AVIATION WEEK Intelligence NETWORK

Rethinking V1

James Albright June 21, 2021

A Boeing KC-135A tanker takeoff with water injection.
Credit: U.S. Air Force

Just about everyone these days has settled on the same litany of callouts during takeoff: “80 knots,” “Vee one,” “Rotate” and “Vee two.” Some operators use 100 kt. instead of 80 kt. and the V2 call is sometimes omitted. But “Vee one” is more or less universal. I have been using it since I started flying multiengine jets with multi-piloted crews. But I am ready for a change. This will seem to be an act of heresy to some. But the fact that most pilots do not understand V1 and the incorporation of V-speeds into many head-up displays (HUDs) begs for us to examine the concept of “Vee one” anew.

How It Used to Be (Life in Slow Motion)

My introduction to crew aircraft was the mighty Boeing KC-135A Stratotanker, outfitted with four Pratt & Whitney J57 engines that put out around 10,000 lb. of thrust each, unless you pumped in demineralized water, which got you up to around 13,000 lb. My fondest memory of KC-135A performance was sitting at the end of the runway at Andersen Air Force Base, Guam, fully loaded with Army troops and cargo headed for Diego Garcia in the Indian Ocean.

It was a typically hot day, and we were at our maximum gross weight of 297,000 lb. As the copilot, my most important duty was to activate the water injection system before brake release and then call “S1,” our version of what we civilians call V1, where the “V” stands for velocity. For these maximum weight takeoffs, both pilots were required to hold the brakes and count down the brake release, in order to preserve every possible inch of runway for all of that thrust. So, we were doing that, holding the brakes with the engines at their “dry thrust limit.” The noise and vibration were incredible, and I am sure the troops in back were wondering what they had gotten themselves into. The pilot ordered me to start the water injection and on this particular day, the system worked as advertised. Our 670 gal. of water were injected into those engines and the noise and vibration doubled. He counted down the brake release. “Five, four, three, two, one, release.”

And then…nothing -- 297,000 lb. of inertia is not easily overcome by 52,000 lb. of thrust. So, I started rocking back and forth in my seat to coax the airplane forward. I thought it was funny. The pilot did not. We slowly accelerated and 11,000 ft. of pavement later we were airborne. Performance typical of those conditions would have a V1 of 130 kt. and a rotation speed of 160 kt.

During our 13-hr. journey west, I overheard a passenger talking to our navigator about the takeoff, asking at what point he would have become scared. He said it was no big deal; he just timed the takeoff since he knew every takeoff takes just over a minute. I didn't know that, so I timed the next few takeoffs and found that for our airplane at heavy weights, 1 min. was about right.

I was thinking about that recently during a Gulfstream GVII takeoff where the takeoff call was "Vee one, rotate" because the numbers were close and the acceleration made both events happen almost simultaneously. V1 occurred 18 sec. after brake release and the "Rotate" call was made a second later, but that might have been a late call as V1 was 116 kt. and rotate was computed at 118 kt.

When it takes nearly a minute to get there, it is easy to keep a mindset of "If anything bad happens, I'm going to abort" until V1, and then shift that to "I'm going to go" after V1. When it all happens in 18 sec., it is easier to get confused.

Getting Confused

Wreckage of N999LJ, Columbia Metropolitan Airport (KCAE), South Carolina, Sept. 19, 2008. Photo credit: NTSB

Imagine the following cockpit "discussion" during a takeoff roll after a tire fails because it was underinflated:

First Officer: "Eighty knots. Crosscheck."

Captain: "Check."

First Officer: "Vee one."

About 1.5 sec. later, the cockpit voice recorder (CVR) captured the beginning of a loud rumbling sound.

First Officer: "Go!"

Captain: (unintelligible)

First Officer: "Go, go, go!"

Captain: “Go?”

First Officer: “No? Ar- alright. Get ah what the [expletive] was that?”

Captain: “I don’t know. We’re not goin’ though.”

This was from the CVR on N999LJ, a Learjet 60, during an attempted takeoff from Columbia Metropolitan Airport (KCAE), South Carolina, on Sept. 19, 2008. Both pilots and four of the six passengers died after the aircraft departed the runway. It is difficult to summarize what caused the crash, but we can list the events.

The initiating event was multiple tire failures due to severe underinflation. The captain initially reduced thrust for a second, added thrust for a second, and then fully committed to the abort about 3 sec. after the first rumbling sounds were heard on the CVR. It appears that 7 sec. later, the aircraft’s wheel speed sensors and weight-on-wheels system sustained damage that caused the thrust reversers to stow even with the thrust reverser levers deployed, resulting in forward thrust.

It is tempting to say the captain violated the seminal principal behind V1, a point at which a decision has been made. We call it “decision speed.” But it isn’t that at all. FAR Part 1.2 says: “V1 means the maximum speed in the takeoff at which the pilot must take the first action [e.g., apply brakes, reduce thrust, deploy speed brakes] to stop the airplane within the accelerate-stop distance. V1 also means the minimum speed in the takeoff, following a failure of the critical engine at Vef, at which the pilot can continue the takeoff and achieve the required height above the takeoff surface within the takeoff distance.”

When I say “We call it decision speed” I mean to say, just about everyone in authority calls it decision speed. Your training vendor, your instructors, even some of your favorite inspectors call it decision speed. The danger is that many of us think of V1 as “a speed at which a decision is happening.” Perhaps that compounded the situation for the captain of N999LJ. She was not expecting the loud rumbling noise and began the process of making a decision. The first officer made a good call: “Go.” As in, “We are going.” But the captain had not yet made up her mind. She was still in “decision making mode.”

I can’t second guess her; I’ve never been in her shoes. She may have never seen anything close to this situation other than in a simulator. Presented with a loud rumble, vibrations and performance that told her she had more than enough runway, no wonder she may have been confused. More importantly, I can see myself falling for the same indecision. You can call it “startle factor” if you like, but if we continue to train to make the decision at “decision speed,” we will continue to be susceptible to this type of confusion.

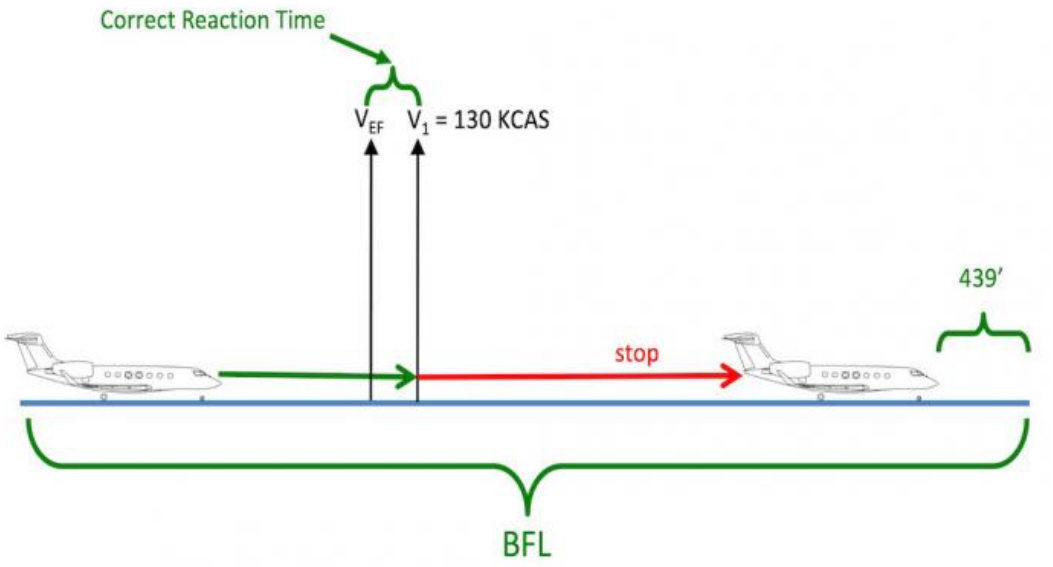
When I get on my soapbox on this topic, I expect a fair amount of head nodding. “Of course, we know that. We will either be aborting or continuing the takeoff at V1.” But if I persist in the discussion, I will invariably be told about the 2-sec. safety factor. I’ve even been told this at a name-brand training vendor on a slide with that vendor’s logo: “At V1, you have a 2-sec. safety factor.” The lesson here is: Make your decision at V1, do it quickly, but don’t worry because the numbers are based on you taking 2 sec. to do that. Hogwash.

The Two-Second Myth

There is a 2-sec. margin used in determining multiengine aircraft performance, but it isn’t used in determining V1. In fact, it is the opposite: V1 determines how the 2 sec. are applied when determining your balanced field length (BFL) numbers.

FAR Part 25.107 says V1 is established in relation to Vef (the calibrated airspeed at which the critical engine is assumed to fail) and that is used to determine accelerate-stop distance. Part 25.109 tells us that accelerate-stop distance is the sum of the distances needed to accelerate from a standing start to Vef with all engines operating, the distance consumed between Vef and V1, the distance needed to come to a full stop from that point, plus “a distance equivalent to 2 sec. at the V1 for takeoff from a dry runway.”

This made perfect sense to the engineer who wrote it, but for us pilots it is misleading. As with many issues like this, an example with a picture can make it clear. Let’s say you are flying a twin-engine Gulfstream GV on a standard conditions day that results in a V1 of 130 KCAS on a balanced field. (It will take you the same distance to abort as to continue the takeoff.) We will also say that the computed BFL equals the runway available; you don’t have an inch to spare.

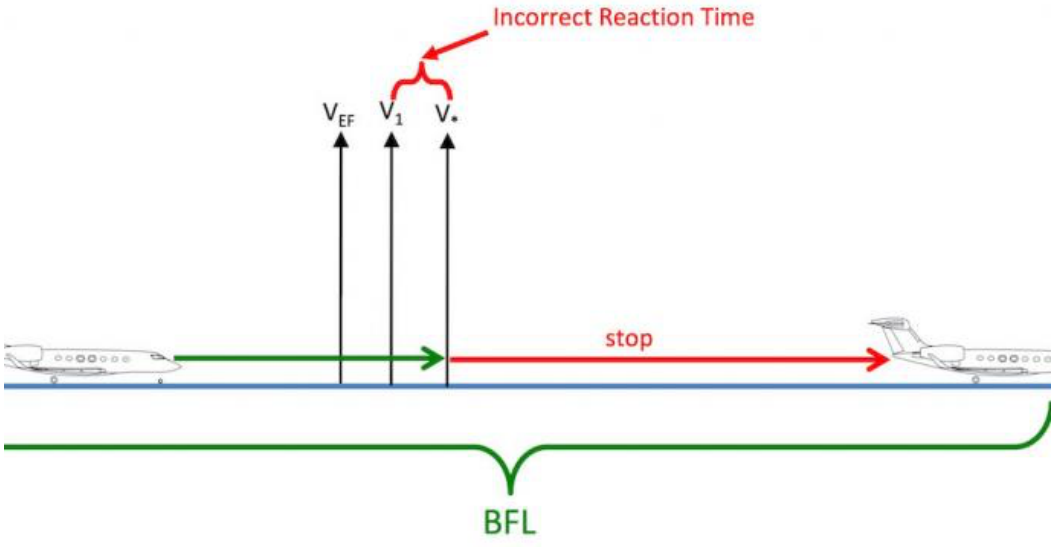


Example of a balanced field margin with a 2-sec. reaction completed at V1. Image credit: James Albright

The regulation requires the performance produce a balanced field number that you then apply to ensure you can take off safely. The given conditions will add a distance to the actual stopping distance equal to the distance your aircraft would traverse at V1 speed. In our example, we would travel 439 ft. in 2 sec. at 130 kt. (Multiply 130 nm/hr. by 6,076 ft./nm by 2 sec. and divide that by 3,600 sec./hr.) So, if you do everything just right, you will have 439 ft. of runway left over.

At this point, you may be tempted to say, "Aha! There is a 2-sec. decision time!" Sort of. Whatever time you take, that decision must be over no later than V1. To prove this point, let's say you begin a 2-sec. decision at V1.

Even with one engine operating you will still be accelerating. So, let's hypothesize that at the end of the 2 sec. you are doing 140 KCAS. Using the average speed of 135 KCAS you will have consumed an additional 456 ft. of runway. In this scenario, if you do everything else right, you will be 17 ft. beyond the end of the runway.



Example of a balanced field margin with a 2-sec. reaction started at V1. Image credit: James Albright

This may seem academic to you because the amount of time it takes to say ‘Vee one” is certainly less than a second for even the slowest talker in the cockpit, and we as pilots have reaction times measured in milliseconds. Or do we?

Editor's note: This is the first in a two-part article series on rethinking V1.

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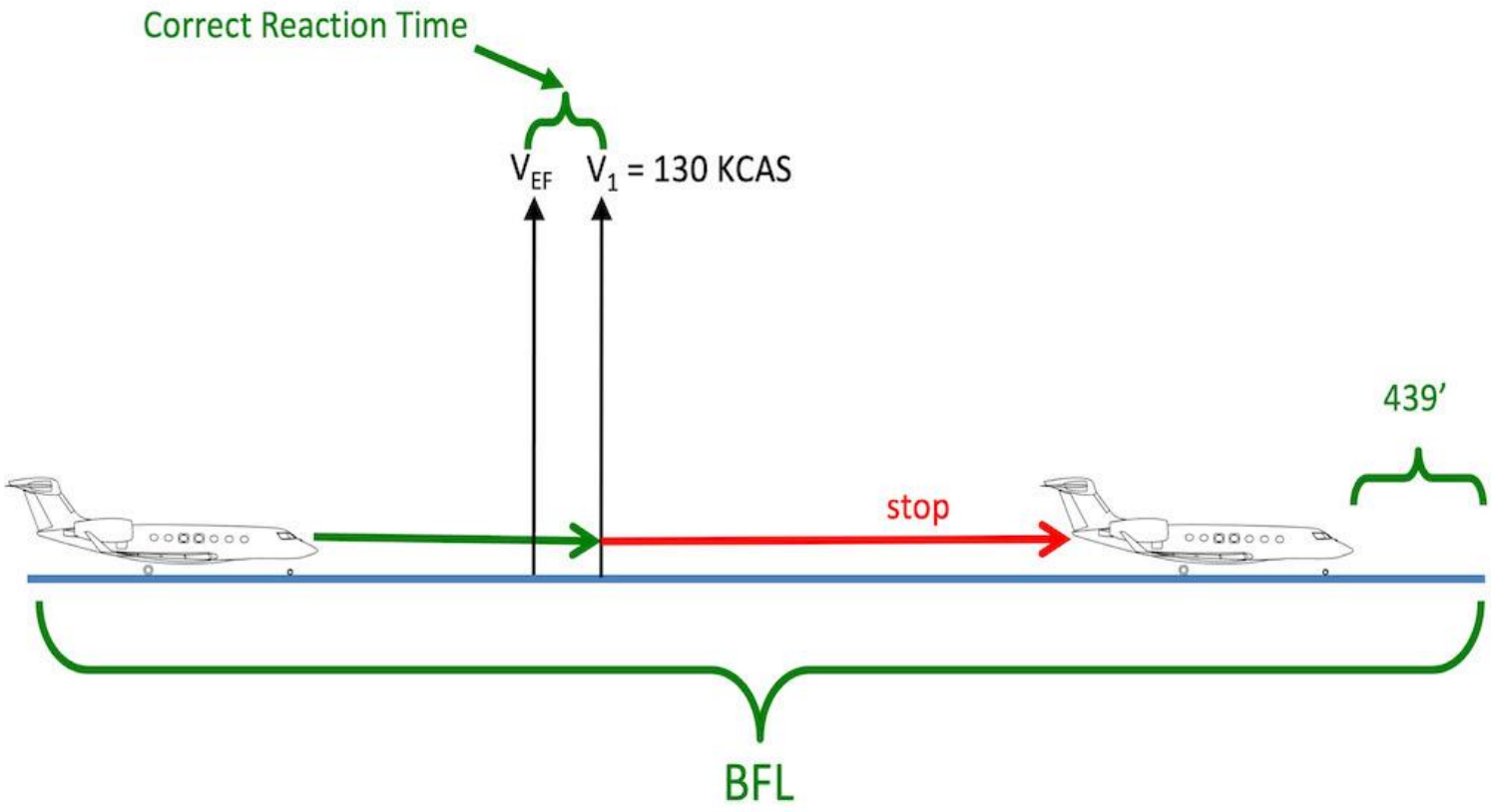
V1: Action Speed, Not Decision Speed

James Albright June 22, 2021



Credit: Image credit: James Albright

Editor's note: The first of James Albright's rethinking V1 article series appears here.

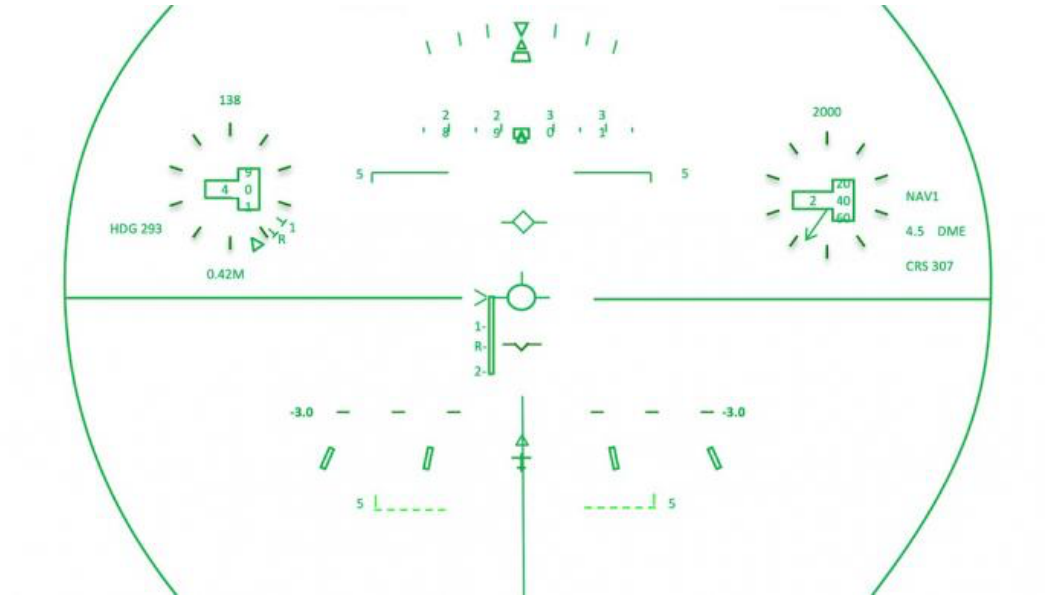
Neural reaction time has been said to be faster than the speed of light. (I must admit that I can't see how that is possible, but the list of things I can't see as possible is rather long.) I think the closest analogue to what we do in the cockpit is the everyday act of driving a car.

The University of Iowa conducted a test placing 192 subjects between the ages of 25 and 66 in a driving simulator. They were told it would be a 30-min. drive just to assess the look and feel of the simulator; they were not warned of a possible need for emergency action. The actual test drive took 15 min. and required a number of laps on a large two-lane "figure 8" course, driving at 45 mph on dry pavement. Each lap contained an intersection at the middle of the figure 8. On the last actual lap, with the drivers anticipating they were only halfway through the test, a vehicle appeared in their way at the intersection. The average reaction time from releasing the accelerator to maximum brake application was 2.2 sec.

You might say that we cannot compare a 30-min. drive to a 1-min. takeoff roll. Or we can say that we pilots are trained to react quickly and would certainly do better than 2.2 sec. Having suffered thousands of such decisions in hundreds of simulator hours (I stopped logging these 20 years ago), I can say that 2.2 sec. is about right for me.

I am betting your reaction time is faster than mine. Even if that is the case, you should by now agree that the words “Vee one” need to be articulated by the other pilot in time for you to hear those words, understand them, and then initiate your actions. If the pilot monitoring (PM) gets the “Vee” out at the same time you hear the “kaboom,” will your hearing and perception times allow you to continue the takeoff, as you should? It depends on when the PM says those words. When I am the PM, I try to say “Vee one” so as to finish the last syllable a few knots prior to V1. I used to assume my PMs were doing the same for me. All that changed when I started flying with head-up displays (HUDs).

Using a Head-Up Display



The HUD presentation prior to takeoff in a Gulfstream G450. Image credit: James Albright

Before flying with a HUD, the takeoff decision process was fairly simple for me. If something worthy of an abort happened before hearing “Vee one,” I would abort. Otherwise, I continued the takeoff. During takeoff in a Gulfstream G450, I incorporated a crosscheck of the airplane’s flight path vector (FPV) while maintaining directional control of the airplane. There is a vertical bar to the left of the FPV during takeoff that shows the V-speeds to come. As you accelerate, the tape shrinks and the speeds move up. In the example diagram, the aircraft has not yet released brakes, so you can see a “1” followed by an “R” and a “2” to denote V1, rotation speed and V2.

If this seems cosmic, consider that some Boeing and Airbus aircraft have a synthetic voice that makes the aural calls for you.

As I became more and more comfortable with the HUD, I subconsciously added the speed tape in my decision making. During one particular training session, I continued the takeoff before the PM’s “Vee one” call. The instructor let me know that I was a worthless human being and that I would have to try that again. I did it again. And again.

On my third try I figured out what was happening. When the speed tape showed us at V1, I shifted to the “go mode” even without the PM’s call. He wasn’t starting to enunciate “Vee one” until we had passed V1, because that’s how he was taught. The instructor still thought I was in the worthless category because the rules he had to evaluate me on said the abort criteria was based on the call, not the speed. Of course, that started a battle of seeing who could look up the regulations fastest. I am happy to say I prevailed.

That was almost 10 years ago. In the time since, I’ve noticed most pilots I’ve flown with in the simulator don’t start to say “Vee one” until passing V1. I blame it all on the name we give it: “decision speed.” V1 is not a decision speed. It is an action speed.

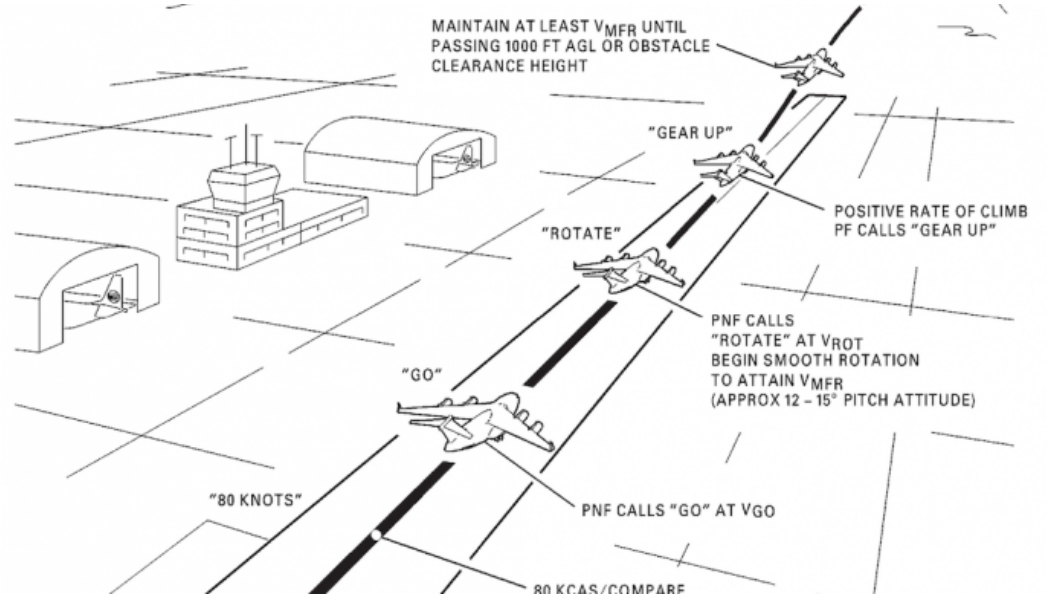
Action Speed

You may not have noticed this or think you have a problem, because you grew up making the V1 call at a certain point and don't have any evidence that you are making the call late. If you have a HUD with a V-speed tape, it will be easy enough to check. If not, try this exercise in the simulator. Ask your instructor to freeze the simulator right after the "Vee one" call during one of your takeoffs. You might be in for a surprise.

By the time you hear "Vee one," you have no takeoff/abort decisions left to make; if the airplane is flyable, you are going. The call itself is old news. I am wondering if we should ditch it altogether. Instead of saying "Vee one" at V1, we should be saying "Go!"

In the case of N999LJ, the first officer's "Go!" and "Go, go, go!" calls were suggestions from one pilot to the other. These calls did not have the same gravity as the V1 call. In the captain's mind, she was making a decision at V1. The first officer's "Go!" calls were added data that she chose to discount. I think had she been conditioned to think "go" at the "Go!" call, the outcome may have been different.

The word "Go!" should be complemented with the word "Stop!" in the case of an abort. We pilots like having a language all our own, but sometimes this goes too far. You know what "abort" or "reject" mean. But if you really want to get the other pilot's attention and action, there is no better word than "Stop!"



U.S. Air Force C-17 V-speeds. Image credit: U.S. Air Force

At least one part of the U.S. Air Force has adopted a system similar to this. Several of its airlift aircraft, such as the C-5 Galaxy and C17, replace V1 with Vgo. These, of course, are not FAR Part 25 certified aircraft and are not constrained by our civilian "we've always done it this way" mindset.

Can we adopt this idea when the entire industry has decades of "Vee one" at V1 experience? I don't know. But at the very least, we should be saying it to ourselves. If you have something like a V-speed tape, you should be thinking the word "Go!" when you get close to V1. If you don't have that kind of tech, you should discuss the issue with your PM. My preference is to say "Go!" when the time comes, but you should at the very least be thinking it: "Go!"