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Building Better
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**Advanced
Ultrasonic
Inspection**

Preventing Loss of
Control in Flight

Commercial
Operations on
Runways with
Arresting Systems

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Building Better Communication: Readership Survey



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Vice President, Customer Support
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New advanced ultrasonic inspection techniques available to operators reduce inspection time by a factor of five or more.

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Advanced Ultrasonic Inspection

Boeing has introduced advanced ultrasonic inspection techniques that provide operators with significant cost improvements over traditional ultrasonic testing technologies.

By **John Linn**, Technical Fellow, Service Engineering, and
Jeff Kollgaard, Technical Fellow, Nondestructive Test

All in-service airplanes are subject to fatigue, environmental, and accidental damage. Detecting damage may require nondestructive testing (NDT), such as ultrasonic inspection. Portable advanced ultrasonic inspection technologies have improved significantly during the last few years. Two new advanced portable ultrasonic technologies that are now available are the Ultrasonic Testing Phased Array (UTPA) and the Synthetic Aperture Focusing Technique (SAFT).

This article explains these technologies and their importance to operators.

The traditional inspection technology, called pulse echo technique, uses a single

element probe and is widely used in the aviation industry. Two new advanced ultrasonic techniques, which are fundamentally similar in concept to pulse echo, use multiple sensors in a probe to detect damage. The use of multiple sensing elements increases scan coverage and detection capability while providing a display that is more like an x-ray view and far more informative than the traditional oscilloscope trace. The result is improved decision making by those evaluating the ultrasonic signals.

The new technologies, UTPA and SAFT, can dramatically reduce airplane downtime and the labor time associated with inspec-

tions. In one example, this technology eliminated the need to remove paint from large areas of an airplane, reducing downtime by about as much as two days, as required by the pulse echo technique used previously.

The advantages of multiple-element sensor (in comparison to single-element sensor) include:

- A reduction of labor by 400 percent for composite part inspections.
- Enhanced display information.
- Reduced inspection time.
- High-sensitivity inspection of a wide area.

Figure 1: UTPA instrumentation

A UTPA instrument gives enhanced display capabilities to the operator.



The UTPA technology probes (see fig. 1) have been developed in cooperation with Olympus NDT and GE Inspection Technologies; the SAFT technology probes have been developed in cooperation with Toshiba. UTPA shear-wave sector mode is currently used for scribe-line inspections and chemical mill edge inspections.

The UTPA shear-wave probe is composed of 16 multiple small rectangular sensors called elements. Each element is electronically pulsed one at a time in a timed sequence to produce constructive interference at a specific angle and a specific depth in the airplane part. These time delays can be incremented over a range of angles to sweep the beam over the desired range.

For example, a 40- to 75-degree beam sweep would be accomplished by calculating the time delays to produce constructive interference at each point from

40 to 75 degrees. All 16 elements listen for the return echoes after they are pulsed. Software configures the return echo signals based on the timed pulses and the time of the received echoes. The range of angles is displayed in an image of the structure called a sector scan image (see fig. 2).

The advantages of UTPA shear-wave inspection are its capability to:

- Sweep a range of angles.
- Display the image in real time through a range of swept angles.
- Focus the ultrasound signals.
- Eliminate the need to remove paint prior to inspection.

UTPA linear-wave mode is currently used for composite inspections.

The UTPA linear array probe uses five small rectangular elements that are pulsed simultaneously to produce a singular wave front, traveling in the material like the pulse

of a traditional 0.25-inch (0.64-centimeter) diameter transducer but with more control of the ultrasonic behavior and response. All five elements, defined as an aperture, listen for the return echoes. The aperture is incremented down an array of up to 128 elements to sweep across a scan area. The linear array probe can be used with an X-Y scanner to produce an image of the structure (see fig. 3).

The advantages of the linear array scan are the capability to inspect a wide area with high sensitivity and display the image in real time.

Currently SAFT is used for composite laminate inspection.

The SAFT electronically pulses one to five elements while up to 32 other elements listen for the return echo. Although similar to UTPA, the SAFT method employs time-correction of the received signals, rather than pulse timing of the outgoing signals,

Figure 2: UTPA shear-wave sector scan

UTPA shear-wave sector scans can be used to inspect for scribe lines and doubler edge cracks.

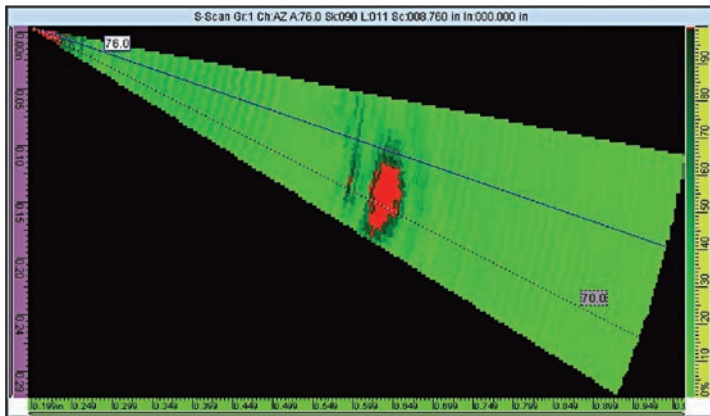
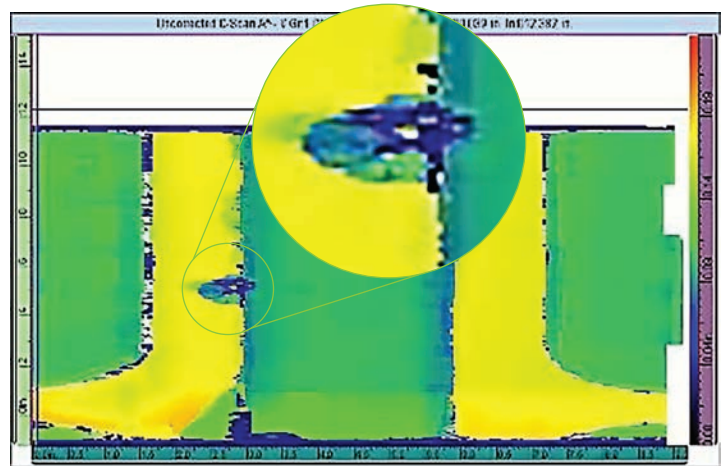


Figure 3: UTPA linear array scan

UTPA linear array can be used to inspect composites for damage and bonded repairs for processing defects. This scan shows impact damage to a stiffener.



to produce sharp ultrasonic images and three-dimensional reconstructions of the data. SAFT can focus at multiple depths simultaneously, providing a precise volumetric data set that can be sliced in various ways for data analysis.

UTPA AND SAFT IN USE

The UTPA method is offered as an option to traditional single-element inspection procedures for scribe-line inspections and to detect cracks in chemically milled fuselage skins. Because paint is not required to be removed prior to UTPA scribe-line inspections, it has been shown that the return on investment is the elimination of one repeat inspection cycle on one airplane.

Both UTPA and SAFT are offered as inspection options to the traditional inspection technology for damage detection of composite materials and for inspection of

bonded composite repairs. Both options offer wide field imagery, increased inspection speed, measurement tools, and easier interpretation of complex signals resulting in significant return-on-investment advantages to maintenance organizations. These UTPA and SAFT procedures are specified in service bulletins, structural repair manuals, and NDT manuals.

Advanced ultrasonic techniques offer significant advantages over traditional pulse echo, such as:

- Detection of cracks at varying angles and orientations.
- Compensation for attenuative effects of coatings.
- Imagery of the structure and suspect damage that assist interpretation of complex signals.
- Measurement tools that speed and improve decision making.

Boeing will continue to evaluate and integrate new nondestructive technologies as they become available to offer operators and maintenance, repair, and overhaul facilities a choice of inspection methods and to enable them to implement the methods that work best for their specific needs.

SUMMARY

New advanced ultrasonic inspection techniques offer a number of advantages over traditional testing approaches, including reducing inspection time by a factor of five or more. Boeing is making these technologies available to operators. **A**



Proposed loss-of-control-in-flight interventions cover a broad spectrum of potential solutions, including flight simulator training.

Preventing Loss of Control in Flight

Boeing, as part of the Commercial Aviation Safety Team, recently completed a multiyear effort to analyze loss-of-control-in-flight events and generate feasible solutions in areas of training, operations, and airplane design. These safety enhancements have now been adopted by the Commercial Aviation Safety Team for implementation in the United States and are being advocated for worldwide adoption.

By **Michael Snow**, Ph.D., Associate Technical Fellow, Human Performance, Aviation Safety, and
Randall J. Mumaw, Ph.D., Associate Technical Fellow, Human Factors, Flight Deck Design Center, Flight Crew Operations Integration

In the last decade, loss of control-in-flight (LOC-I) has become the leading cause of fatalities in commercial aviation worldwide. A subcategory, flight crew loss of airplane state awareness, has risen as a causal factor in these accidents.

This article explains safety enhancements that were recently adopted by the Commercial Aviation Safety Team (see “What is the Commercial Aviation Safety Team?” on page 13) and the process that drove the development of the enhancements. Implementation of the resulting training, operations, and airplane design safety enhancements is estimated to

reduce the risk of future airplane state awareness events approximately 70 percent by 2018 and 80 percent by 2025.

A LARGE, COMPLEX PROBLEM

Accident rates and fatalities in commercial aviation are at historic lows in recent years, even as air traffic has climbed. However, Boeing continues to work with industry and government partners to improve safety for the traveling public. In August 2010, the Commercial Aviation Safety Team chartered the Airplane State Awareness Joint Safety Analysis Team as a follow-on activity to

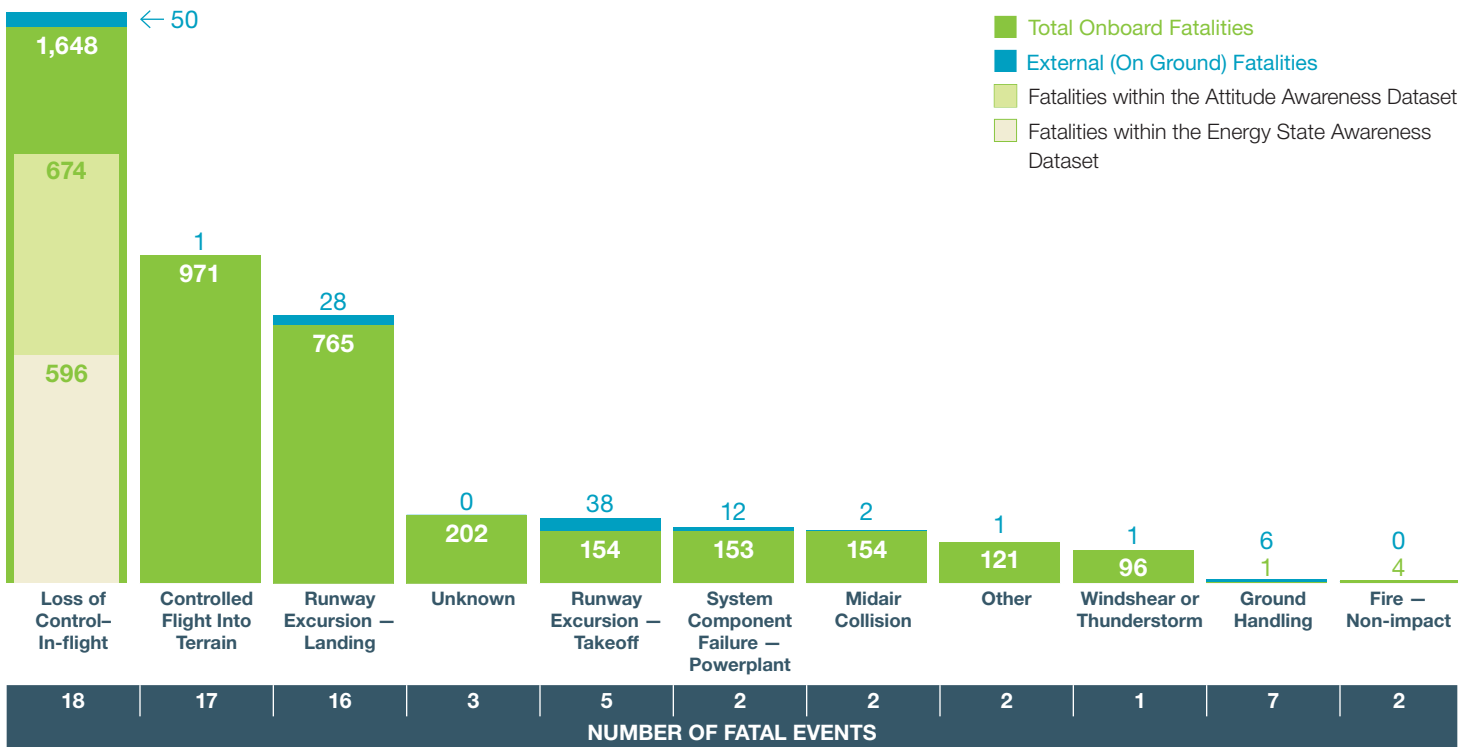
previous work done by a LOC-I Joint Safety Analysis Team in 2000. The primary purpose of the Airplane State Awareness Joint Safety Analysis Team was to analyze a representative set of LOC-I accidents and incidents in which the flight crew lost awareness of the airplane’s state, defined as:

- Attitude (pitch or bank angle) or
- Energy (the combination of airspeed, altitude, vertical speed, thrust, and configuration control surfaces).

A review of worldwide transport airplane accidents during the period from 2003 to 2012 revealed that more than half of all

Figure 1: Worldwide jet transport fatal accidents, 2003–2012

The loss of airplane state awareness has been a major factor in worldwide jet transport fatal accidents during the last 10 years.



LOC-I accidents and resulting fatalities involved flight crew loss of airplane state awareness (see fig. 1).

The Airplane State Awareness Joint Safety Analysis Team was co-chaired by Boeing and the U.S. Federal Aviation Administration and staffed with subject matter experts from major airplane manufacturers and suppliers, pilot unions, airlines, research organizations, data mining organizations, and government aviation safety departments and agencies. Two analysis teams studied 18 events, identified problems and major themes, and developed intervention strategies. A data team complemented the work of the analysis teams by assessing the presence, frequency, and characteristics of airplane state awareness precursors (conditions commonly leading to these events, such as stall warnings or extreme bank angles) in U.S. Part 121 operations, based on information available in the Aviation Safety Information Analysis and Sharing database.

STUDYING LOSS OF CONTROL-IN-FLIGHT

Nine of the events analyzed involved loss of attitude awareness and nine involved loss of energy awareness (see fig. 2). The objective of the analysis was to identify underlying problems that contributed to the accidents and incidents analyzed. In the course of this analysis, the teams identified 161 distinct problems, of which 117 were common with those identified by previous Joint Safety Analysis Teams and 44 were newly developed by the Airplane State Awareness Joint Safety Analysis Team. The analysis teams then identified a total of 274 intervention strategies to address these problems, of which 181 had been documented previously and 93 were newly developed.

COMMON THEMES AMONG LOSS OF CONTROL-IN-FLIGHT

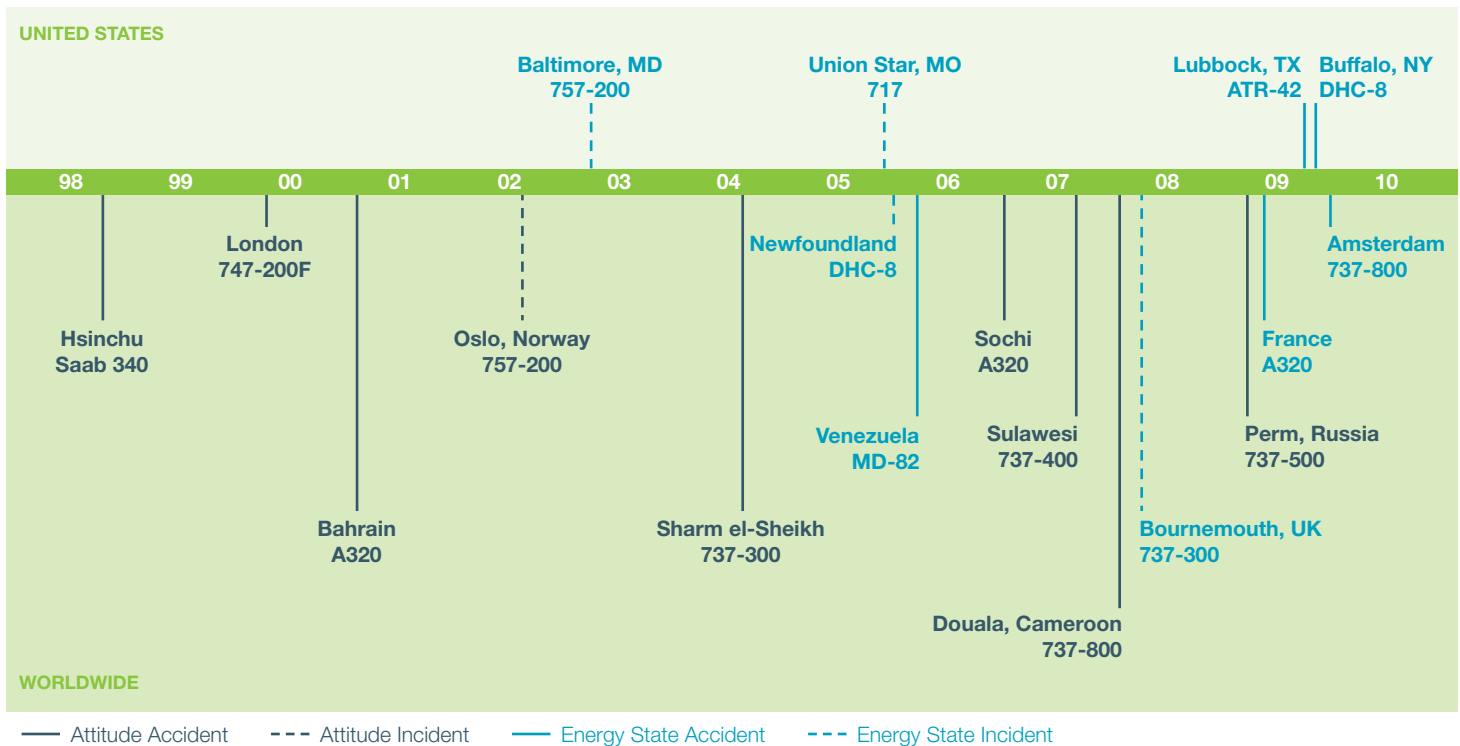
The Airplane State Awareness Joint Safety Analysis Team discovered 12 major themes that appeared across the events in the

airplane state awareness dataset, which may be representative of common issues present in similar events (see fig. 3). Note that no single factor causes an accident or incident. In these events, it took a combination of at least six themes to result in a hazardous situation. The Airplane State Awareness Joint Safety Analysis Team did not assign a ranking to these themes and notes that higher frequency of occurrence (i.e., appearance in more events) should not necessarily imply greater importance.

- **Lack of external visual references.** In 17 of the 18 events, the event airplane was flying at night, in instrument meteorological conditions, or in a combination of night and instrument meteorological conditions, sometimes at high altitude or over dark land or water. As a result, the crew had to rely on instrumentation to establish and maintain orientation.
- **Flight crew impairment.** In seven of the 18 events, at least one member of the flight crew was affected by fatigue, illness, or alcohol consumption, and in some cases by a combination of factors.

Figure 2: Airplane State Awareness Joint Safety Analysis Team event dataset

Of the 18 events studied by the Airplane State Awareness Joint Safety Analysis Team, nine involved loss of attitude awareness and nine involved loss of energy awareness.



- Training.** In nine of the 18 events, flight crew training played a role. In some cases, the crew had not received training that is generally considered industry standard and is widely available. In other cases, the training had taken place but was not recalled properly or did not address the scenario encountered. In some instances, the Joint Safety Analysis Team considered the training that the crew had received counter-productive or negative.
- Airplane maintenance.** Airplane maintenance was an issue in six of the 18 events. In some cases, maintenance was not performed in a timely manner, allowing problems to persist until they became factors in the accident chain. In other cases, maintenance was performed, but it did not directly address the actual problem or was performed on the wrong system.

- Safety culture.** Safety culture played a role in 12 of the 18 events. In some cases, the operator had a poor safety record, extending back for months or years. Many of the flights operated with compromised safety, such as with less than fully functioning systems or with a poorly defined flight plan. In several events, the coordination and interaction with the air traffic management, both in flight planning and during the flight, was poor. Schedule pressure was prevalent, resulting in crews pressing on with flights or other activities despite warning signals that the situation was deteriorating. Crew pairing — particularly the pairing of pilots with low time in type — was also an issue (see the section on crew resource management).
- Invalid source data.** In five of the 18 events, invalid source data from the air data system sensors or probes, inertial or rate gyro systems, angle-of-

attack vanes or sensors, or other signals were used as input to primary flight displays, the autoflight system, or the navigation systems with little or no indication the data were invalid.

- Distraction.** Distraction played a role in all 18 events and manifested itself in two ways. First, a flight crew would make a decision based on faulty information or incorrect reasoning (sometimes when task-saturated) and would be distracted by pursuit of actions or thought processes associated with that decision, a phenomenon known as confirmation bias. Second, the flight crew would become focused on one instrument or one response to the exclusion of all other relevant inputs, comments, or alerts and would essentially block out any information that may have led them to fully understand the problem they faced, a phenomenon known as channelized attention.

Figure 3: Summary of significant themes across all events

	Lack of External Visual References	Flight Crew Impairment	Training	Airplane Maintenance	Safety Culture	Invalid Source Data	Distraction	Systems Knowledge	Crew Resource Management	Automation Confusion/Awareness	Ineffective Alerting	Inappropriate Control Actions	Total
Formosa Airlines Saab 340	x	x			x		x	x	x		x		7
Korean Air 747-200F	x			x		x	x	x			x		6
Flash Airlines 737-300	x		x		x		x	x	x	x		x	8
Adam Air 737-400	x		x	x			x	x	x	x	x	x	9
Kenya Airways 737-800	x		x				x		x	x	x	x	7
Aeroflot-Nord 737-500	x	x	x	x	x		x	x	x	x	x	x	11
Gulf Air A320	x		x				x		x		x	x	6
Icelandair 757-200 (Oslo)	x						x		x	x	x	x	6
Armavia A320	x	x			x		x		x	x	x	x	8
Icelandair 757-200 (Baltimore)	x				x	x	x	x	x	x	x	x	9
Midwest Express 717	x				x	x	x		x		x	x	7
Colgan Air DHC-8-Q400	x	x	x		x		x	x	x	x	x	x	10
Provincial Airlines DHC-8	x		x				x			x	x	x	6
Thomsonfly 737-800	x		x	x	x		x			x	x		7
West Caribbean MD-82	x	x			x		x	x	x	x	x	x	9
XL Airways A320		x	x	x	x	x	x	x	x	x	x		10
Turkish Airlines 737-800	x			x	x	x	x		x	x	x		8
Empire Air ATR-42	x	x			x		x		x	x	x		7
Overall	17	7	9	6	12	5	18	7	16	14	18	12	

- **Systems knowledge.** In seven of the 18 events, the flight crew lacked understanding of how major airplane subsystems — such as autoflight, air data measurement, navigation, and inertial systems — interact and how information from one system influences another.
- **Crew resource management.** In 16 of the 18 events, crew resource management was not practiced effectively. Specifically, flight crews failed to communicate effectively or work together to understand and resolve problems or confusion. In a number of events, the pilot monitoring failed to properly perform the monitoring function. Crews also failed in some instances to manage their workload properly. In a few events, an authority gradient between the captain and first officer likely played a role in preventing the first officer from taking control of the airplane from the captain, even when the captain was clearly failing to correct a hazardous airplane state.
- **Automation confusion/awareness.** In 14 of the 18 events, the flight crew was either confused about the state (i.e., on/off) or mode of the autoflight system or else was unaware of trim or control inputs made by the autoflight system.
- **Ineffective alerting.** In all 18 events, alerting was an issue. The intended function of a flight deck alert is not simply to go off: rather, it is to raise flight crew awareness to a potential hazard, assist the crew in understanding the hazard, and (where possible) provide guidance to avoid or recover from the hazard. The term “ineffective” in this context is meant to convey only that the alert, if present, failed to impact flight crew awareness, understanding, and behavior in the manner intended. It is important to note that alerting effectiveness is not solely the result of airplane design: it is also significantly affected by flight crew training, communication, attention, and other factors in the flight deck environment.
- **Inappropriate control inputs.** In 12 of the 18 events, the flight crew responded to hazardous airplane states and conditions with control inputs that were opposite to what was necessary to recover the airplane. The term “inappropriate” is intended to convey only that the control inputs were not correct for the purpose of recovering the airplane and should not be construed to automatically imply pilot error.

PREVENTING LOSS OF CONTROL—IN-FLIGHT

Hundreds of intervention strategies were identified by the Airplane State Awareness Joint Safety Analysis Team to mitigate the problems observed in the 18 Airplane State Awareness Joint Safety Analysis Team events, and they were grouped into categories, based on how, and by whom, they would be implemented. These categories include airplane design, flight crew training, maintenance, and safety data and research.

What is the Commercial Aviation Safety Team?

The Commercial Aviation Safety Team is a voluntary collaboration between U.S. government and industry that was founded in 1998. Its goal is to reduce fatality risk 50 percent in airline operations by 2025. It operates by consensus, deciding as a group which problems represent the greatest threats to aviation safety, chartering teams (e.g., Joint Safety Analysis Teams) to analyze those problems and underlying issues, determining feasibility of potential solutions (via Joint Safety Implementation Teams), and then tracking the implementation and effectiveness of adopted solutions (i.e., safety enhancements).

Airplane design. These interventions called for action on the part of airplane manufacturers or suppliers related to the design of current and future airplanes. The highest-rated interventions related to airplane design fell into these general areas:

- Flight envelope protection.
- Improved alerting.
- Flight path/control guidance on displays.
- Source data integrity.
- “Day-visual meteorological conditions” display systems.
- Automation design.
- Energy management display/prediction systems.

Flight crew training. These interventions called for updates to current flight crew training curricula, standards, additional training, and improvements to flight simulator fidelity. The highest-rated interventions related to flight crew training fell into these general areas:

- Revised approach-to-stall training.

- Expanded upset prevention and recovery training.
 - Scenario-based situations.
 - Stall recognition and recovery.
 - Spatial disorientation recognition and recovery.
- Reemphasized/expanded crew resource management.
- Flight crew proficiency.
- Flight simulator fidelity.

Airline operations and maintenance. These interventions called for action on the part of operators or air traffic management to improve and expand operating policies or procedures. The interventions related to airline operations, including air traffic control issues and airplane maintenance, fell into these general areas:

- Maintenance procedures.
- Flight crew qualifications.
- Nonstandard flight operations.
- Reemphasis and rationale for standard operating procedures.
- Flight crew impairment.
- Safety culture.

Safety data. These interventions called for expanded data mining and sharing programs and safety management principles. The interventions related to safety data fell into these general areas:

- Sharing of safety-related data (e.g., the Aviation Safety Information Analysis and Sharing Program).
- Operator safety management systems.
- Sharing of service difficulty reports.

Research. Research interventions based on the Joint Safety Analysis Team process do not receive an overall effectiveness score. Ranking of research interventions for priority was based on which research interventions addressed the highest number of high-scoring problems. The top research interventions, based on this methodology, fell into these general areas:

- Spatial disorientation.
 - Displays to prevent spatial disorientation.
 - Alerting of spatial disorientation conditions.

Figure 4: Bank angle alerting with recovery guidance

Boeing is implementing auditory and visual bank angle alerting with recovery guidance in the 737 MAX and the Next-Generation 737.



- Maintaining flight crew awareness in high-workload environments.
- Automatic systems for error detection, prevention, and recovery.
- Human performance benefits of post-stall recovery training using advanced flight simulator aerodynamic models.

DEVELOPING SAFETY ENHANCEMENTS

After the Airplane State Awareness Joint Safety Awareness Team identified intervention strategies, the Commercial Aviation Safety Team chartered the Airplane State Awareness Joint Safety Implementation Team to review them; assess them for technical, financial, operational, schedule, regulatory, and social feasibility; and develop new safety enhancements. The team then developed detailed implementation plans based on the approved safety enhancement concepts. The proposed training and

operations safety enhancements focus primarily on:

- Revisions and improvements to existing flight crew training in upset prevention and recovery, including revised approach-to-stall training.
- Revisions to go-around training.
- Policies and training for prioritizing controlled flight in non-normal situations.
- Training verification and validation.
- Enhancement of crew resource management training to further define and practice the duties of the pilot monitoring.
- Monitoring and understanding of habitual noncompliance to standard operating procedures and improvements to standard operating procedures.
- Policies for conducting nonstandard, nonrevenue flights.

In addition to training and operations safety enhancements, the team generated three airplane design safety enhancements

that the Commercial Aviation Safety Team has adopted and that Boeing and other Commercial Aviation Safety Team-represented airplane manufacturers have committed to implementing on their next all-new type designs:

- **Flight envelope protection.** This safety enhancement has already been implemented by Boeing on its latest fly-by-wire commercial airplanes, the 777 and the 787.
- **Bank angle alerting with recovery guidance.** Boeing is now working to implement this safety enhancement in the 737 MAX and the Next-Generation 737 (see fig. 4).
- **Virtual day-visual meteorological conditions displays.** Boeing's commitment is contingent on successful completion of relevant research and development and supporting industry

The airplane state awareness safety enhancements are integrated into a coordinated safety plan. The goal is to balance short-term tactical mitigations, provided by operational and training programs, with longer term, more strategic solutions resulting from improved design.

standards. Boeing recently demonstrated these displays, also referred to as synthetic vision systems, in the 787 EcoDemonstrator. Because these displays are effective at supporting flight crew attitude awareness, Boeing continues to engage with government and industry partners in research and development to bring these systems to application readiness.

The airplane state awareness safety enhancements are integrated into a coordinated safety plan with a goal of balancing short-term tactical mitigations provided by operational and training programs with longer term, more strategic solutions resulting from improved design.

The airplane state awareness safety enhancement portfolio was constructed by the Airplane State Awareness Joint Safety Implementation Team to provide both near- and far-term solutions that reinforce each other and provide a balanced, redundant

approach to addressing the issue of flight crew loss of airplane state awareness. Like the underlying problem being solved, the solution set is complex and addresses multiple issues. The analysis estimates that implementation of the training, operations, and airplane design safety enhancements would reduce the risk of future airplane state awareness events approximately 70 percent by 2018 and 80 percent by 2025.

The Airplane State Awareness Joint Safety Implementation Team recommended adoption by all U.S. Commercial Aviation Safety Team members of the training, operations, and design safety enhancements, and it recommends these enhancements be communicated to international aviation safety communities for their review and implementation where applicable. The Commercial Aviation Safety Team and its members have now officially adopted and published these safety enhancements as part of the Commercial Aviation Safety Team Safety Enhancement Plan and are working

with the International Civil Aviation Organization and the international safety community to increase adoption worldwide. The plan can be found at http://www.skybrary.aero/index.php/Portal:CAST_SE_Plan.

SUMMARY

Loss of airplane state awareness plays a significant role in at least half of all LOC-I category events.

An industry analysis of a representative set of events identified specific problems and major themes and resulted in proposed interventions that cover a broad spectrum of potential solutions in the areas of airplane design, flight crew training, airline operations and maintenance, and safety data.

The Commercial Aviation Safety Team has now officially adopted the resulting safety enhancements and is working to implement them in the United States and worldwide. **A**



Commercial airplanes can safely use runways with arresting systems designed for military use.

Commercial Operations on Runways with Arresting Systems

A number of airports throughout the world have joint commercial-military operations. Runways at these airports often are equipped with arresting gear systems (such as cables or barriers/nets) for tactical military aircraft to use. These systems pose a potential damage and safety hazard to commercial airplanes that use the same runways. Airports and airlines can take steps to help ensure safe commercial operations under such circumstances, including writing airport procedures specifically for commercial airplane operations, modifying existing arresting systems, reducing declared landing and takeoff distances, and increasing inspections of airplanes with nosegear spray deflectors.

By **Brad Bachtel**, Manager, Airport Compatibility Engineering

Of the nearly 36,000 airports around the world that are classified as civil, military, or joint-use, approximately 3,800 are used for scheduled commercial operations. Worldwide, approximately 2,500 aircraft arresting systems are installed on runways in 74 countries. Approximately 400 airports with arresting gear cable have reported commercial airplane traffic. If the nosegear spray deflectors used on some legacy commercial airplanes come in contact with the arresting systems, there is a possibility that the deflectors could shatter, creating foreign object debris (FOD). In extreme cases, the FOD could damage a critical airplane system.

This article is intended to help minimize the commercial operational impact at airports with runway arresting systems by describing the types of systems, operational concerns for airlines, and measures to help ensure safe commercial operations.

TYPES OF AIRCRAFT ARRESTING SYSTEMS

The three basic systems used to arrest aircraft are aircraft arresting barriers, aircraft arresting cables, and engineered materials arresting systems. The first two systems are primarily military systems used for

tactical aircraft, such as fighter and attack jets, but they are also found on joint-use runways. The third system is used at commercial airports that do not have sufficient safety areas at the end of the runway. (See “U.S. and International Aircraft Arresting Systems” on page 23.)

Aircraft arresting barriers. These devices, which do not depend on arresting hooks on aircraft, stop an aircraft by absorbing its forward momentum in a landing or aborted takeoff overrun. These systems are most commonly net devices (see fig. 1), but they also include older devices that catch the main gear struts. The barriers typically are

Figure 1: Barrier net

Arresting barriers, such as this net system, stop an aircraft by absorbing its forward momentum in a landing or aborted takeoff overrun.

- 1 Auxiliary Energy Absorber
- 2 Stanchion
- 3 Anchor Strap
- 4 Net Webbing
- 5 Runway Overrun Area
- 6 Main Energy Absorber

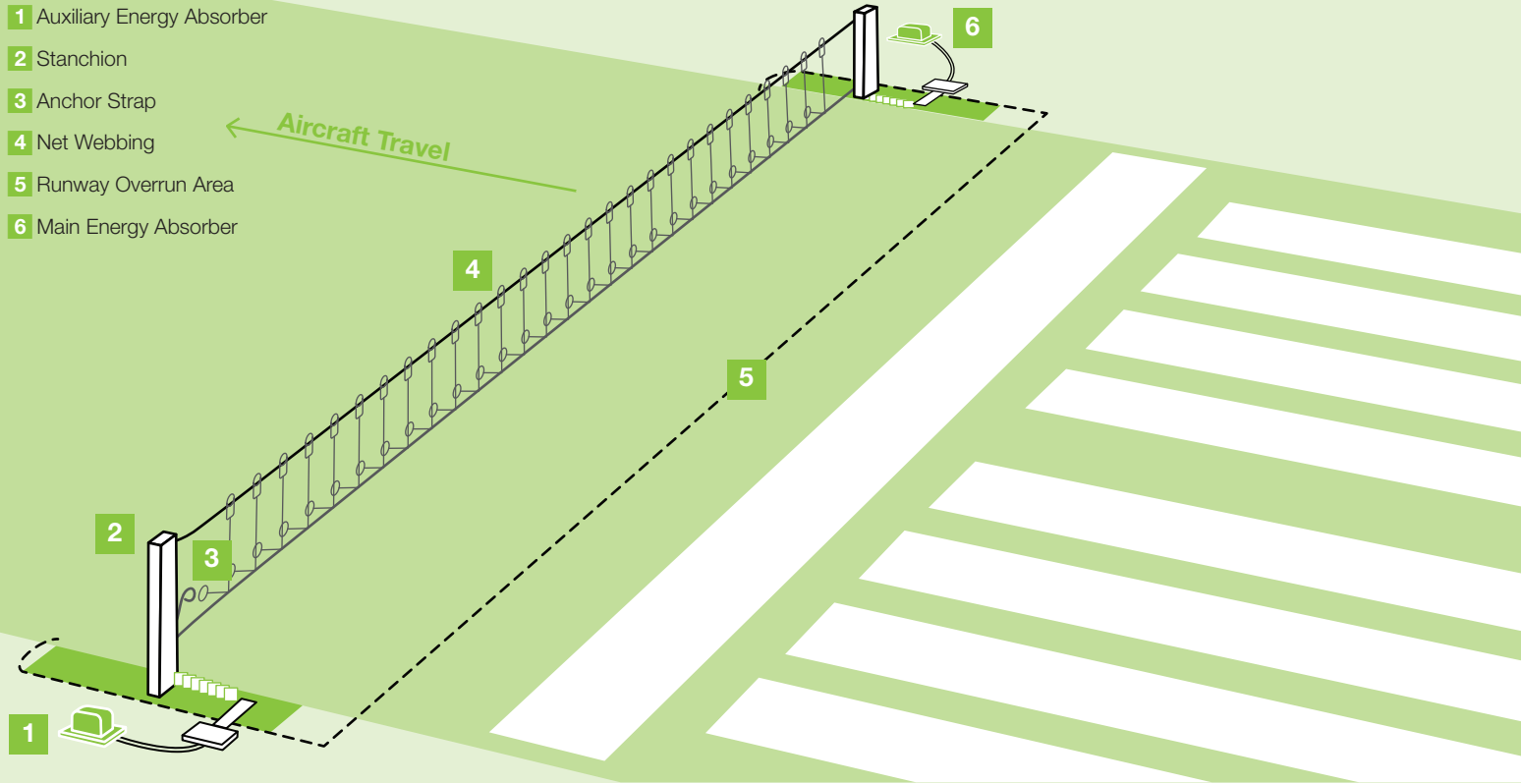


Figure 2: Arresting cables

Arresting cables are engaged by an arresting gear hook on the landing aircraft.

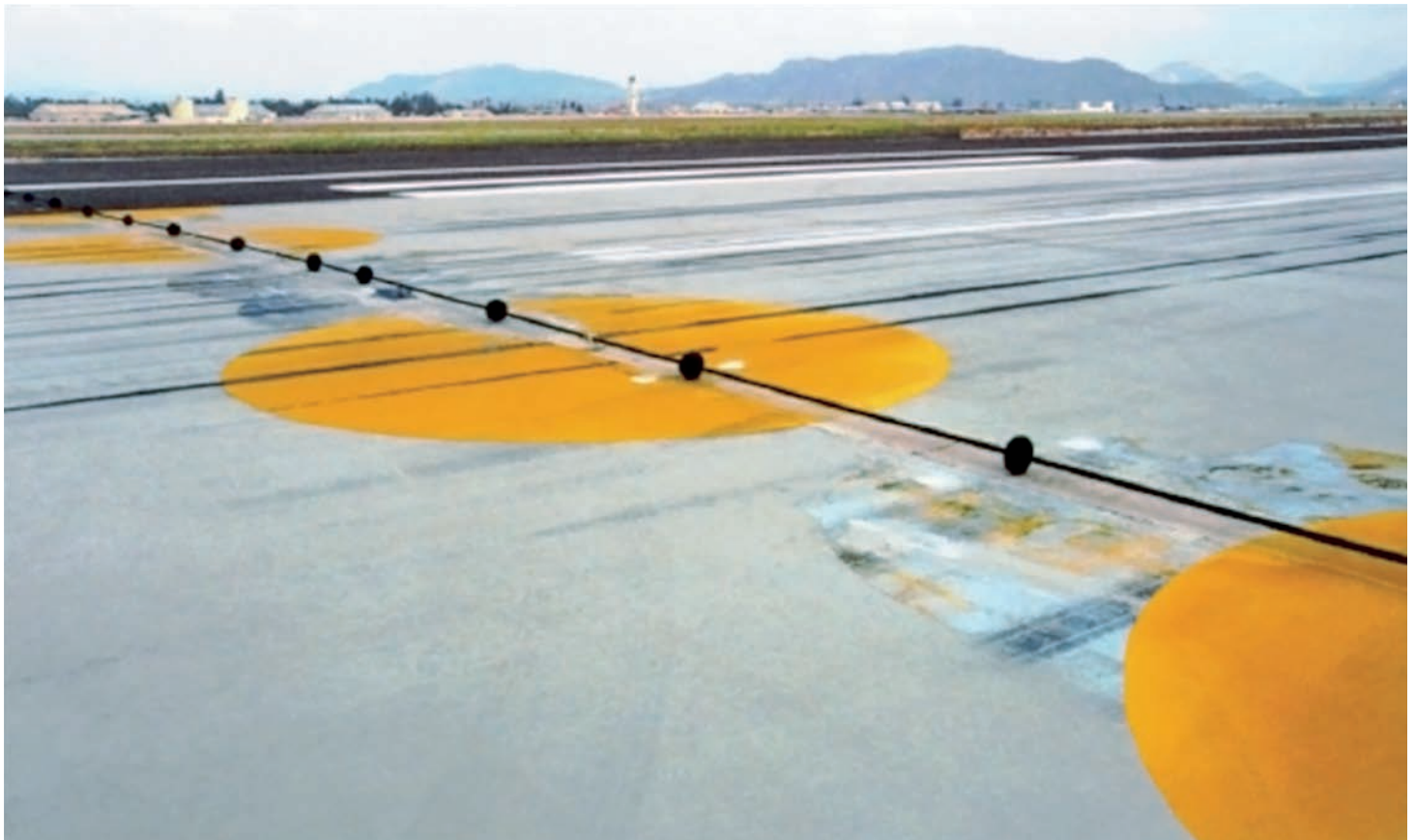
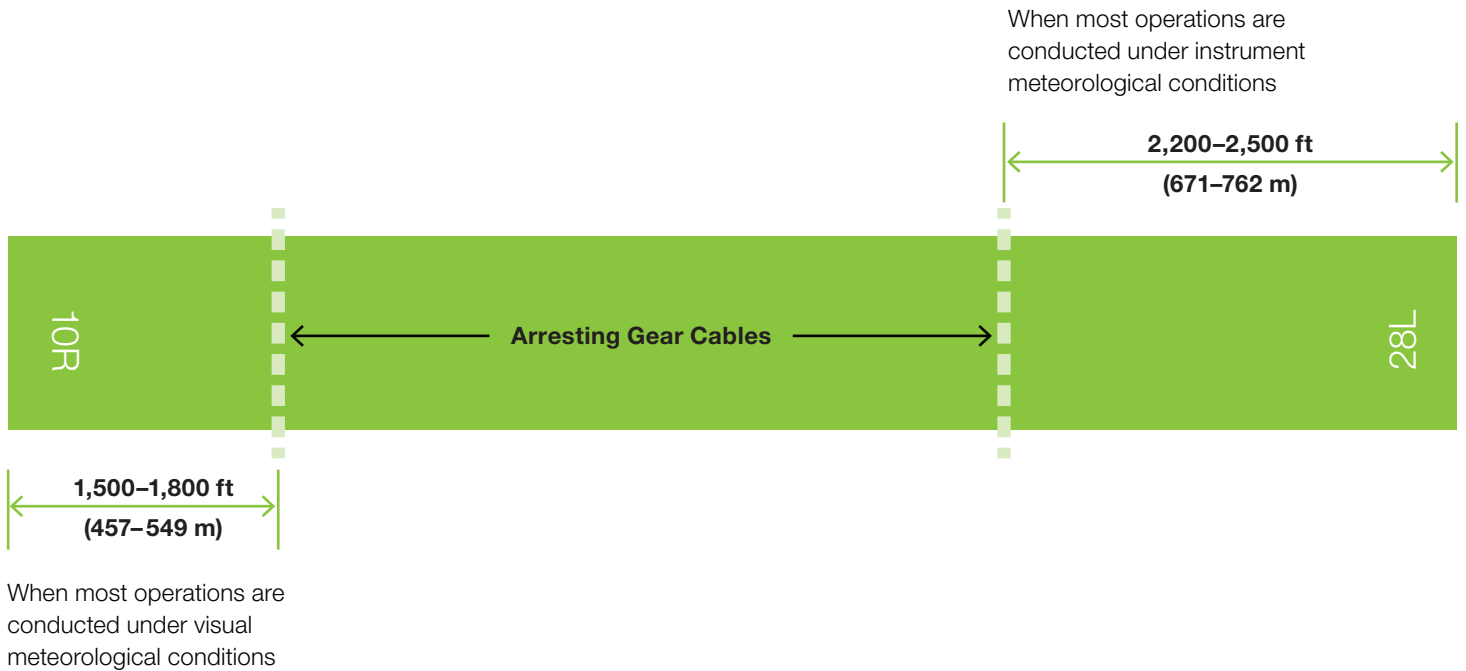


Figure 3: Typical arresting gear cable installation locations

At this airport, an aircraft operating on runway 10R would use the cable at the far end for both landing and aborted takeoff unless the aircraft had an emergency, at which point the arresting gear nearest the approach end of the runway would be used.



located in the overrun of the runway, are unidirectional, and can have collocated or interconnected arresting cables as part of their configuration.

Aircraft arresting cables. Arresting cables span the width of the runway surface and are engaged by the aircraft arresting gear hook (see fig. 2). Cables are typically 1 to 1.25 inches (2.5 to 3.2 centimeters) in diameter and suspended 1.5 to 3 inches (3.8 to 7.6 centimeters) above the pavement surface by rubber donuts 6 inches (15.2 centimeters) in diameter. Used primarily by military aircraft built in the United States and Europe, arresting cables have been used by the military since the late 1920s on aircraft carriers and land-based runways. While commercial airplanes have become engaged or tangled in arresting cables, these occurrences are rare.

Three main factors determine where cables are located on runways:

1. Engagement direction.
2. System runout.
3. Meteorological condition.

The engagement direction is the anticipated direction from which an aircraft will engage the cable. The system runout is the distance from the original cable location to the location at which the aircraft stops, which is typically 950 to 1,200 feet (290 to 360 meters). The meteorological condition is whether the system is used under visual meteorological conditions or instrument meteorological conditions (see fig. 3).

The installation criteria for cable systems on commercial runways are identified in the U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5220-9A, *Aircraft Arresting Systems for Joint Civil/Military Airports*. The location of the cable is marked on the runway by a series of reflective discs 10 feet (3 meters) in diameter painted “identification yellow.” These discs are laid out with 30 feet (9.1 meters) between centers and extend the full width of the runway (see fig. 2). (See the definition of *location identification* in “Common terms” on page 20.)

Engineered materials arresting systems (EMAS). EMAS, which are constructed of high-energy-absorbing materials of specific strengths, are located in the safety area, or overrun, of the runway. They are designed to crush under the weight of commercial airplanes as they exert deceleration forces on the landing gear. Since EMAS are located in the overrun area of the runway, the EMAS do not affect the normal landing and takeoff of airplanes. More information concerning EMAS is in FAA AC 150/5220-22B, *Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns*.

OPERATIONAL CONCERNS FOR AIRLINES

Airlines may have concerns about operating commercial airplanes on runways with aircraft arresting systems. These concerns include airplane nosegear interference, trampling of the arresting cable, adjustments to declared distances, dealing with arresting barriers, runway availability, airplane maintenance, and unintentional engagement of an arresting system.

Figure 4: Nosegear device

An MD-80 type is equipped with a combination nosegear spray-FOD deflector for normal operations. The ground clearance of this deflector is 0.75 to 1.5 inches (1.9 to 3.8 centimeters).



Common terms

Arresting Gear Cable Status:

- **Derigged** — The cable is removed from the runway surface and is not an operational concern.
- **Out of battery** (slack cable) — The cable is extended across the runway but is not under tension.
- **Rigged and down** — The cable is under tension across the runway but not elevated off the surface by use of rubber donuts (BAK-9/-12) or rubber elevation arms (BAK-14 or Type H modification).

- **Rigged and up** — Also referred to as the gear being “in battery.” This means the cable is under tension across the runway and elevated off the surface by use of rubber donuts (BAK-9/-12/-13) or rubber elevation arms (BAK-14 or Type H modification).

BAK — U.S. designation for a barrier arresting system. Non-U.S. arresting systems carry other designations. (See “U.S. and International Aircraft Arresting Systems” on page 23.)

Cycle time — A measure of time between engagement of an aircraft and the point when the arresting system is certified fully operational and ready for another engagement.

Location identification — A description identifying the location of arresting systems by the approach or departure end, runway designation, and position in hundreds of feet from the threshold. For example, the location identification “extended runout BAK-12 at +1,500 on approach runway 36” indicates a 1,200-foot (366-meter) runout BAK-12 arresting system located 1,500 feet (457 meters) beyond the threshold of runway 36.

Reset time — The time required to ready the arresting system for another engagement after aircraft release. (This does not include time to disengage the aircraft from the arresting system but does include the time required to inspect and certify that the system is fully operational.)

Figure 5: Adjusting declared distances

In this example of adjustments to declared distances, an 8,000-foot (2,438-meter) runway could be reduced to 5,000 feet (1,524 meters) of usable runway length for each of the following declared distances: takeoff distance available, takeoff runway available, accelerate stop distance available, and landing distance available.

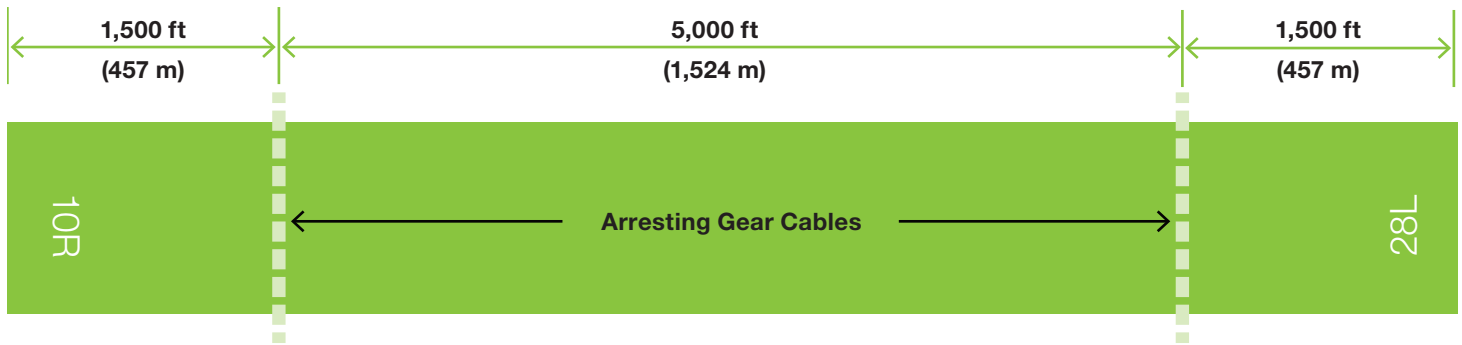


Figure 6: Examples of reduced runway lengths on weight

If the distance between the threshold and the cable is not used, the remaining runway can substantially reduce the available payload on 767-300ERF and 737-800 operations.

Airplane	Airfield Length ft (m)	Takeoff Weight lb (kg)	Weight Loss lb (kg)
767-300ERF	8,000 (2,438)	378,000 (171,458)	70,000 (31,752)
	5,000 (1,254)	308,000 (139,707)	
737-800	8,000 (2,438)	174,000 (78,926)	33,700 (15,286)
	5,000 (1,254)	140,300 (63,640)	

Nosegear interference. Some Boeing early model commercial airplanes have unique nose gear devices to deflect either spray or FOD. DC-9s, MD-80s, MD-90s, and 717s are equipped with nose gear spray-FOD deflectors (i.e., DC-9s having chine tires or the 717 that can have the outboard deflector and support missing). The ground clearance of this deflector is 0.75 to 1.5 inches (1.9 to 3.8 centimeters) (see fig. 4). Because most arresting cables are 1 to 1.25 inches (2.5 to 3.2 centimeters) in diameter and suspended in the center of rubber donuts that are 6 inches (15.2 centimeters) in diameter, nose gear deflectors are at risk of being damaged if a donut is struck.

Typical installation is for the rubber donuts to be approximately 6 feet (1.8 meters) apart, starting 3 feet (0.91 meters) from the runway centerline on runways 200 feet (61 meters) or less in width. For runways wider than 200 feet (61 meters) or that have the additional system to raise/lower the cable, the donuts are placed 8 feet (2.4 meters) apart, starting 4 feet (1.22 meters) from the runway centerline. To minimize potential damage to the nose gear deflectors, airplanes with such attachments should

slow-taxi over the cable, avoiding the donuts (if the cable is raised). If the nose gear spray deflector is damaged and removed, in accordance with the FAA-approved airplane flight manual's configuration deviation list, the airplane is limited to operating on dry runways until the deflector is replaced.

Trampling of the arresting cable. The 737 (excluding those with gravel deflectors), 747, 757, 767, 777, and 787 families can land and taxi over the arresting cable/donuts at any speed without exceeding design limit loads of the main and nose landing gears. However, because the nose gear load increases substantially when taxiing above 25 knots, it is recommended to taxi below 25 knots and initiate takeoff roll once past the cable if raised. Hard braking should be avoided while traversing the cable during taxi. If an operator considers the trampling, or rolling over, of a cable to be too rough on the airplane, the donuts that elevate the arresting cable above the runway surface can be moved to the sides of the runway during commercial operations. This allows the cable to rest directly on the pavement surface, minimizing the bump effect on the airplane.

It is important to note that the cable must be kept under tension, whether lying on the pavement or elevated by the donuts. Otherwise, the cable could be lifted by the airplane landing gear and contact the bottom of the fuselage or antennae located on the lower fuselage. (See definitions of *out of battery*, *rigged and down*, and *rigged and up* in "Common terms" on page 20.)

Adjustments to declared distances. Some airlines that operate on runways with arresting cables have reduced the available runway length by the distance from the approach end of the runway, or threshold, to the cable (see fig. 5).

If the distance between the threshold and the cable is not used, however, the remaining runway available for use substantially reduces the allowable payload on a 767-300ERF and 737-800 operation, based on the conditions of a standard day, optimal flap setting, zero wind, no obstacles, and zero slope (see fig. 6). This method of reducing available runway may be usable for a short-haul flight, but it is not a preferred long-term solution.

Figure 7: Retractable cable

A BAK-14 modification enables air traffic control personnel to remotely raise (left) and lower (right) an arresting cable.



Dealing with arresting barriers. Nets are located in the overrun area near the runway threshold. If the net is in the raised position at the lift-off end, it should be treated as an obstruction that has to be cleared by 35 feet (11 meters) in accordance with typical regulations, and an adjustment should be made to the takeoff runway available. There are rare situations in which a net has been located across the actual runway. If a net is lying on top of the runway, the airplane should not cross it.

Runway availability. A commercial airplane following a military aircraft in to land could experience a delay in landing if the military aircraft engages the arresting gear. The flight crew of the commercial airplane should expect to execute a missed approach while the military aircraft is removed and the arresting gear is reset. Typical cycle times for arresting gear can vary from 3 to 10 minutes depending on the type of system. (See definitions of *cycle time* and *reset time* in “Common terms” on page 20.)

Airplane maintenance. If the flight crew believes the airplane nosegear deflector has contacted one of the hard rubber donuts supporting an arresting gear cable, a visual inspection of the nosegear spray deflector should be conducted to verify whether it has been damaged. A similar visual inspection would apply if the flight crew thought that the cable had made contact with the belly of the airplane. For airlines that routinely operate on runways with arresting-gear cables, additional visual inspections may be conducted depending on the type of arresting systems installed and to what extent the airplane interacts with the system.

MEASURES TO HELP ENSURE SAFE COMMERCIAL OPERATIONS

The key to dealing with the presence of arresting cables on runways is coordination among the airline operator, the airport authority, and the agency having control of

the arresting system. Educating the various parties on the operational needs of commercial airplanes can alleviate many limitations. Six ways to minimize the impact of arresting systems located on runways used by commercial airplanes are:

- If the airport has parallel runways, normally only one of the two runways has the arresting system installed. Consider limiting commercial operations to the runway without the arresting system.
- Coordinate the permanent removal of the arresting system. The military aircraft using the runways may no longer need the arresting cable, which could be removed.
- Install a system to lower the arresting cable flush into a track on the runway (see fig. 7). This modification, referred to as BAK-14 or Type H, allows the air traffic control tower to remotely raise the arresting cable for military operations and lower it into a track flush-mounted on the runway for commercial operations.

Figure 8: Disconnecting an arresting cable

In some situations, an arresting cable can simply be disconnected and laid on the side of the runway during periods of commercial operations.



At the majority of joint-use airports in the United States, this modification has been made to the standard BAK-9/-12/-13 systems that previously were supported by rubber donuts. Worldwide, there are approximately 500 BAK-14 and 25 Type H systems installed. Roughly 95 percent of joint-use runways have BAK-14 or Type H modifications installed. (See the definition of *BAK* in “Common terms” on page 20.)

- Disconnect the cable and lay it on the side of the runway during periods of commercial operations (see fig. 8). Temporarily disconnecting the cable is a workable solution provided the scheduled commercial operations do not interfere with the flight schedule of military aircraft. Alternatively, the rubber donuts could be slid to the edge of the

runway so that the cable lies flat on the pavement but is still under tension. The airplane then can roll over the top of the cable.

- Although not considered an optimal solution, the runway length can be reduced. This is feasible if the runway is of sufficient length that the mission of the airplane can be achieved on the usable runway distance between arresting gears installed at each end of the runway. At a minimum, operators may consider reducing only the distance from the approach end of the runway to the gear.
- Operators may want to increase the frequency of maintenance inspection of the nosegear and lower fuselage areas for airplanes that routinely operate over arresting-gear cables.

SUMMARY

Commercial airplanes can safely use runways with aircraft arresting systems. Approximately 400 airports with arresting gear systems have reported commercial airplane traffic. Safe operation requires coordination among airline operators, airport authorities, and the agencies that control the arresting systems.

For more information, e-mail AirportCompatibility@boeing.com. 

Share your opinions,
insights, and ideas in the
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