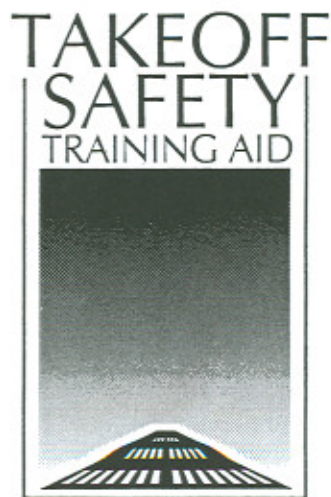


2

# Pilot Guide to Takeoff Safety



# Pilot Guide to Takeoff Safety

## *Table of Contents*

# 2

Section	Page
2.0 Introduction.....	2.1
2.1 Objectives.....	2.1
2.2 “Successful Versus Unsuccessful” Go/No Go Decisions.....	2.1
2.2.1 An In-service Perspective On Go/No Go Decisions.....	2.2
2.2.2 “Successful” Go/No Go Decisions .....	2.3
2.2.3 RTO Overrun Accidents and Incidents .....	2.4
2.2.4 Statistics .....	2.5
2.2.5 Lessons Learned .....	2.6
2.3 Decisions and Procedures— <i>What Every Pilot Should Know</i> .....	2.7
2.3.1 The Takeoff Rules— <i>The Source of the Data</i> .....	2.8
2.3.1.1 The “FAR” Takeoff Field Length.....	2.8
2.3.1.2 $V_1$ Speed Defined.....	2.10
2.3.1.3 Balanced Field Defined .....	2.11
2.3.1.4 (Not Used).....	2.12
2.3.2 Transition to the Stopping Configuration .....	2.12
2.3.2.1 Flight Test Transitions .....	2.12
2.3.2.2 Airplane Flight Manual Transition Times .....	2.12
2.3.3 Comparing the “Stop” and “Go” Margins .....	2.14
2.3.3.1 The “Stop” Margins.....	2.15
2.3.3.2 The “Go” Option .....	2.16
2.3.4 Operational Takeoff Calculations .....	2.18
2.3.4.1 The Field Length Limit Weight.....	2.18
2.3.4.2 Actual Weight Less Than Limit Weight .....	2.19
2.3.5 Factors that Affect Takeoff and RTO Performance.....	2.19
2.3.5.1 Runway Surface Condition .....	2.20
2.3.5.1.1 Hydroplaning.....	2.21
2.3.5.1.2 The Final Stop .....	2.22
2.3.5.2 Atmospheric Conditions.....	2.22
2.3.5.3 Airplane Configuration.....	2.23
2.3.5.3.1 Flaps.....	2.23
2.3.5.3.2 Engine Bleed Air .....	2.23
2.3.5.3.3 Missing or Inoperative Equipment .....	2.23

<b>Section</b>	<b>Page</b>
2.3.5.3.4	Wheels, Tires, and Brakes ..... 2.25
2.3.5.3.5	Worn Brakes ..... 2.27
2.3.5.3.6	Residual Brake Energy ..... 2.28
2.3.5.3.7	Speedbrake Effect on Wheel Braking..... 2.28
2.3.5.3.8	Carbon and Steel Brake Differences ..... 2.30
2.3.5.3.9	High Brake Energy RTOs ..... 2.31
2.3.5.4	Reverse Thrust Effects ..... 2.32
2.3.5.5	Runway Parameters ..... 2.33
2.3.5.6	(Not Used) ..... 2.34
2.3.5.7	Takeoffs Using Reduced Thrust ..... 2.34
2.3.5.8	The Takeoff Data the Pilot Sees ..... 2.34
2.3.6	Increasing the RTO Safety Margins..... 2.35
2.3.6.1	Runway Surface Condition ..... 2.35
2.3.6.2	Flap Selection..... 2.35
2.3.6.3	Runway Lineup ..... 2.36
2.3.6.4	Setting Takeoff Thrust..... 2.36
2.3.6.5	Manual Braking Techniques..... 2.37
2.3.6.6	Antiskid Inoperative Braking Techniques ..... 2.38
2.3.6.7	RTO Autobrakes ..... 2.38
2.3.6.8	(Not Used) ..... 2.39
2.3.6.9	The V <sub>1</sub> Call..... 2.39
2.3.6.10	Crew Preparedness ..... 2.40
2.4	Crew Resource Management ..... 2.40
2.4.1	CRM and the RTO ..... 2.40
2.4.2	The Takeoff Briefing..... 2.40
2.4.3	Callouts ..... 2.41
2.4.4	The Use of All Crew Members ..... 2.41
2.4.5	Summary..... 2.42

# Pilot Guide to Takeoff Safety

# 2

## 2.0 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 subsection numbering used in Sections 2 and 4 are identical to facilitate cross referencing. Those sub sections not used in Section 2 are noted “not used”.

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.

## 2.1 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.

## 2.2 “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 since the 1950s, and to recommend ways of avoiding similar experiences by the pilots of today’s airline fleet.

Takeoffs, RTOs, and Overruns

	Through 2003	Typical Recent Year
Takeoffs	430,000,000	18,000,000
RTOs (est.)	143,000	6,000
RTO Overrun Accidents/Incidents	97	4*

Figure 1  
Takeoffs, RTOs,  
and Overrun  
Statistics

- 1 RTO per 3,000 takeoffs
  - 1 RTO overrun accident/incident per 4,500,000 takeoffs
- \*Accidents/incidents that would occur if historical rates continue.

**2.2.1 An In-service Perspective On Go/No Go Decisions**

Modern jet transport services began in the early 1950s 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 has accumulated approximately 430 million takeoffs by the end of 2003. Recently there have been nearly 18 million takeoffs in a typical year. That's approximately 34 takeoffs every minute, every day!

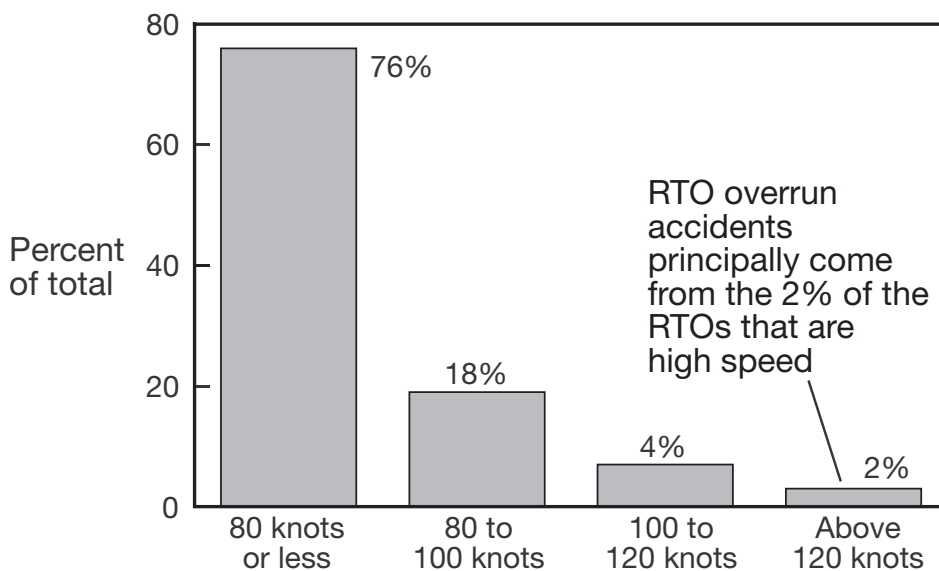
Since no comprehensive fleet-wide records are available, it is difficult to identify the total number of RTOs that have occurred throughout the jet era. However, based on those events which have been documented, our best estimate is that one in 3,000 takeoff attempts ends with an RTO. At this rate, there will be nearly 6000 RTOs during a typical year. That means that every day, 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.

Available data indicates that over 75% of all RTOs are initiated at speeds of 80 knots or less. These RTOs almost never result in an accident. Inherently, low speed RTOs are safer and less demanding than high speed RTOs. At the other extreme, about 2% of the RTOs 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, RTOs 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 many 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.***

Figure 2  
Distribution of  
RTO Initiation  
Speeds



### 2.2.2 “Successful” Go/No Go Decisions

As was mentioned at the beginning of Section 2.2, 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 RTOs were “successful”, but some situations came very close to ending differently. By contrast, the large number of takeoffs that are successfully 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 ensure 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.

**2.2.3 RTO Overrun Accidents and Incidents**

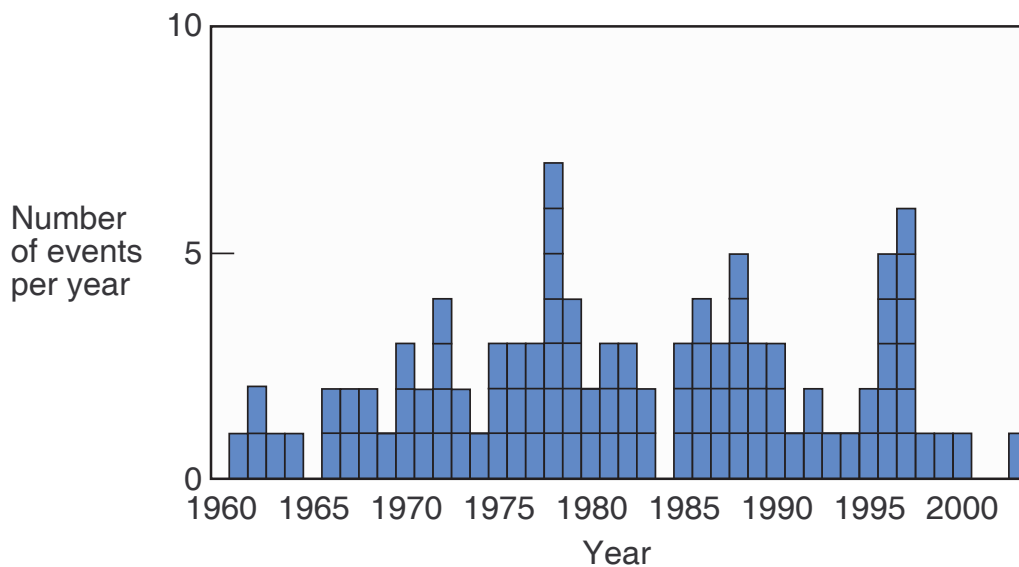
The one-in-one-thousand RTOs that became accidents or serious incidents are the ones that we must strive to prevent. As shown in Figure 3, at the end of 2003, records show 57 in-service RTO overrun accidents for the western built jet transport fleet. These 57 accidents caused more than 400 fatalities. An additional

40 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.

**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 7,000 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

*Figure 3*  
97 RTO overrun accidents/incidents 1959-2003





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 6,000 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 97 reported accidents and incidents.

## 2.2.4 Statistics

Studies of the previously mentioned 97 accidents/incidents have revealed some interesting statistics, as shown in Figure 4:

- Fifty-five 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” 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 in Section 2.3, 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 airplane incapable of being stopped on the runway remaining. It also

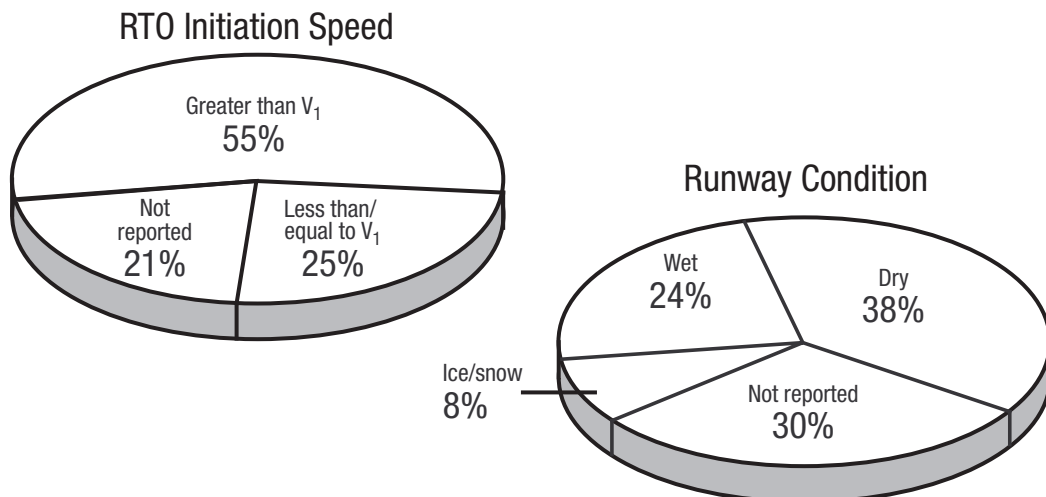


Figure 4  
Major factors  
in previous RTO  
incidents and  
accidents



must be recognized that catastrophic situations could occur which render the airplane incapable of flight.

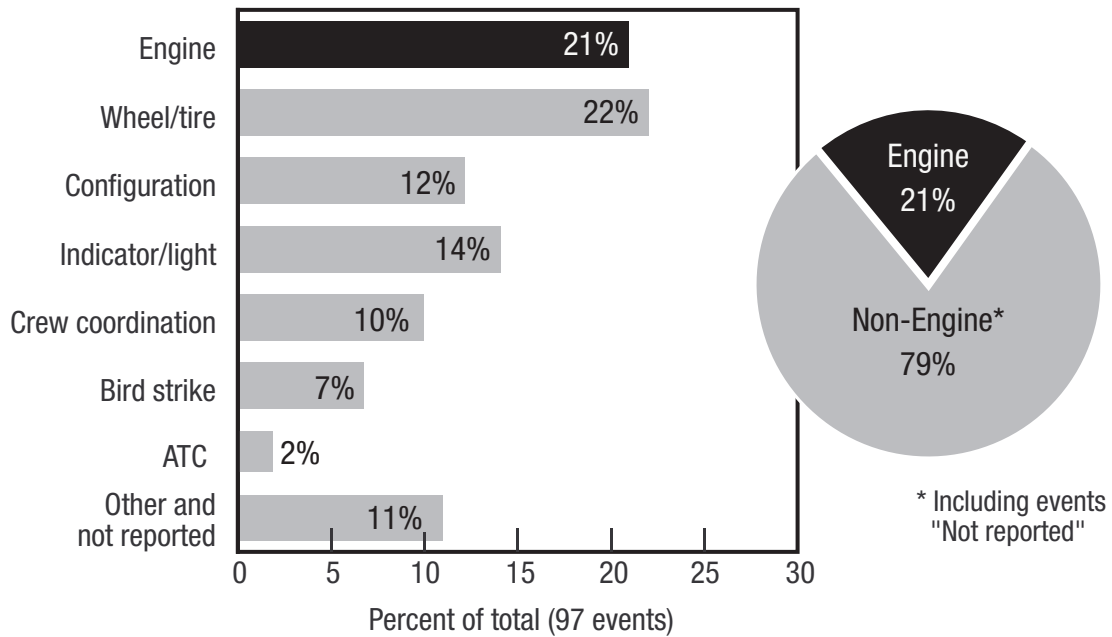
Reasons why the 97 “unsuccessful” RTOs were initiated are also of interest. As shown in Figure 5, approximately one-fifth were initiated because of engine failures or engine indication warnings. The remaining seventy-nine percent were initiated for a variety of reasons which included tire failures, procedural error, malfunction indication or lights, noises and vibrations, directional control difficulties and unbalanced loading situations where the airplane 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  $V_1$ . 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.

**2.2.5 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  $V_1$ . Second, in order to eliminate unnecessary RTOs, the crew must differentiate between situations that are detrimental to a safe takeoff, 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 past RTO history is illustrated in Figure 6. Analysis of the available data suggests that of the 97

Figure 5  
Reasons for initiating the RTO (97 accidents/incident events)



RTO accidents and incidents, approximately 82% were potentially avoidable through appropriate operational practices. These potentially avoidable accidents can be divided into three categories. Roughly 15% 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 15% 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.

Review of the data from the 97 RTO accidents and incidents suggests that in approximately 52% 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.

### 2.3 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

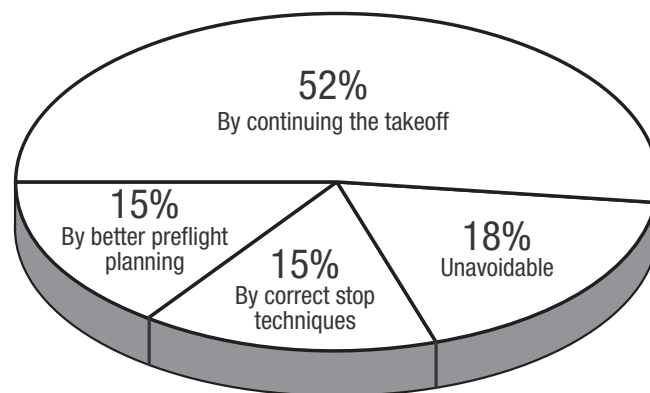


Figure 6  
82% of the RTO accidents and incidents were avoidable

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 is subject to the approval of each operator's management.

### 2.3.1 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 (FARs) 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.

#### 2.3.1.1 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) Accelerate-Stop Distance: The distance required to accelerate with all engines operating, have an engine failure or other event at  $V_{EVENT}$  at least one second before  $V_1$ , recognize the event, 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), except for the wet runway case for airplanes certified under FAR Amendment 25-92.

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. Recent models certified according to FAR Amendment 25-92 also have approved data based on wet, and wet skid-resistant runways. Separate advisory data for wet, if required, 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  $V_1$  will be the primary focus of our discussion here since they more directly relate to preventing RTO overruns.

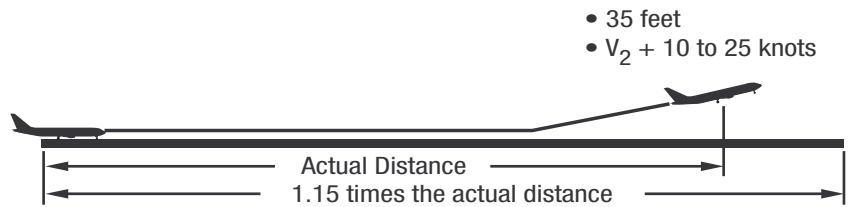


Figure 7  
All-engine go distance

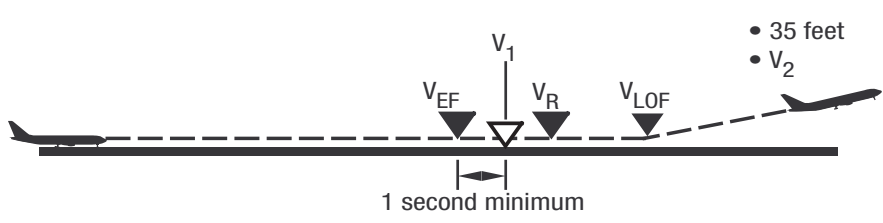


Figure 8  
Engine-out accelerate-go distance

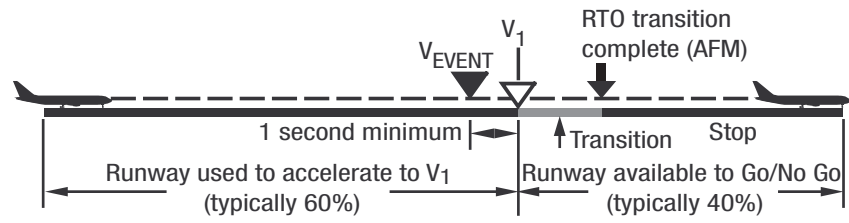
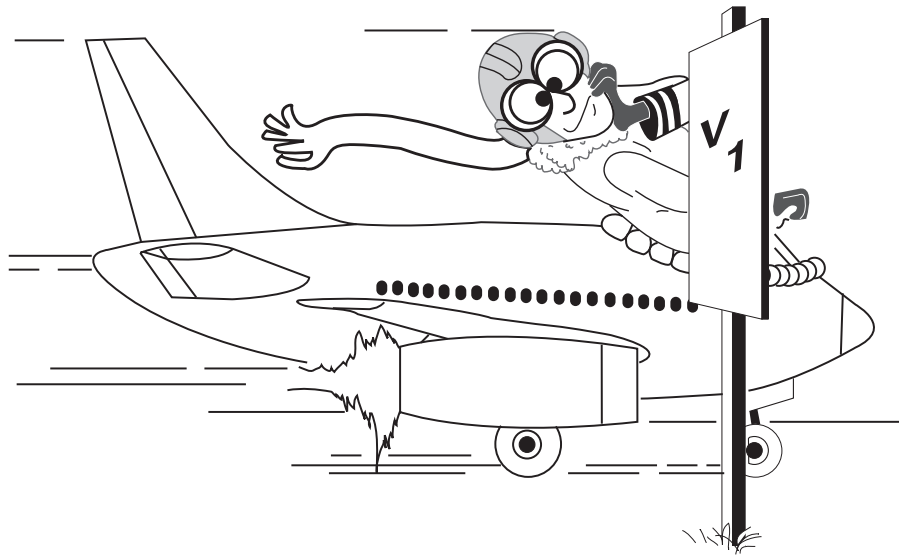


Figure 9  
Accelerate-stop distance

2.3.1.2  $V_1$  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. For our purposes here, the most important statement within this “official” definition is that  $V_1$  is determined from *“...the pilot’s initiation of the first action to stop the airplane 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<sup>1</sup> 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**

<sup>1</sup> 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.

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.

The Go/ No Go decision must be made before reaching  $V_1$ . 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 presentations. 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  $V_1$ .

### 2.3.1.3 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  $V_1$  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  $V_1$  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  $V_1$ , the relationship of the allowable engine-out go takeoff weight to  $V_1$  would be as shown by the “Continued Takeoff” 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”

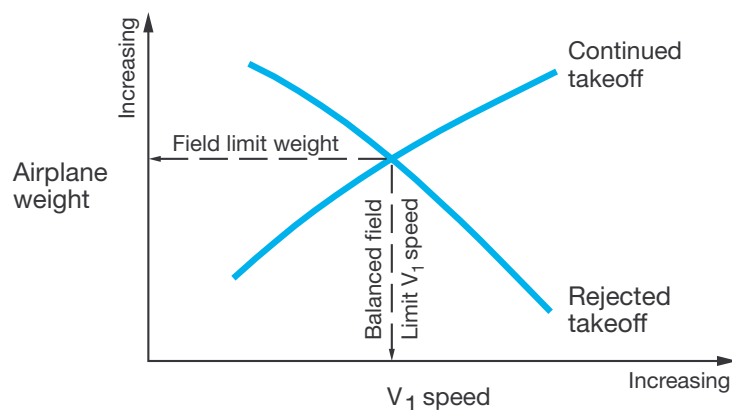


Figure 10  
Effect of  $V_1$  speed  
on takeoff weight  
(from a fixed  
runway length)



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.

#### 2.3.1.4 (Not Used)

### 2.3.2 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.

#### 2.3.2.1 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 RTOs 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.

#### 2.3.2.2 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 “Go/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 he will be doing an RTO. Therefore, his reaction is predictably quick. To account for this, an event recognition time of at least one second has been set as a standard for all jet transport certifications since the late 1960s.  $V_1$  is therefore, at least one second after the event. During this recognition time segment, the airplane continues to accelerate with the operating engine(s) continuing to provide full forward thrust. If the event was an engine failure, 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 throttles-to-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.

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

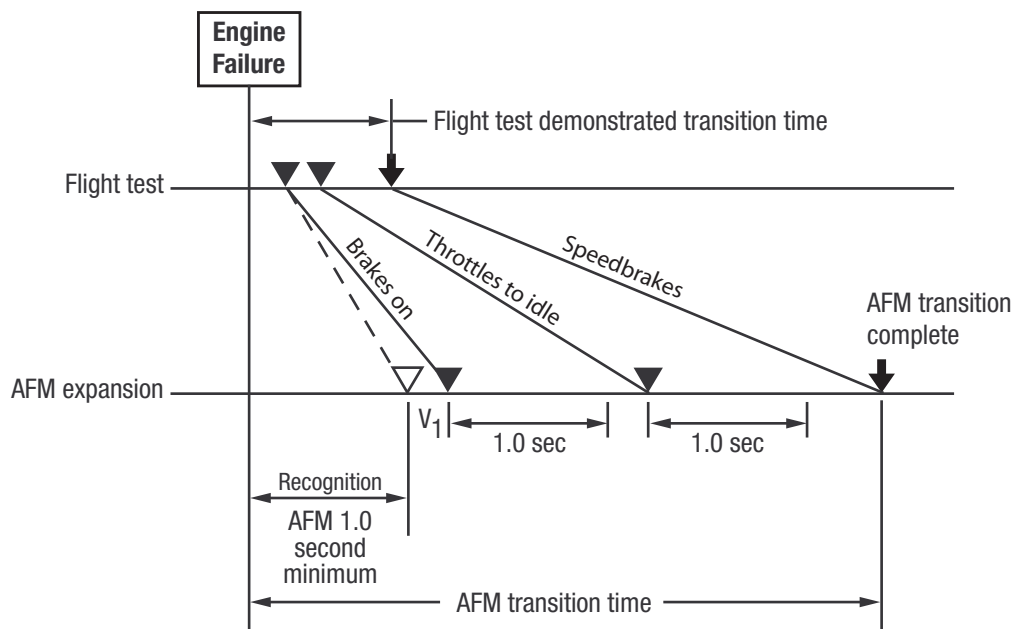


Figure 11  
Early method of  
establishing AFM  
transition time

for older models.

Even more recently, FAR Amendments 25-42 and 25-92 have revised the way in which the two second distance allowance is calculated. 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 keypoint 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 airplane 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

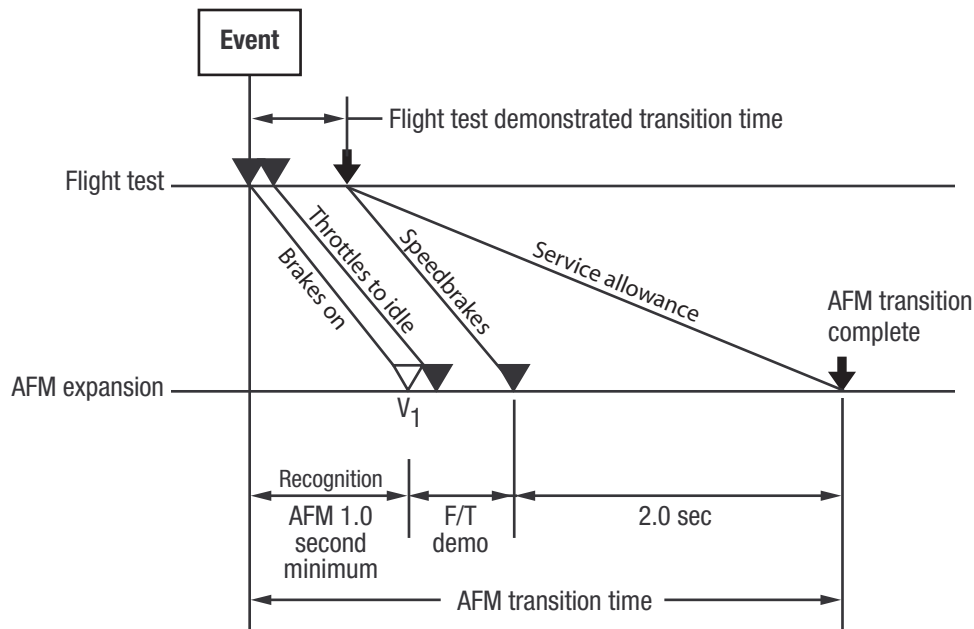
simultaneously initiate maximum braking, retard the thrust levers to idle and then quickly raise the speedbrakes.

**2.3.3 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 FARs if the assumptions of the calculations are met. This means that following an engine failure or event at  $V_{EVENT}$ , the takeoff can be rejected at  $V_1$  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.

Figure 12  
More recent  
method of  
establishing AFM  
transition time



### 2.3.3.1 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  $V_1$  will result in the airplane coming to a stop at the end of the runway. This accelerate-stop distance calculation specifies an engine failure or event at  $V_{EVENT}$ , the pilot’s initiation of the RTO at  $V_1$ , and the completion of the transition within the time allotted in the AFM. If any of these basic assumptions are not satisfied, the actual accelerate-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  $V_1$ . Yet as was noted previously, in approximately 55% of the RTO accidents the stop was initiated after  $V_1$ . At heavy weights near  $V_1$ , 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  $V_1$  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  $V_1$  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  $V_1$ . This is especially true if the RTO 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

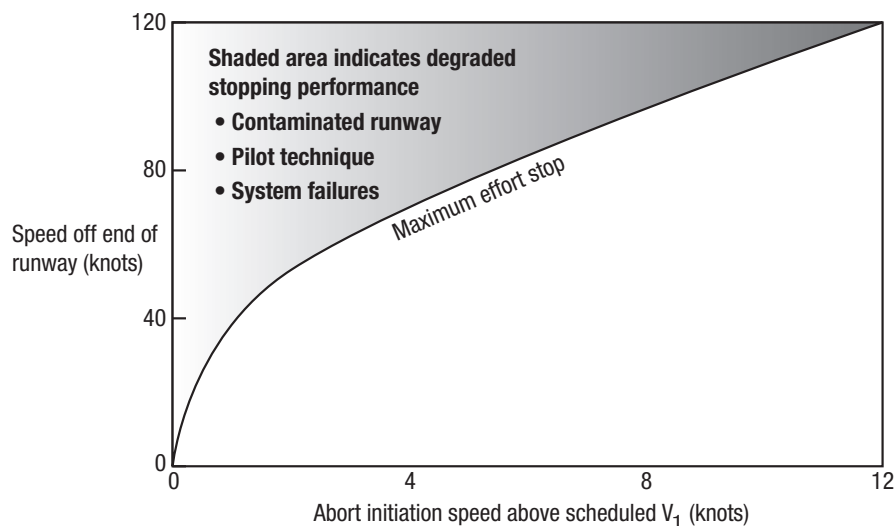


Figure 13  
Overrun Speed for  
an RTO initiated  
after  $V_1$

sufficient runway for a properly performed RTO, the available margins are fairly small. Most importantly, there are no margins to account for initiation of the RTO after  $V_1$  or extenuating circumstances such as runway contamination.

### 2.3.3.2 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 accelerate, 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 certification 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 over 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 ( $V_{mcg}$ ) 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 performance at typical in-service 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 to 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 pre-departure briefing.

Consider a one-engine-inoperative case where the engine failure occurs earlier than the minimum time before  $V_1$  specified in the rules. Because engine-out acceleration is less than all-engine acceleration, additional distance is needed to accelerate to  $V_R$  and, as a consequence, the liftoff point will be moved further down the runway. The altitude (or “screen height”) achieved at the end of 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 may be less than the 35 feet specified in the regulations.

Figure 15 graphically summarizes this discussion of “Go” margins. First, let  $V_{EF}$  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  $V_{EF}$  that the

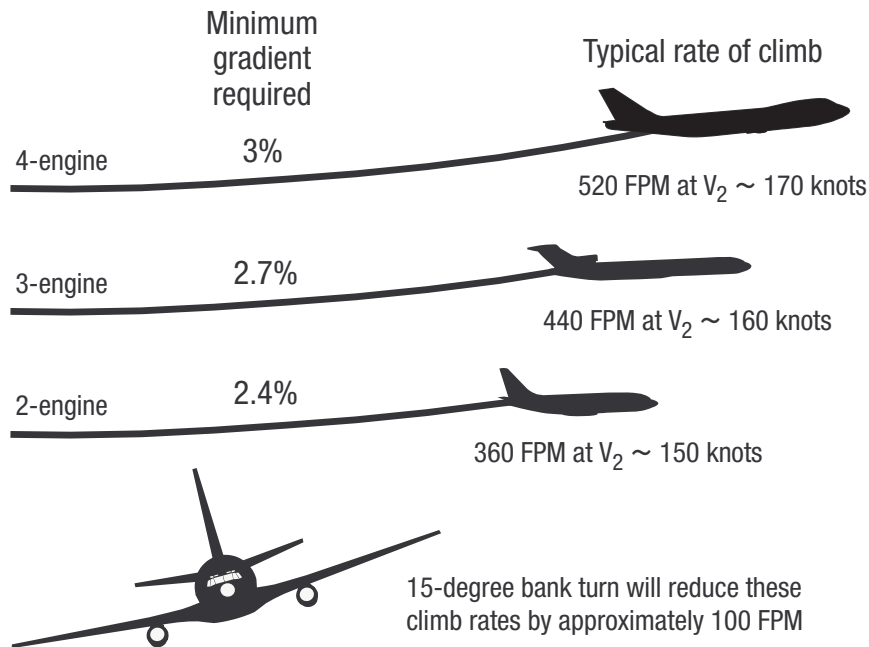


Figure 14  
“GO” performance at climb limit weights

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

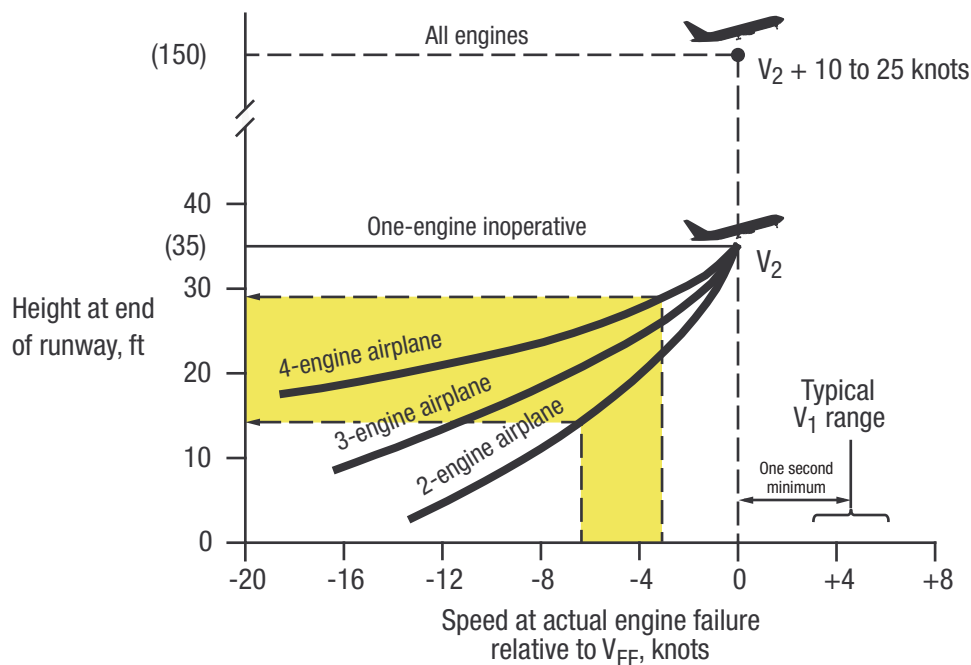


Figure 15  
Effect of engine failure before  $V_{EF}$  on screen height

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.

### 2.3.4 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.

#### 2.3.4.1 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 one second prior to  $V_1$ ;
- 3) Will stop with an engine failure or other event 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 usually determined by one of the engine-out distance 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 accelerate-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 criteria or occasionally by the accelerate-stop case. As a result, a slight margin frequently exists in the engine-out go and accelerate-stop distances on four-engine airplanes.

Three-engine airplanes may be limited by engine-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  $V_1=V_R$ , 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.

#### **2.3.4.2 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.

#### **2.3.5 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.



### **2.3.5.1 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-ft 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 may be affected by a particular runway surface condition.

The certification testing is performed on a smooth, ungrooved, dry runway. For airplanes certified under FAR Amendment 25-92, testing is also performed on smooth and grooved wet runways. Any contamination not covered in the certification data 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.

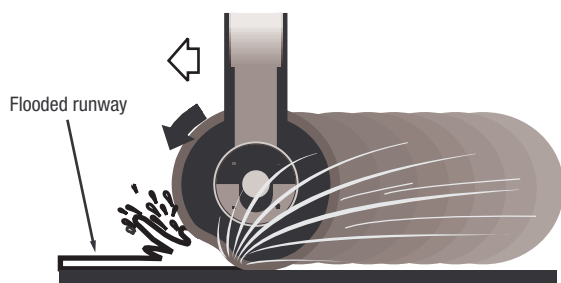


Figure 16A  
Dynamic Hydroplaning

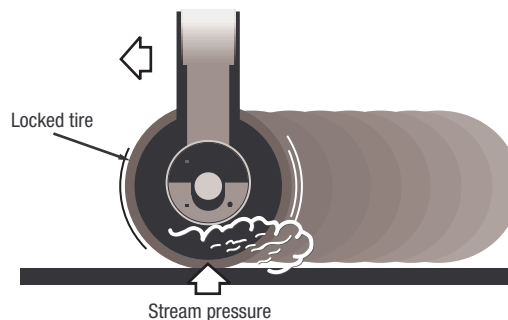


Figure 16B  
Reverted Rubber Hydroplaning

### 2.3.5.1.1 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 tire-to-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 runway 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 decreased considerably. Flight tests of one manufacturer's airplane on a well maintained grooved runway, which was thoroughly drenched with water, showed that the stopping forces were approximately 90% of the 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.

#### **2.3.5.1.2 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.

#### **2.3.5.2 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  $V_1$ , 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 straight forward 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.

### 2.3.5.3 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 inoperative 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.

#### 2.3.5.3.1 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 takeoff analysis used by the flight crew will advise them if climb or obstacle clearance is a limiting factor with a greater flap setting.

#### 2.3.5.3.2 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 conditions.

#### 2.3.5.3.3 Missing or Inoperative Equipment

Inoperative or missing equipment can sometimes 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 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.<sup>3</sup> 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.

<sup>3</sup>UK CAA procedure adds “...apply maximum reverse thrust.”



#### 2.3.5.3.4 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 structural 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 in Section 2.3.5.3.6 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. However, it cannot be overstressed that proper maintenance and thorough walk around inspections 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 increase 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 circumstances, that another problem exists.

Although continuing a takeoff with a failed tire will generally have no significant adverse results, there may be 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, especially if the weight is near the Field Limit Weight. The chances of an overrun are increased 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



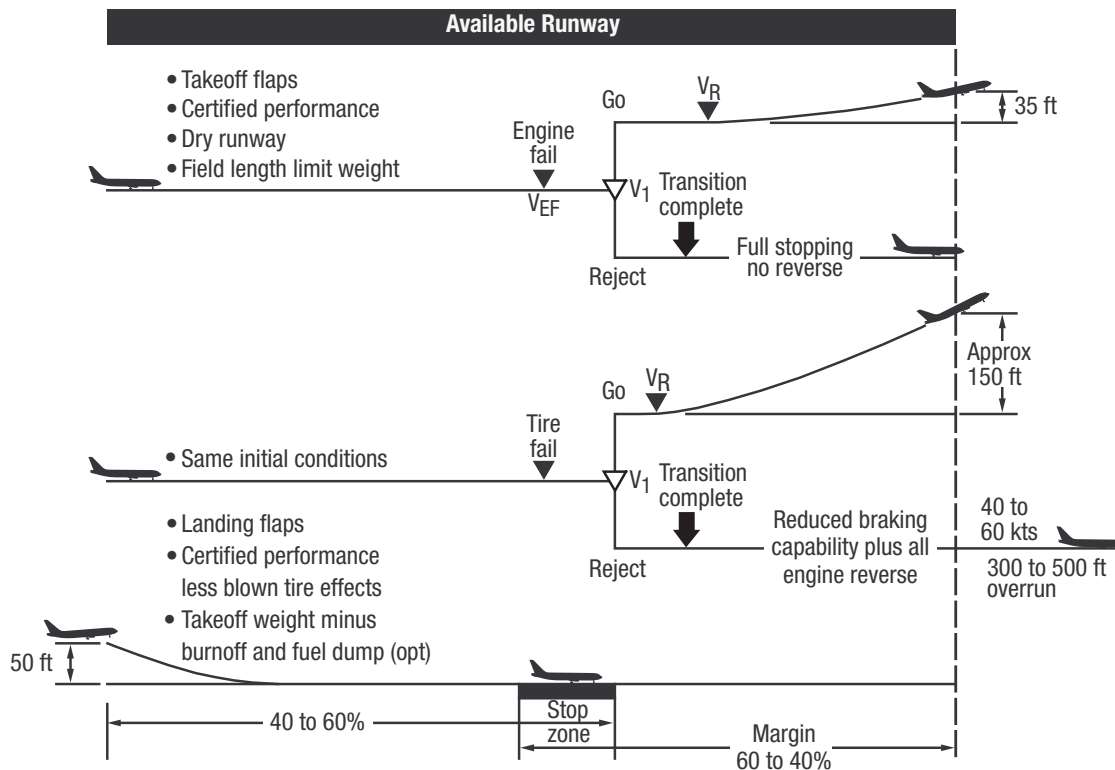


Figure 17  
Margins associated with continuing or rejecting a takeoff with a tire failure

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 an All Operator Letter<sup>4</sup>, 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.

### 2.3.5.3.5 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

<sup>4</sup>McDonnell Douglas All Operators Letter FO-AOL-8-003, -9-006, -10-004, -11-015, *Reiteration of Procedures and Techniques Regarding Wheels, Tires, and Brakes*, dated 19 AUG 1991

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.

### 2.3.5.3.6 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 information on this subject. The brake temperature limitations and/or cooling charts in the airplane 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.

### 2.3.5.3.7 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 wheelbrake 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 lb, the total load on the main wheels at brake release would be approximately 193,000 lb. As the airplane accelerates along the runway, wing lift will decrease 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 lb. 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

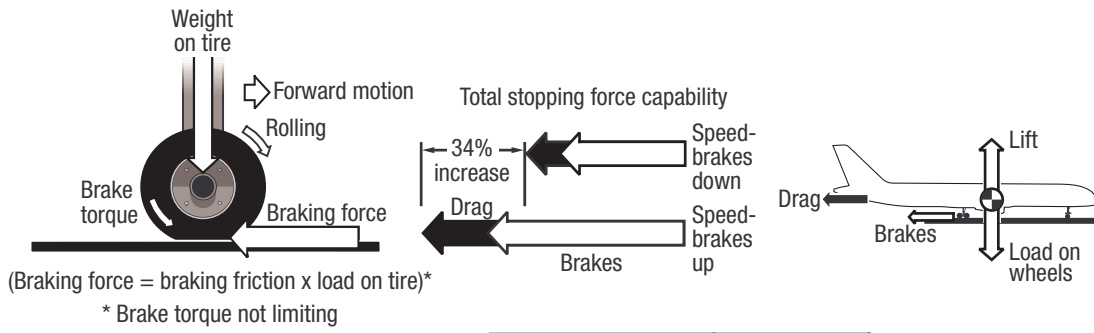


Figure 18  
Effect of speedbrakes on the stopping capability of a typical mid-size two-engine transport

	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 and drag)	84,400	112,700	+34%

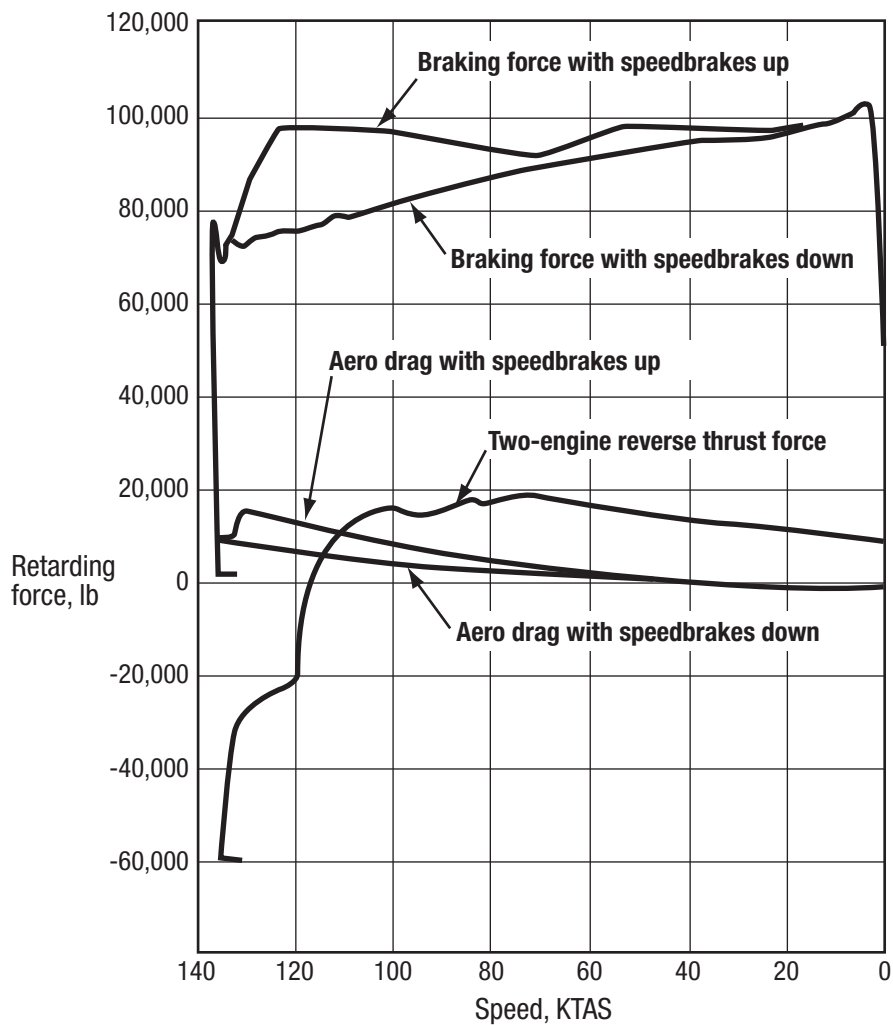


Figure 19  
Summary of forces during a typical mid-size two-engine airplane RTO

closing the thrust levers, the braking force rises quickly to a value in excess of 70,000 lb. The nearly vertical line made by the braking force curve in Figure 19 also shows that the airplane began to decelerate almost immediately, with virtually 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 lb with the speedbrakes down, and would increase by 53,200 lb 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 stopping 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 increase 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, 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.

### 2.3.5.3.8 Carbon and Steel Brake 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 metallic 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 therefore 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 cooling 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 specific 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 RTOs 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.

#### **2.3.5.3.9 High Brake Energy RTOs**

Brake rotor and stator temperatures associated with RTOs 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 do 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.

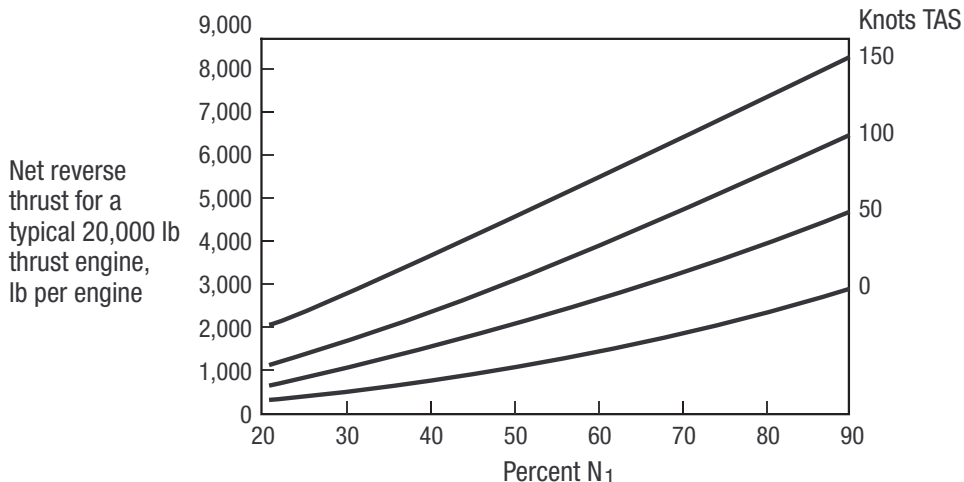
In terms of practical guidelines for flight crews, takeoffs at or near  $V_{MBE}$  are normally encountered at high altitude airports or at very hot temperatures. An RTO from close to  $V_1$  speed under these conditions will require the brakes to absorb a significant amount of

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.

**2.3.5.4 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, except for the wet runway case for airplanes certified under FAR Amendment 25-92. 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

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



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 retarding force as they are on a dry surface. Therefore, the retarding force of the reversers generates a larger percentage of the total airplane deceleration.

### 2.3.5.5 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 usually 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 runway. 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<sup>5</sup>.

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  $V_1$  speed

further along the runway than was planned. If no event occurs which would precipitate an RTO, the final acceleration to  $V_R$  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  $V_1$ , 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 anything other than a catastrophic event is not advisable.

A clearway is an area at least 500 ft 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 increase takeoff weight “unbalances the runway” and results in a lower  $V_1$  speed. The maximum clearway used to calculate takeoff performance is restricted by the regulations to one half the demonstrated distance from liftoff 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  $V_1$  speed. An RTO initiated at this  $V_1$  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

<sup>5</sup>ICAO Circular 91-AN/75, *The Effect of Variable Runway Slopes on Take-Off Runway Lengths for Transport Aeroplanes*, dated 1968.



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.

### 2.3.5.6 (Not Used)

### 2.3.5.7 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 operated at 20,000 lb 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 takeoff 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.

### 2.3.5.8 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 temperatures. 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.

**2.3.6 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.

**2.3.6.1 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.

**2.3.6.2 Flap Selection**

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.

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)

*Figure 21*  
**Typical large two-engine jet transport takeoff performance**

If a flight requires the absolute maximum takeoff weight, the above weight limits would dictate choosing Flaps 15 since 389,000 lb 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 typically, 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 this example and are shown in Figure 22.

*Figure 22*  
Effect of flap selection on RTO stopping margins

Flap setting	5	15	20
Stopping margin	Zero	850 ft	1,000 ft

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 disadvantages 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.

**2.3.6.3 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 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. If they can do it in a shorter distance than taken into account by their company, then there is that much extra margin for the takeoff.

**2.3.6.4 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  $V_1$  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 flight 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 predetermined 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.

### 2.3.6.5 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 transport 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<sup>6</sup> 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.

<sup>6</sup>The Training Aid Working Group is the industry and regulatory team that developed the *Takeoff Safety Training Aid*.

The importance of maintaining maximum braking and full reverse thrust during an RTO until the airplane “rocks to a stop” cannot be overstressed. 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.

#### **2.3.6.6 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.

#### **2.3.6.7 RTO Autobrakes**

Autobrake system functions and crew actions to initiate these functions vary from one airplane 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 illustrates 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 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 RTOs performed with RTO autobrakes ARMED resulted in more runway distance remaining after the stop than did the RTOs 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 stopping 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, between 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 understood 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.

### 2.3.6.8 (Not Used)

### 2.3.6.9 The $V_1$ Call

One important factor in avoiding RTO overrun accidents is for the crew to recognize reaching  $V_1$  when the airplane does, in fact, reach  $V_1$ —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 RTOs 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  $V_1$  is to use a call such as "Approaching  $V_1$ " with the  $V_1$  portion occurring as the airspeed reaches  $V_1$ . 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 by the use of automated “V<sub>1</sub>” 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.

### 2.3.6.10 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 V<sub>1</sub>.
- 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<sub>1</sub>, 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.

## 2.4 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.

### 2.4.1 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 available 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.

### 2.4.2 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 (SOPs) 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 understanding 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  $V_1$ , 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.

### 2.4.3 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.

### 2.4.4 The Use of All Crew Members

It's important to understand that all crew members 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.

**2.4.5 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.