500 Meters to Spare

Dutch report on a high-speed rejected takeoff explores the 'RTO dilemma.'

BY MARK LACAGNINA

Problems began early in the takeoff when the first officer, the pilot flying, had difficulty keeping the Boeing 737-800 tracking the runway centerline at Eindhoven (Netherlands) Airport the morning of June 4, 2010. He also saw an unusual airspeed-trend indication on his primary flight display (PFD). Shortly after the captain called "V_1" and "rotate," the nose began to lift on its own and move left and right.

The first officer pulled back the thrust levers, automatically activating the autobrake and speed brakes. The captain took the controls, per standard operating procedure (SOP), and completed the rejected takeoff (RTO). The 737 came to a stop 500 m (1,640 ft) from the end of the 3,000-m (9,843-ft) runway. There were no injuries or damage to the aircraft.

The first officer told investigators for the Dutch Safety Board (DSB) that he rejected the takeoff after V_1 — the *maximum* airspeed at which the first action should be taken to initiate an RTO — because he believed that the aircraft was not safe to fly.

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In the final report on what it characterized as a serious incident, the DSB did not fault or condone the first officer's decision.[1] A perception that an aircraft is unsafe to fly is *the* universally accepted reason for conducting a high-speed RTO. The board merely said, "Rejecting a takeoff above V_1, especially when the nosewheel is off the ground, is in principle considered to be improper and unsafe."

In addition to presenting the facts gathered about the incident — an effort that was hindered by the board's lack of access to the 737's cockpit voice recorder — the report explores the V_1 concept, the nature of high-speed RTOs and the "dilemma" faced by pilots who must make a split-second decision armed with limited training and guidance.

Return Trip

The flight crew had flown the 737, operated by Ryanair, from Faro, Portugal, to Eindhoven, a joint civil/military airport, earlier that morning. The captain had 3,628 flight hours, including 2,061 in type. The first officer had 2,300 flight hours, including 1,170 in type.

The report did not specify how many passengers were aboard for the return flight to Faro, which was scheduled to depart at 1030 local time.

As the aircraft was taxied from the gate, the first officer performed a flight control check and observed no anomalies.

The airport traffic controller told the flight crew to depart on Runway 04 from an intersection, but the crew requested and received clearance to begin the takeoff from the approach end, thus using the full length of the runway.

The crew had derived the following takeoff speeds from the aircraft flight manual: 140 kt for V_1 and 141 kt for V_R, or rotation speed. V_1 is defined erroneously by the Ryanair flight crew operations manual — and by many other publications — as "takeoff decision speed" (see p. 23). European regulations define V_1 as follows:

> *V_1 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. V_1 also means the minimum speed in the takeoff, following a failure of the critical engine at V_{EF}, at which the pilot can continue the takeoff and achieve the required height above the takeoff surface within the takeoff distance.*

V_{EF} is the speed, set by the airplane manufacturer for performance certification, at which the critical engine is assumed to fail during takeoff.

V_1 and V_R are designated with symbols on the airspeed scales displayed on the captain's and first officer's PFDs. Also relevant to this incident is the display of a trend vector — a green arrow — on the airspeed scale. When the aircraft is accelerating or decelerating, the green arrow points upward or downward from the current airspeed shown on the vertical scale to the airspeed predicted to be reached within 10 seconds. The trends are computed by the air data inertial reference units (ADIRUs) from airspeed and longitudinal-acceleration data.

Troubling Trends

The winds were reported from 030 degrees at 5 kt, gusting to 10 kt, when the crew began the takeoff from Runway 04 at 1045.

The first officer selected the autothrottle takeoff mode, and the captain placed his hand near the thrust levers, per SOP. Typically, Ryanair places the responsibility for an RTO decision solely with the captain. In this case, however, the first officer made the decision, and the captain backed him.

The first officer initially had difficulty maintaining directional control but stabilized the aircraft on the runway centerline before airspeed reached 60 kt. Both pilots told investigators they believed that the heading deviations had been caused by asymmetric engine power.

A cross-check at 80 kt revealed no airspeed deviations, but when heading deviations recurred at 90 kt, the captain suspected an engine problem and again checked the engine indications. However, "the left and right engine parameters were found to be correct and symmetric," the report said.

As airspeed neared 140 kt, the first officer observed that the trend vector on his PFD predicted a large *decrease* in airspeed. At the same time, the airspeed scale on the captain's PFD showed a trend toward an inordinately large increase in airspeed. According to statements made during the investigation, neither pilot commented on the unusual trend indications.

"There is no reference in any manual or training program as to how the speed trend information should be used or monitored during takeoff," the report noted.

'Atmospheric Disturbance'

Shortly after the captain called "V_1" and "rotate," and removed his hand from the thrust levers, large lateral accelerations began, and the aircraft pitched 1.4 degrees nose-up, lifting the nosewheel off the runway for nearly two seconds.

Recorded flight data showed that airspeed was 152 kt, or 12 kt above V_1, when the first officer brought the thrust levers to idle. The 737 reached a maximum of 160 kt during the RTO; maximum deceleration was 0.56 g.

After the 737 was taxied back to the stand, smoke was observed coming from the overheated brakes. "Consequently, the crew decided to disembark the passengers and let the brakes cool off," the report said.

The recorded data showed that different airspeed and angle-of-attack (AOA) values had been computed by the captain's and the first officer's ADIRUs. Investigators concluded that the unusual airspeed trends displayed during the takeoff had been caused by an "atmospheric disturbance" that had affected the airspeed and AOA sensors located on either side of the fuselage. The uncommanded rotation and the large lateral accelerations also were ascribed to an "external, possibly atmospheric phenomenon."

However, "an explanation or cause for the atmospheric disturbance could not be determined," the report said. Investigators ruled out wake turbulence from a light aircraft that preceded the 737 on takeoff. They also found no evidence that mechanical turbulence from buildings and structures near the runway had caused the disturbance.

RTO Dilemma

The report said that pilots face a dilemma when confronted with a situation that might necessitate a high-speed RTO — that is, an RTO initiated above V_1. The dilemma is caused, in part, by current guidance that leaves much to pilot interpretation and judgment.

For example, the quick reference handbook (QRH) for the Ryanair 737 contains both *prescriptive* and *general* rules for rejecting a takeoff. Among the prescriptive rules is that an RTO should be initiated if an engine fire warning occurs below 80 kt. "This 'if-then' rule is accommodating in the decision-making process and takes little processing time if such a circumstance is detected," the report said.

General rules are not so accommodating to decision making. For example, the 737 QRH echoes many other guidance documents in saying that a high-speed RTO should be conducted only if the aircraft is "unsafe or unable to fly."

"This general rule takes time to process, evaluate circumstances, apply and take appropriate actions," the report said. Moreover, the terms are not defined and leave room for interpretation.

At the DSB's request, Boeing provided the following definitions:

> *Unsafe to fly — the circumstance whereby rejecting the takeoff carries significantly less risk than flying the aircraft.*

Only an engineered material arresting system kept this CRJ200 from plunging down a steep cliff during a high-speed RTO at Charleston, West Virginia, U.S., in January 2010.

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Unable to fly — the circumstance where there is a reasonable probability of not being able to control the aircraft if the takeoff is continued and the aircraft becomes airborne.

The report said that these definitions also require interpretation and pilot judgment. "The reason given for not defining circumstances which fall under the 'unable' or 'unsafe' to fly [conditions] is that this may lead to misunderstanding among crews and ultimately to incorrect decision making."

The DSB recommended a re-evaluation of the RTO concept and procedures in light of current technology and human factors research. "During takeoff, the time to make a decision and take action is minimal; guidance and training are therefore essential," the report said. "With rules that require interpretation and judgment, pilots face a dilemma in a potentially critical time situation."

RTO Research

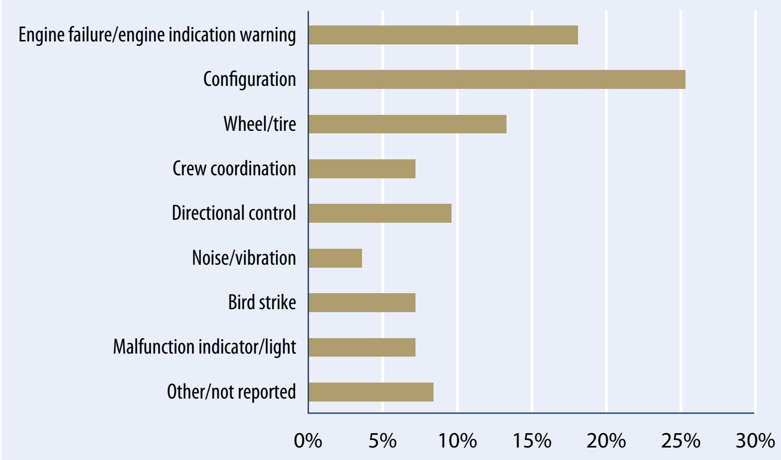
Citing research performed by several organizations, including the National Aerospace Laboratory (NLR)–Netherlands and Flight Safety Foundation (FSF), the DSB report noted that although the RTO concept and pilot training for RTOs focus on engine failures, less than one-quarter of all RTOs actually are conducted because of engine failures.

Gerard van Es, senior consultant on flight safety and operations to the NLR Air Transport Safety Institute, found in a study of 72 high-speed RTOs between 1994 and 2008 that 18 percent were prompted by engine failures or warnings.[2] The study focused on jet and turboprop airplanes with maximum weights above 5,500 kg (12,125 lb).

Configuration issues — including incorrect flap and flight control settings, and weight and balance problems — topped engine failures as prompting 26 percent of the high-speed RTOs during the period (Figure 1).

Among the other reasons for initiating a high-speed RTO were problems with wheels or tires (13 percent); directional control (9 percent); crew coordination, bird strikes and malfunction indications (7 percent each); and noises or vibrations (3 percent).

Causes of High-Speed RTOs, 1994–2008



RTO = rejected takeoff

Source: Gerard W.H. van Es

Figure 1

The study found that nearly half (44 percent) of the high-speed RTOs should not have been conducted. "This is clearly in hindsight, as most pilots really thought they were making the right decision at the time," van Es said, noting that RTOs often are conducted for more than one reason (as in the 737 incident at Eindhoven).

"Assessing such complex situations is difficult and often not well-trained," he said. "There are often no references as to what might make the aircraft 'unsafe to fly.' The data suggest that pilots have difficulty in taking a correct decision to continue the takeoff past V_1."

Detect, Decide, Act

Van Es found that high-speed RTOs led to 1.4 accidents and/or serious incidents per 10 million takeoffs in 1994–2008.

He also found that the rate of accidents and serious incidents involving high-speed RTOs is decreasing. The rate was 1.9 from 1980 to 1993, or 25 percent higher. Van Es noted that the decreasing rate might be due to more reliable engines and tires, improved maintenance and the publication in 1993 of the *Takeoff Safety Training Aid*.[3]

The 298-page training aid, which includes the 1990 report on the U.S. National Transportation Safety Board's special investigation of RTOs, was developed by the U.S. Federal Aviation Administration (FAA) and the aviation industry.

Van Es stressed that although the definition of a high-speed RTO is one in which the first *action* to reject the takeoff is made above V_1, the *decision* to reject often is made below that speed. This was the case in one in every 10 of the high-speed RTO accidents/incidents in the 1994–2008 data set.

Timely reaction to an event requiring an RTO is critical, he said. In many cases, the airplane continues to accelerate at 3 to 6 kt per second, and the available runway length decreases as the crew recognizes and/or calls out a problem, makes a decision to reject the takeoff and takes the first action to do so.

Current transport airplane certification standards build in a detection time of only one second. Then, "for pilots, it is difficult to make the right decision with limited time available," van Es said. Even if the correct decision is made, significant delays in taking action still occur.

Current training practices may be contributing to the delays. "Currently, pilot simulator training often presents RTOs as engine-related events, [although] the majority of RTO accidents are not related to engine problems," he said.

Pilots should be trained for RTO events other than engine failures or fires, van Es said. He also recommended that the *Takeoff Safety Training Aid* be revised and "brought back to the attention of the aviation community."

Common Risk Factor

In a study of takeoff excursion accidents, Flight Safety Foundation found that "the most common risk factor … was an RTO initiated at a speed greater than V_1."[4]

High-speed RTOs were involved in nearly half (45 percent) of the 113 excursion accidents — runway veer-offs and overruns — involving fixed-wing aircraft weighing 12,500 lb/5,700 kg or more from January 1995 through March 2008.

The FSF report on the study said that many high-speed RTOs "resulted from pilots' perceptions that their aircraft may have suffered a catastrophic failure that would not allow safe flight." The perceptions often were erroneous, indicating that "many pilots may be predisposed to respond by stopping, rather than by going," the report said.

"The repeated fear that the airplane might not safely fly, given some disconcerting event occurring at or after V_1, indicates a possible deficit in pilots' understanding of airplane performance and in their appreciation for the low probability of circumstances that would truly prevent safe flight."

The DSB, the NLR's van Es and the Foundation agree with a recommendation made 18 years ago by the *Takeoff Safety Training Aid* — that training is the key to prevent mishaps resulting from high-speed RTOs.

"In the final analysis, the pilots operating the flight are the ones who must make the go/no-go decision and, when necessary, carry out a successful RTO," the training aid said. "They need appropriate training to assure that they can and will do the best job in the very difficult task of performing a high-speed RTO."

Notes

1. DSB. "Rejected Takeoff After Takeoff Decision Speed 'V_1'; Boeing B737-800, at Eindhoven Airport, 4 June 2010." The English version of the report is available at <www.onderzoeksraad.nl/en/index.php/onderzoeken/afgebroken-start-2010040/>.
2. Van Es, G.W.H. "Rejecting a Takeoff After V_1 — Why Does It (Still) Happen?" Presented at the FSF European Aviation Safety Seminar in Lisbon, Portugal, on March 15–17, 2010. A report, NLR-TP-2010-177, based on this presentation is available at <www.nlr-atsi.nl/id~13386.html>.
3. The *Takeoff Safety Training Aid* is available on the Foundation's Web site at <flightsafety.org/files/RERR/TakeoffTrainingSafetyAid.pdf>.
4. FSF. *Reducing the Risk of Runway Excursions: Report of the Runway Safety Initiative*. The report is available at <flightsafety.org/current-safety-initiatives/runway-safety-initiative-rsi>.