National Transportation Safety Board (NTSB)
Special Investigation Report (SIR -90/02)

Runway Overruns Following High Speed
Rejected Takeoffs
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NATIONAL TRANSPORTATION SAFETY BOARD

SPECIAL INVESTIGATION REPORT

RUNWAY OVERRUNS FOLLOWING HIGH SPEED REJECTED TAKEOFFS
The National Transportation Safety Board is an independent Federal agency dedicated to promoting aviation, railroad, highway, marine, pipeline, and hazardous materials safety. Established in 1967, the agency is mandated by the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable cause of accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation.

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### Abstract

This report discusses high speed rejected takeoffs (RTOs) of airplanes. Evidence from investigations conducted from the late 1960s suggests that pilots faced with unusual or unique situations may perform high speed RTOs unnecessarily or may perform them improperly. The Safety Board surveyed a sample of U.S.-based major and national operators to determine how they train their flightcrew members to both recognize the need for and to execute high speed rejected takeoffs. As a result of this special investigation, the Safety Board issued several recommendations to address the guidance and training flightcrew members receive in recognizing the need to execute and in the performance of rejected takeoffs.
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EXECUTIVE SUMMARY

Runway overruns following high speed rejected takeoffs (RTOs) have resulted and continue to result in airplane incidents and accidents. Although most RTOs are initiated at low speeds (below 100 knots) and are executed without incident, the potential for an accident or an incident following a high speed (at or above 100 knots) RTO remains high. In 1988, for example, three RTO-related accidents, two overseas and one in the United States, resulted in injuries to several passengers and crewmembers and in substantial damage to a Boeing 747, a Boeing 757, and in the destruction of a McDonnell Douglas DC-10.

Evidence from investigations conducted from the late 1960s suggests that pilots faced with unusual or unique situations may perform high speed RTOs unnecessarily or may perform them improperly. The Safety Board surveyed a sample of U.S.-based major and national operators to determine how they train their flightcrew members to both recognize the need for and to execute high speed rejected takeoffs. As a result of this special investigation, the Safety Board has issued several recommendations to address the guidance and training flightcrew members receive in recognizing the need to execute and in the performance of rejected takeoffs.
Runway overruns following high speed rejected takeoffs (RTOs) have resulted and continue to result in airplane incidents and accidents. Although most RTOs are initiated at low speeds (below 100 knots) and are executed without incident, the potential for an accident or an incident following an RTO initiated at high speed remains high. In 1988, for example, three RTO-related accidents, two overseas and one in the United States, resulted in injuries to several passengers and crewmembers, in substantial damage to a Boeing 757, a Boeing 747, and in the destruction of a McDonnell Douglas DC-10.

Evidence gathered from previous investigations conducted from the late 1960s suggests that pilots faced with unusual or unique situations may perform high speed RTOs unnecessarily or may perform them improperly. Evidence also indicates that deficiencies exist in (1) pilots’ understanding of the risks associated with high speed RTOs, (2) the training pilots receive in RTOs, and (3) the procedures airlines establish for executing RTOs.

The Safety Board conducted this special investigation of RTO-related issues to determine how the safety of RTOs can be enhanced and how the rate of RTO-related accidents and incidents may be reduced. During this investigation, the Safety Board examined a variety of data on RTO accidents and incidents. The Safety Board also observed RTO-related training and examined RTO-related information and procedures of nine airlines in the United States (Appendix A): American Airlines, Continental Airlines, Delta Air Lines, Federal Express, Midway Airlines, Pan American World Airways, Southwest Airlines, Trans World Airlines (TWA), and United Airlines. The airlines, all operating under Title 14 Code of Federal Regulations (CFR) Part 121, some domestically and some domestically and internationally, were chosen to provide an overview of the guidance airlines provide to pilots and to ascertain how well pilots understand the risks associated with a high speed RTO, how well they recognize the need for an RTO, and how well they execute a high speed RTO. The report addresses these issues as well as aspects of Federal Aviation Administration (FAA) certification pertinent to airplane capabilities during a high speed RTO and pilot familiarity with those airplane capabilities.

1 Throughout this report, a low speed RTO refers to one initiated below 100 knots whereas a high speed RTO refers to one initiated at or over 100 knots.
PREVIOUS RTO INCIDENTS AND ACCIDENTS

According to National Transportation Safety Board data, from 1962 through 1987 there were 45 RTOs involving a variety of domestic and overseas carriers, operating transport category turbojet airplanes in the United States, that caused at least minor damage to the airplane: 22 caused minor damage, 14 caused substantial damage, and 9 destroyed the airplane. Four RTOs resulted in fatalities.

The Boeing Company has analyzed data involving Western-manufactured jet transport airplanes operated worldwide, which have been involved in accidents and incidents, to determine the rate and causes of runway overruns following RTOs. Boeing's analysis (figure 1) indicates that the rate of runway overruns per million departures has decreased considerably from the early 1960s and has remained at a fairly steady rate during the 1980s.

Based on an analysis of its data for transport category aircraft, Boeing projected 1 RTO in every 3,000 takeoffs and 1 high speed RTO in every 150,000 takeoffs. Boeing also predicted that in 1989, 1 RTO incident or accident would occur in every 2,579,000 takeoffs. Boeing projected a total of 4,500 RTOs, 90 of which would be high speed RTOs resulting in an estimated 5 RTO incidents or accidents. According to Boeing, 3 RTO incidents or accidents occurred in 1989.

The Safety Board is aware that some airlines maintain data bases on RTOs involving the airplanes they operate. The data often include variables such as the type of airplane, nature of the precipitating event, and environmental conditions. The Safety Board believes that airlines should maintain similar data on RTOs that involve the airplanes they operate and has issued Safety Recommendation A-90-14 to the FAA to address this issue.

The following summaries of RTO-related accidents and incidents were selected to illustrate their potential for serious injury.

In August 1972, the crew of a JAT (Yugoslavian Air Transport) Boeing 707 rejected the takeoff from John F. Kennedy International Airport in New York City. The RTO was initiated 3 seconds after \( V_t \) after the first officer's window opened partially. The crew was unable to stop the airplane on the runway; as a result, 15 persons were injured and the airplane was destroyed. Following its investigation of the accident, the Safety Board concluded that had the crew continued the takeoff, the first officer, because

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2 Boeing supplied the data to the Safety Board in correspondence dated August 14, 1989.

3 Aircraft Accident Report-"Yugoslovenski Aerotransport (JAT), Boeing 707-331, YU-AGA, John F. Kennedy International Airport, Jamaica, New York, August 13, 1972" (NTSB/AAR-73/7).

4 A full discussion of the definition of \( V_t \) follows later in this report.
RTO OVERRUN RATE
1959 thru 1988

Figure 1. Runway overrun rate.
of the subsequent airplane pressurization, might have been able to close the window in flight.

A month later, a TWA Boeing 707, on a ferry flight from San Francisco, overran the runway and continued into San Francisco Bay following a high speed RTO. The crew initiated the RTO beyond V\textsubscript{1} after encountering severe vibrations. These vibrations were later determined to have been caused by a failure of the main gear tire. The crew was rescued but the airplane was destroyed.

In November 1976, the crew of a Texas International DC-9-14 encountered a stickshaker activation, indicating an impending aerodynamic stall, 2 seconds after the V\textsubscript{2} call during takeoff from Denver's Stapleton International Airport. The crew immediately initiated an RTO; however, the airplane continued its ground roll beyond the end of the runway, traversed drainage ditches, and struck approach light stanchions. The airplane was destroyed and two passengers sustained serious injuries. The investigation determined that the stall warning was false and that a stall was not impending.

In March 1978, the crew of a Continental Airlines McDonnell Douglas DC-10-10 rejected the takeoff from Los Angeles International Airport 3 knots beyond V\textsubscript{1} after hearing loud noises that were later determined to be associated with tire failure. As the airplane continued its ground roll beyond the end of the runway, the airplane struck ground objects and a fire erupted. The airplane was destroyed, 2 passengers were killed, and 31 passengers and crew members were seriously injured in the accident.

In 1982, the crew of a Spanish-registered DC-10-30, operated by Spantax, initiated an RTO following the onset of severe vibrations during rotation upon takeoff from Malaga, Spain. The aircraft overran the runway, struck objects, and was destroyed. Three crew members and 47 passengers were killed.

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6 V\textsubscript{2} is the takeoff safety speed.


9 Information on the accident was obtained from advisors to the United States accredited representative to the investigation. The investigation was conducted by the government of Spain.
The vibrations were determined to have been caused by a failure of the nose gear tire.

More recently, the Safety Board has investigated and participated in the investigation of high speed RTO-related incidents and accidents involving several major airlines. On May 21, 1988, N136AA, a McDonnell Douglas DC-10-30, operated as American Airlines Flight 70, from Dallas-Fort Worth International Airport to Frankfurt, Federal Republic of Germany, overran the runway following an RTO. The captain rejected the takeoff after hearing a takeoff warning horn and observing a slat disagree light, subsequently determined to have been a false warning, as the airplane reached $V_1$. The crew was unable to bring the airplane to a stop on the runway. Two flight crewmembers received serious injuries, one flight crewmember and five passengers received minor injuries, and the airplane was destroyed. The Safety Board concluded that, although the brakes were within FAA-approved wear limits, they were not capable of stopping the airplane on the runway given the airplane’s speed and the existing environmental conditions.

On July 23, 1988, a Boeing 747-200 Combi, N4506H, operated as Air France flight 187, from Beijing, People’s Republic of China, to Paris, France, ran off the runway following a refueling stop in Delhi, India. The investigation determined that a fire warning from the No. 4 engine sounded at or slightly beyond $V_1$. The crew’s reduction of power occurred as the airplane reached 167 knots; $V_1$ was 156 knots. The crew was unable to bring the airplane to a stop on the runway, and the airplane struck a ditch beyond the end of the runway. One passenger sustained minor injuries, and the airplane was damaged beyond economic repair.

On September 29, 1988, N523EA, a Boeing 757, operated as an Eastern Airlines flight from San Jose, Costa Rica, to Miami International Airport, Miami, Florida, sustained substantial damage and seven passengers received minor injuries as a result of a high speed RTO. According to information from the government of Costa Rica, which is investigating the accident with the assistance of the National Transportation Safety Board, an unusual sound emanated from the left side of the airplane at or just after $V_1$. The captain assumed that the noise resulted from a tire failure and initiated the RTO after rotation had begun during takeoff. The cockpit voice recorder indicates that there was no discussion of or commands regarding initiation of the RTO.

On June 17, 1989, N754DL, a Lockheed L-1011 TriStar operated as Delta Airlines Flight 23, en route from Frankfurt, Federal Republic of Germany, to Atlanta, Georgia, sustained minor damage after the airplane partially overran

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10 Special Investigation Report—"Brake Performance of the McDonnell Douglas DC-10-30/40 During High Speed, High Energy Rejected Takeoffs" (NTSB/SIR-90/01)

11 Information on this accident was obtained from advisors to the United States accredited representative to the investigation. The investigation was conducted by the government of India.
the runway following a high speed RTO. According to the government of the Federal Republic of Germany, which is investigating the incident with the assistance of the National Transportation Safety Board, the captain initiated an RTO just beyond $V_1$ after hearing loud noises from the No. 3 engine. No injuries resulted, but the airplane’s brake and wheel assemblies were extensively damaged. The investigation has revealed that a boroscope plug came loose, causing engine damage and an estimated 20 percent loss of thrust. The cockpit voice recorder indicates that the crew was aware that there were no instrument indications of engine failure or engine fire. Contrary to Delta procedures, no callout was made to indicate the nature of the event, and no callout was made to indicate that the captain was initiating an RTO.

On September 20, 1989, a Boeing 737-400, operated as USAir flight 5050, bound for Charlotte, North Carolina, overran the runway following a high speed RTO at New York’s LaGuardia Airport. The airplane was destroyed and two passengers were killed. The Safety Board’s investigation, which is continuing, has revealed that at least some of the required callouts were not made during the RTO. The captain initiated the RTO at or slightly beyond $V_1$.

**EVENTS PRECIPITATING RTOS**

The evidence indicates that engine failures or engine fires are rarely the precipitating events in high speed RTOS. Ostrowski examined data from a variety of domestic and international sources, including the Safety Board’s data base, and found that from 1964 through mid-1976, 171 RTOS resulted in accidents, incidents, or subsequent aircraft repair. Of the 171 RTOS, 149 were initiated, either wholly or in part, because of failures or malfunctions involving tires, wheels or brakes. Tire failures were a factor in 124 of the 149.

In 1985, a Convair 990, operated by the National Aeronautics and Space Administration (NASA), was destroyed by fire following an RTO. Tire failure, which occurred at a speed below $V_1$, precipitated the RTO. None of the 19 passengers or crew were injured. After the accident, NASA examined data on RTO-related incidents and accidents occurring between 1975 and 1987. Of the total 61 RTO-related accidents/incidents found in the data, 34 percent were attributed, at least in part, to tire or wheel failure, 23 percent to engine failure or malfunction, and 43 percent were to a variety of other events.

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12 Information on this investigation was obtained from the United States accredited representative to the investigation.


Boeing's analysis of its data on RTO-related incidents and accidents from 1959 through 1988 indicated that non-engine related problems far outnumbered "propulsion anomalies" among the events precipitating RTOs. These included wheel or tire problems and false warnings (Figure 2). According to Boeing, the leading cause of the overruns that followed the RTOs was late initiation of the RTO; many of the RTOs were initiated after V₁ (Figure 3). Boeing concluded that over half the RTO cases examined did not warrant RTOs. In each of the selected accidents and incidents briefly described earlier in this report, the RTOS should not have been initiated; that is, the airplanes should have been able to continue the takeoff without incident.

RTO-RELATED CERTIFICATION REQUIREMENTS

Before an aircraft can be introduced into service, it must meet the requirements of 14 CFR 25. One requirement specifies that an airplane manufacturer must demonstrate an airplane's stopping performance, at its maximum operating gross weight, during takeoff. The manufacturer is also required to calculate the takeoff speed, accelerate-stop distance, takeoff distance, and takeoff flight path for the airplane's full range of operating weights. Components of the certification process pertinent to RTOS are briefly discussed below.

V₁.--During the certification process, the manufacturer is required to establish the speed for any operating gross weight at which the takeoff could be safely continued when the most critical engine fails suddenly. Before March 1, 1978, this speed was referred to by the FAA as "V₁," the "critical engine failure speed," and was defined as a speed at which, during the takeoff run, the airplane could experience an engine failure and continue to accelerate, lift off, and achieve the required climb gradient.

In actual practice, the process allowed for a delay for the time it took a pilot to recognize that an engine had failed and then to execute the initial RTO action--to retard the throttles on all engines. On March 1, 1978, the FAA amended the pertinent regulations in 14 CFR 1.2 and 14 CFR 25.107 (2) to redefine V₁ as the "takeoff decision speed" and redesignate the "critical engine failure speed" as VEF. Thus, the current airplane certification regulations acknowledge that some amount of time is required by a pilot to recognize and react to an engine failure.

Accelerate-Go Distance.--The runway distance that the airplane uses to accelerate after critical engine failure, lift off, and achieve the required height of 35 feet above the surface is referred to as the "accelerate-go distance."

Accelerate-Stop Distance.--The stipulations of 14 CFR 25 also require the airplane manufacturer to determine the distance required to accelerate the airplane to V₁, and then to bring it to a full stop. This distance, referred to as the "accelerate-stop distance," is determined for the full range of operating weights based upon RTO procedures established by the manufacturer. It includes allowance for a certain amount of delay in the pilot's execution of these procedures, delay that may reasonably be expected.
Note:
RTO accidents and incidents involving commercial jets - 1959 thru 1988

Figure 2. Cause of RTOs. (Source: The Boeing Company.)
Note:
RTO accidents and incidents involving commercial jets - 1959 thru 1988

Figure 3. Cause of Runway Overruns. (Source: The Boeing Company.)
in service due to reaction time. In establishing data on accelerate-stop distances, the manufacturer must also allow for the use of safe and reliable decelerative devices on the airplane being certificated. The FAA has not permitted the manufacturer to consider the use of reverse thrust to shorten the stopping distance because reverse thrust may not be reliable in the event of an engine failure.

Runway Takeoff Distance.—The data derived during a manufacturer's airplane certification process are included in an FAA-approved flight manual for that airplane. Data on minimum runway length for takeoff are derived for the airplane at various takeoff gross weights with the effects of other factors such as altitude, temperature, wind, and runway gradient included in the calculations. The minimum takeoff runway length must be at least as long as the greatest of the following distances: (1) the "accelerate-go" distance assuming failure of the critical engine at VEF (or, before March 1, 1978, at V1 with allowance for pilot reaction time); (2) the "accelerate-stop" distance as established during certification; or (3) 115 percent of the distance required for the airplane to take off and climb to a height of 35 feet above the runway surface with all engines operating, commonly referred to as the "all engines go" distance.\(^1\)

An incremental decrease in V1 will increase the accelerate-go distance and decrease the accelerate-stop distance. Therefore, it is to the manufacturer's advantage to optimize the airplane's performance by selecting a V1 speed for a given set of conditions that will make the accelerate-go and accelerate-stop distances equal. The resultant runway length is said to be "balanced." A balanced runway or balanced field length is the theoretical minimum runway distance needed for an airplane to takeoff unless other criteria—such as minimum control speeds, all engines go performance, obstacle clearance, or brake energy considerations—are limiting.

Airlines use data on minimum runway takeoff distances contained in the FAA-approved flight manual to develop procedures that assure compliance with the appropriate operating rules. Generally, airlines will apply such data to the specific runways at the airports at which they operate to prepare airport analysis charts for quick reference by the flightcrews (an example is given in Appendix B). A chart shows the maximum weight at which the airplane can be operated for a specific runway at various ambient conditions and takeoff flap configurations.

The Safety Board found from its investigations of recent RTO-related accidents that the stopping distance demonstrations for the certification of some airplanes had been conducted with new wheel brakes and from a landing rather than from an actual RTO.\(^2\) The manufacturers then determined the accelerate-stop distance by adding the demonstrated acceleration distance to

\(^1\) The regulations provide allowances for clearways and stopways, which are excluded from this discussion for simplicity.

\(^2\) In 1982, the FAA discontinued accepting demonstrations conducted from a landing as an alternate to demonstration of an actual RTO.
$V_1$ to the distance needed to bring the airplane to a stop from $V_1$. Consequently, the stopping distance determined by this method was predicated on an airplane reaching $V_1$ speed with unspooled engines, already decelerating, and with cool wheel brakes that had minimum previous wear.

The Safety Board also found that when manufacturers established runway length data for the range of airplane operating weights, they used stopping distances based on the deceleration achieved with maximum brake pressure already applied and did not allow for the distance used during the time required to achieve full brake pressure application from brake pedal depression. Thus, even though the manufacturer applied the required allowances for pilot reaction time to initiate the RTO, the airplane's accelerate-stop performance on which the flight manual data were based could not often be achieved in actual line operations.

The changes introduced to the airplane certification process by the March 1, 1978, amendment to the regulations provide a greater stopping margin for the airplanes that have entered service since that date. However, of the air transport airplanes in service today, only the Airbus Industry A-320 has been required to comply with the amended regulations.\textsuperscript{17} Furthermore, even the accelerate-stop distance provided by the amendment to the certification rules might not be achievable in line operations because of the variables affecting takeoff performance that had not been considered in the rules governing certification and operation of the airplane. These variables, discussed below, include runway alignment distance, acceleration rate to $V_1$, runway wind component, accuracy of $V_1$ call and pilot action delays, degraded wheel brake performance, and runway surface friction.

Runway Alignment Distance.--The Safety Board reviewed the methods airlines use to determine the distance they consider in aligning the airplane on the runway before takeoff. United Airlines is the only carrier of the nine observed for the special investigation that considers the length of runway used to align and position the airplane before takeoff is initiated. United calculates this distance to be, on average, about 1.3 times the length of the fuselage and deducts that distance from the runway length available for stopping in the event of an RTO. Other carriers that were observed do not account for this distance because neither the certification data nor the operator's analysis consider the length of the airplane between the main landing gear and nose gear. These factors alone can equal to, and thus negate, the distance margin provided in certification for pilot reaction time delays.

\textsuperscript{17} The 1978 amendment would effectively reduce the allowable airplane takeoff gross weight for a given runway, resulting in additional costs that operators and manufacturers believe to be unwarranted. The FAA did not require manufacturers of airplanes for which the FAA had received applications for certification by March 1, 1978, to comply with the amended regulations, regardless of the date the airplane entered service.
Acceleration Rate to $V_{1a}$--Most transport category airplanes are traveling between 220 and 270 feet per second and are accelerating at a rate of about 3 knots per second at $V_{1}$. Variations in the techniques pilots use to set thrust, and variations in the type of thrust selected (full takeoff or derated) and in generation of engine thrust can result in slower takeoff acceleration. As a result, the runway length available to stop an airplane following a high speed RTO is reduced.

Wind Component--Differences between actual wind direction and velocity and the wind parameters used by the flightcrew to determine the takeoff runway can reduce the stopping distance safety margin in the event of an RTO. For example, an unaccounted-for 5-knot tailwind could reduce the runway stopping distance available in a no-wind condition by 300-500 feet. Further, an airplane will be at a higher ground speed at $V_{1}$ with a tailwind, and, thus, will require more distance to stop.

Accuracy of the $V_{1}$ Call and Delay in Pilot Reaction--A 1-second delay by the pilot initiating the RTO after passing the theoretical $V_{1}$ speed will substantially decrease the margin between stopping distance required and runway length available because of the airplane dynamics at that speed. Standard procedure among airlines requires the nonflying pilot to make the $V_{1}$ call as the airplane passes through that speed. However, often the airplane has surpassed that speed as the pilot makes the $V_{1}$ call. This increases the likelihood that an RTO initiated near $V_{1}$ may actually be initiated past $V_{1}$. The certification process gives some allowance for pilot action, but not for such factors as airspeed indicator accuracy, or the ability of a nonflying pilot to audibly announce $V_{1}$ precisely at the $V_{1}$ speed.

Degraded Wheel Brake Performance--Demonstrations of airplane stopping performance tests are conducted with new brakes. Thus, stopping distances calculated for the FAA-approved flight manual do not account for, and there is no actual evidence to demonstrate the effectiveness of, the worn brakes that are typical of airplanes in service. The Safety Board's special investigation of the brake performance of the DC-10 disclosed that on that airplane a 220-foot to 500-foot increase in stopping distance can be expected if the brakes are worn (See footnote 10).

Runway Surface Friction--There are no regulations requiring a manufacturer to demonstrate the airplane's stopping performance on wet or slippery runways during the certification process or to provide data relating to such performance. Furthermore, there are no regulations requiring air carriers to consider degraded stopping performance when they determine takeoff weight limitations for specific runways. Although the operating rules require that the minimum length of runway needed for landing be extended by 15 percent when the runway is forecast to be wet, no requirement exists for adjusting the length of runway, or for adjusting aircraft maximum weight, for takeoff. Such adjustments will be discussed in more detail later in this report.

The FAA has not permitted reverse thrust to be used either to demonstrate stopping performance during the airplane certification procedures or to determine the stopping distances for the FAA-approved flight manual.
If reverse thrust was considered, the theoretical stopping distances would be reduced. In actual line flight, a flightcrew performing an RTO would be expected to use reverse thrust. The FAA believes the difference between the theoretical stopping distance, which does not include reverse thrust in its assumptions, and the actual stopping distances, where reverse thrust would be expected to be used, provides a safety margin. This margin, the FAA believes, is sufficient to offset the difference between the actual stopping distance of an airplane and its theoretical stopping distance derived in the absence of the variables described above.

Based on its investigations, analyses of airplane performance, and review of the airplane certification process, the Safety Board believes that reverse thrust does not adequately compensate for the increase in stopping distance that can result from the effect of one or more of the variables not considered in the certification process. An airplane near its maximum takeoff weight may, in the event a high speed RTO is performed, have a minimal or, in some circumstances, nonexistent stopping distance margin.

The Safety Board believes changes are needed in the airplane certification requirements. The Safety Board has issued recommendations to the FAA as a result of the special investigation report of the DC-10-30/40 (see footnote 10).

**INCREASING THE V\textsubscript{1} STOPPING DISTANCE MARGIN**

Because many important variables are not considered in the airplane certification process, some experts have suggested modifying \(V\textsubscript{1}\) to increase the RTO stopping distance margin and thereby enhance the safety of this go/no-go action point. For example, Batthauer (see footnote 14) advocates the use of different speeds according to how critical the precipitating event is. He suggested that "...one consideration could be that when takeoff speeds are between 20 knots below \(V\textsubscript{1}\) and \(V\textsubscript{1}\), only an engine failure could cause the initiation of an RTO. Tire failures and less serious anomalies would not automatically prompt an RTO."

Lufthansa has proposed using a takeoff decision speed some knots lower than \(V\textsubscript{1}\) so that a pilot can react to an event and perform an RTO before \(V\textsubscript{1}\) is actually reached.\textsuperscript{18} In the United States, United Airlines requires the nonflying pilot to begin the \(V\textsubscript{1}\) call 5 knots before \(V\textsubscript{1}\) is actually reached so that \(V\textsubscript{1}\) will be heard as that speed is reached. The airline believes this procedure recognizes the necessity for action in initiating an RTO no later than \(V\textsubscript{1}\) and assists crewmembers in the proper initiation of an RTO when necessary.

TWA modified its computation of \(V\textsubscript{1}\) following a series of RTO-related accidents and incidents in the late 1960s. TWA reduces \(V\textsubscript{1}\) by 1 knot for every 1,000 pounds of airplane gross weight under the maximum gross weight for that runway, up to a maximum reduction of 10 knots. The reduction for

the L-1011 TriStar is 1 knot for every 2,000 pounds, up to 10 knots. This reduction moves the $V_1$ go/no-go action point to an earlier point on the runway and at a lower airplane speed, thereby providing more runway distance should a high speed RTO be executed. Moreover, TWA provides information on the reduced $V_1$ to crewmembers on takeoff performance data sheets; for certain aircraft, crewmembers are required to complete the data sheet (see Appendix B). This process provides crewmembers with important information on the determination of $V_1$.

Another method to improve the safety margin of high speed RTOs is to reduce $V_1$ under certain conditions; for example, when additional runway length is available beyond the balanced field length, or when runway conditions could hamper the execution of a successful RTO. In 1982, following its special investigation of large airplane operations on contaminated runways, the Safety Board issued two recommendations to the FAA aimed at reducing $V_1$, when possible, to the lowest possible safe speed that conditions warrant.\(^\text{19}\) The recommendations asked the FAA to:

**A-82-163**

Amend 14 CFR 25.107, 25.111, and 25.113 to require that manufacturers of transport category airplanes provide sufficient data for operators to determine the lowest decision speed ($V_{1d}$) for airplane takeoff weight, ambient conditions, and departure runway length which will comply with existing takeoff criteria in the event of an engine power loss at or after reaching $V_1$.

**A-82-164**

Amend 14 CFR 121.189 and 14 CFR 135.379 to require that operators of turbine engine-powered, large transport category airplanes provide flightcrews with data from which the lowest $V_1$ speed complying with specified takeoff criteria can be determined.

On February 26, 1986, the FAA informed the Safety Board that it has commenced rulemaking activity in response to these recommendations. If adopted, the final rule will satisfy, in part, the intent of the recommendations. As a result, the Safety Board has classified the recommendations as "Open--Acceptable Action." The Safety Board is concerned, however, about the time that has elapsed since these recommendations were issued and urges FAA to expedite the promulgation of a final rule.

The Safety Board also believes that air carriers should provide flightcrew members with the necessary information to allow them to increase the $V_1$ stopping distance margin without incurring substantial costs. For

\(^{19}\) Special Investigation Report---"Large Airplane Operations on Contaminated Runways" (NTSB/SIR-83/02).
example, information on the maximum permissible takeoff weight for an available runway, at the existing conditions, would enable pilots to compare the maximum weight with the actual airplane takeoff weight. By selecting the runway that allows for the greatest difference between the two weights, other conditions being equal, pilots can select the runways with the maximum stopping distance available in the event of a high speed RTO. Information that would enable pilots to select the optimum flap configuration for takeoff would also provide the greatest runway distance available for stopping the airplane.

In addition, airlines generally advise pilots to use thrust settings on takeoff that are less than the available maximum thrust whenever feasible. The lower thrust setting helps to prolong engine life. However, the use of the lower or derated thrust settings reduces the runway distance available to stop the airplane. Airlines should be certain that flightcrew members have sufficient information to use derated thrust judiciously without compromising RTO safety margins.

**PILOT TRAINING IN RTOS**

The requirements of 14 CFR 121, Appendixes E and F, stipulate that pilots of transport category airplanes be presented with "a simulated failure of the most critical engine" either just before or just after $V_1$. The regulations require pilots to demonstrate their ability, at regular intervals, to correctly assess whether an RTO is called for, and if an RTO is considered necessary, to perform one effectively.

Written Guidance and Procedures

Airlines operating under 14 CFR 121 provide their pilots in ground school with information on company general operating procedures and on the particular airplane they will operate. Procedures identifying the crewmember authorized to initiate an RTO are stated within company general operating procedures, and are normally reiterated in manuals or handbooks that flightcrew members are required to master.

For all but one airline the Safety Board observed, the decision to reject the takeoff, regardless of which crewmember is flying the airplane, is the captain's alone. Continental Airlines allows first officers, under certain conditions, to make the decision to initiate an RTO; however, the captain remains responsible for the proper completion of the RTO.

Should a high speed RTO be necessary, the airlines emphasize the use of all deceleration devices available on the airplane, including reverse thrust, ground spoilers, and wheel braking. In addition, crewmembers are assigned specific tasks and are generally required to make certain callouts when initiating an RTO. For example, Delta Air Lines' L-1011 Pilots Reference Manual states that when the first officer is making the takeoff:
...if the Captain decides that a situation warrants an abort (or RTO), the Captain will so state and in a positive manner assume control of the aircraft....The Captain should announce his intentions.

Despite these procedures and Delta’s training, information from the cockpit voice recorder on Delta flight 23 (described in the section "Previous RTO Incidents and Accidents") indicates that the RTO was initiated after $V_2$ and that the captain did not announce he was rejecting the takeoff. Rather, the captain says "pull 'em" three times. After the sound of engine deceleration is heard, the first officer says "going to abort" followed by the flight engineer’s call for "abort checklist."

The airlines surveyed by the Safety Board have generally instructed their pilots to execute high speed RTOs only in the event of engine fires or failures and only before $V_1$. For example, Delta Air Lines’ L-1011 Pilots Reference Manual requires that the "abort decision be made and appropriate procedures initiated" only in situations so serious that they "outweigh the risk to the airplane and occupants that a high speed RTO would impose." According to the cockpit voice recorder, the first officer on Delta flight 23 said, "We started to rotate, I got to about seven or eight degrees, from what the engineer said, ah we got pop-pop-pop-pop-pop, we got guys on final said fire right [engine], fire out of the right hand side of the engine...." Further, he said there was "no engine indication" of thrust difficulties.

The DC-9 Flight Handbook of Midway Airlines directs pilots to "normally continue the takeoff" should a tire failure occur 20 knots or less below $V_1$. Further, the airline disseminates the following information to their pilots during ground school:

The speeds given in the FAA Approved Airplane Flight Manual have been selected so that...a stop may be made on the runway at $V_1$, without the aid of reverse thrust; and without, in either case, exceeding the FAA takeoff field length. These minimum takeoff field lengths are based on stopping if engine failure is recognized before reaching $V_1$, and on continuing the takeoff if engine failure is recognized after $V_1$.

Because the minimal stopping distance margins provided for RTOs in the certification process are minimal, if a precipitating event occurs near $V_1$ and the pilot’s initiation of the RTO is not immediate, the stopping distance of the airplane may exceed the amount of runway remaining, even though the runway length met the predetermined accelerate-stop distance for the given conditions. Yet, the Safety Board’s review of airline guidance on RTOs indicates that few airlines give their flightcrews complete information about the margin of safety during a high speed RTO.

Federal Express distributed to all flightcrew members guidance on rejected takeoffs written by one of its DC-10 check airmen (Appendix C). The material conveys to pilots detailed information about airplane performance for high speed RTO certification and on practices to employ to enhance the execution of high speed RTOs.
United Airlines developed a videotape as part of its efforts to enhance flightcrew situational awareness of airplane stopping capabilities following high speed RTOs. The video addresses RTO-related certification requirements, presents information on factors that were not considered in the determination of accelerate-stop distances (information about which pilots may not be aware) provides guidance for determining whether to execute an RTO and discusses procedures to follow in the execution of high speed RTOs. The airline mailed the video cassettes to the home of each captain.

Despite the special efforts of airlines such as Federal Express and United, the Safety Board's review of airline guidance and procedures related to RTOs indicates that many airlines do not adequately recognize and address the length of time a pilot needs to assess a situation, to decide whether to initiate an RTO, and to perform the requisite steps to complete the maneuver. Some airlines that the Safety Board surveyed gave flightcrew members incorrect information. For example, one airline describes $V_1$ in its manual as: "...the decision speed. At this point the pilots must decide whether to continue the takeoff or to abort." Although the definition of $V_1$ as "the decision speed" is consistent with the FAA definition in 14 CFR 121.2 and 14 CFR 25.107 (2), the decision to continue or to reject the takeoff should be initiated before $V_1$ and action must be taken by $V_1$ for the airplane to be able to be stopped within its predetermined accelerate-stop distance. In addition, some airlines offer vague or ambiguous guidance that gives the flightcrew member little specific information regarding when, in relation to $V_1$, the RTO decision should be made or how to make a proper go/no-go decision.

The Safety Board is concerned that some airlines may be conveying misinformation or insufficient information about RTO procedures and airplane stopping capabilities. Therefore, the Safety Board believes that the FAA should require Principal Operations Inspectors to review the accuracy of information on $V_1$ and RTOs that 14 CFR 121 operators provide to flightcrews to assure that they provide correct information about pilot actions required to maximize the stopping performance of an airplane during a high speed RTO. Further, the Safety Board believes that the FAA should redefine $V_1$ in 14 CFR 121.2 and 14 CFR 25.107 (2) to clearly convey that it is the takeoff commitment speed and the maximum speed at which RTO action can be initiated to stop the airplane within the accelerate-stop distance.

The Safety Board believes that the guidance airlines provide flightcrew members can and should be modified to include information learned from RTO incidents and accidents. The information can improve pilots' understanding of the dynamics of RTOs, the risks associated with performing high speed RTOs, and as a result, enhance the pilots' ability to correctly decide if an RTO can be safely executed. Consequently, the Safety Board believes that the FAA should require 14 CFR 121 operators to present to flightcrews the conditions upon which flight manual stopping performance data are predicated and include information about those variables that adversely affect stopping performance.
Flight Training

Pilot training in the execution of a high speed RTO is conducted during flight training, almost exclusively in highly sophisticated flight simulators. Simulators vary in the fidelity with which they replicate a particular airplane type, but all visual simulators and the more advanced Phase I, II, and III simulators are required to present visual, aural, and kinesthetic cues that closely match corresponding sensations in the airplane.

Simulator Cues.--Pilot training and checking sessions almost always present RTOs as $V_1$, engine failure-related maneuvers. In the sessions, the decision to execute the RTO is based on whether the engine failure occurs just before or just after $V_1$. In the RTO training the Safety Board examined, most airlines presented pilots only the cues associated with engine failure. Because the recognition of engine failure and control of the airplane following such an event is a demanding task for pilots, the Safety Board acknowledges that such training should continue.

RTO-related accident and incident data indicate, however, that tire failures lead to more high speed RTOs than do engine-related anomalies. Airlines may not be presenting cues associated with nonengine-related events partly because FAA regulations require that engine failures are to be presented to pilots in their RTO training. The Safety Board's observations suggest that most flight training in RTO recognition and execution is designed to meet and not to exceed the requirements of the Federal Aviation Regulations (FARs). The acquisition and operating costs of flight simulators are high; the costs that airlines may incur by exceeding the minimum flight training and checking requirements and by the salaries of the flight instructors and the students can be substantial. Consequently, most simulated RTOs present only cues associated with engine failure.

Because most RTO training presents only engine failure, pilots may not be fully prepared to recognize cues of other anomalies during takeoff. In addition, the low probability of events occurring that would lead to an RTO increases the likelihood that pilots encountering unusual cues will be experiencing them for the first time. As a result, pilots may be less prepared to react to such cues than they would be had their simulator training also presented nonengine-related cues.

Compounding the difficulty pilots may face in recognizing and reacting to unusual or unique cues is the brief time that elapses between the point at which a transport category turbojet airplane accelerates beyond 100 knots to the point at which it reaches $V_1$, generally about 4 to 5 seconds. Should an anomaly occur during this time, the crew will have only a second or two to analyze the event and decide if circumstances warrant an RTO. Consequently, pilots encountering unusual sounds or vibrations just before $V_1$ may believe it more prudent to reject the takeoff and keep the airplane on the ground than to continue the takeoff.
The British Accidents Investigations Branch (AIB) investigated a 1983 RTO-related accident of a Pan American World Airways, McDonnell Douglas DC-10-30, at London’s Heathrow Airport. The high speed RTO was precipitated by a main gear tire failure. The AIB described the difficulty pilots face in such situations:

...in the case of a tire failure or suspected tire failure, the pilot’s decision is an extremely difficult one. To assess the extent of the problem when positioned a considerable distance away from the probable source, surrounded by extraneous cockpit noise and vibration and often without any instruments to assist, calls for inspired guesswork aided only by experience. Is the sensory input caused by tire burst or some other problem such as engine breakup? Is more than one tire involved? Is there likely to be any consequential damage, and if so, how serious? Above all, is there a likelihood of fire? These are all questions which the pilot should, ideally, take into account, as well as the aircraft’s progress relative to its takeoff speed. To compound his problem, the time available for decision-making is often minimal because tire failures are most likely to occur at high groundspeeds.

The data indicate that pilots often incorrectly interpret the cues accompanying noncritical events (such as simple tire failure) as events threatening the safety of flight; as a result, the pilots incorrectly decide to perform an RTO. The Safety Board believes that presenting flightcrew members with realistic cues accompanying noncritical events will better prepare them to recognize these events should they be encountered during takeoff.

False or Noncritical Warnings.--False or noncritical cockpit warnings have activated as an airplane was approaching, or had reached $V_1$, and have led to a high speed RTO that resulted in an accident or incident. Recent examples include the 1988 accident of American Airlines DC-10 at Dallas-Fort Worth International Airport in which a slat disagree light incorrectly illuminated at or near $V_1$, and the 1989 incident of a Delta Air Lines L-1011 TriStar incident at Frankfurt, Federal Republic of Germany, in which the crew heard unusual sounds later found to be caused by a loose boroscope plug in the engine, not engine failure. Another RTO-related accident occurred in 1988 when an Air France Boeing 747-200 overran the runway at Delhi, India; the RTO was initiated after a fire warning sounded at or after $V_1$. The warning sounded not because of fire but because a crack in the mid-frame of the No. 4 engine’s turbine caused an overtemperature near an engine heat sensor.

In response to the number of false warnings, manufacturers have incorporated into newer airplanes, such as the Boeing 757, 767 and 747-400, and the Airbus A-320, an internal system logic that inhibits all but the most important warnings just before and just after rotation. In the newer model Boeing airplanes, warnings are inhibited after 80 knots and remain inhibited until the airplane has reached 400 feet above ground level or until 20 seconds have elapsed since rotation. The systems on these airplanes
inhibit one of the most critical alerts, the fire warning, which has both auditory and visual components. Should an engine fire be sensed, the engine indicating and crew alerting system (EICAS) will display the fire warning, but the associated fire warning bell will not sound until 20 seconds after rotation has begun or until the airplane has climbed to 400 feet above ground level. Clearly, the inhibition of such warnings substantially reduces the probability that a high speed RTO will be initiated incorrectly. The Safety Board believes that this design feature is a major enhancement to flight safety.

However, most airplanes operating in revenue service today and those that will operate in the near future do not have such systems and cannot reasonably be redesigned or retrofitted to incorporate them. The Safety Board is concerned that without changes in pilot training, pilots may continue to initiate high speed RTOs in response to warnings in the older model airplanes that may be false, noncritical, or both. One practical solution is to introduce in simulator training the specific alerts and warnings that may occur during the takeoff roll, but for which an RTO should not be initiated after a particular speed has been achieved. Such training may provide pilots with the necessary familiarity with warnings so that should a false or noncritical warning or alert occur during takeoff, the pilots can better recognize the need to continue the takeoff. Consequently, the Safety Board believes that the FAA should require that simulator training for flightcrews of 14 CFR 121 operators present, to the extent possible, the cues and cockpit warnings of occurrences, other than engine failures, that have frequently resulted in high speed RTOs.

Takeoff Scenarios.--The Safety Board’s observation of RTO-related flight training has revealed that some airlines may be using takeoff scenarios in which the simulator can be stopped with runway distance remaining, even though the pilot’s execution of the RTO may not be optimal. The Safety Board believes that RTO scenarios should simulate the most critical conditions and that the airplane should fail to stop on the runway unless the pilot responds as necessary. Without such a scenario, pilots may inadvertently learn that an airplane can stop on a runway in a shorter distance and with greater ability than is true under actual operating conditions; as a result, their decisionmaking regarding RTOs and the execution of the RTOs may be improper. The Safety Board believes that flight simulators should present, as accurately as possible, the airplane’s stopping capabilities under all conditions. Consequently, the Safety Board urges the FAA to require that simulator training of 14 CFR 121 operators present accurately the stopping distance margin available for an RTO initiated near or at VLO for runways where the distance equals or just exceeds balanced field conditions.

CREW COORDINATION IN PERFORMING RTOs

The data indicate that in many of the RTO-related incidents or accidents, the first officer was the pilot flying. These data suggest that a delay may have occurred when control of the airplane was transferred from the first officer to the captain, the crewmember authorized by most airlines to initiate an RTO. The transfer of control involves engine thrust and the
control stick, which require hand input, and the wheel brakes and rudder, which require leg and feet input. Difficulties in transferring control are illustrated by four recent incidents and accidents described earlier in this report: the Air France Boeing 747 in Delhi, India; the American Airlines DC-10 at Dallas-Fort Worth International Airport; the Eastern Airlines Boeing 757 at San Jose, Costa Rica; and the Delta Airlines Lockheed L-1011 TriStar at Frankfurt, Federal Republic of Germany. Other RTO-related accidents and incidents have occurred during the past 20 years that also reveal difficulties in transferring control in RTO execution from the first officer to the captain.

Without effective crew coordination, valuable time may be lost in the transfer of flight control from the first officer to the captain. The Safety Board believes these accidents and incidents illustrate the need to modify existing pilot training and procedures regarding crew coordination during the execution of RTOs. As a result, the Safety Board urges the FAA to require that simulator training for flightcrews of 14 CFR 121 operators emphasize crew coordination during RTOs, particularly those RTOs that require transfer of control from the first officer to the captain.

Some foreign carriers have established policies to preclude difficulties in the transfer of flight control during an RTO. One policy precludes the first officer from performing takeoffs; this policy may limit possible adverse consequences during an RTO, but it may also limit the experience that a first officer could gain from performing takeoffs repeatedly. The Safety Board has investigated accidents that, although not RTO-related, occurred after a relatively inexperienced first officer performed a takeoff under adverse weather conditions. As a result, the Safety Board recommends that the FAA require 14 CFR 121 operators to review their policies which permit first officers to perform takeoffs on contaminated runways and runways that provide minimal RTO stopping distance margins, and encourage the operators to revise those policies as necessary.

CALLOUTS

The Safety Board's review of airline procedures revealed general consistency among the airlines surveyed in the manner in which they require that RTOs be performed. Most airlines require callouts for engine or thrust settings, a speed callout such as "airspeed alive," then callouts for $V_1$, $V_r$, and $V_2$. However, the Safety Board found variation among airlines in the callouts required during takeoffs, particularly during rejected takeoffs. For example, most, but not all airlines, require the nonflying pilot to make a speed callout at 80 or at 100 knots.

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21 $V_r$ is the rotation speed.
The speed callout can alert crewmembers to check their air speed indicators for reliability. The callout also indicates that the airplane is entering the high speed takeoff regime. A callout at that speed alerts the crew that the airplane's stopping capabilities have been diminished; at that speed, only engine-related anomalies or events that jeopardize the safety of flight justify initiating an RTO. Without such a callout, the crew may be unaware that the airplane has entered the high speed regime; as a result, the pilot may initiate an RTO at a speed exceeding the airplane's ability to stop on the remaining runway.

The Safety Board also found that most but not all airlines require the pilot initiating the RTO to make an appropriate callout to the other pilot. The investigation of the accident involving the Eastern Airlines Boeing 757 in Costa Rica indicated that the first officer, the flying pilot, was attempting to continue the takeoff while the captain, the only crewmember Eastern authorized to initiate an RTO, was attempting to execute an RTO. The captain made no statement to the first officer to indicate that an RTO was in progress or that he was taking control of the airplane. The accident illustrates the need for the crewmember initiating the RTO to state the intention to the other flightcrew members. Therefore, the Safety Board recommends that the FAA require that the takeoff procedures of 14 CFR 121 operators are standardized among their airplane types to the extent possible, and that the procedures include appropriate callouts to alert flightcrew members clearly and unambiguously when the airplane is entering the high speed takeoff regime and when an RTO is being initiated.

**AUTOBRAKES**

Many airplanes in service today, such as the McDonnell Douglas MD 80 series and MD 11, the Boeing 757 and 767, and the Airbus series, have been equipped with braking systems known as autobrakes. Autobrakes automatically establish wheel braking upon landing or upon a predetermined throttle reduction once past a certain speed during takeoff. As a result, pilot input is not required to initiate braking action on the airplane wheels. The extent of brake forces can vary from light to heavy pressure on landings, but for RTOs, autobrakes automatically apply maximum brake pressure.

The requirement for setting autobrakes to the RTO mode varies among operators. Some airlines believe that determination of autobrake setting should be left to the captain based on his or her experience. For example, at USAir, autobrake setting during takeoff was a pilot option; on USAir flight 5050 (a Boeing 737-400), which ran off the runway at LaGuardia Airport in New York City in September 1989, the autobrakes had not been set. The Safety Board's investigation of the accident is continuing; the utility of autobrakes in that accident has yet to be determined. However, the Safety Board believes that airlines should require that autobrakes, when available, should be set in the RTO mode when conditions warrant; for example, on a contaminated runway or when the runway length is not substantially greater than the balanced field length. The Safety Board recognizes that pilot discretion should be permitted in the setting of autobrakes under certain takeoff conditions, yet, the Safety Board also believes that the use of autobrakes should be required when warranted. Therefore, the Safety Board
urges the FAA to require 14 CFR 121 operators to adopt a policy to use the maximum brake capability of autobrake systems, when installed on the airplane, for all takeoffs in which minimum stopping distances are available following a rejected takeoff.

The Safety Board also believes that flight training for pilots of airplanes not equipped with autobrakes should emphasize the need for flight crew members to prepare for maximum braking during takeoffs. Such preparation requires that the pilot responsible for initiating an RTO have his or her feet in position to exert maximum brake pressure as soon as an RTO is initiated. The Safety Board’s observation of procedures and training in RTO execution indicates that airlines emphasize the importance of throttle movement by requiring that the pilot authorized to initiate an RTO will place his or her hands on the throttles at some point during the takeoff; for most airlines, the hands are to remain on the throttles until Vₜ is reached. Should an RTO be initiated, the pilot can then reduce the thrust to idle and institute reverse thrust almost immediately. However, foot placement is not generally addressed, and unless the pilot’s feet are in the proper position, valuable time may be lost before maximum braking can be achieved.

During an actual or simulated RTO, a pilot may exert what he or she believes to be maximum braking pressure, only to learn afterwards that maximum pressure was not achieved. Many flight simulators have the ability to record various braking parameters; airlines with such simulators can provide their pilots information on the extent to which they exerted maximum brake pressure and the amount of time needed to achieve the maximum pressure. The Safety Board encourages airlines to modify their training and procedures to emphasize the importance of proper foot placement during takeoffs and to provide information to pilots, when possible, on the maximum brake pressure achieved during a simulated rejected takeoff and the amount of time needed to achieve that pressure.

RECOMMENDATIONS

As a result of this special investigation, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Redefine Vₜ in 14 CFR 1.2 and 14 CFR 25.107 (2) to clearly convey that it is the takeoff commitment speed and the maximum speed at which rejected takeoff action can be initiated to stop the airplane within the accelerate-stop distance. (Class II, Priority Action)(A-90-40)

Require Principal Operations Inspectors to review the accuracy of information on Vₜ and rejected takeoffs that 14 CFR 121 operators provide to flight crews to assure that they provide correct information about pilot actions required to maximize the stopping performance of an airplane during a high speed rejected takeoff. (Class II, Priority Action)(A-90-41)
Require 14 CFR 121 operators to present to flightcrews the conditions upon which flight manual stopping performance is predicated and include information about those factors which adversely affect stopping performance. (Class II, Priority Action)(A-90-42)

Require that simulator training for flightcrews of 14 CFR 121 operators present, to the extent possible, the cues and cockpit warnings of occurrences other than engine failures that have frequently resulted in high speed rejected takeoffs. (Class II, Priority Action)(A-90-43)

Require that simulator training of 14 CFR 121 operators present accurately the stopping distance margin available for a rejected takeoff initiated near or at V1 on runways where the distance equals or just exceeds balanced field conditions. (Class II, Priority Action)(A-90-44)

Require that simulator training for flightcrews of 14 CFR 121 operators emphasize crew coordination during rejected takeoffs, particularly those rejected takeoffs that require transfer of control from the first officer to the captain. (Class II, Priority Action)(A-90-45)

Require 14 CFR 121 operators to review their policies which permit first officers to perform takeoffs on contaminated runways and runways that provide minimal rejected takeoff stopping distance margins, and encourage the operators to revise those policies as necessary. (Class II, Priority Action)(A-90-46)

Require that the takeoff procedures of 14 CFR 121 operators are standardized among their airplane types to the extent possible, and that the procedures include appropriate callouts to alert flightcrew members clearly and unambiguously when the airplane is entering the high speed takeoff regime and when a rejected takeoff is being initiated. (Class II, Priority Action)(A-90-47)

Require 14 CFR 121 operators to require pilots to adopt a policy to use the maximum brake capability of autobrake systems, when installed on the airplane, for all takeoffs in which runway conditions warrant and where minimum stopping distances are available following a rejected takeoff. (Class II, Priority Action)(A-90-48)
BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ James L. Kolstad
Chairman

/s/ Susan M. Coughlin
Acting Vice Chairman

/s/ John K. Lauber
Member

/s/ Jim Burnett
Member

February 27, 1990
APPENDIX A

ACKNOWLEDGMENTS

The Safety Board thanks the following individuals and organizations who assisted in this study:

Midway Airlines
Capt Ross Hutchinson
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Vice President, Engineering and Operations Control

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Manager, Flight Instruction Standards

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System Director, Flight Training

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Boeing 727 Program Manager, Flight Standards and Training

United Airlines
Mr. Lew Kosich
Boeing 757/767 Training Check Airman
Chairman, ATA Flight Operations Review Team

Captain Bob Morton
Manager of Flight Standards and Training
## 747-100/200 Takeoff Performance Data

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INTER-OFFICE MEMORANDUM

DATE: April 27, 1988
FROM: Rick Myers
SUBJECT: REJECTED TAKEOFFS

TO: All Crewmembers
cc: Frank Fato
    Byron Hogue
    Jerry Wynn
    Ron Keller
    Jack Miller

Much has been published over the last few years concerning rejected takeoffs. Some of the concerns relate to the criteria upon which RTO certification is based (during original airplane flight testing for it’s type certificate) versus how RTO’s might manifest themselves in line flying.

Captain John D. Whitehead, DC-10/Check Airman, has devoted a lot of his personal time to this paper. He has taken several articles on this subject and pulled out references that he feels will cut through some of the engineering type talk (while keeping the necessary background information) and get to the points of interest of the line pilot.

I hope you will agree that this is good food for thought. Please take the time to look over this material and discuss it with your fellow pilots.

Thank you for your attention,

[Signature]

Captain Rick Myers
Senior Manager/Pilot Training
Chief Flight Instructor
Extension: 222-6364
Comat: 3211
RM:mj:j3336v
APPENDIX C

REJECTED TAKEOFFS

I'm sure you're all aware that V1 is the GO/NO-GO speed for takeoffs, right? WRONG! Thrust reversers are a good "pad" in RTO's since they aren't considered in rejected takeoff demonstrations for certification, right? NOT ALWAYS!

A good place to start is with some background into transport category certification standards from an paper entitled V1 REJECT. The paper was presented at a safety seminar entitled Safety Focus.

V1 REJECT

V1 Speed

V1 speed is not "engine failure speed". V1 is "engine failure recognition speed". On all current jet aircraft, the critical engine is assumed to have failed below V1 at a speed called Vef. The crew is assumed to have recognized and initiated a response to the engine failure by V1 speed. V1 is not the speed at which failure can occur and begin the recognition-decision-reaction sequence. At V1 speed the crew must already be moving rapidly into a vigorous effort to stop the aircraft.

The certification process for present jets was accomplished when V1 was defined by the FAA and understood by the pilots to mean "engine failure speed". After numerous dramatic failures in rejected takeoffs, the FAA rewrote the regulations to define engine failure speed as Vef and to define V1 as "engine failure recognition speed" to legitimize the procedure. This new rule, adopted in 1978, also requires time delays and engine-out acceleration recognition. No corrective safety margin has been applied to our aircraft certified under the pre-1978 rule to compensate for this change. The FAA does not even require an allowance for runway lost in positioning the aircraft for takeoff.

Certification

The certification scenario works like this; a crew, rested, steely-eyed, iron pumping, racquetball champion, graduate from test pilot school, lashed himself into the left seat of a brand new flying machine. The flying machine has sparkly cold brakes and rubber skins with the paper labels still not worn off. The runway is scrubbed bare and dry for all 15,000 feet. The sky is cloudless, the air is cool, and the wind is right down the runway at zero knots.

Our hero has been programmed, by a multitude of practice runs in the simulator, to reject on a given signal that he knows is coming. This he does, Gretzky style, with his hands and feet just
a blur as he swings into action. As a matter of fact, the aircraft certification is based on the following time intervals demonstrated by Joe Cool: from engine failure to brake application (recognition-reaction time) 0.35 sec. (Yes, that's right, less than half a second!), 0.48 sec. more to throttle chop and 0.51 sec. to spoiler actuation. Another 2 sec. generously added in to a total of 3.44 sec. for the certification.

This Alice-in-Wonderland situation is seldom duplicated by Capt. Flatspin Fumble, your average line driver. As a point of interest, Capt. Fumble, according to a NASA/Douglas simulator test, can only achieve maximum braking during simulator RTO's, 60% of the time.

Tires, Wheels, & Brakes

To further compound the problem, an FAA study determined that 87% of rejected takeoffs were caused by tire, wheel, and brake failures. Douglas estimated the figure at around 50%. Yet, critically, these components are required to be 100% effective to achieve the scheduled stopping distance.

Tire manufacturing standards are suspect in many of the tire failure situations. The FAA revised the 1962 ESO (TS062C) to increase the load bearing capacity of aircraft tires, but just up to existing standards set by the manufacturers. A further 1979 NPRM to further increase strength and rate load has been initially rejected by the carriers as being too costly. Just recently, new tire standards are gradually taking effect.

Weather Conditions

The certification process does not take crosswind effects on aircraft performance into consideration. Aileron and spoiler drag as well as displaced rudder drag will increase the distance covered to reach VI speed.

It is generally conceded that a wet runway gives approximately one-half the braking coefficient of a dry runway.

There are also documented instances of extensive differences between reported airport temperature and runway surface temperature in a calm wind. Aerodynamic and engine propulsive performance can be greatly reduced from the planned due to this factor alone.

Takeoff Alignment Distance

The Australian government is the only certifying authority requiring runway alignment allowance. The opposing factions claim that the scheduled accelerate-stop distance does not take credit for reverse thrust, and this more than compensates for the distance lost in alignment. However, reverse thrust credit is not allowed in certification because the FAA does not consider it to be sufficiently reliable.

Courtesy ACAC via Safety Focus
APPENDIX C

I hope, after reading this safety paper, that you can begin to appreciate what you're up against when you make your next takeoff. Now let's look at each point a little further.

Today's Takeoff

Now let's consider the effects of heat buildup on your tires and brakes as you make that long taxi to the takeoff runway on a hot day. The test airplane began from a standing start with no taxi prior to the takeoff roll and, therefore, no heat buildup. The test airplane's tires were carefully checked to confirm that pressures were exactly as specified by the tire and airplane manufacturers. In contrast, your takeoff today may be the last one before the brake change, or the tire change. Today's takeoff may be the one with rubber deposits at the "reject end" of the runway or the one with water or ice on the runway, each of which may effect your deceleration without constituting clutter and therefore not be accounted for in your takeoff data. (Airplanes operating under British CAA rules must lower V1 speeds on wet runways to allow for degraded stopping performance with a wet runway). Your tire pressures may not have been closely checked by that contract maintenance man assigned to today's charter (the charter that requires you to make a max gross weight takeoff).

In the U.K., it is general policy to undertake performance testing with used tires and 90% worn brakes, in contrast to the FAA practice. The U.K. requirement to stop in a wet demonstration can also be a significant trial variation from U.S. standards. In committee discussion of the U.K. Flight Safety Committee it was argued that performance standards testing, recently updated for new tire designs, should be applied in some similar degree to the typical retread as such a large proportion of the tires used are retreaded. The engine failure definition of V1 is no protection for the tire failure case even with the lately extended pilot recognition and reaction times of the U.K. code. The effect of flat or broken-up tires on braking is gross.(1)

What about those thrust reversers? Since they aren't accounted for during certification testing, shouldn't there be a pad built in to our stopping performance during a RTO? The answer is yes, there is "some" pad, but it is considerably less than you might think. According to a paper by Ronals Ashford of the British CAA, "Poor thrust reversers on some aircraft, for example the 747, are a factor in the runway overrun accident record. Aircraft with good thrust reversers have less than a third of the accidents of those with poor reversers. There are about three a year, of which one is fatal. This is not acceptable and more rational international requirements for stopping on wet runways are needed". Capt. Falko Fruehauf, Lufthansa's manager of performance and operations engineering is quoted as saying, "The influence of reverse thrust is overrated". The use of max symmetrical reverse, in a one-engine inop 4 engine airplane reject, reduces the stopping distance by
400 ft. Just a 10% reduction in runway braking coefficient will cause this advantage to disappear completely. It's no secret that our reversing system on the DC-10 leaves something to be desired.

What Can I Do?

During the preflight, the Second Officer should carefully examine the tire condition including pressures where the guage is installed in the wheel. While some S/0s might argue as to the accuracy of these guages, it's the old "something is better than nothing" routine. If there is a large discrepancy between pressure guages, especially on tires on the same axle, it should be brought to the attention of the Captain and maintenance personnel. Analysis indicates that the predominant cause of tire failure is underinflation and the resultant overdeflection of the tire sidewall. During taxi and takeoff, the heat buildup in the underinflated tire will increase more rapidly while the higher-pressure tire will be carrying a greater portion of the load. Both reduce the safety margin.(2)

Don't Taxi Fast

The heat buildup due to flexing of the sidewalls while the tire is rolling can be influenced by taxi techniques. Due to the low heat conductivity of rubber, tire temperatures continue to rise while the wheels are rolling. Thus, tire temperatures increase with taxi distance. The temperature rise is also influenced by taxi speed. Don't race to the end of the runway and make a rolling takeoff to beat an approaching airplane on final. Increased tire temperature decreases tire strength which reduces some of the design safety margin during takeoff. Douglas recommends a maximum taxi speed of 20 to 30 knots. Lower taxi speeds should be used at high gross weights and/or for long taxi distances. Avoiding high taxi speeds is, by far, the most effective way to keep heat buildup out of tires. Riding the brakes (continuous light application) to control taxi speed will heat the brakes faster than momentary, moderate application to reduce speed followed by complete release of the brakes and allowing the airplane to accelerate before another brake application. In addition, avoid sharp turns where possible. When making tight turns, avoid the use of brakes on the inside wheels.(3)

What Justifies a RTO?

That is the $64,000 question. While no two circumstances will be exactly alike, there are some considerations to look at. Pilots have come to regard V1 as the GO/NO-GO decision speed for any recognized anomaly during the takeoff roll regardless of other favorable factors such as excess runway over that required, all engines operating, etc. Most airplane manufacturers and many of the world's major airlines have begun to adopt the approach that the
APPENDIX C

decision to reject a takeoff should be based on an increasing level of
criticality as the airplane approaches V1. One consideration suggested by
both NASA and Douglas would be that when takeoff speeds are between
20kts. below V1 and V1, only an engine failure could cause the initiation of a
RTO. Tire failures and other less serious anomalies would not automatically
prompt a RTO. This addresses the situation where tire problems manifest
themselves just prior to or at V1 which may compromise the ability to stop
within the available runway remaining. Mr. H.H. Knickerbocker of McDonnell
Douglas has written "It is imprudent to put the full weight of an aircraft
loaded for takeoff, plus the stress of a high-speed maximum braking effort
abort, on an already damaged tire system. The only high-speed tire problem
worth aborting for is one that has caused serious engine anomalies".

Japan Air Lines says, "The following type of abnormalities at or near V1 may justify a
continued takeoff.
(a) Tire failure
(b) Antiskid failure
(c) Caution light concerning engine failure
(d) General electrical failures
(e) Indication failure of instruments not absolutely required

British Airways says in their 737 manual,
(a) Up to 100kts. .....abandon for any malfunction
(b) 100kts. to V1......abandon only for (a) Engine failure-either thrust guage falling below 80%
(b) The Captain observing an emergency and calling 'STOP'
NOTE: Do not abandon for an engine fire or overheat
warning unless accompanied by a loss of thrust.

Boeing says, "Unless the situation which is leading to a GO/NO-GO decision is rapidly assessed
as critical to remain on the ground, the chances of success are better by continuing the takeoff
and then determining the next course of action under less stressful and time critical conditions".
NOTE: On the newer Boeing jets such as the 767, portions of the crew
alerting system that are not critical to the takeoff phase are inhibited after
80kts. and until 20 seconds after liftoff or reaching 400ft. Additionally,
the fire bell and master warning lights are inhibited between nose gear
strut extension and either 20 seconds elapsed time or 400ft. Clearly, Boeing
has determined that items associated with these particular warnings are
not worthy of a RTO.

Lufthansa says, "When comparing the risks of stopping with those of a continued takeoff, one
must note that there is an additional safety margin when continuing the takeoff. This
additional safety margin is the reason for the superiority of the GO decision compared to the
NO-GO decision"
The Reject

"On October 18, 1983, our B-747 freighter D-ABYU departed from Hong Kong Rwy 13 at a takeoff weight of 822,000lbs. It was a field length limited takeoff. The balanced V1 was calculated to be 157kts.

A broken retainer ring in engine #2 resulted in high EGT and later caused N1 to be 11% below target. The decision was made to abort the takeoff very close to V1. The airplane came to rest left of Rwy 13 in soft ground and was considerably damaged. None of the three-man crew was hurt.

In the case of our Hong Kong rejected takeoff, the 4 engine reverse contributed only 460ft. to the stop performance.

A significant aspect of this accident is, however, that the airplane ran off the side of the runway, otherwise there is no doubt that the airplane would have left the end of Rwy 13 when extrapolating the actual speed distance history. The airplane would have crashed into the water of the harbour with serious consequences." (4)

It appears these people were very lucky and apparently skilled in the RTO maneuver itself. A review of crew debriefings when an overrun has taken place reveals that there may be a curious psychological manifestation in the minds of some crew members at the moment of rejecting a takeoff beyond V1 which in some cases almost puts them in the spectator category. The thought seems to be that they are going off the end of the runway and they are sort of along for the ride. Flight data recordings have shown that maximum braking has not been obtained even though the flight crew have testified "full pedal application was used". Full brake pedal application to the stops must be continuously held for the entire deceleration period of the RTO to a complete STOP! Full application of reverse should also be used down to a stop if necessary. As speed decreases below 80kts., there may be a feeling that speed is much lower than actual and that the airplane will surely stop on the remaining runway. At this point there is a tendency to let up slightly on the brakes or start coming out of reverse thrust. Don't fall into this trap. Keep the brakes on full until you have rocked to a stop. Our DC-10 rejected takeoff checklist asks "at what speed was the reject initiated?" so as to determine cool down time. It doesn't ask, "Did the Captain get on the brakes hard or easy?" Going easy on the brakes doesn't save one minute of cool down time so stick with the proven method of bringing the airplane to a complete stop. (5)

In Conclusion

Have you really thought out the reasons for initiating an RTO below, say p100kts. versus just before V1? What will you do if a tire blows at V1 minus 10kts during a light weight takeoff on a long dry runway versus a balanced
APPENDIX C

field length situation with a wet runway? Does your crew know what you are thinking? Flight crew briefings before takeoff should be complete with respect to the greatest potential hazard for that particular takeoff, such as bad weather, critical obstacles, etc. When the takeoff is under runway limited conditions or when the runway is contaminated, an obvious additional candidate subject for a careful pre-takeoff briefing is the RTO maneuver.

In the “real world” many factors are working against you such as weather, wet runways, worn tires and brakes, hot brakes, inoperative systems, and our favorite, crew fatigue.

It is impossible to predict when or how many tires may fail on takeoff, or to anticipate or measure just how wet is wet. In this scientific world, there are still situations in which the Captain must exercise skill and judgement beyond the scope of the book. But, knowledge properly applied can certainly help prevent the need to rely entirely on superior skill.

John D. Whitehead/Mar 1988

(1) From FLIGHT SAFETY FOCUS, a publication of the U.K. Flight Safety Committee.
(2) MDC Newsletter Vol. II, #6, August 1978
(3) MDC Newsletter Vol. II, #8, July 1983
(4) Lufthansa GO/NO-GO Philosophy
    40th Int’l Air Safety Seminar, Tokyo, Japan
(5) MDC Newsletter #8 and MDC letter to all operators titled Rejected Takeoffs/Overruns,
    Dec. 6, 1982
    MDC Newsletter Vol. II, #4, August 1977
Introduction for RTO Overrun Accident/Incident Summary

The following table lists the 74 events involving the Western built commercial jet fleet included in the RTO Overrun Accident and Incident Study and are the basis for the statistical analyses presented in Sections 2 and 4. These events include rejected takeoff accidents wherein the airplane was unable to stop on the runway available (i.e. those events associated with runway length). These incident events were reviewed and only the significant ones were included. These were generally relatively high speed overruns which occurred in hospitable surroundings; Had the same event occurred in less hospitable surroundings, the incident would have been an accident. The study did not include events where directional control was lost during the takeoff roll and the airplane departed the runway side boundaries as a result of the loss of control.

Many of these events involved a combination of factors and some are not thoroughly documented by investigation reports. A degree of judgement was sometimes required in identifying a prime RTO decision factor. Users of these data are cautioned that the reason the crew decided to initiate an RTO and the reason their RTO was unsuccessful may be totally unrelated. Few of these events occurred while operating at field length limit weight.

The reader may be aware of additional RTO overrun events (either accidents or incidents) that are not included in this study. If an event does not appear, it is only because there was no record available as of the time of the study. Several RTO overrun accidents were reported after this study was completed. However, because the data base is now large enough to be statistically "stable", the conclusions and recommendations of the study were not affected.
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## RTO Overrun Accidents/Incidents Summary

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\(^1\) A = Accident, I = Incident  
\(^2\) RTO Initiation Speed = the speed at which the first action was taken relative to V\(_1\).  
\(^3\) Cause = the underlying cause of the RTO decision being made.  
\(^4\) RW Condition = reported runway surface condition at the time of the event.  

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*App. 4-B.1*
# RTO Overrun Accidents/Incidents Summary (Continued)

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¹ A = Accident, I = Incident  
² RTO Initiation Speed = the speed at which the first action was taken relative to V₁.  
³ Cause = the underlying cause of the RTO decision being made.  
⁴ R/W Condtion = Runway Condition;  
⁵ Radio call from a waiting aircraft directed to another aircraft with a similar flight number, mistakenly understood by the accident aircraft.
Other Takeoff Rules

This appendix contains information on takeoff regulations other than the U.S. FAA rules, which have an impact on takeoff decision making, including United States military takeoff regulations.

It is intended that operators who require additional regulatory coverage contact the manufacturer for model specific information, which can be retained in this appendix for easy reference.

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The data contained in this appendix is provided for training purposes only and should not be used for any other purpose. Each manufacturer assumes responsibility only for the data which applies to their specific airplane models. Questions regarding any information presented in this appendix should be addressed to the responsible manufacturer.
U.S. Military Rules Versus FAA Rules

Historically, military services have been the single largest source of airline pilots. Military pilots are generally highly trained and fly in a very structured environment. Military training requires pilots to memorize numerous items including performance definitions. Most lieutenants/ensigns can quote verbatim the definition of the fundamental terms of aircraft performance.

However, when these pilots turn to civil aviation, performance is not always trained to the degree that it is in the military community and the differences between the two worlds is not well defined. This often leads to confusion or the assumption that the two systems are the same. This Appendix will give examples of the fundamental differences between the two systems and illustrate the danger of assuming they are the same.

Line-Up Distance

Under current FAA rules, line-up distance is not required to be taken into account. Military aircraft do. For the C-141B, T.O. 1C-141B-1-1 reads: "Runway available is actual runway length less the aircraft line-up distance. When takeoff EPR is set prior to brake release, subtract 200 feet. When making a rolling or standing takeoff, subtract 400 feet." Other models are less specific, requiring only that the takeoff data be computed based on runway available.

Wet Runway

Under FAA rules, corrections are not required to dry performance numbers when a runway is wet, however some carriers voluntarily make use of manufacturer provided wet runway data. Military manuals use the Runway Condition Reading (RCR) system. Basically, the person calculating the takeoff data either uses the reported RCR or a default value for wet. Again, this value is not standard. The T-43A (737-200 ADV, JT8D-9) uses an RCR of 9 for wet whereas the C-141B uses 12.

\( V_1 \) Defined

A precise operational definition of \( V_1 \) is difficult to find in the FAR's and there are only a few aircraft types that have been certified in accordance with the latest regulations. As stated on Section 4.3.1.2 of the basic document, "In an operational Field Length Limited context, the correct definition of \( V_1 \) consists of two separate concepts:

First, with respect to the 'No-Go' criteria, '\( V_1 \) is the maximum speed at which the rejected takeoff maneuver can be initiated and the airplane stopped within the remaining field length under the conditions and procedures defined in the FAR's.'"
The certified accelerate-stop distance calculation is based on an engine failure at least one second prior to $V_1$. This standard time allowance has been established to allow the line pilot to recognize an engine failure and begin the subsequent sequence of stopping actions. By this definition, $V_1$ is a limit speed. It is the latest point in the takeoff roll where a stop can be initiated.

Second, with respect to the 'Go' criteria, $V_1$ is also the earliest point from which an engine out takeoff can be continued and the airplane attain a screen height of 35 feet at the end of the runway.

**U.S. Air Force - Basic Definitions**

In order to adequately discuss the differences between the FAR’s and the Mil-Spec, some basic terms must be defined. According to MIL-M-7700D (USAF), "Critical engine failure speed shall be the speed at which the most critical engine can fail and the same distance is required to either continue the takeoff or to stop the aircraft."

It should be noted that the screen height afforded by the FAR’s is not included in the Military definition.

"Critical field length shall be the total length of runway required to accelerate with all engines to critical engine failure speed, experience a critical failure, and then continue to takeoff or stop."

"Refusal speed shall be the maximum speed with normal acceleration where a stop may be completed while on the runway."

"Minimum go speed shall be the minimum speed at which an aircraft can experience a failure of the most critical engine and still takeoff under existing conditions of temperature, pressure altitude, gross weight, and runway remaining. The data are based on an engine failure occurring at minimum go speed and allows for a three second decision period with the remaining engines operating at the initial thrust setting."

Paragraph 3.5.7.5.8.7 (MIL-M-7700D (USAF)) regarding critical field length further states: "The critical field length shall be based on the following rules:

a. At engine failure speed the aircraft continues to accelerate for 3 seconds with remaining engines at maximum thrust and zero thrust on the inoperative engine.

b. At the end of the three second acceleration time, thrust on all engines is reduced to idle, brakes applied, and deceleration devices deployed.

c. Sufficient time will be allowed for deployment of the device or for reverse thrust to build up before including its effects on deceleration."

Note: Reverse thrust credit is not normally taken for takeoffs or landings.
Rejected Takeoff

A graphical comparison of the FAR's versus MIL-M-7700D is seen in Figures 1 and 2.

**Figure 1**

**FAA Rules:**
- $V_1$
- 1 second Engine fail
- Approx 1 sec Brakes on
- 2 seconds (constant speed) Throttle idle Speed-brake raised

**Figure 2**

**FAA Rules:**
- Velocity
  - $V_1$
  - $V_{EF}$

**MIL-M-7700D**
- Refusal speed
- 3 seconds (accelerating)
- Engine fail
- Brakes on thrust idle speedbrake raised

**App. 4-C.3**
The basis for the T-43A charts as stated in T.O. 1T-43A-1-1 is as follows: "All stopping distances are based on using the takeoff flap setting, spoilers extended manually, no reverse thrust, and maximum anti-skid braking. A 3 second period has been allowed for transition from takeoff thrust to maximum braking."

The way this is described in the C-141B, T.O. 1C-141B-1-1 is: "A five second period has been allowed for transition from takeoff thrust to maximum braking. This allows time to recognize the situation, make a decision to stop and achieve the braking configuration." The statement would indicate that in addition to the three second engine out acceleration time, an additional two second procedure execution time has been added. The 5 seconds is clearly a significant pad compared to the FAR method.

In both the U.S. Air Force and FAA RTO procedures, the pilot should begin action no later than the "Go" speed be it $V_1$ or VGO, however the consequences of starting the procedure after the "Go" speed in the civilian case when there is no line up distance, no RCR correction and an extremely small stopping pad can be much worse than the case of the Air Force pilot.

Takeoff continued

Figure 3 illustrates the difference between the continued takeoff in the U.S. Air Force versus FAA case.

FAR performance is based on an engine failure 1 second prior to $V_1$ resulting in a 35 foot height over the end of the runway. A civilian pilot faced with a field length limited balanced field takeoff who experiences an engine failure more than 1 second prior to $V_1$ and elects to continue the takeoff rather than reject will see a reduction in the height over the end of the runway and over the critical obstacle (if there is one). This is why many commercial airlines today advocate continuing a takeoff once speed is within approximately 10 knots of $V_1$ unless the airplane is clearly unsafe to fly. The perspective is that there are more pads in the "Go" case than the "Stop" case.

The application of this technique to military aviation is inappropriate. During a critical field length takeoff, the military rules enable an airplane experiencing an engine failure at the "Go" speed to reach takeoff speed at the end of the runway. A critical obstacle is cleared with no margin. A decision to "Go" with an engine failure prior to VGO results in either a low speed rotation or rotating beyond the end of the runway. A critical obstacle will not be cleared.
U.S. Naval Aviation

The U.S. Navy is governed by MIL-M-85025A(AS) rather than MIL-M-7700D.

The use of Runway Condition Reading although not identical, is fundamentally the same as the U.S. Air Force.

Some useful definitions are:

Paragraph 3.19.11.2.3d “Minimum Go Speed, \( V_1 \), shall be the minimum airspeed at which the aircraft can experience an engine failure, and then continue to accelerate to, liftoff speed VLOF, within the remaining runway length. The data is based on an engine failure occurring at the Minimum Go Speed. Engine failure is followed by a three second decision period with the remaining engines operating at the initial thrust setting. In the case of an intermediate thrust takeoff, an additional time period shall be allowed for advancing the operating engine throttle to Maximum Thrust. The time period to be used shall be applicable to the airplane configuration and be approved by the procuring activity. \( V_1 \) shall not be less than \( V_MCG \), Ground Minimum Control Speed."

Paragraph 3.19.11.2.3g “Maximum Abort Speed, \( V_{MAX \, ABORT} \), shall be the maximum airspeed at which an abort may be started and the aircraft stopped within the remaining runway length. The data are based on a three second decision period after reaching maximum abort speed, with the engines operating at the initial thrust setting during this time. At the end of the three second decision period, a time period shall be allowed for brake application, and a time delay allowed for movement of engine throttles to the idle position and activation of deceleration devices (if applicable). The time periods to be used shall be applicable to the airplane configuration and be approved by the procuring activity.”

A comparison with previous definitions make it clear that the margins associated with the Naval \( V_1 \) and that of the FAA \( V_1 \) are not the same. To summarize, in the FAA model, the engine fails one second prior to \( V_1 \), the airplane accelerates to \( V_1 \), continues to accelerate somewhat during the transition period, then is kept at constant speed for two seconds after the transition prior to braking to a stop. In the Navy model, the engine fails at \( V_1 \), the aircraft continues to accelerate with the critical engine out for 3 seconds, then a negotiated period of time passes analogous to the FAA’s transition period, prior to the airplane braking to a stop. It is clear that the naval system is quite close to the U.S. Air Force system. Unfortunately the term \( V_1 \) is used, identical to the FAA’s \( V_1 \), but the definition is different.

50 Feet Obstacle Height

A common point of confusion is the military’s 50 foot obstacle height. In both U.S. military systems there is a 50 foot obstacle height mentioned that is sometimes confused with the FAA’s 35 foot screen height. Under military rules, fifty feet is guaranteed only when all engines are operating. With the critical engine failed at critical engine failure speed during a critical field length takeoff, military aircraft are only guaranteed to become airborne by the end of the runway. As stated in Boeing’s E-6A document D409-12104-1, “Normal takeoff data includes distance from brake release to liftoff and distance from brake release to a 50 foot obstacle height with all engines operating normally.”

Conclusion

It should be quite clear that the application of military procedures and techniques to civil aviation is just as wrong as applying civilian procedures and techniques to military aviation. Neither is appropriate and misapplication is potentially disastrous.
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U.K. CAA REGULATIONS

Operators who wish to include information on United Kingdom Civil Aviation Authority regulations should contact the manufacturer for specific information relating to the certification of their airplanes.
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AUSTRALIAN CAA REGULATIONS

Operators who wish to include information on Australian Civil Aviation Authority regulations should contact the manufacturer for specific information relating to the certification of their airplanes.
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FRENCH DGAC RULES

Operators who wish to include information on French Civil Aviation regulations should contact the manufacturer for specific information relating to the certification of their airplanes.
JOINT AIR REGULATIONS (JARS)

Operators who wish to include information on Joint Aviation Authority regulations should contact the manufacturer for specific information relating to the certification of their airplanes.
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This appendix contains information on the effectiveness of thrust reverser systems on modern high bypass engines. Boeing airplanes with various engine combinations are used as specific examples but the trends noted are typical for similar installations on other manufacturers airplanes.

The data in this appendix is provided for training purposes only and should not be used for any other purpose.
Effect of Engine RPM and Airspeed On Reverse Thrust

For engines with fan reversers, net reverse thrust is defined as the reverse thrust developed by the fan reverser system minus the forward thrust generated by the engine core plus ram drag.

A misconception may exist that it is not beneficial to use high power settings for reverse thrust during a rejected takeoff, or after landing. It appears that some flight crew personnel believe that at the higher power settings, the reverse thrust developed by the fan reverser system will be canceled by the forward thrust developed by the engine core. This assumption is not true for thrust reverser systems installed on Boeing airplanes. The net reverse thrust on high by-pass engines is significantly greater at the higher power settings than at idle reverse.

Data shown on figures 1 through 4 are examples of net reverse thrust vs. engine RPM up to the maximum recommended thrust setting and airspeed. Data for other airplanes and engine combination would result in very similar trends. The net reverse thrust (installed), figures 1 through 4, have been corrected to account for the decrease in airplane drag due to reverse thrust operation. The actual reverse thrust (uninstalled) is greater than indicated on the charts. However, the net reverse thrust shown is the effective reverse thrust available for airplane deceleration.

A significant increase in net reverse thrust is achieved as engine RPM is increased up to the maximum recommended power setting. Airspeed also has a very significant effect on net reverse thrust. The airspeed effect is due to ram drag, which is the product of the engine inlet airflow and the airplane forward speed. The combination of high engine RPM and high airspeed can increase the net reverse thrust by a factor of approximately 3 to 4 (depending on the engine model) above the net reverse thrust available at idle power settings. For this reason, when stopping distance is critical, maximum reverse thrust should be applied immediately after landing touchdown or upon initiating a rejected takeoff, concurrently with speedbrakes and maximum braking.

In summary, it is a misconception that high power settings during reverse thrust operation are not beneficial. A significant difference exists between the reverse thrust obtained at idle power settings and at the maximum recommended power settings. Further, reverse thrust should be applied immediately after landing touchdown or upon initiating a rejected takeoff because reverse thrust is significantly more effective at high speeds than at low speeds. Proper utilization of reverse thrust will result in minimum field lengths under adverse runway conditions or increased brake life during normal conditions.
Takeoff Safety Training Aid Human Performance Study

Introduction

The Boeing Company is presently compiling the information needed to produce a Takeoff Safety Training Aid. This training aid, similar to the Windshear Training Aid, will be used in the crew training environment. The goal of this training aid is to reduce RTO incidents and accidents. To achieve this goal, the Takeoff Safety Training Aid’s objective is to improve Go/No Go decision making and crew performance in the execution of necessary RTO’s. A simulator study was conducted to obtain a better understanding of the areas in which performance can be improved. Once the Training Aid is developed, the study could be used to confirm that the Aid does provide an improvement in RTO performance.

Test Objectives

The primary purpose of this study was to evaluate pilot decision making and performance under various RTO situations. A B-737 full flight simulator was used to accomplish the study. The specific objectives of this research effort was to examine the following factors involved with RTO decision making and execution:

1. Evaluation decision making involved with making Go/No Go decisions due to the following:
   - A. Engine failure
   - B. Master Caution illumination
   - C. Fire lights and warning bells
   - D. Blown tire

2. Evaluate RTO procedure accomplishment under the following conditions:
   - A. Engine failure
   - B. All manual stop
   - C. Maximum use of automatics stop
   - D. Blown tire
   - E. Exchange of aircraft control

3. Evaluate RTO stopping performance under the following conditions:
   - A. Engine failure
   - B. Manual braking
   - C. Autobraking stop
   - D. Crosswind effects
   - E. Blown tire performance
   - F. Exchange of aircraft control

4. Evaluate the relationship between the pilot’s knowledge level about RTO’s and his performance in the simulator.

Test Subjects

A total of 48 experienced transport pilots were used in this study. A mix of Boeing pilots and airline captains was necessary to achieve valid human factors results. The pilots were type rated in the B-737 and had current operational experience.

Test Facility and Requirements

The facility used for this test was a B-737 Flight Crew Training simulator at Boeing Customer Training. It is a state-of-the-art simulation facility, and is fully certified for flight crew training by the FAA and CAA. To conduct the test, a qualified B-737 pilot was required to occupy the first officer’s seat and a qualified simulator instructor was needed to conduct the test as well as operate the simulator. Simulator engineering assistance was required to retrieve data as well as prepare the simulator for testing. A pre-flight questionnaire, post-flight questionnaire, and method of debriefing was required.
Test Method

The basic design for this study was to compare stopping performance with the Airplane Flight Manual (AFM) predicted distance.

All takeoffs were conducted as a runway limited condition configured as follows:

1. Takeoff weight - 130,000 lb
2. Temperature - 30°C
3. Flaps - 5
4. Field length - 6700 feet

The variables chosen for investigation included:

1. Crosswinds
2. Various malfunctions
3. Forced manual braking RTO
4. Exchange of aircraft control during RTO situations

Exposure to the various RTO’s and normal takeoffs was randomized to minimize learning effects and reduce the anticipation normally associated with tests of this type. One and one half hours were required for each pilot to complete the test program. The following is a sample test scenario schedule for a pilot:

A. Normal takeoff, Captain flying
B. Engine failure at V_1-8 knots, Captain flying
C. Engine failure at V_1-8 knots, F/O flying
D. Engine failure at V_1+2 knots, Captain flying
E. Engine failure at V_1+2 knots, F/O flying
F. Fire warning at V_1-5 knots, Captain flying
G. Blown tire at V_1-10 knots, Captain flying
H. Master Caution light at V_1-10 knots, Captain flying
The initial prebrief questionnaire was designed to quickly assess the pilot's relative knowledge about RTO's. The remainder of the prebrief was devoted to the understanding of the simulator and test configuration. The pilot then entered the simulator for a quick orientation prior to the test starting. The order in which the pilots received the events was randomized to prevent order bias from influencing the results. The debriefing consisted of a short questionnaire and de briefing to answer any questions the pilot may have had. An informal interview was recorded to obtain pilot comments.

The prebrief questions were:

Write a definition of $V_1$.

Can a pilot beat the flight manual performance predicted for rejecting at $V_1$? If so, how?

If your takeoff weight equals the runway limit weight in the airfield analysis, what does that mean to you as a pilot?

**Performance Measures**

Performance measures were taken in the two areas of decision making and Go/No Go performance. The measures of the stop decision was recorded as the initiation of thrust reduction, brake application, or spoiler deployment. Go/No Go performance was assessed by comparison of the following parameters:

- Speed (knots) versus time (sec)
- Distance to runway end (feet) versus time (sec)
- $\%N_1$, L Engine versus time (sec)
- $\%N_1$, R Engine versus time (sec)
- Left and Right thrust lever (lever angle) versus time (sec)
- RTO autobrakes (ON/OFF) versus time (sec)
- Left and Right brake force (lb) versus time (sec)
- Speed brake deployed (UP/DOWN) versus time (sec)
- Heading (degrees) versus time (sec)
- Deviation from centerline (feet) versus time (sec)
- Rudder pedal deflection (degrees) versus time (sec)
- Column deflection (degrees) versus time (sec)
- Pitch (degrees) versus time (sec)
- Altitude (feet, RA) versus time (sec)
- Yoke deflection (degrees) versus time (sec)
- Roll angle (degrees) versus time (sec)
- Crosswind velocity (knots) versus time (sec)

**Data Reduction and Analysis**

The data is classified into two general categories: objective performance measurements and subjective data from questionnaires and debriefing.

The results from this analysis provided information to determine if the following were true:

1. There is no effect on RTO performance with crosswinds.
2. There is no effect on RTO performance with the exchange of aircraft control.
3. There is no effect on RTO performance when using full automatic capability as compared to manual performance.
4. Non engine-related problems have no effect on RTO decision time or performance.
Simulator Test Results

Phase 1 of the simulator tests began April 17, 1991 and was completed on May 3, 1991. During this time period, 24 Boeing 737 Training Captains were tested. These pilots averaged 3.5 years with Boeing. After participating as the first captain, one pilot became the first officer for the remaining captains. He was a training captain with considerable line experience and was able to closely emulate the characteristics of a good line first officer.

After evaluating the data and confirming the test process and data reduction techniques, a meeting was held in Seattle with the airlines and agencies participating in the development of the Training Aid. The test results were presented and volunteers were solicited to participate in Phase 2 of the study.

Phase 2 began on July 16, 1991 and was completed on September 12, 1991. Twenty-four 737 Line Captains (no Check Airmen, no simulator instructors, no Training Captains) were evaluated from five airlines. There were no more than eight pilots per airline to keep from biasing the results in the favor of one type of training or one airline's policies.

Two Boeing Training Captains were used as first officers for these captains. The original first officer was used again along with another training captain of similar background and experience. This second first officer had also participated in Phase 1 of the study.

As illustrated in Figure 2, the two pilot groups were surprisingly similar in background and experience.

<table>
<thead>
<tr>
<th></th>
<th>Boeing</th>
<th>Airline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time, hrs</td>
<td>11,546</td>
<td>12,308</td>
</tr>
<tr>
<td>737 time, hrs</td>
<td>1,918</td>
<td>3,748</td>
</tr>
<tr>
<td>Airline years</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>Military years</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>number rejects</td>
<td>3.3</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Figure 2
Comparison
Of Boeing
Subjects
With Airline
Subjects

309

App. 4-E.4
Test Results - Go/No Go Decision Making

Although results varied considerably between airlines, when the airline pilots were taken as one group and Boeing as another, the basic decisions made when presented the study scenario were remarkably similar.

As can be seen in Figure 3, the number of rejects per event varied by 1 in all cases except engine fire. As a result of this similarity, later findings will be presented for the 48 pilots as one group.

<table>
<thead>
<tr>
<th>Event</th>
<th>Rejects</th>
<th>Number of Rejects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boeing</td>
<td>Airline</td>
</tr>
<tr>
<td>Engine fail V₁−8, captain flying</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Engine fail V₁−8, first officer flying</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Engine fail V₁+2, captain flying</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Engine fail V₁+2, first officer flying</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Master caution V₁−10, captain</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Fire warning V₁−5, captain</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Blown tire V₁−10, captain</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Normal takeoff</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total rejects</td>
<td>38</td>
<td>42</td>
</tr>
</tbody>
</table>

Figure 3
"Go/No Go" Decision
As seen in Figure 4, pilots did not reject their takeoffs as often as was anticipated in the "classical" cases that are normally trained, namely engine failures and fires. Another surprise occurred in the "nonclassical" cases. Almost one-third of the pilots rejected for the blown tire although the only indication was a vibration. There were seven rejects for a Master Caution light which in this case came on due to a hydraulic pump overheating 10 knots below $V_1$. Boeing, along with most airlines, specifies that "Once thrust is set and takeoff roll has been established, rejecting a takeoff solely for illumination of the amber MASTER CAUTION light is not recommended."

<table>
<thead>
<tr>
<th>Event</th>
<th>Rejects % Total</th>
<th>Rejects Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine fail $V_1$-8, captain flying</td>
<td>52%</td>
<td>10 20 30 40 50</td>
</tr>
<tr>
<td>Engine fail $V_1$-8, first officer flying</td>
<td>44%</td>
<td></td>
</tr>
<tr>
<td>Engine fail $V_1$+2, captain flying</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Engine fail $V_1$+2, first officer flying</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Master caution $V_1$-10, captain</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Fire warning $V_1$-5, captain</td>
<td>23%</td>
<td></td>
</tr>
<tr>
<td>Blown tire $V_1$-10, captain</td>
<td>31%</td>
<td></td>
</tr>
<tr>
<td>Normal takeoff</td>
<td>0%</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4
"Go/No Go" Decision Making

App. 4-E.6
Test Results - Procedure Accomplishment

When a captain did reject a takeoff, his procedure was evaluated against his published company policy. All Boeing pilots have a procedure which says to “Simultaneously close the thrust levers (disengage the autothrottle, if required) and apply maximum brakes. If RTO autobrakes are selected, monitor system performance and apply manual wheel brakes if the AUTO BRAKE DISARM light illuminates or deceleration is not adequate. Rapidly raise the speedbrakes and apply maximum reverse thrust consistent with the conditions.” Some airlines represented also had this as their procedure, while others had a procedure to raise the speedbrakes through the use of the reverse thrust levers and monitor the speedbrake handle for proper operation. As can be seen in Figure 5, the number of incorrect procedures used was rather high. The incorrect procedure used in each case was selecting reverse thrust prior to raising the speedbrake. This was only applied to those airlines/Boeing which have that procedure in their manuals. For the Boeing subjects, it is immediately apparent that the rate of incorrect procedures is much higher for the “nonclassical” cases than for the “classical”.

<table>
<thead>
<tr>
<th>Event</th>
<th>Percentage</th>
<th>Percentage incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boeing</td>
<td>Airline</td>
</tr>
<tr>
<td>Engine fail V₁-8, captain flying</td>
<td>25%</td>
<td>23%</td>
</tr>
<tr>
<td>Engine fail V₄-8, first officer flying</td>
<td>50%</td>
<td>9%</td>
</tr>
<tr>
<td>Engine fail V₁+2, captain flying</td>
<td>0%</td>
<td>-</td>
</tr>
<tr>
<td>Engine fail V₄+2, first officer flying</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Master caution V₁-10, captain</td>
<td>0%</td>
<td>25%</td>
</tr>
<tr>
<td>Fire warning V₁-5, captain</td>
<td>0%</td>
<td>14%</td>
</tr>
<tr>
<td>Blown tire V₄-10, captain</td>
<td>50%</td>
<td>14%</td>
</tr>
<tr>
<td>Normal takeoff</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Totals</td>
<td>32%</td>
<td>17%</td>
</tr>
</tbody>
</table>

Figure 5
Procedural Accomplishment
It would seem that the Boeing Pilots have a greater propensity to incorrectly accomplish the procedure than airline pilots, however, from Figure 6, it is apparent that airlines using manual speedbrake have about the same error rate as the Boeing pilots. Pilots using auto speedbrake did the procedural steps correctly every time.

During the course of the study, a new variable was unintentionally introduced. Due to a simulator malfunction, the auto speedbrake failed for a period of time resulting in an opportunity to observe the ability of pilots using that device to monitor its deployment. It is apparent that it is not very well monitored. The first officer would only raise the speedbrake if he was briefed by the captain to do so. Only one captain did, so in those 2 out of 9 cases, the first officer raised the speedbrake.

<table>
<thead>
<tr>
<th></th>
<th>Manual S/B Procedure</th>
<th>Auto S/B Procedure</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number rejects</td>
<td>23</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number incorrect</td>
<td>7</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent incorrect</td>
<td>30%</td>
<td>0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auto SB fail</td>
<td>2</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Captain noticed</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6
Procedure Accomplishment For Airline Pilots Only
Test Results - Stopping Performance

Stopping performance as measured by runway remaining was averaged for all rejects for each situation presented. Pilots were able to stop the airplane with the greatest margin in the few cases when the Master Caution illuminated ten knots prior to $V_1$. In this case the pilot had two engine reverse thrust and the malfunction occurred with the greatest margin before $V_1$. The worst case was the reject initiated after $V_1$, followed closely by the rejects for the blown tire. The simulator eliminates braking force from the wheel with the failed tire reducing the total brake retarding force to 75% of what it normally would be. As a result, only 3 of 15 pilots were able to stop the aircraft prior to the end of the runway, and those, just barely.

<table>
<thead>
<tr>
<th>Event</th>
<th>No. Rejects</th>
<th>RWY Remain</th>
<th>Average Runway Remaining, Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine fail $V_1$-8, captain flying</td>
<td>25</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Engine fail $V_1$-8, first officer flying</td>
<td>21</td>
<td>430</td>
<td></td>
</tr>
<tr>
<td>Engine fail $V_1$+2, captain flying</td>
<td>1</td>
<td>-350</td>
<td></td>
</tr>
<tr>
<td>Engine fail $V_1$+2, first officer flying</td>
<td>0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Master caution $V_1$-10, captain</td>
<td>7</td>
<td>640</td>
<td></td>
</tr>
<tr>
<td>Fire warning $V_1$-5, captain</td>
<td>11</td>
<td>430</td>
<td></td>
</tr>
<tr>
<td>Blown tire $V_1$-10, captain</td>
<td>15</td>
<td>-200</td>
<td></td>
</tr>
<tr>
<td>Normal takeoff</td>
<td>0</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7
Stopping Performance

-300-200-100 0 100 200 300 400 500 600
Test Results - Responses to Questions versus Simulator Performance

The data taken did not show any correlation between performance in the simulator and response to the questions asked.

Test Results - Training versus RTO Performance

Training and company policy appear to play a significant role in the decisions pilots make. From Figure 8, it can be seen that as expected, Boeing contributed 50% of the pilots to the study and accomplished 47% of the rejected takeoffs. However, Airline 1 and Airline 2 contributed the same number of pilots yet Airline 1 pilots rejected almost twice as many times as did Airline 2 pilots.

<table>
<thead>
<tr>
<th>Training</th>
<th>Percentage Pilots Contributed</th>
<th>Rejected Percentage Performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing</td>
<td>50%</td>
<td>47%</td>
</tr>
<tr>
<td>Airline 1</td>
<td>17%</td>
<td>28%</td>
</tr>
<tr>
<td>Airline 2</td>
<td>17%</td>
<td>15%</td>
</tr>
<tr>
<td>Airline 3</td>
<td>10%</td>
<td>5%</td>
</tr>
<tr>
<td>Airline 4</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>Airline 5</td>
<td>2%</td>
<td>1%</td>
</tr>
</tbody>
</table>
Data Reduction and Analysis

Once all the data was received it was used to answer the questions posed in the Test Plan.

1. There is no effect on RTO performance with crosswinds.

As can be seen in Figure 9, crosswinds had a minor effect on stopping margins although the expected result of an increase in distance with a crosswind was clearly there. The increase results from pilots steering with differential braking and thus reducing the total braking force applied.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Remaining Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calm winds</td>
<td>390 feet remaining</td>
</tr>
<tr>
<td>15 knot crosswinds</td>
<td>330 feet remaining</td>
</tr>
</tbody>
</table>
2. There is no effect on RTO performance with the exchange of aircraft control.

As can be seen in Figure 10, exchange of aircraft control did have an effect on stopping performance. The stopping margins achieved when the captain was performing the takeoff exceeded those of all first officer takeoffs. There were variations regarding the ability of the copilot to make the reject decision and what technique would be used if the reject decision was made. When the first officer actually performed the reject, the stopping distance margins were smaller yet. During first officer takeoffs with the captain performing the reject, there were few crew coordination problems, however in the situation when the first officer performed the reject, there often were crew coordination difficulties. There is an inherent delay when the captain is required to make the reject decision and verbalize it, then the first officer reacts and performs the procedure. There is also a physical difficulty in the first officer raising the speedbrake.

Engine fail \( V_1 - 8 \)

- Captain flying (25) - 500 feet remaining
- F/O flying (21) - 430 feet remaining
- F/O rejects (7) - 320 feet remaining

Note: All airline rejects done by the captain
3. There is no effect on RTO performance when using full automatic capability as compared to manual performance.

The use of autobrakes significantly increased stopping margins. The most common stopping technique was to apply manual wheel brakes as the last step in the RTO procedure. Since autobrakes come on as soon as the thrust levers come to idle, autobrakes gave a 1-2 second earlier brake application. RTO brakes also applied more consistent braking force. The negative side of autobrakes is that they can be inadvertently disengaged resulting in no braking force being applied for a few seconds until the crew notices it.

- RTO autobrakes increased stopping margin
  - Autobrakes armed: 450 feet remaining (36 cases)
  - Manual braking: 270 feet remaining (40 cases)
  - Autobrake on more than 4 seconds: 610 feet remaining (4 cases)
4. Non engine-related problems have no effect on RTO decision time or performance.

**Decision Time**

As suspected, decision times increased for events that were more difficult to recognize and that are not as well practiced. The shortest time from event to first action occurred for the engine fire warning given at 5 knots prior to $V_1$. This time was taken as the reference to compare the other times. It should be noted that "Go" decision time was not measured since there is no clear activity other than a continued takeoff to indicate the decision.

<table>
<thead>
<tr>
<th>Type Of Event</th>
<th>Reference time</th>
<th>Reference time + .2 seconds</th>
<th>Reference time + .4 seconds</th>
<th>Reference time + .6 seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire warning $V_1$-5, captain</td>
<td>Reference time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine fail $V_1$-8, captain</td>
<td>Reference time + .2 seconds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Master caution $V_1$-10, captain</td>
<td>Reference time + .4 seconds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine fail $V_1$-8, first officer</td>
<td>Reference time + .6 seconds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blown tire $V_1$-10, captain</td>
<td>Reference time + .6 seconds</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Time between event and first stopping action
Procedural Performance

Procedural accomplishment was very similar to the decision time statistics. Again, it appears that the less familiar or more difficult to discern the event is, the more likely the pilot is to do the manual speedbrakes procedure incorrectly.

- Boeing and airlines whose procedure is manual speed brake, 32% of the RTO's were done using auto speedbrake
  - 42% for blown tire, captain flying
  - 35% for the engine fail, V₁-8, first officer flying
  - 30% for the engine fail V₁-8, captain flying
  - 25% for the master caution, captain flying
  - 14% for the fire warning V₁-5, captain flying
LESSONS LEARNED

Certain observations can be made from the data taken. These are divided into the areas of decision making, procedure accomplishment, stopping performance, and knowledge.

Decision Making

The pilots tested were more “Go” oriented than anticipated. From the briefings it was discovered that many of the pilots used an informal “pad” of 5-20 knots less than $V_1$ as a speed beyond which they will not begin a reject when in a runway limit situation.

This “Go” orientation appears to be stronger when the first officer is making the takeoff. It was even more apparent when the first officer is responsible for performing the reject procedure.

The vibration associated with a blown tire appears to induce pilots to reject with no other malfunction indications.

In spite of clear recommendations to the contrary, a few pilots rejected for illumination of the Master Caution light in the high speed regime.

Procedure Accomplishment

For Boeing and Airlines using manual speed-brake:

32% of the RTO’s were done using incorrect procedures
42% for BLOWN TIRE RTO’S, CAPT FLYING
35% for ENG FAIL, $V_1$-8 RTO’S, F/O FLYING
30% for ENG FAIL $V_1$-8 RTO’S, CAPT FLYING
25% for MASTER CAUTION RTO’S, CAPT FLYING
14% for FIRE WARNING $V_1$-5 RTO’S, CAPT FLYING

Non-optimal techniques included:
Improper foot position
Modulating brake pressure (pumping brakes)
Disconnecting RTO Autobrakes and delayed manual application

Crew Coordination Difficulties

Crew coordination when first officer flying:

Worst Case
Captain calling the reject and first officer doing the RTO

Best Case
Captain controlling the thrust levers and doing the RTO

Manual versus RTO Autobraking

Most distance remaining:
RTO Autobrakes left on for entire stop
Few pilots matched or exceeded the performance of the autobrakes.

Most common technique:
Autobrakes initiate the braking and the pilot completes the stop

Knowledge versus Performance

The data taken does not show a correlation between performance in the simulator and responses to the questions asked. However, the questions asked did reveal some general misconceptions about RTO’s:

- 50% said it was not possible to stop shorter than the AFM predicted distance
- Few stated an awareness of the altitude over the end of the runway when continuing a takeoff after an engine failure
- Most gave an incomplete definition of $V_1$
Takeoff Continued

Although it was not a specific study item, it is very significant that of the 70 takeoffs continued by the captains tested with an engine failure, there was not a single crash.

Opportunities for Improvement

The results of the study bring up several areas of operation that can be improved:

Decision Making

Emphasize an accurate meaning of $V_1$

Assure an accurate understanding of Go/No Go margins

Pilots must understand the effects of the reduction in screen height resulting from a continued takeoff with an engine failure prior to $V_1$

The impact of using reverse thrust and quick reaction time to enhance stopping performance requires emphasis

The blown tire problem needs significant emphasis in training

Academic training emphasizing the adverse impact on stopping performance needs to be included

Simulator training to demonstrate the “feel” of the blown tire and the merits of continuing the takeoff should be done

Procedure Accomplishment

Proper (accurate) accomplishment of the RTO procedure needs additional emphasis

Improved crew communication and coordination

Inservice procedure review or

Change the procedure to incorporate the use of auto speedbrake so that it is more like the well-practiced landing procedure.

However, pilots relying on auto speedbrake for conducting the RTO must devise a reliable method of confirming that the speed brake has raised.

A recommendation to standardize the RTO procedure to have the captain control the thrust levers once takeoff thrust is set and perform the rejected appears to be appropriate.

Stopping Performance

Include training/information about foot position for takeoff and landing.

Greater emphasis should be given to the value of RTO autobrakes. Demonstration of autobrake rejected takeoffs may add value, however, manual braking techniques should be emphasized in training.

Experience, Knowledge, and Training

During simulator training, realistic rejected takeoffs should be presented in field length limit situations to confirm proper braking techniques and crew coordination.

The training given should reflect known causes of RTO accidents and incidents.
Airplane Flight Manual Transition Time Details

The data in this appendix is provided as a reference for the instructor. The individual diagrams show the relationship between the average time required to reconfigure the airplane for an RTO in the certification flight tests and the expanded times used in the computation of certified takeoff performance in the AFM.

The AFM transition time data supplied to operators by the various airframe manufacturers should be retained in this appendix as follows:

Table of Contents

<table>
<thead>
<tr>
<th>Airplane Manufacturer</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airbus Industries Airplanes</td>
<td>4-F.ABL1</td>
</tr>
<tr>
<td>Boeing Airplanes</td>
<td>4-F.TBC.1</td>
</tr>
<tr>
<td>McDonnell Douglas Airplanes</td>
<td>4-F.MCD.1</td>
</tr>
<tr>
<td>Other Manufacturers Airplanes</td>
<td>4-F.OTH.1</td>
</tr>
</tbody>
</table>

The data contained in this appendix is provided for training purposes only and should not be used for any other purpose. Each manufacturer assumes responsibility only for the data which applies to their specific airplane models. Questions regarding any information presented in this appendix should be addressed to the responsible manufacturer.
(This page intentionally left blank)
The data in this appendix is provided as a reference for the instructor. The individual charts show the brake pedal force required to apply full brake system pressure, to set the parking brake, and to disarm the RTO autobrake function, if applicable.

The brake pedal force data supplied to operators by the various airframe manufacturers should be retained in this appendix as follows:

Table of Contents

<table>
<thead>
<tr>
<th>Airplane Manufacturer</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airbus Industries Airplanes</td>
<td>4-G.ABI.1</td>
</tr>
<tr>
<td>Boeing Airplanes</td>
<td>4-G.TBC.1</td>
</tr>
<tr>
<td>McDonnell Douglas Airplanes</td>
<td>4-G.MCD.1</td>
</tr>
<tr>
<td>Other Manufacturers Airplanes</td>
<td>4-G.OTH.1</td>
</tr>
</tbody>
</table>

The data contained in this appendix is provided for training purposes only and should not be used for any other purpose. Each manufacturer assumes responsibility only for the data which applies to their specific airplane models. Questions regarding any information presented in this appendix should be addressed to the responsible manufacturer.
Reduced Thrust and Reduced $V_1$ Examples

The data in this appendix is provided as a reference for the instructor. The first page for each airplane model shows the inherent margins associated with the use of the Assumed Temperature Method (ATM) of reduced thrust, as described in Section 4.3.5.7 of the main document.

The second page for each airplane model contains an example of using ATM in combination with a reduced $V_1$ policy as described in Sections 4.3.4.2 and 4.3.6.8 of the main document.

These examples are generally typical of the margins for the derivatives of a given airplane model also, so not all airplane/engine combinations are included.

The reduced thrust and reduced $V_1$ data supplied to operators by the various airframe manufacturers should be retained in this appendix as follows:

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The data contained in this appendix is provided for training purposes only and should not be used for any other purpose. Each manufacturer assumes responsibility only for the data which applies to their specific airplane models. Questions regarding any information presented in this appendix should be addressed to the responsible manufacturer.
The data in this appendix is provided as a reference for the instructor. The data contained in this appendix is based on the manufacturer's data for minimum turn radii consistent with their recommended turn procedures. Operators can use the data in this appendix to develop lineup corrections appropriate to any runway turn geometry. However, the use of data in this appendix does not supersede any requirements that may be already in place for specific regulatory agencies. If further assistance is required, the operator should contact the appropriate manufacturer and regulatory agency to assure compliance with all applicable regulations.

The lineup distance data supplied to operators by the various airframe manufacturers should be retained in this appendix as follows:

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The data contained in this appendix is provided for training purposes only and should not be used for any other purpose. Each manufacturer assumes responsibility only for the data which applies to their specific airplane models. Questions regarding any information presented in this appendix should be addressed to the responsible manufacturer.
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The Effect of Procedural Variations on Stopping Distance

The data in this appendix is provided as a reference for the instructor. The individual diagrams show the approximate effects of various configuration items and procedural variations on the rejected takeoff stopping performance of the airplane.

The procedure variation data supplied to operators by the various airframe manufacturers should be retained in this appendix as follows:

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The data contained in this appendix is provided for training purposes only and should not be used for any other purpose. Each manufacturer assumes responsibility only for the data which applies to their specific airplane models. Questions regarding any information presented in this appendix should be addressed to the responsible manufacturer.
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