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Idle-Thrust versus Zero-thrust Stalls in the C-12C

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The United States Air Force's C-12s were modified to improve their overall performance, particularly in the takeoff and landing environment. Around the beginning of 2015, there were reports from the primary user of the C-12C, the Defense Security Cooperation Agency, that the stall speeds in the first modified aircraft seemed to be a little off from those reported and published by the contractor. So, as Edwards received their first modified aircraft in the Fall of 2015, the USAF Test Pilot School (TPS) started to informally collect stall data to characterize the difference between the published and actual stall speeds. To add some confusion to this work, the flight manual had published a table with "flight idle" stall speeds and a chart with "zero-thrust" stall speeds that appeared to give the same numbers (figure 1). The school's initial findings showed discrepancies up to 5-7 knots using idle-thrust with idle-thrust stall speeds being higher the zero-thrust stall speeds. The zero-thrust speeds looked close to the charted speeds. Up to this point these discrepancies were just a curiosity.

TAKEOFF/CRUISE

POWER: IDLE
FLAPS: UP LANDING
GEAR: UP OR DOWN

GROSS WEIGHT	STALL SPEEDS – KNOTS IAS ANGLE OF BANK				
	0°	15°	30°	45°	60°
10,500	81	83	87	97	113
11,000	84	86	90	100	119
11,500	86	88	92	102	121
12,000	89	91	96	106	125
12,500	91	93	98	108	127

APPROACH

POWER: IDLE
FLAPS: APPROACH LANDING
GEAR: DOWN

NOTES

1. MAXIMUM ALTITUDE LOSS DURING A STALL RECOVERY IS APPROXIMATELY 800 FEET.
2. MAXIMUM NOSE DOWN PITCH ATTITUDE AND ALTITUDE LOSS DURING RECOVERY FROM ONE-ENGINE-INOPERATIVE STALLS PER 23.205 ARE APPROXIMATELY 8° AND 300 FEET RESPECTIVELY.
3. A NORMAL STALL RECOVERY TECHNIQUE MAY BE USED. THE BEST PROCEDURE IS A BRISK FORWARD WHEEL MOVEMENT TO A NOSE DOWN ATTITUDE. LEVEL THE AIRPLANE AFTER AIRSPEED HAS INCREASED APPROXIMATEL 25 KNOTS ABOVE STALL.
4. LANDING GEAR POSITION HAS NO EFFECT ON STALL SPEED.
5. POWER FOR ZERO THRUST (APPROXIMATELY 300 FT-LB TORQUE AND 1600 PROPELLER RPM)

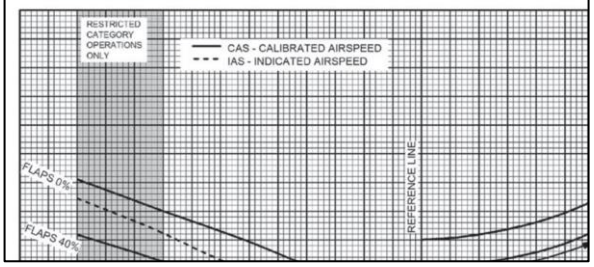

Figure 1: Flight Manual Stall Speed Configuration

That all changed when the author was flying a Functional Check Flight in one of the modified aircraft, in July 2016. The pilot the author flew with took off about 10 knots faster than charted rotation speed. When the author asked him why he did that, he said the aircraft just flew better. Then, when they did an idle-thrust stall series as part of the functional check flight protocol, they saw that the stall speed was 95 knots flaps up, essentially the same as the 0% flaps rotation speed, which was 94 knots. The author's partner's comment at the time was, "see, that is why I take off fast."

Everything clicked. Aircrew were often seen flying faster takeoffs and landings than charted in the modified aircraft. The aircraft handled more comfortably, more like the unmodified aircraft, if one flew it 10 knots fast. Flying the modified charted speeds saw the aircraft handle more like a back-side flying aircraft requiring a slightly higher workload in the terminal environment. Higher speeds, though, meant longer ground runs. But at Edwards, with 12,000- and 15,000-foot runways, takeoff performance was more of a formality. If aircrew flew faster rotation and threshold speeds, their increased ground rolls were inconsequential. But, what

would aircrew do when takeoff performance was critical? Would they fly the charted airspeeds or would they fly comfortable airspeeds for which they would have no published performance data? Since stall speeds help to define takeoff and landing speeds, knowing the correct stall speed becomes essential. This was how the exploration of idle-thrust and zero-thrust stall speeds began.

The modification that precipitated the need to revisit stalls speeds consisted of changing out the original 3-bladed propeller with a 4-bladed swept propeller (figure 2). This new propeller provided for better efficiency and better low-end thrust in the takeoff environment. These attributes would tend to lower stall speed.

Figure 2: 4-Bladed Swept Propellers

The inboard leading edge was also modified to eliminate a slight droop in the original wing design and to re-design the heat exchanger inlet (figure 3). This allowed for a more elliptical lift distribution (figure 4) that would increase the lift produced by the wing. This meant the aircraft would fly at lower angles of attack for a given gross weight. Thus, this part of the modification would also lower the stall speed of the aircraft.

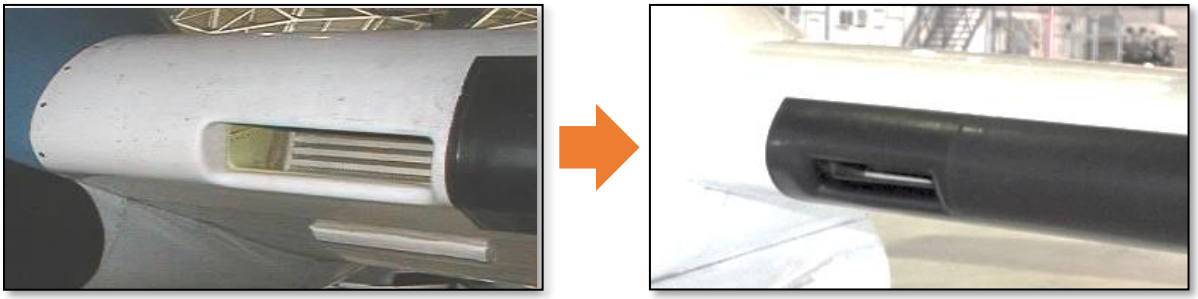

Figure 3: Inboard Leading-Edge Modification (old on the left, new on the right)

Figure 4: Notional lift Distribution (old on the left, new on the right)

Finally, there were three other parts to the modification (figure 5). They included a ram air recovery scoop designed to lower turbine gas temperatures (TGT) in the engine; the addition of dual strakes designed to improve high altitude directional stability and reduce drag; and a main gear door that fully enclosed the wheels on the C-12. The previous gear doors were only half the length and left the wheel exposed to the free stream of air. None of these three modification parts affected stall speed appreciably.

Figure 5: Ram Air Recovery Scoop, Dual Strakes, Fully Enclosed Gear Doors

Before going further, the V speeds used on this paper should be defined to get those with various backgrounds on the same footing (figure 6). First, V_R or rotation speed is the takeoff reference speed used by the FAA. This can be compared to liftoff speed, V_{LO}, that many military aircraft use. Minimum control speed, V_{MC}, refers the minimum aerodynamically controllable airspeed with the most critical engine out in a takeoff or landing configuration. V_1, sometimes referred to as decision speed, is the fastest speed at which a pilot can initiate an abort within the calculated accelerate-stop distance. Takeoff safety speed, or V_2, is initial minimum climb-out speed to be obtained by the specified altitude. This speed is similar to obstacle clearance speed, V_{OBS}. The approach speed, V_{APP}, is the speed to be obtained by 50 feet above the runway such that the calculated landing distance can be met. This airspeed is often referred to as V_{REF}, or reference landing airspeed. Finally, stall speed is represented by V_S. It refers to the stall speed in the configuration noted or the configuration required by regulations.

V Speed	Definition
V_R	Rotation speed, the reference speed used by FAA instead of liftoff speed, V_{LO}
V_{MC}	Engine-out minimum control speed in the configuration specified

V_1	Speed of first pilot action after engine failure to abort takeoff within accel-stop distance
V_2	Initial minimum climb-out speed to be reach by 50' (C-12), 35' (FAA)
V_{APP}	Minimum approach speed at 50'. AKA V_{REF}
V_S	Stall speed in the configuration noted or required

Figure 6: V Speed Translator

Now, back to the topic at hand. The stall speed improvements reported in the Supplemental Type Certificate for the modifications described were significant, in the order of 4-17 knots at various flap settings and gross weights. This allowed for correspondingly large gains in takeoff performance (figure 7). This was primarily due to the reduction in rotation airspeed, V_R (figure 9).

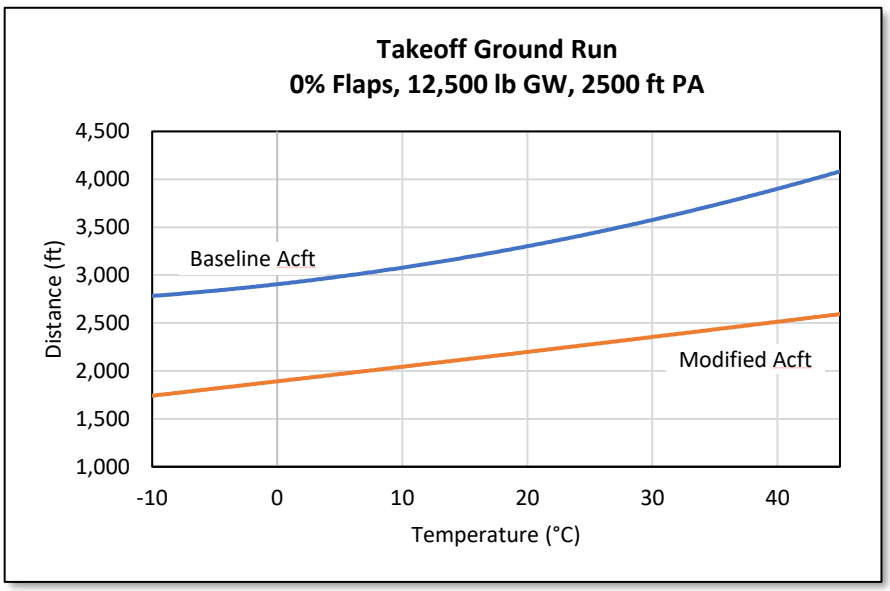

Figure 7: Takeoff Ground Run Comparison

Rotation speed is 3 knots less than liftoff speed, and liftoff speed is the primary driver for ground roll distance as seen in the simplified takeoff model shown in figure 8, where S_G is the ground roll, W is the weight, T is the average thrust, and D is the average drag. Lower liftoff speed significantly and one will get a large decrease in takeoff ground roll. The rotation speeds, in fact, were reduced enough to became limited more by minimum control speed (V_{MC}) than stall speeds (figure 9). But, as this report delves into this story deeper, one will see that stall speed should have played a more prominent role in rotation speed determination.

$$S_G = \frac{W V_{LO}^2}{2g(T - D)}$$

Figure 8: Simplified Takeoff Ground Roll Model

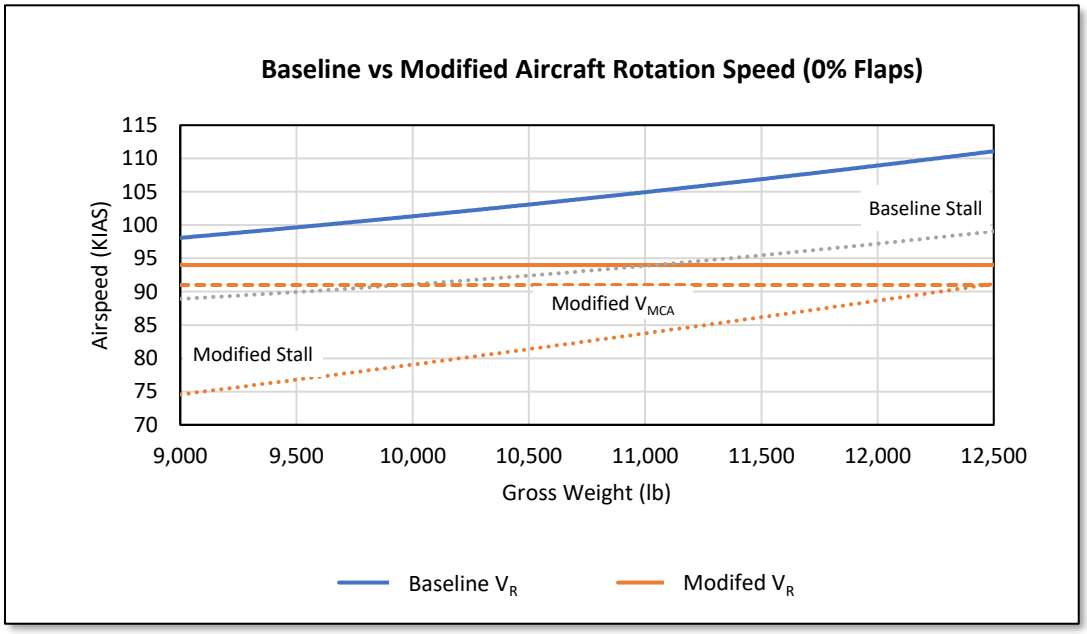

Figure 9: Rotation Speed Comparison to Stall and V_{MC}

After the author's epiphany that occurred during the functional check flight 5 years ago, a discussion ensued between the System Program Office, the contractor and Edwards. The contractor confirmed that the stall speeds reported in the flight manual that included the modification were in fact zero-thrust stall speeds. The idle configurations noted in the flight manual stall tables were a misprint. The program office felt comfortable accepting the stall numbers as well as the takeoff and landing speeds since they were from an approved Supplemental Type Certificate. Edwards wanted to be more conservative, considering the training nature of most of their flights. Thus, the program office approved the base's use of a taylored operational approach.

If one used the reported zero-thrust stalls speeds, they would see our rotation speeds were as low as 1.03 $V_{S\ (0\text{-thrust})}$ and 1.03 V_{MC} depending on weight and flap setting. The current industry standard had the minimum rotation speed as 1.1 V_S or 1.05 V_{MC}, whichever was greater. For landing, one would see that V_{APP} could be as low as 1.34 $V_{S\ (0\text{-thrust})}$. This was above the current industry minimum standard of 1.3 V_S. Even if one used the Test Pilot School's estimated idle-thrust stall speeds, V_{APP} would be greater than the current industry minimum standard for Part 25 aircraft of 1.23 V_S.

With this knowledge, Edwards opted to use the pre-modification takeoff speeds and distances which would be conservative since aircraft acceleration performance had improved. These speeds were also above the currently accepted industry minimum standards. On the other hand, flying an approach using the modified approach speeds had significantly different characteristics than when one flew the approach faster. Hence, since the modified approach speeds, using estimated idle-thrust stall speeds were above Part 25 standards, Edwards chose to continue using the modified speeds and distances. In summary, Edwards' temporary program office-approved solution was to use unmodified takeoff data set from the previous flight manual and the modified landing data set from the current flight manual.

Next, came the push to understand which stall speed should be used to set takeoff and landing speeds. If it turned out that idle-thrust stall speeds were the proper ones to use, a rigorous test would have to be executed to establish those values. The investigation into which stall configuration to use not only looked at the current regulatory terminology, but also the certification basis for the Supplemental Type Certificate. The certification basis is usually the regulations used to obtain the original type certificate for the aircraft. For the C-12C, the basis was the FAR Part 23 regulations that were effective in 1965 and as they were amended in 1969. Looking at the language of the basis regulations, the guidance, the author thought, was somewhat ambiguous.

- Stall Definition, §23.49 (1965-1969)

  "**Engines idling**, throttles closed (**or** at not more than the power necessary for **zero thrust** at a speed not more than 110 percent of the stalling speed)"

The current regulatory language provided a little more clarity but still had ambiguities.

- Stall Definition, §23.49 (1978) to ASTM F3179 (current)

  "**Propulsive thrust not greater than zero** at the stalling speed, **or, if** the **resultant thrust has no appreciable effect** on the stalling speed, **with engine(s) idling** and throttle(s) closed"

In 1989, the Flight Test Guide for Certification of Part 23 Airplanes, AC-23-8, came out. Its language seemed to clarify the regulation a bit.

- "If the airplane has a **flight idle** position, this **would be appropriate**…"
- "**Some** turboprop-powered airplanes may demonstrate a relatively **high positive thrust** … **at flight idle**."
- "This thrust condition [flight idle] **may yield** an **unconservative (lower) stall speed**."
- "Some … method … should be available for **comparison of zero thrust** stall speed **and flight idle stall speed** … Residual jet thrust should be considered."
- "Use of **feathered propellers** is **acceptable if** the feathered stall speeds are **found to be conservative (higher)**."

When taken in its entirety, the circular appeared to say: use the higher, or more conservative, of either the idle-thrust or the zero-thrust stall speeds. The author did confirm this interpretation, as the correct interpretation, through the FAA's Military Certification Office. Thus, if idle-thrust turned out to be more conservative than the zero-thrust case, the recommendation to the program office would be to provide takeoff and landing data based on idle-thrust stall speeds.

Next, came the process of determining, rigorously, the idle-thrust stall speeds and that these speeds were the most conservative. At first, the author started with a Test Pilot School staff test project. To find the right cohorts took time. But eventually, a test plan was developed, and test flights were flown. However, the final test report became elusive because life got in the way. The author's primary engineer got sent to military school, then deployed, and finally

got transferred. This all started immediately after the flight test was completed. No final test report was ever generated. However, enough preliminary data was analyzed to show that the zero-thrust stall data published in the flight manual appeared accurate. Then, by limiting the scope to just idle-thrust stall determination, the author was able to bring the effort to a student test management project (TMP) team in Class 20A. Figure 10 shows the results of this test compared to the flight manual zero-thrust numbers.

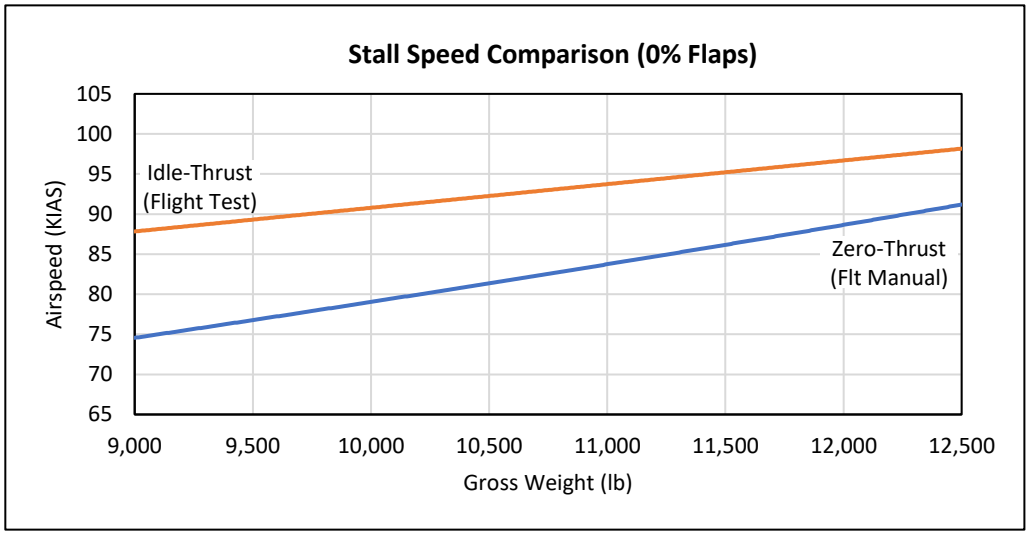

Figure 10: Idle-thrust and Zero-thrust Stall Speed Comparison

With this new knowledge, the author could finally discuss if the takeoff speeds should be adjusted. Looking at the certification basis one could argue that the published modified takeoff speeds, even with the idle-thrust stall speed, met the requirements of the basis.

- Takeoff Speed Definition, §23.51 (1965-1969)

  "**Upon reaching … 50 feet …** the airplane must have reached a speed of not less than 1.3 V_S; **or any lesser speed**, not less than V_X plus [4 knots], **that is shown to be safe** under any condition, including turbulence and complete engine failure."

The published flight manual value for takeoff safety speed, V_2, was at least 1.13 $V_{S\ (zero\text{-}thrust)}$, 1.05 $V_{S\ (idle\text{-}thrust)}$ and 1.11 V_{MC}. Though less than the 1.3 V_S criteria, one could argue that it meets the second criteria. But just because one could define takeoff speeds that low, should they use them? Today, the current industry standards are quite different than what they were in 1969. They take into account the possibility of engine failure near liftoff, and take into account the possibility of an abused, or off-speed, takeoff.

What are these current standards and how have they evolved over the years? In 1978, V_2 minimums increased to 1.1 V_{MC}. In 1987, V_1 was introduced stating it should be the higher of 1.1 V_S or 1.1 V_{MC}. And then in 1993, the minimum airspeed for V_2 was lowered to 1.2 V_S or 1.1 V_{MC}. Finally, in 1996 the current standards came into being, stating V_R should be the greater of 1.1 V_S, 1.05 V_{MC}, or V_1 while the minimums for V_2 did not change and stayed at 1.2 V_S or 1.1 V_{MC}. These current standards have withstood the test of time for over 25 years.

As currently published (figure 11), V_R speeds for the C-12C at both 0% and 40% flaps varied with weight from 1.03 V_{MC} to 1.17 V_{MC} and from 0.96 $V_{S\ (idle)}$ to 1.12 $V_{S\ (idle)}$ using the more conservative idle-thrust stall speeds. The speed at 50 feet, V_2, varied from 1.11 V_{MC} to 1.13 V_{MC} and from 1.05 $V_{S\ (idle)}$ to 1.16 $V_{S\ (idle)}$.

The author believes, mission requirements permitting, V_R and V_2 should be adjusted up as indicated in figure 10 to meet current industry standards. To be clear, these standards are protecting aircrew and passengers in the C-12 for a portion of a continued takeoff that is about 30 seconds after engine failure speed; a speed defined in the definition of V_1. If one lost an engine in this initial portion of the climb, and if their recovery or airspeed control was less than perfect, they would appreciate the extra margins the current standards provide. Now, losing an engine during this short flight period in the C-12 is extremely rare. So, the slower currently published takeoff speeds could be retained for use when mission requirements necessitate the acceptance of a higher degree of risk.

Charted V_R against $V_{S\ (idle)}$ & V_{MC}	To fix V_R, adjust up:
• 0% & 40% Flaps:	• 0% Flaps: 4 – 14 knots
• 1.03 V_{MC} to 1.17 V_{MC}	• 40% Flaps: 0 – 5 knots
• 0.96 $V_{S\ (idle)}$ to 1.12 $V_{S\ (idle)}$	
Charted V_2 against $V_{S\ (idle)}$ & V_{MC}	To fix V_R, adjust up:
• 0% & 40% Flaps:	• 0% Flaps: 4 – 14 knots
• 1.11 V_{MC} to 1.15 V_{MC}	• 40% Flaps: 0 – 5 knots
• 1.05 $V_{S\ (idle)}$ to 1.26 $V_{S\ (idle)}$	

Figure 11: Adjustments Required to Bring Takeoff Speeds Up to Industry Standards

For the reference landing approach speed, V_{REF} or V_{APP}, history is less dynamic. The certification basis had the minimum for V_{APP} as 1.3 V_S. In 1996, the requirement was added to also be greater than 1.05 V_{MC}. The published approach speeds fell into the range of 1.17 $V_{S\ (idle)}$ to 1.31 $V_{S\ (idle)}$. Again, the author believes these airspeeds should be adjusted up to 1.3 $V_{S\ (idle)}$ minimum for normal operations (figure 12).

Current V_{APP} against $V_{S\ (idle)}$ & V_{MC}	To fix V_{APP}, adjust up:
• 0% & 40% & 100% Flaps:	• 0% Flaps: 6 – 11 knots
• 0.87 V_{MC} to 1.08 V_{MC}	• 40% Flaps: 2 – 10 knots
• 1.17 $V_{S\ (idle)}$ to 1.31 $V_{S\ (idle)}$	• 100% Flaps: -1 – 9 knots

Figure 12: Adjustments Required to Bring Approach Speeds Up to Industry Standards

The current Edwards operational guidance that uses an outdated flight manual for mission planning cannot be sustained and a resolution is required. Currently, the proposal presented in this paper is being evaluated by the Air Force's C-12 Systems Program Office. The Class 20A TMP team recommended that the flight manual be updated with the more conservative flight-idle stall numbers and the author recommended that the takeoff and landing data be adjusted to meet the current industry standard minimum requirements for most missions. For those limited mission sets that require better performance, the option should be available to use the current modified aircraft takeoff and landing data with the knowledge that these numbers buy additional risk. Hopefully, the author has convinced the reader that blind faith in the

regulations can unwittingly increase one's operational risks. Selecting between idle-thrust and zero-thrust stalls speeds as well as selecting how one sets their takeoff and landing speeds can have very real ramifications to day-to-day operations.