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JERRY SMITH  The Boeing Component Exchange Program helps airlines reduce fleet repair expenses and inventory investment while improving schedule reliability and stabilizing long-term maintenance budget planning.

GLOBAL NAVIGATION SATELLITE SYSTEM  A new positioning and landing system that integrates satellite and ground-based navigation information improves takeoff and landing capability at reduced cost.

ERRONEOUS GLIDESLOPE  Flight crews can perform glideslope confidence checks to help manage the risk of instrument landing systems capturing erroneous glideslope signals.

747ER AND 747ER FREIGHTER  The new Longer Range 747-400 airplanes offer significant range and payload improvements and provide greater reliability, maintainability, and flexibility.

QUIET CLIMB  The Boeing Quiet Climb System is a new automated avionics feature for quiet procedures that lessens crew workload and helps airlines comply with restrictions.
Three years ago, we introduced the Boeing Component Exchange Program, a service designed to free carriers from costly fleet-support tasks without sacrificing airplane schedule reliability. Today, seven airlines worldwide participate in our program, experiencing substantial savings across their growing fleets of 737-600/-700/-800/-900 airplanes.

With Component Exchange, we maintain a dedicated inventory of selected high-value components so participating airlines don’t need to. Avionics, actuators, display units, and other flight-critical parts can be on their way to airlines before mechanics have even removed a damaged part from an airplane.

Instead of keeping multiple high-value line replaceable units (LRU) in stock, airlines maintain only minimal inventories of LRUs and order exchange replacements from us, which we ship within one day. The airlines send us their removed units, and we arrange for repair, modification, or overhaul through a network of approved service providers. The units are restored to airworthy condition, upgraded to reflect design changes, and returned to the exchange inventory pool, where they are ready once again for any customer in the program.

Participating airlines not only reduce repair expenses and inventory holding costs—which can run into the millions of dollars—they also stabilize their long-term maintenance budget planning.

Under the Component Exchange Program, Next-Generation 737 operators sign up for a term of up to 10 years, paying a rate that covers a potential exchange of approximately 300 different LRUs. The rate is based on fleet size and flight-hours. Supplier parts are included in the program.

For more information about the Component Exchange Program, please contact your Boeing Field Service representative or send us an e-mail message at repairs@boeing.com.

Our goal is to help you reduce your inventory investment and improve schedule reliability.

At Boeing, we are committed to your success.

JERRY SMITH
DIRECTOR
MAINTENANCE, REPAIR, AND COMPONENT MANAGEMENT
BOEING COMMERCIAL AVIATION SERVICES
The aviation industry is developing a new positioning and landing system based on the Global Navigation Satellite System (GNSS). The GNSS landing system (GLS) integrates satellite and ground-based navigation information to provide the position information required for approach and landing guidance. Potential benefits of the GLS include significantly improved takeoff and landing capability at airports worldwide and at reduced cost, improved instrument approach service at additional airports and runways, and the eventual replacement of the Instrument Landing System. Boeing plans to certify the airborne aspects of GLS on the 737, to support Category I operations, by the end of 2003.
For more than 10 years, the aviation industry has been developing a positioning and landing system based on the Global Navigation Satellite System (GNSS). These efforts culminated in late 2001, when the International Civil Aviation Organization (ICAO) approved an international standard for a landing system based on local correction of GNSS data to a level that would support instrument approaches. The ICAO Standards and Recommended Practices (SARPS) define the characteristics of a Ground-Based Augmentation System (GBAS) service that can be provided by an airport authority or an Air Traffic Service provider. The GBAS service provides the radiated signal in space that can be used by suitably equipped airplanes as the basis of a GNSS landing system (GLS). The initial SARPS support an approach service. Future refinements should lead to full low-visibility service (i.e., takeoff, approach, and landing) and low-visibility taxi operations. This article describes
1. Elements of the GLS.
2. Operations using the GLS.
3. Benefits of the GLS.
4. Operational experience.

**1 ELEMENTS OF THE GLS**

The GLS consists of three major elements—a global satellite constellation that supports worldwide navigation position fixing, a GBAS facility at each equipped airport that provides local navigation satellite correction signals, and avionics in each airplane that process and provide guidance and control based on the satellite and GBAS signals (fig.1).

The GLS uses a navigation satellite constellation (e.g., the U.S. Global Positioning System [GPS], the planned European Galileo System) for the basic positioning service. The GPS constellation already is in place and improvements are planned over the coming decades. The Galileo constellation is scheduled to be available in 2008.

The basic positioning service is augmented locally—at or near the airport—through a GBAS radio transmitter facility. Because the ground facility is located at a known surveyed point, the GBAS can estimate the errors contained in the basic positioning data. Reference receivers in the GBAS compare the basic positioning data with the known position of the facility and compute corrections on a satellite-by-satellite basis. The corrections are called pseudorange corrections because the primary parameter of interest is the distance between the GBAS facility and individual satellites. The satellite constellation is continuously in motion, and satellites ascend and descend over the horizon when observed from any point on Earth. The GBAS calculates corrections for all the satellites that meet the specified in-view criteria and transmits that information to the nearby airplanes over a VHF Data Broadcast (VDB) data link.

Boeing airplanes that are currently being produced contain Multi-Mode Receivers (MMR) that support Instrument Landing System (ILS) and basic GPS operations. These MMRs...
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**1 THE GLS**

A single GBAS ground station typically provides approach and landing service to all runways at the airport where it is installed. The GBAS may even provide limited approach service to nearby airports. Each runway approach direction requires the definition of a final approach segment (FAS) to establish the desired reference path for an approach, landing, and rollout. The FAS data for each approach are determined by the GBAS service provider and typically are verified after installation of the GBAS ground station.

One feature that differentiates the GLS from a traditional landing system such as the ILS is the potential for multiple final approach paths, glideslope angles, and missed approach paths for a given runway. Each approach is given a unique identifier for a particular FAS, glideslope, and missed approach combination. FAS data for all approaches supported by the particular GBAS facility are transmitted to the airplane through the same high-integrity data link as the satellite range correction data (i.e., through the VDB data link). The MMRs process the pseudorange correction and FAS data to produce an ILS-like deviation indication from the final approach path. These deviations are then displayed on the pilot’s flight instruments (e.g., Primary Flight Display [PFD]) and are used by airplane systems such as the flight guidance system (e.g., autopilot and flight director) for landing guidance.

The ILS-like implementation of the GLS was selected to support common flight deck and airplane systems integration for both safety and economic reasons. This implementation helps

**2 OPERATIONS USING THE GLS**

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The ILS-like implementation of the GLS was selected to support common flight deck and airplane systems integration for both safety and economic reasons. This implementation helps
provide an optimal pilot and system interface while introducing the GLS at a reasonable cost. The use of operational procedures similar to those established for ILS approach and landing systems minimizes crew training, facilitates the use of familiar instrument and flight deck procedures, simplifies flight crew operations planning, and ensures consistent use of flight deck displays and annunciations. For example, the source of guidance information (shown on the PFD in fig. 2) is the GLS rather than the ILS. The scaling of the path deviation information on the pilot’s displays for a GLS approach can be equivalent to that currently provided for an ILS approach. Hence, the pilot can monitor a GLS approach by using a display that is equivalent to that used during an ILS approach.

Figure 2 shows a typical PFD presentation for a GLS approach. The Flight Mode Annunciation on the PFD is “GLS” for a GLS approach and “ILS” for an ILS approach.

To prepare for a GLS approach, the pilot selects GLS as the navigation source and chooses the particular approach to be flown. This is accomplished by selecting a GLS approach through the FMS (fig. 3) or by entering an approach designator on a dedicated navigation control panel (fig. 4). In either case, a unique five-digit channel number is associated with each approach. With the FMS interface, the pilot does not need to enter a channel number; tuning is accomplished automatically based on the approach selected, just as is now done for ILS. However, for an airplane equipped with separate navigation tuning panels, the pilot tunes the MMRs by entering a GLS channel number in that panel. This is similar to the equivalent ILS flight deck interface where a pilot tunes the ILS by using a designated VHF navigation frequency. As with the ILS, certain GLS identification data are available on other FMS pages such as the APPROACH REF page, which shows the runway identifier, GLS channel, and associated approach identifier (fig. 3).

Regardless of the selection method, the five-digit GLS channel number is encoded with the frequency to be used for the VDB data link receiver and with an identifier for the particular approach and missed approach path (FAS data set) that corresponds to the desired approach.

Figure 4 shows a navigation control panel used to tune navigation radios, including GLS, for the 737-600/-700/-800/-900.

The approach plate shows the channel number for each approach and a four-character approach identifier to ensure consistency between the selected channel and the approach procedure chosen by the pilot. The approach identifier is read from the FAS data block and displayed to the pilot on the PFD to provide positive confirmation that the desired approach has indeed been selected.

Figure 5 shows a typical GLS approach procedure. The procedure is similar to that used for ILS except for the channel selection method and the GLS-unique identifier. The approach chart is an example of a Boeing flight-test procedure and is similar to a chart that would be used for air carrier operations, with appropriate specification of the landing minima.

Figure 6 is an example of a possible future complex approach procedure using area navigation (RNAV), Required Navigation Performance (RNP), and GLS procedures in combination. Pilots could use such procedures to conduct approaches in areas of difficult terrain, in adverse weather, or where significant nearby airspace restrictions are unavoidable. These procedures would combine an RNP transition path to a GLS FAS to the runway. These procedures can also use GBAS position, velocity, and time (PVT) information to improve RNP.
The GBAS is intended to support multiple levels of service to an unlimited number of airplanes within radio range of the VDB data link. Currently, ICAO has defined two levels of service: Performance Type 1 (PT 1) service and GBAS Positioning Service (GBAS PS). PT 1 service supports ILS-like deviations for an instrument approach. The accuracy, integrity, and continuity of service for the PT 1 level have been specified to be the same as or better than ICAO standards for an ILS ground station supporting Category I approaches. The PT 1 level was developed to initially support approach and landing operations for Category I instrument approach procedures. However, this level also may support other operations such as guided takeoff and airport surface position determination for low-visibility taxi.

The GBAS PS provides for very accurate PVT measurements within the terminal area. This service is intended to support FMS-based RNAV and RNP-based procedures. The improved accuracy will benefit other future uses of GNSS positioning such as Automatic Dependent Surveillance—Broadcast and Surface Movement Guidance and Control Systems.

The accuracy of the GBAS service may support future safety enhancements such as a high-quality electronic taxi map display for pilot use in bad weather. This could help reduce runway incursion incidents and facilitate airport movements in low visibility. The service also may support automated systems for runway incursion detection or alerting.

As important as the accuracy of the GBAS service is the integrity monitoring provided by the GBAS facility. Any specific level of RNP operation within GBAS coverage should be more available because the user receivers no longer will require redundant satellites for satellite failure detection (e.g., Receiver Autonomous Integrity Monitoring).

Because the GBAS PS is optional for ground stations under the ICAO standards, some ground stations may only provide PT 1 service. The messages uplinked through the VDB data link indicate whether or not the ground station supports the GBAS PS and specify the level of service for each approach for which a channel number has been assigned. When the GBAS PS is provided, a specific five-digit channel number is assigned to allow selection of a non-approach-specific GBAS PS from that station. Consequently, the channel selection process allows different users to select different approaches and levels of service.

The GBAS PS and the PT 1 service are not exclusive. If the ground station provides the GBAS PS, selecting a channel number associated with any particular approach automatically will enable the GBAS PS service. The receiver provides corrected PVT information to intended airplane systems as long as the GBAS PS is enabled. ILS-like deviations also are available when the airplane is close enough to the selected approach path.
ICAO is continuing development of a specification for service levels that would support Category II and III approaches.

3 BENEFITS OF THE GLS

From the user perspective, the GBAS service can offer significantly better performance than an ILS. The guidance signal has much less noise because there are no beam bends caused by reflective interference (from buildings and vehicles). However, the real value of the GLS is the promise of additional or improved capabilities that the ILS cannot provide. For example, the GLS can

- Provide approach and takeoff guidance service to multiple runways through a single GBAS facility.
- Optimize runway use by reducing the size of critical protection areas for approach and takeoff operations compared with those needed for ILS.
- Provide more flexible taxiway or hold line placement choices.
- Simplify runway protection constraints.
- Provide more efficient airplane separation or spacing standards for air traffic service provision.
- Provide takeoff and departure guidance with a single GBAS facility.

From the service provider perspective, the GBAS can potentially provide several significant advantages over the ILS. First, significant cost savings may be realized because a single system may be able to support all runways at an airport. With the ILS, each runway served requires an ILS and a frequency assignment for that ILS, which can be difficult because of the limited numbers of available frequencies. Operational constraints often occur with the ILS when an Air Traffic Service provider needs to switch a commonly used ILS frequency to serve a different runway direction. This is not an issue with the GBAS because ample channels are available for assignment to each approach. In addition, because the GBAS serves all runway ends with a single VHF frequency, the limited navigation frequency spectrum is used much more efficiently. In fact, a GBAS may even be able to support a significant level of instrument approach and departure operations at other nearby airports.

The siting of GBAS ground stations is considerably simpler than for the ILS because GBAS service accuracy is not degraded by any radio frequency propagation effects in the VHF band. Unlike the ILS, which requires level ground and clear areas on the runway, the siting of a GBAS VHF transmitter can be more flexible than ILS. The removal of the requirement to provide a large flat area in front of the ILS glideslope alone can represent a very significant savings in site preparation cost and opens up many more locations for low-minima instrument approach service.

Although GBAS accuracy can be affected by multipath interference, careful siting of GBAS receivers can readily eliminate multipath concerns because GBAS receivers do not need to be placed near a runway in a specific geometry, as is the case with the ILS or MLS. Hence, this virtually eliminates the requirements for critical protection areas or restricted areas to protect against signal interference on runways and nearby taxiways.

Finally, the GBAS should have less frequent and less costly flight inspection requirements than the ILS because the role of flight inspection for GBAS is different. Traditional flight inspection, if needed at all, primarily would apply only during the initial installation and ground station commissioning. This flight inspection would verify the suitability of the various approach path (FAS) definitions and ensure that the GBAS-to-runway geometry definitions are correct. Because verifying the coverage of the VDB data link principally is a continuity of service issue rather than an accuracy or integrity issue, it typically would not require periodic inspection.

GBAS systems capable of supporting Category II and III operations internationally are envisioned. Airborne system elements that would be necessary for the enhanced GLS capability (e.g., MMR and GLS automatic landing provisions) already are well on the way to certification or operational authorization. Airborne systems and flight deck displays eventually will evolve to take full advantage of the linear characteristic of the GLS over the angular aspects of the ILS.
To date, flight-test and operational experience with the GLS has been excellent. Many GLS-guided approaches and landings have been conducted successfully at a variety of airports and under various runway conditions.

Both automatic landings and landings using head-up displays have been accomplished safely through landing rollout, in both routine and non-normal conditions.

On the pilot’s flight displays, the GLS has been unusually steady and smooth when compared with the current ILS systems even when critical areas necessary for the ILS approaches were unprotected during the GLS approaches.

The Boeing Technology Demonstrator program has used a 737-900 to demonstrate successful GLS operations to airline customers, airplane and avionics manufacturers, airport authorities, Air Traffic Service providers, and regulatory authority representatives.

The GLS represents a mature capability ready for widespread operational implementation. When implemented, the GLS will improve safety, increase capacity, and provide operational benefits to airlines, pilots, passengers, airports, and Air Traffic Service providers. Boeing plans to certify the airborne aspects of the GLS on the 737 by the end of 2003 to support Category I operations, with other models to follow. Work is continuing for the airborne certification of the GLS to support Category II and III operations when suitable GBAS ground facilities are specified and made available.
SUMMARY

The aviation industry is developing the GLS, a new positioning and landing system that integrates satellite and ground-based navigation information. Potential benefits of the GLS include significantly improved takeoff and landing capability at airports worldwide at reduced cost, instrument approach service at additional airports and runways, and eventual replacement of the ILS. Boeing plans to certify the airborne aspects of the GLS on the 737 by the end of 2003 to support Category I operations, with other models to follow.
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All airplanes equipped with instrument landing systems are vulnerable to capturing erroneous glideslope signals. Boeing, the International Civil Aviation Organization, and the U.S. Federal Aviation Administration are working together to improve awareness and prevent such errors. Flight crews can help manage the risk by understanding the problem and performing glideslope confidence checks.

SAFETY

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HAZARDS of ERRONEOUS GLIDESLOPE INDICATIONS
In the 1940s came the possibility of erroneous or false glideslope indications under certain circumstances. One such erroneous indication recently occurred on several 767, 777, and Airbus airplanes, resulting in coupled ILS approaches being flown toward a point short of the runway. This kind of problem can occur on any airplane with any ILS receiver.

Boeing has taken action to help prevent such incidents by revising operations manuals and working with the International Civil Aviation Organization (ICAO) and the U.S. Federal Aviation Administration (FAA) to address maintenance errors that can cause erroneous glideslope signals. The subtle nature of the indications makes it imperative that flight crews also help manage the risk by understanding the problem and performing glideslope confidence checks.

This article describes
1. Incident involving an erroneous glideslope signal.
2. Causes of erroneous glideslope signals.
3. Flight crew actions.
4. Industry actions.

**INCIDENT INVOLVING AN ERRONEOUS GLIDESLOPE SIGNAL**

On the night of July 29, 2000, an Air New Zealand 767 was on a routine flight from Auckland, New Zealand, to Apia, Western Samoa. The night was moonless, with scattered clouds that prevented visibility of the runway lights.

The flight crew members were experienced in conducting routine automatic landing approaches in low visibility. They considered a routine automatic landing approach to be safe if the autopilot was coupled to the airplane, no warning indications were visible, and a valid Morse code identifier signal came from the ground navigation aids.

Well prepared before descent, the flight crew thoroughly briefed for the approach. When the crew selected...
the approach mode, the glideslope capture occurred almost immediately. All ILS indications appeared to be correct. With all three autopilots engaged, the captain concentrated on configuring the airplane and slowing it for landing. The crew attributed the slightly steep descent of the airplane to its heavy weight and tailwinds. The crew noted a good Morse code identifier signal and no warning indications. At 1,000 ft, the crew completed the landing checks. Shortly thereafter, the first officer observed the close proximity of the island lights out his side window. The captain noticed that the distance measuring equipment (DME) indications differed slightly from what he would have expected.

The captain executed a timely go-around 5.5 mi from the runway at an altitude of less than 400 ft. The crew successfully executed a second approach by using the localizer and ignoring the on-glideslope indications.

### Causes of Erroneous Glideslope Signals

Investigation of the Air New Zealand incident revealed important information about the causes of erroneous glideslope signals. Understanding these causes requires a discussion of the ILS and its normal operation.

ILS ground equipment provides horizontal and vertical guidance information to airplane instrumentation. The equipment typically comprises five components: a localizer transmission system, a glideslope transmission system, a DME or marker system, a standby transmitter, and a remote control and indicator system (fig. 1).

During normal ILS operation, the localizer and glideslope transmitters each radiate a carrier wave of 90- and 150-Hz signals of equal amplitude. These signals alone do not provide guidance but are compared with separate 90- and 150-Hz sidelobe signals radiated by the localizer and glideslope to create complex interference patterns. The patterns are designed so that when an airplane is below the desired glideslope, the instruments will sense a predominance of 150-Hz signals; when the airplane is above the desired glideslope, the instruments will sense a predominance of 90-Hz signals; and when the airplane is on the glideslope, the instruments will sense equal amounts of 90- and 150-Hz signals (fig. 2).

The ILS was designed to protect against transmitter malfunctions. If a primary transmitter malfunctions, the system automatically will transfer to the standby transmitter. If the ILS does not change over to the standby transmitter, or if the standby transmitter is faulty, the system automatically will shut down, and an alarm will sound in the control tower.

It is important to note that, because the Morse code identifier signal is carried only on the localizer carrier signal, the flight crew only knows whether or not the localizer is transmitting. No information on the health of the glideslope, localizer, or other functions is provided.

On the night of July 29, 2000, the glideslope sidelobe amplifier was not operating in Apia. In addition, the ILS ground equipment had been left in bypass mode following calibration maintenance. This prevented system transfer to the standby transmitter. No alarm sounded in the control tower because the cable that fed information to the tower navigation status displays had been cut during construction. As a result, the Air New Zealand flight received only the glideslope carrier wave transmission, which was interpreted by the instruments as being on glideslope, with no warning indications.

### Flight Crew Actions

The Air New Zealand incident exemplifies why flight crews need to be aware of the potential for erroneous glideslope signals, even when the ILS is indicating correctly and a distance-altitude check is performed at glideslope capture. Frequent crosschecks and crew vigilance are key in detecting potential problems.

**Crosschecks.**

A single distance-altitude check does not guarantee the subsequent descent path will be correct. Similarly, a single altitude check crossing the outer marker does not guarantee the glideslope is correct. The best strategy is to crosscheck the airplane altitude against distance periodically during descent. Methods to accomplish this include:

- Crosschecking altitude and DME distance periodically.
- Crosschecking altitude and flight management system (FMS) threshold distance.
- Crosschecking altitude and the crossing altitude of the outer marker (or locator, very-high-frequency omni-range [VOR] navigation equipment, or FMS).
- Crosschecking radio altitude and barometric altitude.
- Crosschecking ground speed and rate of descent.
- Questioning air traffic controllers when indications do not appear to be correct.

Similar erroneous indications can occur with the localizer signal. Cross-checking the signal with other navigation indicators, such as VOR and navigation database course heading and tracking information, can help reduce risks in such occurrences.

Crew vigilance.
Human factors were very important in the successful outcome of the Air New Zealand incident. Crewmembers were alert to possible ILS problems because notice to airmen (NOTAM) bulletins had informed them that the ILS was unmonitored, and they discussed this during their approach briefings. They also paid attention to subtle cues that something might be wrong, even though the automatic flight system was indicating normally. Last, the crewmembers were willing to execute a go-around to give them more time to sort through the conflicting information (fig. 3).

Maintenance guidance.
ICAO and the FAA have released guidance for the proper conduct of ILS ground maintenance activities. The guidance includes:
- Clarifies the content of NOTAMs that are sent when maintenance work is in progress and the possibility of false indications prohibits the use of a particular approach aid.
- Recommends that maintenance personnel confirm whether or not a NOTAM has been issued before beginning ILS maintenance testing.
- Recommends that maintenance personnel turn off the glideslope transmitter during localizer testing and turn off the localizer transmitter during glideslope testing.

Equipment improvements.
In the case of the Air New Zealand flight, the ground proximity warning system (GPWS) did not warn the crew flying the erroneous glideslope. This is because the airplane did not have an excessive closure rate with terrain and the flaps were in landing configuration. However, an airplane equipped with a terrain awareness warning system (TAWS) (e.g., the Honeywell enhanced GPWS) would have warned the crew of the situation because TAWS compares the flight path with a terrain database.
The transmission of erroneous ILS information at Apia on July 29, 2000, was caused by an unusual set of circumstances. However, technicians will continue to conduct testing and maintenance of airfield navigation aids. A similar situation could occur in any ILS-equipped airplane during what appears to be a routine instrument approach.

The best defenses against erroneous glideslope indications are understanding how the ILS works, equipping airplanes with modern warning systems, and implementing training and procedures that ensure crewmembers are prepared to take appropriate action. Flight crew action should include crosschecking the airplane altitude against distance periodically during descent.

Special recognition is given to investigators David Stobie, Rod Smith, Chris Kriechbaum, Bob Henderson, Joey Anca, and Dr. Gordon Vette for their contributions to understanding this incident.

**SUMMARY**

The transmission of erroneous ILS information at Apia on July 29, 2000, was caused by an unusual set of circumstances. However, technicians will continue to conduct testing and maintenance of airfield navigation aids. A similar situation could occur in any ILS-equipped airplane during what appears to be a routine instrument approach.

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INTRODUCING THE 747 ER AND 747
The Longer Range 747-400 airplanes — the 747-400 Extended Range and 747-400 Extended Range Freighter — are the newest members of the 747 family. Through structural and system enhancements, these airplanes offer significant improvements in range and payload and provide greater reliability, maintainability, and flexibility.
The 747-400 Extended Range and 747-400 Extended Range Freighter are the newest members of the 747 family. The same size as today’s 747-400 airplanes, the Longer Range 747-400s provide additional range or greater payload, allowing airlines and cargo carriers to fly longer routes or carry more cargo and passengers on existing routes.

The Longer Range 747-400 program was officially launched in November 2000 with an order from Qantas Airways for six passenger airplanes. Formal design of the 747-400ER began that same month. The first 747-400ER rollout was in June 2002, and Qantas took first delivery in October 2002.

The 747-400ER Freighters were launched in April 2001, with a five-airplane order from International Lease Finance Corporation. The first 747-400ER Freighter rollout was in September 2002, with the first delivery in October 2002 to Air France.

The 747-400ER and 747-400ER Freighters can be configured with General Electric CF6-80C2B5F, Pratt & Whitney 4062, or Rolls-Royce RB211-524H2-T engines. (The General Electric and Pratt & Whitney engines are offered on the standard 747-400 as optional, higher thrust engines.)

With the same shape as standard 747-400s, Longer Range 747-400s are able to use the same airport gates and can operate on the same runways and taxiways. The derivatives use the same pool of spare parts as standard 747-400s; new parts were made to be one-way interchangeable with existing parts. The new airplanes also have a common type rating with the 747-400 and 747-400 Freighter, which minimizes flight crew training requirements and disruptions to flight operations.

The most significant differences between the standard 747-400 and the newest members of the 747 family are:

1. Systems and structural revisions to support increased maximum takeoff weight.
2. Flight deck enhancements.
3. New auxiliary fuel system on the 747-400ER.
4. New interior on 747-400ER.
The wing box skins were thickened, and the leading edge and trailing edge flaps and flap drive systems were strengthened.

The landing gear and supporting structure were redesigned and larger, 50-in radial tires and wheels were installed. To accommodate those tires and to provide sufficient room to retract the wheels, the shape of the landing gear doors was modified. The systems located in the wheel wells were rerouted to protect against larger burst tire volumes.

The Halon fire suppression system bottles were enlarged and relocated along the side of the aft cargo compartment.

Liquid crystal displays. The six cathode ray tube (CRT) displays on the standard 747-400 flight deck have been replaced with liquid crystal displays (LCD) identical to those on the 767-400. Compared with CRT displays, LCDs weigh less, generate less heat, and have a longer mean time between failures. LCDs are able to display more information than CRT displays and are required on the 747-400ER to present the additional synoptics for the auxiliary fuel tank. The LCDs are line replaceable and can be intermixed with the 747-400 CRT displays, thereby reducing the cost of spares.

Integrated standby flight display. Today’s 747-400 flight decks include three standby displays—an attitude display, an airspeed display, and an altimeter. On the 747-400ER and 747-400ER Freighter, those three displays are combined into one LCD, the integrated standby flight display (ISFD). (The ISFD currently is an option on 747-400s but is expected to become standard late in 2003.) The ISFD has the same look as the primary flight display, which is the primary situational display. This similarity makes it easier for the crew to transition to the ISFD in the unlikely event that all main flight displays malfunction. The ISFD also weighs less and has a significantly longer life than its mechanical predecessors.

Reduced flight deck noise. On the 747-400ER and 747-400ER Freighter, sound-damping insulation blankets in the overhead area of the flight deck reduce ambient noise. (All subsequent 747s will contain the blankets.) During flight tests, the blankets reduced overhead noise levels by more than 2 dBA. An optional treatment for flight deck windows two and three reduces ambient noise by an additional 1.5 dBA. When these two features are combined, the flight deck noise of the 747-400ER and 747-400ER Freighter is comparable to that of the quietest widebody jets now in production or planned for the future.
One of the most significant differences between the standard 747-400 and the 747-400ER is the auxiliary fuel system, which is available with one fuel cell or two. (The auxiliary fuel system is not used on the 747-400ER Freighter.) The 747-400ER is configured with a single fuel cell, which accommodates an additional 3,210 gal (12,151 L) of fuel when compared with the 747-400. Structural and systems provisions are provided for a second fuel cell, which can be ordered as an option or installed later. The one- and two-cell installations look like and are managed as a single auxiliary tank (fig. 3).

The auxiliary tank is located in the lower lobe, immediately in front of the center wing tank, where cargo containers usually are carried. To accommodate the auxiliary fuel tank, the potable water system was moved to the aft end of the aft cargo compartment, and the size of the forward cargo compartment was reduced. Whenever possible, common fuel systems components were used.

The fuel cell suspension system and attaching structure were designed to allow for quick installation. The cells are installed or removed with a special tool rolled in and out on the cargo system rollers. Fuel cells and components are readily accessible — without removing the cells from the airplane — through line replaceable units mounted on the front panel and walkways to the right of and between the cells.

The fuel cells are constructed from double-walled aluminum honeycomb panels that are reinforced and stiffened with a metallic secondary structure. Fuel cells are protected from shifting cargo by a barrier attached to the front side of the forward-most auxiliary fuel cell. The fuel tank is suspended 5 in above the cargo floor and 4 in below the cargo ceiling and is isolated from normal airplane deflections by a six-point suspension system anchored with titanium fittings.

The body structure in this zone was completely redesigned to protect the auxiliary tank from damage in the event of an emergency such as a wheels-up landing. Existing sheet-metal frames were replaced with single-piece machined frames. To ensure adequate strength for decompression, a higher strength material is used for the chords of the main deck floor beams. To minimize the possibility of fuel cell damage in the event of a burst engine rotor, a titanium shield is installed on the forward body and wing ribs.

The auxiliary tank is segregated from the cargo compartment by a structural cargo barrier and cargo liners. The tank and its immediate environment were designed to keep the tank within structural temperature and fuel temperature limits in the rare event of a cargo fire.

During flight, fuel is used first from the center fuel tank. As the flight progresses, fuel is transferred from the auxiliary tank to the center tank using air pressure provided by one of two independent sources. The primary source is cabin air pressure. The secondary source, which is used at low altitudes or when the airplane is on the ground (during fuel jettison or on-the-ground defueling), is an electrically powered blower. A switch for the auxiliary tank transfer valves has been added to the fuel management area of the pilot’s overhead panel, which allows the crew to operate the fuel tank manually.

Although auxiliary fuel systems that use air pressure to transfer fuel have been used before on Boeing and other airplanes, this is the first such system designed by Boeing Commercial Airplanes.

From the passenger perspective, perhaps the most notable change is the updated interior of the 747-400ER. The award-winning Boeing signature interior, first developed for the 777, is distinguished by curved architecture and a brighter color scheme than on the standard 747-400. The new interior has a blended ceiling and bin line and pivot bins that provide approximately 30 percent more space for roll-aboard luggage than the standard 747-400. The new bins and bin line offer more passenger headroom, afford better...
access to luggage, and hold stowed luggage in place more securely. The upper deck of the 747-400ER also has twice the stowage capacity of standard 747-400s. (Boeing is considering whether to offer this new interior on future 747-400s and as part of a retrofit for standard 747-400s already in service.)

During the design process, each interior system was evaluated for reliability and maintenance costs. System enhancements include the following.

An electrically activated passenger oxygen system replaces the passenger oxygen system on the 747-400. The new system, which uses many components developed for the 777, is easier to rig and maintain than the system on the 747-400.

A two-pump potable water system replaces the pressurized potable water system on the standard 747-400. On the 747-400, the system is located in the forward cargo hold. Because this space is occupied by the auxiliary fuel tank on the 747-400ER, a new potable water tank was designed and located in the bulk cargo area. This tank is fitted with a two-pump water delivery system, similar to that on the 777. The two-pump system increases dispatch reliability; if one pump fails, the system switches automatically to the functional pump. After each flight, the system toggles from one pump to the other. This distributes operating hours between the pumps and provides a backup if one pump fails on the ground or during flight.

A quick-charge emergency lighting battery replaces the trickle-charge battery. The new battery weighs less, is slightly less expensive, and has a longer life expectancy, which makes it more economical. More significant, the quick-charge battery can be recharged in approximately 1 hr, compared with 8 to 10 hr for the trickle-charge battery. This difference allows operators to return airplanes to service much more quickly after using, maintaining, or testing emergency lighting.

Light-emitting-diode–illuminated sign packs replace incandescent bulb information sign packs. The new signs are brighter, are similarly priced, and have a significantly longer life expectancy, which translates into less maintenance and lower maintenance costs.

New backbone wiring for the in-flight entertainment interface, which will accommodate any interior layout. Because each airline has a different interior layout with different in-flight entertainment (IFE) equipment, the wiring for each IFE installation also differs significantly, making it cumbersome to modify the interior layout after delivery. All 747-400ERs equipped with an IFE system include the new IFE interface backbone wiring, making it easier, quicker, and more efficient to change the interior layout. (All subsequent 747-400 passenger airplanes will include the new wiring.)

### SUMMARY

The 747-400 ER and 747-400ER Freighter—the newest derivatives of the 747 family—are unique in their classes. Features include a maximum takeoff weight of 910,000 lb, which makes it possible to fly farther or carry more payload, and an enhanced flight deck that offers new LCDs, a new ISFD, and additional insulation to reduce noise. The 747-400ER also has a new auxiliary fuel system, available with one fuel cell or two; a newly designed interior; and enhanced interior systems.

### About the Author

Kurt Kraft has held engineering and leadership positions on a variety of Boeing propulsion and airplane programs since 1979, including 747 Airplane Level Integration Team (ALIT) leader, 767-400 Propulsion Platform team leader, and Propulsion chief engineer for the 737/757 Programs.
### TECHNICAL CHARACTERISTICS OF THE 747-400 AND 747-400ER

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<th>747-400</th>
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<tr>
<td><strong>Seating</strong> (typical three-class configuration)</td>
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<td><strong>Maximum landing weight</strong></td>
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<td>567 mi/h (912 km/h)</td>
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<td>Rolls-Royce RB211-524H2-T</td>
<td>59,500 lb (26,990 kg)</td>
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<td>General Electric CF6-80C2B5F</td>
<td>62,100 lb (28,165 kg)</td>
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<td><strong>Maximum fuel capacity</strong></td>
<td>57,285 U.S. gal (216,840 L)</td>
<td>63,705 U.S. gal (241,140 L)*</td>
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<td><strong>Length</strong></td>
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<td>231 ft 10 in (70.6 m)</td>
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<td>211 ft 5 in (64.4 m)</td>
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<td><strong>Tail height</strong></td>
<td>63 ft 8 in (19.4 m)</td>
<td>63 ft 8 in (19.4 m)</td>
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<td><strong>Cargo volume</strong></td>
<td>6,025 ft³ (170.5 m³)</td>
<td>5,599 ft³ (158.6 m³)</td>
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<td>or 5,332 ft³ (151 m³)**</td>
<td>or 4,837 ft³ (137 m³)**</td>
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<tr>
<td><strong>Exterior diameter</strong></td>
<td>21 ft 3.5 in (6.5 m)</td>
<td>21 ft 3.5 in (6.5 m)</td>
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<tr>
<td><strong>Interior cross-section width</strong></td>
<td>20 ft 1.5 in (6.1 m)</td>
<td>20 ft 1.5 in (6.1 m)</td>
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</table>

*With two auxiliary body fuel tanks in the forward lower cargo hold. The fuel capacity with one body tank is 60,495 U.S. gal (228,990 L).

**6,025 ft³ (170.5 m³) = 30 LD-1 containers + bulk; 5,332 ft³ (151 m³) = five pallets, 14 LD-1 containers + bulk (one pallet = 96 in x 125 in, 244 cm x 318 cm).

***5,599 ft³ (158.6 m³) = 28 LD-1 containers + bulk; 4,837 ft³ (137 m³) = four pallets, 14 LD-1 containers + bulk (one pallet = 96 in x 125 in, 244 cm x 318 cm). These volumes are reduced relative to the 747-400 because of the addition of one body fuel tank, basic on the 747-400ER, in the forward lower cargo hold.
Boeing has developed the Quiet Climb System, an automated avionics feature for quiet procedures that involve thrust cutback after takeoff. By reducing and restoring thrust automatically, the system lessens crew workload and results in a consistently quiet footprint, which helps airlines comply with restrictions and may allow for an increase in takeoff payload.
ADVANCED AVIONICS FOR QUIET OPERATIONS

System

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TECHNOLOGY/PRODUCT DEVELOPMENT

First-Quarter 2003 — January
With higher density populations surrounding airports throughout the world, the sound of airplanes has become an issue of increasing importance in recent years. Noise-abatement requirements and procedures imposed by local airport authorities have affected airline operations in many ways, resulting in restricted hours of operation, required weight offloads, fines, and surcharges.

Airplane and engine manufacturers have been successful in producing quieter airplanes, but more stringent noise-abatement requirements and the high cost of engine modification have prompted the industry to consider additional ways to decrease airplane sound in communities.

One alternative is a maneuver in which the flight crew takes off with full takeoff power, climbs rapidly, and then cuts the thrust manually to a predetermined value at a specified cutback altitude. The airplane continues to climb, albeit at a much slower rate, until it is high enough that sound in the community is not an issue. The crew then adds more power to continue flight.

One potential problem with this maneuver is that the pilot must cut back and restore engine thrust manually at the correct altitudes. The Boeing Quiet Climb System (QCS), which is selected during the takeoff procedure, automatically reduces and restores engine thrust at the specified altitudes, thereby reducing pilot workload.

In an effort to standardize noise-abatement procedures, the Federal Aviation Administration (FAA) has issued advisory guidelines that define departure profiles, including the minimum thrust required and the cutback altitude. This article discusses

1. FAA advisory guidelines.
2. The Boeing QCS.
4. Effect of the Boeing QCS on sound in communities.

### FAA Advisory Guidelines

In 1993, the FAA issued advisory circular AC91-53A, “Noise Abatement Departure Profiles,” which standardizes procedures by defining acceptable criteria for speed and minimums for thrust cutback settings and altitudes for various airplane takeoff configurations.

**Minimum Thrust Cutback.**

The minimum thrust cutback represents the minimum level of thrust that would ensure a sufficient climb gradient if an engine were to fail. This thrust value is determined by the number of engines on the airplane. On a two-engine airplane, the minimum thrust cutback ensures an engine-inoperative climb gradient of 1.2 percent. If one engine fails after cutback, the thrust from the operating engine must maintain a climb gradient of at least 1.2 percent. On three-engine and four-engine airplanes, the minimum thrust cutbacks are engine-inoperative climb gradients of 1.5 percent and 1.7 percent, respectively.

**Zero Percent Gradient Cutback.**

Under certain conditions, the advisory circular also allows a thrust cutback that maintains a zero percent engine-inoperative climb gradient. This type of cutback is permitted for airplanes with avionics systems that can detect engine failure and automatically increase the thrust on the remaining engine or engines to a value that maintains the minimum climb gradient. These minimum climb gradients are 1.2 percent on a two-engine airplane, 1.5 percent on a three-engine airplane, and 1.7 percent on a four-engine airplane.

**Cutback Altitude.**

The advisory circular also specifies that the minimum altitude at which the thrust can be reduced, or cut back, is 800 ft above ground level (AGL).

### The Boeing QCS

Boeing developed the QCS, an advanced avionics feature, to directly assist flight crews in flying the quiet departure profiles defined in the advisory circular. The QCS controls thrust reduction and restoration automatically, thereby eliminating the need for manual control and ensuring consistency.

During the takeoff checklist procedure, the pilot selects the QCS and enters the altitudes at which thrust should be reduced (≥800 ft AGL) and restored. With the autothrottle system engaged, the QCS reduces engine thrust when the cutback altitude is reached to maintain the optimal climb angle and airspeed. When the airplane reaches the chosen thrust restoration altitude (typically 3,000 ft AGL), the QCS restores full climb thrust automatically. As such, QCS reduces pilot workload during a phase of flight that already is task intensive.

QCS incorporates multiple safety features and will continue to operate even with system failures. If a system failure does occur, there are several methods for exiting QCS. In the most common method, the pilot selects the takeoff/go-around switches on the throttle control stand. The pilot can take control of the throttles easily by disconnecting the autothrottle and controlling the thrust manually, as appropriate.

**QCS AVAILABILITY.**

The QCS is available on all 737-600/-700/-800/-900 airplanes and provides an automatic thrust cutback engine-inoperative climb gradient of 1.2 percent. The zero percent climb gradient QCS is scheduled to become available in first-quarter 2003 on the 737-600/-700/-800/-900. Boeing also is considering the QCS for the 747-400, which would have an
automatic thrust cutback engine-inoperative climb gradient of 1.7 percent.

Other Boeing systems.
A system similar to the QCS is available on the MD-90 series. That system, however, requires that the pilot calculate the necessary thrust and then enter it manually for automatic thrust cutback during takeoff. The 757 also has an option similar to QCS that provides an engine-inoperative climb gradient of 1.2 percent. To be activated, the crew must select the system manually at the cutback altitude.

3 BASICS OF SOUND MEASUREMENTS

Airplane sound is measured along the flight path using monitors located near the ground. The level measured by each monitor is a function of the airplane, engine type, altitude, and thrust. An airplane event consists of a single flyover with incremental measurements recorded by the monitors (fig. 1). A time history, which is a composite of the individual measurements, shows changes in the sound level over time. The history provides information on the maximum (peak) level and the duration of the event.

Three common ways of representing sound.

One common way to represent airplane sound uses peak A-weighted decibels (typically referred to as peak dBA), which are decibels adjusted for how the human ear hears sound (fig. 1).

Another way to represent sound is time-integrated measurement (fig. 2). With this method, individual measurements of energy taken over time are summed.

A third way to represent airplane sound uses a contour, or footprint. A footprint shows the impact of sound on communities near the airport and provides information about how variables such as airplane configuration, flight procedures, and new airplane technology (e.g., QCS) affect the size and shape of the footprint (fig. 3).

London Heathrow Airport.
London Heathrow Airport, in the United Kingdom, is one of the world’s most heavily regulated airports. It has four departure runways for commercial airplanes and 10 sound monitors. To regulate airplane noise and its impact on local communities, the airport has established peak dBA noise limits for daytime, shoulder period, and nighttime operations. The daytime (7 a.m. to 11 p.m.) limit is 94 dBA; the shoulder period (11 p.m. to 11:30 p.m. and 6 a.m. to 7 a.m.) limit is 89 dBA; the nighttime (11:30 p.m. to 7 a.m.) limit is 87 dBA. For long-haul carriers with heavy fuel and passenger payloads, the lower two limits are difficult to meet.

John Wayne Airport.
John Wayne Airport, in Orange County, California, is another of the most heavily regulated airports. The airport has one departure runway for commercial airplanes and seven monitors. Airplane sound is measured using a single-event noise-exposure level (SENEL), which is a type of time-integrated measurement. The SENEL also uses dBA time history, but rather than reporting only the peak dBA, the energy of all sound levels >65 dBA is added to produce a single value.
EFFECT OF THE BOEING QCS ON SOUND IN COMMUNITIES

The QCS reduces takeoff sound by reducing thrust, which helps airlines comply with noise restrictions that carry increasingly severe economic penalties for violations. At John Wayne Airport, for instance, fines can be as much as $500,000. To avoid such penalties, airlines that use a manual procedure to cut back and restore thrust during takeoff often reduce takeoff weight to ensure that sound levels stay within designated limits. Because the QCS standardizes the noise-abatement maneuver, the system minimizes the need to reduce takeoff weight. This, in turn, provides airlines with the added economic benefit of allowing airplanes to carry more passengers, cargo, or fuel.

The Quiet 737-800.

On current-production 737-800s with CFM International CFM56-7B26 engines, the QCS reduces the acoustic footprint by 14 percent. On these airplanes, the zero percent climb gradient QCS is expected to reduce the acoustic footprint by 21 percent. At John Wayne Airport monitor three (the most critical monitor for the 737-800), a typical departure with the 1.2 percent climb gradient QCS would lower the SENEL by ~3.2 dB. This improvement would permit an ~5,500-lb increase in payload with the same sound level registered at takeoff as on similar airplanes without QCS. The zero percent climb gradient QCS would lower the SENEL by an additional 1 dB at the same payload.

A Quieter 747-400.

Approximately 90 percent of the 747-400s operating out of London Heathrow Airport could be quieter by slightly more than 1 dBA if they were equipped with the 1.7 percent QCS. The reduction would be even more significant for airplanes with lower takeoff weights. Alternatively, with the QCS, 75 percent of the 747-400s departing from Heathrow could increase their takeoff weight by an additional 25,000 lb and be as quiet at the monitors as similar airplanes without QCS.
SUMMARY

In response to increasingly stringent noise regulations and customer need, Boeing has developed the QCS, an advanced avionics systems feature that reduces pilot workload during the labor-intensive period of takeoff while helping airlines meet requirements without incurring penalties. The QCS automatically moves the throttle controls and retards engine thrust to maintain an optimal climb angle and airspeed, thereby reducing sound in the community and minimizing the impact on communities near an airport. An airplane equipped with the QCS may be able to carry more cargo, fuel, or passengers and still be quiet. The QCS currently is available on 737-600/-700/-800/-900 airplanes and is being considered for use on 747-400s. Some other Boeing models have systems similar to QCS.

Jerry Friedrich has been with Boeing for 15 years and is an avionics design engineer and a Designated Engineering Representative in the thrust management/autothrottle group that supports 737, 757, 767, and 777 airframes.

Daniel McGregor has been with Boeing since 1985 and has extensive experience developing prediction applications that support airplane certification, community noise research, and interior noise. He is a lead engineer in Noise and Emissions and develops operational procedures to reduce the impact of airplanes in communities. He also is leader of the Boeing John Wayne Airport Air Carrier support team, which has streamlined airport review and qualification requirements resulting in cost savings for airlines and John Wayne Airport.

Douglas Weigold is a 14-year veteran of the aerospace industry and has worked on airplane programs that include Longer Range 777, 717, MD-11, and High Speed Civil Transport. As part of the Production and Fleet Support Aerodynamics group, he currently works on narrow-body performance issues and is group noise focal for all airplane models.
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Marty Bentrott
Phone 206-766-1061
Fax 206-766-1339
E-mail martin.a.bentrott@boeing.com

**FIELD SERVICE REPRESENTATIVES**

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**Region 2**
Western United States/Canada

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<td>L. Kuhn</td>
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**Region 3**
Central United States

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**Region 4**
Northern Europe/ Tel Aviv

**Region 5**
Central and Southern Europe

**Region 6**
Middle East/ Africa/Asia
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