Preventing Runway Conflicts: The Role of Airport Surveillance, Tower-Cab Alerts, and Runway-Status Lights

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■ Runway incursions and conflicts present a persistent problem in airport ground operations. Numerous critical conflicts and several fatal accidents have occurred as a result of unauthorized or otherwise inappropriate entry of aircraft or surface vehicles onto an active runway. This article describes a detailed survey of runway-conflict accidents and high-hazard incidents resulting from inappropriate entry onto or movement on an active runway. The patterns that emerge allow us to determine the role that three different safety systems can be expected to play in reducing the incidence or consequences of runway incursions and conflicts. The three systems are a surface-surveillance system (such as a surface radar), a tower-cab alerting system, and runway-status lights. Judging from the history of runway conflicts, it appears that runway-status lights, operating automatically with inputs from a surface radar, can prevent over half of these conflicts. A surface radar alone or combined with tower-cab alerts promises to be effective in preventing another one-third. The three systems in combination can offer protection in an estimated 90% of high-hazard conflicts.

Runway incursions present a persistent problem in airport ground operations. Numerous critical conflicts and several fatal accidents have occurred as a result of unauthorized or otherwise inappropriate entry by an aircraft or an airport surface vehicle onto an active runway. In particular, three major runway collisions occurred in the United States during a thirteen-month period in 1990 and 1991 [1, 2, 3]. As a result, the Federal Aviation Administration (FAA) began examining potential alternative technological solutions to the runway-incursion problem, focusing first on those solutions which could be accomplished without modifying existing aircraft equipment.

Three primary technologies have been identified: (1) surface-surveillance radar to give air traffic controllers an all-weather view of airport traffic, (2) a tower-cab alerting system to warn controllers of impending conflicts, and (3) a system of automatically activated runway-status lights on the airfield to indicate to pilots and surface-vehicle operators when conditions are not safe to enter a runway or begin takeoff. The last two technologies require the addition of digital tracking to the surface-surveillance radar to permit automated evaluation of the state of traffic on the airport surface and in the surrounding airspace.

The FAA is currently deploying high-performance surface-surveillance radars, called ASDE-3 (ASDE stands for Airport Surface Detection Equipment), at about forty of the nation's major airports. Tower-cab alerting and runway-status light systems have been developed in prototype form and shown to be technically feasible, with no need to modify existing aircraft equipment to provide cooperative surveillance or positive aircraft identification.

Cost considerations require that we clearly understand the relative value of these three candidate safety systems. Not surprisingly, air traffic control policy makers would like to know whether the improved situational awareness provided by the ASDE-3 radars might be enough by itself to prevent serious runway conflicts in the future, thus obviating the need for expensive tower-cab alerting and runway-status light systems.

This article describes a detailed survey of historical data on runway-conflict accidents and high-hazard incidents, which was conducted to help address these implementation issues by developing an understanding of the relative importance of the three candidate runway-safety approaches. The patterns that emerge allow us to determine the role that each airport safety technology can be expected to play in reducing the incidence or consequences of runway incursions and conflicts.

The survey results suggest that a surface-surveillance radar by itself will not adequately reduce the rate of surface accidents and incidents. Several fatal runway collisions and approximately 80% of high-hazard runway conflicts have occurred in good visibility when the tower controller's attention is likely to be focused out the tower-cab windows rather than on the radar display. Furthermore, a large proportion of these events, as well as many that occurred in low-visibility conditions, developed too quickly to permit intervention via the tower cab. Conflict resolution via the tower cab is a time-consuming multistep process involving controller reaction, communication, and pilot reaction. This process is estimated to take a minimum of twelve seconds, but it could conceivably take as much as thirty seconds or more, depending on the circumstances [4, 5].

For the purposes of this work, a high-hazard incident is defined as a non-contact conflict between two aircraft or between an aircraft and a surface vehicle, in which at least one aircraft is at high speed at the time the conflict situation develops, and in which the two come within a small distance (one hundred feet or less) of each other. High speed generally means that at least one aircraft is either taking off, or landing, or in landing rollout and traveling at a speed in excess of about forty-five knots. In a few cases involving crossing conflict in the horizontal plane (such as simultaneous takeoffs on intersecting runways) the miss-distance criterion is generalized to include situations in which the two aircraft occupy the same spot on the airport surface within two seconds. Specifically excluded are situations in which one aircraft is holding short of the runway in normal fashion at the taxi-hold line, and also go-arounds that appear to fall within the normal parameters for this procedure.

A surface-surveillance radar and a tower-cab alerting system would have been the most effective means of averting conflict in approximately one-third of the conflict events studied. As mentioned above, tower-cab alerts are useful when the hazardous situation can be detected relatively early. In particular, tower-cab alerts are appropriate for many conflicts involving aircraft on final approach, when using surface lights to convey a warning to the cockpit is not advisable. In most of these events we cannot judge whether the conflict would in fact have been prevented by surface surveillance alone, because of uncertainty about whether the controller would have noticed the developing conflict on the surface-traffic display.

Runway-status lights would have been the best defense in more than half of the reported conflicts. These were time-critical conflicts that developed quickly from perfectly routine and apparently safe situations, leaving insufficient time for intervention by the air traffic controllers. Runway-status lights provide a direct, prompt link between the surveillance system and the cockpit, which is a crucial advantage in time-critical conflict situations.

There are two kinds of runway-status lights [6, 7]. *Runway-entrance lights* warn a pilot that the runway is unsafe to enter because high-speed traffic is on the runway. These lights are located at every runway-taxiway intersection and oriented to face the taxiway. *Takeoff-hold lights* warn a pilot in position for takeoff that the runway is not safe for takeoff. These lights are located in front of every normal takeoff location and illuminate when two conditions are satisfied: first, an aircraft is in position on the runway at that location; second, the runway ahead is not clear, or high-speed traffic is on an intersecting runway and a potential for conflict exists.

We conclude that surface-surveillance radars, tower-cab alerts, and runway-status lights are all essential elements of an effective airport-surface safety system. In particular, the high proportion of time-critical runway conflicts in the past argues for the inclusion of automatic runway-status lights in the inventory of collision-prevention technologies. These status lights would have been the most effective means of preventing several runway-conflict accidents that have occurred in the past, as well as most of the near misses.

Types of Runway-Conflict Scenarios

Runway conflicts can be described and classified in various ways, depending on the perspective that best suits the purpose. Our perspective in this work is decidedly high level. That is, we are primarily concerned with *what* happened and *how* it happened, rather than *why*. This is not to say that the question of why a conflict occurred is unimportant; on the contrary, the fundamental causes of these conflicts, whether they are based in technology or human factors, are important in understanding the incidents [8]. But this information is generally unavailable to an automatic surveillance system, and it is therefore of no consequence to the control logic of a surveillance-based safety system.

Table 1 shows the conflict classification scheme chosen for this work. Conflict categories are defined in terms of the phase of operation of the two aircraft and the geometry of the interaction. The phase of operation is specified as arriving, departing, or taxiing; no distinction is made—at this level of classification—between arrival, landing, and landing rollout or between takeoff and holding in position. The geometry of the interaction is specified as tail chase, crossing, and head on. A total of twenty-seven conflict categories can be expected for two aircraft, each in one of three phases of operation, interacting in three different ways. Symmetry arguments and the elimination of taxi-taxi conflicts (conflicts that occur off the runway are of secondary interest) reduce the number of categories to sixteen. A seventeenth category, designated RC(veh), accounts for runway conflicts involving surface vehicles. These vehicles could also perhaps be treated as taxiing aircraft, but such a classification is undesirable because surface vehicles do not always behave like taxiing aircraft.

The following notation is used in the present discussion to denote the conflict categories: arrival, departure, and taxi are abbreviated as A, D, and T, respectively; tail-chase, crossing, and head-on geometries are abbreviated tc, cr, and ho. Where it matters, the phase of operation of the high-speed aircraft is given first. Thus, AD(tc) refers to a scenario in which an arriving aircraft is overtaking a departing aircraft, as shown in Figure 1; this was the situation in

Table 1. Classification of Runway-Conflict Scenarios*

	Arrival	*Departure*	*Taxi*
Arrival	tail chase	tail chase	tail chase
	crossing	crossing	crossing
	head on	head on	head on
Departure	tail chase	tail chase	tail chase
	—	crossing	crossing
	—	head on	head on

* An additional category accounts for runway conflicts between aircraft and surface vehicles.

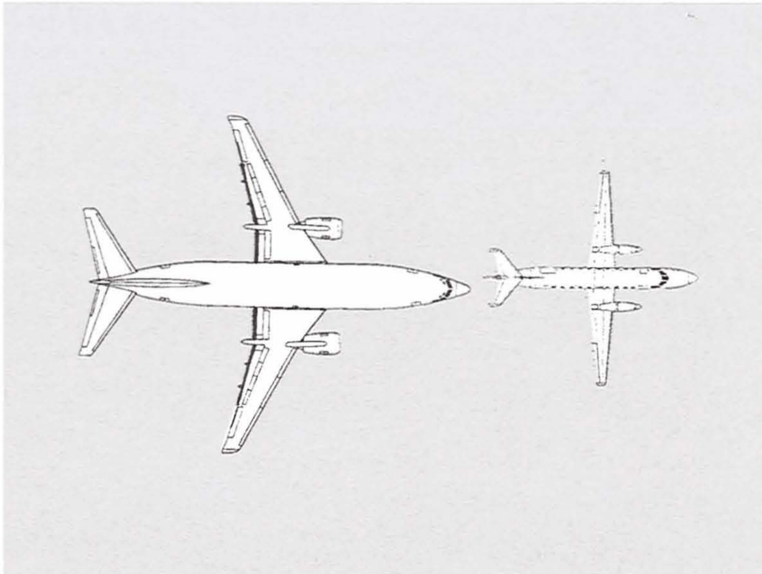


FIGURE 1. Collision geometry in the Los Angeles accident on 1 February 1991. The smaller aircraft was holding in position for takeoff on the runway as the larger aircraft was landing on the same runway.

the most recent major U.S. runway-conflict accident, at Los Angeles International Airport on 1 February 1991 [3]. DA(tc), on the other hand, denotes a situation in which an aircraft is taking off on a runway that is still occupied by a prior arrival. The distinction is important because the available warning time is often considerably less in the second case than in the first.

The conflict classification does not depend on an estimate of the speed of the aircraft (in the Los Angeles accident, the departing aircraft was actually holding in position on the runway, but it need not have been), just its phase of operation. This is appropriate for purposes of classification for two reasons. First, detailed information about aircraft speed is seldom available in accounts of conflict incidents in which damage and injury was averted and no investigation was carried out. Second, aircraft speed usually varies during the evolution of the scenario. The details of the dynamics of motion are often important for the outcome of the situation, but they ought not affect the classification.

From the above discussion we see that an aircraft's phase of operation is broadly defined. Broad definitions are chosen deliberately to bring out the statistical pattern in the conflicts. An aircraft is considered to be an arrival until it is ultimately clear of the runway. An aircraft is considered to be a departure from the moment it enters the runway zone for the purpose of taking off. This operationally based scenario-classification scheme is used only for the purposes of classifying runway conflicts in this survey. The safety logic that drives the runway-status lights uses a related but different classification scheme. It classifies targets according to their dynamic state and state history—essentially, their present and past velocity and acceleration.

There is also a secondary but nevertheless important reason for choosing a simple classification scheme. This reason has to do with establishing a perspective on the problem and developing an intuitive grasp of the pattern of conflict scenarios. Both are easier when the number of conflict categories is small.

Runway-Conflict Accidents

The first step in assessing the potential effectiveness of an airport safety system is to evaluate the contribution the system could have made in past accidents, had it been in place. Table 2 lists ten fatal or otherwise major runway-conflict accidents that have occurred since 1972. Eight of these accidents happened in the United States and two happened at foreign airports. Other major accidents occurred in this time period, but the ten listed in the table are the ones for which sufficient information was readily available. The accidents are listed in inverse chronological order and further identified according to scenario category. The death toll in the eight fatal accidents ranged from one to 583; the latter represents the worst disaster in the history of commercial aviation.

Table 2 also shows which of the three elements—surface-surveillance radar, a tower-cab alerting system, and runway-status lights—of an integrated airport safety system would have been the best defense against each of the accidents. By best defense we mean the safety element that would have broken the error chain leading to the accident earliest or most decisively. In other words, the best defense is the most robust defense—the defense that is least dependent on things going just right.

The technology needed for an effective airport safety system was unavailable during much of the time span of the accidents listed in Table 2, especially in the areas of signal processing and computing. The exercise of analyzing past accidents to determine how they could have been prevented must therefore be understood for what it is: an attempt to learn from past misfortune. This exercise is not meant to suggest that the safety systems identified as potentially effective could actually have been in place at the time. Nor are they necessarily a cost-effective option at the particular airports in question, even today. Such speculations are not the issue. The purpose here is to understand past accident scenarios so as to learn what can prevent a similar accident from happening in the future.

A study of the scenarios of the ten accidents in Table 2 reveals that no one safety element is capable of providing effective protection in all of these different situations, but the three elements working in concert could have done so with high probability. In some instances there is more than one line of defense. When this is the case, a complete safety system would have provided *defense in depth*, thus enhancing the system's overall robustness and effectiveness.

Three of the ten accidents probably could have been prevented if the controller had had the support of a good surface-surveillance radar. The most recent of the three, which occurred at Detroit, Michigan, on 3 December 1990 [2], happened when the pilots of one aircraft became disoriented in dense fog and inadvertently entered the active runway, causing a collision with another aircraft that was in the process of taking off. Figure 2 illustrates the geometry of this

Table 2. Accidents and Best Defense

Event	*Category*	*Best Defense*		
		ASDE	Alert	Lights
Los Angeles 1991	AD(tc)		✔	
Detroit 1990	DT(ho)	✔		
Atlanta 1990	AA(tc)		✔	
Birmingham 1985	AD(tc)		✔	
Anchorage 1983	DD(ho)	✔		
Sioux Falls 1983	RC(veh)	✔		
Madrid 1983	DT(cr)			✔
Chicago 1979	AT(cr)			✔✔
Tenerife 1977	DT(ho)			✔
Chicago 1972	DT(cr)			✔✔

✔✔ indicates that runway-status lights are the only effective defense in these time-critical conflicts.

collision. Another accident, at Anchorage, Alaska, on 23 December 1983 [9], likewise occurred in dense fog; in this case crew disorientation was also a major factor. The Anchorage pilots commenced takeoff on the wrong runway, from an intersection only about 2400 feet from the departure end, and collided head on with an aircraft that was holding in position there, waiting for the visibility to improve. Given the poor visibility at the time of these two accidents, the controller's attention probably would have been focused on the ASDE radar display, which would have enabled him to observe the errant aircraft and issue corrective instructions long before a critical situation developed.

Three days before the Anchorage accident just described, a collision had occurred at Sioux Falls, South Dakota, between a landing aircraft and a snow sweeper in the process of clearing snow from the active runway [10]. The sweeper, which was nearly invisible in the prevailing white-out conditions, was not noticed by the landing crew until it was too late to avoid the collision. The controller apparently forgot that the runway was occupied and cleared the aircraft to land. This lapse might not have occurred had a surface-surveillance radar been available. An audible alert in the tower cab would have presented an effective second line of defense in the event the controller had failed to notice the developing conflict on the radar screen.

Runway-status lights—specifically, takeoff-hold lights—would have provided a solid second line of defense in the Detroit accident. The departing pilots would have seen these lights as they taxied onto the runway for takeoff, indicating that the fog-shrouded runway ahead was not clear and that conditions were unsafe for the plane to take off. Takeoff-hold lights would have offered a robust defense in this situation; they are nevertheless relegated to secondary status on the assumption that a good ASDE radar would have given the controller the means to break the sequence of events long before it got to this point. This acci-

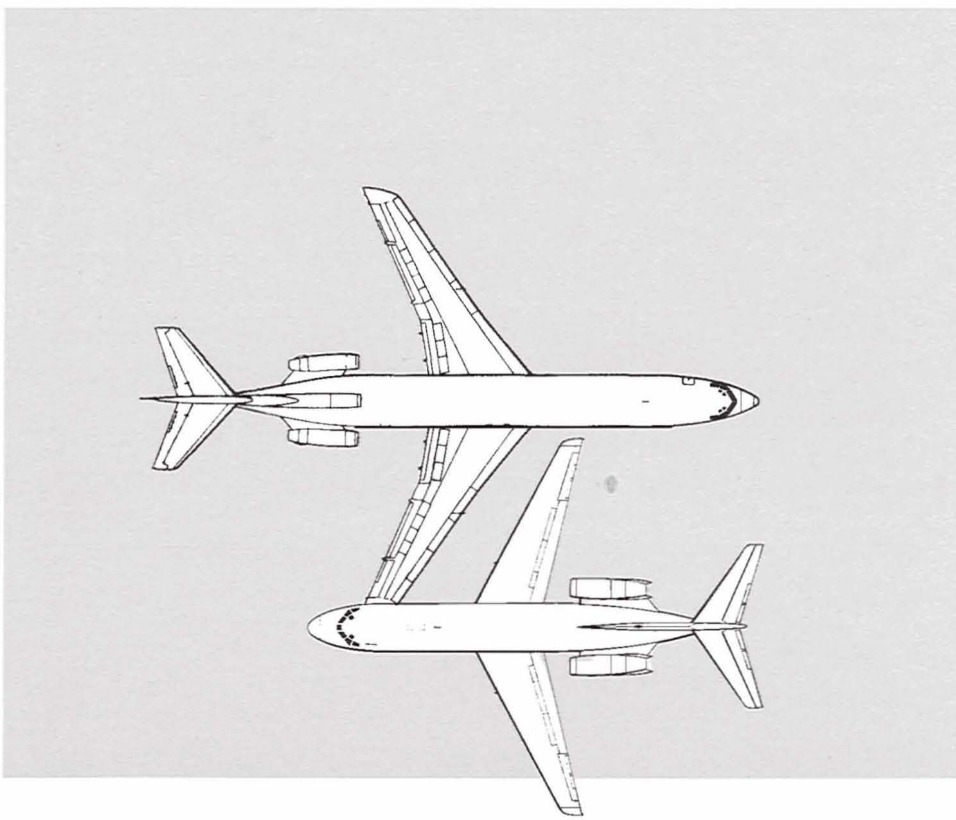


FIGURE 2. Collision geometry in the Detroit accident on 3 December 1990. The pilots of the smaller aircraft became disoriented in dense fog and inadvertently entered an active runway, causing a collision with another aircraft that was taking off.

dent scenario provides a good illustration of the concept of defense in depth.

Another three accidents, at Los Angeles, California, on 1 February 1991 [3], at Atlanta, Georgia, on 18 January 1990 [1], and at Birmingham, Alabama, on 20 June 1985 [11], could have been prevented by a tower-cab alerting system. All of these accidents involved landing on an occupied runway. A surface-surveillance radar by itself probably would not have been sufficient, because the accidents occurred under conditions of good visibility and heavy controller work load. In such circumstances, the air traffic controller tends to control traffic by direct observation out the window, and the occasional brief visual scan of the ASDE radar display would probably not have brought the impending conflict to the controller's attention. A runway-status-light system would have played no role in these three accident scenarios; thus a tower-cab alerting system would have provided the only high-confidence defense.

The remaining four accidents, at Madrid, Spain, on 7 December 1983 [12, 13], at Chicago, Illinois, on 15 February 1979 [14], at Tenerife, the Canary Islands, on 27 March 1977 [15], and at Chicago on 20 December 1972 [16], could probably all have been prevented by runway-status lights. The first and last of these accidents involved a collision between one aircraft taxiing across a runway and another on its takeoff roll, in the process of rotation and lift-off. Both accidents occurred in heavy fog. An analysis of the time line for this type of conflict shows that runway-entrance lights can prevent a runway incursion in almost all situations. In rare circumstances, such as when the runway crossing is performed at exceptionally low taxi speed, protection is provided by the takeoff-hold lights instead.

The 1979 accident at Chicago involved the crash of a heavy freighter aircraft that was forced to swerve off the runway just after touchdown, to avoid colliding with another aircraft that was crossing the runway. The visibility was poor at the time, with low ceiling, drizzle, and fog; yet much of the airport surface, including the area of the conflict, could be seen from the tower cab. There were 122 passengers and crew on board the two aircraft, which missed colliding at high speed by an estimated ten feet. Figure 3 shows a reconstruction in plan view of the near-collision geometry of this accident, based on the official accident report by the National Transportation Safety Board [14]. This runway incursion and the accident that resulted could have been prevented by runway-entrance lights, which would have caused the taxiing pilot to stop well short of the runway. The time-line graph in Figure 4 details the events immediately preceding the runway excursion; this figure also indicates when (at the latest) the runway-entrance lights would have turned on in front of the taxiing aircraft and when an alert would have sounded in the tower cab. Figure 4(b) is a ground view of the positions of the two aircraft at the time of the near miss.

The Tenerife collision was the result of an unauthorized takeoff on an occupied runway. As with four of the accidents described above, the Tenerife collision occurred in heavy fog. It could have been prevented by takeoff-hold lights, which would have given an unambiguous indication to the crew that the runway was not clear. In this particular scenario, the

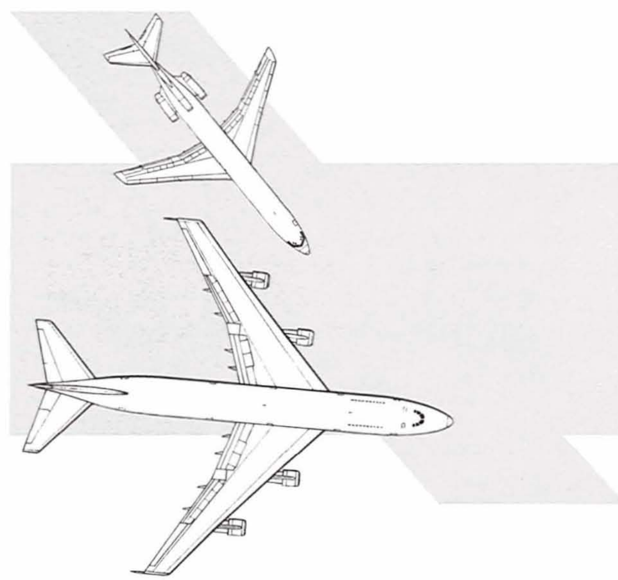
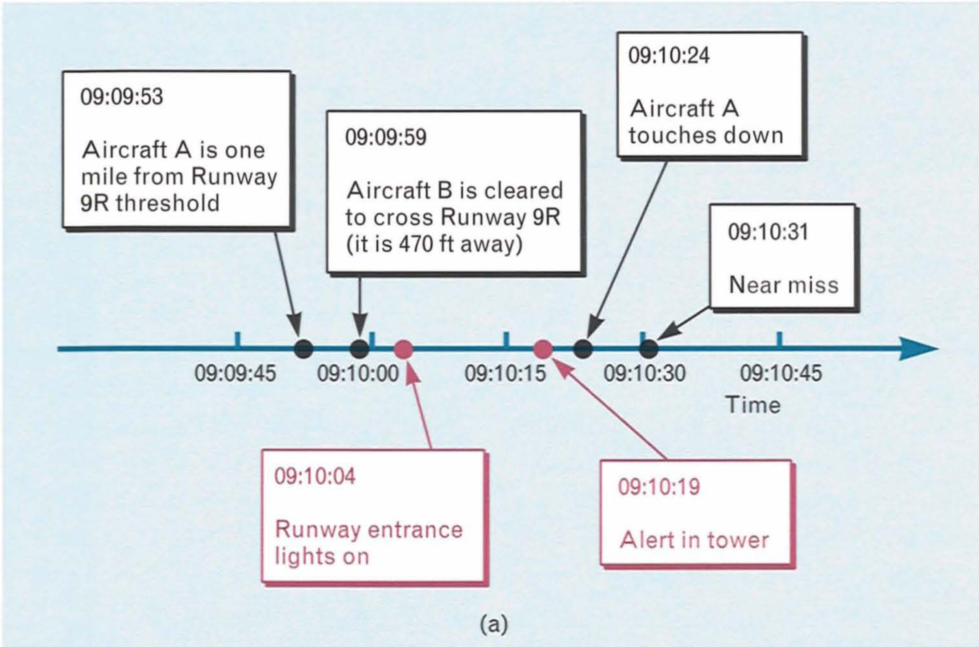


FIGURE 3. Near-collision geometry in the Chicago accident on 15 February 1979, in which a heavy freighter aircraft was forced to swerve off the runway just after touchdown to avoid colliding with another aircraft that was taxiing across the runway. The two aircraft missed colliding at high speed by an estimated ten feet. This plan view is a reconstruction of the positions of the two aircraft, based on the official accident report by the National Transportation Safety Board.



(b)

FIGURE 4. (a) Time line for the Chicago accident on 15 February 1979, showing the sequence of events immediately preceding the runway excursion by the landing aircraft. (b) A ground view of the two aircraft at the time of the near miss. The runway incursion by the taxiing aircraft and the accident that resulted could have been prevented by runway-entrance lights, which would have caused the taxiing pilot to stop well short of the runway. The red boxes in part *a* indicate when (at the latest) the runway-entrance lights would have turned on in front of the taxiing aircraft and when an audible alert would have sounded in the tower cab.

takeoff-hold lights would have been illuminated for more than a minute while the crew was holding in position at the end of the runway and awaiting takeoff clearance. The lights would have remained illuminated as the crew prepared to advance the throttles in the mistaken belief that they were cleared for takeoff. The illuminated lights would in all likelihood have caused the crew to question the clearance they believed they had received, but that in reality had not been issued. Figure 5 shows the collision geometry and Figure 6 shows the time line for the Tenerife accident. The red boxes in Figure 6(a) indicate approximately when the takeoff-hold lights would have illuminated and when an audible alert would have sounded in the tower cab. Figure 6(b) is a ground view of the two aircraft an instant before the collision. Both Figure 5 and Figure 6 are reconstructed from a transcript of the official Spanish accident report [17] and a supplementary report issued by the Dutch authorities [18].

In only two of the above ten accident scenarios does there appear to have been a solid secondary defense that would have contributed to preventing the accident. A secondary defense could perhaps also be postulated for some of the other accidents, but it would not be a robust one. The Tenerife accident is a case in point; an ASDE radar might possibly have allowed controller intervention in this scenario just in time. But intervention would have been possible only if the controller had been consulting the ASDE radar display within the first ten or fifteen seconds after the beginning of the takeoff roll, which cannot be assumed. A tower-cab alerting system would not have sounded the alarm until the safety logic had determined that a takeoff was in progress. In a practical alerting system this determination would be made some ten seconds into the takeoff roll, leaving little time for the controller to warn the pilot and for the pilot to abort the takeoff safely. Likewise, there would have been little time for the other aircrew to exit the runway. Thus, even with a radar and alerting system in place, the outcome would have been uncertain at best. Similar arguments and similar reservations apply to some of the other runway-conflict events, including the accidents in Chicago in 1972 and 1979. An ASDE radar was in use at the time of both of these accidents, but for a variety of reasons it did not help the controller to notice the developing conflict.

Conceivably, basic surface-movement aids such as standardized conspicuous signs and markings would have been useful in some of these accident scenarios. Such fundamental and relatively inexpensive remedies might have helped when crew disorientation was a factor in the events, such as in the Detroit accident and in one or possibly two of the accidents in 1983. Furthermore, taxi hold-position (wig-wag) lights might have helped at Detroit in 1990, as well as at Chicago in 1972, but only if they had been installed at taxiways near the runway midpoints.

Runway-conflict accidents seem to occur mainly when the visibility is poor, but we should note that this is not true in general for high-hazard conflict incidents in which a collision was averted by a narrow margin. If surface-movement guidance and control lights—in particular, wig-wag lights—are intended only for low-visibility conditions, history suggests that they will not play a major role in reducing high-hazard incidents.

Table 2 might give the impression that the types of accidents that are likely to occur in today's airport environment can be addressed with a good surface surveillance-radar system coupled with a tower-cab alerting system, and that the need for runway-status lights is for some reason less acute now than in the past. This type of conclusion cannot be justified on the basis of the limited data of Table 2. A larger database, which can be constructed by adding high-hazard near-miss conflicts to the accidents, shows that time-critical conflicts continue to occur. Thus the need for runway-status lights remains.

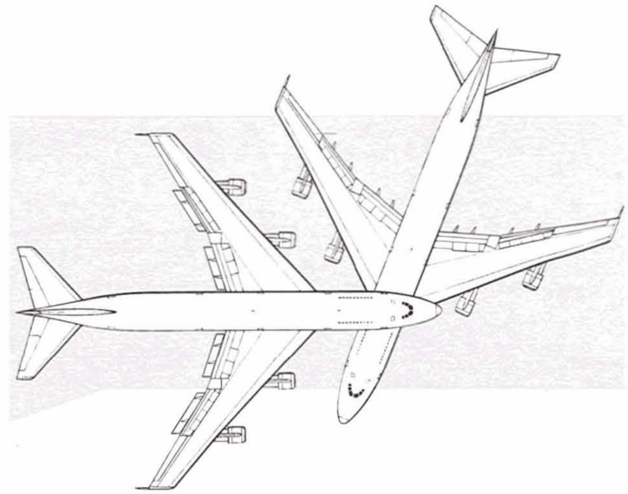


FIGURE 5. Collision geometry in the Tenerife, Canary Islands, accident on 27 March 1977. This accident, which occurred in heavy fog and resulted in the loss of 583 lives, was the result of an unauthorized takeoff on an occupied runway. It represents the worst disaster in the history of commercial aviation.

Incident Data Sources

Reports on runway-conflict incidents are available from two primary sources: the Aviation Safety Reporting System (ASRS) [19, 20] and the FAA. The ASRS collects incident reports that are submitted voluntarily and anonymously by flight crews and air traffic control personnel. ASRS database management and analysis is performed by Battelle Memorial Institute for the National Aeronautics and Space Administration (NASA Ames), under contract from the FAA. The FAA maintains its own database on certain errors committed by air traffic controllers, aircrews, and vehicle operators or pedestrians on the airport surface. These errors are called operational errors, pilot deviations, and vehicle/pedestrian deviations, respectively,

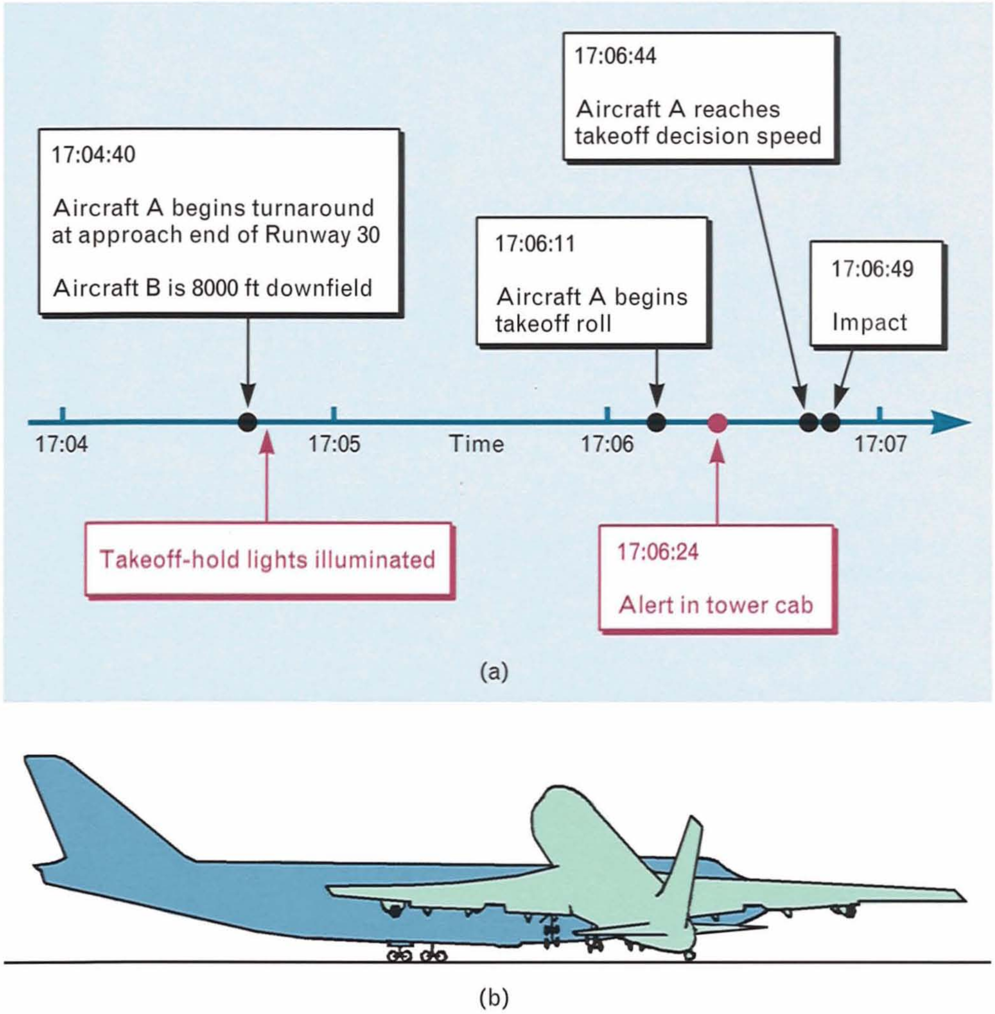


FIGURE 6. (a) Time line for the Tenerife accident, showing the sequence of events immediately preceding the collision. (b) A ground view of the two aircraft moments before the collision. This accident could have been prevented by takeoff-hold lights, which would have given an unambiguous indication to the crew of the departing aircraft that the runway was not clear. The red boxes in part *a* show the approximate time the takeoff-hold lights would have been illuminated and when an audible alert would have sounded in the tower cab. In this scenario, the takeoff-hold lights would have been illuminated for more than a minute while the crew was holding in position. The illuminated lights would have caused the crew to question the takeoff clearance they believed they had received, but that had not been issued.

with the adjective *surface* (where appropriate) when the error occurs on the airport surface.

The ASRS database has been in existence since 1975 and by 1993 had grown to more than 250,000 reports [20]. Fewer than 5% of these reports pertain to runway transgressions (excluding unauthorized landings) or ground conflicts, and only a small fraction of these have to do with near-miss runway conflicts at major airports. The FAA collects surface operational-error, pilot-deviation, and vehicle/pedestrian-deviation reports at a rate of about two hundred per year, and again, only a small fraction of these pertain to near-miss conflicts at major airports.

We must note an important distinction between the ASRS and FAA databases. The former is made up of reports submitted on a voluntary basis, in most cases based on one person's perception of an incident, and subjected to little or no follow-up investigation.

Misperceptions and various kinds of biases cannot be ruled out, and this aspect of the ASRS must be kept in mind. The FAA reporting system, by contrast, is a more structured program. It is mandatory, formal, and less subjective than the ASRS. Both databases are important and valuable resources.

The ASRS and FAA databases have developed under different circumstances and with different ground rules. It would seem to be significant, therefore, if the patterns of incident reports produced by the two were found to be consistent. Such an agreement would suggest that the database patterns were indeed reflections of real patterns in airport operations.

Most of the data presented in this article are derived from the ASRS database. The fact that the ASRS incident reports are anecdotal and unverified is unlikely to affect the survey's conclusions, because the purpose of the survey is to classify incidents in terms of broad scenario categories. No obvious mechanism exists that would systematically skew the distribution over these categories. It could be argued that a high-profile accident and the resulting heightened awareness might result in more frequent reporting of similar incidents for a while, thus biasing the data, but this effect is likely to be a relatively short-lived phenomenon with little impact on multiyear averages, such as those presented here. In any event, no such trend is evident.

Incident Data

The ASRS database contributed more than 80% of the runway-conflict reports used in the present analysis. The remainder were FAA operational-error and pilot-deviation reports. The two databases produced essentially the same picture with regard to the types of near-miss conflicts that were reported.

In analyzing the ASRS reports we assumed that the event occurred essentially as described, unless there was compelling evidence to the contrary. The reports were thoroughly studied in an effort to extract the in-

GLOSSARY OF CONFLICT DEFINITIONS

Operational Error An occurrence attributable to an element of the air traffic control system which results in less than the applicable separation minima between two or more aircraft, or between an aircraft and terrain or obstacles and obstructions as required by Handbook 7110.65 [Air Traffic Control] and supplemental instructions. Obstacles include vehicles/equipment/personnel on runways. *(FAA definition)*

Pilot Deviation The actions of a pilot that result in the violation of a Federal Aviation Regulation or a North American Aerospace Defense Command (NORAD) Air Defense Identification Zone (ADIZ) tolerance. *(FAA definition)*

Runway Incursion Any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing, or intending to land. *(FAA definition)*

Vehicle/Pedestrian Deviation An entry or movement on an airport movement area by a vehicle operator or pedestrian that has not been authorized by air traffic control (includes aircraft operated by a nonpilot). *(FAA definition)*

Runway Transgression Any erroneous occupation of a runway at a controlled airport by an aircraft or other controlled vehicle. *(NASA definition)* formational content of the narrative. Locations, distances, velocities, and other information in the narratives were carefully noted and employed in various cross checks to verify internal consistency. In this process we used airport maps and a knowledge of airport operations and general aircraft dynamics to the extent possible. In cases when additional reports were submitted by another aircrew or controller, further cross checks were sometimes possible. In general, we assumed that the pilots and others who report an incident by and large do so for good cause and attempt to describe the event accurately, and that what amounts to minor deviations from normal traffic conditions does not move pilots or controllers to file reports.

A total of 1123 ASRS reports were screened to extract reports of interest. The 1123 reports represent all the full-form reports (i.e., all the reports that contain a narrative description of the event) classified as *conflict/ground-critical* for the period from January 1986 through March 1992. This classification is rather broad and includes conflicts that are of no interest for the purposes of this analysis, such as gate and ramp conflicts and other off-runway taxi conflicts. This broader classification was nevertheless used instead of a more specific subset requiring that the event also be a runway transgression, because the latter was found to exclude some conflicts that were of interest.

The first step in the screening process was to eliminate reports that did not pertain to runway conflicts. The remaining reports were further screened on the basis of airport size and aircraft category. The airport-size filter eliminated reports from smaller airports, retaining only those from the busiest one hundred U.S. airports, as ranked by 1988 enplanements. The aircraft-category filter eliminated conflicts between small aircraft weighing less than 5000 pounds. Only a few reports were rejected in this step, because most of the reports describing such conflicts had already been eliminated by the airport-size filter.

The final step was to screen the remaining reports on the basis of miss distance. Because the main purpose of an airport safety system is to prevent runway collisions, we chose to adopt a stringent miss-distance criterion; that is, we wanted to focus on incidents that almost resulted in a collision. This emphasis on critical conflicts does not imply, of course, that less critical conflicts are necessarily less significant. Many such occurrences yield important insights into the chain of events that lead to conflicts. Many might also have resulted in critical conflicts under slightly different circumstances. Nevertheless, emphasizing the near-miss incidents makes sense in the present context. It focuses attention on those situations in which the system as it now exists came close to breaking down, that is, when most of the built-in safeguards and backups—human, technical, or procedural—failed. This kind of situation is precisely where an airport safety system would make its most important contribution.

The miss-distance screening eliminated reports in which the miss distance appeared to have been more than one hundred feet. There is one exception: occasionally the screening criterion was generalized to be spatiotemporal. This generalization was allowed to include certain conflicts involving a high-speed near miss in the horizontal plane, where two aircraft occupied the same spot on the airport surface within approximately two seconds or less. The miss distance in these cases could be as much as four hundred feet. In any event, the intent of the miss-distance screening, whether based on a spatiotemporal or purely spatial filter, was to pass only critical conflicts. A certain amount of judgment was sometimes involved because of the nature of the reports. We can account for the resulting uncertainty by viewing the miss-distance filter-cutoff characteristics as quasi-probabilistic. This aspect of the screening process does not introduce distortion in the distribution of the reported conflicts over the scenario categories.

Some reports were excluded even though the miss distance appeared to be on the order of one hundred feet. These reports were excluded when the narrative suggested that the particular situation described was under control and little danger existed; the report was filed more to call attention to a *potential* for critical conflict than to describe an actual critical occurrence. Examples include go-arounds (whether initiated by pilot or controller) executed at or near the missed-approach point because of an occupied runway, even though in some cases the vertical separation may have been as little as one hundred feet. Likewise, reports describing the crossing of a hold line by an unspeci-

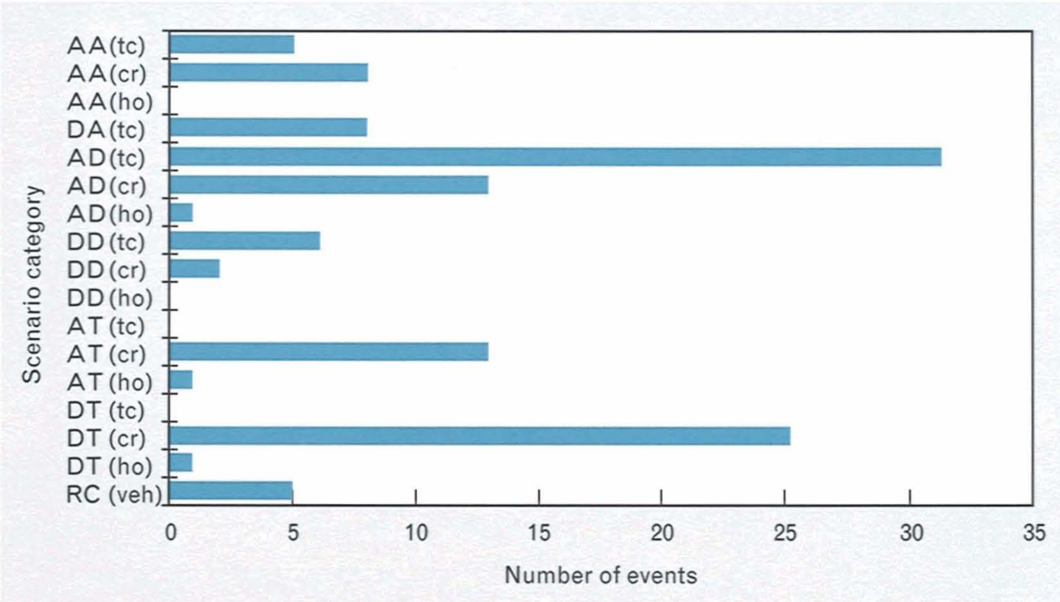


FIGURE 7. The distribution of the 119 near-miss runway-conflict incidents as taken from the Aviation Safety Reporting System (ASRS) database, for the busiest one hundred U.S. airports from January 1986 through March 1992. These incidents are classified according to the seventeen scenario categories listed in Table 1. The four scenario categories most heavily represented account for 70% of the reported incidents, while the eight that are least represented account for only 5% of the reported incidents.

fied amount are generally not counted, unless the report conveyed a distinct sense of danger.

The screening process reduced the 1123 reports to a total of 133, representing 119 different events. This corresponds to a yield of approximately 12% of the complete conflict/ground-critical database for the period, or approximately 0.2% of all reports with narratives. The one hundred airports included in the survey account for over 90% of all operations at airports with air carrier service, representing more than seventy million operations for the period of interest [21]. Fewer than sixty of the one hundred airports contributed reports that passed the miss-distance filter.

Figure 7 shows the distribution of the 119 ASRS incidents over the seventeen scenario categories described in connection with Table 1. The categories are arranged from top to bottom according to the columns of Table 1, with the vehicle category RC(veh) last. The distribution reveals a definite pattern in the incident reports: the four scenario categories that are most heavily represented account for 70% of the reports, while the eight that are least represented account for only about 5%.

A partial search of the FAA operational-error and pilot-deviation databases produced results broadly consistent with Figure 7. Applying the same screening process to operational-error reports from January 1986 to September 1989 and pilot-deviation reports from December 1987 to November 1989, we identified a total of twenty-six reports—nineteen operational errors and seven pilot deviations. Nine of them referred to incidents that had also resulted in reports to the ASRS. The total from both the ASRS and FAA databases was therefore 136 near-miss incidents. Approximately two-thirds of the FAA reports (seventeen out of twenty-six) belonged in the four main scenario categories.

The 136 near-miss incidents from the ASRS and FAA databases are combined in Figure 8, with the scenario categories rearranged so that the four major categories are at the top and the eight minor ones at the bottom. In between are the five intermediate categories that together account for about 25% of the reports. No great significance should be ascribed to the exact arrangement of categories within the groups. An overly rigid interpretation of the division between

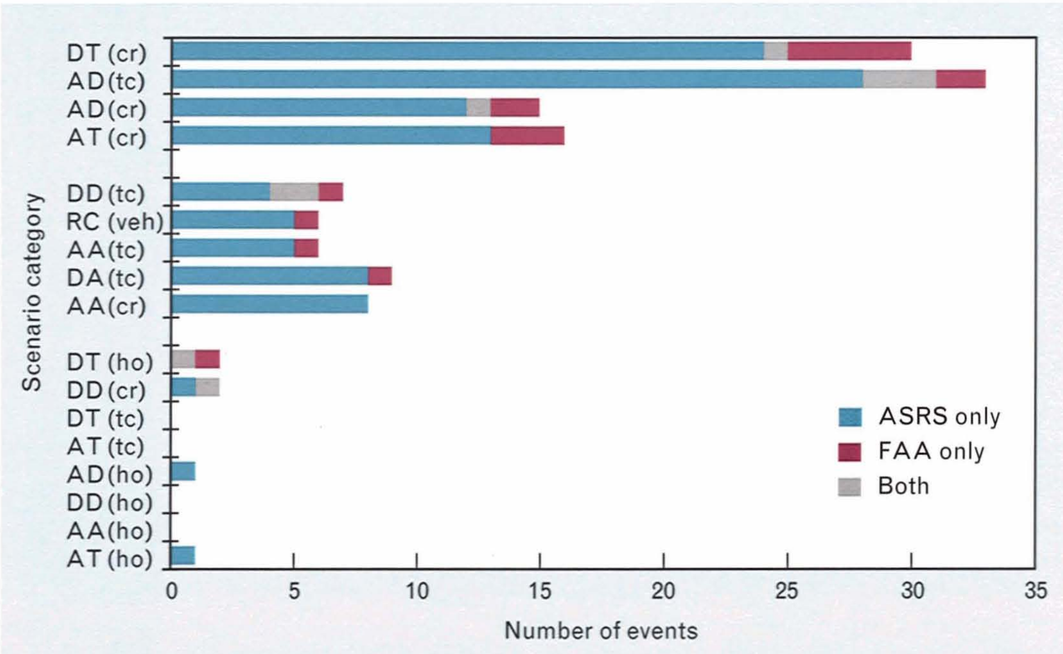


FIGURE 8. The near-miss runway-conflict incidents from the ASRS database (as shown in Figure 7) with the addition of operational-error and pilot-deviation reports from the FAA database. The 136 incidents are arranged so that the four major conflict categories are at the top of the figure and the eight minor categories are at the bottom. These categories account for 70% and 5%, respectively, of the reported conflicts. The five intermediate categories shown in the middle of the figure together account for approximately 25% of the reported conflicts.

groups or the ranking of categories within a group is neither justified nor necessary for the present purposes; it is sufficient to be able to identify a primary, secondary, and tertiary group, approximately as shown.

An interesting fact comes to light when we read the reports describing these 136 conflicts: only about 20% occurred in instrument meteorological conditions, the rest in visual meteorological conditions. This division is different from what was found for the major runway-conflict accidents, most of which happened in poor visibility. We might have expected that critical conflicts of the type discussed here, in which a collision was averted by a narrow margin, should reflect a markedly greater predominance of low-visibility conditions than airport traffic in general. Such an effect, if it exists at all, is evidently not pronounced.

The last step in the screening process for the ASRS reports—namely, the application of the miss-distance filter—reduced the number of reports for the period from January 1986 to March 1992 from 310 to 133 and the number of reported events from 293 to 119. Of the 293 events that passed the screening steps before the application of the miss-distance filter, 13 occurred in the first three months of 1992; the total for the six-year period from January 1986 through December 1991 was therefore 280 reported events. Figure 9 shows the distribution of these 280 events over the scenario categories. Figure 9(a) shows the distribution for the period 1986 through 1991 while, for comparison, Figure 9(b) shows the distribution for the three-year periods 1986 through 1988 and 1989 through 1991. The similarity to the distribution of Figure 8 is evident. The major conclusions that can be drawn from Figure 8 for critical conflicts can thus also be drawn from Figure 9 for more general conflicts. Apparently, the application of the miss-distance filter does not materially affect the distribution of the reported runway-conflict events over the categories.

This insensitivity to the miss-distance filter is not an obvious feature of the distribution. The number of critical-conflict reports found for a given scenario category should depend not only on how frequently this type of situation is encountered in normal airport operations, but also on the probability that this type of

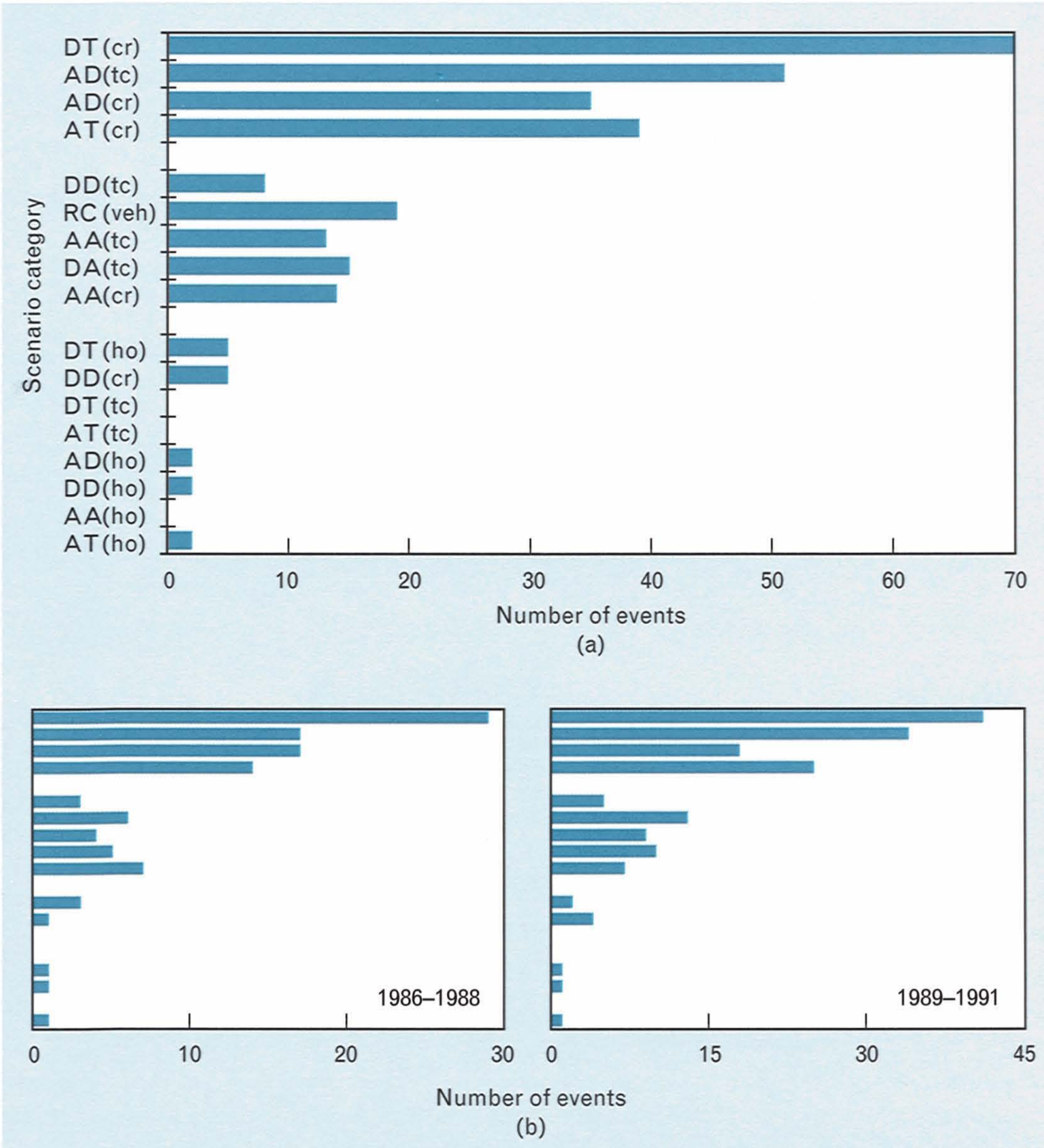


FIGURE 9. (a) Reported runway-conflict events classified Conflict/Ground Critical in the ASRS database for one hundred U.S. airports, for the six-year period from January 1986 through December 1991. (b) For comparison, the figure shows the distribution of these events for the three-year periods from 1986 through 1988 and 1989 through 1991.

scenario gives rise to a reported critical conflict. In principle there could be wide variability in this second factor, and such variability should manifest itself as a gradual change in the distribution as the miss-distance filter is tightened or relaxed. A hint of this kind of effect exists in the second scenario category, AD(tc), and also in some of the categories of the second group. With regard to the AD(tc) category in particular, a greater than average fraction of the reported conflicts describe near misses. This observation, while perhaps not surprising, must nevertheless be viewed as tentative.

Figure 9(b) shows the distribution of incidents separately for the first three years and last three years of the six-year period. The patterns show a general consistency, suggesting that the multiyear average distribution of reported incidents does not vary significantly over time. Again, there appear to be relatively

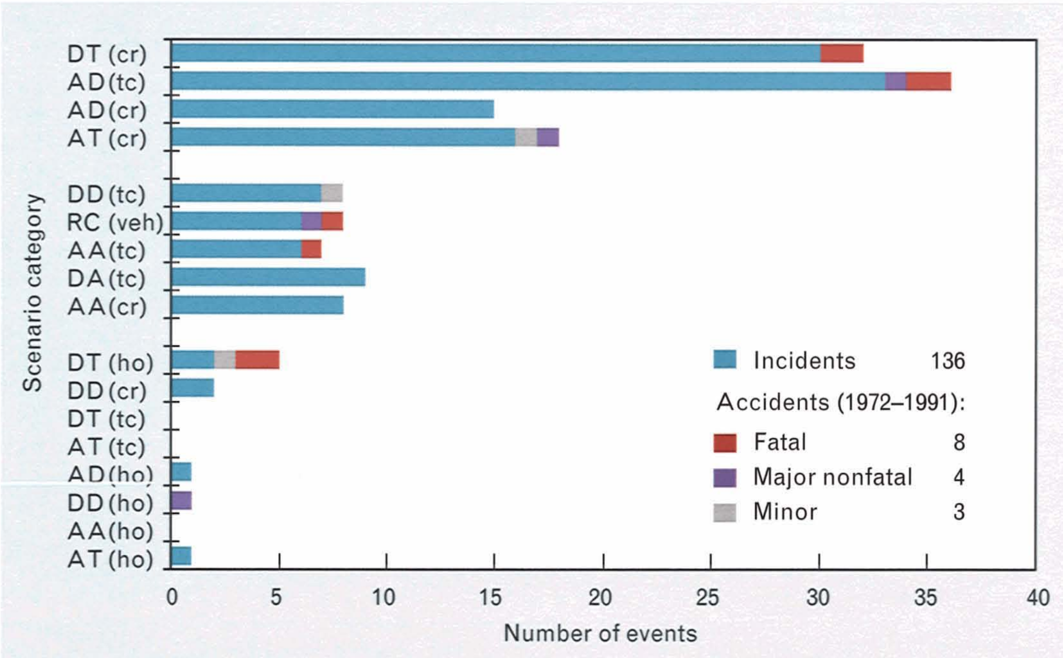


FIGURE 10. The 136 near-miss runway conflicts from the ASRS and FAA databases, as shown in Figure 8, combined with fifteen runway-conflict accidents from the eighteen-year period from late 1972 to early 1991. This figure shows that the accident pattern is roughly consistent with the pattern of near-miss incidents.

more reports in the second scenario category during the second three-year period. We might perhaps suspect that this increase is due to increased reporting after the fatal accident of this type in Los Angeles early in 1991, but the rate at which this type of incident was reported did in fact not increase that year. Overall, the ASRS runway-conflict-report intake in the second three-year period was about 60% greater than in the first three-year period. No firm conclusion can be drawn from this fact. The string of three runway-conflict accidents in 1990 and 1991 might possibly have resulted in increased reporting of surface conflicts in general, but the trend was also evident in 1989, the year before the first of these accidents.

Figure 10 combines the recent near-miss runway-conflict incident reports of Figure 8 with fifteen accidents from the approximately eighteen-year period from late 1972 to early 1991. These fifteen accidents include the ten listed in Table 2 plus an additional five. Two of the five were major accidents: a collision between a heavy freighter aircraft and a truck at Anchorage, Alaska, on 19 December 1983 [13], and a collision between an air-carrier and a light aircraft at Lille, France, on 5 December 1989 [22]. Both occurred in fog. The three minor accidents occurred in 1978, 1979, and 1987 [23, 24, 25]. A major accident is defined here as one that results in loss of life or serious injury, or destruction of or serious damage to a high-value airframe.

Figure 10 shows that the accident pattern is roughly consistent with the pattern of near-miss incidents, with the exception of the three accidents in the first scenario category, DT(ho), of the third scenario group. There are seven accidents in the first group of four scenario categories, four accidents in the second group of five categories, and four accidents in the third group of eight categories. We emphasize that this correspondence between high-hazard incidents and accidents could not have been expected *a priori*, nor does it necessarily indicate future accident patterns, as the DT(ho) category amply demonstrates. Still, it is a historical fact, important in its own right.

Time-Critical Conflicts

The conflict-scenario categories of Figures 7 through 10 are operational categories. This method of classification is convenient, because it enables us to estimate, directly from the scenario distributions, the roles that a tower-cab alerting system and a runway-status light system could have played in past high-hazard conflicts. The reason this is possible is that certain routine operations in the movement area of a major airport have a well-defined dynamic signature. A runway crossing, for instance, usually involves traveling approximately two hundred meters from hold line to hold line. At typical taxi speeds, the crossing is completed in twenty to forty seconds. The aircraft is therefore on the runway centerline within ten to twenty seconds from the time it enters the runway safe zone, which is the zone where the safety logic recognizes runway entry or occupancy. An analogous argument can be made for departures. Although there are obvious differences between, for instance, a lightly loaded, modern, high-performance twin-engine transport and its heavily loaded, older, four-engine counterpart, most departing commercial aircraft reach a speed of a hundred knots within approximately twenty seconds after the first sign of forward motion. A practical safety logic cannot declare takeoff at the first sign of forward motion, because this would result in frequent false declarations, nuisance alerts, and erroneous light operation. Typically, takeoff is declared about ten seconds into the takeoff roll. Only then could a dangerous situation be recognized by the safety logic. Ten seconds later the aircraft would be traveling at about one hundred knots, and sometimes considerably faster. In some cases the aircraft would be in the process of rotating or even already airborne.

These are generic examples of time-critical scenarios. A warning time of ten or even fifteen seconds is generally not enough to ensure that the controller gets a message out to the flight crew. Furthermore, even if the controller's message did get to the cockpit in as little as twelve seconds, which is near the extreme low end of the distribution of times required to complete the alerting sequence, an aircraft in the process of crossing the runway would already be well onto the runway, and a departing aircraft would be traveling at over one hundred knots and in many instances be approaching rotation speed.

Three of the four scenario categories in the first group in Figure 8 are time critical. The first and fourth categories, DT(cr) and AT(cr), involve aircraft taxiing across the runway. The fact that runway incursions can happen suddenly in these situations has been noted before [19]. The third category, AD(cr), involves departure with an arrival to an intersecting runway. The second category, AD(tc), usually involves an aircraft that has been holding in position on the active runway for some time; conflicts of this type are generally not time critical. The second group of categories is about evenly divided between time-critical and non-time-critical conflicts. We can conclude, therefore, that many of the high-hazard incidents that have been reported at the nation's major airports were time critical.

The predominance of time-critical runway conflicts is reflected in Figure 11. This figure shows the potential effectiveness of the three elements of an airport safety system in the 136 high-hazard runway-conflict incidents represented in Figure 8. A combination of a high-quality surface-surveillance radar and a tower-cab alerting system could have prevented or at least reduced the degree of danger in approximately one-third of the conflicts. Runway-status lights would generally not have been effective in these situations, because the aircraft that was in the best

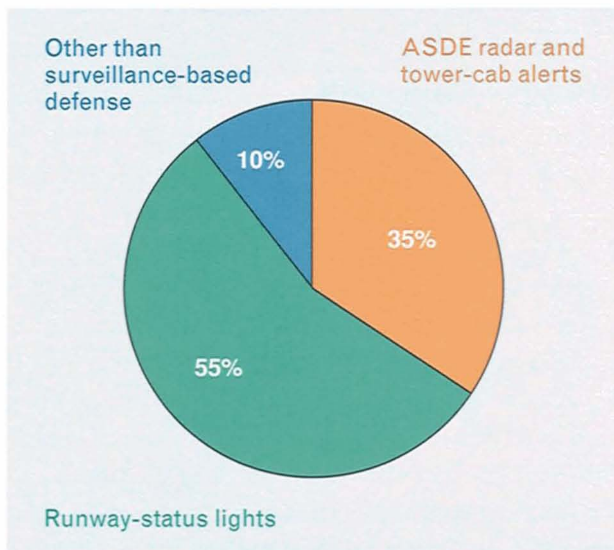


FIGURE 11. The potential effectiveness of the three elements of an airport safety system in the 136 high-hazard runway-conflict incidents shown in Figure 8. The figure shows the probable contributions to airport safety in future runway conflicts, based on historical evidence.

position to take evasive action was on final approach. Runway-status lights are not intended for this situation. These lights, however, would have been the best line of defense in most of the remaining conflicts; overall they would have provided the best defense in about 55% of the conflicts. Most of these conflicts were in fact sufficiently time critical that runway-status lights would have provided the only defense.

The results illustrated in Figure 11 were actually obtained by a detailed study of the 159 individual conflict reports for the 136 reported high-hazard conflict events, and not by the kind of general considerations described above. The two approaches, however, would have produced the same results. There is one exception to this statement. General considerations cannot shed much light on questions relating to the limitations of a surveillance-based safety system. A reading of the individual reports, on the other hand, can. In a small number of the reported events (perhaps 10% or less), no surveillance-based safety system could have been counted on to prevent the conflict. An example of such a situation might be a pilot who lands on an occupied runway against the controller's instructions. The solution in these cases is not to be found in better surveillance and automatic safety systems, but rather in the areas of training, proficiency, and procedures.

Summary and Conclusions

An effective safety system for the airport movement area can be constructed from three functional elements. The first element is a surface-surveillance radar that provides reliable and complete surveillance of the runway environment and gives the air traffic controller a clear, all-weather view of the surface traffic. The second element is an automatic tower-cab alerting system that warns the controller of impending conflicts that may have escaped his or her notice. The third element is a fast-acting runway-incursion prevention system of automatically activated runway-status lights that can prevent those sudden conflicts in which the time available for conflict resolution is too short for the controller to intervene.

The relative utility of these three elements cannot easily be determined from first principles. We must study the history of past runway-conflict accidents and near-miss incidents to learn what conflicts are most likely to happen and what constitutes the best defense in each of the generic conflict-scenario categories. Runway-conflict accidents are exceedingly rare events and, although thoroughly investigated and carefully documented, form too narrow a basis to support general conclusions. A larger database is needed to support general conclusions. Such a database is provided by the history of runway-conflict incidents—specifically, near-miss conflicts in which a collision was averted by a narrow margin. Both the FAA and NASA maintain such databases. The large NASA database—called the Aviation Safety Reporting System (ASRS)—is especially useful for identifying conflict-scenario patterns. A complete survey of a large fraction of this database uncovered a substantial number of reports of near-miss runway conflicts and clearly indicated the major conflict categories.

Two major conclusions emerged from this survey. The first is that the pattern of runway-conflict accidents is generally consistent with the pattern of high-hazard incidents, insofar as the types of conflict scenarios that are represented. In view of the small number of accidents, this conclusion must be viewed as tentative. The second conclusion has a more solid foundation; about half of the reported near-miss incidents were of the time-critical variety, when the conflict develops suddenly and without warning, often from a perfectly routine and apparently safe situation. A tower-cab alerting system, although effective and even essential in many circumstances, cannot provide reliable protection in these situations because of the time required to alert the cockpit crew or vehicle operator to the danger by way of the tower cab and the VHF radio channel. A system of automatic runway-status lights, by contrast, is an effective defense, not only because the lights warn the pilots and vehicle operators directly, but also because the information conveyed relates to runway status rather than an actual conflict situation. In other words, the lights warn about the potential for conflict rather than an actual conflict in the making. The heightened situational awareness that results is important in circumstances in which the potential for a time-critical conflict exists, and in which an automatic surveillance system has no way to identify or predict errors and break the error chain except near the very end when the time available for corrective action is critically short.

In about half of the runway collisions and one-third of the high-hazard incidents the circumstances were such that the conflict probably could have been averted had the controller had the benefit of a surface radar and a tower-cab alerting system. In most of these events we cannot judge whether the conflict would in fact have been prevented by surface surveillance alone, because of uncertainty about whether the controller would have noticed the developing conflict on the surface-traffic display. In some situations in which the events unfolded over an extended period, and especially when the visibility was poor or when radio communication suggested that crew disorientation was a problem, a good surface-traffic display by itself probably would have given the controller the means to detect and assess the situation in time to take appropriate action. But such relatively clear-cut cases are the exception rather than the rule. In general, we cannot assume that a controller would notice a developing conflict on the surface-radar display under conditions of good visibility when the controller's attention is probably directed out the window; an audible alert is required to ensure that the controller becomes aware of the situation. The controller can then issue the appropriate resolution advisories to the crew or crews involved—if there is enough time.

The history of past runway-conflict accidents and high-hazard incidents shows that no one technology can prevent all types of runway conflicts. Surface-surveillance radar, automatic tower-cab alerts, and runway-status lights are all needed.

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