Neutral Point and CG Location for Longitudinal (Pitch) Stability

by Jeff Annis

While working on the 1940 Miss World's Fair model, I noticed that the plans did not include the location for the center of gravity (CG). This led me to investigate various methodologies proposed in symposium reports and online resources in the spring of 2020, during the COVID-19 pandemic. Looking for a project to pass the time while being stuck at home, I decided to dust off a kit titled "1940 Miss World's Fair Old Timer Model." The reason I wanted to know the CG location was to calculate it based on the wood I planned to use before construction, allowing me to make adjustments accordingly. This would help determine if tail or nose weight would need to be added after the model was completed. My goal was to avoid adding any ballast weight at all by planning the CG location in advance.

Longitudinal or Pitching Stability

Longitudinal stability refers to an aircraft's inherent ability to resist and counteract pitching motions about its lateral axis, which can develop into violent stall and diving oscillations known as phugoid oscillations. This stability ensures that if the aircraft experiences a disturbance causing the nose to pitch up or down, the stabilizer will naturally generate corrective forces to level out the longitudinal flight path.

The Neutral Point

The neutral point is a critical concept in assessing an aircraft's longitudinal stability (pitch stability). It represents the specific location of the center of gravity (CG) where the aircraft's pitching moment coefficient becomes zero. At this point, the aircraft neither pitches up nor down when disturbed; it remains at the new attitude without returning to its original position or diverging further. The relationship between the CG and the neutral point determines the aircraft's static stability:

- **CG Ahead of Neutral Point**: The aircraft exhibits positive static stability, tending to return to its original attitude after a disturbance.
- **CG Behind Neutral Point**: The aircraft becomes statically unstable, with disturbances causing it to diverge from its original attitude.

The distance between the CG and the neutral point is known as the static margin. A positive static margin indicates stable behavior, while a negative margin suggests instability.

For free-flight models, a stability margin of about 10% to 15% is recommended for longitudinal stability. The stability margin is the percentage of the root wing chord that the CG is ahead of the neutral balance point. For a rectangular wing planform, the center of pressure of lift is approximately 25% from the leading edge. If the wing is tapered or swept back, the wing center of pressure (Cp) will shift ahead or behind this 25% location.

Calculating the Neutral Point

In its simplest form, the neutral point location is calculated using the tail volume coefficient. The neutral point location is obtained by multiplying the root wing chord by the tail volume coefficient, which assumes the stabilizer (stab) is 100% effective. The tail volume coefficient is calculated by taking the stabilizer area, multiplying it by the distance from the wing's center of pressure (Cp) to the stabilizer's Cp, and dividing by the wing area multiplied by the mean chord of the wing. For free-flight model aircraft, tail volume coefficients typically range from 0.8 to 1.8. When multiplied by 100%, this would place the CG at around 80% to 180%, which we know isn't correct. In reality, the stabilizers on our model airplanes are only about 25% to 35% effective, which is where it gets interesting in calculating the stabilizer effectiveness or "knockdown factor." This knockdown factor brings the CG more in line with the expected range, usually around 40% to 80%.

Stabilizer Overall Effectiveness

Three factors influence stabilizer effectiveness: stabilizer efficiency, wing versus stabilizer lift slope, and wing downwash factors. Typically, a stabilizer is about 60% efficient for stabs located in the wing and fuselage wake, and about 90% for T-tail planes, where the stab is out of the wake.

Lift slope is defined as the change in lift coefficient relative to the change in angle of attack for both the wing and the stabilizer. On a graph, this is the lift coefficient on the y-axis and the angle of attack on the x-axis, where the line is linear prior to stall. The lift slope factor can be estimated based on the aspect ratio of the wing versus the stabilizer. Most stabilizers have a much smaller aspect ratio than the wing and are less effective with a lower lift slope.

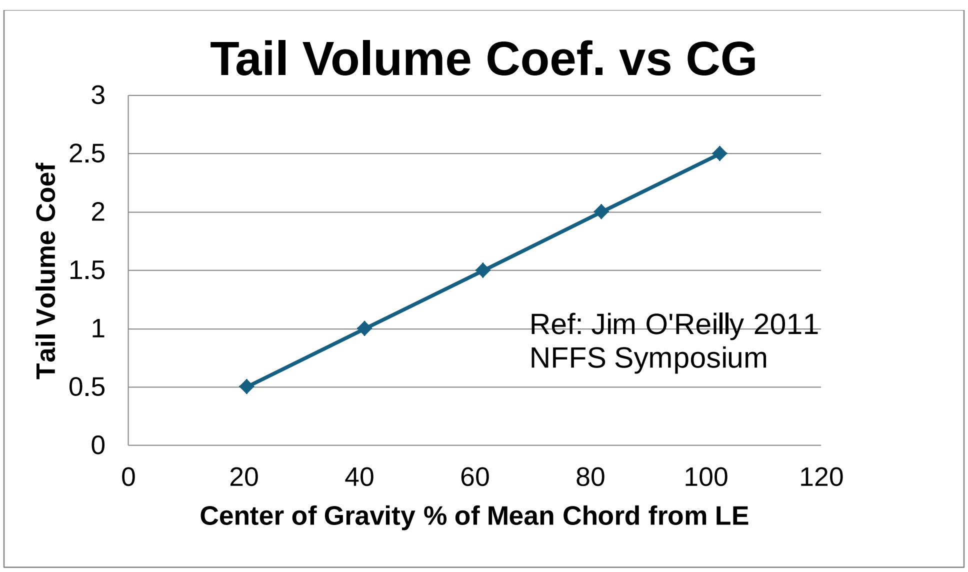
Finally, the wing downwash factor reduces the angle of attack on the stabilizer, thus making it less effective. All three of these factors are multiplied together to determine the overall stabilizer effectiveness.

Empirical Data for CG Location

Over the years, free-flight modelers have determined the best CG locations based on empirical flight testing. By plotting the CG locations for various well-flying models against the tail volume coefficient, the data tends to fall fairly close to a straight line. A simplistic yet effective approach is to find a graph from symposiums or other model aircraft references, calculate the tail volume coefficient, and then use the graph to find the CG location. Following is one such graph taken from a 2011 NFFS Symposium titled "CG vs. Tail Volume Coefficient" by Jim O'Reilly.

Neutral Point and CG Spreadsheet Program

I have derived some of the equations for the lift slope factor and used other references for lift slope factors and downwash factors. Using these equations, I developed an Excel spreadsheet program to calculate the tail volume coefficient, neutral point, center of gravity, and all stabilizer knockdown factors. This spreadsheet program is now used for all my new airplane models prior to construction and is compared with CG locations shown on the plans, if available. Following is an example of this program used on a recent build, the Go Devil embryo model. For those interested, feel free to email me, and I can send you a copy of the program and the equation documentation to go with it.



Where: Tvo=(As*D)/(Aw*C)

With: Tvo-Tail Volume Coefficient

Aw-Wing Area

As-Stabilizer Area

C-Mean Wing Chord

D-Tail Length Wing Cp to Stabilizer Cp

Cp-Center of pressure 25% from LE Rect. Plan form

<u>Neutral Point and Static Margin Calculations by Jeff Annis</u>

Model Airplane Name:	Go Devil Neutral Point	10/2/2024
Wing Parameters		
Area (in^2)	50	
Average Chord (in)	2.59	
Chord at Wing Center (in.)	2.75	
Aspect Ratio	7.67	
Mean Aerodynamic Center %	30	
Static Margin %	10	
Stab Parameters		
Area(in^2)	16.3	
Aspect Ratio	4.1	
Moment arm (in.)	9.56	
Stab Efficiency %	60	
Calculated Parameters		
Tail Volume Coef.	1.20	
Lift Slope Wing (CL/deg)	0.0568	
Lift slope Stab(CL/deg)	0.0415	
Lift slope Ratio Factor (stab/wing)	0.73	
Downwash Factor	0.30	
Downwash Correction Factor	0.70	
Stab Effectiveness %	31	
Neutral Point From LE (in.)	1.84	
Neutral Point %	66.9	
CG from LE (in.)	1.56	
CG %	56.9	