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AERO

Cover photo: *Part of the 737-800 Inboard Wing Leading Edge Assembly.*

AERO

Contents

AERO

***AERO* Online**
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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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Optimizing Airplane Maintenance Programs

Developing maintenance programs that fit operators' needs is an important area of customer support for Boeing. We know that maintenance programs are an integral part of an airline's successful operation. They ensure safe, reliable, and cost-effective airplane performance.

Maintenance programs are not meant to remain unchanged. As our expertise with an airplane model's performance increases, that experience can be used to further optimize the airplane's maintenance program.

In recent years, we have made significant progress in improving maintenance programs on Boeing airplanes as operators, original equipment manufacturers, and regulators work together at an industry level. We've created value by reducing maintenance cost, minimizing airplane downtime, and maximizing availability to generate revenue.

To further improve maintenance programs, Boeing has implemented a new statistical analysis process that you can read more about beginning on page 13 of this issue of *AERO*. Statistically analyzing airplane performance data allows us to optimize maintenance programs more efficiently.

The enabler for this statistical analysis is operators' performance data provided in a standard industry format, called SPEC2000. We encourage you to support this new process by sharing your performance data in this format. It will allow us to provide better and faster optimization of maintenance programs for your Boeing fleet.

LYNNE THOMPSON
Vice President
Product Support Engineering

In regions with volcanic activity, airline operations can be safely conducted by following fundamental guidelines.

Safe, Efficient Flight Operations in Regions of Volcanic Activity

Volcanoes continue to erupt around the world, from Iceland to Ecuador and from Chile to Africa, causing disruption to air travel. Airspace monitoring and flight operational procedures have been put in place and commercial jet aviation has been operating safely in areas with volcanic eruptions. Boeing's recommendation is to avoid areas of visible ash. However, if a flight crew inadvertently encounters volcanic ash, there are steps that they can take to safely exit the ash cloud. Additional efforts are being made to improve the efficiency of air traffic in the event of a volcanic eruption.

By Douglas Kihm, Technical Fellow, Airworthiness and Extended Operations, and
Darren Macer, Lead Engineer, Boeing Commercial Aviation Services Operations Center

Since the significant Eyjafjallajökull volcanic event of 2010, the aviation industry has developed additional guidance for safe, efficient flight operations in the event of a volcanic eruption. The International Civil Aviation Organization (ICAO) International Volcanic Ash Task Force (IVATF) is leading this effort. The industry is accumulating and reviewing the world's best practices for addressing airspace control during a volcanic eruption and developing recommendations that accommodate all global situations. Boeing provides significant support to this effort.

This article details ongoing work to improve the efficiency of air traffic in the event of a volcanic eruption, provides information about operating in the vicinity of a volcanic ash cloud, explains how to detect the presence of a volcanic ash cloud, and offers practical information for flight crew operations and maintenance inspections if a volcanic ash cloud is encountered.

MONITORING AND RESPONDING TO VOLCANIC ASH EVENTS

Although some information about volcanic eruptions had been available at the time of eruptions in the 1980s and 1990s, the aviation industry recognized that it was insufficient. The industry then collaborated with the volcanological and meteorological communities in a joint effort to find ways to avoid future volcanic ash encounters.

ICAO has laid much of the foundation for volcanic ash monitoring through its Volcanic Ash Warnings Study Group.

ICAO also formed the International Airways Volcano Watch Operations Group in 1987. These groups formalized the international arrangements for monitoring and providing warnings to the aviation community about volcanic ash in the atmosphere.

ICAO's Annex 3 *Meteorological Service for International Air Navigation* and the World Meteorological Organization's Technical Regulation C.3.1 introduced standards to disseminate information about volcanic ash to the aviation community in the form of Significant Meteorological Information (SIGMET) and Notices to Airmen (NOTAM).

One of the results of these efforts was the establishment of today's Volcanic Ash Advisory Centers (VAACs). VAACs provide an important link among volcano observatories, meteorological agencies, air-traffic control centers, pilots, and operators. Currently, nine VAACs continuously monitor and report on a particular region of the world (see fig. 1).

ICAO has also published the *Handbook on the International Airways Volcanic Watch* (Document 9766). It defines responsibility and operational procedures for distributing information on volcanic eruptions and associated ash clouds that could affect routes used by international flights.

IMPROVING OPERATIONAL EFFICIENCY DURING VOLCANIC ASH EVENTS

Commercial jet aviation has been operating safely and efficiently for many years since the hazards associated with operations in volcanic ash have been identified and airspace and flight operational procedures have been established. This successful history has been based on avoiding operations in a visible ash cloud or one discernable by satellite imagery, ground observers, flight crew, and pilot reports, augmented by forecasting model predictions and SIGMETs as required.

In most of the world, flight operations in the event of a volcanic eruption have been based on information provided by the VAAC to airlines about the location and forecasted movement of the visible ash cloud. The calculated ash concentration values produced by trajectory/dispersal models are strongly dependent on the input values of the models — including the total amount, composition, height of the plume, and particle size of ash being ejected from the volcano. Input values are difficult to estimate, which leads to inaccuracies in the forecasted concentration charts. These inaccuracies can vary from one eruption to another, even from the same volcano. As a result, trajectory/dispersal model forecasts need to be correlated with other observations. For the 2010 Eyjafjallajökull event, the areas where high ash concentration was forecasted appear to correlate roughly to areas of visible ash as seen from satellite images.

In the aftermath of the Eyjafjallajökull eruption, ICAO's European and North Atlantic (EUR/NAT) Office revised the existing EUR/NAT volcanic ash contingency plan. A key enhancement was the decision to control airspace as is done by other airspace control authorities: After an initial eruption, the volcanic ash cloud is treated like a meteorological event and advisory and SIGMET information is provided to operators to allow them to determine how best to avoid operations in the volcanic ash cloud (see fig. 2). This approach proved successful in other areas of the world.

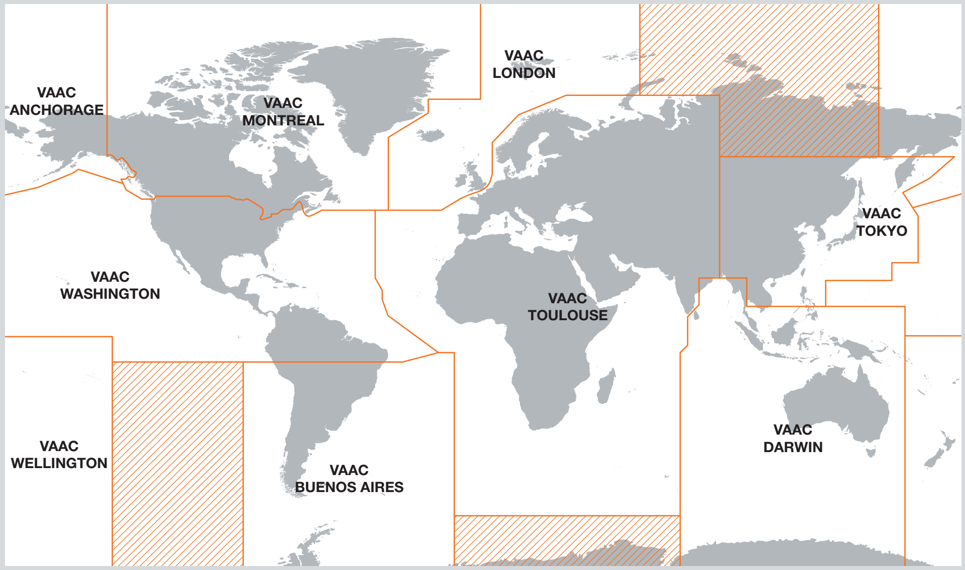
ICAO's IVATF is currently working to consolidate successful practices from around the world to provide enhanced volcanic ash contingency procedures and improve the accuracy and consistency of the VAAC advisories.

Visible ash

The term "visible ash" is used by Boeing to refer to various situations where ash can be seen visually or observed. Although the term is somewhat ambiguous, visible ash has been used successfully to describe areas where flight planners should avoid scheduling flights and flight crews should avoid flight operations. From a flight-crew perspective, visible ash is ash that can be seen by looking out the windows or observed in other ways, such as electrostatic discharge on the airplane exterior or haze in the flight deck. Boeing's recommendation to operators to avoid operations in visible ash also relies on observations by Volcanic Ash Advisory Centers (VAACs) to define a volcanic ash cloud location and its forecasted movement. The VAACs use methods such as visual examination of satellite imagery, either visible or infrared, to discern where a volcanic ash cloud is located. This VAAC-observed volcanic ash cloud information is also used to develop the volcanic ash Significant Meteorological Information, which is used by operators to avoid the visible volcanic ash cloud.

Figure 1: Volcanic Ash Advisory Centers

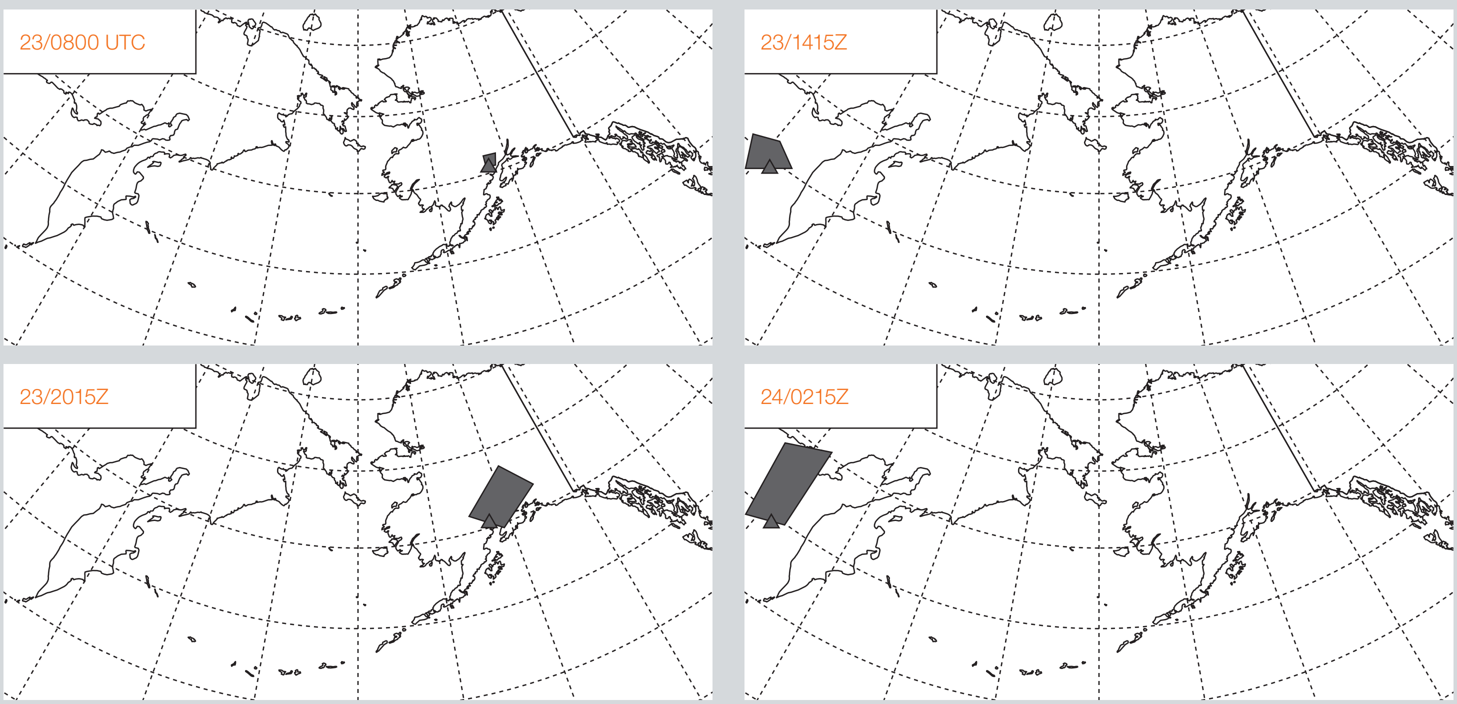
There are nine Volcanic Ash Advisory Centers (VAACs) located around the world. Each VAAC focuses on a specific geographical region.



Area not covered

Figure 2: 2009 Mt. Redoubt Volcanic Ash Advisory

This Volcanic Ash Advisory graphic from the 2009 Mt. Redoubt eruption was created using satellite imagery, ground observers, flight crew, pilot reports (PIREPs), and forecasting models.



VOLCANIC ASH ADVISORY
DTG: 20090326/2040
VAAC: ANCHORAGE
AREA: SOUTH CENTRAL ALASKA
SUMMIT ELEV: 10198FT (3109m)
ADVISORY NUM: 2009–18

INFO SOURCE: POES/GOES/AVO/PILOT REPORT/RADAR
ERUPTION DETAILS: EXPLOSIVE ERUPTION AT 26/1724 UTC
REMARKS: LIGHT ASHFALL REPORTED AT HOMER BY TRUSTED OBSERVER.
NEXT ADVISORY: 20090327/0240Z

Figure 3: Aviation color-code notifications

Aviation color-code notifications provide concise information about potential volcanic ash hazards. Airline flight planners can use this information to route flights away from potential ash clouds.

Green Alert	Yellow Alert	Orange Alert	Red Alert
Volcano is in normal, non-eruptive state. *Or, after a change from a higher alert level:* Volcanic activity considered to have ceased and volcano returned to its normal, non-eruptive state.	Volcano is experiencing signs of elevated unrest above known background levels. *Or, after a change from higher alert level:* Volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.	Volcano is exhibiting heightened unrest with increased likelihood of eruption. *Or:* Volcanic eruption is under way with no or minor ash emission (specify ash-plume height if possible).	Eruption is forecasted to be imminent with significant emission of ash into the atmosphere likely. *Or:* Eruption is under way with significant emission of ash into the atmosphere (specify ash-plume height if possible).

Note: The color code for the level of alert indicating the status of activity of the volcano and any change from a previous status of activity should be provided to the area control center by the responsible volcanological agency in the state concerned (e.g., "Red alert following yellow" or "Green alert following orange").

Boeing supports efforts to continue to understand the susceptibility of airplanes and jet engines to volcanic ash clouds. Because of the unique characteristics of each volcanic eruption and the ensuing ash cloud, it is not practical to define a single ash concentration threshold for airplanes or jet engines. Boeing continues to recommend avoiding visible ash and is also working with the aviation community through the ICAO IVATF to refine and enhance ICAO's volcanic ash regional contingency plans.

AIRLINE FLIGHT PLANNING TO AVOID VOLCANIC ASH

Airline flight planning staffs and flight crews should be aware of potential volcano eruptions near their routes. One way is through aviation color-code notifications (see fig. 3). These notifications are used to provide succinct information about volcanic ash hazards to the aviation industry. The color codes are in accordance with recommended ICAO procedures to help pilots, dispatchers, and air traffic controllers who are planning or executing flights over broad regions of the globe quickly ascertain the status of numerous volcanoes. They can use this information to determine whether continued attention, flight rerouting, cancellation, diversion, or extra fuel is warranted.

DETECTING THE PRESENCE OF A VOLCANIC ASH CLOUD

Despite all precautions and planning, it is still possible to encounter an ash cloud. Boeing provides training and instructions for flight crews to use when there is an indication that an airplane has entered an ash cloud, which can be found via the Web portal MyBoeingFleet.com. Discernable indicators that an airplane is penetrating volcanic ash can include odor, haze, changing engine conditions, air speed, pressurization, and static discharges.

Significant volcanic ash events

Several past volcanic ash events have resulted in either significant damage to jet-powered commercial airplanes or caused significant disruption to air traffic:

- Eyjafjallajökull, Iceland, 2010. The eruption's ash plume drifted eastward, reaching as far as the United Kingdom and parts of Western Europe. Air travel over western and northern Europe was disrupted for six days because of the amount of ash ejected into the atmosphere and the forecast that the ash would reach some areas of very high air traffic volume. The contingency plans and procedures for airspace control during this event were not adequately defined or understood, resulting in significant disruption to European and North Atlantic air traffic.
- Mt. Pinatubo, Philippines, 1991. More than 20 volcanic ash encounters occurred after the Mt. Pinatubo eruption, which was one of the largest volcanic eruptions of the past 50 years. Commercial flights and various military operations were affected; one U.S. operator grounded its airplanes in Manila for several days.
- Mt. Redoubt, United States, 1989. On a flight from Amsterdam to Anchorage, Alaska, a 747-400 encountered an ash cloud from the erupting Mt. Redoubt near Anchorage. All four engines ingested ash and subsequently flamed out. The crew successfully restarted the engines and landed safely at Anchorage. All four engines were replaced, and many airplane systems also had to be repaired or replaced before the airplane was returned to service.
- Galunggung, Indonesia, 1982. Several 747 airplanes encountered ash from this eruption. One airplane lost thrust from all four engines and descended from 36,000 feet to 12,500 feet before all four engines were restarted. That airplane, on a flight from Kuala Lumpur, Malaysia, to Perth, Australia, diverted to Jakarta and landed safely despite major engine damage. The airplane subsequently had all four engines replaced before returning to service.
- Mt. Saint Helens, United States, 1980. A 727 and a DC-8 encountered separate ash clouds during this major eruption. Both airplanes experienced damage to their windshields and to several systems, but both landed safely despite the windshield damage.

Odor. When encountering a volcanic ash cloud, flight crews usually notice a smoky or acrid odor that can smell like electrical smoke, burned dust, or sulfur.

Haze. Most flight crews, as well as cabin crew or passengers, see a haze develop within the airplane. Dust can settle on surfaces.

Changing engine conditions. Surging, torching from the tail pipe, and flameouts can occur. Engine temperatures can change unexpectedly, and a white glow can appear at the engine inlet.

Air speed. If volcanic ash fouls the pitot tubes and static ports, the indicated airspeed can decrease or fluctuate erratically, with associated effects on airplane systems.

Pressurization. Cabin pressure can change, including possible loss of cabin pressurization.

Static discharges. An electrostatic phenomenon similar to Saint Elmo's fire or glow can occur. In these instances, blue-colored sparks can appear to flow up the outside of the windshield or a white glow can appear at the leading edges of the wings or at the front of the engine inlets.

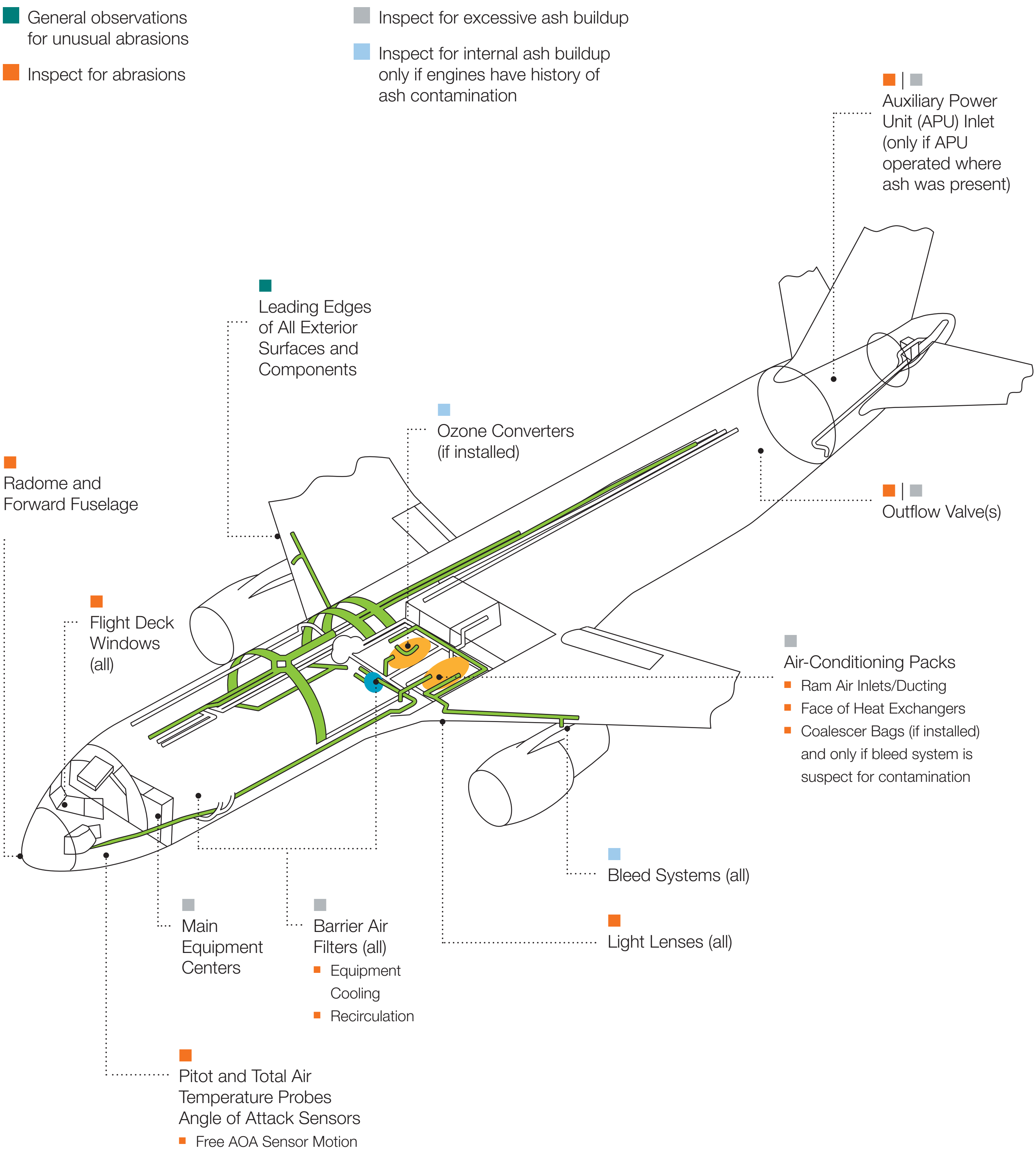
RECOMMENDATIONS FOR FLIGHT CREW IF A VOLCANIC ASH CLOUD IS ENCOUNTERED

If an airplane does encounter a volcanic ash cloud, Boeing provides flight crew procedures for dealing with the situation. The following are general recommendations (each operator's flight operations manuals include more specific instructions):

- Flight conditions permitting, reduce thrust to idle immediately.
- Turn the autothrottles off.
- Exit the ash cloud as quickly as possible. A 180-degree turn out of the ash cloud, using a descending turn, may be the quickest exit strategy.

Figure 4: Volcanic ash conditional inspection

This illustration shows airframe and systems areas of particular interest for operations in areas contaminated with volcanic ash.



- Turn on the engine and wing anti-ice devices.
- Turn on all air-conditioning packs.
- If possible, start the auxiliary power unit.
- If volcanic dust fills the flight deck, the crew may need to use oxygen.
- Turn on the continuous ignition.
- Monitor the engine exhaust gas temperature.
- Fly the airplane by monitoring air speed and pitch attitude.

Following these procedures will ensure the highest possible level of flight safety. Although this information has been available for several years, flight crews need to continue to be vigilant of the signs of volcanic ash and to be familiar with the proper procedures to prevent serious incidents.

RECOMMENDATIONS FOR MAINTENANCE CREWS IF A VOLCANIC ASH CONTAMINATION IS REPORTED OR SUSPECTED

Following a volcanic ash encounter, or suspected encounter, a volcanic ash conditional inspection should be performed as detailed in the Aircraft Maintenance Manual, Chapter 05 (see fig. 4). As a result of the 2010 Eyjafjallajökull event, based on operator feedback Boeing has restructured the inspections to a phased approach. Whereas the previous inspections required extensive and time-consuming inspections after reported operation in an environment that contained volcanic ash, the new approach allows the inspections to cease if no signs of damage or ash exist at certain points in the phased inspections. The initial phase is designed to be conducted at a remote location without the need of specialized tools, thus ensuring that an airplane can quickly be returned to service if no evidence of ash is detected. Only if evidence of ash is found is the operator required to continue to the next phase, each becoming more involved proportionately to the potential damage due to the encounter.

SUMMARY

Boeing believes that operations in regions with volcanic activity can be conducted safely by avoiding visible ash. A volcanic ash event should be treated like a meteorological event, such as a severe weather condition. Operators should be provided advisory information regarding the location of an ash cloud to use in determining the most appropriate action to take, such as rerouting flights, diverting flights to alternate airports, or cancelling flights. If flight crews unexpectedly encounter an ash cloud, they should take appropriate action.

For more information, contact Doug Kihm at douglas.j.kihm@boeing.com.

Example of a regional volcano plan

In support of the International Civil Aviation Organization (ICAO) Annex 3 standards and the *Handbook on the International Airways Volcanic Watch* procedures, regions of the world have implemented their own regional plans. One example is the U.S. government's interagency plan for volcanic ash events.

This plan coordinates the operations of the Alaska Volcano Observatory, the Federal Aviation Administration (FAA), and the National Weather Service (NWS), among others. The NWS includes the Alaska Aviation Weather Unit (AAWU), which is both a Volcanic Ash Advisory Center (VAAC) and a Meteorological Watch Office (MWO). The AAWU, as an International MWO, issues volcanic eruption and volcanic ash Significant Meteorological Information.

In this plan, the AAWU, acting as the Anchorage VAAC, issues a Volcanic Ash Advisory during an ash event, which provides guidance to the aviation community. The FAA disseminates pilot reports (PIREPs), Notices to Airmen (NOTAM) and current conditions information to the air traffic controllers and Center Weather Service Unit (CWSU) personnel. The AAWU runs forecast models to predict where the discernible ash cloud will be. The forecasts are calibrated against satellite imagery, PIREPs, ground observation, and spotter aircraft. This approach to providing advisory information to operators is similar to how other significant meteorological events are handled, such as hurricanes. The collaborative interagency approach worked very effectively during the 2009 Mt. Redoubt eruption. For example, it helped one major airline operating in the area avoid any significant inflight volcanic ash encounters. (This is not to say, however, that the airline did not have numerous schedule disruptions as a result of the Mt. Redoubt volcanic ash cloud.)

A new statistical tool is designed to ensure safe, reliable, and cost-effective airplane performance, and participation by operators is key.

Improving Maintenance Programs Through Statistical Analysis

Maintenance programs help ensure safe, reliable, and cost-effective airplane performance. Boeing works with operators and regulatory agencies to develop and manage maintenance programs for its commercial fleet. As knowledge of airplane performance increases over time, that experience is applied to maintenance programs in the form of new information and optimized requirements. In recent years, Boeing has made significant progress in optimizing maintenance programs by applying statistical analyses of in-service performance data as part of its work with operators and regulatory agencies.

By Brian McLoughlin, Senior Manager, Maintenance Program Engineering;
Farshad Doulatshahi, Program Manager, Maintenance Program Engineering; and
Jason Onorati, Business Architect, Maintenance Program Engineering

Boeing has a long history of working with the aviation industry to develop maintenance programs that help ensure the highest safety and operational reliability levels. To further improve these programs, Boeing has implemented a new statistical analysis process. This process analyzes data from every aspect of airplane maintenance lifecycle and uses a series of algorithms and advanced statistical analysis techniques to identify the optimum maintenance intervals for maintenance inspections. This process has been approved for use by the U.S. Federal Aviation Administration, the European Aviation Safety Agency, and Transport Canada Civil Aviation Authority.

This article provides an overview of this new statistical analysis process and how it works and presents examples of how Boeing is applying this process to optimize maintenance intervals for operators.

THE CONTINUOUS PROCESS OF IMPROVING MAINTENANCE

Knowing the optimum interval for scheduled maintenance helps airlines maintain a safe, reliable, and cost-effective operation. Understanding that optimum interval also minimizes airplane out-of-service time due to scheduled maintenance requirements (see fig. 1). Boeing has worked with operators and regulatory agencies for many years to help airlines meet these objectives.

Statistical Analysis for Scheduled Maintenance Optimization (SASMO) is a tool designed specifically to determine optimum scheduled maintenance intervals based on the fleet performance of in-production airplanes. The analysis is based on reliability and cost-management models that allow for an optimum interval to be determined. The SASMO process uses a broad range of maintenance data sources that represent an airplane's lifecycle (see fig. 2), such as maintenance actions, schedule interruptions, and shop data. The data supporting the analysis is in the industry-sanctioned SPEC2000 format. This comprehensive

Figure 1: Scheduled maintenance optimization since entry into service

Boeing works continuously to optimize airplane maintenance programs to help ensure safety and reliability and reduce the amount of time an airplane is out of service.

Optimizations of Typical Hangar Scheduled Maintenance Intervals Since Entry into Service

data analysis helps reduce maintenance cost, increase dispatch reliability, and improve safety.

SASMO was developed to efficiently optimize fleet scheduled maintenance requirements and minimize in-service maintenance interruptions. This process helps support fleet dispatch reliability while reducing the cost of maintenance.

SASMO uses a set of algorithms designed to maximize the opportunity to determine the likelihood of system and structural degradation while minimizing in-service maintenance findings related to these tasks. The tool's statistical process can determine that optimum level in a timely manner.

OPTIMIZING RELIABILITY AND COST-EFFECTIVENESS

Reliability and risk management. The statistical analysis for task optimization is based on reliability and risk management in terms of the potential impact on the airplane's operation (see fig. 3).

Cost-effectiveness. The statistical analysis also calculates the point where the cost of a scheduled maintenance inspection and the cost of schedule interruption are minimized.

IMPLEMENTATION OF STATISTICAL ANALYSIS PROCESS

The Next-Generation 737 was the first model to implement this statistical analysis process. Based on analyses of maintenance tasks occurring at 4,000 flight hours, 80 percent of scheduled maintenance tasks were escalated, 10 percent remained at their current interval, and 10 percent were de-escalated to minimize unscheduled maintenance events.

Analyses were also performed on the 777 tasks occuring at 7,500 flight hours. As a result of these analyses, 68 percent of task intervals were escalated, 26 percent remained the same, 6 percent were de-escalated, and one task was deleted. While the maintenance interval escalations are significant, these analyses also demonstrate that maintenance optimization can also result in de-escalation, minimizing unscheduled maintenance-related events.

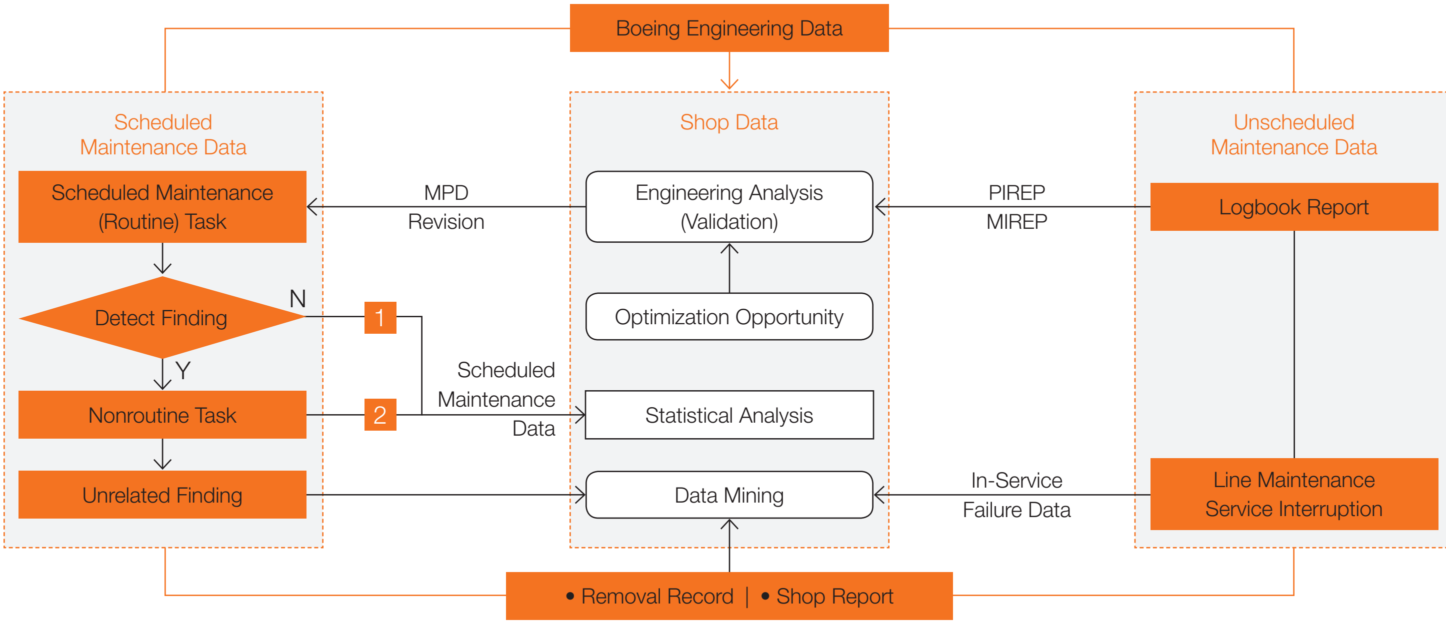
SUMMARY

Boeing's new SASMO analysis process enables Boeing engineers to determine the optimum intervals for fleet scheduled maintenance programs by using a statistical algorithm to analyze hangar and line maintenance data. The optimum intervals resulting from SASMO analysis process are reflected in Boeing Maintenance Planning Documents and are available for implementation for participating operators. SASMO is designed to support safe, reliable, and cost-effective airplane performance. Participation by operators through data sharing is key to Boeing's ability to optimize airplane maintenance programs.

For more information, please contact Brian McLoughlin at brian.m.mcloughlin2@boeing.com.

Figure 2: Data used in the statistical analysis process

Boeing's analytical tool, Statistical Analysis for Scheduled Maintenance Optimization (SASMO), uses comprehensive data sources to determine optimal scheduled maintenance intervals.

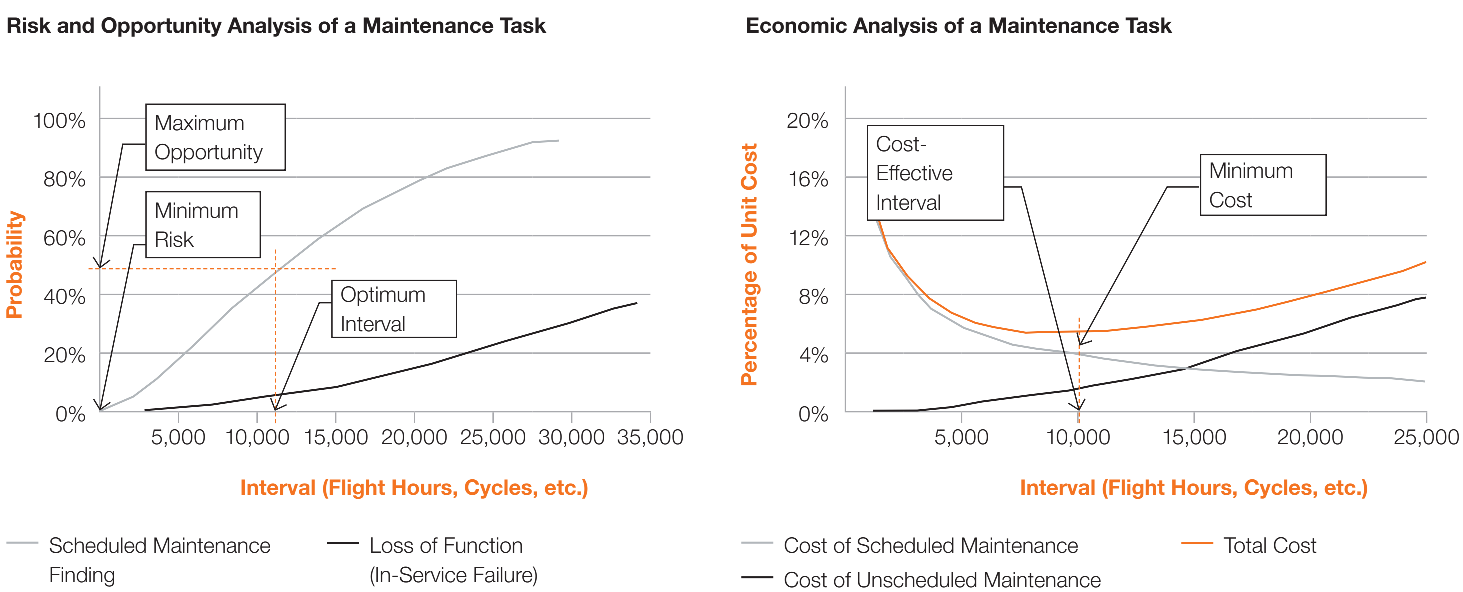


Legend: MPD: Maintenance Planning Document
PIREP: Pilot Logbook
MIREP: Maintenance Logbook

1 Clean Check
2 Defect

Figure 3: Establishing scheduled maintenance intervals

SASMO considers two aspects of task analysis: risk opportunity and economics. The risk opportunity management analysis (left) determines the probability of capturing a minor defect during scheduled maintenance while also measuring the risk of having in-service unscheduled maintenance on the system or structure. The optimum task interval offers the maximum opportunity to capture defects at the earliest stage. Additionally, SASMO can also perform an economic optimization analysis (right) based on the pure economics of performing a scheduled maintenance. The curves show the trend of cost associated with scheduled maintenance compared to unscheduled maintenance. The task should be performed at the point at which total maintenance cost is at a minimum.



Flight crews can reduce the possibility and effects of a bird strike by increased awareness and by following recommended procedures.

Strategies for Prevention of Bird-Strike Events

Bird-strike events are relatively common, occur most often on the ground or at low altitude, and are usually benign. However, bird strikes can have significant economic and occasional safety consequences for flight operations. Pilots and operators should be knowledgeable about the hazard, and flight crews should use facts, data, and standard operating procedures to reduce the potential for and consequences of a bird strike.

By Roger Nicholson, Ph.D., Associate Technical Fellow, Aviation System Safety, and
William S. Reed, Safety Pilot, Boeing Flight Technical and Safety

Bird strikes are a lesser hazard to aviation than other well-known hazards such as loss of control in flight, controlled flight into terrain, and runway excursions, but they can and do present risk that needs to be addressed. The first bird strike was recorded by the Wright brothers in 1905, and the aviation wildlife hazard has been a risk to aviation ever since. The January 15, 2009, ditching of US Airways flight 1549 on the Hudson River in Weehawken, New Jersey, was the dramatic result of dual engine thrust loss arising from an airborne encounter with a flock of Canada geese. Although Boeing airplanes meet and exceed the government regulations for bird strikes, accidents and serious incidents can occur. Aviation wildlife hazards encompass birds on the ground and in flight, terrestrial animals (e.g., deer, coyotes, cattle, camels), and even airborne animals such as fruit bats; however, this article focuses on bird strikes in particular. Operators and flight crews should be aware of the risk of bird strikes, prevention strategies, and actions to take following a bird strike.

This article discusses the characteristics of bird strikes, presents practical information for flight crews, highlights the importance of reporting bird strikes, and provides resources for additional bird-strike information.

CHARACTERISTICS OF BIRD STRIKES

According to Bird Strike Committee USA, an organization that was formed in 1991 to facilitate the exchange of information and promote the collection and analysis of accurate wildlife strike data, bird and other wildlife strikes cause more than $650 million in damage to U.S. civil and military aviation annually. In addition, bird strikes put the lives of crew members and passengers at risk — more than 200 people have been killed worldwide as a result of wildlife strikes since 1988. The Bird Strike Committee takes a similar data-driven approach to the bird strike issue that organizations such

Figure 1: Example of bird-strike damage

Bird-strike damage can be quite severe and can shut down jet engines.

as the Commercial Aviation Safety Team (CAST) takes to reduce commercial aviation fatality risk. (See www.cast-safety.org.)

Experts within the U.S. Federal Aviation Administration (FAA), the U.S. Department of Agriculture, and the U.S. Navy and U.S. Air Force expect the risk, frequency, and potential severity of wildlife-aircraft collisions to grow over the next decade, based on increasing air traffic, bird populations, and the trend to twin-engine aircraft. (See http://wildlife-mitigation.tc.faa.gov/wildlife/downloads/BASH90-09.pdf.)

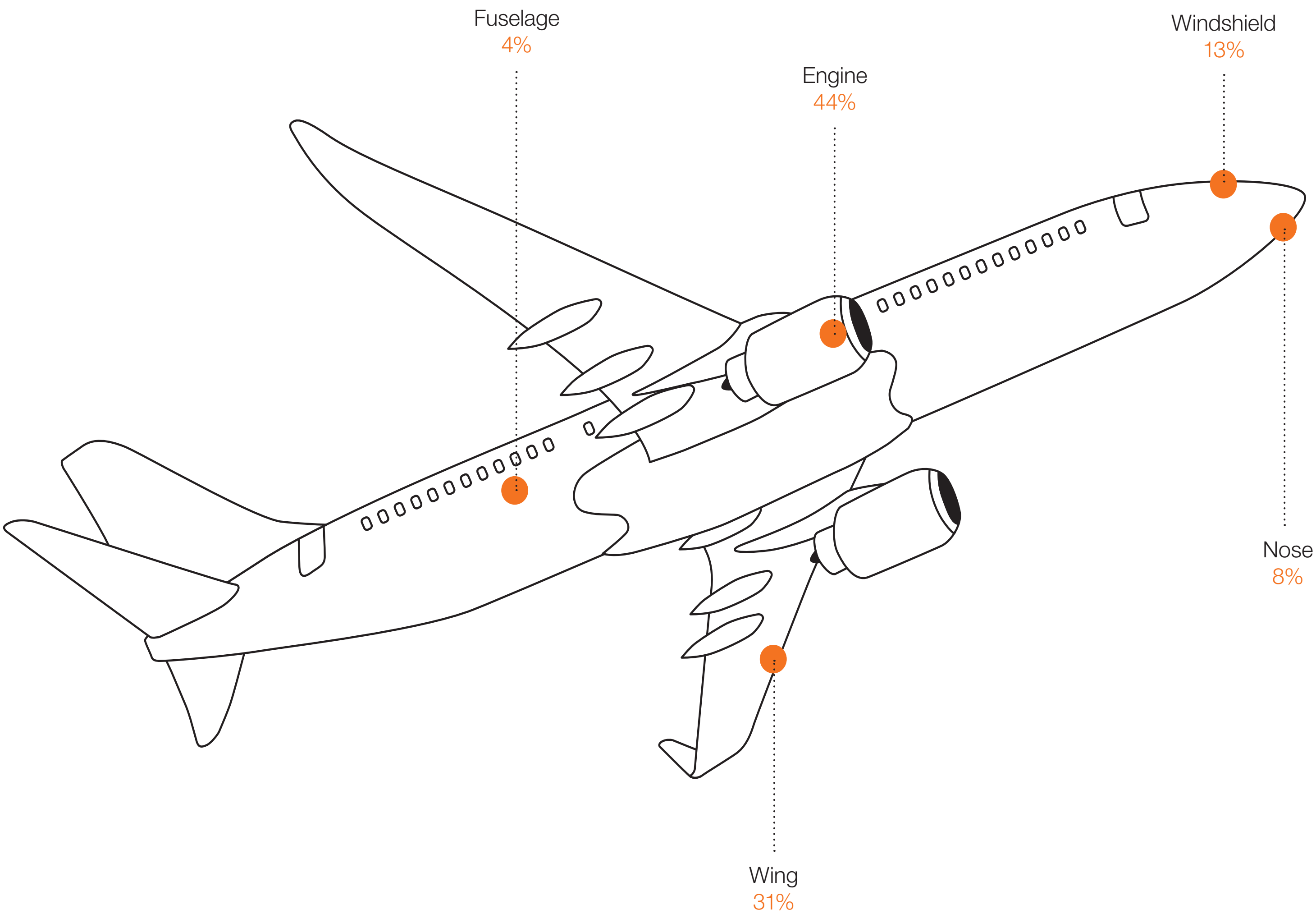
While bird strikes usually inflict most damage on the engines, all areas of an airplane can be damaged (see figs. 1 and 2). Airplane damage and effect on flight from bird strikes are closely correlated to kinetic energy, derived from the mass (determined by bird species) and the square of the speed of the collision. (A 20 percent increase in speed raises the kinetic energy by 44 percent.)

Single or multiple large birds, relatively small numbers of medium-size birds, and large flocks of relatively small birds are all problematic and have resulted in accidents. In the United States, a list of birds most hazardous to flight has been identified: large flocking waterfowl (Canada goose); gulls; pigeons and doves; blackbirds, starlings, and sparrows; and raptors (hawks and kestrels). Most bird strikes occur on or near the ground, highlighting the need for wildlife management on airport grounds and in the vicinity. (See http://wildlife-mitigation.tc.faa.gov/wildlife/downloads/BASH90-09.pdf.)

The aviation bird-strike hazard is a global and industrywide issue affecting all aviation stakeholders, including pilots, mechanics, airlines, airport operators, air traffic controllers, wildlife personnel, aviation safety analysts, airplane and engine manufacturers, flight training organizations, and the traveling public. Boeing participates in national and international groups dedicated to exploring and addressing the problem of

Figure 2: Locations of bird-strike damage

Three-quarters of bird strikes involve the wing or engines, but they can damage almost any part of an airplane.



bird strikes, and Boeing airplanes meet and exceed regulatory bird-strike requirements. Boeing has many design features, including system separation, system redundancy, and structural attributes, to protect against bird strikes beyond the four-pound regulatory general bird-strike FAA requirement (eight pounds for empennage).

COMMON MISCONCEPTIONS ABOUT BIRD STRIKES

A number of widespread misconceptions about bird strikes may give pilots a false sense of security and prevent them from reacting appropriately to the threat of a bird strike or an actual event. These misconceptions include:

- Birds don't fly at night.
- Birds don't fly in poor visibility, such as in clouds, fog, rain, or snow.
- Birds can detect airplane landing lights and weather radar and avoid the airplane.
- Airplane colors and jet engine spinner markings help to repel birds.
- Birds seek to avoid airplanes because of aerodynamic and engine noise.
- Birds dive to avoid an approaching airplane.

In fact, none of these statements is scientifically proven.

PREVENTIVE STRATEGIES

Airports are responsible for bird control and should provide adequate wildlife control measures. If large birds or flocks of birds are reported or observed near the runway, the flight crew should consider:

- Delaying the takeoff or landing when fuel permits. Advise the tower and wait for airport action before continuing.
- Take off or land on another runway that is free of bird activity, if available.

Wildlife strike facts

- More than 219 people traveling by airplane have been killed worldwide as a result of bird strikes since 1988.
- Between 1990 and 2009, bird and other wildlife strikes cost U.S. civil aviation more than $650 million per year.
- About 5,000 bird strikes were reported by the U.S. Air Force in 2010.
- More than 9,000 bird and other wildlife strikes were reported for U.S. civil aircraft in 2010.
- Between 1990 and 2004, U.S. airlines reported 31 incidents in which pilots had to dump fuel to lighten load during a precautionary or emergency landing after striking birds on takeoff or climb. An average of 11,600 gallons of jet fuel was released in each of these dumps.
- Waterfowl (31 percent), gulls (25 percent), raptors (18 percent), and pigeons/doves (7 percent) represented 81 percent of the reported bird strikes causing damage to U.S. civil aircraft between 1990 and 2009.
- More than 950 civil aircraft collisions with deer and 320 collisions with coyotes were reported in the United States between 1990 and 2009.
- About 90 percent of all bird strikes in the United States are by species federally protected under the Migratory Bird Treaty Act.
- Between 1990 and 2009, 415 different species of birds and 35 species of terrestrial mammals were involved in strikes with civil aircraft in the United States that were reported to the Federal Aviation Administration.

Source: Bird Strike Committee USA

To prevent or reduce the consequences of a bird strike, the flight crew should:

- Discuss bird strikes during takeoff and approach briefings when operating at airports with known or suspected bird activity.
- Be extremely vigilant if birds are reported on final approach. If birds are expected on final approach, plan additional landing distance to account for the possibility of no thrust reverser use if a bird strike occurs.

ADDITIONAL RESOURCES

Additional information is available online through a number of industry groups. Information includes significant strike events, key issues to reduce strikes, risk assessment, system information, papers and newsletters, and discussion forums.

- Bird Strike Committee USA (www.birdstrike.org).
- International Bird Strike Committee (www.int-birdstrike.org).
- International Civil Aviation Organization (ICAO) (www.icao.int/icao/en/ro/nacc/acilac/index.html).
- Embry-Riddle Aeronautical University (http://wildlifecenter.pr.erau.edu).
- National Bird Strike Committees or Aviation Wildlife Hazard Groups.

THE IMPORTANCE OF REPORTING BIRD STRIKES

Flight crews and maintenance and line personnel are encouraged to report all bird strikes because data are essential to quantify and manage the hazard. Reporting bird strikes enables aviation authorities to monitor the risk to aviation and the effectiveness of wildlife hazard mitigation measures. Bird-strike data, together with

Factors contributing to the increase in wildlife strikes

- The Great Lakes cormorant population increased from only about 200 nesting adults in 1970 to more than 260,000 nesting adults in 2006.
- In 1890, about 60 European starlings were released in New York City's Central Park. Starlings are now the second-most abundant bird in North America with a late-summer population of more than 150 million birds. Starlings are considered "feathered bullets," having a body density 27 percent higher than herring gulls.
- The North American nonmigratory Canada goose population increased about fourfold from 1 million birds in 1990 to more than 3.9 million in 2009. About 1,500 Canada geese strikes with civil aircraft were reported in the United States between 1990 and 2009. About 42 percent of these strike events involved multiple birds.
- A 12-pound Canada goose struck by a 150-mph airplane at liftoff generates the kinetic energy of a 1,000-pound weight dropped from a height of 10 feet.
- The North American population of greater snow geese increased from about 50,000 birds in 1966 to more than 1 million birds in 2009.
- The nesting population of bald eagles in the contiguous United States increased from fewer than 400 pairs in 1970 (two years before DDT and similar chlorinated-hydrocarbon insecticides were banned) to more than 13,000 pairs in 2010. Between 1990 and 2009, 125 bald eagle strikes with civil aircraft were reported in the United States. The mean body mass of bald eagles is 9.1 pounds for males and 11.8 pounds for females.

Source: Bird Strike Committee USA

knowledge of the operational environment, are utilized by Boeing as a basis of many airplane design features beyond regulatory requirements. Bird-strike data also help researchers understand the nature of strikes and develop a scientific approach to reduce the cost and safety consequences of bird strikes.

Aviation stakeholders should report all known or suspected bird strikes to their national or recognized wildlife strike data repository (e.g., the FAA National Wildlife Strike Database in the United States) and share the strike information with the airport operator, the airline safety department, and the aircraft and engine manufacturers. Each of these individual reports will be combined into a single composite data record. Reporters should provide as much information as possible, including:

- Airplane model and series designation (e.g., 777-300).
- Airplane serial number or registration.
- Phase of flight.
- Speed and altitude of the airplane.
- Geographical location of the airplane.
- Date and time of day.
- Origin and destination airport.
- Number and species of bird observed and struck.
- Impact locations of strikes and damage on airplane.
- Effect on flight (e.g., rejected takeoff, air turnback, diversion).

If bird remains are available, trained personnel should identify the species involved, or the bird remains should be collected using the correct procedure (as outlined at http://wildlife-mitigation.tc.faa.gov/wildlife/speciesid.aspx) and bird-strike collection kit and shipped to a qualified laboratory. It is crucial to determine the species of the bird or birds involved in a bird strike and the location of the strike, so that wildlife management can take appropriate actions. Effective wildlife management involves controlling attractants, often species-specific, including food, foraging, roosting, and nesting opportunities. Managing the environment may be necessary, even to the extent of grass

The bird strike should be reported by the flight crew in the pilot's log or by the maintenance crew in the maintenance log. After a bird strike, the airplane should be inspected for possible damage to airplane structure and airplane systems.

type and height, insects, rodents, and invertebrates, along with water sources and land use, such as agriculture.

In the event of a bird strike, maintenance personnel should follow the appropriate maintenance procedures for bird strike inspection in the Airplane Maintenance Manual. Maintenance personnel must be cognizant of the possibility that the bird remains can contain infectious material. The bird strike should be reported by the flight crew in the pilot's log or by the maintenance crew in the maintenance log. After a bird strike, the airplane should be inspected for possible damage to airplane structure and airplane systems.

In the United States and Canada, bird-strike information can be reported online at http://wildlife-mitigation.tc.faa.gov/wildlife/strikenew.aspx or via FAA form 5200-7 Bird/Other Wildlife Strike Report.

HOW AIRLINES CAN GET INVOLVED

Airlines and other stakeholders can help address the ongoing problem of bird strikes by participating in local, regional, national, or international aviation wildlife hazard activities, such as bird-strike committees or equivalent groups.

Airlines can also form their own internal aviation wildlife hazard group and designate a single point of contact for coordinating all aviation wildlife hazard activity, both internally and externally.

SUMMARY

Bird strikes have always been a part of aviation. While they usually cause no more than minor damage, they can pose a threat to air safety. By being aware of the ongoing possibility of bird strikes and by following recommended procedures, flight crews can reduce the possibility and effects of a bird strike.

For more information, please contact Roger Nicholson at roger.nicholson@boeing.com.

Practical bird-strike information for flight crews

Although it is not possible to avoid all bird strikes, flight crews can take steps to reduce the chance of a bird-strike event. If a bird strike does occur, the appropriate action can improve the flight crew's ability to maintain control of the airplane and land safely.

This information from the Boeing Flight Crew Training Manual provides flight crews and flight operations personnel with practical information about preventing and managing bird-strike events.

PREVENTION STRATEGIES

- Pilots should not rely on onboard weather radar, landing lights, airplane markings, time of day, or visibility to prevent bird strikes.
- Flight operations may need to be modified in the presence of known or anticipated bird activity.
- Delay takeoff or landing in the presence of bird activity.
- Below 10,000 feet, keep speed below 250 knots if operationally possible.
- Below 2,000 feet, climb at the maximum rate to reduce the flight time exposure to a strike hazard.
- Descend with idle power and avoid extended low-altitude level flight, particularly over water courses, nature reserves, or other areas of known or expected bird activity.
- When landing is assured, consider landing through birds versus a missed approach to avoid birds. This reduces the energy of the collision, the potential for increased damage associated with engines at a high power level, and the potential for multiple engine ingestions at low airplane energy states and low altitude.
- Avoid or minimize maneuvering at low altitude to avoid birds.

BIRD STRIKES DURING TAKEOFF ROLL

If a bird strike occurs during takeoff, the decision to continue or reject the takeoff is made using the criteria found in the Rejected Takeoff maneuver of the QRH. If a bird strike occurs above 80 knots and prior to V1, and there is no immediate evidence of engine failure (e.g., failure, fire, power loss, or surge/stall), the preferred option is to continue with the takeoff followed by an immediate return, if required.

DETECTING A BIRD STRIKE WHILE IN FLIGHT

- Visual: Birds seen in close proximity to the airplane or colliding with the airplane, bird remains on windshield, cracked windshield.
- Tactile: Vibration of airframe or engine, thrust loss, asymmetric thrust, increased drag, abnormal airplane handling characteristics.
- Auditory: Noise of strike or noise attributed to resulting damage: engine surging, compressor stalls, aerodynamic noise from damaged radome, loss of pressurization from pressure vessel penetration.
- Olfactory: Smoke, odor, or cooked bird smell.
- Engine indications: Reduction or fluctuation in primary power parameter (e.g., engine pressure ratio, fan speed, or equivalent), abnormal fuel flow, abnormal engine vibration monitoring (e.g., error vector magnitude or equivalent), engine failure, engine exceedances.
- Flight instruments: Loss of data or erroneous indications arising from damage to air data sensors or angle-of-attack sensors.
- Other airplane systems or structure affected directly by a strike: Damaged communications or navigation antennas, damage to exposed electrical wiring or hydraulic lines, damaged radome or weather radar, broken landing lights, or cascading and multiple effects from sensor damage or engine damage.

RESPONSES TO A KNOWN OR SUSPECTED BIRD STRIKE

Immediate action

- Fly the airplane and maintain flight path control.
- Monitor flight and engine instruments.

Multiple engine failure or thrust loss

- Attempt to restart engine(s).

Severe engine damage

- Shut down engine according to procedure.

Strong engine vibration

- Reduce thrust, which will often reduce vibration.
- Shut down engine per flight crew operations manuals guidance.

Multiple engine ingestion and abnormal engine indications

- Air turnback or diversion to nearest suitable airport.

Known or suspected multiple engine ingestion, with normal engine indications

- Consider air turnback or diversion to nearest suitable airport.
- Reevaluate decision to continue with extended-range twin-engine operational performance standards, extended range operations, or overwater flight because engine damage or performance degradation may manifest later in the flight.

Known or suspected strikes with large flocking birds, such as Canada geese

- Consider air turnback or diversion to nearest suitable airport, because damage may affect aerodynamic lift and drag, subsequent fuel burn, and ability to complete the flight safely.

Known or suspected airframe damage or engine damage

- Maintain or reduce speed — do not accelerate unless necessary for safety of flight or to maintain flight path control.

Damaged windshield or depressurization

- Below 10,000 feet, discontinue climb and level off.
- Above 10,000 feet, descend to 10,000 feet or the minimum safe altitude.

Known or suspected strike with landing gear extended or in takeoff or landing configuration with high lift deployed

- Use available system information to assess possible damage to flight controls and high lift devices, and make minimal and prudent changes in airplane configuration in accordance with the flight phase.
- Use available system information to assess possible damage to landing gear and associated systems, including exposed electrical, pneumatic, and hydraulic systems, and potential effects on the ability to steer and stop on the runway.

Known or suspected strikes to air data and angle-of-attack sensors

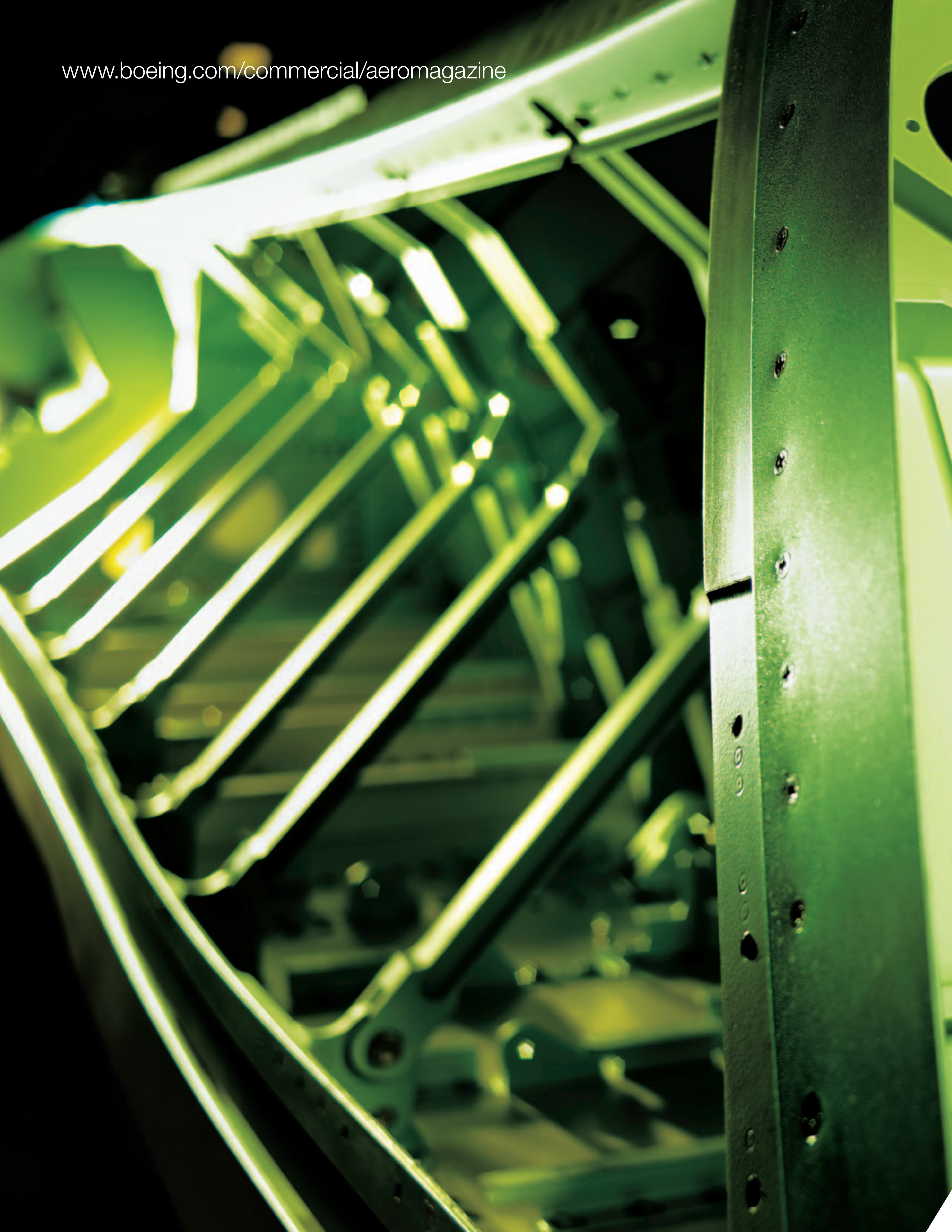
- Be aware that this may affect other airplane systems and have cascading effects.
- Be aware of the potential for loss or erroneous air data and degraded flight control modes, including loss of envelope protection or limiting, unreliable airspeed, propulsion systems in alternate mode.

Bird strikes during approach or landing

- If the landing is assured, continuing the approach to landing is the preferred option. If more birds are encountered, fly through the bird flock and land.
- Maintain as low a thrust setting as possible.
- If engine ingestion is suspected, limit reverse thrust on landing to the amount needed to stop on the runway. Reverse thrust may increase engine damage, especially when engine vibration or high exhaust gas temperature is indicated.

Postflight actions following a known or suspected bird strike

- Report all known or suspected bird strikes or bird activity on or in the vicinity of the airport via established procedures. Ideally this information reaches all stakeholders, including air traffic control, the airport operator, the airline, airplane and engine manufacturers (particularly the local representative), the national regulatory authority, and the appropriate national bird-strike committee or aviation wildlife hazard group.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