FLIGHT AND CABIN CREW RESPONSE to in-flight smoke

SAFETY

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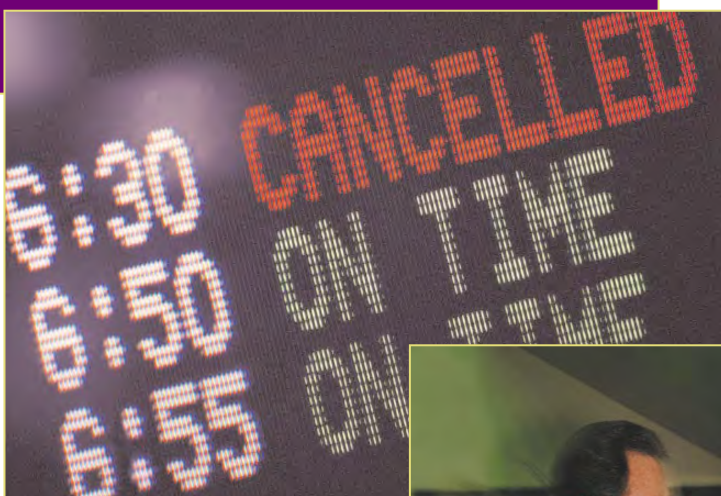
Engineering design by airplane manufacturers, oversight by regulators, and maintenance practices by operators combine to minimize occurrences of smoke, fumes, and fire in the pressurized areas of airplanes. When smoke does occur, timely and appropriate action by the flight and cabin crews is imperative. Boeing has analyzed in-service smoke, fumes, and fire events and reviewed airplane systems and crew procedures for its commercial airplane models.

An in-flight fire or smoke event is a time-critical situation that demands immediate action by the flight and cabin crews. Cigarettes aside, any smoke in an airplane is not normal. Crew response must be timely and use available airplane controls and non-normal procedures.

To help ensure that appropriate steps are taken, the following issues need to be understood:

1. Operational consequences and safety risks of smoke events.
2. Analysis of past smoke events and review of crew procedures.
3. Recommended crew action for known and unknown smoke sources.
4. Capabilities for the remainder of the flight.



1 OPERATIONAL CONSEQUENCES AND SAFETY RISKS OF SMOKE EVENTS

Although most smoke events in the pressurized area of an airplane are resolved and rarely affect continued safe flight, landing, or egress, smoke is always a significant issue with operational consequences. These consequences include flight cancellations, flight schedule disruptions, air turnbacks, airplane diversions, declared emergencies, airport emergency equipment responses, airplane evacuations, accommodations for displaced passengers, diminished goodwill, and extensive unscheduled maintenance following non-normal procedures such as overweight landing inspection, recharging of oxygen, and repacking of escape slides.

Direct crew response to smoke and fumes originating from readily accessible equipment, referred to as *known smoke*, is key to minimizing operational consequences. Timely and prudent crew response to smoke events of undetermined origin, or *unknown smoke*, minimizes risks during the remaining flight, landing, and egress.

Based on past smoke events, Boeing and other air transport industry leaders are pursuing initiatives to further reduce the likelihood of in-flight smoke. In addition to enhancements to

airplane design and maintenance (see “Aging Airplane Systems Investigation,” *Aero* no. 7, July 1999), these initiatives include improvements to the procedures used by the flight and cabin crews during a smoke event in the pressurized area of the airplane.

2 ANALYSIS OF PAST SMOKE EVENTS AND REVIEW OF CREW PROCEDURES

Boeing performed an analysis of reported in-service events that involved smoke, fumes, fire, and overheating in the pressurized areas of its airplanes between November 1992 and June 2000. Data were compiled for each model and included the following: the area affected in the pressurized area of the airplane, the smoke source perceived by the flight crew, the smoke source identified by the maintenance crew, the category of the smoke source, the airplane system or equipment involved, the means of detection (typically sight or smell by passengers or crew), and the effect on flight completion. (*Note:* The term *smoke* in the preceding list and in the remainder of this article refers to odors, smells, fumes, or overheating as well as visible smoke.)

The smoke events under study were categorized into three classes: air conditioning, electrical, and material. Air-conditioning smoke events were cases in which incoming bleed air was contaminated, perhaps from engine oil or contaminated outside air. Electrical events were cases in which electrically powered equipment overheated or emitted smoke or fumes. Material events involved material that gave off smoke or fumes such as food burning in an oven, lavatory waste ignited by a discarded cigarette, or spilled chemicals in the cargo compartment.

Figure 1 depicts a summary profile of air-conditioning, electrical, and material smoke events for each airplane model included in the study. This format enables comparison across airplane models of the three major smoke source categories. For each model, the number of events in each source category was divided by the total number of smoke events for that model, yielding the percentage contributions depicted in the profile. (*Note:* The three categories for each model may not sum to 100 percent because of insufficient information available to categorize an event.) The models in figure 1 are listed in order of airplane complexity, starting with the most complex on the left. Larger airplanes with more complex systems show a predominance of smoke events of electrical origin, compared with air-conditioning and material smoke events.

For each airplane model, the air-conditioning, electrical, and material events were subdivided by airplane system. Figure 2 illustrates such a detailed categorization of smoke event sources for a representative model. The subcategories within the electrical category include systems or functions such as environmental control, electrical power, galleys, and flight deck equipment. Presenting the smoke sources in percentages by airplane system or function allows comparison of multiple models with different fleet sizes, ages, and missions.

Data also were collected on how the crews perceived the in-flight smoke events on all models. The data were grouped in a structure similar to the flight crew *Quick Reference Handbook (QRH)* produced by airplane manufacturers and operators. Figure 3 shows such a portrayal for a representative model. Most smoke events occurred with the flight crew on board. For many in-flight events, flight crews took action consistent with having identified the smoke source, such as removing electrical power to (i.e., depowering) that equipment. There was a significant number of events in which crew actions suggest that the smoke source could not be identified while in flight. For smoke events in which the flight crew could not determine the smoke source, most were subsequently determined by maintenance crews to be of electrical origin.

3 RECOMMENDED CREW ACTION FOR KNOWN AND UNKNOWN SMOKE SOURCES

The Boeing *QRH* includes procedural steps for smoke, fumes, fire of air-conditioning and electrical origin, and smoke removal. When a flight crew has determined that smoke is of air-conditioning origin, the Boeing *QRH* procedure is to isolate the air source, halting the introduction of contaminated air into the pressurized area of the

FIGURE 1 SUMMARY PROFILE OF REPORTED SMOKE EVENTS IN PRESSURIZED AREAS OF THE AIRPLANE

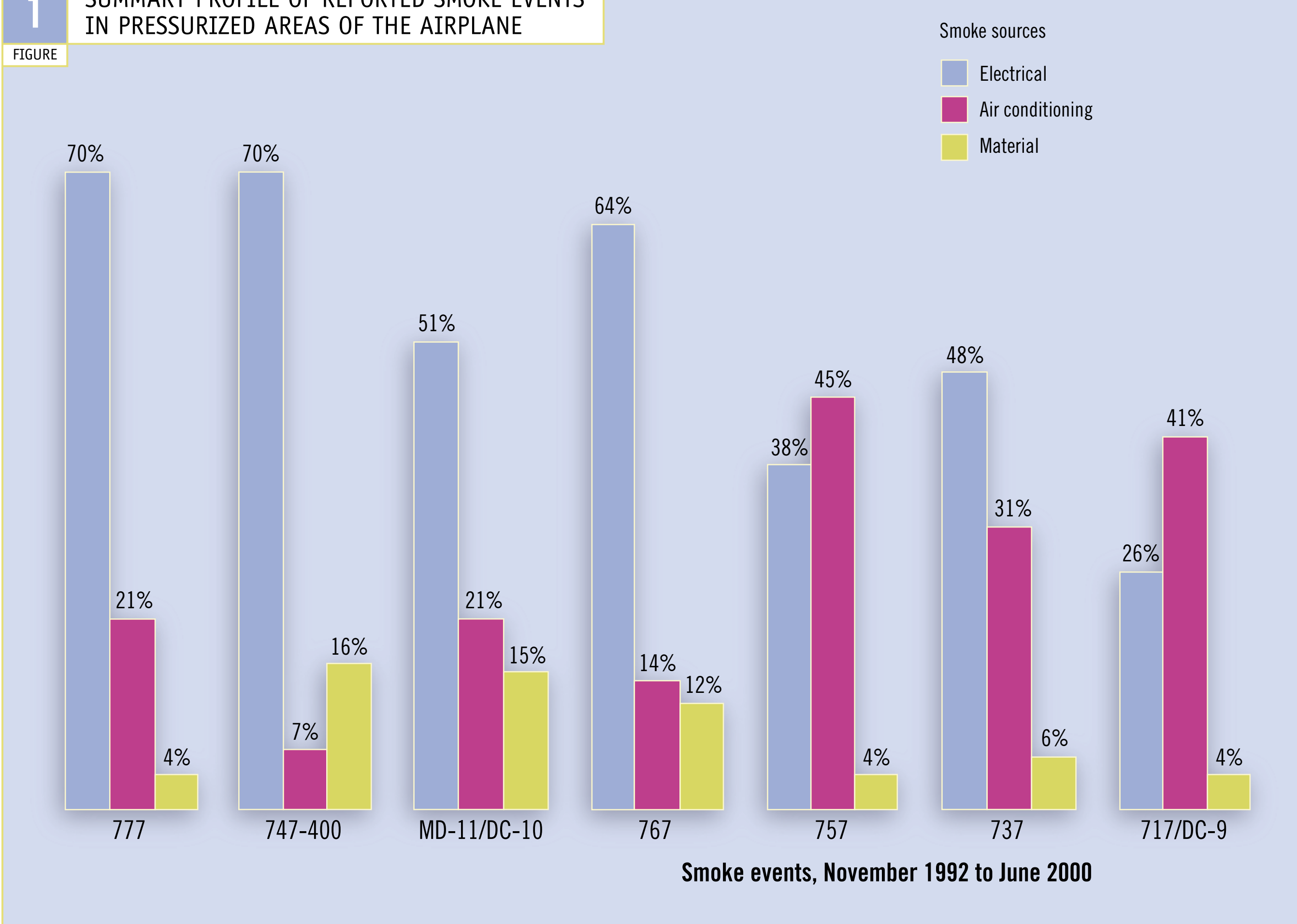


FIGURE 2

SMOKE EVENT SOURCES FOR A REPRESENTATIVE AIRPLANE MODEL

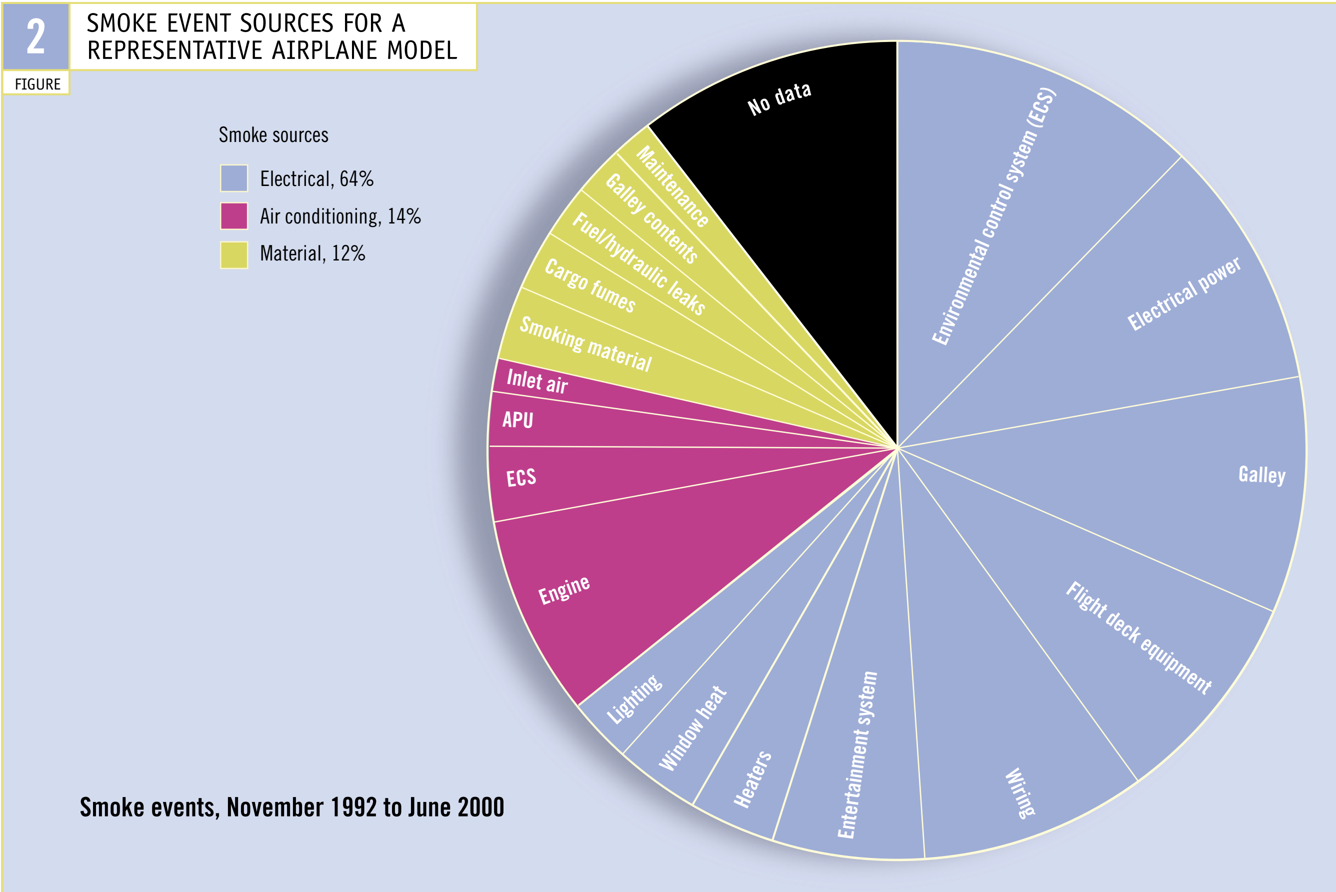
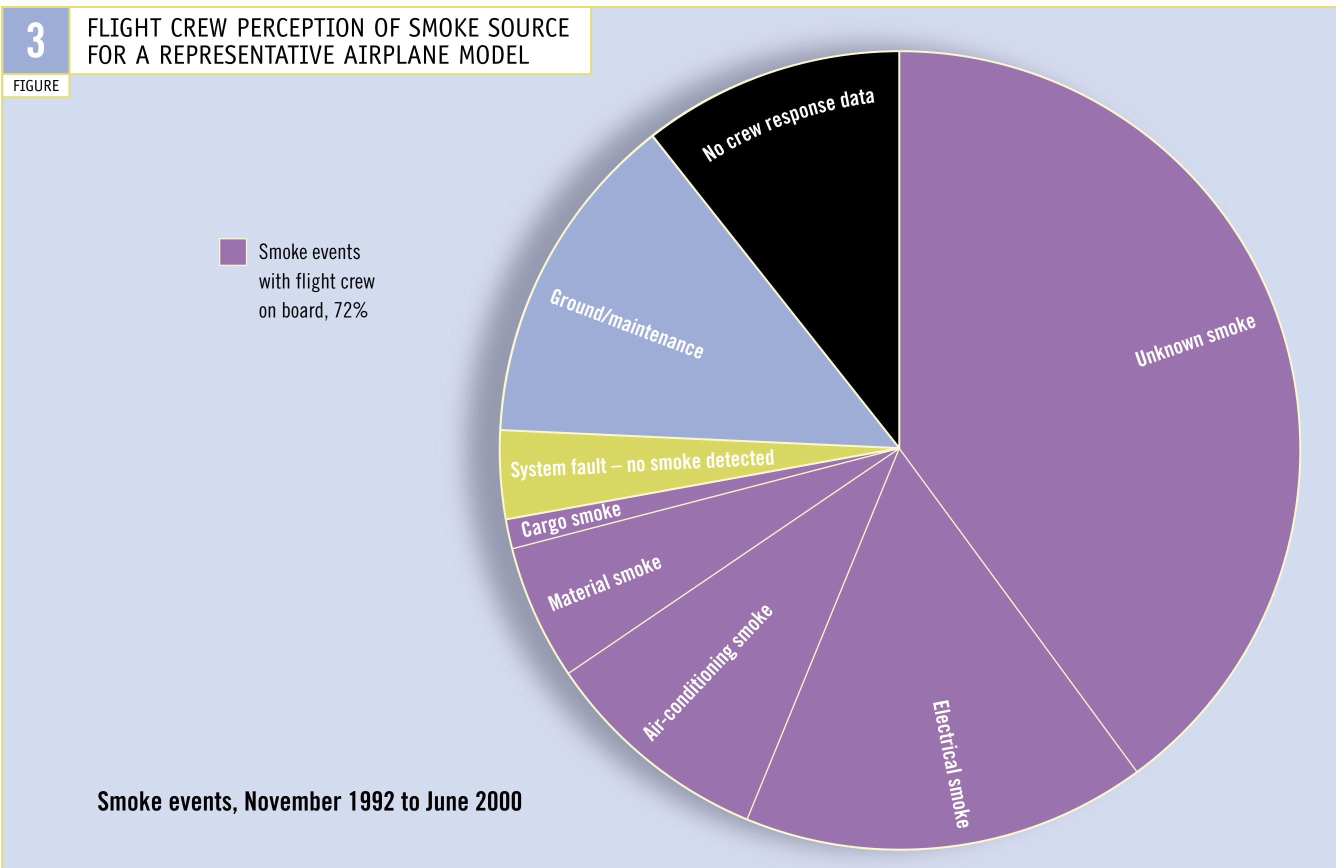


FIGURE 3

FLIGHT CREW PERCEPTION OF SMOKE SOURCE FOR A REPRESENTATIVE AIRPLANE MODEL



airplane. An example of air-conditioning smoke is from engine oil, followed by abnormal engine parameters and odor in the cabin and flight deck. Once the crew has isolated the incoming engine bleed air, continuing fresh air from another source should quickly improve cabin air quality.

When a flight crew determines smoke is of electrical origin, the Boeing *QRH* procedure is to depower the affected equipment. For example, if a flight crew sees smoke from a window-heating element, appropriate action would be to switch off that electrical equipment. An example of known smoke in the cabin would be a flight attendant seeing and smelling smoke from a coffee maker; after turning off electrical power to that galley, the smoke stops and subsequent surface temperatures are normal. The key to properly handling a known smoke event is for the crew to be confident of both the smoke source and the effectiveness of removing electrical power.

Known smoke sources. Many smoke events involve smoke or fumes produced by equipment readily accessible to the crew. Often, the event source can be identified by direct observation, such as seeing smoke exiting a piece of equipment, tracing a smell to its strongest location, or feeling an unusually warm surface.

For a known smoke event, confirming that the situation has been resolved is as important as identifying the source. The smoke or fumes must dissipate and any overheating condition must improve for the crew to be confident the situation is under control. Only if the crew can confidently identify the smoke source and confidently ascertain that the condition is under control should continuation of the flight be considered. Hand-held extinguishers ought to be at the ready, as the crew continues monitoring the equipment during the remainder of the flight.

Factors to evaluate in deciding whether to continue the planned flight include the level of confidence in identifying the smoke source, success in extinguishing the source, functionality of the remaining systems, success in removing cabin smoke, passenger distress, and position of the airplane along the intended route. Any combination of these factors may make a diversion or turnback the appropriate choice.

Completing a planned flight has its advantages given the significant operational costs of substitute equipment, schedule disruption, potential passenger compensation, and diminished goodwill. The best prospect for minimum disruption from a smoke event comes from crew training in responding to smoke, crew familiarity with smoke-clearing procedures, and direct power control to cabin amenities (e.g., an electrical power cutoff switch at each galley location). If the crew cannot confirm that a persistent onboard smoke or fire situation is completely resolved, however, Boeing recommends the earliest possible descent, landing, and evacuation of the airplane.

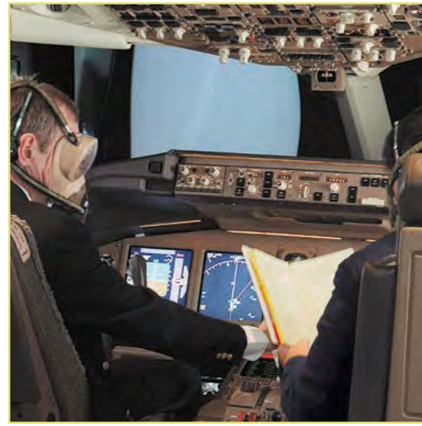
Unknown smoke sources. A crew may not be able to identify a smoke source because of the location of the failed equipment or because of air circulation throughout the pressurized cabin. Unknown smoke sources include environmental control systems, equipment cooling fans, door heaters, plumbing heaters, avionics equipment, fluorescent lights, and wiring faults.

The serious consequences of compromised structural integrity, system function, or survivable environment warrant timely and prudent action by the crew. Review of historical data on the rare fire events that resulted in hull loss indicates that the time from first indication of smoke to an out-of-control situation may be very short — a matter of minutes. For this reason, flight crew actions when responding to unknown smoke must be timely and appropriate.

QRH procedural steps for addressing an undetermined electrical smoke source call for the removal of electrical power for specific systems not necessary for safe flight, landing, and egress. This accounts for the majority of systems with a significant history of in-service smoke events. Also, as directed by the Boeing *QRH* non-normal checklist, the crew should plan to land at the nearest suitable airport.

During the remainder of the flight, the crew should be alert to any new signs that suggest the smoke source and remain mindful of operational functions needed to accomplish the diversion.

Many unknown smoke situations are later attributed to electrical sources, substantiating the positive step of depowering specific equipment not necessary for the remaining flight, landing, and egress. Flight-critical systems do not have a significant smoke-event history.



4 CAPABILITIES FOR THE REMAINDER OF THE FLIGHT

QRH procedural steps to remove power from affected equipment must ensure that

sufficient system capability remains to accommodate adverse weather, a replanned route, and an approach into an unfamiliar airport. In-service data show that inordinate depowering of airplane systems beyond *QRH* procedures is not likely to be of benefit in an unknown smoke situation. Further, such action would significantly reduce airplane capabilities for the remainder of the flight.

During the study, several depowering strategies beyond current procedures were considered but ultimately not incorporated into the Boeing *QRH* non-normal checklists based on a risk-benefit evaluation. The elements of continued safe flight and landing were determined according to four safety requirements: controlled flight path, controlled airplane energy, navigation, and survivable environment. Conditions during the remainder of the flight could necessitate the availability of flight management system navigation, autopilot, multiple communication channels, first officer's displays, smoke detection, fire suppression, cabin lighting, and electrical power for removing smoke.

Exterior lighting illustrates the important difference between a prudent crew response and an inordinate depowering of airplane systems during an unknown smoke event. Equipment used for red anti-collision strobes includes high-energy components, such as a high-intensity flasher, and is an occasional source of smoke in the pressurized area of the airplane. From this standpoint, using the overhead switch to depower red anti-collision strobes may be beneficial during an unknown smoke event. Turning off all exterior lighting, however, would be an overreaction that would increase the risk of traffic conflict without commensurate likelihood of addressing the smoke source.

Without complicated troubleshooting-type procedures, it is a practical impossibility to depower all potential sources of unknown smoke without compromising necessary systems. The key to depowering potential unknown smoke sources while protecting necessary airplane functions involves balancing a series of risk assessments. Because the *QRH* must facilitate timely and prudent crew action appropriate for a broad range of scenarios, the *QRH* procedures cannot resort to a severely depowered electrical configuration. Boeing *QRH* procedures are developed with the understanding that, at a flight crew's discretion, additional action may be taken that is deemed necessary to ensure safe flight.

If a flight crew considers action beyond the *QRH* procedures, the action must be based on the particular situation and knowledge of airplane system operation. Procedural alternatives that may be reasonable near a familiar airport under visual meteorological conditions may not be appropriate in adverse weather or unfamiliar surroundings with a compromised airplane. The crew may also have additional flight deck effects or information beyond those explicitly identified in the *QRH* (e.g., tripped circuit breakers, synoptic information, or reports from cabin crew) that may assist in identifying the smoke source.

A flight crew in an extreme situation will benefit from airplane system knowledge that would be inappropriate to detail in time-critical procedures. For example, on most Boeing-designed two-engine airplanes, the right electrical bus powers a higher proportion of nonessential equipment, while the left electrical bus powers the higher proportion of flight-critical equipment.

The best response to an event of unknown smoke combines use of prudent *QRH* non-normal checklists and flight crew discretion based on the particular situation and a thorough knowledge of airplane systems.

SUMMARY

- Engineering design by airplane manufacturers, oversight by regulators, and maintenance practices by operators combine to minimize occurrences of smoke, fumes, and fire in the pressurized areas of airplanes.
- When an in-flight smoke or fire event does occur, it can be a time-critical situation that demands immediate action by the flight and cabin crews.
- Crews should follow *QRH* procedures, which must be structured to allow flight and cabin crews to promptly respond to an in-flight smoke event.
- In known smoke events, direct crew response minimizes operational consequences, such as flight cancellations and air turnbacks.
- If a crew cannot confirm that persistent onboard smoke or fire has been completely extinguished, Boeing recommends the earliest possible descent, landing, and evacuation of the airplane.
- In unknown smoke events, a prudent crew response minimizes risk during remaining flight. Inordinate depowering of airplane systems is not likely to benefit an unknown smoke situation because such action significantly reduces airplane capabilities for the remainder of the flight without commensurate likelihood of depowering the unknown smoke source.
- Many unknown smoke sources are later determined to be electrical, substantiating the positive step of depowering specific equipment not crucial to the remaining flight, landing, and egress. Historically, flight-critical systems have not significantly contributed to smoke events.
- In an extreme situation, a flight crew will benefit from knowledge of airplane systems that would be inappropriate to detail in time-critical *QRH* procedures.