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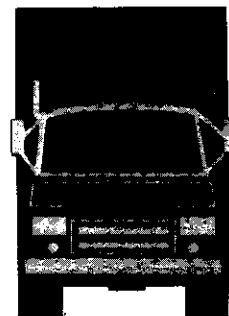
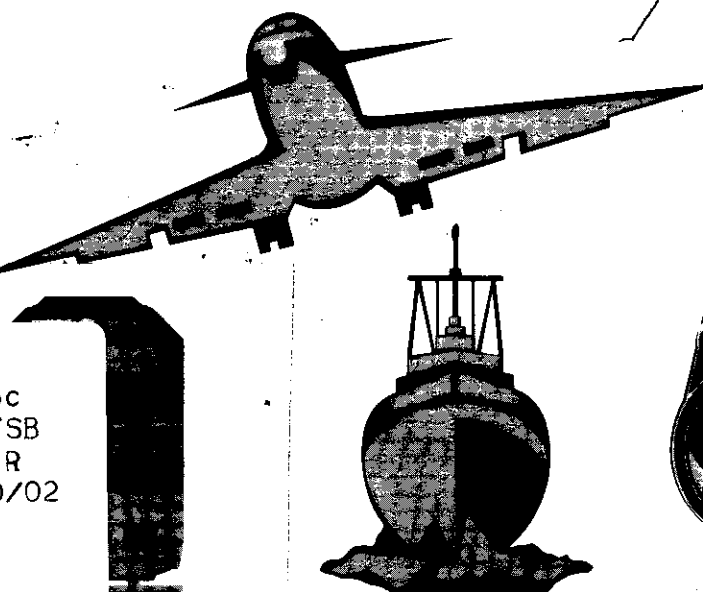
NATIONAL TRANSPORTATION SAFETY BOARD



SPECIAL INVESTIGATION REPORT

RUNWAY OVERRUNS FOLLOWING HIGH SPEED REJECTED TAKEOFFS

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16. Abstract <p>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.</p>			
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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.

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WASHINGTON, D. C. 20594**

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RUNWAY OVERRUNS FOLLOWING HIGH SPEED REJECTED TAKEOFFS

INTRODUCTION

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.¹ 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,² 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.

LATE RTO ↓
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.³ The RTO was initiated 3 seconds after V_1 ⁴ 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

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

³ Aircraft Accident Report--"Jugoslovenski 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_1 follows later in this report.

RTO OVERRUN RATE

1959 thru 1988

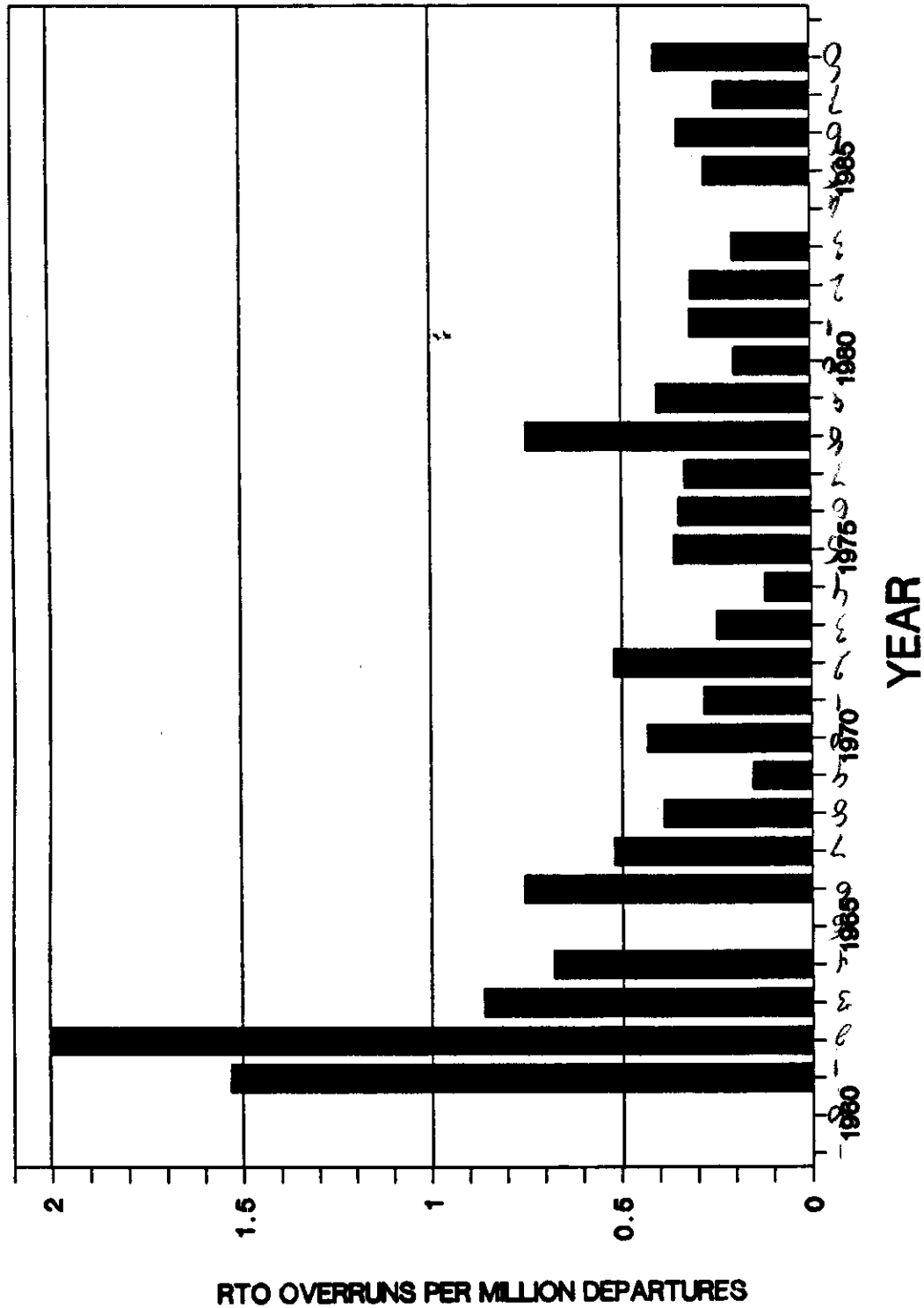


Figure 1. Runway overrun rate.

0 1.55 2 .85 .7.8.

of the subsequent airplane pressurization, might have been able to close the window in flight.

V₁ + RTO
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.⁵ The crew initiated the RTO beyond V₁ 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 V₂ call⁶ during takeoff from Denver's Stapleton International Airport.⁷ 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.

V₁ + RTO
Tire Failure
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 V₁ after hearing loud noises that were later determined to be associated with tire failure.⁸ 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 crewmembers were seriously injured in the accident.

Tire Failure
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.⁹ The aircraft overran the runway, struck objects, and was destroyed. Three crewmembers and 47 passengers were killed.

⁵ Aircraft Accident Report--"Trans World Airlines, Inc., Boeing 707-331C, N15712, San Francisco International Airport, San Francisco, California, September 12, 1972" (NTSB/AAR-73/4).

⁶ V₂ is the takeoff safety speed.

⁷ Aircraft Accident Report--Texas International Airlines, Inc., Douglas DC-9-14, N9104, Stapleton International Airport, Denver, Colorado, November 16, 1976" (NTSB/AAR-77/10).

⁸ Aircraft Accident Report--"Continental Air Lines, Inc., McDonnell-Douglas DC-10-10, N68045, Los Angeles, California, March 1, 1978" (NTSB/AAR-79/1).

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.

Brake Failure
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.¹⁰ 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 V₁. 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.

New
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.¹¹ The investigation determined that a fire warning from the No. 4 engine sounded at or slightly beyond V₁. The crew's reduction of power occurred as the airplane reached 167 knots; V₁ 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 V₁. 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

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.¹² 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_2 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.

V(4)
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.¹³ 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.

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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 1987.¹⁴ 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.

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

¹³ Ostrowski, D.W., "Jet transport rejected takeoffs." FAA Report AFS-160-77-2, Federal Aviation Administration, Washington, DC, February 1977.

14
¹⁴ Batthauer, Byron E., "Analysis of Convair 990 rejected takeoff accident with emphasis on decision making, training and procedures." NASA Technical Memorandum 100189. NASA Lewis Research Center, 1987.

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 V_1 (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.

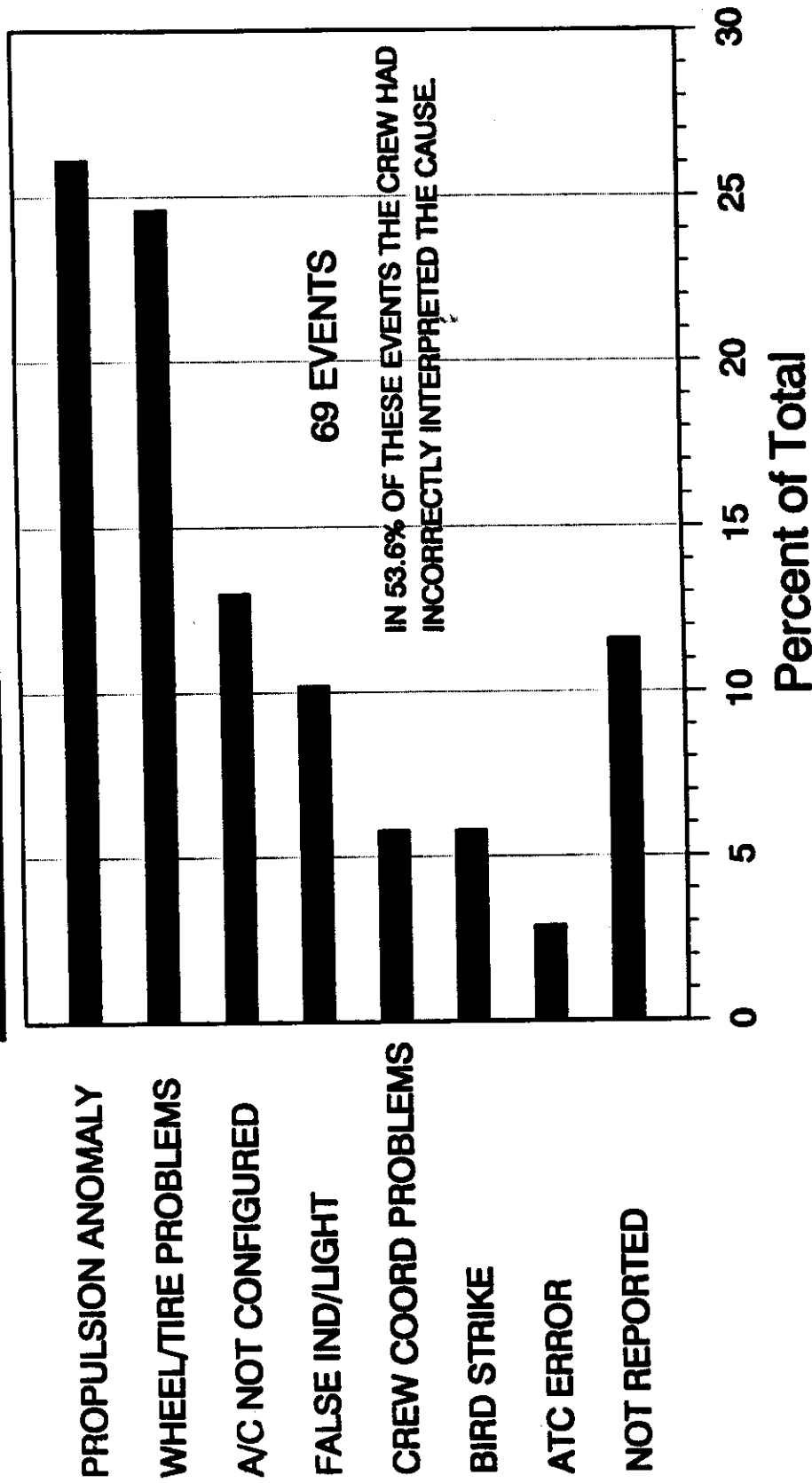
V_1 --During the certification process, the manufacturer is required to establish the speed for any operating gross weight at which the takeoff could be safely continued when the most critical engine fails suddenly. Before March 1, 1978, this speed was referred to by the FAA as " V_1 ," the "critical 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 V_1 as the "takeoff decision speed" and redesignated the "critical engine failure speed" as V_{EF} . 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 V_1 , 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

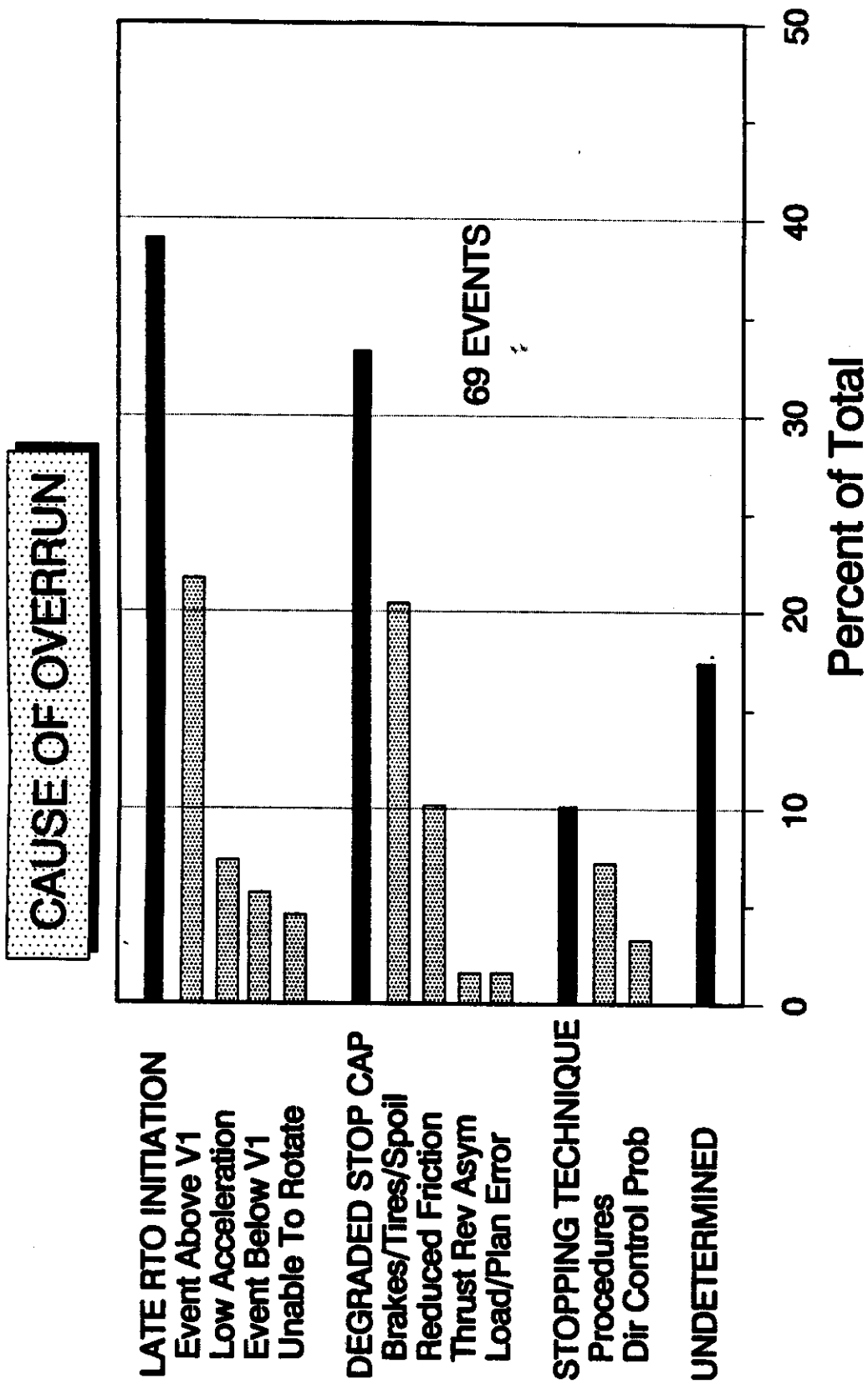
CAUSE OF RTO EVENT



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 V_{EF} (or, before March 1, 1978, at V_1 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.¹⁵

An incremental decrease in V_1 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 V_1 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.¹⁶ The manufacturers then determined the accelerate-stop distance by adding the demonstrated acceleration distance to

¹⁵ The regulations provide allowances for clearways and stopways, which are excluded from this discussion for simplicity.

¹⁶ 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.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.

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_1 --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 reduce 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_1 STOPPING DISTANCE MARGIN

Because many important variables are not considered in the airplane certification process, some experts have suggested modifying V_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_1 and V_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_1 so that a pilot can react to an event and perform an RTO before V_1 is actually reached.¹⁸ In the United States, United Airlines requires the nonflying pilot to begin the V_1 call 5 knots before V_1 is actually reached so that V_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_1 and assists crewmembers in the proper initiation of an RTO when necessary.

TWA modified its computation of V_1 following a series of RTO-related accidents and incidents in the late 1960s. TWA reduces V_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

¹⁸ Limley, E.A., "Lufthansa Go/No Go Philosophy." Boeing 737 Flight Operations Symposium. September 1985. 3.1.1 - 3.1.10.

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.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_1) 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 to 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 saw, 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 1.2 and in 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 1.2 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 lead 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 V_1 on 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.²⁰ 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 ,²¹ 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.

²⁰ (a) Aircraft Accident Report--"Continental Airlines, Inc., Flight 1712, McDonnell-Douglas DC-9-14, N626TX, Stapleton International Airport, Denver, Colorado, November 15, 1987" (NTSB/AAR-88/09). (b) Aircraft Accident Report--"AVAir Inc., Flight 3378, Fairchild Metro III, SA227 AC, N622AV, Cary, North Carolina, February 19, 1988" (NTSB/AAR-88/10).

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 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 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 flightcrew 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 V_1 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 V_1 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 V_1 and rejected takeoffs 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 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 V_1 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

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Manager of Flight Standards and Training

APPENDIX B

TWA FLIGHT DATA SHEET FOR JFK'S RUNWAY 4L

NEW YORK, NEW YORK
KENNEDY INT'L
JFK

3/30/88 R

747-100/200 AIRCRAFT PERFORMANCE
TRANS WORLD AIRLINES

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747-100/200										747-100/200									
TRANSITION ALT <u> </u> V ₁ <u> </u> V _R <u> </u> V ₂ <u> </u> V _{MAX} <u> </u> STANDARD <u> </u> MAXIMUM <u> </u> EPR <u> </u> N ₁ % <u> </u> INITIAL CLIMB N ₁ % <u> </u> STAB <u> </u> TEMP °F <u> </u> °C <u> </u> ALT <u> </u> WIND <u> </u> -ELEV <u> </u> PERF TEMP <u> </u> STA PR <u> </u> RWY ZERO WIND <u> </u> PERFORMANCE ADJ(±) <u> </u> ADJ RWY ZERO WIND <u> </u> RWY WIND ADJ(±) <u> </u> RWY LIMIT WT <u> </u> ASI/SLUSH ADJ(-) <u> </u> ASI/SLUSH MAX WT <u> </u> STRUCT/CLIMB <u> </u> MAX TAKEOFF WT <u> </u> ACTUAL WT <u> </u> LDG WT <u> </u> GA EPR <u> </u> TRANS LEVEL <u> </u> ATIS <u> </u>										747 J90-TA OFF DAY 10 POS FLAPS LENGTH 1135L CLAS 0-0 V ₁ <u> </u> V _R <u> </u> V ₂ <u> </u> V _{MAX} <u> </u> STANDARD <u> </u> MAXIMUM <u> </u> EPR <u> </u> N ₁ % <u> </u> INITIAL CLIMB N ₁ % <u> </u> STAB <u> </u> TEMP °F <u> </u> °C <u> </u> ALT <u> </u> WIND <u> </u> -ELEV <u> </u> PERF TEMP <u> </u> STA PR <u> </u> RWY ZERO WIND <u> </u> PERFORMANCE ADJ(±) <u> </u> ADJ RWY ZERO WIND <u> </u> RWY WIND ADJ(±) <u> </u> RWY LIMIT WT <u> </u> ASI/SLUSH ADJ(-) <u> </u> ASI/SLUSH MAX WT <u> </u> STRUCT/CLIMB <u> </u> MAX TAKEOFF WT <u> </u> ACTUAL WT <u> </u> LDG WT <u> </u> GA EPR <u> </u> TRANS LEVEL <u> </u> ATIS <u> </u>									
DO NOT EXCEED STRUCTURAL LIMIT WEIGHT 747-100 747-200 734,000 775,000										DO NOT EXCEED STRUCTURAL LIMIT WEIGHT 747-100 747-200 734,000 775,000									

APPENDIX C

FEDERAL EXPRESS HANDOUT ON REJECTED TAKEOFFS



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,

A handwritten signature in cursive script that reads "Rick Myers". The signature is written in black ink and is positioned above a horizontal line.

Captain Rick Myers
Senior Manager/Pilot Training
Chief Flight Instructor
Extension: 222-6364
Comat: 3211

RM:mlj:3336v

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 programed, 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 0.61 sec. to spoiler activation. 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 V1 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

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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 Ronald 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/Os 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

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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.

- °Tire failure
- °Antiskid failure
- °Caution light concerning engine failure
- °General electrical failures
- °Indication failure of instruments not absolutely required

British Airways says in their 737 manual,

- °Up to 100kts.abandon for any malfunction
 - °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 100kts. 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

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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