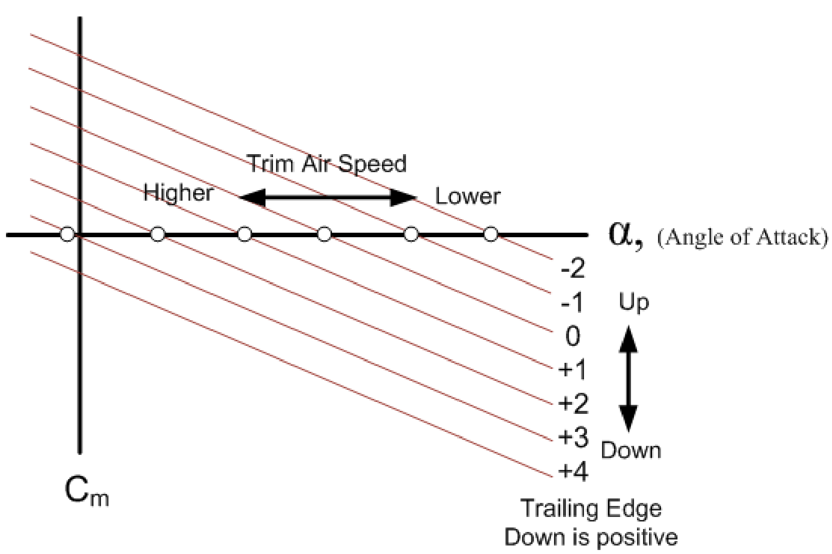

Figure 5, Effect of Elevator Deflection on Trim Speed

The Neutral Point

The neutral point can be determined both analytically and by flight test. For the analytical approach, many details of the aircraft geometry are required: Aircraft plan form, incidence angles, airfoil data, etc. The neutral point is defined by Equation 1.

$$h_n = h_{nw} - \frac{a_f}{a_w} + V_h \frac{a_t}{a_w} \left(1 - \frac{d\varepsilon}{d\alpha}\right) \qquad \text{Equ. 1}$$

Where,

$$V_h = l_t \frac{S_t}{S_w C} \qquad \text{Equ. 2}$$

And,

- V_h is the tail volume ratio
- l_t is distance between mean aerodynamic center of the tail and the aircraft CG
- S_t is the effective area of the tail
- S_w is the area of the wing
- C is the mean aerodynamic chord
- h_{nw} is the aerodynamic center of the wing
- a_f is the lift curve slope of the fuselage
- a_w is the lift curve slope of the wing
- a_t is the lift curve slope of the tail
- $\frac{d\varepsilon}{d\alpha}$ is the effect of down wash on the tail with respect to angle of attack

The neutral point can also 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 at moderate power 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. If for example, the trim speed was 168 KIAS, the test points would be: 175, 160, 185,155, 190, 150, 195, 145, 200, 140, 205 KIAS, etc.

Since each aircraft speed is converted to a lift coefficient, weight must also be known. Scales and a fuel totalizer can be used to obtain instantaneous weight during the flight. Elevator position needs to be captured to a resolution of better than $1/10^{th}$ of a degree. This fine resolution is needed since each test flight will see the total elevator position vary by less than one degree.

N91CZ was instrumented with air data transducers and an elevator position transducer. All data was recorded to a micro SD card via a PIC micro controller. Aircraft weight and CG location were measured prior to each flight.

Each CG position will produce a curve similar to Figures 6 & 7. It is the slope of these curves that is of interest. As the CG moves aft and approaches the neutral point, the slope reduces. At the neutral point it would become a horizontal line as lift coefficient would become independent of elevator input. The slopes obtained from these two curves are plotted in the next chart.

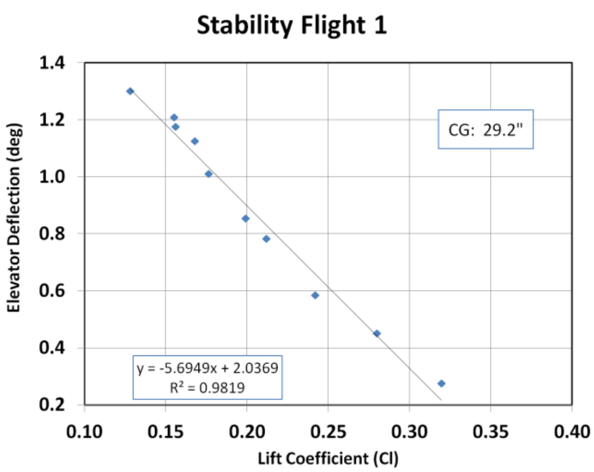

Figure 6, Stability Test, Forward CG

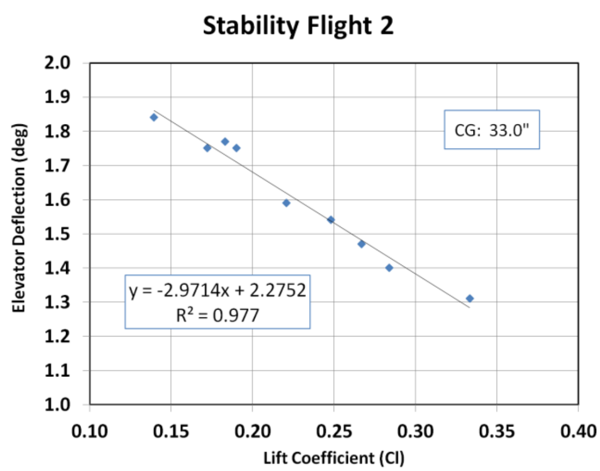

Figure 7, Stability Test, Aft CG

Figure 9 shows the slope points plotted. A line is then drawn through these points and extrapolated until crossing zero on the x-axis. This intersection represents the CG location where pitch is no longer a function of elevator position, in other words, the neutral point.

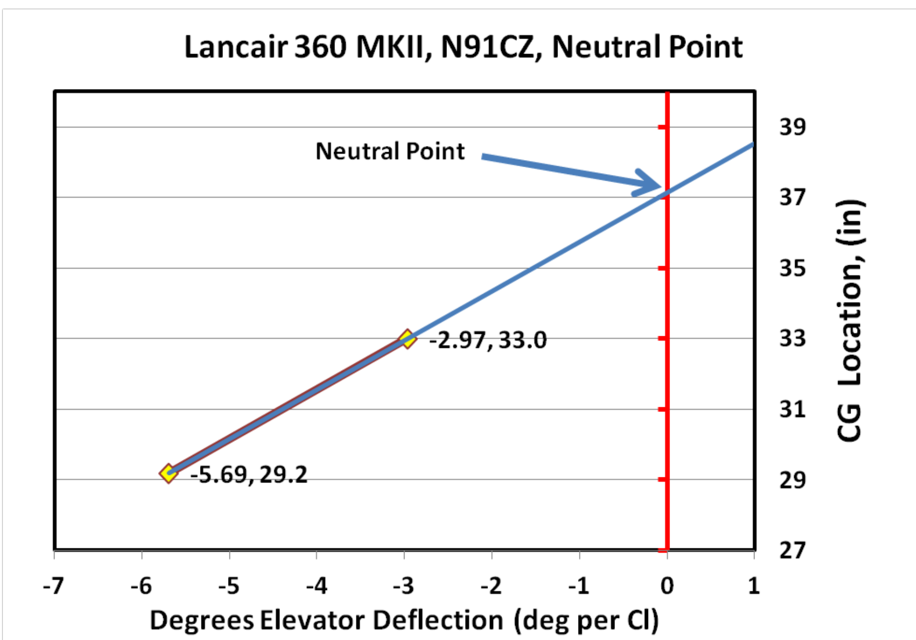

Figure 8, Neutral Point Result by Flight Test

Results

Table 2, Results

	Static Margin at published limit (30.3”)	Neutral Point*
Original Tail**	8.0%	33.5”
MKII Tail	16.5%	37.0”

*Referenced to Firewall

**by analysis

Both the analytical results and flight test determined the neutral point on the aircraft tested with the large MKII tail to be approximately 37” behind the firewall datum. The analytical results for the original small tail placed the neutral point at 33.5”. At the published aft CG limit the large tail 360 has 16.5% static margin while the small original tail provides 8% static margin. For a given CG position the large tail will provide significantly more stability, or conversely, for a given degree of stability the CG on the small tail Lancair must on the order of 3.5” farther forward.