Pilot Guide to Takeoff Safety

TAKEOFF SAFETY TRAINING AID

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Factors that affect takeoff performance (continued)

Introduction

The Pilot Guide to Takeoff Safety is one part of the *Takeoff Safety Training Aid.* The other parts include the Takeoff Safety Overview for Management (Section 1), Example Takeoff Safety Training Program (Section 3), Takeoff Safety Background Data (Section 4), and an optional video.

The goal of the training aid is to reduce the number of RTO related accidents by improving the pilot's decision making and associated procedural accomplishment through increased knowledge and awareness of the factors affecting the successful outcome of the "Go/No Go" decision.

The educational material and the recommendations provided in the *Takeoff Safety Training Aid* were developed through an extensive review process to achieve consensus of the air transport industry.

Objectives

The objective of the Pilot Guide to Takeoff Safety is to summarize and communicate key RTO related information relevant to flight crews. It is intended to be provided to pilots during academic training and to be retained for future use.

"Successful Versus Unsuccessful" Go/ No Go Decisions

Any Go/No Go decision can be considered " successful" if it does not result in injury or airplane damage. However, just because it was "successful" by this definition, it does not mean the action was the "best" that could have been taken. The purpose of this section is to point out some of the lessons that have been learned through the RTO experiences of other airline crews over the past 30 years, and to recommend ways of avoiding similar experiences by the pilots of today's airline fleet.

Takeoffs, RTOs, and Overruns

	Through 1990	Projected 1995
Takeoffs	230,000,000	18,000,000
RTOs (est.)	76,000	6,000
RTO Overrun Accidents/Incidents	74	6

- 1 RTO per 3,000 takeoffs
- 1 RTO overrun accident/incident per 3,000,000 takeoffs

Figure 1 Takeoffs, RTOs, and Overrun Statistics

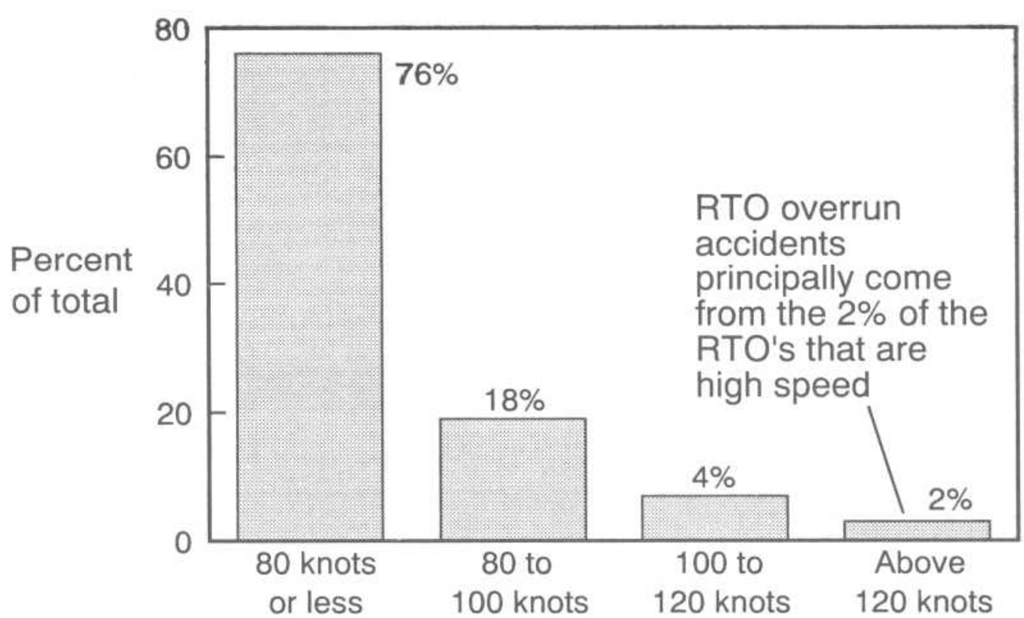
An Inservice Perspective On Go/No Go Decisions

Modern jet transport services began in the early 1950's and significantly increased later that decade after introduction of the Boeing 707 and the Douglas DC-8. As shown in Figure 1, the western built jet transport fleet will have accumulated approximately 230 million takeoffs by the end of 1990. The projec tion for 1995 alone is nearly 18 million takeoffs. That's approximately 34 takeoffs every minute, every day!

Since no comprehensive fleet-wide records are available, it is difficult to identify the total number of RTO's that have occurred throughout the jet era. However, based on those events which have been documented, our best estimate is that one in 3000 takeoff attempts ends with an RTO. At this rate, there will be nearly 6000 RTO's during the year 1995. That means that every day in 1995, 16 flight crews will perform an RTO. Statistically, at the rate of one RTO per 3000 takeoffs, a pilot who flies short-haul routes and makes 80 departures per month, will experience one RTO every three years. At the opposite extreme, the long-haul pilot making only eight departures per month will be faced with only one RTO every 30 years.

The probability that a pilot will ever be required to perform an RTO from high speed is even less, as is shown in Figure 2.

Figure 2
Distribution of RTO Initiation Speeds



Available data indicates that over 75% of all RTO's are initiated at speeds of 80 knots or less. These RTO's almost never result in an accident. Inherently, low speed RTO's are safer and less demanding than high speed RTO's. At the other extreme, about 2% of the RTO's are initiated at speeds above 120 knots. Overrun accidents and incidents that occur principally stem from these high speed events.

What should all these statistics tell a pilot? First, RTO's are not a very common event. This speaks well of equipment reliability and the preparation that goes into operating jet transport airplanes. Both are, no doubt, due in large part to the certification and operational standards developed by the aviation community over the thirty plus years of operation. Second, and more important, the infrequency of RTO events may lead to complacency about maintaining sharp decision-making skills and procedural effectiveness. In spite of the equipment reliability, **every pilot must be prepared to make the correct Go/No Go decision on every takeoff — just in case.**

"Successful" Go/No Go Decisions

As was mentioned at the beginning, there is more to a "good" Go/No Go decision than the fact that it may not have resulted in any apparent injury or aircraft damage. The following examples illustrate a variety of situations that have been encountered in the past, some of which would fit the description of a "good" decision, and some which are, at least, "questionable".

Listed at the beginning of each of the following examples, is the primary cause or cue which prompted the crew to reject the takeoff:

1. Takeoff Warning Horn: The takeoff warning horn sounded as the takeoff roll commenced. The takeoff was rejected at 5 knots. The aircraft was taxied off the active runway where the captain discovered the stabilizer trim was set at the aft end of the green band. The stabilizer was reset and a second takeoff was completed without further difficulty.

2. Takeoff Warning Horn: The takeoff was rejected at 90 knots when the takeoff warning horn sounded. The crew found the speed brake lever slightly out of the detent. A normal takeoff was made following a delay for brake cooling.

3. Engine Power Setting: The throttles were advanced and N_1 increased to slightly over 95%. N_1 eventually stabilized at 94. 8% N_1. The target N_1 from the FMC Takeoff Page was 96.8% N_1. The throttles were then moved to the firewall but the N_1 stayed at 94.8%. The takeoff was rejected due to low N_1 at 80 knots.

4. Compressor Stall: The takeoff was rejected from 155 knots due to a bird strike and subsequent compressor stall on the number three engine. Most of the tires subsequently deflated due to melted fuse plugs.

5. Nose Gear Shimmy: The crew rejected the takeoff after experiencing a nose landing gear shimmy. Airspeed at the time was approximately V_1-10 knots. All four main gear tires subsequently blew during the stop, and fires at the number 3 and 4 tires were extinguished by the fire department.

6. Blown Tire: The takeoff was rejected at 140 knots due to a blown number 3 main gear tire. Number 4 tire blew turning onto the taxiway causing the loss of both A and B hydraulic systems as well as major damage to flaps, spar, and spoilers.

These examples demonstrate the diversity of rejected takeoff causes. All of these RTO's were " successful", but some situations came very close to ending differently. By contrast, the large number of takeoffs that are success-fully continued with indications of airplane system problems such as caution lights that illuminate at high speed or tires that fail near V_1, are rarely ever reported outside the airline's own information system. They may result in diversions and delays but the landings are normally uneventful, and can be completed using standard procedures.

This should not be construed as a blanket recommendation to "Go, no matter what." The goal of this training aid is to eliminate RTO accidents by reducing the number of improper decisions that are made, and to en-sure that the correct procedures are accomplished when an RTO is necessary. It is recognized that the kind of situations that occur in line operations are not always the simple problem that the pilot was exposed to in training. Inevitably, the resolution of some situations will only be possible through the good judgment and discretion of the pilot, as is exemplified in the following takeoff event:

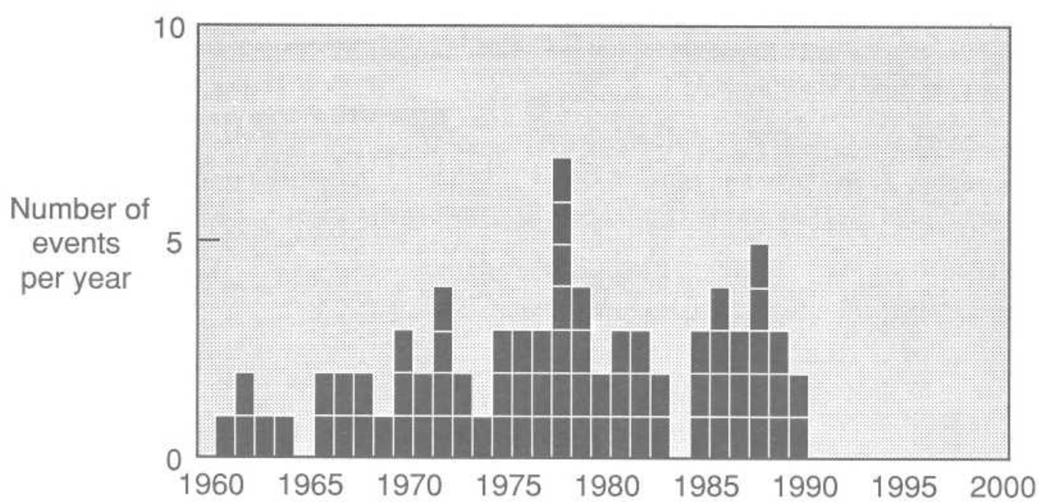
> After selecting EPR mode to set takeoff thrust, the right thrust lever stuck at 1.21 EPR, while the left thrust lever moved to the target EPR of 1.34. The captain tried to reject the takeoff but the right thrust lever could not be moved to idle. Because the light weight aircraft was accelerating very rapidly, the Captain advanced the thrust on the left engine and continued the takeoff. The right engine was subsequently shut down during the approach, and the flight was concluded with an uneventful single-engine landing.

The failure that this crew experienced was not a standard training scenario. Nor is it included here to encourage pilots to change their mind in the middle of an RTO procedure. It is simply an acknowledgment of the kind of real world decision making situations that pilots face. It is perhaps more typical of the good judgements that airline crews regularly make, but the world rarely hears about.

RTO Overrun Accidents and Incidents

The one-in-one-thousand RTO's that became accidents or serious incidents are the ones that we must strive to prevent. As shown in Figure 3, at the end of 1990, records show 46 inservice RTO overrun accidents for the western built jet transport fleet. These 46 accidents caused more than 400 fatalities. An additional 28 serious incidents have been identified which likely would have been accidents if the runway overrun areas had been less forgiving. The following are brief accounts of four actual accidents. They are real events. Hopefully, they will not be repeated.

Figure 3
74 RTO overrun accidents/incidents 1959-1990



ACCIDENT: At 154 knots, four knots after V_1, the copilot's side window opened, and the takeoff was rejected. The aircraft overran, hitting a blast fence, tearing open the left wing and catching fire.

ACCIDENT: The takeoff was rejected by the captain when the first officer had difficulty maintaining runway tracking along the 7000 foot wet runway. Initial reports indicate that the airplane had slowly accelerated at the start of the takeoff roll due to a delay in setting takeoff thrust. The cockpit voice recorder (CVR) readout indicates there were no speed callouts made during the takeoff attempt. The reject speed was 5 knots above V_1. The transition to stopping was slower than expected. This was to have been the last flight in a long day for the crew. Both pilots were relatively inexperienced in their respective positions. The captain had about 140 hours as a captain in this airplane type and the first officer was conducting his first non-supervised line takeoff in this airplane type. The airplane was destroyed when it overran the end of the runway and broke apart against piers which extend off the end of the runway into the river. There were two fatalities. Subsequent investigation revealed that the rudder was trimmed full left prior to the takeoff attempt.

ACCIDENT: A flock of sea gulls was encountered "very near V_1." The airplane reportedly had begun to rotate. The number one engine surged and flamed out, and the takeoff was rejected. The airplane overran the end of the wet 6000 foot runway despite a good RTO effort.

ACCIDENT: At 120 knots, the flight crew noted the onset of a vibration. When the vibration increased, the captain elected to reject and assumed control. Four to eight seconds elapsed between the point where the vibration was first noted and when the RTO was initiated (just after V_1). Subsequent investigation showed two tires had failed. The maximum speed reached was 158 knots. The airplane overran the end of the runway at a speed of 35 knots and finally stopped with the nose in a swamp. The airplane was destroyed.

These four cases are typical of the 74 reported accidents and incidents.

Statistics

Studies of the previously mentioned 74 accidents/incidents have revealed some interesting statistics, as shown in Figure 4:

- Fifty-eight percent were initiated at speeds in excess of V_1.
- Approximately one-third were reported as having occurred on runways that were wet or contaminated with snow or ice.

Both of these issues will be thoroughly discussed in subsequent sections. An additional, vitally interesting statistic that was observed when the accident records involving Go/No Go decisions were reviewed, was that virtually no revenue flight was found where a "Go"

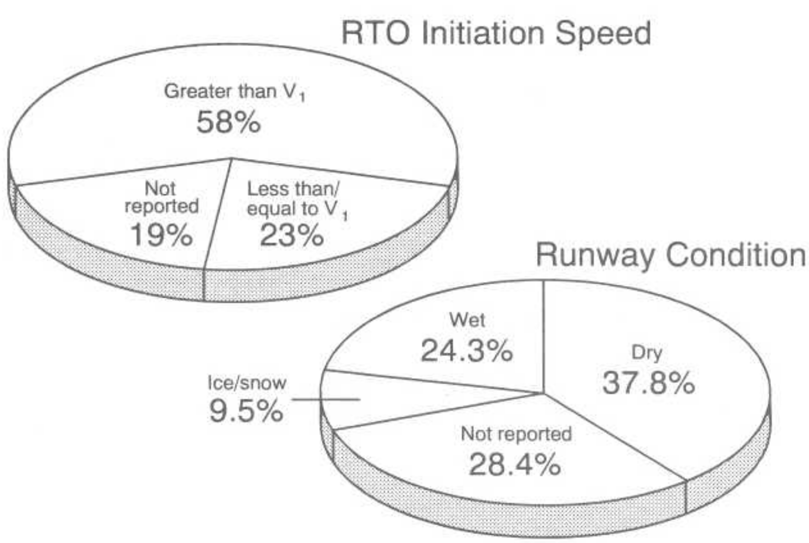
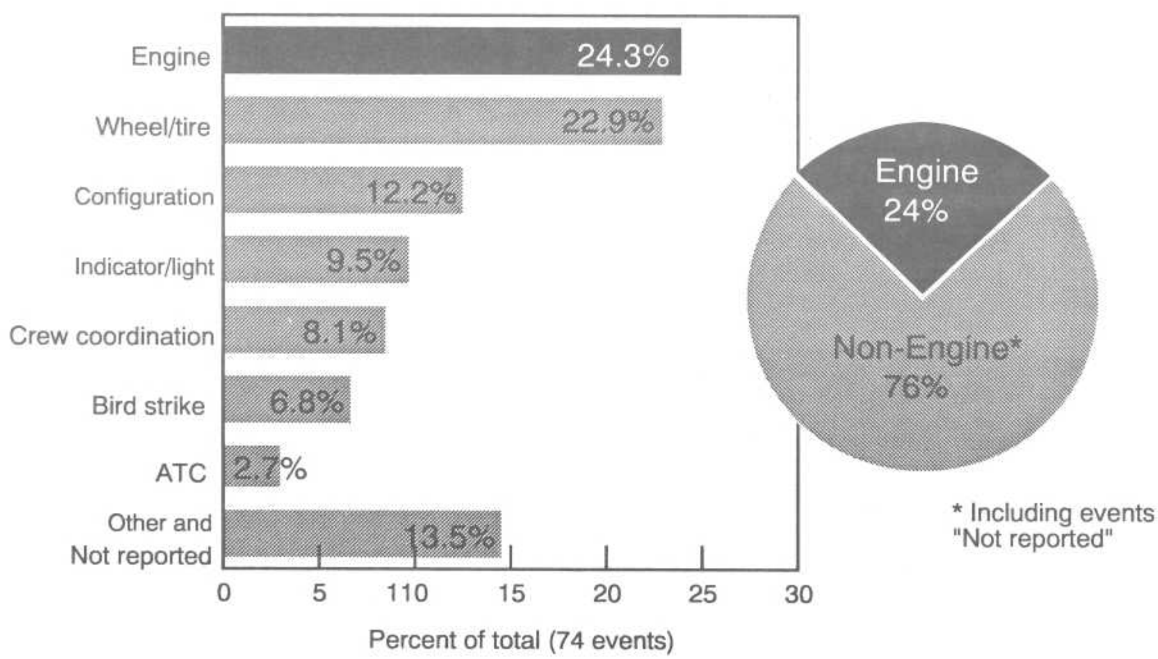


Figure 4
Major factors in previous RTO accidents

decision was made and the airplane was incapable of continuing the takeoff. Regardless of the ability to safely continue the takeoff, as will be seen , virtually any takeoff can be "successfully" rejected, IF the reject is initiated early enough and is conducted properly. There is more to the Go /No Go decision than "Stop before V_1" and "Go after V_1. " The statistics of the past three decades show that a number of jet transports have experienced circumstances near V_1 that rendered the air-plane incapable of being stopped on the run-way remaining. It also must be recognized, that catastrophic situations could occur which render the airplane incapable of flight.

Reasons why the 74 "unsuccessful" RTO's were initiated are also of interest. As shown in Figure 5, approximately one-fourth were initiated because of engine failures or engine indication warnings. The remaining seventy-six percent were initiated for a variety of reasons which included tire failures, procedural error, malfunction indication or lights, noises and vibrations, directional control difficulties and unbalanced loading situations where the air-plane failed to rotate. Some of the events contained multiple factors such as an RTO on a contaminated runway following an engine failure at a speed in excess of V_l. The fact that the majority of the accidents and incidents occurred on airplanes that had full thrust available should figure heavily in future Go/ No Go training.

Figure 5
Reasons for initiating the RTO (74 accident/ incident events)



Lessons Learned

Several lessons can be learned from these RTO accidents. First, the crew must always be prepared to make the Go/No Go decision prior to the airplane reaching V_1 speed. As will be shown in subsequent sections, there may not be enough runway left to successfully stop the airplane if the reject is initiated after V1. Second, in order to eliminate unnecessary RTO's, the crew must differentiate between situations that are detrimental to a safe take-off, and those that are not. Third, the crew must be prepared to act as a well-coordinated team. A good summarizing statement of these lessons is, **as speed approaches V_1, the successful completion of an RTO becomes increasingly more difficult.**

A fourth and final lesson learned from the past 30 years of RTO history is illustrated in Figure 6. Analysis of the available data suggests that of the 74 RTO accidents and incidents, approximately 80% were potentially avoidable through appropriate operational practices. These potentially avoidable accidents can be divided into three categories. Roughly 9% of the RTO accidents of the past were the result of improper preflight planning. Some of these instances were caused by loading errors and others by incorrect preflight procedures. About 16% of the accidents and incidents could be attributed to incorrect pilot techniques or procedures in the stopping effort. Delayed application of the brakes, failure to deploy the speedbrakes, and the failure to make a maximum effort stop until late in the RTO were the chief characteristics of this category.

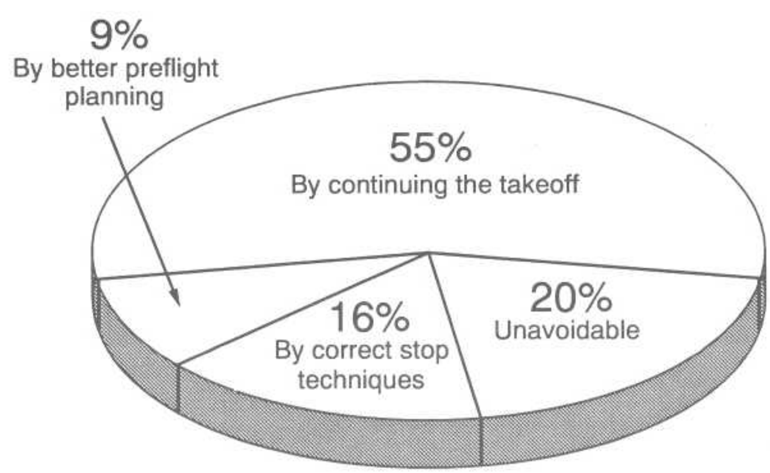


Figure 6
80% of the RTO accidents were avoidable

Review of the data from the 74 RTO accidents and incidents suggests that in approximately 55% of the events, the airplane was capable of continuing the takeoff and either landing at the departure airport or diverting to an alternate. In other words, the decision to reject the takeoff appears to have been "improper." It is not possible, however, to predict with total certainty what would have happened in every event if the takeoff had been continued. Nor is it possible for the analyst of the accident data to visualize the events leading up to a particular accident "through the eyes of the crew", including all the other factors that were vying for their attention at the moment when the "proper" decision could have been made. It is not very difficult to imagine a set of circumstances where the only logical thing for the pilot to do is to reject the takeoff. Encountering a large flock of birds at rotation speed, which then produces loss of thrust on both engines of a two-engine airplane, is a clear example.

Although these are all valid points, debating them here will not move us any closer to the goal of reducing the number of RTO accidents. Several industry groups have recently studied this problem. Their conclusions and recommendations agree surprisingly well. The areas identified as most in need of attention are decision making and proficiency in correctly performing the appropriate procedures. These are the same areas highlighted in Figure 6. It would appear then, that an opportunity exists to significantly reduce the number of RTO accidents in the future by attempting to improve the pilots' decision making capability and procedure accomplishment, through better training.

Decisions and Procedures - - What Every Pilot Should Know

There are many things that may ultimately affect the outcome of a Go/No Go decision.

The goal of the *Takeoff Safety Training Aid is* to reduce the number of RTO related accidents and incidents by improving the pilot's decision making and associated procedure accomplishment through increased knowledge and awareness of the related factors. This section discusses the rules that define takeoff performance limit weights and the margins that exist when the actual takeoff weight of the airplane is less than the limit weight. The effects of runway surface condition, atmospheric conditions, and airplane configuration variables on Go/No Go performance are discussed, as well as what the pilot can do to make the best use *of any* excess available runway.

Although the information contained in this section has been reviewed by many major airframe manufacturers and airlines, the incorporation of any of the recommendations made in this section are subject to the approval of each operator's management.

The Takeoff Rules - - The Source of the Data

It is important that all pilots understand the takeoff field length/ weight limit rules and the margins these rules provide. Misunderstanding the rules and their application to the operational situation could contribute to an incorrect Go/No Go decision.

The U.S. Federal Aviation Regulations (FAR's) have continually been refined so that the details of the rules that are applied to one airplane model may differ from another. However, these differences are minor and have no effect on the basic actions required of the flight crew during the takeoff. In general, it is more important for the crew to understand the basic principles rather than the technical variations in certification policies.

The "FAR" Takeoff Field Length

The "FAR" Takeoff Field Length determined from the FAA Approved Airplane Flight Manual (AFM), considers the most limiting of each of the following three criteria:

1) All-Engine Go Distance: 115% of the actual distance required to accelerate, liftoff and reach a point 35 feet above the runway with all engines operating (Figure 7).

2) Engine-Out Accelerate-Go Distance: The distance required to accelerate with all engines operating, have one engine fail at ^{V}EF, at least one second before V_1, continue the takeoff, liftoff and reach a point 35 feet above the runway surface at V_2 speed (Figure 8).

3) Engine-Out Accelerate-Stop Distance: The distance required to accelerate with all engines operating, have an engine fail at VEF, at least one second before V_1, recog nize the failure, reconfigure for stopping and bring the airplane to a stop using maximum wheel braking with the speed-brakes extended. Reverse thrust is not used to determine the FAR accelerate-stop distance (Figure 9).

The FAR criteria provide accountability for wind, runway slope, clearway and stopway. FAA approved takeoff data are based on the performance demonstrated on a smooth, dry runway. Separate advisory data for wet or contaminated runway conditions are published in the manufacturer's operational documents. These documents are used by many operators to derive wet or contaminated runway takeoff adjustments.

Other criteria define the performance weight limits for takeoff climb, obstacle clearance, tire speeds and maximum brake energy capability. Any of these other criteria can be the limiting factor which determines the maximum dispatch weight. However, the Field Length Limit Weight and the amount of runway remaining at V_l will be the primary focus of our discussion here since they more directly relate to preventing RTO overruns.

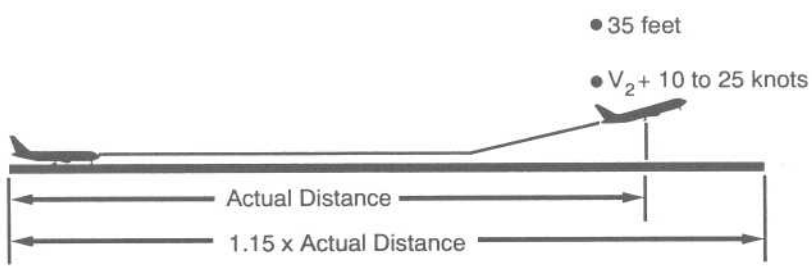


Figure 7
All-engine go distance

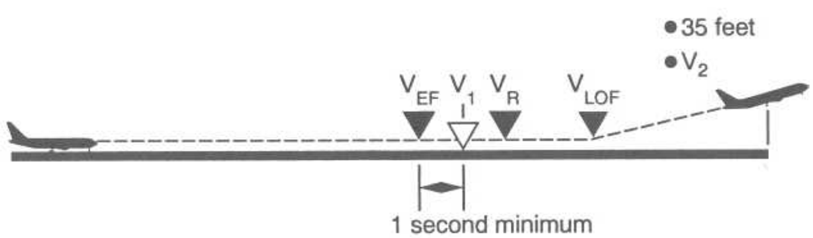


Figure 8
Engine-out accelerate-go distance

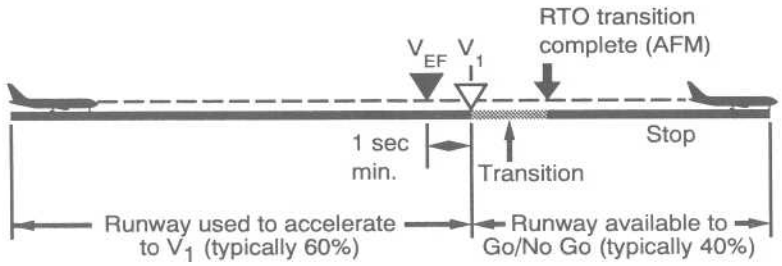
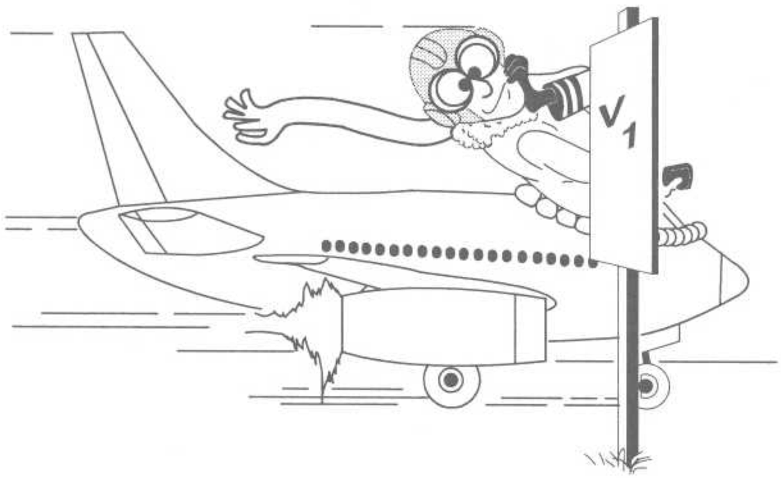


Figure 9
Engine-out accelerate-stop distance

V_1 Speed Defined



What is the proper operational meaning of the key parameter "V_1 speed" with regard to the Go/No Go criteria? This is not such an easy question since the term "V_1 speed" has been redefined several times since commercial jet operations began more than 30 years ago and there is possible ambiguity in the interpretation of the words used to define V_1.

Paragraph 25.107 of the FAA Regulations defines the relationship of the takeoff speeds published in the Airplane Flight Manual, to various speeds determined in the certification testing of the airplane. Although the terms engine failure speed, decision speed, recognizes, and reacts are all within this "official" definition, for our purposes here, the most important statement within this "official" definition is that V_1 is determined from "...the **pilot's application of the first retarding means during the accelerate-stop tests."**

One common and misleading way to think of V_1 is to say "V_1 is the decision speed." This is misleading because V_1 is not the point to begin making the operational Go/No Go decision. **The decision must have been made by the time the airplane reaches V_1** or the pilot will not have initiated the RTO procedure at V_1 Therefore, by definition, the airplane will be traveling at a speed higher than V_1 when stopping action is initiated, and if the airplane is at a Field Length Limit Weight, an overrun is virtually assured.

Another commonly held misconception: "V_1 is the engine failure recognition speed", suggests that the decision to reject the takeoff following engine failure recognition may begin as late as V_1. Again, the airplane will have accelerated to a speed higher than V_1 before stopping action is initiated.

The certified accelerate-stop distance calculation is based on an engine failure at least one second prior to V_1. This standard time allowance [1] has been established to allow the line pilot to recognize an engine failure and begin the subsequent sequence of stopping actions.

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. 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 height of 35 feet at the end of the runway.** This aspect of V_1 is discussed in a later section.

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[1] The time interval between V_EF and V_1 is the longer of the flight test demonstrated time or one second. Therefore, in determining the scheduled accelerate-stop performance, one second is the minimum time that will exist between the engine failure and the first pilot stopping action.

The Go/ No Go decision must be made before reaching V1. **A "No Go" decision after passing V_1 will not leave sufficient runway remaining to stop if the takeoff weight is equal to the Field Length Limit Weight.** When the airplane actual weight is less than the Field Length Limit Weight, it is possible to calculate the actual maximum speed from which the takeoff could be successfully rejected. However, few operators use such takeoff data pre sentations. It is therefore recommended that pilots consider V_1 to be a limit speed: Do not attempt an RTO once the airplane has passed V_1 unless the pilot has reason to conclude the airplane is unsafe or unable to fly. **This recommendation should prevail no matter what runway length appears to remain after V_1.**

Balanced Field Defined

The previous two sections established the general relationship between the takeoff performance regulations and V_1 speed. This section provides a closer examination of how the choice of V_l actually affects the takeoff performance in specific situations.

Since it is generally easier to change the weight of an airplane than it is to change the length of a runway, the discussion here will consider the effect of V_l on the allowable takeoff weight from a fixed runway length.

The Continued Takeoff - - After an engine failure during the takeoff roll, the airplane must continue to accelerate on the remaining engine(s), lift off and reach V_2 speed at 35 feet. The later in the takeoff roll that the engine fails, the heavier the airplane can be and still gain enough speed to meet this requirement. For the engine failure occurring approximately one second prior to V_l, the relationship of the allowable engine-out go takeoff weight to V_1 would be as shown by the "Continued Take-off" line in Figure 10. The higher the V_1, the heavier the takeoff weight allowed.

The Rejected Takeoff - - On the stop side of the equation, the V_1/weight trade has the opposite trend. The lower the V_1, or the earlier in the takeoff roll the stop is initiated, the heavier the airplane can be, as indicated by the "Rejected Takeoff" line in Figure 10.

The point at which the "Continued and Rejected Takeoff" lines intersect is of special interest. It defines what is called a "Balanced Field Limit" takeoff. The name "Balanced Field" refers to the fact that the accelerate-go performance required is exactly equal to (or " balances") the accelerate-stop performance required. From Figure 10 it can also be seen that at the "Balanced Field" point, the allowable Field Limit Takeoff Weight for the given runway is the maximum. The resulting unique value of V_1 is referred to as the "Balanced Field Limit V_1 Speed" and the associated takeoff weight is called the "Balanced Field Weight Limit." This is the speed that is typically given to flight crews in handbooks or charts, by the onboard computer systems, or by dispatch.

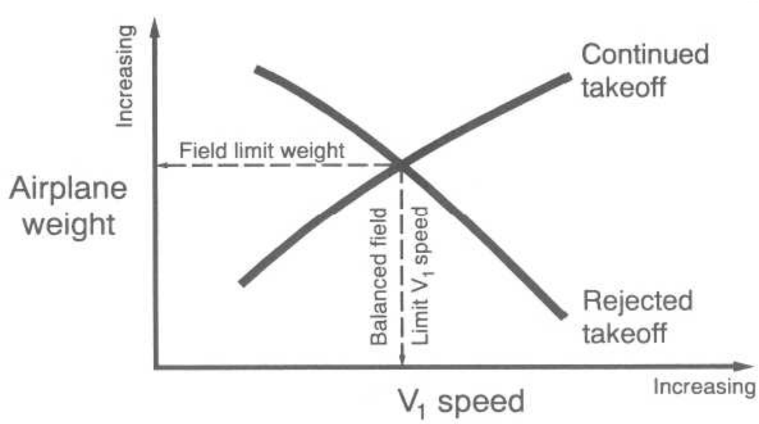


Figure 10
Effect of V_1 speed on takeoff weight (from a fixed runway length)

Transition to the Stopping Configuration

In establishing the certified accelerate-stop distance, the time required to reconfigure the airplane from the "Go" to the "Stop" mode is referred to as the "transition" segment. This action and the associated time of accomplishment includes applying maximum braking, simultaneously moving the thrust levers to idle and raising the speedbrakes. The transition time demonstrated by flight test pilots during the accelerate-stop testing is used to derive the transition segment times used in the AFM calculations. The relationship between the flight test demonstrated transition times and those finally used in the AFM is another frequently misunderstood area of RTO performance.

Flight Test Transitions

Several methods of certification testing that produce comparable results have been found to be acceptable. The following example illustrates the intent of these methods.

During certification testing, the airplane is accelerated to a pre-selected speed, one engine is "failed" by selecting fuel cut-off, and the pilot flying rejects the takeoff. In human factors circles, this is defined as a "simple task" because the test pilot knows in advance that an RTO will be performed. Exact measurements of the time taken by the pilot to apply the brakes, retard the thrust levers to idle, and to deploy the speedbrakes are recorded. Detailed measurements of engine parameters during spooldown are also made so that the thrust actually being generated can be accounted for in the calculation.

The manufacturer's test pilots, and pilots from the regulatory agency, each perform several rejected takeoff test runs. An average of the recorded data from at least six of these RTO's is then used to determine the "demonstrated" transition times. The total flight test "demonstrated" transition time, initial brake application to speedbrakes up, is typically one second or less. However this is not the total transition time used to establish the certified accelerate-stop distances. The certification regulations require that additional time delays, sometimes referred to as "pads", be included in the calculation of certified takeoff distances.

Airplane Flight Manual Transition Times

Although the line pilot must be prepared for an RTO during every takeoff, it is fairly likely that the event or failure prompting the Go/ No Go decision will be much less clear-cut than an outright engine failure. It may therefore be unrealistic to expect the average line pilot to perform the transition in as little as one second in an operational environment. Human factors literature describes the line pilot's job as a " complex task" since the pilot does not know when an RTO will occur. In consideration of this "complex task", the flight test transition times are increased to calculate the certified accelerate-stop distances specified in the AFM. **These additional time increments are not intended to allow extra time for making the "No Go" decision after passing V_1.** Their purpose is to allow sufficient time (and distance) for "the average pilot" to transition from the takeoff mode to the stopping mode.

The first adjustment is made to the time required to recognize the need to stop. During the RTO certification flight testing, the pilot knows that the engine will be failed, therefore, his reaction is predictably quick. To account for this, an engine failure recognition time of at least one second has been set as a standard for all jet transport certifications since the late 1960's. V_1 is therefore, at least one second after the engine failure. During this recognition time segment, the airplane continues to accelerate with the operating engine(s) continuing to provide full forward thrust. The "failed" engine has begun to spool down, but it is still providing some forward thrust, adding to the airplane's acceleration.

Over the years, the details of establishing the transition time segments after V_1 have varied slightly but the overall concept and the resulting transition distances have remained essentially the same. For early jet transport models, an additional one second was added to both the flight test demonstrated throttlesto-idle time and the speedbrakes-up time, as illustrated in Figure 11. The net result is that the flight test demonstrated recognition and transition time of approximately one second has been increased for the purpose of calculating the AFM transition distance.

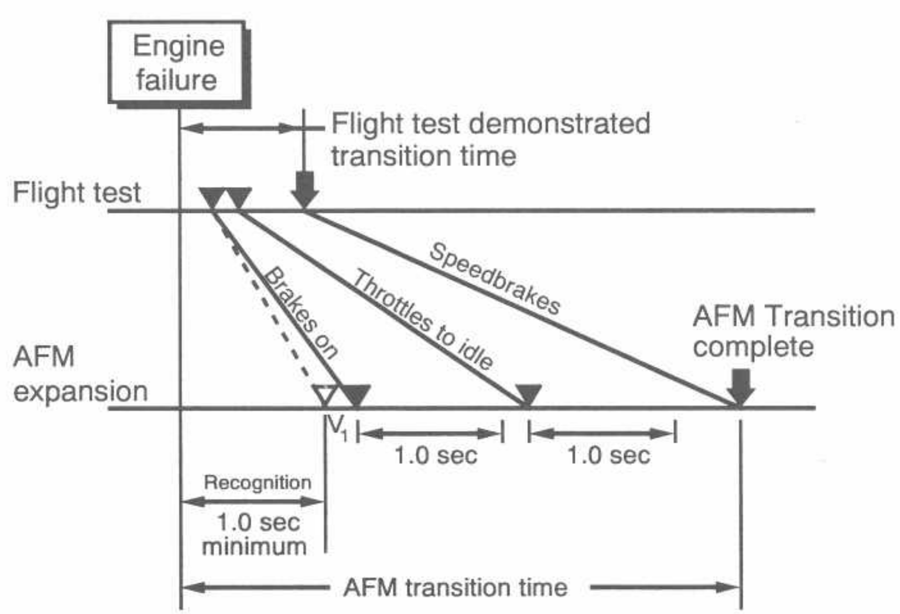


Figure 11
Early method of establishing AFM transition time

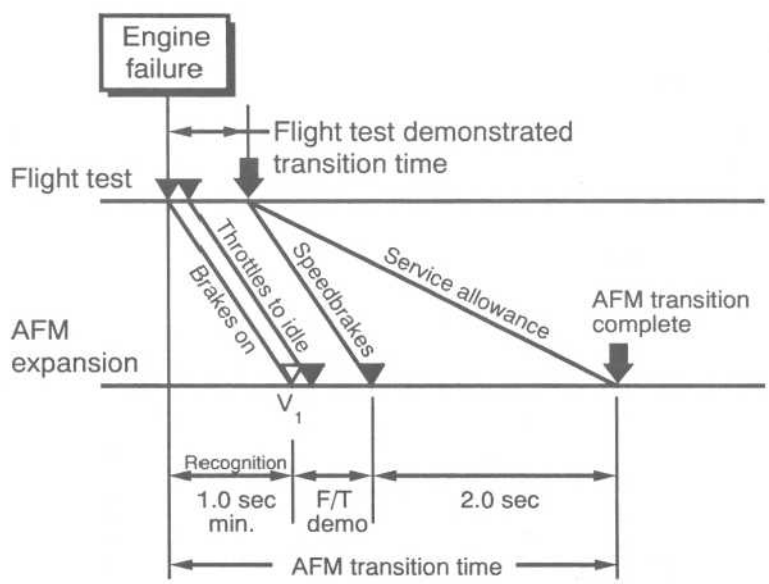
In more recent certification programs, the AFM calculation procedure was slightly different. An allowance equal to the distance traveled during two seconds at the speedbrakes-up speed was added to the actual total transition time demonstrated in the flight test to apply brakes, bring the thrust levers to idle and deploy the speedbrakes, as shown in Figure 12. To insure "consistent and repeatable results," retardation forces resulting from brake application and speed brake deployment are not applied during this two second allowance time, i.e. no deceleration credit is taken. This two second distance allowance simplifies the transition distance calculation and accomplishes the same goal as the individual one second "pads" used for older models.

Regardless of the method used, the accelerate - stop distance calculated for every takeoff from the AFM is typically 400 to 600 feet longer than the flight test accelerate - stop distance.

These differences between the past and present methodology are not significant in so far as the operational accelerate-stop distance is concerned. **The key point is that the time/distance "pads" used in the AFM transition distance calculation are not intended to allow extra time to make the "No Go" decision.** Rather, the "pads" provide an allowance that assures the pilot has adequate distance to get the air -plane into the full stopping configuration.

Regardless of the airplane model, the transition, or reconfiguring of the airplane for a rejected takeoff, demands quick action by the crew to simultaneously initiate maximum braking, retard the thrust levers to idle and then quickly raise the speedbrakes.

Figure 12
More recent method of establishing AFM transtion time



Comparing the "Stop" and "Go" Margins

When performing a takeoff at a Field Length Limit Weight determined from the AFM, the pilot is assured that the airplane performance will, at the minimum, conform to the requirements of the FAR's if the assumptions of the calculations are met. This means that following an engine failure at VEF, the takeoff can be rejected at V1 and the airplane stopped at the end of the runway, or if the takeoff is continued, a minimum height of 35 feet will be reached over the end of the runway.

This section discusses the inherent conservatism of these certified calculations, and the margins they provide beyond the required minimum performance.

The "Stop" Margins

From the preceding discussion of the certification rules, it has been shown that at a Field Length Limit Weight condition, an RTO initiated at VI will result in the airplane coming to a stop at the end of the runway. This accelerate-stop distance calculation specifies a smooth, dry runway, an engine failure at ^{V}EF, the pilot's initiation of the RTO at V1, and the completion of the transition within the time allotted in the AFM. If any of these basic assumptions are not satisfied, the actual accel erate-stop distance may exceed the AFM calculated distance, and an overrun will result.

The most significant factor in these assumptions is the initiation of the RTO no later than V1, yet as was noted previously, in approximately 58% of the RTO accidents the stop was initiated after V1. At heavy weights near V1, the airplane is typically traveling at 200 to 300 feet per second, and accelerating at 3 to 6 knots per second. This means that a delay of only a second or two in initiating the RTO will require several hundred feet of additional runway to successfully complete the stop. If the takeoff was at a Field Limit Weight, and there is no excess runway available, the airplane will reach the end of the runway at a significant speed, as shown in Figure 13.

The horizontal axis of Figure 13 is the incremental speed in knots above V1 at which a **maximum effort** stop is initiated. The vertical axis shows the **minimum speed** in knots at which the airplane would cross the end of the runway, assuming the pilot used all of the transition time allowed in the AFM to reconfigure the airplane to the stop configuration, and that a maximum stopping effort was maintained. The data in Figure 13 assumes an engine failure not less than one second prior to V1 and does not include the use of reverse thrust. Therefore, if the pilot performs the transition more quickly than the AFM allotted time, and/or uses reverse thrust, the line labeled "MAXIMUM EFFORT STOP" would be shifted slightly to the right. However, based on the RTO accidents of the past, the shaded area above the line shows what is more likely to occur if a high speed RTO is initiated at or just after $_{Vi.}$ This is especially true if the RTO

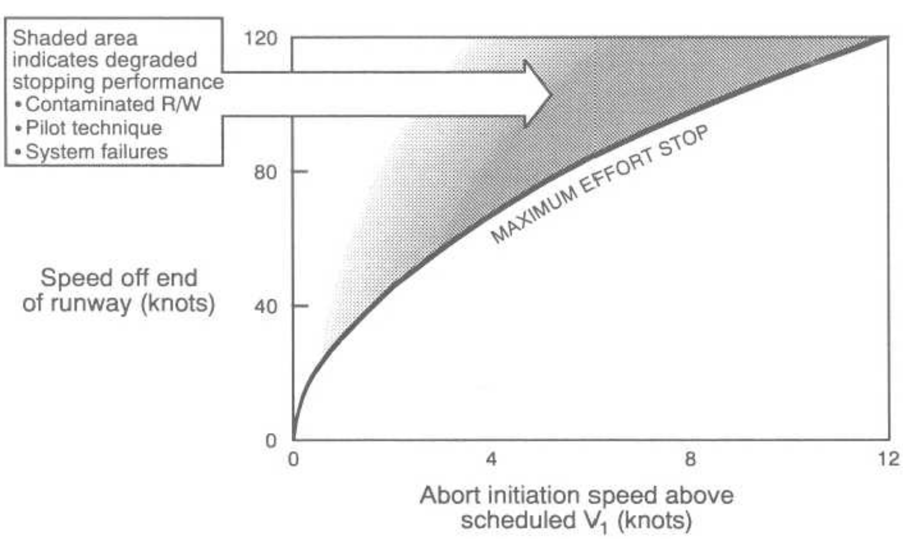


Figure 13
Overrun Speed for an RTO initiated after V_1

was due to something other than an engine failure, or if the stopping capability of the airplane is otherwise degraded by runway surface contamination, tire failures, or poor technique. The data in Figure 13 are typical of a large, heavy jet transport and would be rotated slightly to the right for the same airplane at a lighter weight.

In the final analysis, although the certified accelerate-stop distance calculations provide sufficient runway for a properly performed RTO on a dry runway, the available margins are fairly small. Most importantly, there are no margins to account for initiation of the RTO after V1 or extenuating circumstances such as runway contamination.

The "Go" Option

FAR rules also prescribe minimum performance standards for the "Go" situation. With an engine failed at the most critical point along the takeoff path, the FAR "Go" criteria requires that the airplane be able to continue to accel erate, rotate, liftoff and reach V_2 speed at a point 35 feet above the end of the runway. The airplane must remain controllable throughout this maneuver and must meet certain minimum climb requirements. These handling characteristics and climb requirements are demonstrated many times throughout the cer tification flight test program. While a great deal of attention is focused on the engine failure case, it is important to keep in mind, that **in nearly three-quarters of all RTO accident** cases, full **takeoff power** was **available.** It is likely that each crew member has had a good deal of practice in engine inoperative takeoffs in prior simulator or airplane training. However, it may have been done at relatively light training weights. As a result, the crew may conclude that large control inputs and rapid response typical of conditions near minimum control speeds (Vmcg) are always required in order to maintain directional control. However, at the V_1 speeds associated with a typical Field Length Limit Weight, the control input requirements are noticeably less than they are at lighter weights.

Also, at light gross weights, the airplane's rate of climb capability with one engine inoperative could nearly equal the all-engine climb perfor mance at typical inservice weights, leading the crew to expect higher performance than the airplane will have if the actual airplane weight is at or near the takeoff Climb Limit Weight. Engine-out rate of climb and acceleration capability at a Climb Limit Weight may appear to be substantially less than the crew anticipates or is familiar with.

The minimum second segment climb gradients required in the regulations vary from 2.4% to 3.0% depending on the number of engines installed. These minimum climb gradients translate into a climb rate of only 350-500 feet per minute at actual climb limit weights and their associated V_2 speeds, as shown in Figure 14. The takeoff weight computations performed prior to takeoff are required to account for all obstacles in the takeoff flight path. All that is required to achieve the anticipated flight path is adherence by the flight crew to the planned headings and speeds per their predeparture briefing.

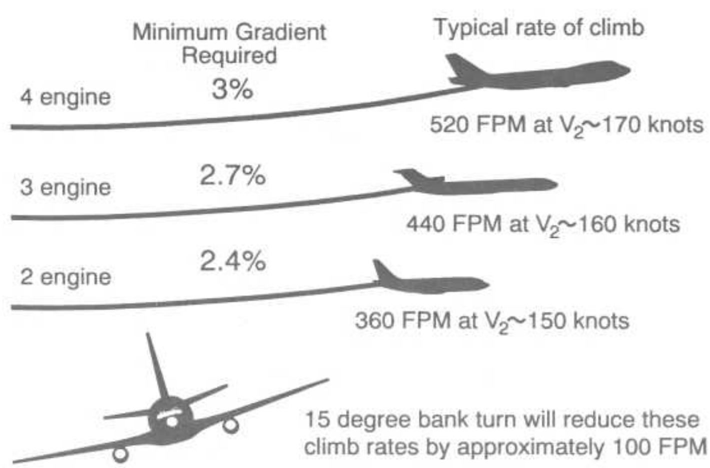


Figure 14
"GO" performance at climb limit weights

Consider a one-engine-inoperative case where the engine failure occurs earlier than the minimum time before V_l specified in the rules. Because engine -- out acceleration is less than all -engine acceleration, additional distance is needed to accelerate to VR and, as a consequence, the liftoff point will be moved further down the runway. The altitude (or "screen height") achieved at the end the runway is somewhat reduced depending on how much more than one second before V_1 the engine failure occurs. On a field length limit runway, the height at the end of the runway maybe less than the 35 ft specified in the regulations.

Figure 15 graphically summarizes this discussion of "Go" margins. First, let VEF be the speed at which the Airplane Flight Manual calculation assumes the engine to fail, (a minimum of one second before reaching V_1). The horizontal axis of Figure 15 shows the number of knots prior to VEF that the engine actually fails instead of the time, and the vertical axis gives the "screen height" achieved at the end of the runway. A typical range of acceleration for jet transports is 3 to 6 knots per second, so the shaded area shows the range in screen height that might occur if the engine actually failed " one second early", or approximately two seconds prior to V_1. In other words, a "Go" decision made with the engine failure occurring two seconds prior to V_1 will result in a screen height of 15 to 30 feet for a Field Length Limit Weight takeoff.

Figure 15 also shows that the "Go" performance margins are strongly influenced by the number of engines. This is again the result of the larger proportion of thrust loss when one engine fails on the two-engine airplane compared to a three or four-engine airplane. On two-engine airplanes, there are still margins but they are not as large, a fact that an operator of several airplane types must be sure to emphasize in training and transition programs.

It should also be kept in mind that the 15 to 30 foot screen heights in the preceding discussion were based on the complete loss of thrust from one engine. If all engines are operating, as was the case in most of the RTO accident cases, the height over the end of the Field Length Limit runway will be approximately 150 feet and speed will be V_2+10 to 25 knots, depending on airplane type. This is due to the higher acceleration and climb gradient provided when all engines are operating and because the required all-engine takeoff distance is multiplied by 115%. If the "failed" engine is developing partial power, the performance is somewhere in between, but definitely above the required engine-out limits.

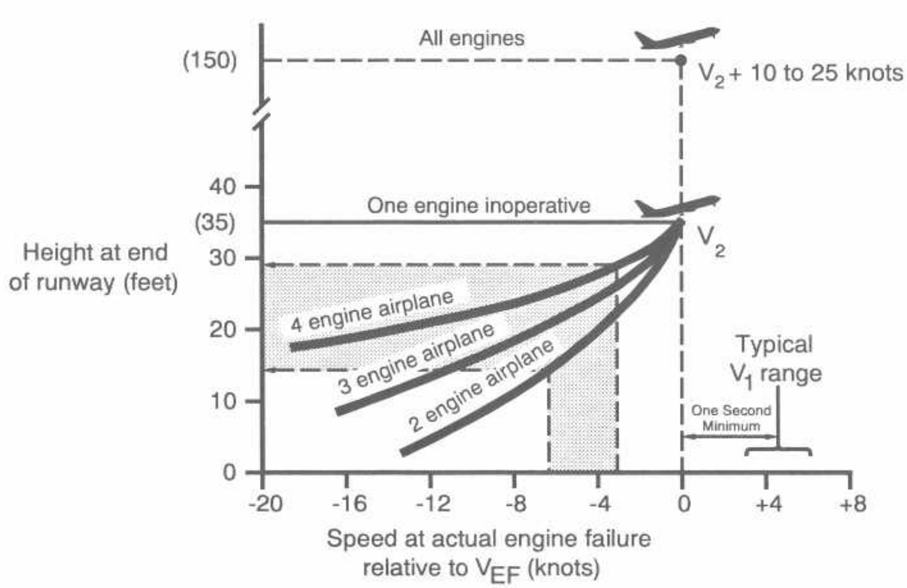


Figure 15
Effect of engine failure before V_{EF} on screen height

Operational Takeoff Calculations

As we have seen, the certification flight testing, in accordance with the appropriate government regulations, determines the relationship between the takeoff gross weight and the required runway length which is published in the AFM. By using the data in the AFM it is then possible to determine, for a given combination of ambient conditions and airplane weight, the required runway length which will comply with the regulations. Operational takeoff calculations, however, have an additional and obviously different limitation. The length of the runway is the Limit Field Length and it is fixed, not variable.

The Field Length Limit Weight

Instead of solving for the required runway length, the first step in an operational takeoff calculation is to determine the maximum airplane weight which meets the rules for the fixed runway length available. In other words, what is the limit weight at which the airplane:

1) will achieve 35 ft altitude with all engines operating and a margin of 15% of the actual distance used remaining;

2) will achieve 35 ft altitude with the critical engine failed prior to V_1;

3) will stop with an engine failed prior to V_1 and the reject initiated at V_1;

...all within the existing runway length available.

The result of this calculation is three allowable weights. These three weights may or may not be the same, but the lowest of the three becomes the Field Length Limit Weight for that takeoff,

An interesting observation can be made at this point as to which of these three criteria will typically determine the Takeoff Field Limit Weight for a given airplane type. Two-engine airplanes lose one-half their total thrust when an engine fails. As a result, the Field Length Limit Weight for two-engine airplanes is usu ally determined by one of the engine-out dis tance criteria. If it is limited by the accelerate-stop distance, there will be some margin in both the all-engine and accelerate-go distances. If the limit is the accelerate-go distance, some margin would be available for the all-engine-go and engine-out-stop cases.

By comparison, four-engine airplanes only lose one-fourth of their takeoff thrust when an engine fails so they are rarely limited by engine-out go performance. The Field Length Limit Weight for a four-engine airplane is typically limited by the 115% all-engine distance crite ria or occasionally by the engine-out stop case. As a result, a slight margin frequently exists in both of the engine-out distances on four-engine airplanes.

Three-engine airplanes may be limited by en gine out performance, or for some models, by a more complex criterion wherein the rotation speed V_R becomes the limiting factor. Since the regulations prohibit V_1 from exceeding V_R, some tri-jets frequently have V_1=VR, and a small margin may therefore exist in the accelerate-stop distance. Two-engine airplanes may occasionally be limited by this $V_1=V_R$ criterion also.

The possible combinations of airport pressure altitude, temperature, wind, runway slope, clearway and stopway are endless. Regardless of airplane type, they can easily combine to make any one of the three previously discussed takeoff field length limits apply. Flight crews have no convenient method to determine which of the three criteria is limiting for a particular takeoff, and from a practical point of view, it really doesn't matter. The slight differences that may exist are rarely significant. Most RTO overrun accidents have occurred on runways where the airplane was not at a limit takeoff weight. That is, the accidents occurred on runways that were longer than required for the actual takeoff weight. Combining this historical evidence with the demanding nature of the high speed rejected takeoff, it would seem prudent that the crew should always assume the takeoff is limited by the accelerate-stop criteria when the takeoff weight is Field Length Limited.

Actual Weight Less Than Limit Weight

Returning to the operational takeoff calculation, the second step is to then compare the actual airplane weight to the Field Length Limit Weight. There are only two possible outcomes of this check.

1) The actual airplane weight could equal or exceed the Field Length Limit Weight, or

2) The actual airplane weight is less than the Field Length Limit Weight.

The first case is relatively straightforward, the airplane weight cannot be greater than the limit weight and must be reduced. The result is a takeoff at a Field Length Limit Weight as we have just discussed. The second case, which is typical of most jet transport operations, is worthy of further consideration.

By far, the most likely takeoff scenario for the line pilot is the case where the actual airplane weight is less than any limit weight, especially the Field Length Limit Weight. It also is possibly the most easily misunderstood area of takeoff performance since the fact that the airplane is not at a limit weight is about all the flight crew can determine from the data usually available on the flight deck. Currently, few operators provide any information that will let the crew determine how much excess runway is available; what it means in terms of the V_1 speed they are using; or how to best maximize the potential safety margins represented by the excess runway.

Factors that Affect Takeoff and RTO Performance

Both the continued and the rejected takeoff performance are directly affected by atmospheric conditions, airplane configuration, runway characteristics, engine thrust available, and by human performance factors. The following sections review the effects of these variables on airplane performance. The purpose is not to make this a complete treatise on airplane performance, rather, it is to emphasize that changes in these variables can have a significant impact on a successful Go/No Go decision. In many instances, the flight crew has a degree of direct control over these changes.

Runway Surface Condition

The condition of the runway surface can have a significant effect on takeoff performance, since it can affect both the acceleration and deceleration capability of the airplane. The actual surface condition can vary from perfectly dry to a damp, wet, heavy rain, snow, or slush covered runway in a very short time. The entire length of the runway may not have the same stopping potential due to a variety of factors. Obviously, a 10,000 foot runway with the first 7,000 feet bare and dry, but the last 3,000 feet a sheet of ice, does not present a very good situation for a high speed RTO. On the other hand, there are also specially constructed runways with a grooved or Porous Friction Coat (PFC) surface which can offer improved braking under adverse conditions. The crews cannot control the weather like they can the airplane's configuration or thrust. Therefore, to maximize both the "Go" and "Stop" margins, they must rely on judiciously applying their company's wet or contaminated runway policies as well as their own understanding of how the performance of their airplane maybe affected by a particular runway surface condi tion.

The certification testing is performed on a smooth, ungrooved, dry runway. Therefore, any contamination which reduces the available friction between the tire and the runway surface will increase the required stopping distance for an RTO. Runway contaminants such as slush or standing water can also affect the continued takeoff performance due to "displacement and impingement drag" associated with the spray from the tires striking the airplane. Some manufacturers provide advisory data for adjustment of takeoff weight and/or V_1 when the runway is wet or contaminated. Many operators use this data to provide flight crews with a method of determining the limit weights for slippery runways.

Factors that make a runway slippery and how they affect the stopping maneuver are discussed in the following sections.

Hydroplaning

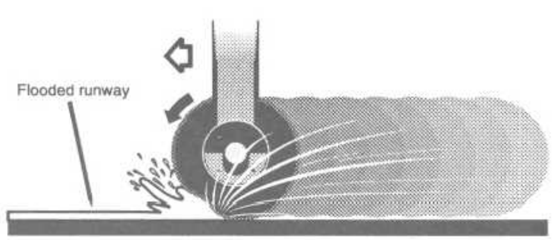
Hydroplaning is an interesting subject since most pilots have either heard of or experienced instances of extremely poor braking action on wet runways during landing. The phenomenon is highly sensitive to speed which makes it an especially important consideration for RTO situations.

As a tire rolls on a wet runway, its forward motion tends to displace water from the tread contact area. While this isn't any problem at low speeds, at high speeds this displacement action can generate water pressures sufficient to lift and separate part of the tire contact area from the runway surface. The resulting tireto-ground friction can be very low at high speeds but fortunately improves as speed decreases.

Dynamic hydroplaning is the term used to describe the reduction of tire tread contact area due to induced water pressure. At high speeds on runways with significant water, the forward motion of the wheel generates a wedge of high pressure water at the leading edge of the contact area, as shown in Figure 16A. Depending on the speed, depth of water, and certain tire parameters, the portion of the tire tread that can maintain contact with the run-way varies significantly. As the tread contact area is reduced, the available braking friction is also reduced. This is the predominant factor leading to reduced friction on runways that have either slush, standing water or significant water depth due to heavy rain activity. In the extreme case, total dynamic hydroplaning can occur where the tire to runway contact area vanishes, the tire lifts off the runway and rides on the wedge of water like a water-ski. Since the conditions required to initiate and sustain total dynamic hydroplaning are unusual, it is rarely encountered. When it does occur, such as during an extremely heavy rainstorm, it virtually eliminates any tire braking or cornering capability, at high speeds.

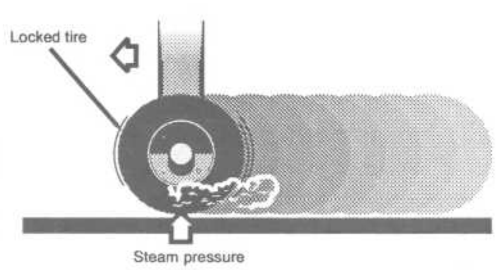
Another form of hydroplaning can occur where there is some tread contact with the runway surface but the wheel is either locked or rotating slowly (compared to the actual airplane speed). The friction produced by the skidding tire causes the tread material to become extremely hot. As indicated in Figure 16B, the resulting heat generates steam in the contact area which tends to provide additional upward pressure on the tire. The hot steam also starts reversing the vulcanizing process used in manufacturing the rubber tread material. The affected surface tread rubber becomes irregular in appearance, somewhat gummy in nature, and usually has a light gray color. This "reverted"
rubber hydroplaning results in very low friction levels, approximately equal to icy runway friction when the temperature is near the melting point. An occurrence of reverted rubber hydroplaning is rare and usually results from some kind of antiskid system or brake malfunction which prevented the wheel from rotating at the proper speed.

In the last several years, many runways throughout the world have been grooved, thereby greatly improving the potential wet runway friction capability. As a result, the number of hydroplaning incidents has de-creased considerably. Flight tests of one manufacturer's airplane on a well maintained grooved runway, which was thoroughly drenched with water, showed that the stop-ping forces were approximately 90% of the



Dynamic Hydroplaning

Figure 16A



Reverted Rubber Hydroplaning

Figure 16B

forces that could be developed on a dry runway. Continued efforts to groove additional runways or the use of other equivalent treatments such as porous friction overlays, will significantly enhance the overall safety of takeoff operations.

The important thing to remember about wet or contaminated runway conditions is that for smooth runway surfaces there is a pronounced effect of forward ground speed on friction capability — aggravated by the depth of water. For properly maintained grooved or specially treated surfaces, the friction capability is markedly improved.

The Final Stop

A review of overrun accidents indicates that, in many cases, the stopping capability available was not used to the maximum during the initial and mid-portions of the stop maneuver, because there appeared to be "plenty of runway available". In some cases, less than full reverse thrust was used and the brakes were released for a period of time, letting the airplane roll on the portion of the runway that would have produced good braking action. When the airplane moved onto the final portion of the runway, the crew discovered that the presence of moisture on the top of rubber deposits in the touchdown and turnoff areas resulted in very poor braking capability, and the airplane could not be stopped on the runway. When an RTO is initiated on wet or slippery runways, it is especially important to use full stopping capability until the airplane is completely stopped.

Atmospheric Conditions

In general, the lift the wings generate and thrust the engines produce are directly related to the airplane's speed through the air and the density of that air. The flight crew should anticipate that the airplane's takeoff performance will be affected by wind speed and direction as well as the atmospheric conditions which determine air density. Properly accounting for last minute changes in these factors is crucial to a successful Go/No Go decision.

The effect of the wind speed and direction on takeoff distance is very straightforward. At any given airspeed, a 10 knot headwind component lowers the ground speed by 10 knots. Since V_l, rotation, and liftoff speeds are at lower ground speeds, the required takeoff distance is reduced. The opposite occurs if the wind has a 10 knot tailwind component, producing a 10 knot increase in the ground speed. The required runway length is increased, especially the distance required to stop the airplane from V_1. Typical takeoff data supplied to the flight crew by their operations department will either provide takeoff weight adjustments to be applied to a zero wind limit weight or separate columns of limit weights for specific values of wind component. In either case, it is the responsibility of the flight crew to verify that last minute changes in the tower reported winds are included in their takeoff planning.

The effect of air density on takeoff performance is also straightforward in so far as the crew is normally provided the latest meteorological information prior to takeoff. However, it is the responsibility of the crew to verify the correct pressure altitude and temperature values used in determining the final takeoff limit weight and thrust setting.

Airplane Configuration

The planned configuration of the airplane at the time of takeoff must be taken into consideration by the flight crew during their takeoff planning. This should include the usual things **like** flap selection, and engine bleed configuration, as well as the unusual things like in-operative equipment covered by the Minimum Equipment List (MEL) or missing items as covered by the Configuration Deviation List (CDL). This section will discuss the effect of the airplane's configuration on takeoff performance capability and/ or the procedures the flight crew would use to complete or reject the takeoff.

Flaps

The airplane's takeoff field length performance is affected by flap setting in a fairly obvious way. For a given runway length and airplane weight, the takeoff speeds are reduced by selecting a greater flap setting. This is because the lift required for flight is produced at a lower V_2 speed with the greater flap deflection. Since the airplane will reach the associated lower V_1 speed earlier in the takeoff roll, there will be more runway remaining for a possible stop maneuver. On the "Go" side of the decision, increasing the takeoff flap deflection will increase the airplane drag, and the resulting lower climb performance may limit the allowable takeoff weight. However, the take-off analysis used by the flight crew will advise them if climb or obstacle clearance is a limiting factor with a greater flap setting.

Engine Bleed Air

Whenever bleed air is extracted from an engine and the value of the thrust setting parameter is appropriately reduced, the amount of thrust the engine generates is reduced. Therefore, the use of engine bleed air for air conditioning / pressurization reduces the airplane's potential takeoff performance for a given set of runway length, temperature and altitude conditions.

When required, using engine and/or wing anti-ice further decreases the performance on some airplane models. This "lost" thrust may be recoverable via increased takeoff EPR or N_1 limits as indicated in the airplane operating manual. It depends on engine type, airplane model, and the specific atmospheric condi**tions.**

Missing or Inoperative Equipment

Inoperative or missing equipment can some-times affect the airplane's acceleration or deceleration capability. Items which are allowed to be missing per the certified Configuration Deviation List (CDL), such as access panels and aerodynamic seals, can cause airplane drag to increase. The resulting decrements to the takeoff limit weights are, when appropriate, published in the CDL . With these decrements applied, the airplane's takeoff performance will be within the required distances and climb rates.

Inoperative equipment or deactivated systems, as permitted under the Minimum Equipment List (MEL) can also affect the airplane's dispatched "Go" or "Stop" performance. For instance, on some airplane models, an inoperative in-flight wheel braking system may require the landing gear to be left extended during a large portion of the climbout to allow the wheels to stop rotating. The "Go" performance calculations for dispatch must be made in accordance with certified " Landing Gear Down" Flight Manual data. The resulting new limit takeoff weight may be much less than the original limit in order to meet obstacle clearance requirements, and there would be some excess runway available for a rejected takeoff.

An MEL item that would not affect the "Go" performance margins but would definitely degrade the "Stop" margins is an inoperative anti-skid system. In this instance, not only is the limit weight reduced by the amount determined from the AFM data, but the flight crew may also be required to use a different rejected takeoff procedure in which the throttles are retarded first, the speedbrakes deployed second, and then the brakes are applied in a judicious manner to avoid locking the wheels and failing the tires.[3] The associated decrement in the Field Length Limit Weight is usually substantial.

Other MEL items such as a deactivated brake may impact both the continued takeoff and RTO performance through degraded braking capability and loss of in-flight braking of the spinning tire.

The flight crew should bear in mind that the performance of the airplane with these types of CDL or MEL items in the airplane's maintenance log at dispatch will be within the certified limits. However, it would be prudent for the flight crew to accept final responsibility to assure that the items are accounted for in the dispatch process, and to insure that they, as a crew, are prepared to properly execute any revised procedures.

[3] U.K. CAA procedure adds "...apply maximum reverse thrust."

Wheels, Tires, and Brakes

The airplane's wheels, tires, and brakes are another area that should be considered in light of the significant part they play in determining the results of a Go/No Go decision.

One design feature which involves all three components is the wheel fuse plug. All jet transport wheels used for braking incorporate thermal fuse plugs. The function of the fuse plug is to prevent tire or wheel bursts by melting if the heat transferred to the wheels from the brakes becomes excessive. Melting temperatures of fuse plugs are selected so that with excessive brake heat, the inflation gas (usually nitrogen) is released before the struc tural integrity of the tire or wheel is seriously impaired. Both certification limitations and operational recommendations to avoid melting fuse plugs are provided to operators by the manufacturer, as is discussed under the heading, Residual Brake Energy.

While fuse plugs provide protection from excessive brake heat, it is also important to recognize that fuse plugs cannot protect against all types of heat induced tire failures. The location of the fuse plug in the wheel is selected to ensure proper response to brake heat. This location in combination with the inherent low thermal conductivity of tire rubber means that the fuse plugs cannot prevent tire failures from the rapid internal heat buildup associated with taxiing on an underinflated tire. This type of heat buildup can cause a breakdown of the rubber compound, ply separation, and/ or rupture of the plies. This damage might not cause immediate tire failure and because it is internal, it may not be obvious by visual inspection. However, the weakened tire is more prone to failure on a subsequent flight. Long taxi distances especially at high speeds and heavy takeoff weights can aggravate this problem and result in a blown tire. While underinflation is a maintenance issue, flight crews can at least minimize the possibility of tire failures due to overheating by using low taxi speeds and minimizing taxi braking whenever possible.

Correct tire inflation and fuse plug protection are significant, but will never prevent all tire failures. Foreign objects in parking areas, taxiways and runways can cause severe cuts in tires. The abrasion associated with sustained locked or skidding wheels, which can be caused by various antiskid or brake problems can grind through the tire cords until the tire is severely weakened or a blow-out occurs. Occasionally, wheel cracks develop which deflate a tire and generate an overloaded condition in the adjacent tire on the same axle. Some of these problems are inevitable. How-ever, it cannot be overstressed that proper maintenance and thorough walk around in-spections are key factors in preventing tire failures during the takeoff roll.

Tire failures may be difficult to identify from the flight deck and the related Go/No Go decision is therefore, not a simple task. A tire burst may be loud enough to be confused with an engine compressor stall, may just be a loud noise, or may not be heard. A tire failure may not be felt at all, may cause the airplane to pull to one side, or can cause the entire airplane to shake and shudder to the extent that instruments may become difficult to read. Vibration arising out of failure of a nosewheel tire potentially presents another complication. During takeoff rotation, vibration may actually in-crease at nosewheel liftoff due to the loss of the dampening effect of having the wheel in contact with the runway. A pilot must be cautious not to inappropriately conclude, under such cir-cumstances, that another problem exists.

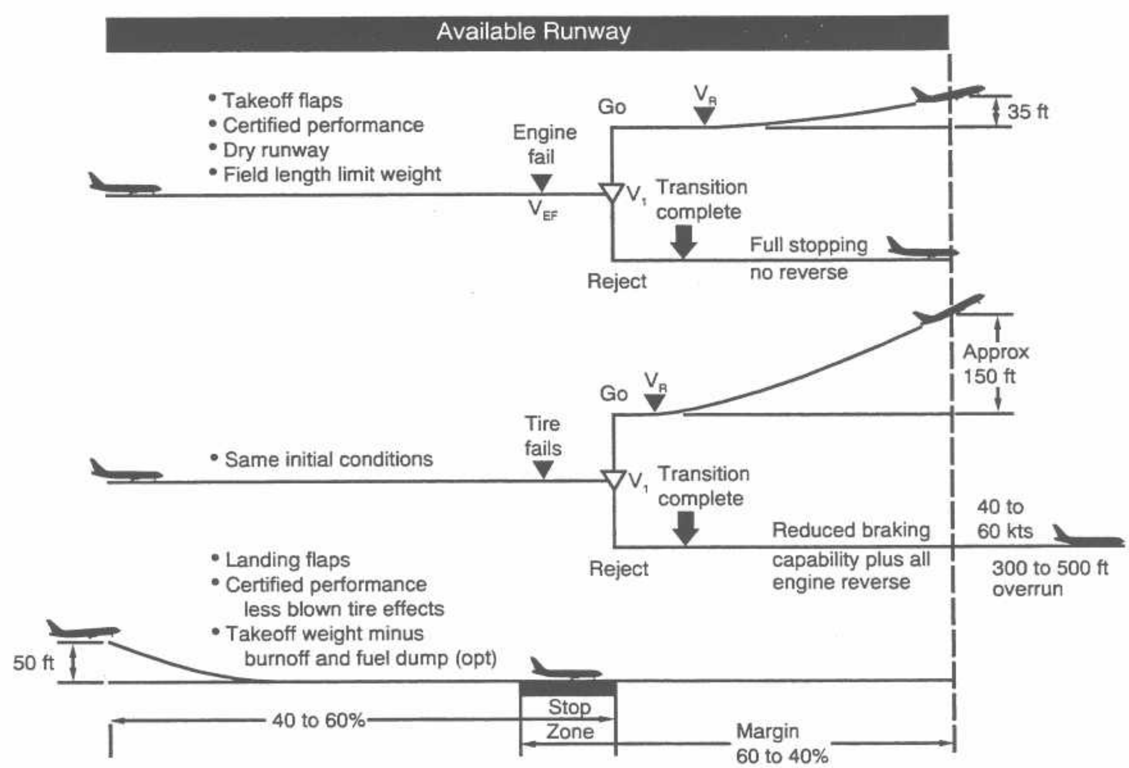
Although continuing a takeoff with a failed tire will generally have no significant adverse results, there maybe additional complications as a result of a tire failure. Failed tires do not in themselves usually create directional control problems. Degradation of control can occur, however, as a result of heavy pieces of tire material being thrown at very high velocities and causing damage to the exposed structure of the airplane and / or the loss of hydraulic systems. On airplanes with aft mounted engines, the possibility of pieces of the failed tire being thrown into an engine must also be considered.

An airplane's climb gradient and obstacle clearance performance with all engines operating and the landing gear down exceeds the minimum certified engine-out levels that are used to determine the takeoff performance limits. Therefore, leaving the gear down after a suspected tire failure will not jeopardize the aircraft if all engines are operating. However, if the perceived tire failure is accompanied by an indication of thrust loss, or if an engine problem should develop later in the takeoff sequence, the airplane's climb gradient and/ or obstacle clearance capability may be significantly reduced if the landing gear is not retracted. The decision to retract the gear with a suspected tire problem should be in accordance with the airline' s/manufacturer's recommendations.

If a tire failure is suspected at fairly low speeds, it should be treated the same as any other rejectable failure and the takeoff should be rejected promptly. When rejecting the takeoff with a blown tire, the crew should anticipate that additional tires may fail during the stop attempt and that directional control may be difficult. They should also be prepared for the possible loss of hydraulic systems which may cause speedbrake or thrust reverser problems. Since the stopping capability of the airplane may be significantly compromised, the crew should not relax from a maximum effort RTO until the airplane is stopped on the pavement.

Rejecting a takeoff from high speeds with a failed tire is a much riskier proposition, espedaily if the weight is near the Field Limit Weight. The chances of an overrun are in-creased simply due to the loss of braking force from one wheel. If additional tires should fail during the stop attempt, the available braking force is even further reduced. In this case, it is generally better to continue the takeoff, as can be seen in Figure 17. The subsequent landing may take advantage of a lower weight and speed if it is possible to dump fuel. Also, the crew will be better prepared for possible vibration and/or control problems. Most important, however, is the fact that the entire runway will be available for the stop maneuver instead of perhaps, as little as 40% of it. As can be seen from this discussion, it is not a straightforward issue to define when a takeoff should be continued or rejected after a suspected tire failure. It is fairly obvious however, that an RTO initiated at high speed with a suspected tire failure is not a preferred situation. McDonnell Douglas Corporation, in a recent All Operator Lette r[4], has addressed this dilemma by recommending a policy of not rejecting a takeoff for a suspected tire failure at speeds above V_1-20 knots. The operators of other model aircraft should contact the manufacturer for specific recommendations regarding tire failures.

Figure 17 Margins associated with continuing or rejecting a takeoff with a tire failure



[4] McDonnell Douglas All Operators Letter FO-AOL-8-003,-9-006,-10-004,41-015, **Reiteration of niques Regarding Wheels Tires and Brakes,** Dated 19 AUG 1991

Worn Brakes

The investigation of one recent RTO incident which was initiated "very near V_1", revealed that the overrun was the result of 8 of the 10 wheel brakes failing during the RTO. The failed brakes were later identified to have been at advanced states of wear which, while within accepted limits, did not have the capacity for a high energy RTO.

This was the first and only known accident in the history of commercial jet transport operation that can be traced to failure of the brakes during an attempted RTO. The National Transportation Safety Board (NTSB) investigated the accident and made several recommendations to the FAA. The recommendations included the need to require airplane and brake manufacturers to verify by test and analysis that their brakes, when worn to the recommended limits, meet the certification requirements. Prior to 1991, maximum brake energy limits had been derived from tests done with new brakes installed.

Virtually all brakes in use today have wear indicator pins to show the degree of wear and when the brake must be removed from the airplane. In most cases, as the brake wears, the pin moves closer to a reference point, so that when the end of the pin is flush with the reference (with full pressure applied), the brake is "worn out". As of late 1991, tests have been completed which show that brakes at the allowable wear limit can meet AFM brake energy levels. As a result, "wear pin length" is not significant to the flight crew unless the pin indicates that the brake is worn out and should be removed from service. There are no changes to flight crew or dispatch procedures based on brake wear pin length.

Residual Brake Energy

After a brake application, the energy which the brake has absorbed is released as heat and until this heat is dissipated, the amount of additional energy which the brake can absorb without failure is reduced. Therefore, takeoff planning must consider the effects of residual brake energy (or brake temperature) if the previous landing involved significant braking and/or the airplane turnaround is relatively short. There are two primary sources of infor mation on this subject. The brake temperature limitations and/or cooling charts in the air-plane operating manual provide recommended information on temperature limitations and/or cooling times and the procedures necessary to dissipate various amounts of brake energy. In addition, the Maximum Quick Turnaround Weight (MQTW) chart in the AFM is a regulatory requirement that must be followed. This chart shows the gross weight at landing where the energy absorbed by the brakes during the landing could be high enough to cause the wheel fuse plugs to melt and establishes a minimum waiting/cooling time for these cases. The MQTW chart assumes that the previous landing was conducted with maximum braking for the entire stop and did not use reverse thrust, so for many landings where only light braking was used there is substantial conservatism built into the wait requirement.

Speedbrake Effect on Wheel Braking

While jet transport pilots generally understand the aerodynamic drag benefit of speedbrakes and the capability of wheel brakes to stop an airplane, the effect of speedbrakes on wheel brake effectiveness during an RTO is not always appreciated. The reason speedbrakes are so critical is their pronounced effect on wing lift. Depending on flap setting, the net wing lift can be reduced, eliminated or reversed to a down load by raising the speedbrakes, thereby increasing the vertical load on the wheels which in turn can greatly increase braking capability.

Speedbrakes are important since for most braking situations, especially any operation on slippery runways, the torque output of the brake, and therefore the amount of wheel brake retarding force that can be developed is highly dependent on the vertical wheel load. As a result, speedbrakes must be deployed early in the stop to maximize the braking capability. During RTO certification flight tests, the stopping performance is obtained with prompt deployment of the speedbrakes. **Failure to raise the speedbrakes during an RTO or raising them late will significantly increase the stopping distance beyond the value shown in the AFM.**

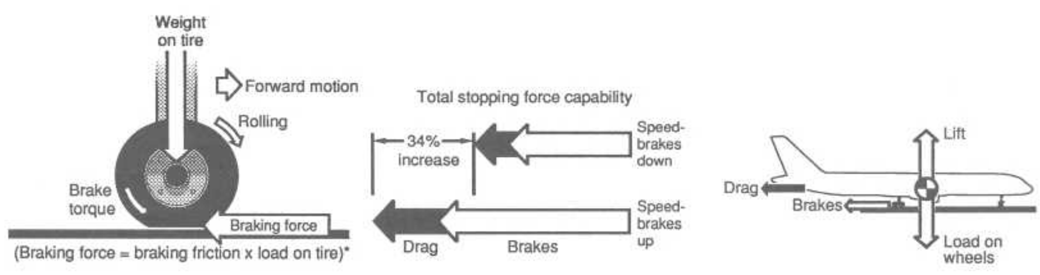
Figures 18 and 19 summarize the effect of speedbrakes during an RTO. For a typical mid-sized two-engine transport, at a takeoff weight of 225,000 lbs, the total load on the main wheels at brake release would be approximately 193,000 lbs. As the airplane accelerates along the runway, wing lift will de-crease the load on the gear, and by the time the airplane approaches V_1 speed, (137 knots for this example), the main gear load will have decreased by nearly 63,000 lbs. The data in Figure 19 graphically depicts how the forces acting on the airplane vary with airspeed from a few knots before the RTO is initiated until the airplane is stopped. When the pilot begins the RTO by applying the brakes and closing the thrust levers, the braking force rises quickly to a value in excess of 70,000 lbs. The nearly vertical line made by the braking force curve in Figure 19 also shows that the airplane began to decelerate almost immediately, with virtu-ally no further increase in speed.

The next action in a typical RTO procedure is to deploy the speedbrakes. By the time this action is completed, and the wheel brakes have become fully effective, the airplane will have slowed several knots. In this example of an RTO initiated at 137 knots, the airspeed would be about 124 knots at this point. The weight on the main gear at 124 knots would be approximately 141,600 lbs with the speedbrakes down, and would increase by 53,200 lbs when the speedbrakes are raised. The high speed braking capability is substantially improved by this 38% increase in wheel load from 141,600 to 194,800 pounds, which can be seen by noting the increase in braking force to 98,000 pounds. In addition, the speedbrakes have an effect on aerodynamic drag, increasing it by 73%, from 8,500 to 14,700 pounds. The combined result, as indicated by the table in Figure 18, is that during the critical, high speed portion of the RTO, the total stop-ping force acting on the airplane is increased by 34% when the speedbrakes are deployed.

Since both the force the brakes can produce and the aerodynamic effect of the speedbrakes vary with speed, the total effect for the RTO stop is more properly indicated by averaging the effect of the speedbrakes over the entire stopping distance. For this example, the over-all effect of raising the speedbrakes is an in-crease of 14% in the average total stopping force acting throughout the RTO.

One common misconception among pilots is that the quick use of thrust reversers will offset any delay or even the complete lack of speedbrake deployment during an RTO. This is simply not true. On a dry runway, delaying the deployment of the speedbrakes by only 5 seconds during the RTO will add over 300 ft. to the stop distance of a typical mid-sized two-engine jet transport, including the effects of engine-out reverse thrust. As a worst case illustration, if reverse thrust was not used and the speedbrakes were not deployed at all, the stopping distance would be increased by more than 700 ft. Although the exact figures of this example will vary with different flap settings and from one airplane model to another, the general effect will be the same, namely that speedbrakes have a very pronounced effect on stopping performance.

Figure 18
Effect of speedbrakes on the stopping capability of a typical mid-size two-engine transport



* Brake torque not limiting

	Speedbrake position		Difference speedbrake up
	Down	Up	
Drag	8,500 lbs	14,700 lbs	+73%
Lift	52,000 lbs	-1,200	-102%
Net load on wheels	141,600	194,800	+38%
Max. braking force	75,900	98,000	+29%
Max. stopping force (brakes & drag)	84,400	112,700	+34%

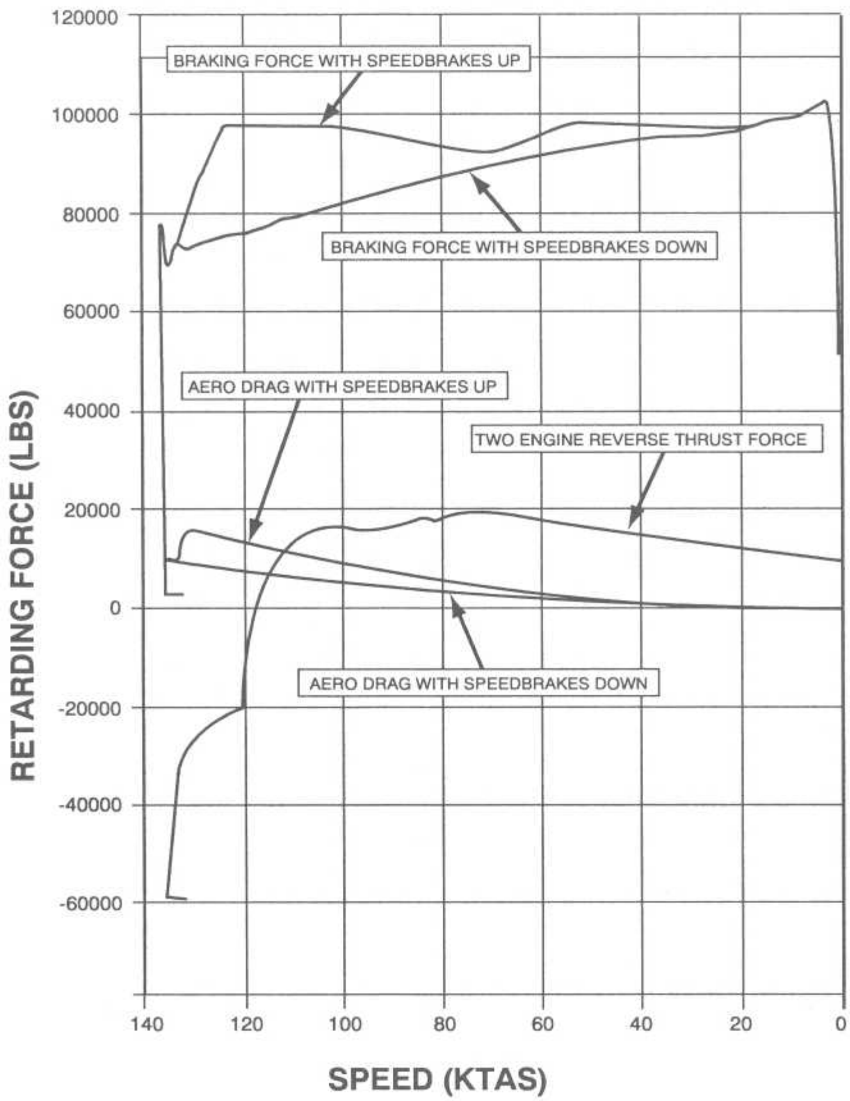


Figure 19
Summary of forces during a typical mid-size two-engine airplane RTO

Carbon and Steel Brakes Differences

Recent emphasis on the apparent tendency for carbon brakes to wear out in proportion to the total number of brake applications, as opposed to steel brakes which wear out in proportion to energy absorbed by the brakes, has generated interest in other operational differences between the two types of brakes. While the emphasis on wear difference is necessary, since the economics of brake maintenance is so significant, for most other operational aspects the two brakes can be considered equivalent.

As far as RTO capability is concerned, the type of brake involved does not matter since each brake installation is certified to its particular takeoff energy capability. This means that either carbon or steel brakes, even fully worn, will be able to perform the maximum certified RTO condition applicable to that installation in a satisfactory manner,

One difference between steel and carbon brakes that is often claimed is an increased tolerance to thermal overload. To understand this in proper perspective, recognize that although the friction elements in a carbon brake (rotating and stationary disks) are made of carbon material, which has good strength and friction characteristics at high temperatures, the brake structure, brake hydraulics, the wheel, and the tire are essentially the same as used for an equivalent steel brake. Within the limitations represented by this non-carbon equipment then, an overheated carbon brake will continue to function reasonably well in situations where an equivalent steel brake with its metal lic disks might not. An overload condition could be caused by excessive taxi braking, riding the brakes, or inappropriate turnaround procedures after landing. In this type of situation, carbon brakes will generally demonstrate better friction characteristics and there -fore develop more torque and stopping force than equivalent steel brakes.

The difficulty with this carbon brake thermal advantage is that it is nearly impossible to judge the extra amount of braking that could be done before affecting the ability of the non -carbon components to perform in an RTO situation. This is because the thermal effects on the limiting hardware are so highly time and ambient condition dependent. For instance, whether an airplane has carbon brakes or steel brakes will not matter if enough time has elapsed after a heavy brake application such that the wheel fuse plugs release before the airplane can complete the next takeoff or a subsequent RTO attempt. Pilots should concentrate on proper braking procedures rather than attempt to capitalize on any extra carbon brake advantage. Attention to the brake cool ing chart recommendations will avoid these thermal problems and ensure that the airplane stopping performance can be achieved regardless of whether steel or carbon brakes are installed.

The increased thermal overload capability of carbon brakes is closely related to the idea that carbon brakes do not "fade". In other words, they always produce the same torque throughout the stop even as the brake temperature increases. Although many carbon brakes do develop nearly constant torque, some fade considerably in certain conditions. On the other hand, some steel brakes do not fade very much at all, depending to a large extent on the degree of conservatism built into the brake. In either case, brake fade is taken into account in the AFM performance, for the spe cific brake installed on each particular airplane. Therefore, brake fade does not need to be an operational concern to the flight crew.

A second factor with steel brakes is the potential loss of structural strength of the rotors and stators at the extreme operating temperatures associated with limiting energy values. This could cause a structural failure of one or more brake stators near the end of the stop. In this case the brake will continue to function but with reduced torque capability. The remaining components, which are common to carbon and steel brakes, are less likely to be affected.

An RTO from at or near the brake energy limits can also mean that after stopping on the runway, the brakes may not be capable of stopping the airplane again, even from low taxi speeds. This is especially true for steel brakes due to the increased chance of structural failure. Therefore, it is important that the crew consider the probable condition of the airplane wheels, brakes, and tires after completing a high speed RTO before attempting to move the airplane from the runway.

One other difference between carbon and steel brakes that might be evident in certain RTO's is brake welding. Steel brakes, which usually have rotors of steel and stators of a copper-iron mix (with a number of special ingredients) can weld together, preventing further wheel rotation. This can even happen before the airplane comes to a full stop, particularly in the last several knots where the antiskid system is not effective.

High Brake Energy RTO's

Brake rotor and stator temperatures associated with RTO's which involve brake energies at or near certified maximum values, reach approximately 2000 °F for steel brakes, and 2500 °F for most carbon brakes. These high temperatures may, in some situations, ignite certain items in the wheel, tire, and brake assembly. While considerable design effort is made to preclude fires whenever possible, the regulations recognize the rarity of such high energy situations and allow brake fires after a maximum energy condition, provided that any fires that may occur are confined to the wheels, tires and brakes, and which would not result in progressive engulfment of the remaining airplane during the time of passenger and crew evacuation. It is important then, for flight crews to understand the nature of possible fires and the airplane takeoff parameters that could involve these very high brake energies.

There are two primary combustibles in the assembly, namely the tire, and brake grease. Brake hydraulic fluid will also burn if there is a hydraulic leak directed at a very hot brake disk. Tire fires can occur if the rubber compound temperature exceeds approximately 650 °F. Tire fires usually burn fairly slowly for the first several minutes when started by brake heat. Grease fires are even less active, typically involving a small, unsteady, flickering flame, sometimes with considerable smoke. The probability of a crew experiencing a brake fire at the conclusion of an RTO is very low, considering brake design factors, the dispatch parameters, and service history.

In terms of practical guidelines for flight crews, takeoffs at or near VMBE, are normally encountered at high altitude airports or at very hot temperatures. An RTO from close to VI speed under these conditions, will require the brakes to absorb a significant amount of energy during the stop. Flight crews can use the Brake Cooling Chart of the airplane operating manual to determine brake energy values if the situation warrants such a review. In cases where an extremely high brake energy might be encountered, the possibility of a brake fire should therefore be considered by the flight crew during the pre-takeoff briefing. If a high speed RTO is subsequently performed the tower should immediately be advised that the airplane is still on the runway, that a high brake energy stop was made, and that emergency equipment is requested to observe the tires and brakes for possible fires.

Reverse Thrust Effects

Most of the takeoffs planned in the world do not include reverse thrust credit. This is because the rejected takeoff certification testing under FAA rules does not include the use of reverse thrust. An additional stopping margin is produced by using maximum reverse thrust. We stress the word "maximum" in relation to the use of reverse thrust because of another commonly held misconception. Some pilots are of the opinion that idle reverse is "equally or even more" effective than full or maximum reverse thrust for today's high bypass ratio engines. This is simply not true. The more EPR or N1 that is applied in reverse, the more stopping force the reverse thrust generates. The data shown in Figure 20 is typical for all high bypass engines.

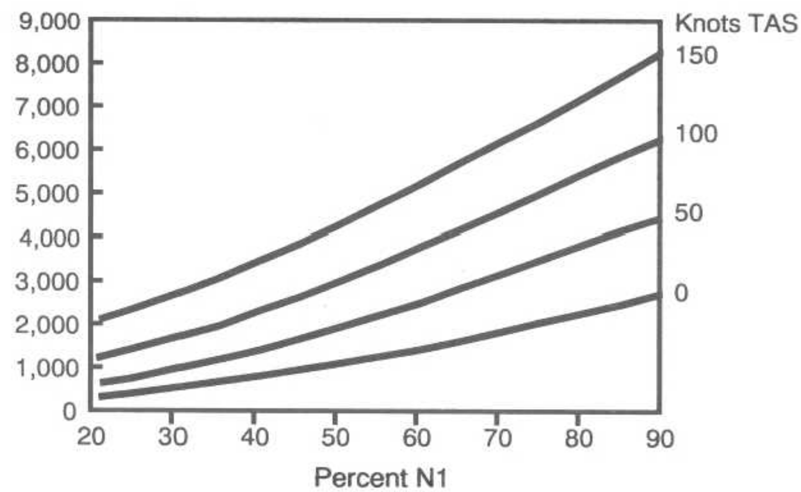
On wet or slippery runways, the wheel brakes are not capable of generating as high a retard ing force as they are on a dry surface. Therefore, the retarding force of the reversers generates a larger percentage of the total airplane deceleration.

Runway Parameters

Runway characteristics which affect takeoff performance include length, slope, clearway and/ or stopway. The effect of runway length is straightforward, however, slope, clearway, and stopway deserve some discussion.

A single value of runway slope is typically chosen by the operator to perform takeoff analysis calculations. This single value is usu-

Figure 20
Effect of engine RPM and airspeed on reverse thrust of a typical high bypass engine



ally taken from information published by the navigation chart services or the airport authorities. On closer inspection however, many runways are seen to have distinct differences in slope along the length of the run-way. The single published value may have been determined by a variety of methods, ranging from a simple mathematical average of the threshold elevations, to some weighted average methods proposed by ICAO in an advisory publication[5].

As a simple example, consider a runway which has only one slope discontinuity. The first two-thirds of the runway has an uphill slope of +2% and the last third has a downhill slope of -2%. The equivalent single slope for this runway, as determined from the ICAO Circular methods, could vary from +1.3% to -0.3%. When the takeoff analysis is made for this runway, the limit weights will be the same as would be determined for an actual single slope runway. However, as the airplane commences a takeoff on the 2% upslope runway, it will accelerate more slowly than it would on any of the equivalent single slope runways, which will result in its achieving V1 speed further along the runway than was planned. If no event occurs which would precipitate an RTO, the final acceleration to VR and liftoff will be higher than planned and the overall performance will probably come out close to what was scheduled.

On the other hand, if an event worthy of an RTO should occur just prior to the airplane reaching V1, most, if not all of the stop maneuver will have to be carried out on a 2% downhill slope surface instead of the equivalent single slope value, and the RTO will have been initiated with less runway remaining than was assumed in determining the limit weight for that takeoff. There is little the crew can do in this type of situation, other than in the vein of situational awareness, emphasize in their briefing that an RTO near V_1 for any-thing other than a catastrophic event is not advisable.

A clearway is an area at least 500 feet wide centered about the extended centerline of the runway with a slope equal to or less than 1.25%. This area is called the clearway plane. No obstructions, except threshold lights, can protrude above this clearway plane. The acceleration to V_2 and 35 feet is completed over the clearway, the use of clearway to in-crease takeoff weight " unbalances the run-way" and results in a lower V1 speed. The maximum clearway used to calculate takeoff performance is restricted by the regulations to one-half the demonstrated distance from lift-off to 35 ft.

A stopway is an area at least as wide as the runway and centered about the extended centerline. It must be capable of supporting the weight of the airplane without causing damage. Use of stopway also "unbalances the runway" resulting in a higher takeoff weight and increased V1 speed. An RTO initiated at this V1 will come to a stop on the stopway. For the sake of completeness, it should be pointed out that not all stopways will qualify as clearways, nor will a clearway necessarily qualify as a stopway. The specified criteria for each must be met independently before it can be used for takeoff performance calculations.

The use of clearway and/or stopway does not necessarily offer any additional margin for RTO stopping. In both cases, the takeoff performance is "unbalanced" by adjusting V_1 speed to plan that the stop will be completed by the end of the paved surface.

[5]ICAO Circular 91-AN/75, **The Effect of Variable Runway Slopes on Take-Off Runway Lengths for Transport Aeroplanes, 1968**

Takeoffs Using Reduced Thrust

There are two methods of performing a reduced thrust takeoff. The first is to use a fixed derate of the engine to a lower thrust rating. For example, a JT9D-7F engine operated at a JT9D-7 rating, or a CFM56-3C-1 engine oper ated at 20,000 lbs of thrust (-B1 rating) instead of the full 23,500 lb rating. When a fixed derate is used, the engine EGT and RPM limits are reduced and the crew are not to exceed the reduced limits in normal operation. As a result of the lower limit thrust with a fixed derate, the minimum control speeds V_{mcg} and V_{mca} are also reduced. Since the choice of derate thrust levels is usually restricted to one or two preselected values, it is rare that the takeoff performance at the derated thrust would be reduced to field length limit levels.

The second way of reducing takeoff thrust is to use the Assumed Temperature Method. The fundamental difference between fixed derates and the Assumed Temperature Method is that the operating limits of the engine are not reduced when using Assumed Temperature Method reduced thrust. The flight crew may increase the thrust to the full engine rating at any time during the takeoff if it is deemed appropriate. For instance, British CAA Flight Manuals include a recommendation to increase thrust on the operating engines to the full rating in the event that an engine fails during the takeoff. As a result, the V_{mcg} and V_{mca} speeds are not reduced below the full rating values when using the Assumed Temperature Method.

Fixed derates and the Assumed Temperature Method also differ in terms of the performance margins that are inherent to their use. As was previously mentioned, at limit weights, a takeoff performed using a fixed derate take -off thrust will conform to the minimum performance levels of the regulations, just as a limit weight takeoff would when using full rated takeoff thrust. The associated V_1 speed provides the standard certification "margins" of a 35 foot screen height or a stop at the end of the runway in the event of an engine failure.

When using the Assumed Temperature Method, additional "margins" are created in both the "Go" and "Stop" cases. As the name implies, the technique used to calculate the performance with the Assumed Temperature Method is to assume that the temperature is higher than it actually is, and to calculate takeoff thrust and speeds at the higher temperature.

The primary reason that the use of the Assumed Temperature Method results in performance margins is that the true airspeed of the airplane is lower than would be the case if the actual temperature were equal to the assumed temperature.

The Takeoff Data the Pilot Sees

The typical takeoff data table (sometimes referred to as runway analysis or gross weight tables) shows the limit takeoff weight for a specific runway over a range of ambient tem peratures. There may also be corrections for wind, pressure altitude, bleed configurations, and runway surface conditions. Each table usually shows the limit weights for only one flap setting. Some airlines show the takeoff speeds and the takeoff thrust EPR or N_1 setting along with the limit weights. The tables can display limit weights for Field Length, Climb, Obstacle Clearance, Tire Speed and Brake Energy, and tell which factor is limiting for each wind and temperature. This tabular display of the takeoff data has become the standard tool for using the assumed temperature method to reduce the takeoff power setting and thereby improve engine life.

This takeoff data is some of the most important data used on any flight. It is essential that flight crews know their actual takeoff weight and that they use the proper takeoff speeds. It is equally important that the flight crew be aware of their proximity to the limit weights for that takeoff's ambient conditions. These limit weights and speeds are more than just numbers. They represent the maximum certified takeoff performance of the airplane. If the actual takeoff weight is equal to or near the runway limit weight, the crew should note that fact and be extra alert that a reject from near or at V_1 will require prompt application of the full stopping capability of the airplane to assure stopping on the runway.

If the actual airplane weight is less than the limit weight, the crew should treat the normally obtained V_1 speed as a "limit speed" unless their operations department has provided them with a specific method of unbalancing the V_1 speed to utilize the excess runway available. The operator should assure that a suitable, non-ambiguous method of presenting the V_1 speed is chosen, whether it is a balanced or unbalanced speed.

Increasing the RTO Safety Margins

There are a number of choices and techniques the crew can make and practice that will increase the RTO margins for takeoff. Some involve airline policy and require the publication of additional data (such as multiple flap setting takeoff weight and speed data) and some are just good personal technique.

Runway Surface Condition

The crew cannot control the weather like they can the airplane's configuration or thrust. Therefore, to maximize both the "Go" and "Stop" margins, they must rely on judiciously applying their company's wet or contaminated runway policies as well as their own understanding of how the performance of their airplane may be affected by a particular runway surface condition.

Flap Selection

Figure 21
Typical Large Two-Engine Jet transport Takeoff Performance

8,700 FT RUNWAY SEA LEVEL 37° C	FLAP SETTING			
	1	5	15	20
Runway limit weight, lb (kg)	358,300 (162,494)	374,200 (169,705)	389,000 (176,417)	393,600 (178,503)
Climb/Obstacle limit weight, lb(kg)	414,100 (187,800)	407,300 (184,717)	393,600 (178,503)	383,000 (173,696)

Often the RTO safety margin can be increased by selection of an alternative takeoff flap setting. Consider for example, the effect of takeoff flap selection on the performance limit weights of a typical large two-engine airplane, as shown in Figure 21.

If a flight requires the absolute maximum takeoff weight, the above weight limits would dictate choosing Flaps 15 since 389,000 pounds is the highest weight allowed. Flaps 20 is Climb / Obstacle limited to a lower weight and Flaps 1 and 5 are Runway limited to lower weights. If the actual takeoff weight desired is equal to the maximum limit weight, there is no flap selection option. The takeoff will need to use Flaps 15.

More typical, however, the airplane's actual takeoff weight is well below the maximum. There are then two viable ways to improve RTO stopping distance margin: either by flap selection or by reduced V_1 techniques.

If the flight's actual takeoff weight was 374,200 pounds, investigating the above table indicates Flaps 5, Flaps 15, or Flaps 20 are all acceptable. Flaps 5 is runway limited so it offers no additional RTO margin. However, Flaps 15 and Flaps 20 both offer an opportunity for additional stopping distance margin. These additional stopping margins have been calculated for the above example and are shown in Figure 22.

Thus, if there are no other constraints such as obstacles or critical noise abatement procedures that would prevent the selection of a greater flap setting, the crew could give themselves 1000 feet of extra stopping distance in case an RTO was required on this takeoff.

Remember that there are some disadvantages to selecting a higher flap setting. These disad vantages include diminished climb performance and slightly more fuel consumed due to the higher drag configuration and the additional flap retraction cleanup time that will **be required.**

Figure 22
Effect of Flap selection on RTO stopping margins

FLAP SETTING	5	15	20
STOPPING MARGIN	ZERO	850 FT	1000 FT

Runway Lineup

Positioning the aircraft on the runway in preparation for takeoff is an important element in maximizing the amount of pavement available for a possible to RTO maneuver. Correction to the available runway length can be made to the takeoff analysis on those runways where it is not possible to position the airplane at the beginning of the published distance.

Correct runway lineup technique should always be practiced regardless of whether or not there is excess runway available. Even if an allowance has been made, it is up to the crew operating the flight to align the airplane on the runway using the shortest possible distance than taken into account by their company, then there is that much extra margin for the takeoff.

Setting Takeoff Thrust

At takeoff thrust settings, gas turbine (jet) engines operate at very high RPM. It typically takes several seconds for the engines to spool up from a low idle or taxi thrust to takeoff power after the thrust levers are advanced. During this time, the aircraft is not accelerating at full potential because the engines are not yet developing full power.

The demonstrated takeoff distance is achieved when the takeoff thrust is set prior to releasing the brakes, but this technique is often not practical in line operations due to expedited takeoff clearances, engine FOD hazards, and passenger comfort. As a result, most takeoffs are performed as "rolling takeoffs", with the thrust being set as the airplane begins the takeoff roll. However, this technique must be accomplished promptly to avoid compromising the takeoff performance. A delayed application of takeoff thrust will increase the time and distance to reach V_l speed, consequently, less runway will be left to stop the airplane should an RTO be necessary. The thrust should be set promptly, according to the airframe manufacturer's recommendations. The non-flying pilot or fight engineer then typically makes any final adjustments and monitors the engines for any abnormalities.

On airplanes equipped with autothrottles, an additional item to be aware of is that some autothrottle systems incorporate "Thrust Hold" features which will stop advancing the thrust levers after the airplane reaches a pre-determined threshold airspeed value. A delay in engaging the autothrottle can result in the thrust stabilizing below the takeoff target setting and the initial acceleration being less than required.

The engine instruments should be monitored closely for any abnormal indications. Past RTO accidents have occurred after an engine problem was identified early in the takeoff roll, but no action was initiated until the airplane had reached or exceeded V_1.

Company operations manuals or training manuals contain correct procedures for setting takeoff thrust. Observing these procedures assures efficient engine acceleration and, as a consequence, proper aircraft acceleration throughout the entire takeoff roll.

Manual Braking Techniques

Modulation of brake pressure or "pumping the brakes" was the way most people were taught to apply automobile brakes when braking conditions were less than favorable. This prevented sustained skids and therefore afforded both better braking and directional control. Both benefits occur because a skidding tire produces less frictional force than a tire which continues to rotate. Flight deck observation and simulator testing, however, both indicate that this technique has at times been carried over into the cockpit of jet transports. With the antiskid control systems in jet trans-port airplanes this technique is not only unnecessary, it results in degraded stopping capability and therefore excessive stopping distance especially for adverse runway conditions. **Proper braking technique in an RTO is to apply full brake pedal force ("stand on it") and maintain full brake pedal force until the airplane comes to a complete stop.**

The pilot's foot position relative to the rudder pedal can also have an effect on the achievement of full brake pressure. It was noted during a study conducted by the Training Aid Working Group[6] that foot position during the takeoff roll tends to be an individual preference. Some pilots prefer to have their feet "up on the pedals" to be ready to apply full brakes if required. Pilots who prefer this technique also noted that their toes are "curled back" to avoid unwanted brake applications when applying rudder. The other technique is to rest the heels on the floor during the takeoff roll, and then raise them to be on the pedal to apply full braking. No problems were noted with either technique.

One technique which did not work well was also noted. It is not possible to apply maximum brake pedal deflection, and hence full brake pressure, if the heel of the foot is left on the floor unless the pilot has very big feet. In an RTO stop maneuver, the feet should be up on the rudder pedals and steady, heavy pressure applied until the airplane is completely stopped. Pilots should develop a habit of adjusting their seat and the rudder pedals prior to leaving the gate. The ability to apply maximum brake pedal force as well as full rudder should be checked by both pilots.

The importance of maintaining maximum braking and full reverse thrust during an RTO until the airplane "rocks to a stop" cannot be over stressed. During a reject from V_1 the goal is safety, not passenger comfort. The amount of distance required to decelerate from a given speed at the high weights associated with takeoff is significantly greater than from the same speed at a typical landing weight. If the pilot tries to judge the amount of runway remaining against the current speed of the airplane, the visual perception that the airplane will stop on the runway ("we've got it made"), will prompt a decrease in the stopping effort. It is precisely at this point in the RTO that the difference between a successful Go/No Go decision and an accident can occur. The brakes may be nearing their energy absorption limits and the airplane may be entering a portion of the runway contaminated with rubber deposits, which can be very slick if wet. In several of the RTO accidents and incidents of the past, there was excess runway available to complete the stop, but the premature relaxation of the stopping effort contributed to an overrun.

An additional consideration in completing a successful RTO is that the crew should assess the condition of the airplane after it comes to a stop. If there is evidence of a fire or other significant hazard to the passengers, an evacuation on the runway is definitely preferable to "clearing the active." Every second counts in an actual emergency evacuation. In at least one RTO accident, many of the fatalities were caused by delaying the evacuation until the aircraft was clear of the runway.

[b]The Training Aid Working Group is the industry and regulatory team that developed the Takeoff Training Aid

Antiskid Inoperative Braking Techniques

Antiskid inoperative dispatches represent a special case for brake application techniques. In this situation the pilot executing the RTO should apply steady moderate pedal pressure consistent, in his judgement, with runway conditions, airplane dispatch weight and the available runway length. Full brake pressure should not be applied with the antiskid system inoperative due to the risk of tire failure. To minimize the possibility of skidding a tire, which can lead to a blowout, the speedbrakes should be deployed before brakes are applied. This provides the highest possible wheel loads to keep the wheels rotating with the forward motion of the airplane.

RTO Autobrakes

Autobrake system functions and crew actions to initiate these functions vary from one air-plane model to another. For example, some systems include automatic spoiler extension, others do not. Therefore, training in use of the system must be tailored to the particular system installed. The following discussion iIlustrates the general intent of autobrake systems.

Brake application is an immediate pilot action when initiating an RTO, and this application should be of maximum effort. An automatic brake application system called "RTO AUTOBRAKES" is being installed on more and more airplanes today to insure that this critical step is performed as rapidly as possible when an RTO is initiated. This system is designed to automatically apply maximum brake pressure if during the takeoff roll, all of the thrust levers are retarded to idle, and the aircraft speed is above a specified value (usually 85-90 knots). RTO Autobrakes, therefore, achieve the same airplane stopping performance as a proper, manual application of full foot pedal braking. No time delays are built in to the RTO autobrakes such as are used in some landing autobrake settings.

The use of "RTO AUTOBRAKES" eliminates any delay in brake application and assures that maximum effort braking is applied promptly. Possible application delays arising from distractions due to directional control requirements in crosswinds, or application of less than maximum brake force, are completely eliminated. The results of a simulator study conducted by the Training Aid Working Group also suggest that, on the average, those RTO's performed with RTO autobrakes ARMED re-sulted in more runway distance remaining after the stop than did the RTO's performed using manual braking only. This result is more significant because few pilots left the autobrakes engaged for more than a few seconds before overriding them and applying full manual braking. The difference in stop-ping performance is attributed to the first few seconds of high deceleration with the autobrakes at full pressure.

When the RTO autobrakes are ARMED for takeoff, the pilot not flying must monitor the system and advise the pilot flying if a DISARM condition occurs. The pilot flying should also monitor the deceleration of the airplane for acceptability and be prepared to apply manual braking if required or, the pilot performing the reject procedure should apply maximum manual braking during the RTO. In this latter case arming the RTO autobrake function only serves as a backup if for some reason manual braking is not applied.

The brake pedal forces required to disarm the autobrakes may vary significantly between the landing autobrake settings and the RTO autobrake setting of any given airplane, be-tween one airplane model and another of the same manufacturer, as well as between the various manufacturers' airplanes. It is not surprising that this point is not fully under-stood in the pilot community. It is important that pilots be made aware of how the details of any particular airplane's autobrake system might affect RTO performance and that they obtain the necessary information from their training department.

The V_1 Call

One important factor in avoiding RTO over-run accidents is for the crew to recognize reaching V_1 when the airplane does, in fact, reach V_l — not after. The airplane's stopping performance cannot match that specified in the Airplane Flight Manual if the assumptions used to derive that performance are violated - - knowingly or inadvertently. Operationally, careful attention to procedures and teamwork are required to match the human performance recognized by the AFM.

Basic operating procedures call for the pilot flying the airplane to include airspeed in his instrument scan during the takeoff ground roll. Hence he is always aware of the approximate speed. The pilot not flying monitors airspeed in more detail and calls-out "Vee-One" as a confirmation of reaching this critical point in the acceleration.

The pilot flying cannot react properly to V_1 unless the V_1 call is made in a timely, crisp, and audible manner. One method of accomplishing this by a major U.S. carrier is their adoption of a policy of " completing the V_1 callout by the time the airplane reaches V_1." This is an excellent example of the way airlines are implementing procedures to improve RTO safety. It is a good procedure and it should preclude a situation where the "No Go" decision is inadvertently made after V_1. However, the success of such a policy in reducing RTO's after V_1, without unduly compromising the continued takeoff safety margins, hinges on the line pilot's understanding of the specific airplane model's performance limitations and capabilities.

Another proposal for calling V_l is to use a call such as "Approaching V_1" with the V_l portion occurring as the airspeed reaches V_l. Either of these proposals accomplish the task of advising the flying pilot that the airplane is close to the speed where an RTO for all but the most serious failures is not recommended.

A frequently cited factor in RTO accidents that occurred when the First Officer was flying, is the lack of any airspeed calls by the Captain during the takeoff. This type of poor crew coordination may be overcome in future air-plane designs by the use of automated "V_1" and "Engine Failure" calls which will eliminate much of the variability experienced in today's operations. Even with an automated call system however, an "Approaching" call by the non-flying pilot would still seem to be an appropriate method of ensuring airspeed situational awareness for both pilots.

Crew Preparedness

Important crew factors directly related to eliminating RTO overrun accidents and incidents are:

- Brief those physical conditions which might affect an RTO that are unique to each specific takeoff.
- Both pilots must be sure to position the seat and rudder pedals so that maximum brake pressure can be applied.
- Both pilots should maintain situational awareness of the proximity to V1.
- Use standard callouts during the takeoff.
- Transition quickly to stopping configuration.
- Don't change your mind. If you have begun an RTO, stop. If you have reached V_1 go, unless the pilot has reason to conclude that the airplane is unsafe or unable to fly.
- Use maximum effort brake application.
- Assure deployment of speedbrakes.
- Use maximum reverse thrust allowable.

The accident records frequently show that slow or incomplete crew action was the cause of, or contributed to, an RTO overrun event. The crew must be prepared to make the Go/ No Go decision on every takeoff. If a "No Go" decision is made, the crew must quickly use all of the stopping capability available. Too often, the records show uncertainty in the decision process and a lack of completeness in the procedures. Be ready to decide and be ready to act.

Crew Resource Management

Crew Resource Management (CRM) is a term that can mean many things. In this context it is simply intended to encompass the factors associated with having the crew members work effectively together to make optimal Go /No Go decisions and effectively accomplish related procedures. It is recognized that the content of a CRM discussion on Go/No Go decisions must reflect the needs and culture of each individual operator. Therefore, the material contained in this section is provided only as an example of the type of CRM information which could be provided to the line pilot.

CRM and the RTO

Effective CRM can improve crew performance and in particular, decision making during takeoff. Often, Go/No Go decisions must be made " instantaneously" and as a result, the significance of CRM is not readily apparent. However, the fact that a critical decision must be made and implemented using rapidly changing, often incomplete information in a dynamic environment in which the time avail-able decreases as the criticality of the decision increases, is reason for effective CRM. Some aspects of CRM are especially important with respect to the Go/No Go decision.

The Takeoff Briefing

Crew members must know what is expected of them and from others. For optimum crew effectiveness, they should share a common perception - - a mental image - - of what is happening and what is planned. This common perception involves a number of CRM areas: communications, situational awareness, workload distribution, cross-checking and monitoring.

A variety of means are used to achieve this common perception. This begins with airline standard operating policies (SOP's) that clearly define captain and first officer as well as pilot flying and pilot not flying responsibilities and duties. Training reinforces the crew's knowledge and skill, while standardization insures acceptable, consistent performance, across all fleets and cultures within an airline.

A takeoff briefing is another means of improving the crew's awareness, knowledge, and team effectiveness; especially when special circumstances or conditions exist. The briefing is not necessarily a one-way process. In fact, asking for clarification or confirmation is an excellent way to insure mutual under-standing when required. A simple, "standard procedures" takeoff briefing might be improved by adding, "I'm not perfect, so back me up on the speedbrakes and my use of the RTO autobrakes" or, "if we're not sure of an engine failure 5 knots before V_l, we'll continue the takeoff and I'll state 'CONTINUE TAKEOFF'" . These briefings can improve team effectiveness and understanding of the Go/No Go decision planning and communications to be used. Such additions might be especially appropriate on the first segment of a flight with a relatively new first officer or a crew's first flight of the month.

A review of actions for a blown tire, high speed configuration warning, or transfer of control are examples of what might be appropriate for before takeoff (or before engine start) review. Such a briefing should address items that could affect this takeoff, such as runway contamination, hazardous terrain or special departure procedures. The briefing should not be a meaningless repetition of known facts, but rather a tool for improving team performance, that addresses the specific factors appropriate to that takeoff.

Callouts

Meaningful communication, however brief, regarding a non-normal situation during takeoff and RTO can often mean the difference between success and disaster. For this reason, communications must be precise, effective, and efficient. Standard callouts contribute to improved situational awareness. These callouts, coupled with all crewmembers being aware of airspeed, maximize the opportunity for a common understanding of what actions are proper in the event of a non-normal situation. The crewmember noting a problem should communicate clearly and precisely without inferring things that may not be true. For example, the loss of fuel flow indication alone does not necessarily mean an engine failure. Use of standard terms and phraseology to describe the situation is essential. The pilot tasked to make the RTO decision should clearly announce this decision, whether it be to continue or reject.

The Use of All Crew Members

It's important to understand that all crewmembers on the flight deck play an important role in the Go/No Go decision and RTO maneuver. Company policies shape these roles, however, how the team is organized for each takeoff can make a difference in team performance. Knowing your own capabilities and that of the other crewmembers is part of situational awareness and should be used in planning for a given takeoff. Although it's "the first officer's leg", it might not be an effective plan to task an inexperienced first officer with a marginal weather takeoff when weight is also limited by field length. Consider the possibility of an RTO when assigning takeoff duties.

Summary

Each airline approaches CRM in a slightly different manner, but the goal of effective teamwork remains the same. This material is an example of the type of CRM information that could be used to promote a common perception of RTO problems and actions.

UPDATE

ON REJECTED TAKEOFF SAFETY STATISTICS

In 1989 the U.S. Federal Aviation Administration (FAA) urged the aviation industry to take steps to reduce the number of overrun accidents and incidents resulting from high-speed rejected takeoffs (RTO). This led to the formation of an international takeoff safety task force, with members from airlines, regulatory agencies, pilot unions, and manufacturers. The task force produced nine recommendations, including the following three directly related to training:

- Develop model training practices.
- Develop model operational guidelines.
- Improve simulator fidelity.

When the task force concluded its study, Boeing led an industrywide effort to develop the *Takeoff Safety Training Aid* (TOSTA). The TOSTA was released in 1992 with the endorsement of the FAA. The TOSTA specifically addressed the task force's first two recommendations and indirectly caused an improvement to the third. Along with the TOSTA, FAA Advisory Circular 120-62 provides direction and guidelines for airlines to implement the lessons learned (as presented in the TOSTA) in their own training programs. Many airlines around the world did incorporate these lessons into their training programs, and the results show that we—the aviation

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industry—made a positive difference. The number of RTO overrun accidents and incidents that occurred in the 1990s was 22. This compares to 28 RTO overrun accidents and incidents during the 1980s, despite a nearly 50 percent increase in the number of takeoffs in the 1990s.

All of us in the industry should be proud of this important achievement in aviation safety. It resulted from the regulators, airlines, pilots, and manufacturers working together to define the root causes of RTO events, and from airlines and other training agencies incorporating important lessons learned into their training programs.

Appendix 4B of the TOSTA contains a list of the 74 RTO overrun accidents and incidents studied during development of the training aid. The additional 20 events reported since the TOSTA study are shown in table 1 (see p. 11). The total 94 events are all the RTO runway overrun accidents and incidents for the Western-built jet fleet associated with the length of the runway available for takeoff. The incidents are events that could have been accidents had the overrun area been more hostile.

Figure 3 in sections 2 and 4 of the TOSTA shows the occurrence of RTO overrun accidents and incidents by year. Figure 1 in this article shows RTO statistics updated through the end of the 20th century. Despite the relatively high number of RTO overrun events that occurred in both 1996 and 1997, the rate of RTO overruns in the 1990s was significantly less than in the previous decade.

Figure 5 in sections 2 and 4 of the TOSTA shows a chart describing seven categories of reasons for initiating an RTO in the 74 cases listed in appendix B. Figure 2 in this article incorporates the additional 20 RTO events that occurred from April 1990 through December 1999. It shows that the percentage of RTO accidents and incidents precipitated by perceived or real engine failures dropped slightly to 21 percent from 24 percent. The figure also shows an increase in the percentage of RTO events related to tire failures (real or perceived), lack of flight crew coordination, and indicator/light problems.

Figure 4 in sections 2 and 4 of the TOSTA shows a distribution of speeds at which the overrun RTOs were initiated and a breakout of the reported runway condition for the 74 cases in the study. Figure 3 in this article shows the breakout of RTO initiation speed for the total 94 RTO accidents and incidents reported through the end of the 20th century. The number of overrun events that began after V_1 remains at more than 50 percent. Figure 4 in this article shows the updated percentages for the runway condition. These numbers remain fairly constant, with 39 percent of RTO events occurring on dry runways and 32 percent of them occurring on wet or contaminated runways.

Unfortunately, RTO overrun accidents and incidents continue to occur. However, the rate of occurrence continues to drop. Table 2 shows the number of departures and RTO accidents and incidents by decade. Figure 5 in this article shows the rate of RTO overrun accidents and incidents expressed as events per 10 million takeoffs. Compared to the 1960s, the 1990s showed a 78 percent decrease in the rate of RTO overrun accidents and incidents.

The industry can attribute this major improvement in RTO safety to many factors, but especially to better airplane systems, better and more reliable engines and, in the 1990s, better training and standards, such as the Evergreen International Airlines example in the accompanying article. At Boeing, we will continue to improve our airplanes and work with our engine, tire, and brake suppliers to improve their products. We urge all airlines to continue their good efforts related to effective training in the areas of takeoff decisionmaking and RTO procedure execution.

TABLE 1 RTO OVERRUN ACCIDENTS/INCIDENTS SINCE RTO TAKEOFF SAFETY TRAINING AID STUDY

Event number	Date	Operator	A/P type	Location	A/I (1)	RTO initiation speed (2)	Cause (3)	R/W condition (4)
75	04/18/90	OKD	BAC111	Lagos	I	$>V_1$	Ind/lt	?
76	03/12/91	ATI	DC8	New York	A	$>V_1$	Config	?
77	04/15/92	USA	F28	Charlotte	I	$<V_1$	Crew	?
78	11/20/92	ARG	B737	San Luis	A	V_1-10	Crew	Dry
79	03/20/93	DLH	B747	Frankfurt	I	V_1+10	Bird	Dry
80	03/02/94	CAL	MD80	New York	A	V_1+5	Ind/lt	Ice/snow
81	09/24/95	SWS	A3xx	Tel Aviv	I	?	Ind/lt	?
82	10/19/95	CDI	DC10	Vancouver	A	$>V_1$	Engine	Dry
83	05/01/96	FLF	B727	Quito	A	$<V_1$	Crew	Wet
84	06/13/96	Ahmad Air	B707	Cairo	I	?	Crew	Dry
85	07/08/96	SWA	B737	Nashville	I	$>V_1$	Bird	Dry
86	08/02/96	ALG	B737	Tlemcen	A	?	Ind/lt	Dry
87	11/17/96	LAM	B737	Johannesburg	I	$>V_1$	Ind/lt	Dry
88	01/10/97	AFR	A300	Jeddah	A	$>V_1$	?	?
89	01/20/97	COP	B737	Panama City	I	$<V_1$	Tire	Dry
90	06/25/97	SUS	B727	Bogota	A	$<V_1$	Tire	Wet
91	07/20/97	SHY	MD80	Dalian	A	$<V_1$	Ind/lt	Wet
92	08/03/97	AFR	B737	Douala	A	$<V_1$	Tire	Wet
93	12/28/97	PIA	B747	Dubai	I	?	Engine	Dry
94	02/07/99	Avistar	B707	Bratislava	I	$>V_1$	Config	?

(1) A = accident, I = incident

(2) RTO initiation speed (the speed at which the first action was taken relative to V_1)

(3) Cause (why the RTO decision was made)

- Engine — Actual, temporary, or perceived loss of thrust
- Tires — Main or nosegear tire vibration or failure
- Configuration — Incorrect control or high lift surface setting for takeoff
- Indicators/lights — A reading observed on an indicator or a warning light illuminating
- Flight crew coordination — Miscellaneous events where inappropriate flight crew action resulted in the RTO decision
- Bird strike — Crew observed birds along runway and experienced or perceived a subsequent problem
- Air traffic control (ATC) — ATC or other radio messages caused flight crew to elect to reject takeoff

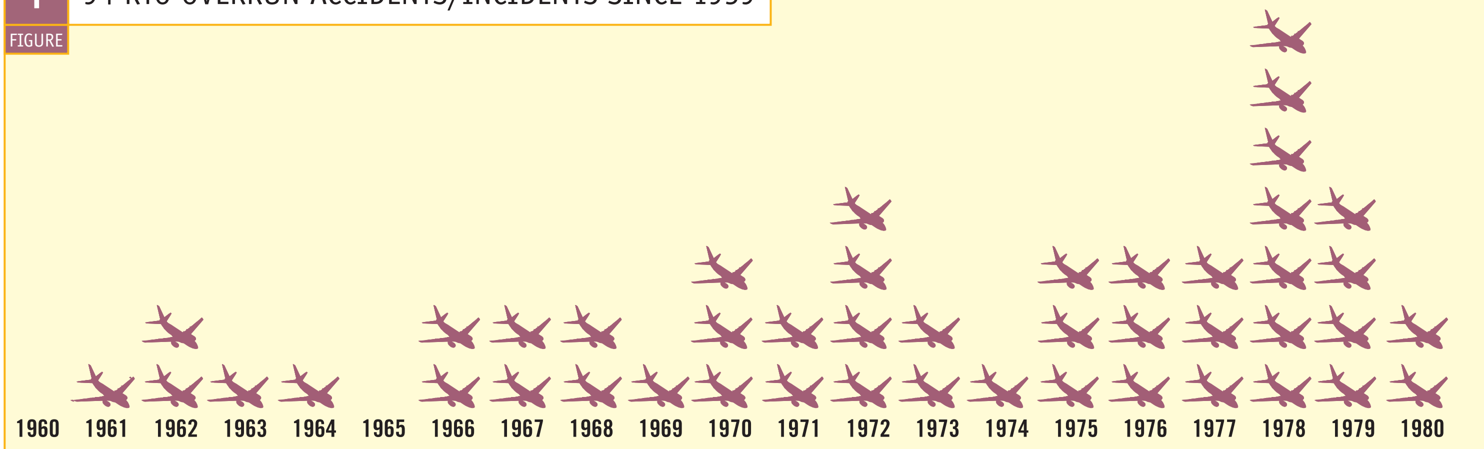
(4) R/W (runway) condition (reported condition of the runway surface at the time of the event)

TABLE 2 RTO OVERRUN ACCIDENTS/INCIDENTS PER 10 MILLION TAKEOFFS

Decade	Departures	RTO overrun accidents/incidents	Rate per 10 million takeoffs
1960 to 1969	19,045,363	12	6.3
1970 to 1979	75,984,954	32	4.2
1980 to 1989	108,963,013	28	2.6
1990 to 1999	161,957,587	22	1.4

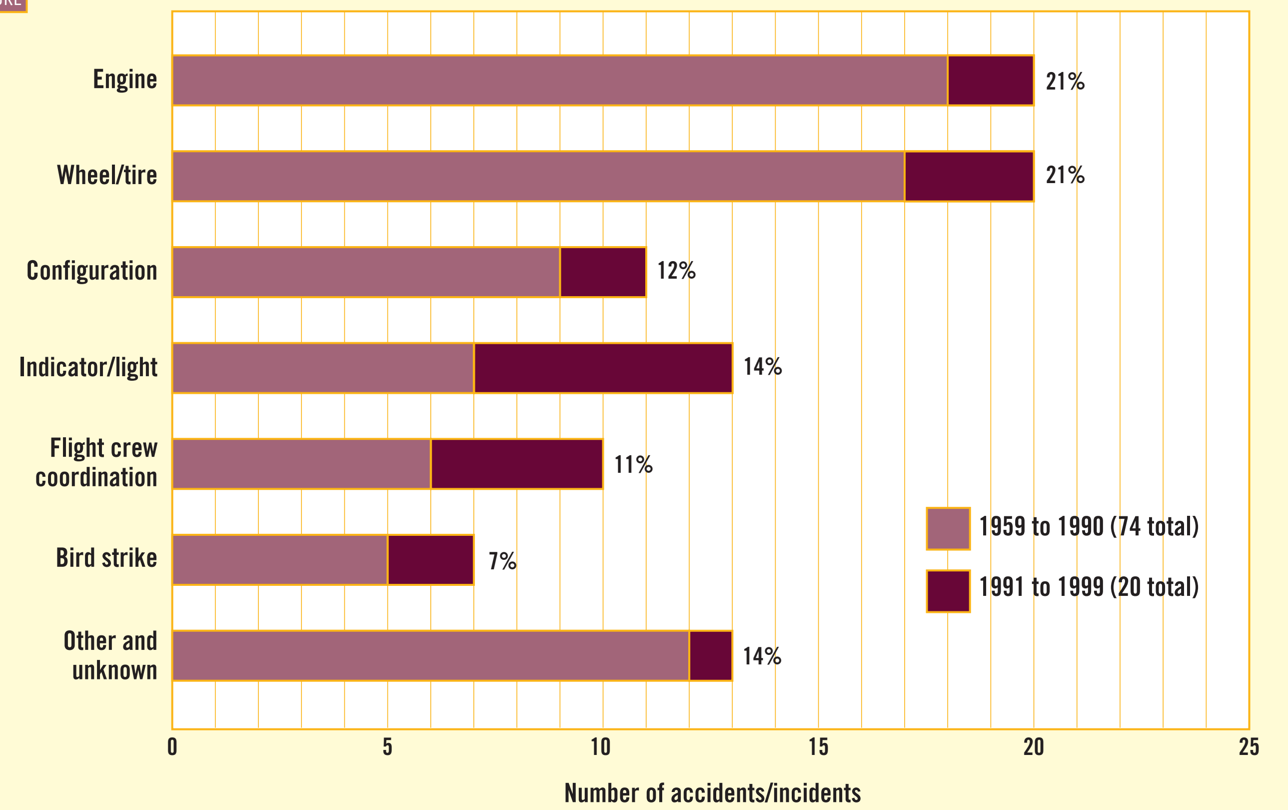
1 FIGURE

94 RTO OVERRUN ACCIDENTS/INCIDENTS SINCE 1959



2 FIGURE

REASONS FOR INITIATING RTO (94 ACCIDENTS/INCIDENTS)



Compared to the 1960s, the 1990s showed a 78 percent decrease in the rate of RTO overrun accidents and incidents.

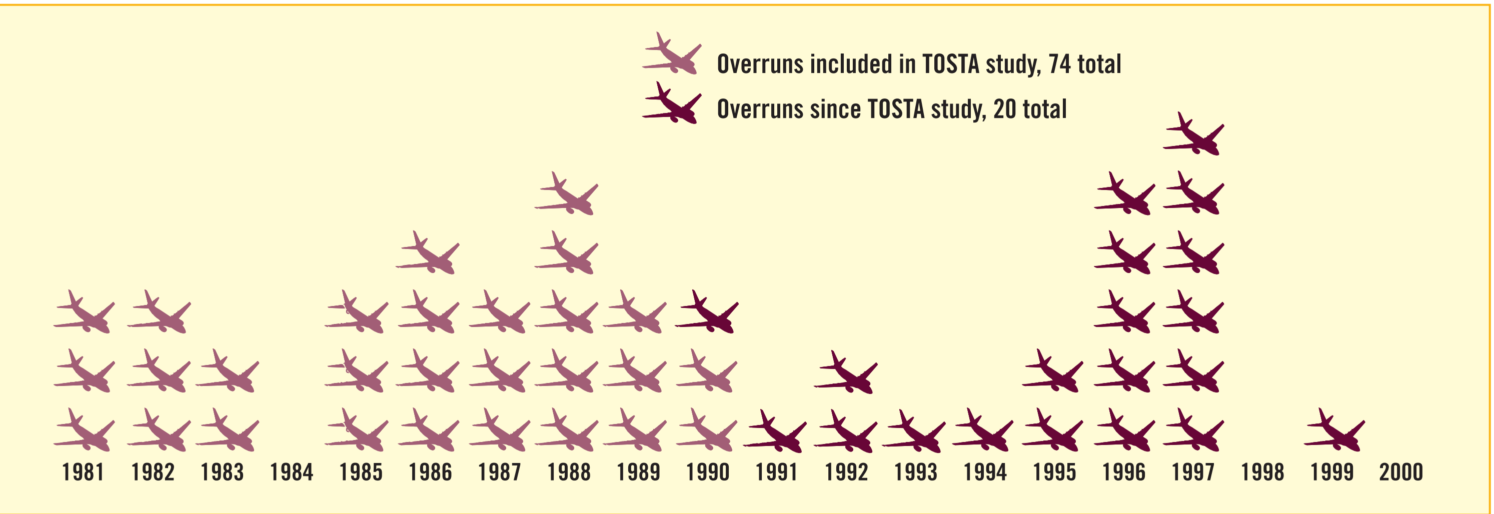
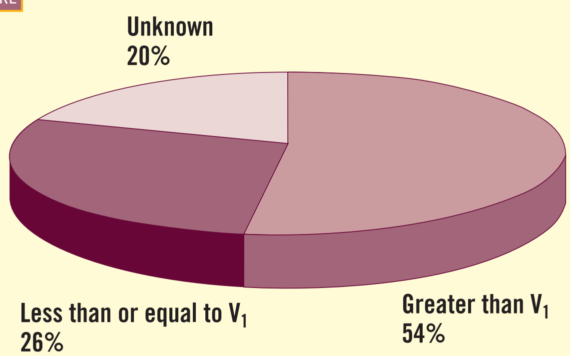
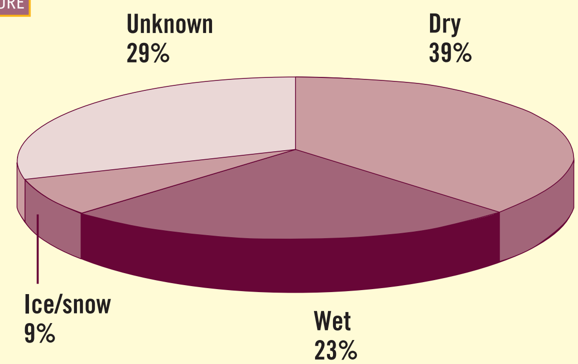


FIGURE 3 RTO INITIATION SPEED



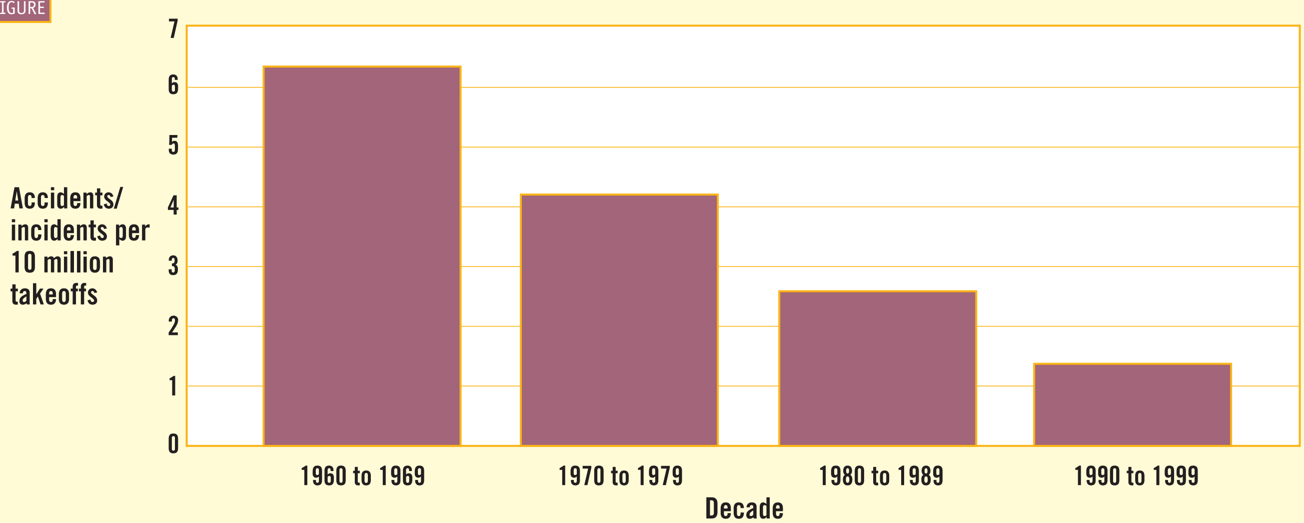
Based on 94 RTO overrun accidents/incidents, 1961 to 1999

FIGURE 4 RUNWAY CONDITION



Based on 94 RTO overrun accidents/incidents, 1961 to 1999

FIGURE 5 RATE OF RTO OVERRUN ACCIDENTS/INCIDENTS



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FLIGHT SAFETY FOUNDATION
Accident Prevention
Vol. 47 No. 9 For Everyone Concerned with the Safety of Flight September 1990

Facing the Runway Overrun Dilemma

If speeds and procedures are correct, an aircraft should be able to stop on the runway after a takeoff is abandoned. So what's the problem?

by
John A. Pope
Aviation Consultant

Whether the event is called a rejected takeoff (RTO) or an aborted takeoff, there has been growing concern about runway overruns following an abandoned takeoff, the meaning given to V_1, the "go/no go" decision and cockpit procedures for executing an aborted takeoff.

The U.S. National Transportation Safety Board (NTSB) has made a number of recommendations to the U.S. Federal Aviation Administration (FAA); Boeing Commerial Airplane Group has concluded a study on RTO runway overruns; and Delta Air Lines has published a standard policy regarding the takeoff and go/no go decision. Each sheds some light on the subject, but the most appropriate corrective action begs further analysis and discussion.

NTSB Special Investigation Report

It is NTSB's contention that although most RTOs are initiated at low speeds (below 100 knots) and are executed without incident, the potential for an accident or incident following a high-speed RTO remains high. In 1988, according to the NTSB, three RTO-related accidents, two overseas and one in the United States, resulted in injuries to passengers and crew members, substantial damage to a Boeing 757 and a Boeing 747, and in the destruction of a McDonnell Douglas DC-10.

NTSB conducted a 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.

The NTSB reported as follows: **Pilot Training in RTOs**

Some airlines may be conveying misinformation or insufficient information to their pilots during training in RTO procedures and in aircraft stopping capabilities. Some of the misinformation may arise from the FAA's definition of V_1 in CFR 1.2 and 14 CFR 25.107(2).

Simulator Cues

Pilot training and checking sessions almost always present RTOs as V_1, engine failure-related maneuvers despite the fact that RTO-related accident and incident data indicated that tire failures lead to more high-speed RTOs than do engine-related problems. As a result, pilots may not be fully prepared to recognize cues of other problems during takeoff.

False or Noncritical Warnings

False or noncritical cockpit warnings have activated as an airplane was approaching or had reached V_1 and led to a high-speed RTO that resulted in an accident or incident. In response to the number of false warnings, manufacturers have incorporated into newer airplanes internal system logic that inhibits all but the most important warnings just before and just after takeoff rotation. However, most airline aircraft operating in revenue service today, and those that will operate in the near future, do not have such systems. Without changes in pilot training, pilots of older model aircraft may continue to initiate high-speed RTOs in response to warnings that may be false, noncritical, or both.

Takeoff Scenarios

Some airlines may be using takeoff scenarios in which a simulator can be stopped with runway distance remaining, even though the pilot's execution of the RTO may not be optimal. As a result, pilots may inadvertently learn that an aircraft can stop on a runway in a shorter distance than is possible under actual operating conditions.

Crew Coordination in Performing RTOs

In many of the RTO-related accidents and incidents, the first officer was the pilot flying. This suggests that a delay may have occurred when control of the airplane was transferred from the first officer to the captain, the crew member authorized by most airlines to initiate an RTO.

Callouts

Most airlines require callouts for engine or thrust settings and callouts for V_1, V_r and V_2. However, the NTSB found variation among airlines in the callouts required during takeoffs, particularly during rejected takeoffs.

Autobrakes

Many airplanes in service today have been equipped with braking systems known as autobrakes, which automatically establish wheel braking upon landing or upon a predetermined throttle reduction once past a certain speed during takeoff. However, not all airlines require autobrakes to be set to the RTO mode during takeoff.

The NTSB made the following recommendations to the FAA:

1. Redefine V_1 to clearly convey that it is the take-off commitment speed and the maximum speed at which rejected takeoff action can be initiated to stop the airplane within the accelerate-stop distance.

2. Require principal operations inspectors (POIs) to review the accuracy of information on V_1 and rejected takeoffs that FAR Part 121 operators pro-vide 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.

3. Require Federal Aviation Regulation (FAR) Part 121 operators to represent to flight crews the conditions upon which flight manual stopping performance is predicated, and to include information about those factors which adversely affect stopping performance.

4. Require that simulator training for flight crews 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.

5. Require that simulator training 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.

6. Require that simulator training emphasize crew coordination during rejected takeoffs, particularly those instances that require transfer of control from the first officer to the captain.

7. Require FAR Part 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.

8. Require that the takeoff procedures of FAR Part 121 operators are standardized among their aircraft types to the extent possible, and that the procedures include appropriate callouts to alert flight crew members clearly and unambiguously when the airplane is entering the high-speed takeoff regime and when a rejected takeoff is being initiated.

9. Require FAR Part 121 operators to require pilots to adopt a policy to use the maximum brake capability of autobrake systems, when installed on the aircraft, for all takeoffs in which runway conditions warrant and where minimum stopping distances are available following rejected takeoff.

Boeing RTO Overrun Study

Boeing recently concluded a rejected takeoff overrun and runway excursion study spanning the 29-year period from 1959 through 1988 and found that more than 80 percent of the events could have been prevented through either procedural changes or improved crew training.

Of the 69 events in the study, 41 were accidents and 28 were incidents. Most occurred in the latter half of the study period, an average of three per year, but because of the markedly higher number of departures in the last 15 or so years, the rate is one-half that of the first 15 years.

Propulsion anomalies and wheel-tire problems caused almost 51 percent of all rejected takeoffs. Most rejected takeoffs were initiated at speeds above V_1, which was the greatest cause of overruns, followed by degraded stopping capability. The majority of events occurred on dry runways.

The April-June, 1984, issue of the *Boeing Airliner* has this to say: "Typically at V_1, the airplane rate of acceleration is about three to five knots per second with all engines operating. For every second that passes before a decision to stop or go is made, the speed of the airplane is increasing by approximately three to five knots and approximately 225 feet of run-way is used. If the problem that is necessitating a go/no go decision occurs on the low side but in the vicinity of V_1, the combination of high acceleration rate, the state of mind of the crew and the probability of a more complicated set of circumstances surrounding the decision than experienced in the simulator all tend to indicate that the airplane speed will be above V_I by the time the failure is recognized and any real stopping procedures have been implemented.

`By being predisposed to stopping, adequate thought may be given to the meaning of V_I or airplane performance characteristics. The FAA defines V_I as the speed at which an engine failure has been recognized and *action* initiated to either *continue* or *stop* the takeoff. It is simply the speed at which a pilot changes his pre-planned response. The time to begin the decision making process is not at, or near, V_1.

"If we realistically look at the airplane acceleration rate around V_I, the state of mind of the crew, the fact that maximum effort braking stopping is hardly ever practiced in normal operations and the fact that clearing slightly less than 35 feet at the end of the runway is not nearly as detrimental as running off the end of the runway, one might come to a conclusion that on a runway-limited takeoff, the go decision may be better than the stop decision."

Delta Air Lines

The February 1990, issue of Delta's flight safety publication *Up Front* is titled "Takeoff Performance Edition" and contains two articles pertinent to this discussion.

The first is "Go/No Go Decision - or How Do You Handle Rejection" written by Capt. Howard A. Long and John Tocher. Their article delves into the definition of V_I and its effect on line operations. The authors state: "V_1 had been defined, explained, redefined, and re-explained many times. The current FAR Part 1 definition is simple: 'V_1 means takeoff decision speed.'

"This definition implies, and pilots have usually assumed, that at V, they could choose between aborting or con tinuing the takeoff. In other words, V_I has been associated with the *beginning* of the decision making process. Most pilots when asked would estimate that the allowable decision time is about 2 or 3 seconds."

The article repeats the *Boeing Airliner* discussion of V_I and goes on to say:

"The meaning under this definition is that V_I is the 'Engine Failure Reaction Speed,' meaning that no time is allowed after V_I for reaction or decision. The critical point in the above quote is that the action must be initiated before V_1. Clearly, the decision to stop has to occur before V_1.

"To further cloud this issue, for many of us V_I has lost this direct relationship only to engine failure and frequently is misunderstood to be `Any Failure Decision Speed,' i.e., the speed that we can stop with any malfunction.

"Over the years, many of us have incorrectly become accustomed to thinking of V_I as the point in time when the abort decision needs to be made.

"Let us consider a new but absolute correct definition of V_1: "V, is the Critical Engine Failure *Recognition* Speed. If an engine failure is *recognized* before V1, an abort can be made within the remaining runway. If an engine failure is *recognized* at or after V_I, the takeoff can be continued within the remaining takeoff distance.

"The next question is what really constitutes engine failure recognition? FAA Advisory Circular 25-7 (the Flight Test Guide for Certification of Transport Category airplanes) clearly shows that the pilot's activation of the first deceleration device indicates recognition of the engine failure.

"A decision to stop must be completed and maximum braking initiated at or before V_I to assure a safe abort

"V_I is the end of the go/no go decision process, not the beginning. If you have not applied the brakes by the time you hear the V_I call, you have made the go decision by default."

when you are at or near runway length limiting conditions.

"V_1 is the *end* of the go/no go decision process, not the beginning. If you have not applied the brakes by the time you hear the V_1 call, you have made the go decision by default."

Factors which affect the go/no go decision, according to the Delta article, included the following:

1. Decision Time. In the certification demonstration, the test pilots didn't need time to make a decision - they knew that they were going to abort before they started their takeoff roll.

   The line pilot, on the other hand, must first recognize the unexpected condition when it happens, evaluate its significance, decide on a course of action, and then execute the decision. During this period of time, at the normal acceleration of 3 to 5 knots per second, the aircraft could easily accelerate well past V_1, particularly if the malfunction occurred near the V_1 speed.

2. Braking Force. Tests have shown that the typical pilot neither recognizes maximum braking nor applies maximum braking force when called for in line operations (although he might believe that he has).

   Furthermore, this same pilot is likely to apply braking in the same order he applies them during a normal landing - that is, apply the brakes only after retarding the throttles and extending the speed brakes, thus delaying the braking action.

   The proper sequence for a rejected takeoff at V_1 is clearly different from a normal landing. Braking provides the primary stopping forces, followed by spoilers and reverse thrust.

3. Line-up Allowance. Runway allowable weights are computed based on the full runway length, with no provision for line-up. In actual fact, an average of 200 feet is normally used to line-up on the runway. Therefore, that concrete is not available for stopping purposes in the event of an abort.

4. Runway Surface. Certification tests are normally conducted on clean and dry concrete surfaces. Very few of the runways in our normal line operations are perfectly clean concrete with no moisture, dirt, oil or rubber residue to affect deceleration. Wet or cluttered runways present additional problems outside the scope of this discussion, but the need to have brakes applied no later than V_1 does not change.

5. Brake and Tire Condition. During certification, stopping capability is based on all brakes and tires being intact, fully operational and capable of maximum energy stops.

   In our line operations, we make no adjustments for brake or tire wear or for residual heat buildup from previous landings or extended taxi time.

   If a high-speed rejected takeoff is made because of a blown tire, it is unlikely that the aircraft will stop on the runway at the Maximum Runway Allowable Weight. The lack of any braking forces from the blown tire reduces the stopping capability and adjacent tires may also blow during the abort, further degrading stopping capability.

6. Reverse Thrust. Reverse thrust is not utilized in aircraft certification and is therefore considered by some as a safety margin. However, the use of reverse thrust during a properly executed abort with maximum braking will have little effect on stopping distance. Use of reverse thrust from one engine may create directional problems. Braking has top priority and attempting to maintain directional control with differential braking will reduce total braking force, increasing the stopping distance.

The article suggests three major aspects to making the proper decision during a takeoff:

1. Possession of a good practical knowledge of aircraft performance.

2. Knowledge of how to perform a maximum effort abort, if critical circumstances demand it.

3. Use of training and experience to make good go/no go decisions.

Delta's Takeoff and Go/No Go Decision Policy

1. It is always the captain's responsibility to make the go/no go decision and that decision should be based on all available information with consideration given for gross weight, field length, field conditions and weather. A comprehensive takeoff plan should be formulated during the departure briefing. Prior to taking the runway, the captain should verify there are no changes to this plan.

2. The decision to continue or reject a takeoff rests solely with the captain. As the speed approaches V_1, a decision to stop is recommended only for an engine failure/fire or a malfunction where a safety of flight

condition exists. To reduce decision time, system malfunctions which do not affect flyability should be systematically disregarded by the captain as the speed approaches V_1.

3. On every takeoff, the captain shall be prepared to initiate maximum deceleration including maximum braking, throttles, spoilers and reverse thrust as required for that particular aircraft.

4. The captain's hand shall be on the top part of the throttles following initial power application until at least V_1. The pilot not flying shall make the V_l callout precisely at V_1.

5. The decision to reject the takeoff should be made before V_l and maximum braking should begin no later than V_1.

6. Nothing in this takeoff and go/no go decision policy should be interpreted as limiting the captain's emergency authority. These guidelines are based on the best available information and are designed to provide the maximum overall safety in our line operations.

Points to Consider

NTSB's recommendation to FAA to redefine V_1, 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, could put a halt to individual interpretations and give birth to universal understanding.

For instance, Boeing's interpretation that V_l "is defined by FAA rules as the speed at which an engine failure has been recognized and *action* initiated to either *continue* or *stop* the takeoff' apparently clouds the issue for Delta. Delta would present a "new but absolutely correct definition of V_l as the Critical Engine Failure Recognition Speed."

If other aviation experts were asked for their precise definitions, the wording would probably be different but the point taken would be very similar.

What is extremely important is the pilots' understanding of exactly what V_l means to them in their particular circumstance.

Time Allowed For Decision Making

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

Simulator training can be a great value, but the NTSB points out that pilot training and check sessions almost always present RTOs as V_1, engine failure-related maneuvers. This sort of training is similar to instrument approach training where the same approach to the same airport is always on the agenda.

To change the pattern and introduce variations, simulator training should include an assortment of anomalies (blown tires, runway excursions, etc.) to test the pilot's ability to think and act quickly in a variety of rejected takeoff situations.

Crew Coordination

NTSB points out that in many of the RTO-related accidents and incidents, the first officer was the pilot flying, and suggests that a delay may have occurred when control of the airplane was transferred from the first officer to the captain. The NTSB implies that most airlines have a policy where the captain is the only pilot authorized to initiate an abort or rejected takeoff.

Delta's policy is specific. "It is always the captain's responsibility to make the go/no go decision..." and, "The decision to continue or reject a takeoff rests solely with the captain."

Can issue be taken with a policy which permits only the captain to make the abort or rejected takeoff decision?

From an airline point of view, the reasons for a captain-only policy could be based a number of factors such as:

1. All first officers are not equal in flying experience, decision making capability or familiarity with the captain. Airline deregulation created new airlines and a subsequent turnover in pilots which, in some cases, has resulted in first officers with low time in aircraft type being paired with newly appointed captains. Captains might not wish to delegate the responsibility for declaring a rejected takeoff to a lower-time first officer.

2. The captain, by virtue of training, flight experience and time in the aircraft type is presumably the best qualified to think and react in an emergency situation. The first officer may overreact to engine instrument readings and be prone to declare an emergency when none exists.

3. There is a reluctance to usurp the captain's authority by allowing a junior officer to take command of the aircraft.

Yet, the NTSB makes the point that in many of the RTO-related accidents and incidents, the first officer was flying and there may have been a problem with transferring control of the airplane from one pilot to another. In this circumstance, it is important to bear in mind that only three to five seconds are available to make a decision. The NTSB recommends that FAR Part 121 operators review policies which permit first officers to perform takeoffs on contaminated runways and runways that provide minimal rejected takeoff stopping distance margins and encourages operators to revise those policies.

In the Future

The U.S. National Aeronautics and Space Administration (NASA) Langley Research Center has developed a system designed to help pilots make the go/no go takeoff decision by consolidating summarized data into a single, easily understood display. (See "To Go - Or Not to Go; Situation Awareness on Takeoff," October 1989 FSF *Flight Safety Digest.)*

The Takeoff Performance Monitoring System (TOPMS) provides continual real-time information updates during acceleration down the runway, presenting the aircraft's progress relative to a normal takeoff for that aircraft and existing flight conditions. The system indicates graphically the aircraft's position on the runway, the points at which lift off and other events should occur, whether the engines are functioning properly, and if acceleration is adequate.

Whether TOPMS is the answer to the runway overrun dilemma remains to be seen. In the meantime, pilots who recognize the problem and are prepared to take timely action on a rejected takeoff reduce the possibility of being involved in a runway overrun.

About the Author

John A. Pope established John A. Pope & Associates, an aviation consulting firm located in Arlington, VA, U.S., after retiring in 1984 as vice president of the U.S. National Business Aircraft Association. He specializes in developing comprehensive operation manuals for corporate flight departments.

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