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Faulty Angle-of-attack Sensor Provokes Go/No-go Decision with an Inadequately Coordinated Crew

Barely one second after rotation, the first officer, who was flying the Lockheed L-1011, decided that the aircraft was not going to fly and told the captain "You got it." The captain, faced with a split-second decision, chose to reject the takeoff.

by
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On July 30, 1992, Trans World Airlines (TWA) flight 843, a Lockheed L-1011, underwent an aborted takeoff shortly after liftoff from John F. Kennedy International Airport (JFK), Jamaica, New York, U.S. The aircraft was destroyed, but there were no fatalities.

The accident occurred at 1741 local time in daylight visual meteorological conditions.

That takeoff focuses attention once again on decision time and transfer of command and control in the cockpit.

Exactly how much time does the pilot of an aircraft have to make the decision to reject or abort a takeoff or to continue with the takeoff and get airborne? Depending on the aircraft's airspeed, is it better to abort or continue with the flight?

When the first officer is the pilot flying and a problem develops during the takeoff roll, does that pilot retain control of the aircraft or give it to the captain, and, if so, is this the best course of action?

These questions are not new to the U.S. National Transportation Board (NTSB). The NTSB's viewpoints, among others, were discussed in "Facing the Runway Overrun Dilemma," published in the September 1990 *Accident Prevention*.

"There is little question that a decision to abort or take off must be made in a matter of seconds," the article said. “That time frame does not cater to procrastination and pilots are forced to evaluate the aircraft’s problem, runway length, airplane speed and other factors correctly and quickly.”

The NTSB makes the point that in many of the RTO (rejected takeoff) related accidents and incidents, the first officer was flying and there may have been a problem with transferring control of the airplane from one pilot to another.

NTSB *Aircraft Accident Report PB93-910404*, NTSB/AAR-93/04, adopted March 31, 1993, details the NTSB’s investigation and findings of the TWA accident.

There were 280 passengers and a crew of 12 on board flight 843. In addition to the captain, first officer and flight engineer, there were nine flight attendants. Two off-duty TWA pilots (seated in the cockpit jumpseats) and five off-duty flight attendants (three seated in cabin attendant positions) were among the passengers. Every available seat was occupied.

The captain chose to reject he takeoff. At 1741:38, the JFK tower broadcast, “TWA 843 heavy, numerous flames.”

The captain was hired by TWA in May 1965. He had an airline transport pilot rating. He had a total flight time of 20,149 hours, including 15,854 hours as a pilot with TWA. The captain had spent 2,397 hours in the L-1011; 1,574 were as captain.

The first officer was hired by TWA in February 1967 and had an airline transport pilot rating and a total flight time of 15,242 hours, including 13,793 hours with TWA. He had spent 4,842 hours as a first officer, 2,953 hours of which were in the L-1011, plus 2,230 hours as a flight engineer in the L-1011.

The flight engineer was hired by TWA in September 1988 and had a total flight time of 3,922 hours, 2,302 of which were with TWA. He had a total time of 2,266 hours as a flight engineer on the L-1011.

The airplane had a gross weight of 431,773 pounds (195,852 kilograms) when it taxied from the gate for takeoff. The maximum allowable taxi weight for this model was 432,000 pounds (195,955 kilograms). With an estimated 2,800 pounds (1,270 kilograms) of fuel expended during taxiing for takeoff, the airplane had a takeoff gross weight of about 428,973 pounds (194,582 kilograms). The maximum allowable takeoff weight was 430,000 pounds (195,048 kilograms); the maximum allowable landing weight was 358,000 pounds (162,389 kilograms).

The flight was cleared to push back from the gate at 1716:12 and cleared to taxi to runway 13R, 14,572 feet (4,444 meters) long. The first officer was at the controls for takeoff.

The cockpit voice recorder (CVR) recorded the captain calling out “V_1” at 1740:58. At 1741:03, he called “V_R.” At 1741:11, the first officer said, “Gettin’ a stall,” and 1.4 seconds later he said, “You got it.” At 1741:13, the captain said, “OK,” and at 1741:15, there was a sound of a snap, followed by the captain saying, “Oh Jes—.” The first officer then said, “Abort, get it on.” The flight engineer said, “Get it off.” The first officer then said, “Get it on,” followed by the flight engineer who said “Get it off.” At 1741:20, the captain said, “What was the matter?” The first officer said, “Getting a stall.” At 1741:32, the first officer said, “Stay with it,” followed by “Stay on the brakes, stay on the brakes.”

The captain chose to reject the takeoff. At 1741:38, the JFK tower broadcast, “TWA 843 heavy, numerous flames.” The flight data recorder (FDR) showed that the airplane was airborne for about six seconds.

The NTSB report said, “Tire marks on the runway and furrows in the soil indicated that the left main landing gear departed the left side of the runway about 11,350 feet [3,462 meters] from the runway threshold. The right main landing gear departed the left side of the runway about 13,250 feet [4,041 meters] from the threshold. There was also a blackened and burned streak on the runway, beginning about 12,650 feet [3,858 meters] from the threshold. The streak ran in conjunction with the tire marks off the left side of runway and continued to the point where the airplane came to rest, upright and on fire, on grass-covered soil, about 296 feet [90 meters] to the left of the departure end of runway 13R, on a heading of about 100 degrees, approximately 14,368 feet [4,382 meters] from the threshold of the departure runway.”

Witnesses reported that “fuel escaped and ignited soon after the airplane touched down.” After the aircraft came to a stop, the captain ordered the evacuation of the aircraft and entered the cabin to direct the evacuation (which took one to three minutes) through the most forward right and two forward left cabin exits. Smoke and fire prevented evacuation from another exit on the right side. The captain was the last person to exit the airplane. The NTSB said the crew, including those off duty, “performed exceptionally well in the evacuation.”

Ten reported injuries, mostly minor, occurred during the evacuation. The aircraft, valued at US$12-13 million, was destroyed by fire.

The captain told the NTSB that the takeoff was made using standard TWA procedures: When the first officer was making the takeoff, the captain maintained control of the thrust levers until the landing gear was retracted. The captain stated that he advanced the power for takeoff and that acceleration was normal. He called V_1 and removed his hand from the thrust lever knobs and placed his hand behind the levers. He called V_R and the rotation was made smoothly and normally.

The first officer told the NTSB that he felt the stall warning stickshaker on the control column activate as the airplane lifted off the runway. After becoming airborne, "he sensed a loss of performance and felt the airplane sinking."

The captain said that when the airplane broke ground, the stickshaker remained on and the airplane began to sink back toward the runway. The captain said that the "first officer stated something to the effect of it's not flying or it won't fly, 'you've got it.' " The first officer turned control of the airplane over to the captain, who stated that he had a *split second* [emphasis added] to decide whether to "continue to take off or to abort, when he probably would not be able to stop on the runway," the report said. It added: "He saw a considerable amount of runway remaining and chose to abort. The captain also stated that the airplane had the proper attitude and airspeed, but was not flying. He [the captain] said he positively did not believe that the airplane would fly."

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The captain said that he closed the thrust levers, put the airplane back on the runway, applied full reverse thrust and used maximum braking, but the airplane did not decelerate as quickly as he had expected. The report said, "He concluded that with approximately 1,500 feet [457 meters] of runway remaining and the airspeed still about 100 knots, he would not be able to stop before reaching the blast fence at the end of the runway. He was able to maintain directional control throughout the landing. When it became apparent that he would not be able to stop before hitting the barrier at the end of the runway, he turned the airplane left off of the runway onto an open area covered with grass. Beyond the grass was concrete. He was sure he would be able to stop either on the grass or concrete.

"The captain stated that he sensed a 'sharp thump' about the time the airplane departed the runway. He was intent on maintaining directional control and stopping but he knew later that the thump was the collapse of the nose wheel. Examination of the airplane revealed that the nose gear strut fractured so that it collapsed back and up, against the underside of the forward fuselage."

The airplane landed extremely hard at a vertical-descent rate of about 14 feet-per-second (4 meters-per-second), considerably more than the maximum structural design limit of 6 feet-per-second (2 meters-per-second), and at a weight of about 71,000 pounds (32,206 kilograms) more than the design maximum landing weight. This resulted in overload fractures in the right-wing rear spar.

The airplane was in a slight right-wing-low attitude when the right main landing gear touched down first, near the runway centerline crown.

The NTSB determined that the probable causes of this accident were "design deficiencies in the stall warning system that permitted a defect to go undetected, the failure of TWA's maintenance program to correct a repetitive malfunction of the stall warning system, and inadequate crew coordination between the captain and first officer that resulted in their inappropriate response to a false stall warning."

The NTSB determined that the right angle-of-attack (AOA) sensor had malfunctioned, but the L-1011 stall warning system allowed false stall warning stickshaker activations, especially immediately after liftoff.

In this accident, the malfunctioning AOA activated the stall warning stickshaker after the aircraft lifted off and the main landing gear strut sensing switch moved from "ground" to "air."

The design of the stall warning circuitry prevented detection of the malfunction during ground operations. The NTSB said "the single-point failure that occurred in this instance was undetected and lead to a false stall warning to which the flight crew reacted inappropriately."

The report added: "In this case, it was likely that the flight crew did not observe any cockpit warning lights that would have prompted them to immediately assess the warning as false. Although certain lights on the overhead panel (ATS FAIL) and the lower center instrument panel (FLT CONT PANEL) may have illuminated, they would not have done so until at least two seconds following liftoff. Further, these lights would not have been easily observable by the pilots and the legends on the lights would not have been readily associated with a stall warning system malfunction."

According to the NTSB, the history of the stall warning stickshaker system on the accident airplane showed that about three weeks earlier on July 8, 1992, a pilot-written aircraft maintenance log entry stated: "Control column shakes during rotation and in flight for no apparent reason and ATS [autothrottle system] fail lights on. Fault isolated to stall warn[ing] sys[tem] 2. By pulling 2F2 CB [circuit breaker] fault was isolated. Unlatching stall warning switches on FCES [flight-control electronics system] panel did not stop control column shake. (Reset on approach OK).”

TWA maintenance reported its corrective actions: “Replaced FCES, Ops good.”

TWA maintenance records showed that the right AOA sensor was obtained in January 1989 through an exchange program with the American Trans Air Corp. Information on a previous repair accompanied the sensor; “Reason for Removal: Stall warn fails test (ATA unit).”

The airline’s maintenance records revealed that the right AOA sensor was installed on a TWA L-1011 airplane for 2,640 hours without a discrepancy. The NTSB said that, “Beginning November 30, 1989, it was removed and repaired eight times by TWA maintenance with the following elapsed flight hours between failures: 31, 42, 56, 349, 19, 1, and 24. After each maintenance action, the part was reinstalled on various TWA L-1011s, until it was installed on [the accident aircraft]” and accumulated an additional 1,467 flight hours until the accident. In several of the maintenance actions, the problem could not be duplicated, no cause was determined and the sensor was reinstalled on other aircraft.

Thus, the accident aircraft was flying with a part that had a discrepancy history — a fact that was probably not known by cockpit crews.

“Specifically, after each malfunction, the component was inspected by maintenance and subsequently cleared for service,” said the NTSB. “However, the sensor was returned to supply as a spare part before being reinstalled on another airplane. Therefore, many calendar days elapsed before the part was reinstalled on another airplane and placed in a situation in which it could fail again.” Thus, the accident aircraft was flying with a part that had a discrepancy history — a fact that was probably not known by cockpit crews.

The NTSB said that the chronic problem “in the AOA sensor that caused the warning should have been detected and repaired by TWA’s maintenance and quality assurance programs, thereby eliminating the precipitating event in this accident.” TWA’s quality assurance trend monitoring program, approved by the U.S. Federal Aviation Administration (FAA), was based on calendar days, not flight hours, and failed to detect the repetitive and unsafe trend of the component. The NTSB recommended that the FAA “review the airlines’ maintenance and quality assurance programs and take appropriate actions to verify that the trend monitoring programs are structured to detect repetitive malfunctions by means of flight-hour monitoring, as well as calendar-day monitoring.”

The NTSB recommended that an airworthiness directive be issued “to require that a caution or warning light illuminates on the pilot’s caution-warning panel in the event of a failure within the circuitry of L-1011 stall warning systems during ground or flight operations.”

NTSB also recommended all transport category aircraft be equipped with ground-test features and self-monitoring systems to alert pilots to malfunctions in redundant stall warning systems.

The NTSB examined training and procedures for the takeoff sequence through interviews and meetings with TWA senior and standardization captains, and operational and maintenance managers. The NTSB noted that in the late 1960s, with jet transports established in its fleet, TWA adopted a philosophy when nearing V_1 to continue a takeoff rather than to reject it. With that philosophy in mind, a senior captain stated that the decision to reject must be made before V_1 and that by V_1 the rejection must be fully in progress with maximum braking initiated and throttles back to idle.

In TWA simulator training sessions, engine failure and other malfunctions were experienced at high speed during takeoff. TWA training personnel said that these emphasized “go” considerations at high speed. Results from RTO studies indicated that on average a pilot required two seconds to identify and initiate the RTO procedure. Assuming an acceleration value of three to six knots per second, TWA training and check personnel stated that if a pilot identified an engine failure at V_1 minus five knots, it would be appropriate to continue with the takeoff. These concepts and procedures were emphasized in annual symposia given to TWA check airmen and instructor pilots.

Through meetings and interviews, the NTSB found that training and simulation concerning the decision whether to continue or reject a takeoff focused on an airplane on the runway. No formal training or procedures specifically addressed abnormal events or false warnings immediately after liftoff. Further, TWA did not require a verbal pretake-off briefing about the handling of abnormal or emergency events on takeoff.

NTSB’s review of TWA’s *Flight Operations Policy Manual*, dated September 10, 1982, showed the following regarding RTO procedures: “During the takeoff roll, immediate attention should be given to any abnormal conditions which would indicate the desirability of rejecting the takeoff as a precautionary measure. If at all possible, this decision should be reached before attaining high speed. Rejecting a takeoff at a *high speed* is a critical maneuver. Considering a condition of maximum weight for the runway, a rejected takeoff at V_1 that is perfectly executed will require all of the remaining runway.

"V_1 has been referred to as the 'decision speed.' It is interesting to note that two seconds are allowed for this decision. By definition, V_1 is the speed at which the pilot is offered two prerogatives, to continue, or to stop. Considering that the aircraft is loaded for the runway, it is only at this point that the aircraft has the capability of doing either. Below V_1, the aircraft does not have the capability of accelerating to the required liftoff speed and climbing to 35 feet [11 meters] by the end of the runway. Above V_1, the aircraft does not have the capability of stopping on the remaining runway. V_2 provides 20 percent protection over stall for takeoff flap configuration."

The TWA procedure for stall recovery (practiced in the simulator at altitude) was to advance the thrust levers to maximum and to reduce the pitch attitude appropriately. There was no specific training for stall encounters immediately after liftoff from the runway.

Given the evidence that there was a malfunction in one of the two AOA sensors, the NTSB focused on activity in the cockpit. The stall warning stickshaker activated and the airplane began to descend back to the runway. The first officer made a statement about the airplane stalling and said to the captain, "You got it."

The captain assumed control of the airplane and made what he described as a "split-second decision" to retard the throttles and land on the remaining runway. The airplane only ascended about 16 feet (5 meters) before descending. "The evidence also showed that the airplane was performing properly, had accelerated well above V_2 and could have climbed out successfully," the report said.

According to the NTSB, the first officer perceived that an emergency existed when the stall warning stickshaker activated as the airplane lifted off. The NTSB acknowledged that the activation of a stickshaker immediately after liftoff is an abnormal event intended to alert the crew to a potentially dangerous flight condition.

The NTSB said that the flight crew should have been "immediately attentive to the airplane's airspeed, flap and leading edge configuration, particularly in the absence of other cues that could have confirmed that the stickshaker activation was false warning a consequence of a fault within the airplane's stall warning system."

The NTSB did not consider the onset of the stickshaker stall warning an emergency condition justifying actions that can place an airplane in jeopardy.

"The stickshaker activation is a warning indication that the wing is at an AOA approaching a stall condition, but a significant margin of safety is provided before the aerodynamic stall angle occurs," the report said. "Moreover, the captain had called out V_1 and V_R, presumably by reference to the airspeed indicator, and the airplane was accelerating through V_2 and beginning to climb. Based on their awareness of airspeed and flap configuration, the pilots should have concluded that the stickshaker was a false stall warning."

The first officer made a statement about the airplane stalling and said to the captain, "You got it."

The feeling that the airplane "didn't seem to want to fly" and the "sinking feeling" described by the cockpit occupants was most likely due to either the first officer's relaxing the control yoke back pressure or his pushing the yoke forward in the natural reaction to the stall warning, the NTSB said. "It was possible that the impression of an aerodynamic stall was reinforced by the activation of the stall warning stickshaker. That sensory input, coupled with the sinking sensation because of the transition from climbing flight to descending flight (reduced load factor) very likely accounts for the impressions of the pilots that the airplane was 'not going to fly.'" The NTSB said it was unable "to identify any other aerodynamic or mechanical explanation for the pilots' stated belief."

The NTSB's analyses of the FDR data and modeling of the takeoff verify that the control column moved forward and that the airplane reacted properly to the control inputs when the flight crew abandoned the climb phase of flight and elected to land the airplane. The NTSB's comparison of data from eight previous takeoffs of the airplane with the data from the accident takeoff revealed that the forward movement of the control yoke immediately after takeoff, and the nose-down deflection of the horizontal stabilizer, were unlike any of the eight previous takeoffs.

The results of the NTSB's airplane performance analysis showed that the motion of the airplane during liftoff and subsequent descent "was the result of pilot action — either pushing or allowing the control yoke to move forward. The first officer initiated this control input, which might not have been detectable by the captain."

Inexplicably, the NTSB said, the first officer reacted to the stall warning stickshaker by immediately deciding that the captain should be flying, and by abandoning control of the airplane to the captain without warning or proper coordination. "This improper and untimely action occurred when the airplane was about 15 feet [4 meters] above the ground and approximately 14 knots above the V_2 speed. The decision and subsequent action of the first officer to 'give up' control of the airplane, instead of the captain 'taking control' of the airplane is not consistent with the nearly universal practice in the aviation community of transfer of control in two-pilot aircraft."

The NTSB stated that TWA's philosophy regarding flight crew training and operational procedures, including crew resource management, was based on the "quiet cockpit" concept. Each pilot was trained in a particular skill position (captain, first officer or flight engineer) and that individual was expected to perform both normal and abnormal procedures at the appropriate time. "Also inherent in this philosophy is the idea that crew member briefings (takeoffs and approaches) are not necessary because of the expectation that the individuals know their duties and will perform those duties at the appropriate time," the report said.

"This improper and untimely action occurred when the airplane was about 15 feet [4 meters] above the ground and approximately 14 knots above the V_2 speed."

The NTSB said that the expectations placed on individual crew members under this philosophy "could promote a higher probability of confusion and poor crew coordination because the primary information for decisions and actions is not actively disseminated among the individuals during routine flight operations. For example, there are no predeparture briefings concerning such items as a standard instrument procedure, the length of time required to dump fuel in the event that a return to the departure airport is necessary, abnormal procedures for rejected takeoffs (RTOs), possible effects of local environmental conditions or other abnormal events during critical phases of flight."

The report said that at a minimum, certain information should be briefed during each flight as it applies to particularly critical phases of operations. The actions taken during an RTO or similar time-critical events, for example, "should be verbalized to reinforce training and procedures and to serve as a rehearsal in preparation for possible use."

The NTSB report said: "It is an established procedure at many airlines for the captain to maintain a 'hands-on' position on the throttles during the takeoff phase, regardless of which pilot is flying the airplane. It is also an established procedure that the captain will execute an RTO by first announcing the RTO, and by retarding throttles. At almost all airlines, including TWA, first officers are not permitted to take such actions. In this case, however, by allowing the control column to move forward, the first officer actually initiated the rejection of the takeoff when the airplane was barely airborne.

"During both initial and recurrent training at TWA, first officers are required to demonstrate their ability to carry out an RTO as well as other emergency procedures. Therefore, it is possible that a first officer's performance in rejecting a takeoff in the simulator promotes a false sense of command authority that is contrary to procedures stated in the *TWA Flight Handbook* or performed on the line. Specifically, in the event of an RTO during simulation training, the first officer commands and executes the RTO, including manipulating the flight controls and retarding the throttles. This training is contrary to the 'real world' procedure that the captain will command and execute the RTO, regardless of the captain's flying duties."

The report added: "The training provided to both pilots regarding RTOs is intended to instill a 'go' attitude after V_1 has been reached. There was no specific training in reacting to abnormal events, such as a false stall warning or other 'nuisance' warning after V_1 shortly after becoming airborne. However, it is common practice in the airline industry that in the event of an abnormal occurrence which would require the captain to assume the flying duties, the first officer would continue flying the airplane until the captain announced that he was physically taking control of it."

The NTSB's review of flight operations revealed that TWA "neither incorporates in its flight crew training nor practices the principle of the first officer initiating the transfer process by giving up command of the aircraft when performing the duties of the flying pilot. The industry standard is that the captain will take command and control of the aircraft when deemed necessary. The typical and proper method of transferring control of the airplane involves direct verbal interaction and understanding between the pilots."

The NTSB expressed concern about the prudence of the common practice of many airlines of requiring the captain to initiate rejected takeoffs with his hand on the throttles for all takeoffs, even when the first officer is making the takeoff. This divided control responsibility, said the NTSB, "may not be in the best interest of proper crew coordination during such a critical phase of flight." The NTSB recommended that the FAA study this practice, in cooperation with the U.S. National Aeronautics and Space Administration (NASA), to evaluate and revise, as appropriate, airline procedures and training.

The NTSB found that TWA's pilot training syllabus, along with those of many other commercial air carriers, did not include any type of system anomaly training.

"This type of training," said the NTSB, "is best described as an unusual event, such as a stall warning at liftoff, overspeed warning, speed brake deploy warning at takeoff ... or a ground-proximity warning system (GPWS) alert during takeoff, that is out of the realm of normal operation or is an expected abnormal condition that the pilots would become familiar with during training. This type of training scenario would be of an unannounced nature and would occur at a point in the simulator flight when the crew would least expect it."

The typical and proper method of transferring control of the airplane involves direct verbal interaction and understanding between the pilots

The NTSB also found that TWA did not address during training, either in a written procedure or verbally, "any technique to use in the event of a false warning including, as in this case, the stall warning stickshaker during takeoff."

To the NTSB, it was obvious that the first officer's actions "occurred in a manner that precluded the captain from gaining an accurate 'feel' for the airplane and assessing the nature of the perceived problem." He was placed in a position in which he had to "take control and assess the nature of the anomaly," and make a decision "in an inordinately short amount of time as to whether to continue the takeoff while the airplane was descending as a result of the first officer's improper actions."

The report concluded: "The captain, in the performance of his duties as the nonflying pilot, is responsible for calling the V speeds during takeoff and should have been well aware of the airplane's speed at all times. When the airplane broke ground and the stickshaker activated, he should have been aware that the airplane had sufficient flying speed, based on airspeed indications, to sustain flight. Also, when the stickshaker activated (indicative of a near-stall condition), all available information (airspeed and engine power) should have been evaluated and, if necessary, the proper stall recovery procedure of increasing engine thrust and making a controlled change in pitch attitude could have avoided this accident. These actions were not taken."

The NTSB said that it was likely that if this event had occurred at an airport with a shorter runway, the captain would not have considered the option to reject the takeoff and attempt to land. "Nevertheless, the decision made by both pilots regarding the urgency of the situation and the course of action to take should not have been influenced by the amount of runway remaining." The NTSB noted that several other flight crews had experienced false stall warnings at liftoff, including a flight crew flying the same aircraft less than a month earlier. In these cases, the flight crews flew the airplane successfully.

The NTSB recommended that the FAA's principal operation inspection for airliners operating under U.S. Federal Aviation Regulations (FAR) Part 121 and Part 135 "include in the training and procedures a requirement for crew coordination briefings on actions to take in the event of abnormal situations during the takeoff and initial climb phase of flight, and the proper techniques for the transfer of control of the airplane, especially during time-critical phases of flight."

The NTSB said it was aware that the subject of RTOs is complex as is the decision-making involved when pilots are confronted with an abnormal condition or emergency after reaching high speed. The NTSB said it was also aware that "the focus of training for emergencies during the takeoff phase generally involves go/no-go decisions while the airplane is on the runway approaching the V_1 speed. While this accident was not a typical RTO, the circumstances that necessitated the split-second decision to continue the flight or land the airplane were similar to emergencies at or beyond V_1 requiring rapid decision making. Both situations require proper crew coordination and timely pilot decision making.

"TWA training and procedures, although not specific to the particular situation, were intended to prepare the pilots for the proper decisions and actions. However, the decisions and actions of this flight crew called into question the adequacy of the training and procedures."♦

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