Bugatti 100P Longitudinal Stick Forces – Revision A

Stick-free static longitudinal stability (stick force-per-knot) and stick-free longitudinal maneuvering stability (stick force-per-g) were computed for the Bugatti 100P over a range of weights, CG positions, and airspeeds. Elevator control surface hinge moment coefficients were estimated using U.S. Air Force Stability & Control DATCOM handbook methods. The 100P elevators were assumed to be flat-sided with no aerodynamic balance, no horns or leading edge overhangs (Figure 1). An elevator control system gearing ratio was calculated based on the dimensions given in the schematic shown in Figure 2 and additional measurements taken on the aircraft (Figure 3).

Figure 1. Bugatti 100P Elevators/Ruddervators

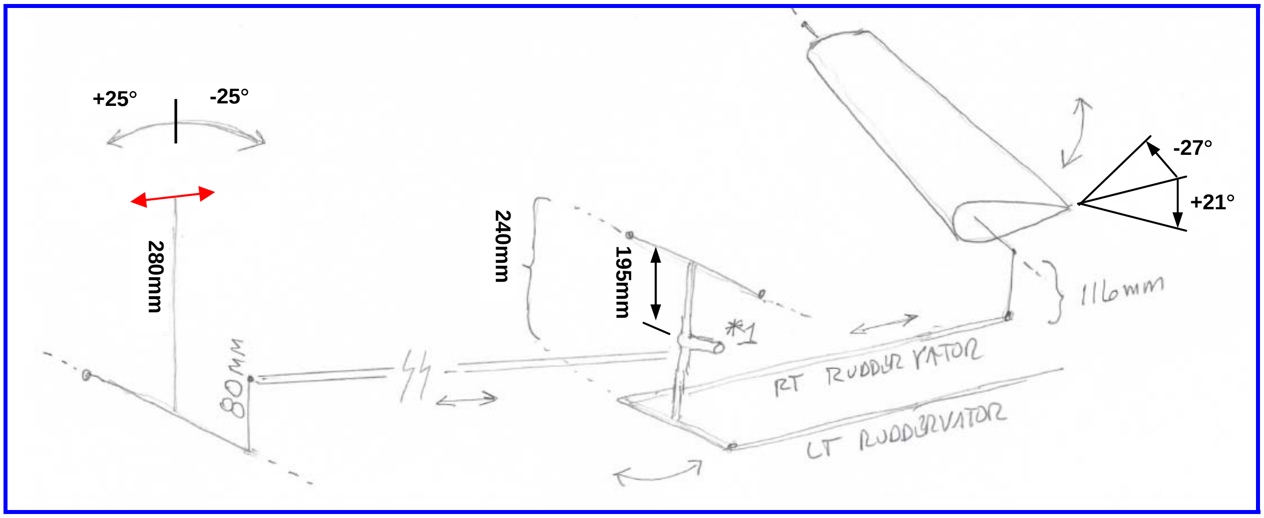

Figure 2. 100P Elevator Control System Schematic (from ScottyCad)

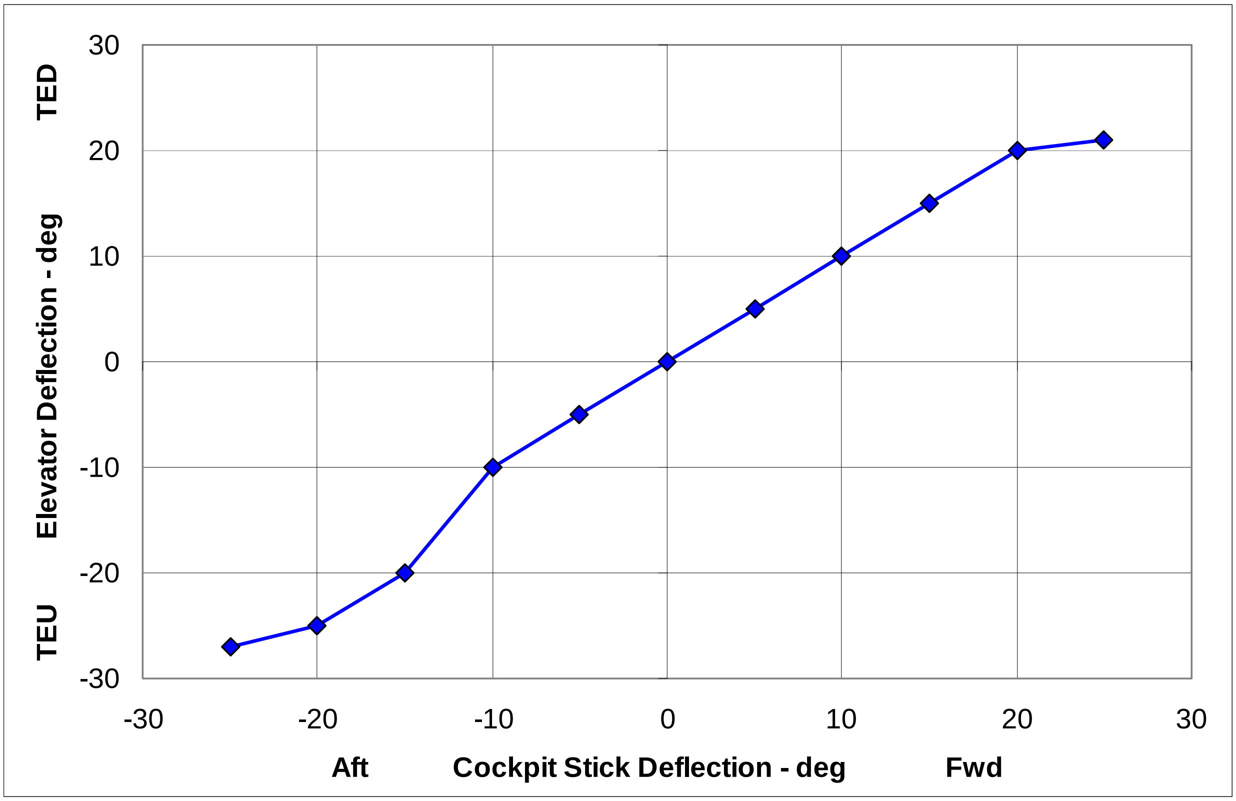

Figure 3. 100P Elevator Control System Gearing Measured on the Aircraft

Static Longitudinal Stability (Stick Force-per-knot)

Stick forces were computed for a 20 knot pull and a 20 knot push from trim for the light weight 100P. Light aircraft weights are critical because they produce the lowest stick force gradients. For the purpose of this analysis, 2350 lbs was considered light weight. Mid weight would be 2500 lbs and heavy 2650 lbs. Stick forces are plotted in Figure 4 for three trim speeds, 1.2Vs+20 kts, V_A and V_{NE}-20 kts. The values of V_A and V_{NE} were selected somewhat arbitrarily. Forces are plotted at each trim speed for forward, mid and aft CG positions of 10%c, 15%c and 20%c, respectively. For reference, a 1 lb/6 kts stick force gradient curve is plotted at each trim speed. This stick force gradient is generally considered a **minimum** for good longitudinal Handling Qualities.

Figure 4 shows that 100P stick force gradients fall below the 1 lb/6 kts criteria at aft CG for all airspeeds. Mid and aft CG stick force gradients fall below the criteria for the high speed (230 kts) trim point. At high speed and aft CG, it takes about 1 lb of stick force to decelerate or accelerate 20 kts from trim. Just +/-2 lb of friction would be enough to swamp all of the aft CG stick force gradients plotted in Figure 4.

If this aircraft were intended to be certified, a number of fixes would be available for raising these low stick force gradients. Those fixes include a control system gearing ratio increase, down-springs, a trailing edge heavy elevator control surface (pending flutter clearance) and/or an anti-servo tab. However, for demonstration flights the aircraft could be loaded with the CG at 15%c. At this mid CG position, stick force gradients will meet the 1 lb/6 kts criteria at speeds below 150 kts. Above 150 kts, stick force gradients will still be light.

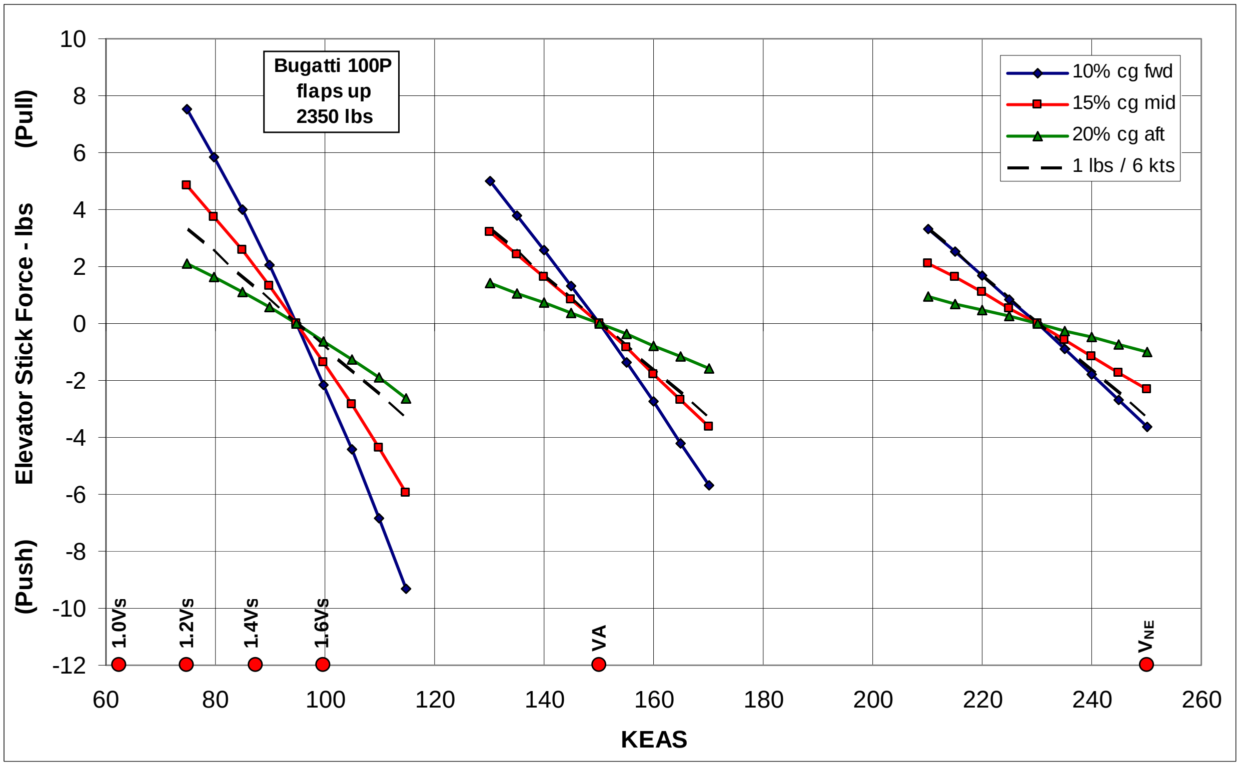

Figure 4. 100P Stick Force-per-knot, Flap Up, Light Weight

The stick forces plotted in Figure 4 assume that the pilot can trim longitudinal forces to zero throughout the envelope. In the absence of a longitudinal trim system (tab or spring cartridge), stick forces are just what is required to hold the elevator at the deflections shown in Figure 5. The associated stick forces are plotted in Figure 6 as a function of airspeed for the forward, mid and aft CG positions.

The flap up elevator curves plotted in Figure 5 cross the zero elevator deflection line at one unique airspeed for each CG position. This means there will be one “natural” trim point in the envelope for each CG position. Figure 6 shows that this trim point will occur at 205 kts for the mid CG loading. Stick force gradients will be the same as those shown in Figure 4 at speeds just above and just below this trim point (~+/-20kts). As you move away from that trim point, stick force gradients will decrease.

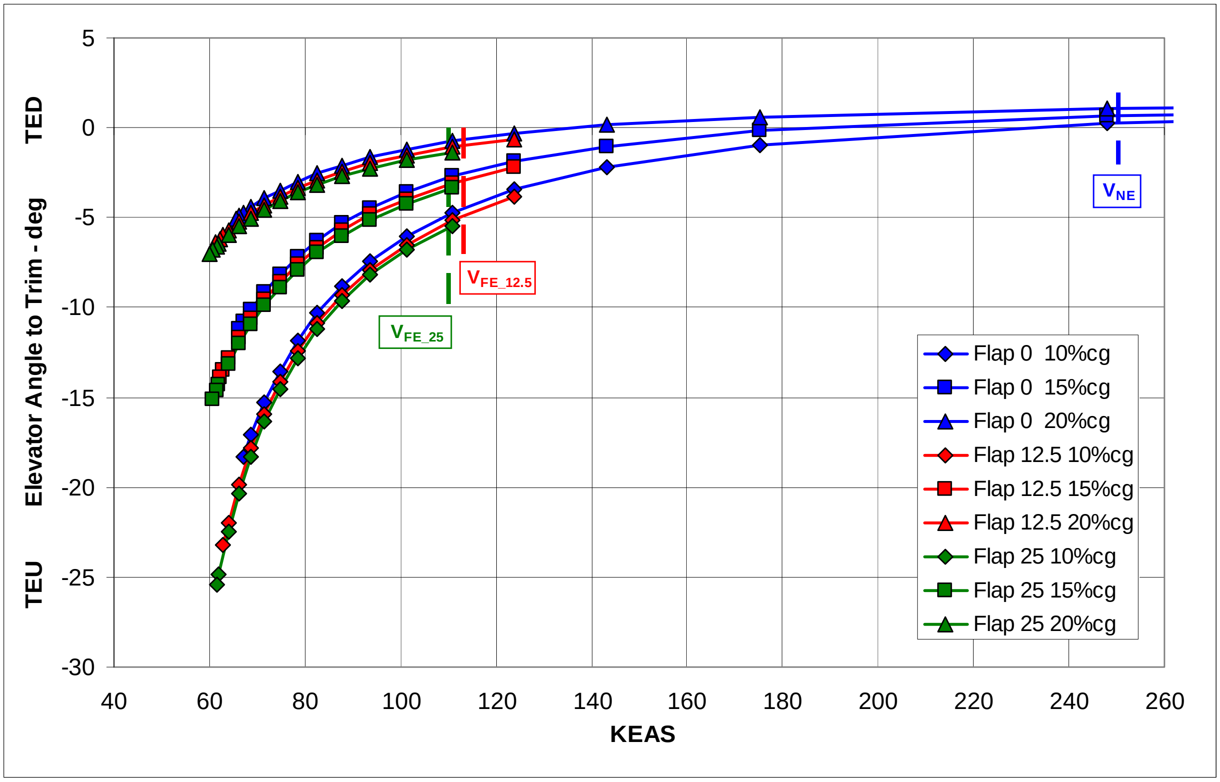

Figure 5. 100P Required Elevator Deflections

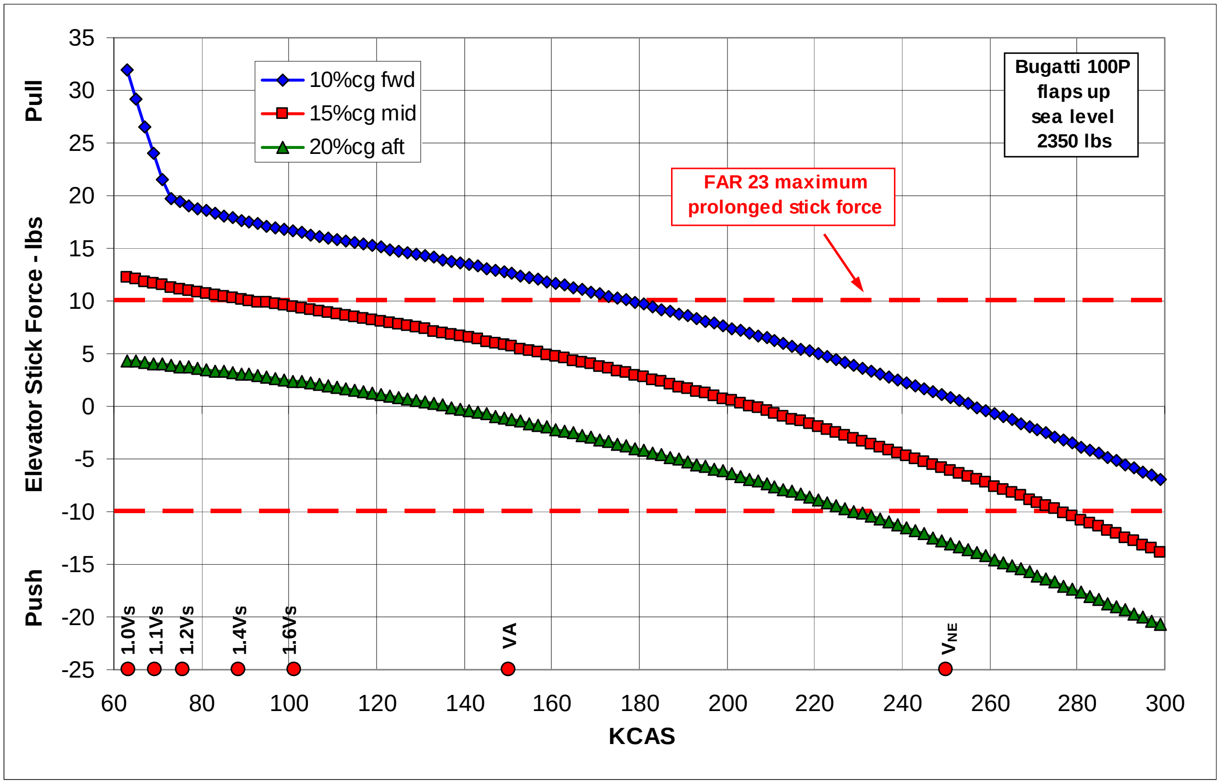

Figure 6. 100P Longitudinal Stick Forces without the Ability to Trim

Stick force gradients drop as you accelerate or decelerate away from the trim point. An elevator trim tab (or spring cartridge) helps create a stable stick force gradient at other trim airspeeds. Figure 7 from Perkins & Hage *Airplane Performance Stability & Control* shows stick forces for two trim speeds (two tab deflections). The stable stick force slopes occur close to the trim speed. Far from the trim speed, the gradients fall off.

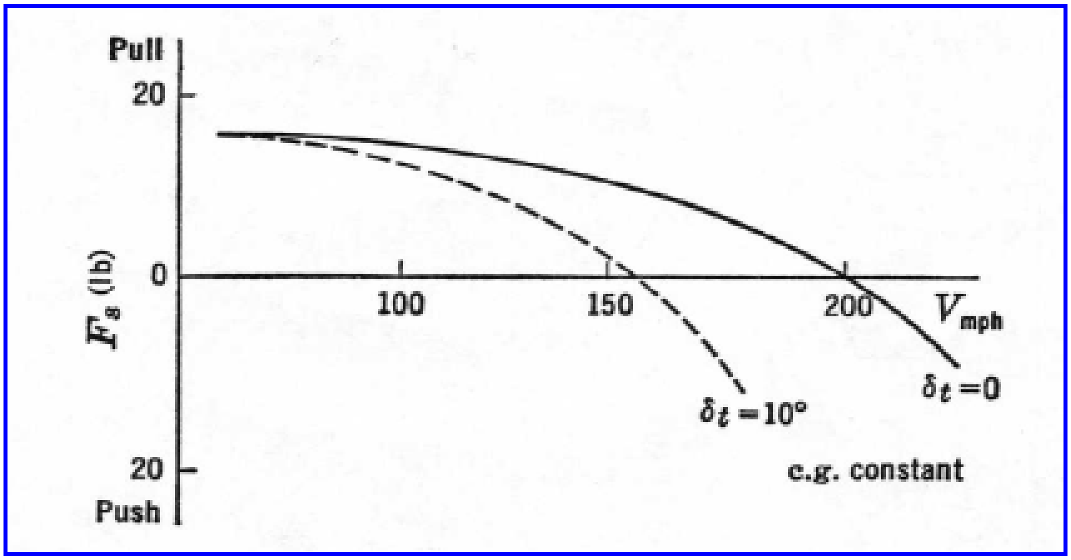

Figure 7. The Effect of Elevator Trim Tab Deflection on Stick Force
Far from Trim Speed there is no Stick Force Gradient
(Figure 6-19 from Perkins & Hage *Airplane Performance Stabilty & Control*)

The fix for this issue would be the addition of an elevator trim tab or spring trim cartridge. However, the aircraft could then be flow at or around the one available trim speed for the first flight series.

The changing stick force gradient above or below the single “natural” trim speed is one concern with the missing trim system. A second concern is the level of stick force the pilot needs to hold over a prolonged period of time. The FAR 23 maximum in pitch is just 10 pounds. Figure 6 shows that it may be possible to pick an airspeed and CG envelope to stay under that prolonged limit. Problems could arise if stick forces were higher than predicted.

Longitudinal Maneuvering Stability (Stick Force-per-g)

Stick force-per-g is plotted in Figure 7 for the flap up configuration at forward, mid and aft center of gravity and light, mid and heavy weights at low, medium and high altitudes. Stick force-per-g ranges from 29 lbs/g at fwd, heavy, low altitude to 9 lbs/g at aft, light, high altitude. For a mid weight, mid CG and mid altitude condition, stick force-per-g is on the order of 18 lbs/g. For reference, the LSA minimum stick force at maximum maneuvering load factor equates to about 5¼ lbs/g at the critical light weight, aft CG, high altitude condition. The 100P would comply with this LSA maneuvering stability requirement. This level of stick force-per-g seems reasonable for this type of aircraft.

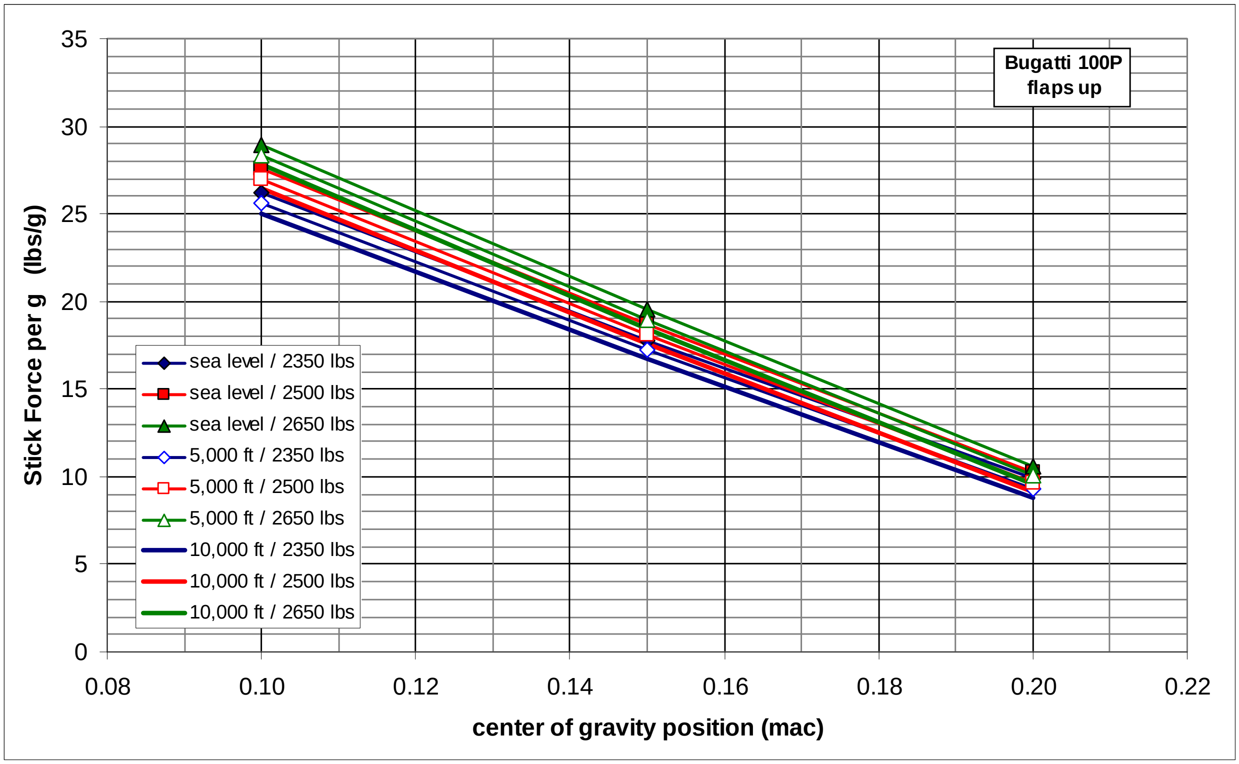

Figure 7. 100P Stick Force-per-g

Summary:

- **With the ability to trim**, 100P stick force gradients are going to be low. Stick force-per-knot is predicted to fall below 1 lb/6 kts at aft CG positions for all trim airspeeds for the light weight (2350 lb) aircraft. The recommendation is to load the aircraft at a mid CG of 15%c.

- **Without the ability to trim**, the pilot will be required to hold force throughout the flight except at the one “natural” trim speed (205 kts at mid CG). This could be an issue if actual stick forces are higher than predicted.

- The installation of some form of longitudinal trim system is recommended.

- Stick force-per-g at mid weight, CG and altitude is predicted to be around 18 lbs/g which is appropriate for this type of aircraft.

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