BACKGROUND

The RTO maneuver has been a fact of a pilot's life since the beginning of aviation. Each takeoff includes the possibility of an RTO and a subsequent series of problems resulting from the actions taken during the reject. Historically, the RTO maneuver occurs approximately once each 3,000 takeoffs. Because the industry now acknowledges that many RTOs are not reported, however, the actual number may be estimated at 1 in 2,000 takeoffs. For example, an unreported RTO may occur when a takeoff is stopped very early in the takeoff roll because the flight crew hears a takeoff warning horn, stops to reset trim, then taxis back to the runway and continues takeoff.

According to these statistics, a pilot who flies primarily long-haul routes, such as in our Boeing 747 fleet, may be faced with an RTO decision only once in 20 years. In contrast, a pilot in our DC-9 short-haul fleet who makes 30 takeoffs per month may see an RTO every 7 years. Unfortunately, the pilot in each of these fleets must be prepared to make an RTO decision during every takeoff.

Boeing studies indicate that approximately 75 percent of RTOs are initiated at speeds less than 80 kt and rarely result in an accident. About 2 percent occur at speeds in excess of 120 kt. The overruns and incidents that occur invariably stem from these high-speed events.

A takeoff may be rejected for a variety of reasons, including engine failure, activation of the takeoff warning horn, direction from air traffic control (ATC), blown tires, or system warnings. In contrast, the large number of takeoffs that continue successfully with indications of airplane system problems, such as master caution lights or blown tires, are rarely reported outside the airline's own information system. These takeoffs may result in diversions or delays, but the landings are usually uneventful. In fact, in about 55 percent of RTOs the result might have been an uneventful landing if the takeoff had been continued, as stated in the *Takeoff Safety Training Aid* published in 1992 with the endorsement of the U.S. Federal Aviation Administration (FAA).

Some of the lessons learned from studying RTO accidents and incidents include the following:

- More than half the RTO accidents and incidents reported in the past 30 years were initiated from a speed in excess of V_1.
- About one-third were reported as occurring on runways that were wet or contaminated with snow or ice.
- Only slightly more than one-fourth of the accidents and incidents actually involved any loss of engine thrust.
- Nearly one-fourth of the accidents and incidents were the result of wheel or tire failures.
- Approximately 80 percent of the overrun events were potentially avoidable by following appropriate operational practices.

HISTORY OF RTO OPERATIONS AT EVERGREEN

Evergreen International Airlines began a study of the RTO maneuver in 1991. Resources included information from the FAA and industry studies, notably RTO data produced by Boeing.

Our standard procedure was to use the V speeds generated from Boeing airplane flight manuals (AFM) in the form of speed cards. These cards list the appropriate speeds for a given weight and flap configuration. However, the speeds given provide only the FAA minimum recognition interval. In addition, a definition of V_1 was in use that referred to "decision speed." This term implied that the airplane could accelerate to that speed, that the decision to reject or continue could then be made, and that the resulting maneuver would have a successful outcome.

All the data we collected pointed toward some weaknesses in this philosophy. In addition, the FAA-approved takeoff data is based on performance demonstrated on a clean, dry runway. Separate adjustments for a wet or contaminated runway are published in operational documents. The takeoff accelerate-stop distance shown in the AFM is based on a specified amount of time allocated to accomplish an RTO from V_1 speed. Time delays in addition to those demonstrated in actual flight tests are included in the AFM computations. Simulator studies conducted in the 1970s showed that a flight crew requires anywhere from 3 to 7 seconds to recognize and perform an RTO, especially when the cause is other than a power plant fire or failure. More recent studies with higher fidelity simulations, such as those conducted in conjunction with the development of the *Takeoff Safety Training Aid,* indicate that the times for the pilot to recognize and perform the RTO procedure are within the time allotted in the AFM.

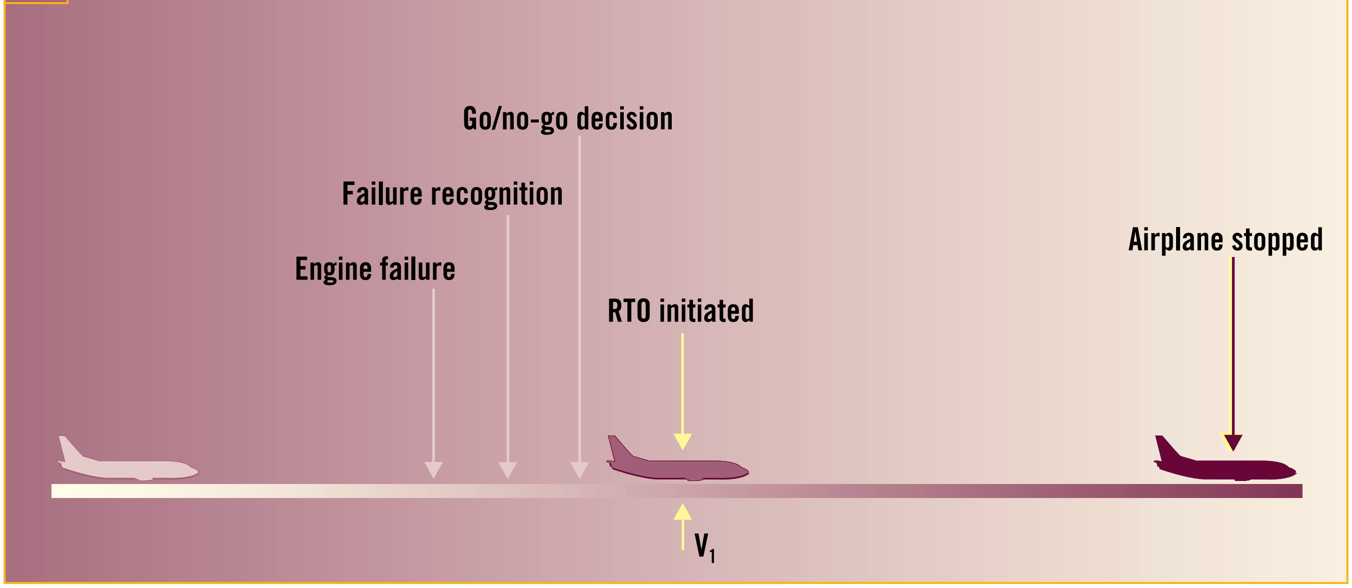
INITIAL PROPOSALS

Although we did not have a history of high-speed RTOs to use for our data, we determined that a better method must be designed to improve the flight crew's chances for an uneventful RTO. Using the Boeing data, quoted below from FAA Advisory Circular 120-62, we first changed the definition of V_1. We used the definition of V_1 as:

> The speed selected for each takeoff, based upon approved performance data and specified conditions, which represents:
>
> 1. The maximum speed by which a rejected takeoff must be initiated to assure that a safe stop can be completed within the remaining runway, or runway and stopway;

1 RTO GO/NO-GO DECISION

FIGURE



2. The minimum speed which assures that a takeoff can be safely completed within the remaining runway, or runway and clearway, after failure of the most critical engine at a designated speed; and

3. The single speed which permits a successful stop or continued takeoff when operating at the minimum allowable field length for a particular weight.

Note 1: Safe completion of the takeoff includes both attainment of the designated screen height at the end of the runway or clearway and safe obstacle clearance along the designated takeoff flight path.

Note 2: Reference performance conditions for determining V_1 may not necessarily account for all variables possibly affecting a takeoff, such as runway surface friction, failures other than a critical power plant, etc.

The "go/no-go" decision must be made prior to reaching the published V_1 (fig. 1). As the speed approaches V_1 the "go" decision becomes more appealing. Our goal became to identify a reduced "decision speed" to provide increased flight crew recognition time in case of a catastrophic situation. Using the Boeing data, we initially approached the FAA with a proposal to call a reduced V_1 the "decision speed" and treat it as a V_1 speed. The flight crew would remove their hands from the thrust levers, and the takeoff would continue. The initial proposed speed was 10 kt less than published V_1.

We presented this proposal to our principal operations inspector (POI) in 1991. After several months of dialogue and deliberation, it was disapproved because it was too different from certification criteria.

APPROVED PROCEDURES

In late 1992, after we received the Boeing *Takeoff Safety Training Aid* in draft form, we decided to again seek approval of the "decision speed" concept. This time we chose a speed of 8 kt for a reduction, which added approximately 2 seconds of recognition time. In the worst case the screen height was degraded to approximately 15 to 20 ft. We also expanded our efforts to include a revised airspeed call. We had been using an airspeed call of 80 kt, both for airspeed verification and for power setting completion in the 747. A 100-kt call was added, which indicates entry to a high-speed regime where an RTO would be more difficult and dangerous. We also refined the guidelines for an RTO as follows:

- Although V_1 will be obtained from the appropriate speed cards, 8 kt will be subtracted from this value and the airspeed bug will be set at that point. In no case will this speed be less than ground minimum control speed.
- The call at this new speed will be V_1 and the takeoff will be continued.
- If an adjustment is required for contamination, the 8-kt reduction will not be made.
- Above 100 kt the takeoff should be rejected only for engine failure or other catastrophic failure.
- Improved climb procedures will use the 8-kt reduction.

Again with the help of our POI, the revised procedure was presented to the FAA in early 1993 and approved after much discussion. It was implemented throughout our fleet in June 1993.

We believe that this reduced V_1 procedure provides a valuable increase in the safety margin over that provided in the AFM in the event of an RTO. At V_1, the decision to initiate an RTO must already have been made and the RTO must already have begun. If there is any hesitation, the remaining time may be insufficient to allow a successful high-speed RTO (see information on simulator studies in the previous section, History of RTO Operations at Evergreen). With our reduced V_1, we increase the stopping margins on every takeoff. If an engine failure did

occur just before V_1, screen height is reduced. However, engine failure was not involved in nearly 75 percent of all RTO accidents. In addition, because we fly earlier generation airplanes that lack the automatic inhibit of lower level warnings after 80 kt, the use of 100 kt as a notification of entry to high-speed operations provides the pilots with more incentive to continue a takeoff if a nuisance warning occurs.

During training, our instructors traditionally used simple engine failures to teach the RTO maneuver. This technique, however, may condition pilots to think an engine failure is the only cause of all rejects. After the new procedures were implemented, the check airmen were instructed to use other failures, such as tires, warning lights, or system failures, to force pilots to make an RTO decision. In the high-speed regime above 100 kt, rejects should be performed only for engine failure or other catastrophic failure. The takeoff should be continued if noncritical alerts, tire failures, or system problems not related to the safe completion of the takeoff occur. Introduction of these problems requires a decision by the pilots and makes the RTO maneuver more realistic.

The reject itself is now taught as an emergency maneuver, with emphasis on full braking and correct use of spoilers and reverse as essential to the successful outcome of the maneuver.

RESULTS

Since the introduction of our RTO procedures, we have had only one related incident. This incident, however, proves the point of the procedure.

A DC-9 was departing Portland International Airport on runway 10L. Conditions included a crosswind, wet runway, and the airplane at balanced-field maximum weight. Near 100 kt during the takeoff roll, the captain felt something strange occur in the nose area. Because he was not sure if a tire had blown or failed in another manner, he elected to continue takeoff. A noise similar to a deflated tire thump was heard as the airplane accelerated. The takeoff continued uneventfully, however, and the airplane diverted to Seattle-Tacoma International Airport. After landing, it was discovered that the left nose tire had come apart and deflated.

This incident could have had other consequences had the captain attempted an RTO from high speed. Given the conditions of the runway, and the fact that the tire was deflated, the airplane could have been very difficult to stop on the available runway.

The captain reported that, when he first heard the noise from the nose tire area, he remembered our training and cautions regarding a high-speed reject for any reason other than a catastrophic failure.

SUMMARY

Although we sacrifice about 15 to 20 ft of screen height on the DC-9 and less on the 747 if an engine actually fails at V_1, the airplane is flying when it reaches the end of the runway. We believe that the procedures and training we have developed, using flight operations data and other information from Boeing and other sources, have helped give our pilots an edge in takeoff safety.

(All references to Boeing studies are from the Boeing Takeoff Safety Training Aid *as endorsed by the FAA in 1992, in draft and final form, and other documents produced by Boeing, the Air Transport Association, the FAA, and the U.S. National Transportation Safety Board. Statistics noted in this article appeared in either the draft or final version of the training aid. Doug Smuin, then director of flight training at Evergreen and currently DC-9 captain, assisted in the preparation of this article and initial approval of the RTO studies project.)*

UPDATE
ON REJECTED TAKEOFF SAFETY STATISTICS

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

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

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

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

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

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

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

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

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

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

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

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

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

(1) A = accident, I = incident
(2) RTO initiation speed (the speed at which the first action was taken relative to V_1)
(3) Cause (why the RTO decision was made)

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

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

TABLE 2 RTO OVERRUN ACCIDENTS/INCIDENTS PER 10 MILLION TAKEOFFS

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

FIGURE 1 94 RTO OVERRUN ACCIDENTS/INCIDENTS SINCE 1959

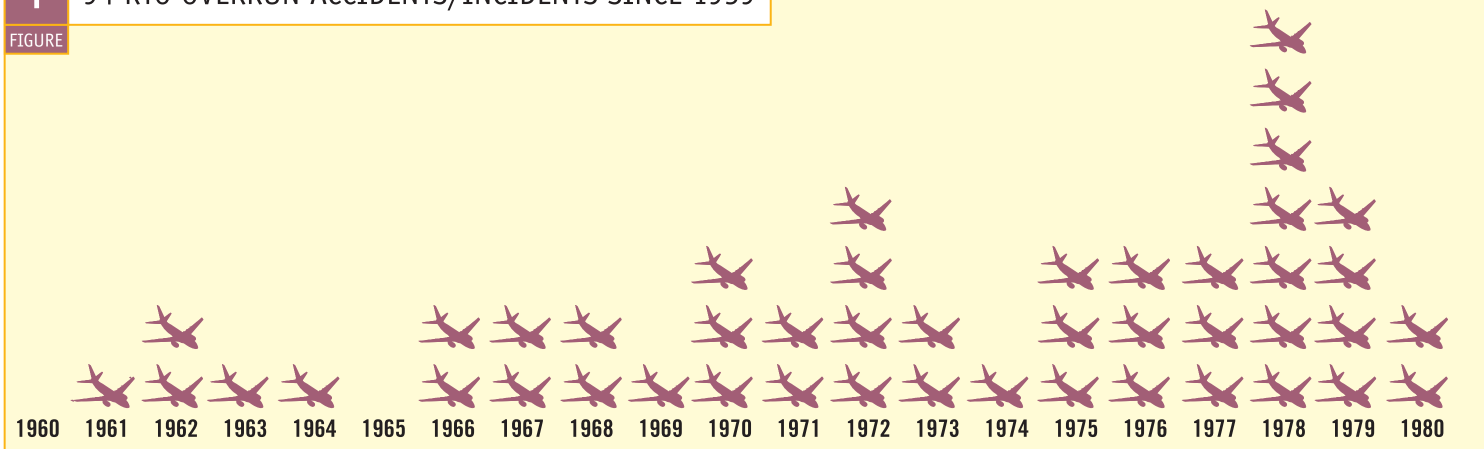
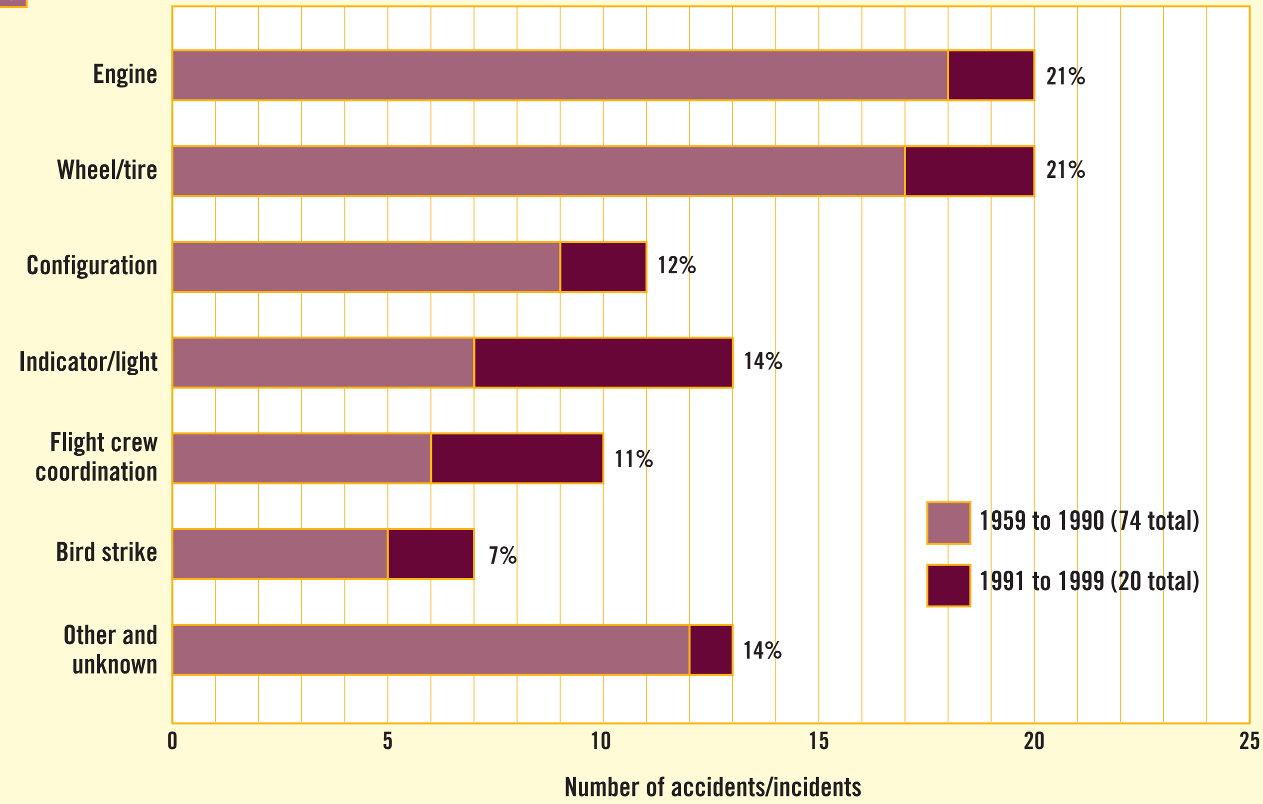


FIGURE 2 REASONS FOR INITIATING RTO (94 ACCIDENTS/INCIDENTS)



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

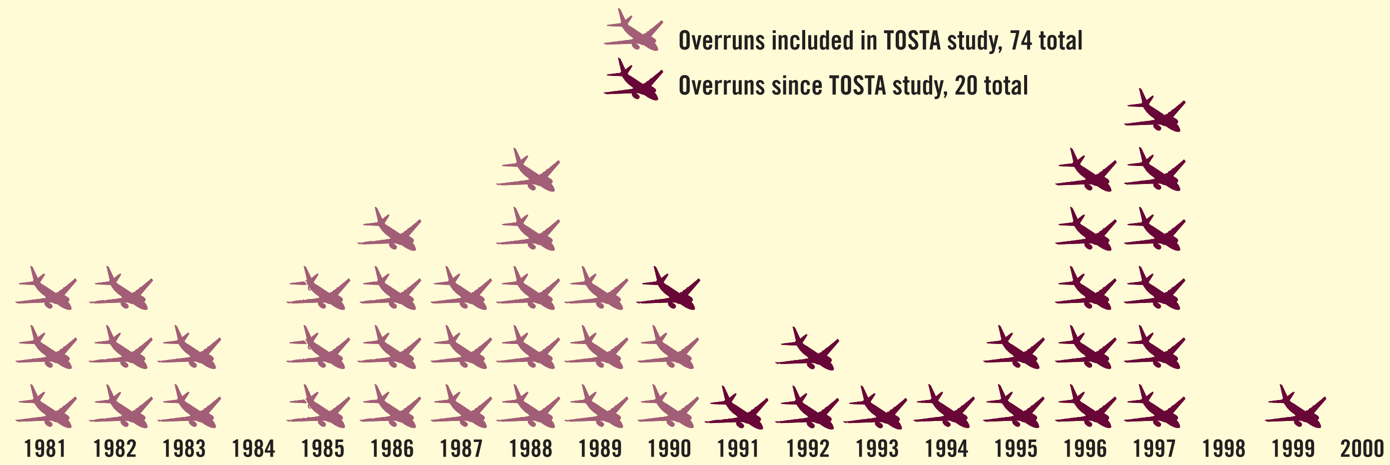


FIGURE 3 RTO INITIATION SPEED

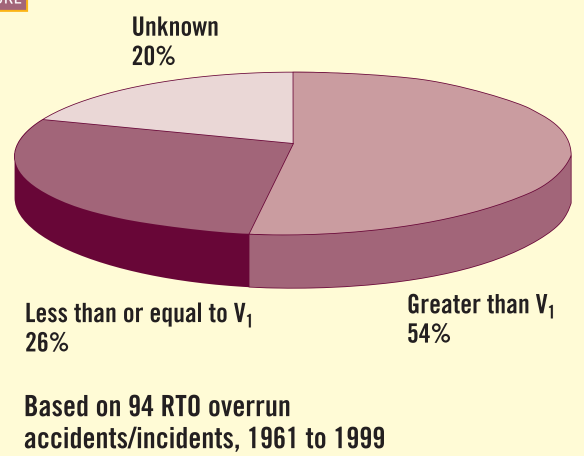


FIGURE 4 RUNWAY CONDITION

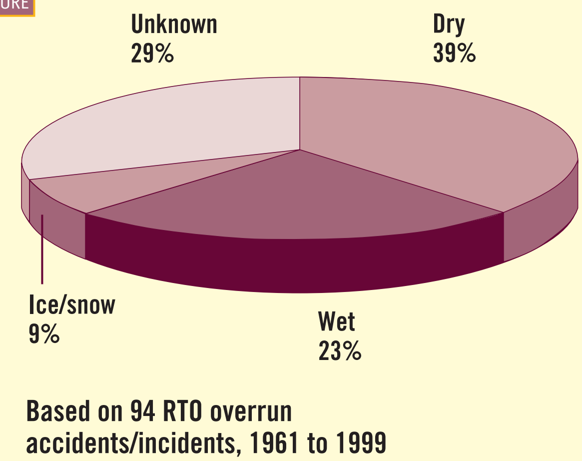


FIGURE 5 RATE OF RTO OVERRUN ACCIDENTS/INCIDENTS