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787 Takes Flight

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**Optimizing  
Airplane  
Maintenance  
Economics**

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Reducing Laser  
Illumination Threats

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Class 2 Electronic  
Flight Bag Offers  
Comprehensive  
Functionality

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Avoiding Convective  
Weather and  
Ice-Crystal Icing  
Engine Events

**AERO**



# AERO

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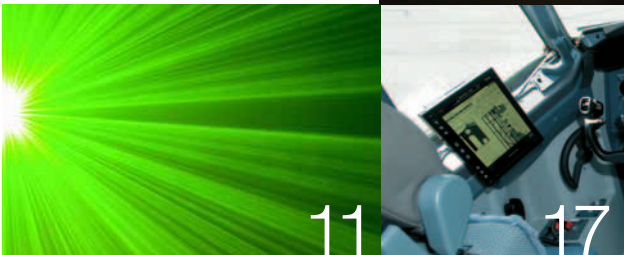
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# AERO

**Publisher**

Shannon Frew

**Editorial director**

Jill Langer

**Editor-in-chief**

Jim Lombardo

**Design**

Methodologie

**Writer**

Jeff Fraga

**Distribution manager**

Nanci Moultrie

**Cover photography**

Jeff Corwin

**Printer**

ColorGraphics

**Web site design**

Methodologie

**Editorial Board**

Gary Bartz, Frank Billand, Richard Breuhaus, Darrell Hokuf, Al John, Doug Lane, Jill Langer, Duke McMillin, Wade Price, Bob Rakestraw, Frank Santoni, Jerome Schmelzer, Paul Victor, Constantin Zadorojny

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*AERO* magazine is published quarterly by Boeing Commercial Airplanes and is distributed at no cost to operators of Boeing commercial airplanes. *AERO* provides operators with supplemental technical information to promote continuous safety and efficiency in their daily fleet operations.

The Boeing Company supports operators during the life of each Boeing commercial airplane. Support includes stationing Field Service representatives in more than 60 countries, furnishing spare parts and engineering support, training flight crews and maintenance personnel, and providing operations and maintenance publications.

Boeing continually communicates with operators through such vehicles as technical meetings, service letters, and service bulletins. This assists operators in addressing regulatory requirements and Air Transport Association specifications.

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E-mail: [WebMaster.BCA@boeing.com](mailto:WebMaster.BCA@boeing.com)

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# The Future Takes Flight

On Dec. 15, 2009, the eyes of the world watched as the Boeing 787 Dreamliner took flight for the first time in Everett, Washington. It was an historic moment as this industry game-changer took to the skies.

The 787 is truly a 21st-century airplane — from its advanced technologies to the way it creates a new, redefined passenger experience. The spaciousness of the cabin, larger windows, cleaner air, and smoother ride will create a more comfortable and relaxing flight. The extensive use of composites, advanced systems and aerodynamics, and breakthroughs in engine technology give the airplane significant advantages in efficiency and performance. The 787 will transform the economics of

flight — including a 30 percent reduction in maintenance — and it will help contribute to a cleaner environment.

But there still is much work to be done before the 787 enters service. We are tackling a rigorous flight-test program, ramping up our production rates, and implementing an entry-into-service plan that lets customers take full advantage of the 787 at the time of airplane delivery. We are working closely with customers, partner suppliers, and regulators to ensure service readiness on all fronts.

Once the airplane is in service, our 787 support and services package will help airlines continue to increase their operational efficiencies. It will leverage technology to ensure information is easy

to find, use, and integrate with operators' document management systems.

The 787 is the first airplane for the new century, and it represents the way airplanes will be made for the next 75 to 80 years. Its success will ultimately be judged by our customers during the decades to come. Boeing will be there offering the support and services to make this 21st-century airplane a true game-changer for you.

On a personal level, I will never forget standing in Everett, watching this beautiful airplane take off for the first time.

**LOU MANCINI**

Senior Vice President,  
Boeing Commercial Aviation Services



Benchmarking is one of the key ways TOPICS helps airlines understand and reduce maintenance costs.

# Optimizing Airplane Maintenance Economics

Reducing the cost of operations is a major concern to airlines, and Boeing is partnering with them to understand, control, and optimize airplane maintenance economics, as well as providing tools to help airlines lower costs without compromising quality.

By **Tom Buyers**, Regional Director, Airline Economics

Boeing and airlines are working together to gain valuable insights into the economics of airlines' maintenance operations. The Technical Operations Performance Improvement and Cost Solutions (TOPICS) working groups and annual TOPICS regional meetings offer benchmarking, best practices, solutions, networking, and identification of key financial metrics. Participants include airlines; leasing

companies; suppliers; maintenance, repair, and overhaul facilities (MROs); and Boeing.

This article details the development of TOPICS, provides examples of the types of information available to operators, and details how airlines are using this information to lower maintenance costs while continuing to improve overall maintenance performance.

## THE DEVELOPMENT OF TOPICS

In 2005, Boeing began exploring ways to help customer airlines better understand their maintenance costs, the factors that drive high costs, and how their costs compare to those of other operators. The goal was to provide airlines with solutions and best practices that would help improve their maintenance operations, optimize their maintenance costs, and increase their profitability.

## Figure 1: Objectives for TOPICS working group participants

There are substantial and important industry benefits for all stakeholders being actively engaged in the TOPICS working group meetings and process. Optimizing airplane economics is not just the responsibility of airlines, but takes the combined efforts of leasing companies, suppliers, MROs, and Boeing. With this participation and transparency, many benefits, including those listed in this figure, will be realized.

<b>Airlines/ Operators/ Leasing Companies</b>	<ul style="list-style-type: none"> <li>■ Gain a better understanding of fleet maintenance economics.</li> <li>■ Use year-over-year benchmarking to compare airline to others.</li> <li>■ Identify opportunities for improvement.</li> <li>■ Learn about best practices and solutions.</li> <li>■ Take advantage of networking opportunities.</li> <li>■ Get key financial metrics and performance indicators.</li> <li>■ Discuss maintenance cost challenges, opportunities, and successes.</li> <li>■ Learn how to optimize fleet maintenance economics.</li> </ul>
<b>Suppliers</b>	<ul style="list-style-type: none"> <li>■ Take advantage of benchmarking, networking, and business opportunities.</li> <li>■ Hear customers' concerns about maintenance cost optimization.</li> <li>■ Collaborate with customers on maintenance cost improvements.</li> <li>■ Gather product in-service information and market intelligence.</li> </ul>
<b>MROs</b>	<ul style="list-style-type: none"> <li>■ Take advantage of benchmarking, networking, and business opportunities.</li> <li>■ Gain a better understanding of fleet maintenance costs and the high cost drivers.</li> <li>■ Participate in discussions with customers centered on maintenance cost optimization.</li> <li>■ Listen to customers' maintenance economic challenges, opportunities, and successes.</li> <li>■ Discuss solutions with customers that will help them lower their maintenance economics.</li> <li>■ Gather market intelligence.</li> </ul>
<b>Boeing</b>	<ul style="list-style-type: none"> <li>■ Help customers be more successful and profitable.</li> <li>■ Assist customers in maintenance cost benchmarking.</li> <li>■ Facilitate and lead discussions with all maintenance cost stakeholders (i.e., airlines, suppliers, MROs, and Boeing) on maintenance cost optimization.</li> <li>■ Understand maintenance cost concerns of customers and help formulate solutions.</li> <li>■ Gain a better understanding of customers' maintenance concerns.</li> </ul>

At that time, there was no industry standard for tracking and reporting airplane maintenance costs. It was difficult for some operators to understand maintenance cost methodology, the maintenance cost performance of airplanes in their fleets, and whether their maintenance costs were in line with the rest of the industry. There was no industry forum in which airlines, suppliers, MROs, and Boeing could discuss the financial impact of airplane maintenance and opportunities for cost improvement and optimization.

This led to the development of the TOPICS working groups, which are led by an airline steering team that guides the decisions of the working groups. The groups focus on reducing maintenance costs of Boeing airplane fleets and on leveraging Boeing's technical expertise.

TOPICS provides the venue to benchmark the maintenance costs of participating airlines annually. The benchmarking, which is completely anonymous, enables each airline to see how its maintenance cost performance compares to others; leads to an awareness of each airline's standing in the industry

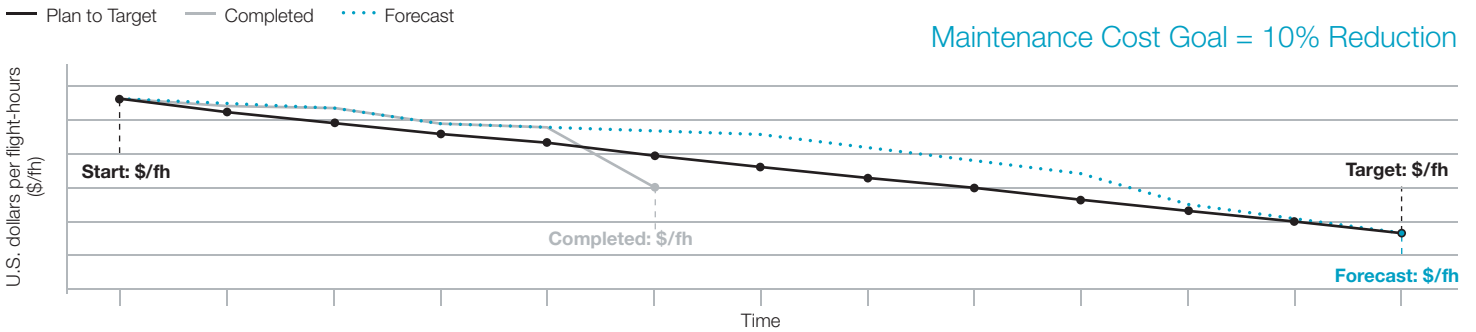
(best in class, worst in class, or somewhere in the middle); and provides a baseline for improvement.

TOPICS is also an open forum that allows members to share maintenance cost-related challenges, successes, and opportunities with each other. TOPICS is a way for all stakeholders — airlines, suppliers, MROs, leasing companies, and Boeing — to become involved in the process of systematically reducing the maintenance cost of Boeing airplanes.



## Figure 2: TOPICS working group scorecard

Working group participants use scorecards such as this to set goals and track progress. Scorecards can be individually tailored for each participant.



## Cost-Reduction Opportunities

Month/year	Action	Forecast \$/fh	Completed \$/fh
Jan. 2007	Improve reliability of potable water pres elect viv	(\$0.89)	(\$1.32)
Apr. 2007	Escalate C check tasks ATA 52, 53, 55, 57	(\$2.29)	(\$8.31)
July 2007	Improve reliability of digital flight data recorder	(\$1.39)	(\$9.00)
Oct. 2007	Revised FOPM Procedures (Taxi Brakes)	(\$5.99)	(\$7.50)
Jan. 2008	Erosion Protection Kit	(\$2.25)	(\$5.25)
Apr. 2008	Escalate A check task ATA 24, 32	(\$6.81)	(\$8.51)
July 2008	Improve repair costs for IDG ATA 24	(\$5.11)	(\$7.25)
Oct. 2008	Improve tire and brake wear life by 250 cycles	(\$7.21)	(\$5.78)
Jan. 2009	Escalate C check tasks for ATA 32	(\$20.00)	(\$15.00)
Apr. 2009	Escalate D check structural tasks	(\$34.33)	(\$17.00)
July 2009	Improve reliability of starter air pressure sensor	(\$0.35)	
Oct. 2009	Improve reliability of PRSOV	(\$2.61)	(\$4.44)
Jan. 2010	Escalate A check tasks for ATA 21, 22, 23, 38	(\$2.78)	
Apr. 2010	Improve reliability of ADIRU	(\$4.12)	
July 2010	Improve reliability of TCAS computer	(\$5.71)	

These results are presented only as examples. Actual costs will vary from airline to airline.

### TOPICS WORKING GROUP MEETINGS

The first regional TOPICS working group meeting was held in Shanghai in 2006, followed by meetings in Berlin, Dubai, and Miami. More than 60 Next-Generation 737 operators, 10 suppliers, and 10 MROs participated in TOPICS during the program's first year. In 2007, Boeing added TOPICS meetings for 777 operators. Last year, Boeing held five regional TOPICS working group meetings: three focused on the Next-Generation 737 and two on the 777.

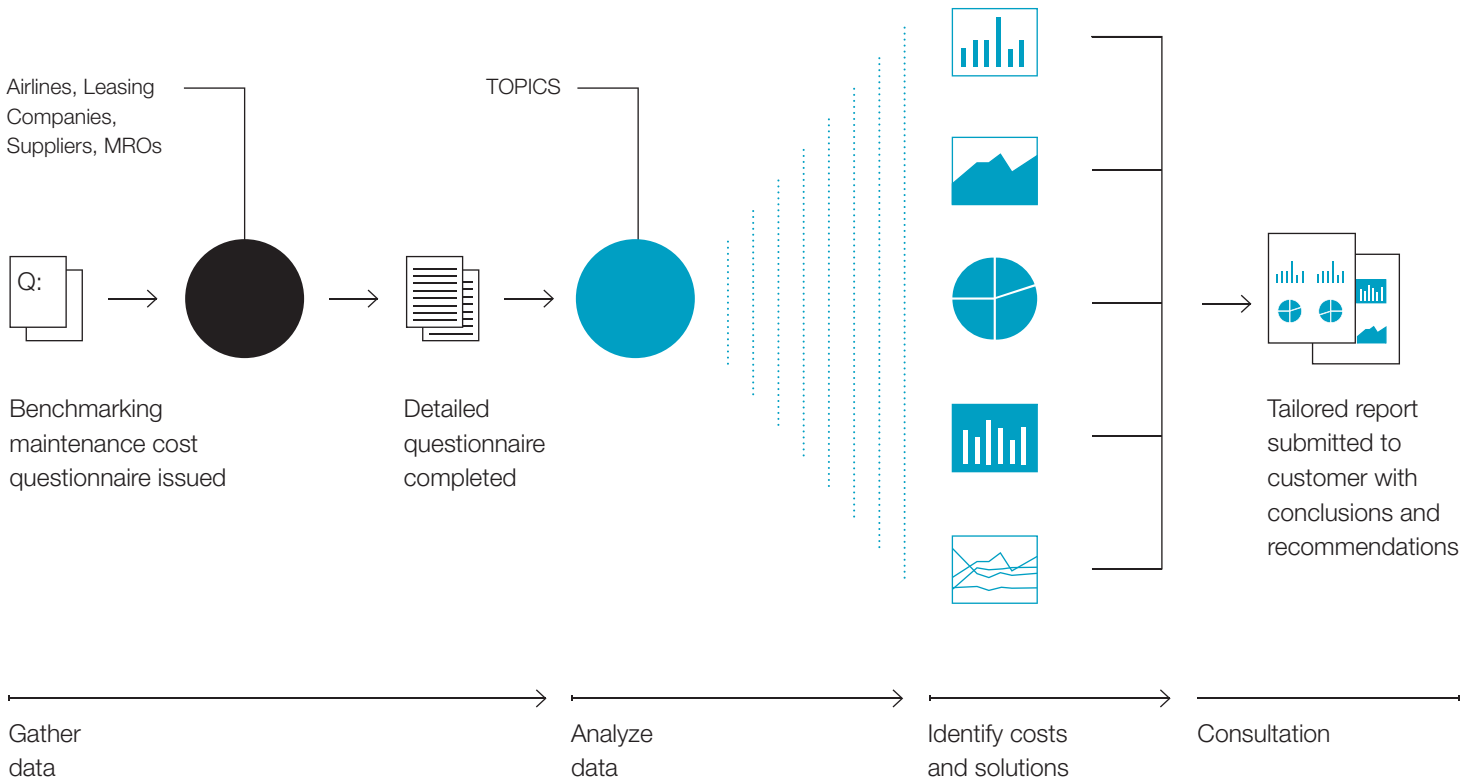
At the meetings, airlines, suppliers, MROs, and Boeing share maintenance cost drivers and operational experiences, with a goal of improving maintenance practices that result in reduced maintenance costs and improved utilization of the operators' Boeing airplanes (see fig. 1). Airlines, suppliers, and MROs give presentations on various topics related to maintenance cost-reduction solutions and accomplishments.

The meetings also include cost-reduction and project-tracking technical panels, and the sharing of maintenance cost benchmarking results are provided for

participating airlines. Boeing helps identify maintenance costs and the sharing of opportunities for optimization and assists airlines in implementing solutions for optimizing maintenance costs. Solutions can be technical or nontechnical, such as best practices and accounting standards. A working group scorecard helps airlines track their progress (see fig. 2). Participants have reported that sharing best practices among all stakeholders often results in the biggest cost-reduction opportunities.

### Figure 3: Comparing maintenance costs to the industry

TOPICS helps airlines turn data into information and identify ways to reduce maintenance costs. Boeing makes the questionnaire available to the airlines, leasing companies, suppliers, and MROs. Each stakeholder fills out the appropriate sections (yearly summary, airframe, engine, components, scheduled event checks, etc.) and submits back to Boeing for analysis and input into the TOPICS maintenance cost modeling tool. Tailored output reports are provided to each participating stakeholder showing how their maintenance costs compare to the industry in various categories (best in class, worst in class, somewhere in the middle) with conclusions and recommendations for improvements. All participants receive a four-digit code only they will know, so when they view the report they know their results but cannot identify other participants' identity. Annual working group meetings provide networking and best practices sharing for additional opportunities for improvements to maintenance cost performance.



### TOPICS working groups help participating airlines:

- Identify maintenance costs and drivers.
- Identify maintenance and engineering financial metrics.
- Benchmark maintenance costs.
- Identify solutions to maintenance cost issues.
- Prioritize maintenance cost solutions.
- Implement maintenance cost solutions.
- Quantify, track, monitor, and report on improvements made in their maintenance operations.

### HOW TOPICS HELPS AIRLINES REDUCE MAINTENANCE COSTS

Benchmarking is one of the key ways TOPICS helps airlines understand — and reduce — maintenance costs. Participating airlines complete and submit detailed TOPICS benchmarking maintenance cost questionnaires. These questionnaires help airlines get a better understanding of maintenance costs and the key factors that drive up those costs. Each airline receives a tailored maintenance cost benchmarking report that compares its costs to other airlines, MROs, and suppliers (see fig. 3).

Examples from a tailored maintenance cost benchmarking report are shown in figure 4.

### SUMMARY

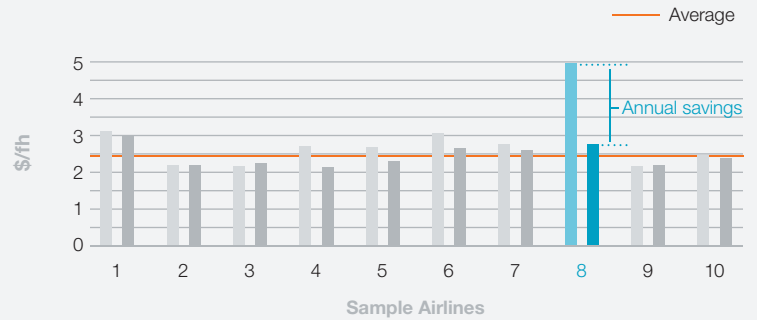
Through TOPICS, Boeing is helping operators understand, control, and optimize airplane maintenance economics. The TOPICS working groups give airlines information and insights they can use to lower maintenance costs while improving overall maintenance quality.

For more information, contact Tom Buyers at [tom.a.buyers@boeing.com](mailto:tom.a.buyers@boeing.com).

**Figure 4: Examples from a tailored maintenance cost benchmarking report**

**Reported scheduled event check costs**

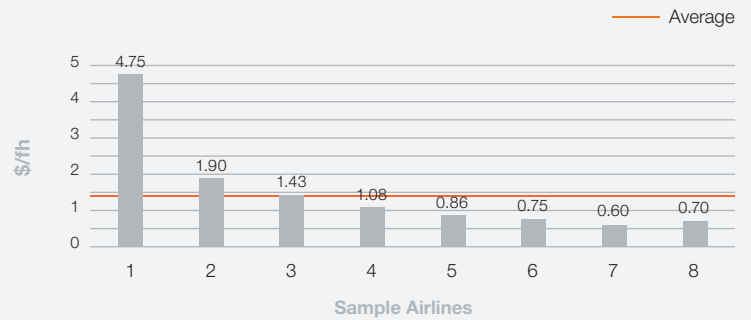
This graph shows how an actual airline (blue bars) used the TOPICS benchmarking report to lower its year-over-year maintenance costs for event check maintenance (scheduled maintenance checks). In 2007, the airline discovered that its costs were more than 100 percent higher than the TOPICS industry average for those maintenance events. After discussing and analyzing various solutions, it implemented changes in its maintenance operations that resulted in US\$4 million total annual savings for this airline.



Each set of bars represents one airline's results, from two years: ■ 2007 ■ 2008

**Components benchmarking report**

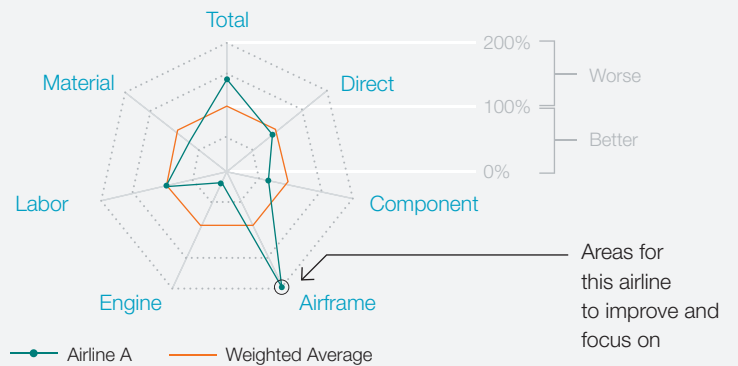
This graph shows the average maintenance cost per flight hour (x axis) for a component on the Next-Generation 737. The y axis represents airlines. As indicated by the solid orange line, the average cost per flight hour for this component is US\$1.44. Airline 1 reported costs that were US\$3.31 above the average. Prompted by this TOPICS benchmarking report, the airline implemented a solution that lowered its maintenance costs for this component. This solution has the potential to save the airline more than US\$8 million in maintenance costs over 15 years — on a single component.



Each bar represents one airline's results

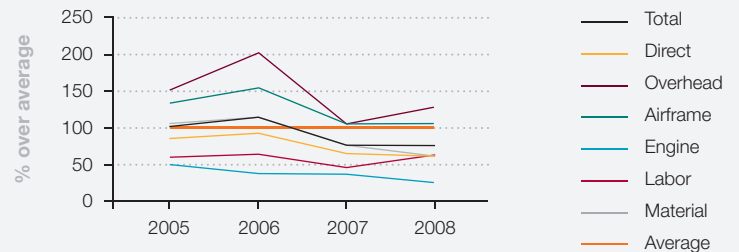
**Radar improvement chart**

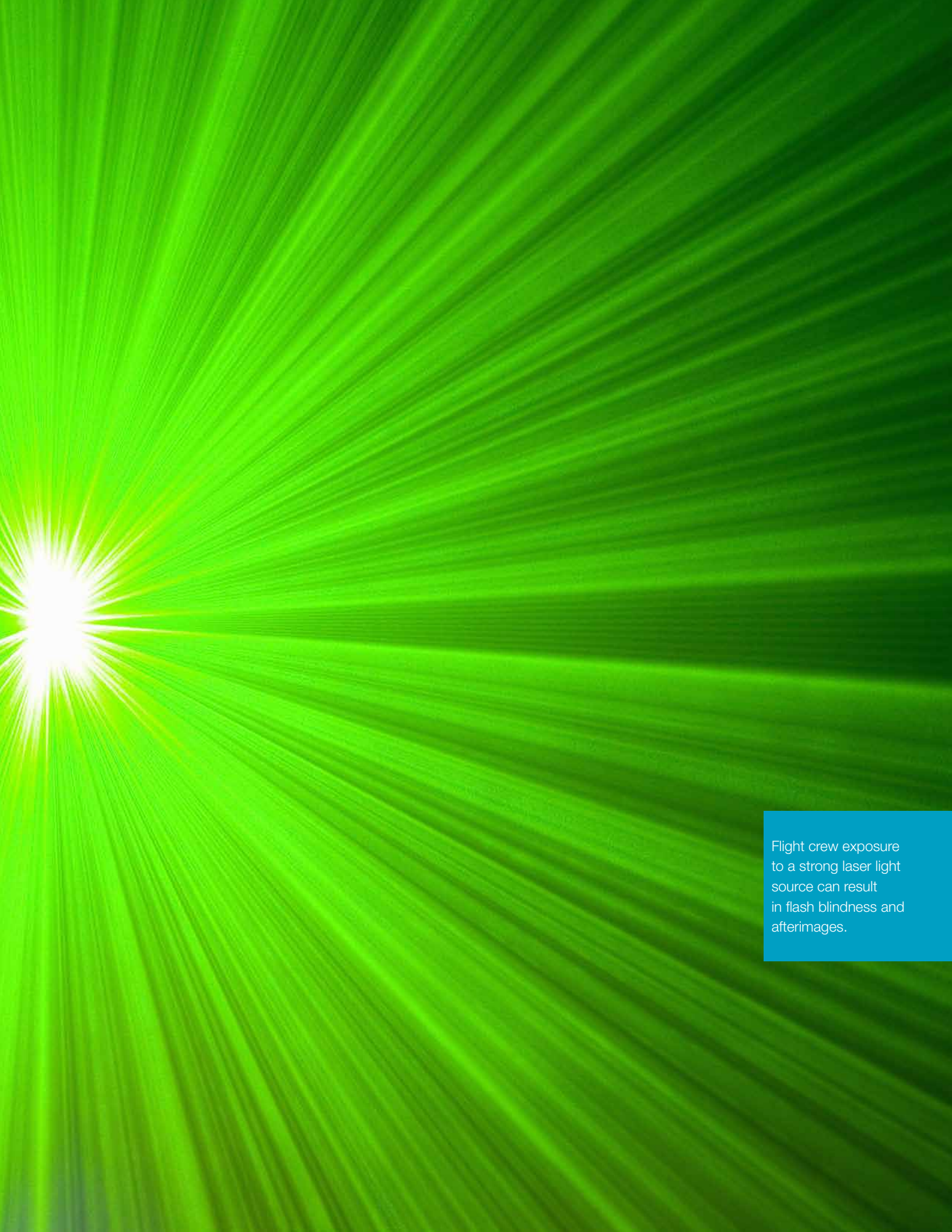
This chart shows an airline where its maintenance cost performance is better or worse than the baseline average cost in each of seven cost categories: total, direct, component, airframe, engine, labor, and material. Airlines participating in the benchmarking activity submit their annual costs in each of these categories, and an average is derived. Costs are normalized for flight length, airplane age, and labor. The orange line represents the average cost for each category. The chart helps airlines determine where to focus improvement efforts. Additional detailed charts are provided in each of these categories to help identify the "right" solutions.



**Improvement trend chart**

This chart allows participating airlines to compare their maintenance costs in various categories year-over-year to the TOPICS average. It uses the same information as the radar improvement chart, but shows trends over four years for each category. The orange line represents the TOPICS average: trends below this line indicate better than average maintenance cost performance while trends above the line indicate worse than average performance.





Flight crew exposure to a strong laser light source can result in flash blindness and afterimages.

# Reducing the Threat of Laser Illuminations

Laser illumination of commercial airplanes is a growing threat to operational safety, and the number of incidents is increasing. The U.S. Federal Aviation Administration (FAA) laser-incident database contains more than 3,200 reports of incidents since 2004 and provides information on the locations, altitudes, color of light, and phases of flight that show the most activity. By knowing how the laser affects the eye and following recommended procedures, pilots can reduce this safety threat.

By **Peter A. Derenski**, Technical Fellow, Human Systems Integration

A growing threat to air transportation safety involves laser pointers directed at commercial airplanes by people near flight routes and airports. Because laser light can distract flight crews and damage eyes, the commercial aviation industry needs to be aware of the threat posed by laser illumination, the protective technologies available and their effects on flight deck lighting, and the recommended defensive procedures for pilots to follow. This article describes typical laser incidents, discusses laser properties and effects on eyesight, and provides recommendations for mitigating the effects of laser illumination.

## LASER ILLUMINATION INCIDENTS

Lasers are a source of collimated, monochromatic, coherent light that can travel long distances with very little loss of intensity. This coherent property is what allows a laser to maintain a narrow, high-powered beam over long distances. Lasers are available in a variety of colors, intensities, and power outputs. Green lasers, which have become increasingly more affordable, have been reported in more than 90 percent of the documented laser incidents.

There was a time when the only lasers pilots needed to worry about came from Las Vegas hotels or a light show at one of the Disney properties (see fig. 1). But small

laser pointers have been available to the public for quite some time, and their number is increasing as they become more affordable.

Since Advisory Circular 70-2 on *Reporting of Laser Illumination of Aircraft* was published by the FAA in late 2004, more than 3,200 laser incidents have been reported within the United States, along with hundreds more internationally. A laser illumination incident begins quite suddenly as the flight deck is filled with a bright light. The glare makes it difficult to concentrate on the flight instruments and can remove the crew's visual references with the runway environment, making pilots unsure of their position relative to the runway and the ground. According to the FAA incident

## Figure 1: Professional laser light show

Until recently, the expense of lasers had limited their use to professional shows, but lower prices on handheld laser pointers have made this type of device widely available. (Photo courtesy of Dr. Leon McLin.)



database, 50 percent of reported incidents occurred at 5,000 feet or below and usually during evening hours. Some incidents have been reported during cruise at much higher altitudes. The western Pacific region of the United States has had the greatest number of reports, with the highest number of incidents occurring in the San Jose and Los Angeles areas.

Under the USA PATRIOT Act, it is a federal offense to interfere with the safe operation of an airplane, and that includes the flight crews. Recently an individual was sentenced to two and a half years in prison for directing a laser at an airplane near the John Wayne Airport in Los Angeles.

Incidents are occurring not only in the United States but internationally as well. Reports of laser incidents have come from Australia, Canada, England, Germany, and Ireland. In one incident at Sydney, Australia, in March 2008, a number of people armed with lasers and cell phones performed what was described as a “coordinated attack” on landing airplanes. Some airplanes landed, others executed missed approaches, and others diverted to other airports. During this incident, air traffic controllers were forced to change the active runway to get airplanes away from the laser pointers.

### THE EFFECT OF LASER LIGHT ON EYESIGHT

How a laser affects the eye depends on the wavelength of the laser, the power level, and the duration of the exposure. The optics of the human eye can take available light and multiply it 100,000 times, allowing people to see on dark, moonless nights. That dark adaptation can be lost in the presence of a strong light source and can take several minutes to readapt.

The human eye sensitivity peaks in the green range and perceives green 30 times brighter than red. When comparing a green and a red laser of equal power output, the green one will appear much brighter than the red.

Visible light lasers (380 to 750 nanometers) enter the optical system and are magnified and focused on the back of the eye (retina), making the retina the target of the laser energy. The eye’s natural defense for bright visible light is the blink response, which can take effect within a quarter of a second.

Nonvisible light can be in the wavelength range of ultraviolet (200 to 380 nanometers), near infrared (750 to 1,400 nanometers), or mid to far infrared (1,400 nanometers to 1 millimeter). Nonvisible lasers also enter the optical system and affect the eye, but they are not visible and present a different challenge: the blink

response only works with visible light, so there is no natural protection for the eye when outside the visible spectrum. Near infrared light has the same effect on the retina as visible light, but cannot be seen. Ultraviolet and mid- to far-infrared wavelengths affect the cornea and lens and can cause corneal clouding or cataracts.

With visible light (380 to 750 nanometers), a range of effects can occur during and after a visible laser exposure. Starting from the mildest form, lasers can cause glare — an interference that inhibits the viewer from seeing details in the visual scene due to excess brightness. At lower power levels or long distances from the source, this can simply be a distraction (see fig. 2). At stronger levels or closer to the source, the high brightness can preclude a viewer from seeing outside landmarks and references and can affect pilots’ ability to clearly see an instrument panel directly in front of them (see figs. 3 and 4).

Exposure to a strong laser light source can result in flash blindness and afterimages. In flash blindness, exposure to a very bright light source can deprive pilots of vision for a period of time ranging from a few seconds to a few minutes. This can be followed by afterimages, such as the yellow and purple dots seen after a flash photo. Again, these afterimages will disappear in time.

**Figures 2–4: Simulations of laser light in an airplane flight deck**

These photos, which were taken in a simulator during a study on the effects of laser light, demonstrate varying levels of laser intensity, from a distraction (fig. 2) to potentially disabling (figs. 3 and 4). Notice the runway lighting and the effects of the glare. This simulates a 5-milliwatt laser pointer seen from 3,000 feet away. (Photo series courtesy of Dr. Leon McLin.)



This is the effect of the same laser pointer seen from 1,000 feet away.



This is the effect of the same laser pointer seen from 330 feet away. Note the degraded visual cues around the runway.



The number of laser incidents involving commercial airplanes continues to increase every year. The best way for flight crews to protect themselves is by being aware of the problem and by following proper procedures if affected by laser light.

In the most serious exposures to lasers, the lens of the eye concentrates the light energy on the retina and can actually burn the retinal tissue. The human eye can compensate for small area retinal burns by looking around them, but large area retinal burns can mean permanent loss of vision for the affected area.

#### PROTECTION FROM VISIBLE LASER LIGHTS

There are two primary ways flight crews can protect themselves from the effects of laser lights.

**Protective glasses.** A variety of safety glasses are available that can protect the wearer from green laser energy; however, airlines should consider the drawbacks that are associated with them. Filtering light reduces the total amount of light entering the eye, which can adversely affect normal viewing, especially at night when most laser incidents occur. In addition, filtering green light can remove some green flight symbology on flight deck displays and change the appearance of some of the other colors used. As a result, protective glasses should be used with care. Regular sunglasses do not provide any protection from lasers.

**Procedural changes.** Flight crews who find themselves in a situation involving laser light in the cockpit should consider taking these steps:

- Look away from the beam or shield eyes from the light.
- Execute a missed approach if the light is severe enough to warrant it.
- Engage the autopilot or transfer airplane control to the other pilot if that pilot is not affected.
- Use Autoland if available. Autoland, included on all Boeing production models, works with a ground-based instrument landing system and uses the autopilot to fly an approach all the way to roll out without the direct involvement of the pilot.
- Increase the brightness of the interior lights to reduce some of the effects of the laser and put additional light on the instrument panel.
- Inform the controlling agency and provide the approximate location of the source.
- Avoid rubbing the eyes after an exposure to laser light and seek professional medical help, if necessary. If the surface of the eye is damaged, rubbing will make it worse.

#### ADDITIONAL INFORMATION

Additional information about laser safety can be found in these publications:

- The American National Standards Institute (ANSI) publication Z 136.1: Safe Use of Lasers.
- SAE Aerospace Recommended Procedures (ARP) 5535: Observers For Laser Safety in the Navigable Airspace.
- SAE ARP 5572: Control Measures for Laser Safety in the Navigable Airspace.
- SAE ARP 5598: Laser Visual Interference: Pilot Operational Procedures.

#### SUMMARY

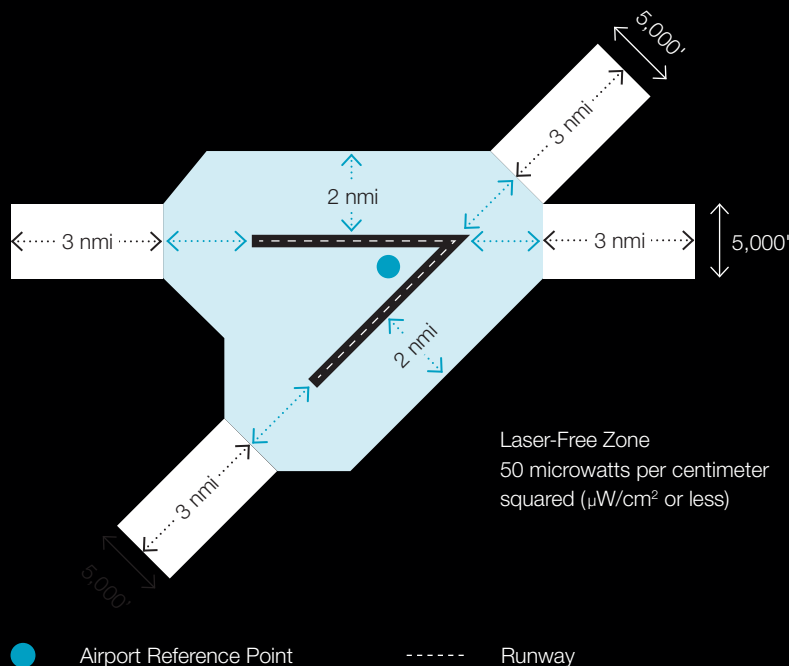
The number of laser incidents involving commercial airplanes continues to increase every year. The best way for flight crews to protect themselves is by being aware of the problem and by following proper procedures if affected by laser light.

For more information, contact Peter Derenski at [peter.a.derenski@boeing.com](mailto:peter.a.derenski@boeing.com). [A](#)



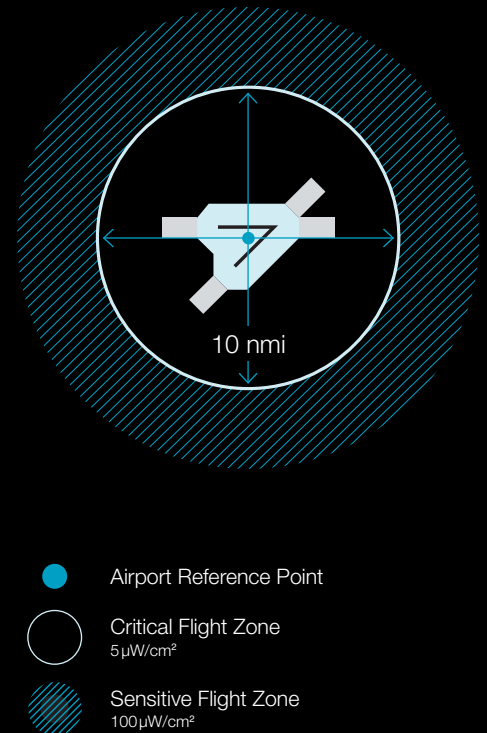
**Figure A: Laser-free zone**

The FAA prohibits the use of any visible laser beam that can cause any visual distraction or disruption in the immediate airport landing area.



**Figure B: Airspace flight zones**

Critical and sensitive flight zones, as defined by the FAA.



## Airspace zones at U.S. airports

In the United States, the Federal Aviation Administration (FAA) has established airspace zones designed around airports and other sensitive airspace that should be protected from the hazards of visible laser light exposure.

**Laser-Free Zone (LFZ).** Airspace in the immediate proximity of the airport, up to and including 2,000 feet above ground level (AGL), extending two nautical miles (nmi) in all directions measured from the runway centerline (see fig. A). Additionally, the LFZ includes a three-nmi extension that is

2,500 feet on each side of the extended runway centerline, up to 2,000 feet AGL of each usable runway surface. The effective irradiance of a visible laser beam is restricted to a level that should not cause any visual distraction or disruption.

**Critical Flight Zone (CFZ).** Airspace within a 10-nmi radius of the airport reference point, up to and including 10,000 feet AGL (see fig. B). The effective irradiance of a visible laser beam is restricted to a level that should not cause transient visual effects (e.g., glare, flash blindness, or afterimage).

**Sensitive Flight Zone (SFZ).** Airspace outside the critical flight zones that authorities (e.g., FAA, local departments of aviation, military) identify to be protected from the potential visual effects of laser beams (see fig. B).

**Normal Flight Zones (NFZ).** Airspace not defined by the laser-free, critical flight, or sensitive flight zones. As with all the zones, the NFZ must be protected from a laser beam that exceeds the maximal permissible exposure, as defined by the FAA.



The new Class 2 EFB helps airlines increase operational efficiency while enhancing safety and security.

BACK REST MUST BE IN  
ORIGINAL FLIGHT POSITION WHEN  
SEAT IS MOVING OUTBOARD

ACTIVE DISPLAY  
13000  
123350  
FLOOD PANEL  
LEFT DOWN

# Class 2 Electronic Flight Bag Offers Comprehensive Functionality

Boeing is leveraging its Class 3 Electronic Flight Bag (EFB) experience to provide airlines with a Class 2 EFB with similar functionality with the current fully integrated Class 3 offering. Boeing estimates that the Class 2 EFB can potentially save operators approximately US\$80,000 to US\$115,000 per airplane per year by increasing their operational effectiveness. It is initially available on the Next-Generation 737, both in production and for retrofit.

By **Ed Tobon**, Electronic Flight Bag Product Specialist

Boeing is offering a common application suite and ground infrastructure for use across Class 1, Class 2, and Class 3 to maximize the value of the EFB infrastructure. Boeing delivered its first Class 3 EFB in October 2003, its first Class 1 EFB in December 2009, and is offering a Class 2 EFB in production and for retrofit starting with the Next-Generation 737. Other models will follow based on operator demand.

This article provides background about the development of Boeing EFBs, describes the features of the new Class 2 EFB offering, and outlines some of the advantages it offers to operators. (More information about the Boeing Class 3 EFB and Electronic Logbook can be found in *AERO* second-quarter 2008.)

## THE EVOLUTION OF BOEING EFBs

The goal of an e-Enabled airline is to connect everything and everyone to a single secure network designed to help the airline meet its business and operational objectives. The EFB system creates a link between the airplane and the airline enterprise. This link, coupled with the software applications on the ground and in the EFB, allows airlines to realize fuel cost savings, enhanced safety and security, reduced insurance premiums, fewer flight schedule delays, and less document handling.

Since Boeing delivered the first Class 3 EFB certification and integration in 2003, approximately 75 percent of 777 airplanes are being equipped with EFB systems

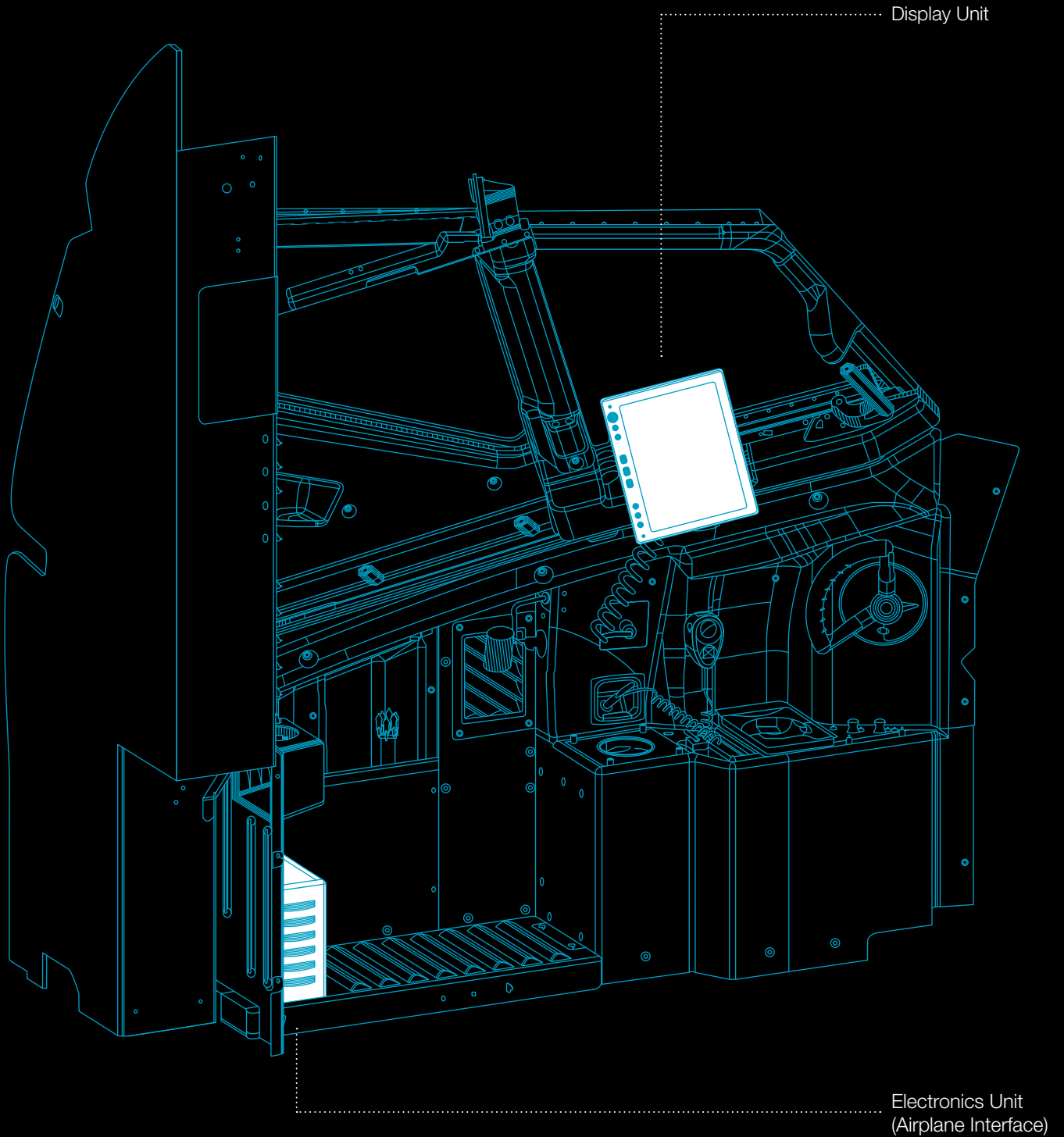
during production. The Class 3 EFB is a basic offering on the Boeing Business Jet and 787, and it is a production option on the 777, Next-Generation 737, and 747-8. The Class 3 EFB is also a retrofit option for 747-400, 757, and 767. More than 1,200 airplanes are scheduled to use Boeing Class 3 EFBs.

Understanding that a complete airline fleet solution for EFBs can include multiple classes, Boeing has developed Class 1 and 2 products that complement its Class 3 EFB. Common EFB applications run on multiple classes, depending on operator requirements.

Boeing Class 1 and 2 EFBs provide a common look and feel to the Class 3 EFB. They use the same application software

**Figure 1: Next-Generation 737 Class 2 EFB installation and location**

In response to feedback from operators, Boeing installs Class 2 EFB display units in a location that provides easy access and a good viewing angle for the pilot.



# The Class 2 EFB offers the same hardware in production and for retrofit, with the Next-Generation 737 being the first model supported. The system is fully integrated with flight deck and airplane systems.

packages and common ground support and administration software. This commonality allows operators to utilize common EFB infrastructure and processes when deploying mixed-class EFBs across the fleet. This also significantly reduces cross-training requirements. In addition, operators can load their own or third-party applications on to any of the EFB classes.

## BOEING CLASS 2 EFB

The new Class 2 EFB is a comprehensive, fully integrated system that offers the following features:

- Class 2 hardware and wiring installed in production or as a retrofit kit (initially for the Next-Generation 737).
- Hardware system (i.e., electronic and display units).
- Flight crew power cutoff switch for EFB system.
- Core software.
  - Application manager.
  - Maintenance.
  - Security and communication.
- Integration with same airplane systems as for Class 3.
- Integration with Class 2-hosted communication systems.
- An integral terminal wireless local area network unit (802.11b/g) capability with an antenna contained in the display unit (see fig. 1).

## Product support for the new Class 2 EFB includes:

- Maintenance documentation.
- Operations documentation.
- Maintenance and operational training.
- Operational approval assistance.
- Technical support 24 hours a day, seven days a week.
- Hardware warranty.
- Spare parts.

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In response to customer requests, the location of the Class 2 EFB Next-Generation 737 flight deck does not require a new sidewall or relocation of the oxygen mask, both of which can add to the cost of the installation. The location also provides easier access to the EFB and allows the pilot to view information without looking down (see fig. 1).

## CLASS 2 EFB SOFTWARE APPLICATIONS

Several software applications will be available for the EFB from Boeing and Boeing subsidiary Jeppesen. These modules enable operators to customize the EFB for their particular operations. Operators can add these software modules during initial installation or at any point in the

future. Each provides increased operational efficiency to airlines (see fig. 2).

- **Airport Moving Map** provides high-resolution airport diagrams with own-ship position. Airport databases with global-positioning-system tracking depict the airport environment with a high degree of accuracy and visual detail.
- **Electronic Charts** offers clear, concise airport, airspace, and approach charts; standard instrument departures; and standard terminal arrivals. The worldwide coverage can be customized to provide specific content for individual operators.
- **Electronic Documents** gives access to up-to-date information, reducing lookup times and eliminating sources of error. It incorporates Boeing-provided and customer-originated and -controlled documents. Documents are available in both day and night formats.
- **Onboard Performance Tool** provides airplane performance calculations that airlines need to optimize the performance of their airplanes. The onboard performance tool automatically factors in minimum equipment list and configuration deviation list items into all calculations.
- **Electronic Logbook** works with Boeing Airplane Health Management to monitor and forward in-flight fault information to the appropriate ground maintenance facility before the airplane arrives at the gate (see *AERO* third-quarter 2007).

- **Electronic Flight Folder** enables airlines to collect data, assemble the initial flight folder, and transmit it to the EFB. The flight folder is populated with flight information and airplane system data and includes the means for the crew to review and digitally sign it.
- **Video Surveillance** is integrated into EFB, enabling the crew to monitor activity outside the flight deck and in the cabin while in a normal seated position. EFB accommodates a variety of third-party camera systems.

Boeing also provides a software development kit under a separate license that allows an airline to load its own or third-party applications. In addition, the system is designed to provide significant growth and expansion opportunities to add future applications.

#### BENEFITS TO OPERATORS

Like the Class 3 EFB, the Class 2 EFB offers a number of benefits to operators, in terms of flight and maintenance operations as well as safety and cost. The overall increase in operational effectiveness can potentially save operators approximately US\$80,000 to US\$115,000 per airplane per year, depending on the airline's technical expertise, infrastructure, number of flights, flight patterns, and other factors considered in Boeing's cost-benefit analysis.

#### Flight Operations

The Boeing Class 2 EFB can improve fuel burn performance, help produce higher revenue by optimizing payloads, enhance flight operations' response to the day-to-day events reported by pilots, and reduce usage of the airplane communications addressing and reporting system. It can also increase pilot efficiency, partly by eliminating the need for them to manually enter pilot reports.

#### Maintenance Operations

The greater accuracy of pilot reports increases mean time to failure and mean time between overhaul for components. The Class 2 EFB also eliminates transcription of pilot reports into another computing system and reduces technical schedule interruptions, no-fault founds,

inventory, and line maintenance labor. The result is lower airplane out-of-service costs, increased dispatch reliability, improved correlation between faults reported and maintenance, and increased regulatory compliance.

#### Safety

The Class 2 EFB, with its available airport moving map, makes accessing an airport layout map easier for pilots than searching for a paper map. It also increases familiarity with each airport's layout, enhances taxi situational awareness, and reduces the probability of runway incursions. It also helps ensure the appropriate takeoff and landing speeds based on runway conditions. For added safety inside the airplane, video surveillance provides increased visibility to cabin and flight deck door area activity.

#### Cost

The Boeing Class 2 EFB can reduce costs by lowering insurance premiums and increasing operational effectiveness through improvements to flight and maintenance operations.

#### SUMMARY

Boeing EFBs help airlines increase operational effectiveness while enhancing safety and security. The new Class 2 EFB reflects Boeing's commitment to develop several EFB platforms that can be installed on any airplane with common applications and tools, regardless of EFB class.

For more information, contact Ed Tobon at [edward.a.tobon@boeing.com](mailto:edward.a.tobon@boeing.com). [A](#)

## EFB Classes

### Class 1

A portable Class 1 EFB, such as a laptop, generally only has an interface to airplane power and must be stowed below 10,000 feet. Boeing offers the software as well as laptop specifications.

### Class 2

The hardware does not allow direct connection to airplane systems. It must have the ability to be removed by the crew without tools and without leaving the flight deck. A separate airplane interface module allows connection to airplane systems.

### Class 3

Class 3 features installed avionics covered by type design approval, with a type designed software partition. It may have a Class 2 partition. The existing Boeing Class 3 falls into this category.

**Figure 2: Operational value of Boeing Class 2 EFB software applications**

Software Option	Value
Airport Moving Map (as available)	<ul style="list-style-type: none"> <li>▪ Fuel cost savings for each minute of taxi time delay saved per flight.</li> <li>▪ Reduced insurance premiums from the addition of safety enhancements.</li> <li>▪ Enhanced safety.</li> <li>▪ Provides situational awareness of ground location of the airplane.</li> </ul>
Electronic Charts and Documents	<ul style="list-style-type: none"> <li>▪ Document handling savings from eliminating document preparation, maintenance, and distribution.</li> <li>▪ Weight saved onboard by reducing or eliminating flight deck paper, thereby reducing clutter.</li> <li>▪ Improved pilot efficiency.</li> </ul>
Onboard Performance Tool	<ul style="list-style-type: none"> <li>▪ Fuel cost savings for each minute of taxi time delay saved per flight.</li> <li>▪ Dispatch delay costs saved for each minute of delay saved per flight.</li> <li>▪ Engine maintenance costs saved by flying more takeoffs at lower derates.</li> <li>▪ Revenues gained or costs avoided by optimizing payload for current takeoff conditions.</li> <li>▪ Improved pilot efficiency.</li> </ul>
Electronic Logbook	<ul style="list-style-type: none"> <li>▪ Dispatch delay costs saved for each minute of delay saved per flight.</li> <li>▪ Maintenance troubleshooting time saved per flight by improved pilot squawk capture.</li> <li>▪ Document handling savings from eliminating document preparation, maintenance, and distribution.</li> <li>▪ Reduction in no fault found.</li> <li>▪ Improved pilot efficiency.</li> </ul>
Electronic Flight Folder	<ul style="list-style-type: none"> <li>▪ Eliminate paper printing, handling, and storage costs.</li> <li>▪ Flight crew and ground report-processing labor efficiencies.</li> </ul>
Video Surveillance	<ul style="list-style-type: none"> <li>▪ Enhanced security.</li> <li>▪ Reduction in number of displays.</li> <li>▪ Reduction in crew procedures for access to the flight deck.</li> </ul>



In a majority of ice-crystal icing engine events, convective weather occurs in a very warm, moist, tropical-like environment.



# Avoiding Convective Weather Linked to Ice-Crystal Icing Engine Events

Understanding the weather conditions that have been linked to ice-crystal icing can help pilots avoid situations that may put airplane engines at risk for power loss and damage.

By **Matthew L. Grzych**, Meteorologist, Atmospheric Physics and Flight Test Engineering

High-altitude ice crystals in convective weather can cause engine damage and power loss in multiple models of commercial airplanes and engines. (More information about engine power loss in ice crystal conditions can be found in *AERO* fourth-quarter 2007.)

Pilots typically use the term “icing conditions” to refer to weather conditions usually below 22,000 feet where supercooled liquid droplets form ice on cold airframe surfaces. On the contrary, ice-crystal icing conditions connected to engine power loss are thought to be due to completely frozen ice crystals. When flying near convective weather through ice

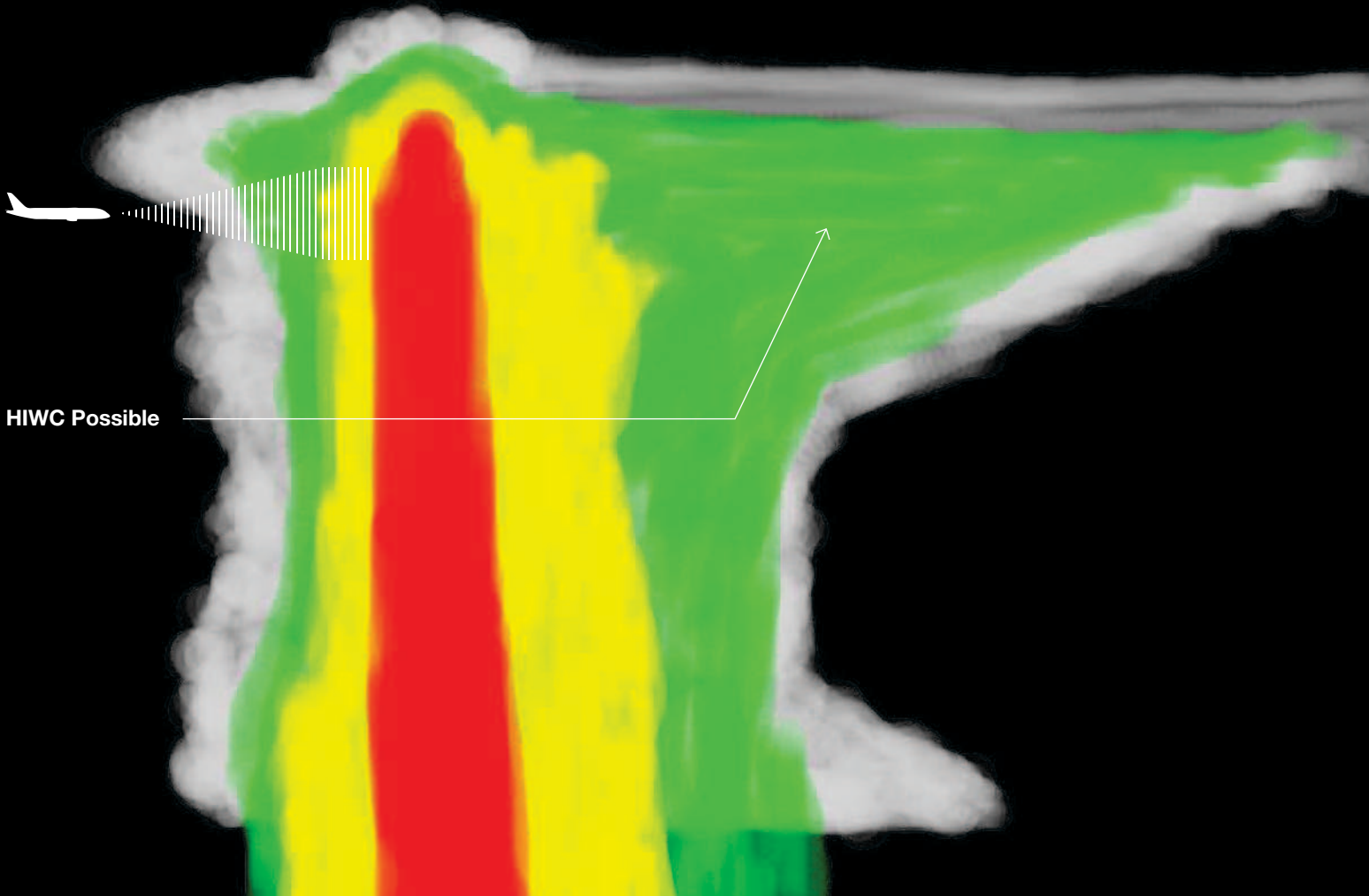
crystal conditions, pilots have reported a lack of airframe icing or ice detection (no supercooled liquid present), but they do notice the appearance of rain on the windscreen, sometimes at temperatures too cold for liquid water to exist. It has been confirmed that the appearance of rain is caused by small ice particles melting on impact with the heated windscreen. Pilots also have noted that the sound made by flight through ice crystals is different from the sound they hear when flying through rain. Although it’s not present on all airplanes, a total air temperature (TAT) anomaly also has occurred simultaneously during some engine events.

The TAT anomaly is due to ice crystals building up in the area in which the sensing element resides, where they are partly melted by the heater, causing a 0 degrees C reading. This phenomenon seems to depend on where the TAT sensor is installed on the fuselage. In some cases, TAT has stabilized at 0 degrees C during a descent and may be noticeable to pilots. In other cases, the error is more subtle and not a reliable-enough indicator to provide early warning to pilots of high concentrations of ice crystals.

This article provides detailed information about the convective weather associated with engine-power-loss events and

### Figure 1: Classic convection: Cores readily detectable by radar

This image depicts a vertical cross-section view as an airplane is headed for a classic convective cell. Colors represent standard airplane radar returns where green is light, amber is moderate, and red is heavy. In this scenario, the radar beam pointed straight ahead detects heavy precipitation and the airplane diverts and avoids the weather. There is, however, an area of high ice water content (HIWC) possible in the anvil cloud downwind from the convective core that pilots need to be aware of and avoid.



recommendations on how to increase pilots' awareness of this weather and help them avoid conditions that can result in power loss.

#### OVERVIEW OF ENGINE EVENTS ASSOCIATED WITH CONVECTIVE ICE CRYSTALS

Engine-power-loss and -damage events are being reported within anvil cloud regions of convective storms at high altitudes. The engines in all events have recovered to normal thrust response quickly.

It has been accepted that ice crystals are the primary source of the engine icing because of the lack of airframe icing reports, lack of radar reflectivity, and the

fact that many of these events are occurring at extremely cold temperatures where only frozen particles can exist.

There appear to be certain environments and particular regions within each storm system that most often lead to engine events. The most common observations during these events include:

- The airplane is traversing a convective anvil cloud.
- Pilots are avoiding heavy radar return regions at flight level by 20 miles or more.
- Only light to moderate turbulence is reported leading up to and during the engine events.
- No hail is reported.

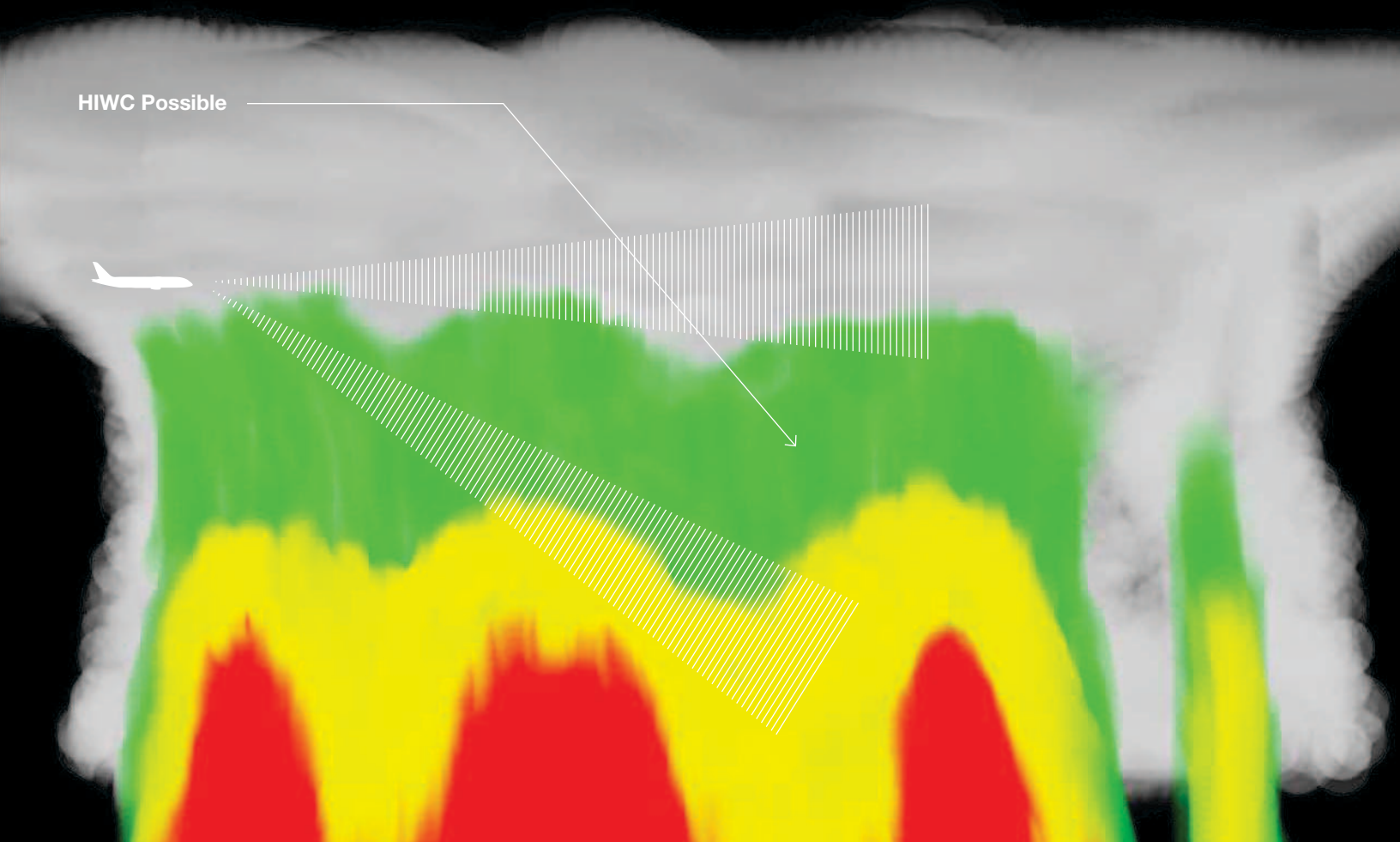
- There is no lightning.
- Either a lack of airplane weather radar returns or light radar returns present at flight level.
- Moderate to heavy precipitation (amber or red radar returns) is located below the airplane and the freezing level.

#### WEATHER ASSOCIATED WITH ICE CRYSTAL ENGINE EVENTS

Because it is believed that the clouds where engine events occur are composed of high concentrations of small ice crystals, scientists and meteorologists refer to these as regions of high ice water content (HIWC). Engine events associated with

## Figure 2: Radar view of typical ice crystal engine conditions

This image depicts a cross-section view as an airplane is headed for a nonclassic convective system. During a typical ice crystal engine event, the airplane will be flying in convective cloud with light radar returns at flight level. However, if the pilot uses the radar tilt function to scan below the airplane, moderate to heavy radar returns will be seen. These are regions to avoid because they are associated with regions of HIWC.



HIWC have occurred in two distinct types of cloud: classic convection and nonclassic HIWC-producing convection (referred to as nonclassic convection from here forward). Roughly 20 percent of engine events occur in classic convection, while the remaining 80 percent occur in nonclassic convection.

**Classic convection:** Classic convection has vigorous updrafts, is typically found over land, and will have moderate to heavy radar signatures present up to high altitudes, making the core areas and danger zones detectable so the flight crew can avoid them (see fig. 1). Because this region of convective weather can be detected by the airplane's radar system, pilots can avoid the cell by diverting to the upwind side. In

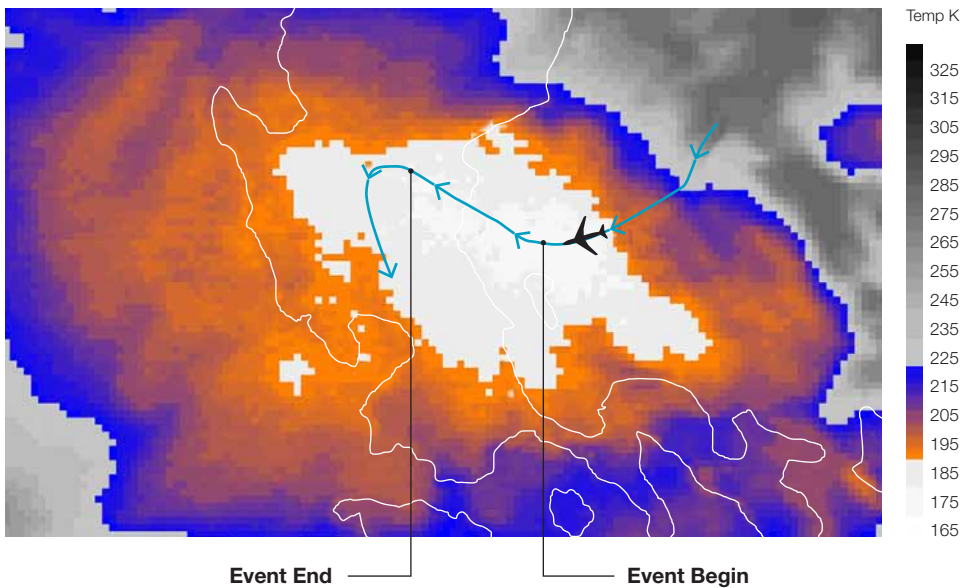
these more typical convective clouds, engine events have been recorded in the anvil cloud downwind from the cell's core. In the anvil, even though there can be HIWC, ice particles return only enough radar energy to occasionally record green signatures on the pilot's radar. At other times, there may be no radar returns at all.

Pilots should avoid the region of anvil cloud downwind from heavy cores near these typical convective cells, especially if light radar returns are present at high altitudes. However, in the majority of ice crystal engine events, pilots unknowingly pass directly over heavy convective precipitation through the anvil cloud into regions of high ice content within

nonclassic convective cells, as discussed in the next section.

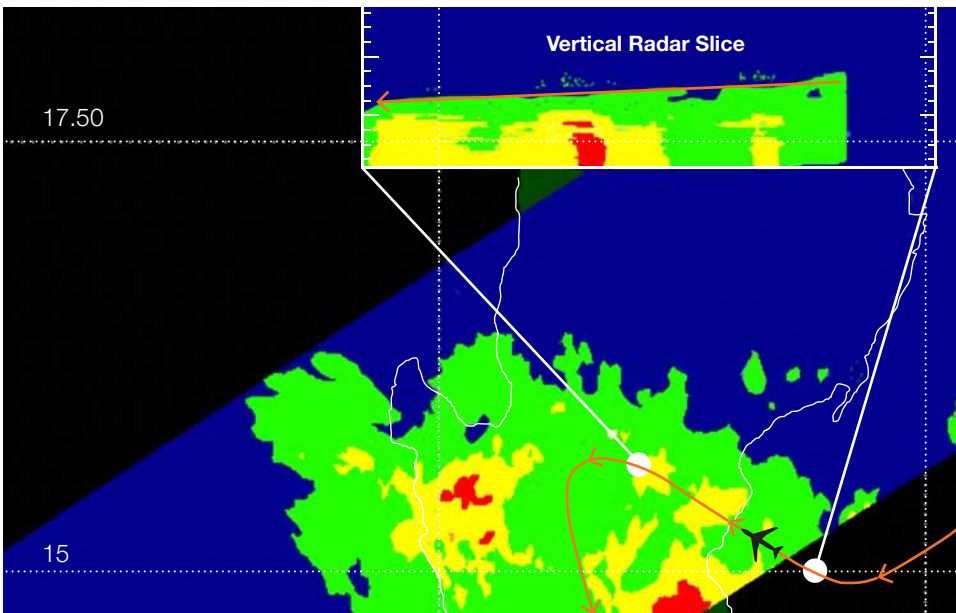
**Nonclassic convection:** The type of weather that is most associated with ice crystal icing and subsequent engine events is not what is generally considered typical convection, which has vigorous cores that can be detected at flight level. Instead, the convective weather that is of greatest concern is associated with nonclassic convective clouds that have weak updrafts, regions of decaying convection, and regions of HIWC aloft, but lacks reflectivity at flight level, making it more difficult for pilots to identify (see fig. 2).

Many times areas of HIWC may be associated with residual areas of merging



**Figure 3: Infrared satellite image of a large convective system where an engine icing event occurred**

This satellite image shows a typical scenario for ice crystal engine events in which an airplane enters a large convective system while on ascent or descent at temperatures well below freezing.



**Figure 4: Satellite-based radar view of convective system where an engine icing event occurred**

Radar data for this event shows a top-down view (main image) and a vertical slice looking northeast through the storm (inset). The red arrow depicts the airplane flight trajectory.

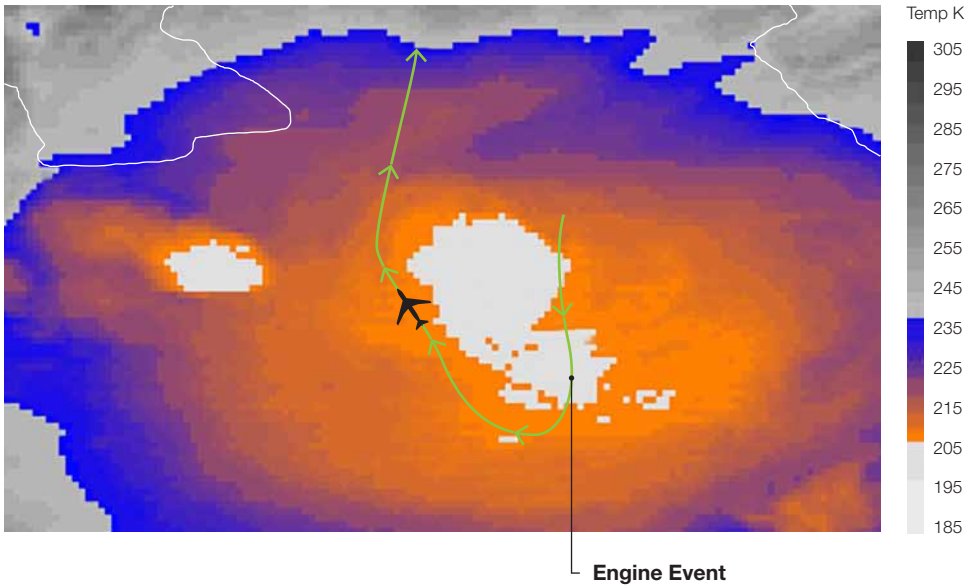
and decaying cell updrafts within a larger convective system. HIWC regions are typically characterized by relatively weak updrafts that are not strong enough to loft large ice particles, such as hail, to high altitudes, but are able to loft high concentrations of small ice particles up to the tropopause (tropopause height varies depending on the latitude and the season). Large ice particles, such as hail or graupel, are effective radar reflectors and show up on weather radar readily. However, radar returns are not reported during ice crystal engine events, leading meteorologists to conclude that only small ice particles can be present during these events.

#### ICE CRYSTAL ENGINE EVENT: A CASE STUDY

Airlines can gain valuable insights into convective weather associated with engine power loss and damage by examining an actual engine icing event (see fig. 3). In the enhanced infrared satellite image of a large convective system where an engine icing event occurred, the colored areas represent regions of deep convection and the bright white region is where cloud tops have penetrated through the tropopause into the lower stratosphere. The airplane flew along the path from right to left, entering a large anvil cloud associated with a tropical convective system. A TAT anomaly was observed shortly after the airplane entered

the anvil cloud, followed by a series of engine events as the airplane penetrated the deepest part of the storm at temperatures well below freezing. The engines recovered quickly, and the airplane continued safely to its destination.

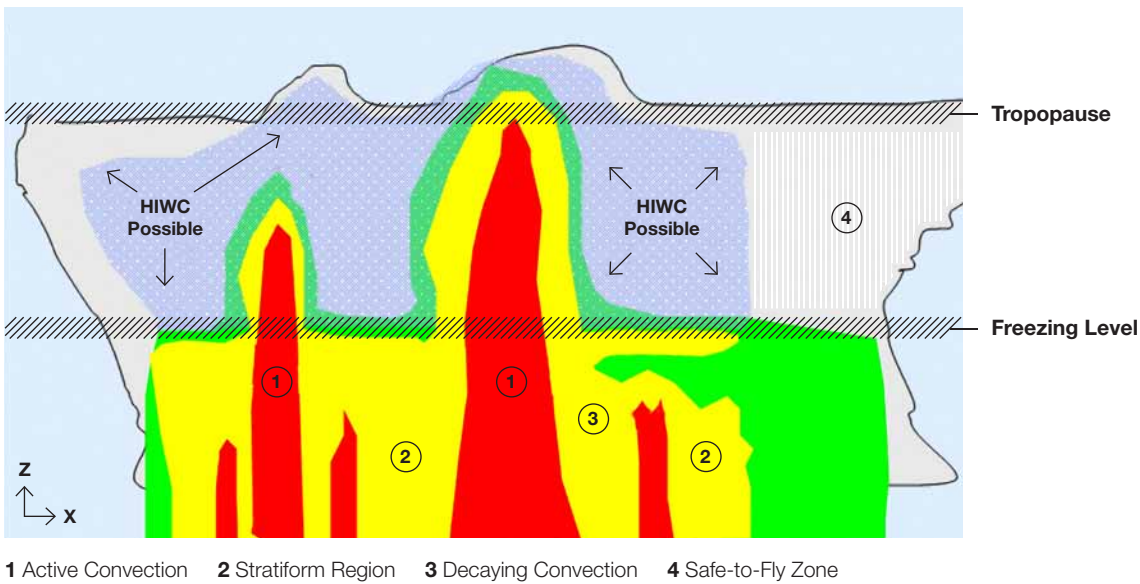
In this region of the convective system, large amounts of moisture are lifted, converted to ice crystals, and then lofted to high altitudes. This event represents a fairly typical scenario for ice crystal engine events in which an airplane enters a large tropical-like convective system while on ascent or descent at temperatures well below freezing. The engine event then occurs while passing through a region of deep glaciated convective cloud with moderate to heavy rain below the airplane.



**Figure 5: Conceptual model showing areas of high ice content**

An infrared satellite image of a tropical mesoscale convective system where an engine event occurred (top) and an idealized east-west vertical cross-section through the storm's center viewing it from south looking north (bottom). Green, yellow, and red areas represent light, moderate, and heavy radar return regions, respectively. Ice content is labeled HIWC.

**Cross-section**



1 Active Convection   2 Stratiform Region   3 Decaying Convection   4 Safe-to-Fly Zone

Radar data provides another view of this ice crystal engine event (see fig. 4). The red arrow represents the airplane's flight trajectory; a series of engine events occurred between the white dots. Low-level radar returns along the path were mostly moderate with some embedded heavy return regions. However, at flight level — where the series of events occurred — radar returns were only scattered light return (green) areas. Using the radar's tilt function to scan below the airplane would have revealed moderate to heavy returns below.

**CHARACTERISTICS OF SYSTEMS WITH AREAS OF HIGH ICE CONTENT**

Although the exact physics and dynamics that contribute to ice crystal engine events are not completely understood, there are many similarities among events.

For example, a majority of the events has occurred in tropical and subtropical regions of the world (usually between 30 degrees south and 30 degrees north latitude). In these cases, the airplane penetrated into the deepest part of a nonclassic convective system, flying directly over heavy rain in the glaciated cloud above.

Nonclassic convection events have also occurred at higher latitudes during

summer months; for example, they have been reported in the eastern United States and Japan.

A smaller percentage of engine events, on the order of 20 percent or less, has occurred in classic convection. These events typically occur in mid-latitude, continental storms as an airplane diverts from a heavy weather core at altitude and flies into a region of HIWC adjacent to or downwind of the core.

A conceptual model helps illustrate where areas of high ice content might be found (see fig. 5). In these systems, there can be several areas of active convection where heavy returns may be present to high altitudes, as well as broad regions of decaying

# What can flight crews do to assess and avoid weather associated with ice-crystal icing engine events?

## Recognize areas where ice crystals may exist.

- Above the freezing level in convective weather.
- Near the deepest part of a convective cloud.

## Recognize common conditions.

- Moderate to heavy rain is present below the airplane, producing amber and red radar returns, but little or no returns at flight level.
- Weak to modest updraft velocities.
- Light to moderate turbulence.

## Operating instructions.

- During flight in instrument meteorological conditions, avoid flying directly above significant amber or red radar returns.
- Use the weather radar gain and tilt functions to assess weather radar reflectivity.

convection and moderate to heavy stratiform precipitation regions at lower levels.

Engine event threat areas include regions above the freezing level either adjacent to or downwind of heavy convective cores or above moderate to heavy rain associated with decaying convection or stratiform regions within the convective system. Both regions are labeled “HIWC Possible” in figure 5.

From an observer’s perspective at high altitudes, the anvil region may grow so large that it can take on the appearance of a thick cirrus cloud shield and lose its visual convective qualities. Essentially, many individual convective cells and their

associated anvil clouds all merge into one large, broad system and each individual anvil cloud loses its identity.

Engine events most commonly occur at altitudes of 20,000 to 35,000 feet at temperatures ranging from -10 degrees C to -40 degrees C. However, some outlier events have occurred at altitudes as low as 9,000 feet with a temperature of -8 degrees C and at altitudes as high as 41,000 feet with temperatures down to -63 degrees C.

In a majority of the ice crystal engine events, convective weather occurs in a very warm, moist, tropical-like environment. The atmosphere is generally slightly to moderately unstable, resulting in weak to modest updraft strength. During engine events, pilots report only light to moderate turbulence. These convective systems are generally large, heavy rain producing storms that have life cycles ranging from several hours to 24 hours or more.

Typically, events do not occur in severe convection with strong updrafts because these cells are detectable at altitude, and pilots are able to avoid them. However, in some cases high concentrations of ice crystals can be present within the anvils of these storms either adjacent to or downwind from heavy cores.

- During flight in instrument meteorological conditions (IMC), avoid flying directly above significant amber- or red-depicted map weather radar regions.
- Use the weather radar gain and tilt functions to assess weather radar reflectivity below the airplane.

For example, if an airplane is flying in IMC above the freezing level and there are amber or red radar returns in the vicinity or cloud tops up to the tropopause, or the airplane is known to be in a convective cloud, regions of HIWC may be in the area. In this scenario, the pilot should point the radar down to look below the freezing level. If amber and red areas indicating heavy rain are detected below the freezing level, HIWC areas are possible above these low-level moderate to heavy rain regions. Under these conditions, the pilot should consider evasive action.


## What is convective weather?

Convective weather, or atmospheric convection, is the result of an unstable atmosphere where ascending air parcels condense moisture to high altitudes sometimes resulting in one or more of the following:

- Vertically deep cloud with a large cirrus (anvil) region.
- Areas of strong wind shear and turbulence.
- Lightning.
- Areas of high condensed-water content.
- Heavy precipitation and hail.
- Regions of highly concentrated ice particles.

## SUMMARY

To date, the engines affected in all recorded ice crystal events have recovered to normal thrust response quickly. However, due to the possibility of continued power loss and the risk of engine damage, airlines can use this information to help them avoid flying in convective weather associated with engine-power-loss events.

For more information, contact Matthew Grzych at [matthew.l.grzych@boeing.com](mailto:matthew.l.grzych@boeing.com). 

## RECOMMENDED ACTIONS

Based on an analysis of the ice crystal engine event database, Boeing has developed the following recommendations to help flight crews avoid regions of HIWC:



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