Calculating ERRORS

Mistakes in determining takeoff parameters are frequent, a French study says, and methods of detecting them are not always effective.

BY LINDA WERFELMAN

Errors involving the entry of takeoff data into flight management systems, or other performance calculators, are frequent and occur regardless of aircraft type, equipment type and airline, according to a report released by the French civil aviation authority and accident investigation agency.[1]

These errors typically are detected by use of the airline's operating modes or by "personal methods," such as mental calculations, said the report on the study by Laboratoire d'Anthropologie Appliquée (LAA).

Half of the pilots surveyed at one of the two airlines that participated in the study said that they had experienced errors in parameters or configuration at takeoff, some of which involved the input of aircraft weight into the flight management system (FMS).

The study was prompted by two similar serious incidents — the first involving an Air France Airbus A340-300 at Charles de Gaulle Airport in Paris in July 2004 and the second involving a Corsairfly Boeing 747-400 at Orly Airport in Paris in December 2006.

"The common cause of these two events was the crew entering much lower than normal takeoff weights and values for associated parameters (thrust and speed)," the report said. "The effect in each case was an early rotation with a tail strike on the runway, followed by a return after dumping fuel. Beyond the damage to the aircraft, these takeoffs were undertaken with inadequate thrust and speed, which could have led to a loss of control of the aircraft."

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Other similar incidents have occurred elsewhere in recent years. Typical incidents involve new-generation aircraft and errors in entering takeoff parameters that went undetected by flight crews, the report said.

The most serious event was the fatal Oct. 14, 2004, crash of an MK Airlines 747-200SF that failed to gain altitude on takeoff from Halifax, Nova Scotia, Canada, because of the flight crew's unknowing use of an incorrect aircraft weight when crewmembers calculated takeoff speeds and thrust settings. All seven crewmembers were killed in the crash and subsequent fire, and the airplane was destroyed (*ASW*, 10/06, p. 18).

The study, which was initiated after the Bureau d'Enquêtes et d'Analyses (BEA) completed its investigation of the 2006 incident at Orly, was designed to review the "processes for errors specific to the flight phase prior to takeoff and to analyze the reasons why skilled and correctly trained crews were unable to detect them," the report said.

Manufacturer Definitions

Both Airbus and Boeing have published documents discussing takeoff speeds. Airbus characterizes takeoff speeds as a "key element of safety for takeoff" and cautions that "using erroneous values can lead to a tail strike, a takeoff rejected at high speed or a climb with reduced performance." Errors in speed calculations frequently result from last-minute changes, time pressure or a heavy workload, and cross-checking calculations can be difficult because of the workload of the pilot flying during pushback and taxi, Airbus said.

The Boeing document said that, if input values are correct, other related errors can occur in several areas, including data conversion, selecting weight on a load sheet, selecting the table to be used in manual calculations or selecting high-lift flaps.

Procedural Analysis

The report included an analysis of procedures used to input and verify takeoff performance data for Air France 777s, A340s and 747s, and Corsairfly 747s; ergonomic inspections to identify conditions that can result in operating difficulties for flight crews; and a review of 10 incident reports that involved the use of inappropriate takeoff parameters.

The incident report reviews paid particular attention to methods of obtaining weight data, calculating takeoff speeds, inputting parameters into the FMS (when one existed) and displaying speeds.

For example, a crew must determine its fuel needs before the airplane is loaded and the weight is known; as a result, they may estimate the required fuel based on the forecast load data, with the last of the fuel being added after the final load has been determined, the report said.

A variable in the function is the quality of communication between the flight crew and ground personnel. Procedures are not identical at all airports, and communication sometimes suffers, the report said.

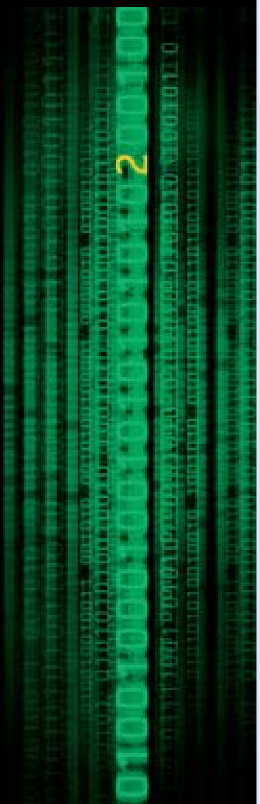
An effective check of the amount of fuel in the airplane can be obtained by observing the FMS or a fuel gauge; the indicated quantity varies as fueling progresses. Gauge accuracy may improve when tanks contain little fuel, the report said, noting that the amount of onboard fuel can be estimated "by adding the fuel remaining to the quantity flowed."

Load sheet data include the aircraft basic weight; the load, which can be known only after embarkation has been completed; and the fuel quantity — the amount of fuel decided on by the flight crew.

"The time the load sheet becomes available is one of the main factors in variability," the report said. "Several versions of this document can follow one another; the forecast report sometimes used for the refueling decision is eventually replaced by a final version issued to the crew after the completion of embarkation."

Calculations

Takeoff weight (TOW) is one item included in calculations of takeoff parameters — calculations that are performed either manually or by computer and either by the flight crew or remotely, with ACARS (aircraft communications addressing and reporting system) transmission, for example.



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Of the 10 incident reports examined in the study, nine described events involving a "major failure" that occurred during calculations, including two events in which the previous flight's weight parameters were used. In another event, the manual used to calculate speed did not match the aircraft type. In six events, an incorrect weight was used in the calculations; for example, zero fuel weight (ZFW) instead of TOW was entered into ACARS or into a laptop computer, the report said.

"These failures highlight the ineffectiveness of controls on this function," the report said. "Even an input with cross-check doesn't guarantee the absence of an error, as one of the studied incidents shows: The captain calls out the value to be input and confirms the input made by the copilot. However, the captain doesn't read the appropriate value, so calls out an erroneous value and the verification of input is ineffective."

The report suggested that a more effective check might be a double calculation. However, the report said, "Not only must the calculation be done twice, but the selection of input data [must be performed twice] as well.

"In one of the incidents studied, the captain carried out a check of the calculation without confirming the TOW and so used the erroneous TOW to check the speeds and hence obtained the same (erroneous) values as the copilot."

Input of FMS Data

Six of the 10 incidents involved airplanes equipped with an FMS. In one incident, a major failure was associated with the input of FMS data: A typing error associated with a late change that was made without a cross-check resulted in an incorrect entry of V1 (defined in the report as "decision speed").

"In the other five cases, the input speed values were erroneous," the report said. "The error arose from the parameter calculation function. … During verification of the calculation, the input of these values is one of the steps where inconsistency of the values with the aircraft load and takeoff condition could be detected. However, simple verification of a match between the elements input and the data shown on the 'card' does not allow the error to be detected."

Some FMSs calculate reference speeds — V1, Vr (rotation speed) and V2 (takeoff safety speed) — and the report suggested that these speeds could be displayed and used for comparisons when flight crews check the speed input function. Nevertheless, the report noted that two incidents involved airplanes equipped with this type of FMS, and the feature did not enable the flight crew to identify mistakes in speed calculations.

Four incidents involved airplanes without an FMS, and in these situations, the reference speeds displayed on the primary flight display (PFD) also are derived from the parameter calculation function, using either the takeoff card or a laptop screen.

Crews can verify that the correct speeds are being displayed by checking those numbers against those on the takeoff card, or by noting the relative position of the speed index and the redundancy of displays, the report said. However, in the four incidents in which the airplanes did not have an FMS, the presence of these elements did not aid in error detection, the report said.

"Even an input with cross-check doesn't guarantee the absence of an error."

Takeoff Parameters

The report identified five steps in the takeoff phase of flight: acceleration to V1, callout of V1, acceleration to Vr, callout of Vr and rotation at Vr. If the crew detects an anomaly before the airplane reaches V1, the takeoff can be rejected.

"V1 is a reference in the decision to continue or reject takeoff," the report said. "However, this reference comes from a calculated value, and in the event of an erroneous value, safety aspects — either a possible stop before the end of the runway or continuation with an engine failure — are no longer guaranteed."

In one of the incidents, the flight crew determined that the aircraft's behavior was atypical and rejected the takeoff after V1 was displayed but before the airplane actually reached that speed, the report said.

In another incident, the pilot not flying (PNF) called out Vr just after the airplane had accelerated to V1. "The failure rises here from the erroneous link made by the PNF between the achievement of V1 and the achievement of Vr," the report said. "This underlines the time pressure placed on the PNF as soon as he detects the signal indicating that Vr has been reached, as well as the inadequate control of this function."

Proposals for Improvement

Analysis of the 10 incidents included the identification of four types of "barriers" designed to prevent errors:

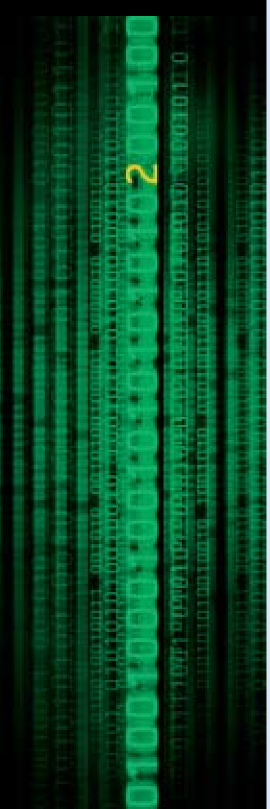
- Physical barriers, such as an aircraft "tail shoe" designed to mechanically protect the fuselage and physically prevent an unwanted event from occurring. Such systems typically present more disadvantages than advantages.

- Functional barriers, which are designed to limit input errors by enabling automated systems to perform basic checks. The report suggested that software controls could be strengthened — for example, software could be developed to check consistency between the V1, Vr and V2 values entered into the system.

- Symbolic barriers in procedures and guidance, which require "interpretive action" to achieve their goal. For example, the report cited the inclusion in all FMSs of a function for the calculation and presentation of reference speeds. The function currently is available only in some FMSs. Nevertheless, the report said that incidents have shown that "the simple presentation of reference speeds by the FMS does not constitute an effective symbolic barrier. Strengthening of this barrier could be considered by providing a warning message in the event of significant differences, or a display of these differences."

- Barriers in safety policy and user knowledge, which may be directed toward strengthening training for emergency situations and enhancing pilot familiarity with — and memory of — takeoff parameters. The results of these barriers are more difficult to measure than the results of other types of barriers.

This MK Airlines Boeing 747 crashed on takeoff from Halifax, Nova Scotia, Canada, in 2004, after the crew unknowingly used an incorrect aircraft weight to calculate takeoff speeds and thrust settings, investigators said.



Airline Survey

A survey of 19 captains and 11 first officers at Corsairfly found that 50 percent had experienced a takeoff that "was or could have been carried out with reduced safety margins because of erroneous parameters."

The most frequently reported errors occurred in two categories:

- Five errors inputting weights into the FMS. Two of the five errors were detected after takeoff, two others were detected before takeoff, and a description of the fifth error said that it was detected when the copilot "was reading speeds following a disagreement with the captain."

- Five errors inputting the runway in use into the FMS. All five were detected before takeoff, although one input error was discovered during of application of thrust at takeoff, with the appearance of the "verify INS [inertial navigation system] position" warning.

Other reported errors involved two cases of mistakes in configuration, two cases in which reference speeds were either miscalculated or not displayed on the PFD and one case of an erroneous thrust display.

When questioned about their "principal constraints … from preparation until takeoff," 15 pilots cited time constraints, 12 cited interruptions and two cited the late delivery of the final load sheet to the cockpit.

Flight Observations

Observations of flight preparations showed that the flight crews' workload increased as departure time approached and that the captain's activities were especially subject to interruption.

Observations also showed that flight crews arrived in the cockpit one hour to 2 ½ hours before takeoff, and that the final load sheet was delivered to them about 20 to 45 minutes before takeoff. Some crews calculated takeoff parameters before arriving in the cockpit. Others waited until after their arrival, and times varied from 16 minutes to one hour before takeoff.

In some cases, calculations were repeated; for example, to account for a tail wind and for wet runway conditions.

On one observed flight, reference speeds were not input into the FMS, the report said.

"During this flight, reference speeds were calculated by the FMS [and] a 'card' was edited by the crew, but speeds were not entered into the FMS," the report said. "During takeoff, the crew used the takeoff card to call out V1, which would have been called out by the equipment if the speeds had been entered, and Vr. This omission highlights the lack of robustness in the system that enables takeoff to be carried out without input of speeds into the FMS."

The report said that theoretically, the final TOW should be used to calculate parameters — a provision that means the calculations cannot be performed until after the crew has received the final load sheet. In five of the 14 observed flights, however, the parameters were calculated before delivery of the load sheet.

There are two types of controls — checking input data and speed data, the report said. Crews typically assigned priority to one or another of these controls, but usually not to both, the report said, adding that there was no control based on a comparison of the final load sheet, the takeoff card or laptop information, and the FMS.

"The final load sheet is actually the reference source, whatever the airline and the equipment used," the report said. "Obtaining this document is the determining step that influences calculation and input of takeoff parameters into the FMS. Making these final data available late generates a great number of tasks to be carried out in a limited time and creates time pressure. To deal with this, airlines and crews adopt different operating methods."

Note

1. LAA. *Use of Erroneous Parameters at Takeoff*, report prepared for the BEA and the Direction Générale de l'Aviation Civile, DOC AA 556/2008. May 2008.