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A QUARTERLY PUBLICATION  
BOEING.COM/COMMERCIAL/  
AEROMAGAZINE

Material  
Management:  
Providing Customer  
Solutions

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777 Freighter:  
Greater Efficiency  
for Long-Haul  
Operators

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Landing Gear  
Program Provides  
Overhaul Alternative

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Exceeding Tire  
Speed Rating  
During Takeoff

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Contribution of  
Flight Systems to  
Performance-Based  
Navigation

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# AERO



# AERO

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# AERO

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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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# Material Management: Providing Customer Solutions



**DALE WILKINSON**

Vice President, Material Management  
Boeing Commercial Aviation Services

Before joining Boeing last year as vice president of Material Management, I worked in the airline business for more than 27 years. I was directly involved in purchasing materials and repair services for airplanes, engines, and components. During that time, I experienced the very best in customer service and product support. I also experienced the worst. I know firsthand how important it is to get the right part at the right time and at the right price.

Understanding the specific needs of each individual customer — and doing everything reasonably possible to meet

those needs — are what Boeing's Material Management organization is all about. We are absolutely committed to delivering the very best support. Yes, we are in business to sell parts (500,000 different types) and repair services, but more importantly we're in business to ensure that operators of Boeing airplanes get solutions from us that help them run a safe, efficient, and reliable operation.

All of our services are designed to create solutions to help you maximize the value of your fleet by operating more efficiently while reducing costs to your bottom line (<http://boeing.com/commercial/spares/index.html>). Our Material Management Services include Integrated Materials Management, a next-generation supply chain service in which you can transition materials management responsibility to Boeing, who then manages the consolidated supply chain. This offers a better service level for parts and more reliability to maintenance operations. You pay for parts when issued to maintenance or on a flight-by-hour basis. Integrated Materials Management also provides a method to measure and share benefits among airlines, suppliers, and Boeing.

We also offer a Component Services Program in which you can receive a replacement part within one day of placing an order. Boeing, or its partners Air France Industries or KLM, restore your faulty unit

to airworthy condition, upgrade it to reflect the latest design changes, and return it to the exchange inventory pool.

Our Landing Gear Program offers you a “rotatable” program as a repair option. You can exchange unserviceable or time-expired landing gears for overhauled or restored product from a pool of inventory. After being placed in the pool, your landing gear undergoes repair and is then placed back in the pool for other customer exchanges. You can read more about this program on page 11 of this issue.

We face many challenges every day delivering the service and support that you deserve and expect — just as you face challenges doing the same for your customers. But we never stop working an issue until your airplane is back in service. We proudly process more than 4,000 shipments to customers every day. Our team knows that every box leaving one of our eight worldwide distribution centers means a customer's need for parts is being satisfied.

Whenever you have a need for parts or services, please contact us and we will work together on a Boeing genuine parts solution that works. We appreciate your business. Thank you for operating Boeing airplanes.

A handwritten signature in black ink, appearing to read 'Dale', written in a cursive style.



By providing more capacity than any other twin-engine freighter, the 777F brings new levels of efficiency to the long-haul market.

# 777 Freighter: Efficiency for Long-Haul Operators

The Boeing 777 Freighter (777F), which entered service earlier this year, brings efficiency to long-haul operators while offering the advanced features of the 777 family. Designed to fill the need expressed by cargo operators around the world, the 777F is an efficient, long-range, high-capacity freighter.

By **Jason S. Clark**, 777 Freighter Deputy Program Manager; and **Kenneth D. Kirwan**, 777 Freighter Deputy Chief Project Engineer

The range capability of the 777F provides significant savings for cargo operators. It enables them to take advantage of fewer stops and associated landing fees, less congestion at transfer hubs, lower cargo handling costs, and shorter cargo delivery times. The new freighter also integrates smoothly with existing cargo operations and facilitates interlining with 747 freighter fleets.

This article provides an overview of the 777F, including its heritage, freighter capabilities, range and capacity, twin-engine design, and ability to fit into existing cargo operations.

## 777 HERITAGE

Launched in May 2005, the 777F inherits the same basic design and flight characteristics of 777 passenger airplanes but is designed specifically to transport cargo. It also shares many of the 777 family's advanced features, such as a fly-by-wire design, an advanced wing design with raked wing tips, and a state-of-the-art flight deck (see fig. 1). It is powered by the

world's most powerful commercial jet engine, the General Electric GE90-110B1.

## UNIQUE FREIGHTER CAPABILITIES

The 777F has been specifically designed as a freighter, with additional strengthening in key structural areas, including:

- New monolithic aluminum floor beams.
- Rigid cargo barrier located in the forward section of the airplane.
- Strengthened fuselage, especially in the area of the main deck cargo door.

### Figure 1: 777F Flight deck

The 777F flight deck will be familiar to crews that have flown 777 passenger airplanes.



1 Triple-channel autopilot with category IIIIB autoland 2 Large flat-panel liquid crystal displays, including three multi-function displays 3 Full-time triple-channel fly-by-wire with thrust asymmetry compensation and flight envelope protection 4 Cursor control interface 5 Airline-modifiable electronic checklist containing all normal and non-normal checklists 6 Integrated communications interface with full future air navigation system functionality 7 Electronic Flight Bag (optional)

Other design enhancements include:

- Enhanced, lightweight cargo-handling system with built-in test equipment that continually monitors the operational health of the system.
- Modified environmental control system.
- An advanced maneuver load alleviation system that redistributes the aerodynamic load on the wing during non-normal flight conditions, reducing the load on its outboard portion (see fig. 2). This allows the 777F to operate in a wide variety of flight environments without compromising payload capability.

The 777F also features a new super-numerary area, which includes business-class seats forward of the rigid cargo barrier, full main deck access, bunks, and a galley (see fig. 3).

The airplane's design reflects information and feedback that Boeing gained at freighter working group meetings held with 20 airlines and cargo operators. Boeing's plan was to ensure that the 777F would operate with procedures and handling similar to other 777 variants. The result is a common type rating with 777 passenger airplanes and only minimal transition required and lower training costs.

### RANGE AND CAPACITY

With a maximum takeoff weight of 766,000 pounds (347,450 kilograms), the 777F has a revenue payload capability of more than 226,000 pounds (102.8 metric tons). It can fly 4,880 nautical miles (9,038 kilometers) with a full payload at general cargo market densities (more than 10 pounds per cubic foot), making it the world's longest-range twin-engine freighter (see fig. 4).

## Figure 2: Changes in the 777F compared to the 777-200LR

The 777F is based on the 777-200LR (Longer Range) but designed specifically to transport cargo.

Supernumerary area <ul style="list-style-type: none"><li>Four business-sized seats</li><li>Two bunks</li><li>Galley and vacuum lavatory</li></ul>	Lower lobe <ul style="list-style-type: none"><li>New 2-in PDUs common with main deck</li><li>Built-in test equipment cargo control system</li></ul>
Strengthened horizontal stabilizer	Installed 145-in (371-cm)-wide x 124-in (315-cm)-high main deck cargo door
Passenger-related items including doors and windows removed (except doors 1L and 1R)	Strengthened wingbox, leading and trailing edges, aileron, and cargo floor support
Strengthened body, rigid cargo barrier installed, and body fuel tank provisions removed	Added maneuver load alleviation system
Main deck <ul style="list-style-type: none"><li>Aluminum cargo floor beams</li><li>Powered cargo handling system (2-in power drive units [PDUs])</li></ul>	Modified environmental control system
	Relocated water and waste tanks from bulk cargo compartment to forward lower lobe
	Maximum takeoff weight: 766,000 lb (347,450 kg)* Maximum landing weight: 575,000 lb (260,810 kg)*
	Maximum zero-fuel weight: 547,000 lb (248,110 kg)*

\*Highest optional weight; loading restrictions apply above 750,000-lb (340,190-kg) maximum takeoff weight

The airplane has been engineered to have essentially the same landing characteristics as the 777-200LR (Longer Range), despite a maximum landing weight that is nearly 17 percent heavier (575,000 pounds; 260,810 kilograms).

The 777F accommodates 27 standard pallets (96 by 125 inches; 2.5 by 3.1 meters) on the main deck. The industry-standard 10-foot-high (3-meter-high) pallets are accommodated by the large main deck cargo door. The lower cargo hold has the capacity for 10 pallets, as well as 600 cubic

feet (17.0 cubic meters) of additional bulk cargo (see fig. 5).

### THE UNIQUE ECONOMICS OF THE 777F

The 777 family has an established history of twin-engine efficiency, with lower fuel consumption, maintenance costs, and operating costs.

The 777F extends these advantages to cargo operators, giving them the lowest trip cost of any large freighter, as well as

excellent ton-mile economics. The freighter is expected to offer a 17 to 28 percent fuel-per-ton advantage to other freighters. The 777F has range, payload, and operating economics superior to any existing airplane freighter.

Its fuel economy also provides environmental benefits because lower fuel consumption means lower carbon emissions. The 777F also meets London-Heathrow noise standards (QC2) for maximum accessibility to noise-sensitive airports.

### Figure 3: Supernumerary area

The supernumerary area includes business-class seats forward of door 1.



The high commonality of 777F airplane systems — such as flight controls, hydraulics, and landing gear — with 777 passenger airplane systems takes advantage of existing maintenance infrastructure (i.e., parts, ground support equipment, task cards, training) at the airline operator.

#### COMPLEMENTS EXISTING BOEING FREIGHTERS


The 777F has been designed to integrate smoothly with existing cargo operations and facilitate interlining with 747 freighter

fleets. Cargo operators can easily transfer 10-foot-high pallets between the two models via the large main deck cargo door.

#### SUMMARY

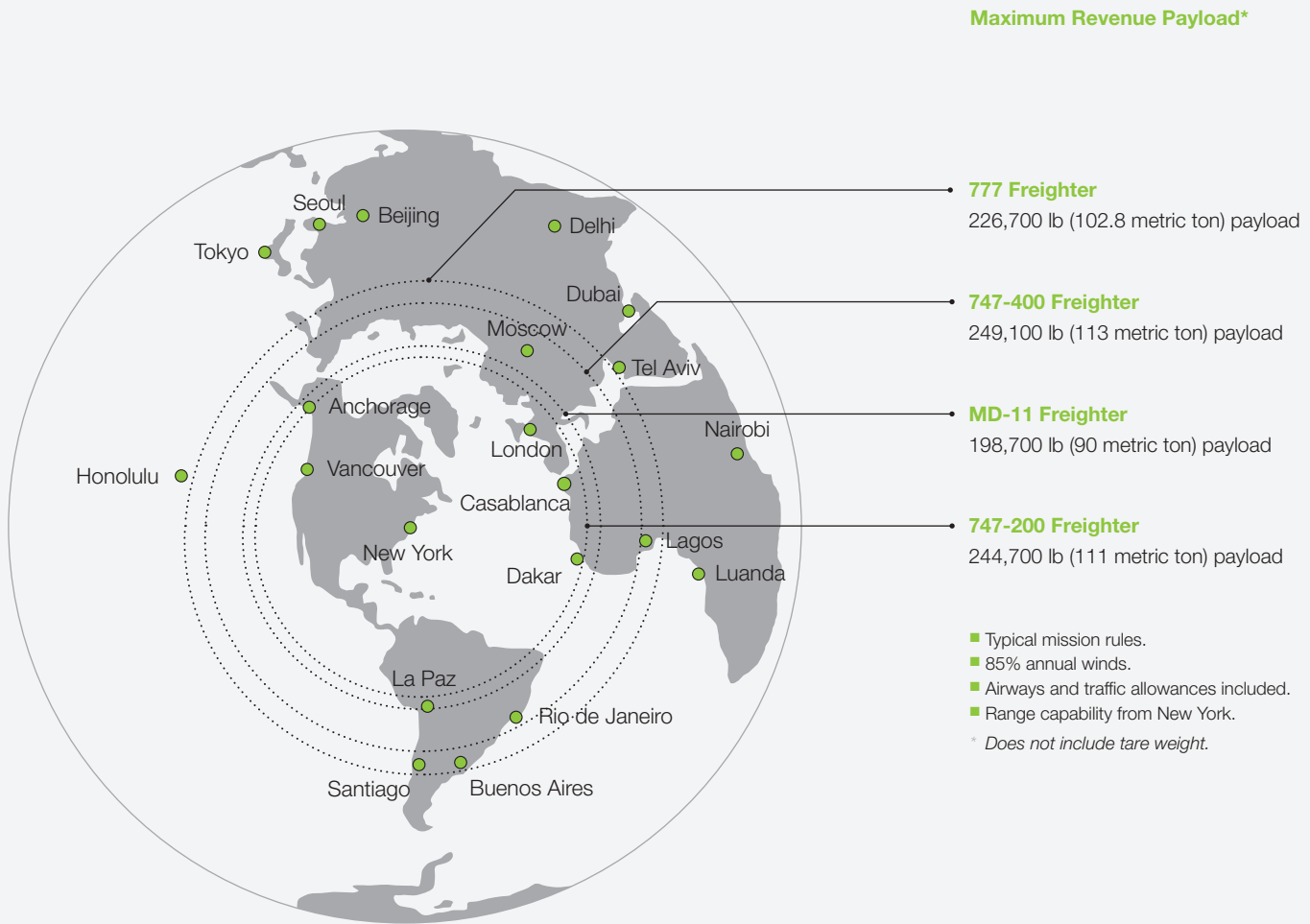
The 777F is Boeing's response to strong demand from cargo operators around the world for an efficient, long-range, and high-capacity freighter. By providing more capacity than any other twin-engine freighter, the 777F brings new levels of efficiency to long-haul markets. At the same

time, its similarity to previous 777 models and ability to facilitate direct-transfer shipments with 747 freighter fleets make it easy to integrate into an operator's fleet.

For more information, please contact Jason Clark at [jason.s.clark@boeing.com](mailto:jason.s.clark@boeing.com) or Ken Kirwan at [kenneth.d.kirwan@boeing.com](mailto:kenneth.d.kirwan@boeing.com). 

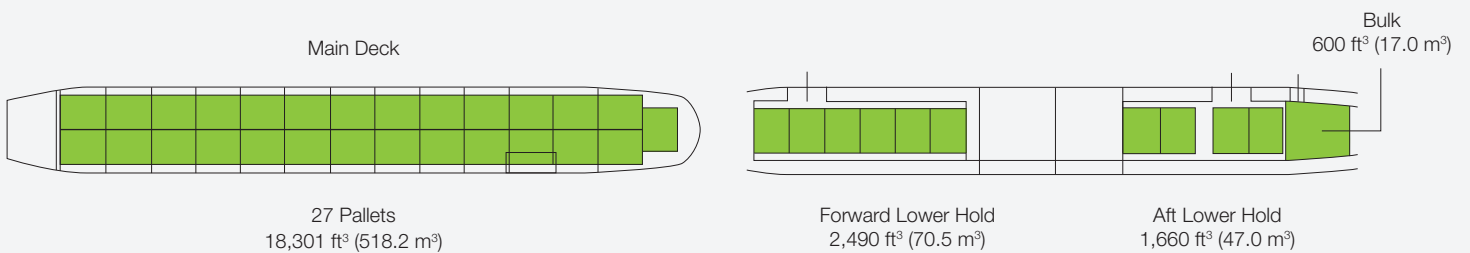
### Figure 4: Longest-range twin-engine freighter

The 777F can fly 4,880 nautical miles (9,038 kilometers) with a full payload at general cargo market densities, opening up new nonstop markets to cargo operators.



### Figure 5: 777F Flexible cargo configurations

The ability to accommodate 27 standard pallets on the main deck, combined with a versatile lower hold, gives the 777F a capacity never before available on a twin-engine freighter.





The Boeing Landing Gear Overhaul and Exchange Program provides operators with a cost-effective, efficient alternative to purchasing new landing gear.

# Landing Gear Program Provides Overhaul Alternative

Boeing has responded to recent supply chain challenges for landing gear overhauls, new gear-sets, exchange gears, and spare parts. A landing gear overhaul and exchange program offers operators an alternative to performing the overhaul work themselves.

By Michael Lowell, Senior Manager, Service Development, Material Management

Commercial airlines are required to remove and overhaul airplane landing gear about every 10 years or 18,000 cycles, depending on the airplane model usage and applicable regulations. In response to operators' need for additional options when servicing landing gear, Boeing launched a landing gear overhaul and exchange program in 2008 designed to meet the needs of operators that don't want to purchase new landing gear or perform their own landing gear overhaul.

This article describes the program and how operators can make use of it.

## PROGRAM OVERVIEW

In 1997, the Boeing Commercial Airplanes Long Beach Division launched a program that enabled operators of the MD-11 to exchange unserviceable landing gear for an overhauled gear set (i.e., nose and main), saving the operator money compared to the cost of a new gear and reducing the amount of time the airplane was out of service. In 2008, Boeing, after working with the industry and customers to enhance the landing gear program, extended it to additional airplane models. It now includes the 717, Next-Generation 737, 737 Boeing

Business Jet, 757-300, 767-300ER (Extended Range), 767-300 Freighter, 777, and MD-11.

Under the Boeing Landing Gear Overhaul and Exchange Program, Boeing works with global component repair and overhaul suppliers to minimize costs and reduce airplane downtime for customers located throughout the world.

Boeing provides total support for the landing gear of airplanes in the program, including parts, scheduling, exchange, warranty, technical assistance, and record-keeping. The operator pays an overhaul and exchange fee plus any "over and

# The program provides complete overhaul and certification of landing gear, including all labor costs; replacement of standards and bushings; and testing and recertification of all hydraulics and electronics according to Component Maintenance Manuals.

above” charges for the service. No initial long-term capital investments are required.

Boeing works closely with airlines’ technical and maintenance departments to address landing gear needs and scheduling requirements. Airlines should plan their overhaul and exchanges well ahead of the mandatory 10-year deadline to ensure the availability of the appropriate landing gear.

## HOW THE PROGRAM WORKS

The Boeing Landing Gear Overhaul and Exchange Program provides operators with complete overhaul and exchange services designed to increase efficiency and minimize the economic implications of landing gear maintenance.

When an airplane covered by the program requires landing gear replacement or overhaul, Boeing provides an overhauled, certified, ready-to-install gear for the airplane’s unserviceable landing gear. Once the serviceable gear is installed by the operator, the operator then ships the removed unserviceable gear to one of the Boeing-designated overhaul facilities (see fig. 1). This process eliminates the need for operators to contract and schedule landing gear overhauls themselves and manage the landing gear overhaul supply chain, which can save them labor and other costs.

All parts in the overhauled gear set provided to the operator meet all worldwide regulatory requirements and are covered by a Boeing three-year warranty.

## BENEFITS TO OPERATORS


The Boeing program is designed to provide operators with an option that minimizes both cost and airplane downtime. Program benefits include:

- *Complete landing gear assets.* Operators receive a fully overhauled and certified landing gear shipset, including left and right mains and nose shock strut, sidebrace, walking beam, drag brace, mechanical and electrical installations, and installation components.
- *Comprehensive offering.* The program provides complete overhaul and certification of landing gear, including all labor costs; replacement of standards and bushings; and testing and recertification of all hydraulics and electronics according to Component Maintenance Manuals. All in-warranty service bulletins are also included in the basic scope of work.
- *Warranty.* Operators receive a three-year warranty for all parts and labor. The program is fully backed by Boeing to ensure the highest quality and timely delivery.
- *Financial advantages.* Customers can reduce or eliminate capital expenditures for extra or leased gear to support their overhaul requirements. The program minimizes upfront costs and spreads out expenditures over time.

- *Experience.* The program is based on more than 10 years of experience in the MD-11 Landing Gear Exchange Program.

## SUMMARY

The Boeing Landing Gear Overhaul and Exchange Program provides operators with a cost-effective, efficient alternative to purchasing new landing gear or performing their own in-house landing gear overhaul. Because of the large global demand for landing gear, it is vital for airlines to plan their overhaul and exchange management well ahead of time.

For more information, please contact Michael Lowell at [michael.p.lowell@boeing.com](mailto:michael.p.lowell@boeing.com). 





Airplane takeoff speeds are designed to ensure the liftoff speed does not exceed the tire speed rating.

# Exceeding Tire Speed Rating During Takeoff

Airplane tires are designed to withstand a wide range of operating conditions, including carrying very high loads and operating at very high speeds. It is common for a jet airplane tire to carry loads as heavy as 60,000 pounds while operating at ground speeds up to 235 miles per hour. To accommodate these operational conditions, each tire has specific load and speed ratings. Tires are carefully designed and tested to withstand operation up to, but not necessarily beyond, these ratings.

By **Ingrid Wakefield**, Flight Operations Engineer; and **Chris Dubuque**, Service Engineer, Landing Gear Systems

It is uncommon to exceed the load rating of tires during normal airline operation because the weight and center-of-gravity position of the airplane are well controlled and well understood. However, on occasion the speed rating of tires can be inadvertently exceeded during takeoff.

This article discusses factors that can lead to a tire speed exceedance during takeoff, provides guidance to help prevent such tire overspeed events, and points out that there are no standardized industry maintenance guidelines if an overspeed event occurs.

## INTRODUCTION

Boeing is receiving an increasing number of operator inquiries about tire speed limits being exceeded during takeoff. This does not appear to be a new issue. Rather, advanced data acquisition tools on modern airplanes have made operators more aware of tire speed exceedance events.

In most cases, the speed exceedance is small, only a few knots. Boeing is not aware of any of these overspeed events resulting in thrown treads, which suggests that airplane tires in good condition can withstand these small speed exceedances without damage. However, it is important to remember that at high speeds, heat is generated within the tire structure. This

heat, combined with extreme centrifugal forces from high rotational speeds, creates the potential for tread loss. Ensuring that tires are operated within their speed ratings will help prevent possible tread losses and the potential for airplane damage.

## CONDITIONS THAT CAN LEAD TO EXCEEDING THE TIRE SPEED RATING DURING TAKEOFF

When dispatching an airplane in compliance with the certified Airplane Flight Manual, the airplane takeoff speeds are designed to ensure that the liftoff speed does not exceed the tire speed rating. While rotation and liftoff speeds are generally expressed in knots indicated airspeed, the tire speed

limit is the ground speed, which is usually expressed in statute miles per hour. This means that a tire rated at 235 miles per hour is designed for a maximum ground speed at liftoff of 204 knots.

A number of factors can lead to a tire-speed-limit exceedance during takeoff. Typically, this occurs when an airplane is dispatched at or near the tire-speed-limit weight and:

- The airplane rotation rate is slower than the Boeing-recommended rotation rate, and/or
- There is a late rotation, and/or
- The tailwind is higher than anticipated.

Dispatch at or near the airplane's tire speed limit is most likely to occur during takeoffs from airports at high altitudes on warm days, because these conditions tend to drive the ground speed at liftoff of the airplane closer to the tire speed limit. However, tire speed limits can be encountered during takeoff in less severe environmental conditions, such as when scheduling an improved climb takeoff.

Crosswinds can aggravate the situation by unexpectedly shifting into a tailwind, which may further increase the ground speed at liftoff. An unexpected (and therefore unaccounted for) tailwind component will directly add to the ground speed at liftoff.

### RECOMMENDED TAKEOFF PROCEDURES FOR ALL BOEING AIRPLANE MODELS

Boeing publishes a recommended all-engine normal takeoff procedure in the Flight Crew Training Manual (FCTM) for 727, 737 Classic, and Next-Generation 737, 747, 757, 767 and 777 models and in the Flight Crew Operations Manual for 717, MD, and DC models. In order to avoid tire-speed-limit exceedance during takeoff, Boeing stresses adhering to the recommended average all-engine takeoff rotation rate of 2 to 3 degrees per second, which provides adequate tail clearance margins with a target liftoff attitude reached after approximately 3 to 4 seconds (see fig. 1).

Tail clearance margins for all 7-series models except the 717 are also outlined in the FCTM. Tail clearance and tail strike concerns are often the reason flight crews give for opting to use a slower rotation rate than recommended by Boeing. (More information about tail strike prevention can be found in *AERO* first-quarter 2007.)

When dispatching at or near the tire-speed-limit weight, which is most likely to occur at hot temperatures and high elevations, a slower rotation than the Boeing-recommended 2- to 3-degrees-per-second average may increase the actual groundspeed at liftoff beyond the certified tire speed limit. In addition, a slow rotation or under-rotation could significantly increase the runway distance required to reach the 35-foot point, which is another important reason for adhering to the Boeing-recommended rotation procedure.

### WIND ACCOUNTABILITY

The certified tire-speed-limit weight does not contain any margin for wind accountability. For instance, the FAA-certified takeoff field-length-limit weight typically contains a conservative factor for wind accountability of 1.5 times the tailwind and 0.5 times the headwind. In comparison, the tire-speed-limit weight lacks any such conservative wind factor. Because of this, an unexpected tailwind component not accounted for in the takeoff analysis, occurring during a takeoff at or near the tire-speed-limit weight, may increase the true ground speed at liftoff beyond the tire speed rating.

To avoid a tire-speed-limit exceedance, Boeing recommends to conservatively account for the tailwind component when dispatching at or near the tire-speed-limit weight in a crosswind situation. General guidelines for crosswind takeoffs are outlined in the FCTM. These guidelines include the recommendation to use a higher thrust setting than the minimum required in order to minimize airplane exposure to gusty conditions during rotation, liftoff, and initial climb.

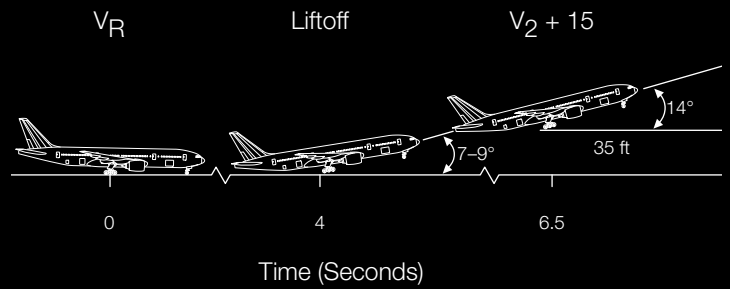
### 747-400 CASE STUDY

A case study of the 747-400 helps illustrate this point. The operator sporadically exceeded the tire speed limit even though the takeoff analyses showed a notable buffer between the tire-speed-limit weight

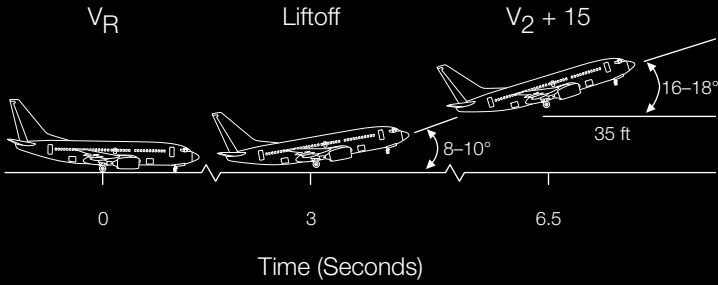
**Figure 1: Typical rotation, all engines**

The recommended rotation rate of 2 to 3 degrees per second provides adequate tail clearance margins with a target liftoff attitude reached after approximately 3 to 4 seconds.

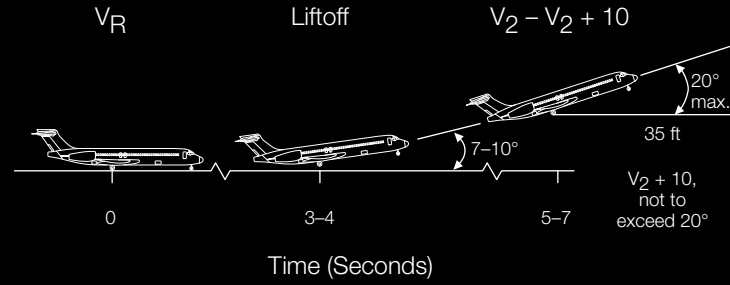
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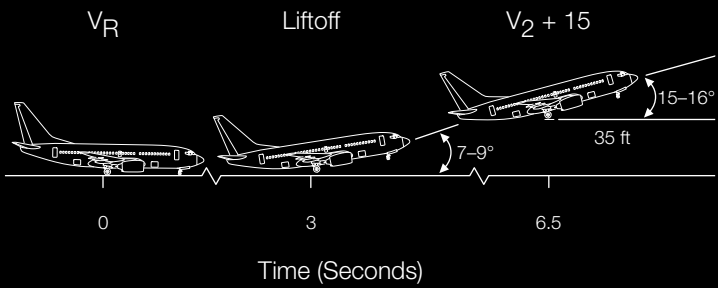
**737-300/-400/-500**



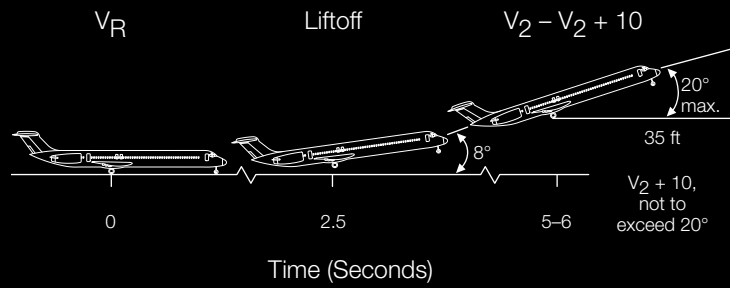
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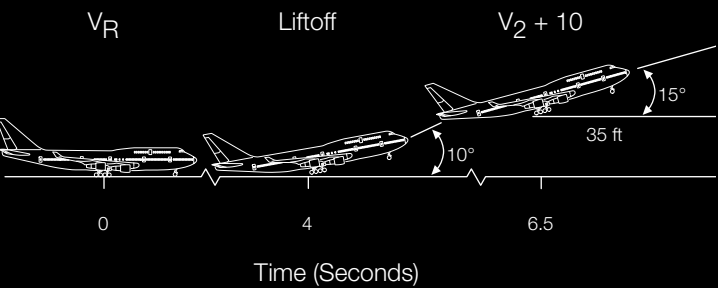
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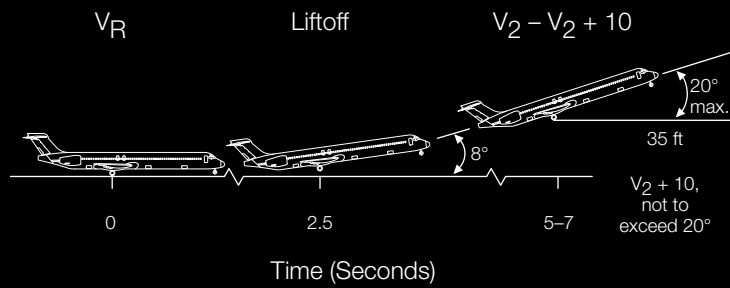
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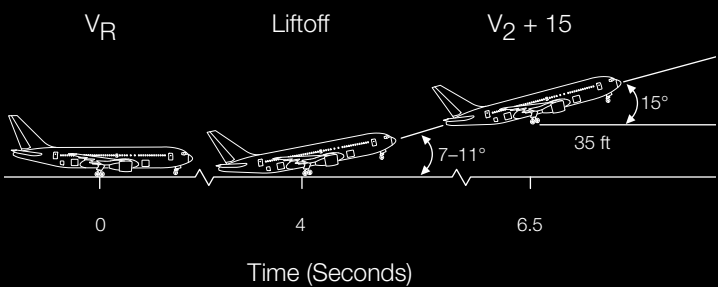
**747-400**



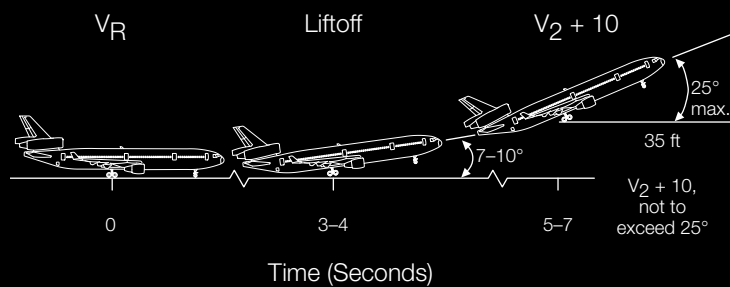
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**757-200 – 767-400**



**MD-11**



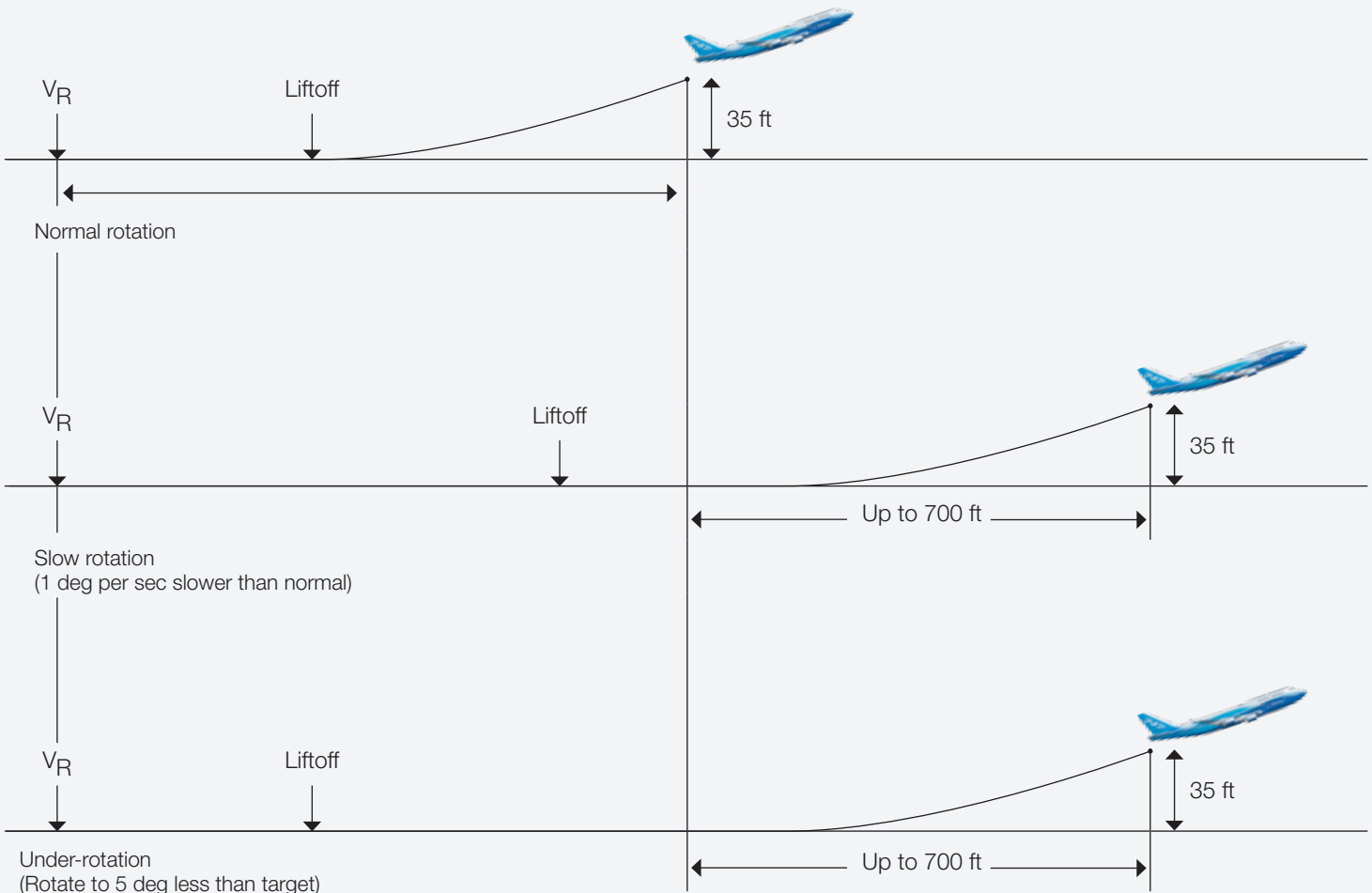
**Figure 2: 747 Case study summary**

Relatively large weight margins did not result in corresponding speed margins.

Takeoff I	Takeoff II
Dispatch Weight: 805,000 pounds	Dispatch Weight: 825,000 pounds
Tire-Speed-Limit Weight: 845,000 pounds	Tire-Speed-Limit Weight: 855,000 pounds
Weight Margin: 40,000 pounds	Weight Margin: 30,000 pounds
Scheduled Ground Speed at Liftoff: 196 knots	Scheduled Ground Speed at Liftoff: 199 knots
Rated Tire Speed: 204 knots (235 miles per hour)	Rated Tire Speed: 204 knots (235 miles per hour)
Speed Margin: 8 knots	Speed Margin: 5 knots

**Figure 3: Effect of slow or under-rotation on all-engine takeoff distance**

A 747-400 taking off with a rotation rate that is 1 degree per second slower than normal can result in a 4- to 5-knot liftoff speed increase.



and the actual dispatch weight. The airline approached Boeing for assistance.

The study was performed at two different dispatch weights: 805,000 pounds and 825,000 pounds. There was a 40,000-pound and a 30,000-pound margin between scheduled dispatch weight and the tire-speed-limit weight. These weight margins, which appear relatively large, only resulted in speed margins of 8 knots and 5 knots between the associated ground speeds at liftoff and the tire speed rating (see fig. 2).

This case study shows the relationship of a tire-speed-weight margin to the associated speed margin for a four-engine airplane. Under similar dispatch conditions on a two-engine airplane, a similarly large weight margin can be expected to result in an even lower speed margin, due to the higher all-engine acceleration.

The same case study showed that a rotation rate that is 1 degree per second slower than normal can result in a 4- to 5-knot liftoff speed increase. This is in addition to the increase in all-engine takeoff distance associated with the slow takeoff rotation (see fig. 3).

This illustrates how a slower-than-normal rotation rate can easily use up what may seem like a large tire-speed-limit margin, especially if paired with a higher tailwind component than accounted for in the takeoff analysis used for dispatch.

#### MAINTENANCE ACTIONS AFTER EXCEEDING THE TIRE SPEED LIMIT DURING TAKEOFF

Although tire-speed-limit exceedance events during takeoff are not a new phenomenon, widespread recognition of these overspeed events is relatively new because of advances in flight data recorder technology that enables easier data acquisition. Airplane manufacturers, tire suppliers, and regulators have not yet developed an industry-accepted set of maintenance

instructions following a tire-speed-limit exceedance event during takeoff.

One maintenance suggestion would be that all wheel/tire assemblies be removed from the airplane before further flight after such an event occurs. In practice, however, replacing all of the wheel/tire assemblies on an airplane represents a major logistical problem and likely results in flight cancellations and/or dispatch delays. It would be difficult to locate and ship 18 wheel/tire assemblies to a 747 at a remote location following one of these events! Additionally, if the overspeed was very small (say, 2 to 3 knots over the tires' speed limit), it is unlikely that the tires would have suffered any damage.

Some operators have elected to simply examine the tires after an overspeed takeoff event using the normal tire inspection criteria in Chapter 32 of the Airplane Maintenance Manual. If no damage is found, the airplanes are dispatched normally and no further maintenance actions are performed. Based on many years of service experience, this approach seems to have worked well because very few, if any, tire tread losses have been attributed to an overspeed event. Based on this service experience, Boeing has typically not objected to this practice even though there is no overspeed takeoff capability specifically designed into the tire.

If an operator has any questions about the integrity of the tires, the wheel/tire assemblies should be replaced before further flight.

Additional information on tire maintenance procedures can be found in the airplane maintenance manuals and in the following documents:

- FAA Advisory Circular 20-97B, "Aircraft Tire Maintenance and Operational Practices," April 18, 2005, U.S. Department of Transportation.
- "Aircraft Tire Care And Maintenance," Goodyear Aviation, 10/04, [www.goodyearaviation.com/img/pdf/aircraftmanual.pdf](http://www.goodyearaviation.com/img/pdf/aircraftmanual.pdf).

- Bridgestone Aircraft Tires, Tire Care, and Maintenance, [http://ap.bridgestone.co.jp/pdf/Care\\_and\\_Maintenance.pdf](http://ap.bridgestone.co.jp/pdf/Care_and_Maintenance.pdf).
- Bridgestone Aircraft Tires, Examination, and Recommended Action, <http://ap.bridgestone.co.jp/candm/recommendedaction.html>.
- Aircraft Tire Care & Service Manual, Michelin, [www.airmichelin.com/pdfs/Care\\_and\\_Service\\_manual.pdf](http://www.airmichelin.com/pdfs/Care_and_Service_manual.pdf).
- General practices manual for aircraft tyres and tubes, Dunlop Aircraft Tyres Limited, 01/08, [www.dunlopaircrafttyres.com/tech\\_support/dm1172/DM1172.pdf](http://www.dunlopaircrafttyres.com/tech_support/dm1172/DM1172.pdf).


#### SUMMARY

Although it is uncommon to exceed the load rating of tires during normal airline operation, Boeing is receiving an increasing number of operator inquiries about tire speed limits being exceeded during takeoff.

There is no industry consensus on the maintenance actions that should be taken following tire-speed-limit exceedance during takeoff. At this time, operators, in conjunction with their regulatory agency, must determine the most appropriate maintenance action based on the tire-speed-limit exceedance event.

The best approach is to try to avoid overspeed takeoffs altogether. By taking the following steps, flight operations personnel can reduce the possibility of tire-speed-limit exceedance during takeoff:

- Follow the Boeing-recommended rotation procedure.
- When dispatching at or near the tire-speed-limit weight in a crosswind situation, consider conservatively, accounting for the tailwind component.
- When dispatching at or near the tire speed limit in gusty wind and strong crosswind conditions, use a higher thrust setting than the minimum required.

For more information, contact Boeing Flight Operations Engineering at [flightops\\_engineering@boeing.com](mailto:flightops_engineering@boeing.com). 



Flight management systems have evolved to a level of sophistication that helps flight crews fly commercial airplanes more safely and efficiently.

# Contribution of Flight Systems to Performance-Based Navigation

Flight Management Systems (FMS) and associated airplane flight systems are the primary navigation tools on board today's commercial airplanes. The evolution of these systems has led the way for performance-based navigation (PBN) and the U.S. Federal Aviation Administration's (FAA) Next Generation Air Transportation System.

By **Sam Miller**, Associate Technical Fellow, Flight Deck, Flight Crew Operations

PBN is a concept used to describe navigation performance along a route, procedure, or airspace within the bounds of which the airplane must operate. For transport airplanes, it typically is specified in terms of required navigation performance (RNP). The PBN concept defines navigation performance in terms of accuracy, integrity, availability, continuity, and functionality. These operations provide a basis for designing and implementing automated flight paths that will facilitate airspace design, terminal area procedure design, traffic flow capacity, and improved access to runways (more information about PBN can be found in *AERO* second-quarter 2008). The PBN

concept is made possible largely by advances in the capabilities of airplane FMS.

This article helps operators better understand how the FMS and other airplane flight systems have evolved over time, how they contribute to PBN operations, and plans for further advancement.

## AIR NAVIGATION TOOLS LEADING UP TO THE FMS

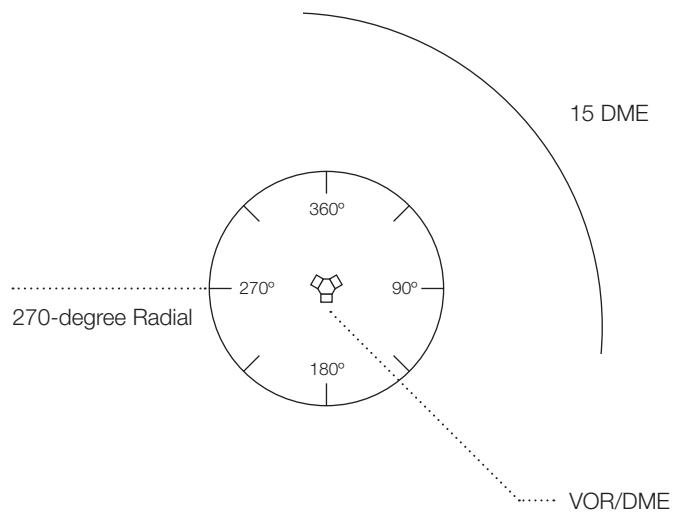
Early aviators relied on very basic instrumentation to keep the airplane upright and navigating toward the desired destination. Early "turn and slip" indicators and ground references such as lighted beacons enabled

aviators to fly coast to coast across the United States. However, these early flights were filled with uncertainties and their use of visual flight rules soon gave way to reliable attitude indicators and ground-based navigation aids, or nav aids. Non-directional radio beacons and the airplane's airborne automatic direction finder equipment allowed aviators to "home in" on the beacon and navigate reliably from station to station. Non-directional radio beacons are still being used today throughout the world.

In the 1940s, the introduction of a radio-magnetic indicator or dual-bearing distance-heading indicator facilitated the use of ground-based nav aids, including

### Figure 1: Typical VOR installation

By 1952, more than 45,000 miles of airways using the VOR were in operation. A DME transmitter was usually located on the ground with VOR stations. DME transmitters would respond to interrogation by transceiver equipment installed on airplanes and provide the pilot with a reliable distance in nautical miles to the transmitter. Pilots operating in areas where VOR and DME coverage was available had both distance and course information readily available.



the very-high-frequency omni-directional range (VOR) navigation system and distance measuring equipment (DME). VORs came into wide use in the 1950s and quickly became the preferred navigation radio aid for flying airways and instrument approaches (see fig. 1). VOR and DME provided the framework for a permanent network of low-altitude victor airways (e.g., V-4) and high-altitude jet routes (e.g., J-2), which are still in place today.

Long-range navigation over remote and oceanic areas, where navigation radio transmitters did not exist, was originally accomplished by dead reckoning and celestial navigation. The introduction of the inertial navigation system (INS) on airplanes facilitated long-range capability by providing a continuous calculation and display of the airplane's position. Flight crews could enter waypoints and the INS would calculate heading, distance, and estimated time of arrival to the respective waypoint.

At the same time, the 1970s fuel crisis provided the drive to optimize navigation capabilities in commercial airplanes. As a result, avionics manufacturers began producing performance management computers and navigation computers to help operators improve the efficiency of their airline operations. Boeing's initial entry into this arena was represented by the implementation of the early Sperry (now Honeywell) automatic navigation systems

on the 727, 707, and 747-100. During this same time, Collins produced the AINS-70, an area navigation (RNAV) computer on the DC-10. Each of these steps reduced the amount of interpretation by the flight crew by presenting more specific indications of airplane positional and situational status. Even so, the reliance on the flight crew to manually interpret and integrate flight information still provided opportunities for operational errors.

### THE FIRST INTEGRATED FLIGHT MANAGEMENT COMPUTER

When Boeing began work on the 767 airplane program in the late 1970s, the company created a flight deck technology group with engineers dedicated to the development of the flight management computer (FMC) and the control display unit (CDU) (see fig. 2). Boeing merged previous designs of the performance management computer and the navigation computer into a single FMC that integrated many functions beyond navigation and performance operations. The company used experience gained from Boeing's other research projects to develop advanced implementations of performance management functions and navigation into a single FMC. The new FMC system was envisioned as the heart of an airplane's flight planning and navigation function.

While Boeing was continuing work on new commercial airplane navigation systems for the new "glass" flight decks, a debate was under way among the airlines about the need for a dedicated flight engineer crewmember. In July 1981, an industry task force determined that two-crew operation was no less safe than three-crew operation. This decision would have a profound effect on the design of all Boeing commercial airplanes, including a short-notice implementation for the new 767. With one fewer crewmember, Boeing engineers focused on a flight deck design that would reduce crew workload, simplify older piloting functions, and enhance flight deck efficiencies.

The early 767 FMC provided airplane performance predictions using stored airframe/engine data and real-time inputs from other onboard systems, such as the air data computer and inertial reference system (IRS). This performance function replaced flight crew back-of-the-envelope-type estimates with relatively precise time and fuel predictions based upon actual airplane performance parameters, such as gross weight, speed, altitude, temperature, and winds.

Then, as now, the navigation function was based on the IRS position and used ground-based nav aids (e.g., DMEs, VORs, localizers) to refine the IRS position and correct for IRS drift. A navigation database (NDB) was included in the FMC's memory



## An RNP system should contain both performance monitoring and alerting: a caution alert is initiated by the FMC and annunciated on the display system to draw flight crew attention in the event that ANP exceeds RNP.

on the 747-400. At the heart of the system was a new, more capable FMC that implemented several new operations:

- Airline operational communications — Digital communication of data (data link) such as flight plans, weather data, and text messaging directly from the airline operations facility to the FMC.
- Controller-pilot data link communications — Digital communication between ATC and the airplane in the form of predefined messages.
- Automatic dependent surveillance — Information about position and intent generated from an ATC request.
- Global positioning system (GPS) — Incorporation of satellite navigation functions in the FMS for the primary means of navigation.
- Air traffic services facilities notification — ATC communication protocol initialization.
- RNP — A statement of the navigation performance necessary for operation within a defined airspace.
- Required time of arrival — Enablement of airplane performance adjustments to meet specified waypoints at set times, when possible.

Although each feature was individually significant, the three primary enablers for FANS operations were RNP, GPS, and data link. RNP defined the confines of the lateral route, and the FMC provided guidance to reliably remain on the route centerline. The FMC's RNP function also provided alerting

to the flight crew when this containment might not be assured. GPS was originally a military navigation sensor that was allowed for commercial use with some limitations. Integrated as the primary FMC position update sensor, GPS provided exceptionally precise position accuracy compared to ground-based sensors and enabled the FMC's capability for precise navigation and path tracking. GPS remains the primary sensor for the current generation FMCs. Data link provided a reliable method of digital communication between the airplane and the air traffic controller. A comprehensive list of preformatted messages was implemented to provide for efficient traffic separation referred to as controller-pilot data link communications.

Concurrent with the FANS 1 FMC, Alaska Airlines teamed with Boeing, Smiths Aerospace (now GE Aviation), and the FAA to develop procedures that would provide reliable access to airports that are surrounded by difficult terrain. By virtue of the surrounding rough terrain, the Juneau, Alaska, airport became the prime candidate for the certification effort. Because the approach to runway (RW) 26 was the most challenging air corridor to Juneau, it was selected as the most rigorous test to prove the real performance capability of RNP (see fig. 3).

In 1995, Alaska Airlines successfully demonstrated its ability to safely fly airplanes to RW 26 using RNP and soon began commercial operations using RNP, which was a first for commercial aviation.

### RNP: ENABLER OF PBN

The concept of a reliable and repeatable defined path with containment limits was not new. Early conceptual work was done at the Massachusetts Institute of Technology in the 1970s, but the modern FMC, with its position accuracy and guidance algorithms, made reliable path maintenance practical.

The first demonstration of the FMC's terminal area precision came at Eagle, Colorado, in the mid-1980s. A team comprising American Airlines, the FAA, and Sperry (now Honeywell) applied RNP-like principles to approach and departure procedures to the terrain-challenged runway. Following simulator trials, the procedures were successfully flown into Eagle and subsequently approved by the FAA. The result: reliable approach and departure procedures that provide improved access to Eagle.

Although Eagle demonstrated the FMC's capability to execute precisely designed terminal area procedures, in the mid-1980s, it would take another 10 years until RNP equipment was available for airline operators. The FMC's navigation position accuracy enhanced with GPS and lateral and vertical guidance algorithms, the development of the vertical error budget, and additions to crew alerting enabled RNP and its future applications.

RNP is a statement of the navigation performance necessary for operation within



**Figure 3: Juneau, Alaska: Site of initial RNP certification efforts**

RNP enabled an approach to runway 26 and access to Juneau that in some weather conditions was not otherwise practical.

a defined airspace. The FMC's navigation function ensures containment within the defined airspace by continuously computing the airplane's position. The FMC's actual navigation performance (ANP) is the computed navigation system accuracy, plus the associated integrity for the current FMC position. It is expressed in terms of nautical miles and represents a radius of a circle centered on the computed FMC position, where the probability of the airplane continuously being inside the circle is 95 percent per flight hour.

Boeing flight decks display both ANP and RNP. With the advent of the navigation performance scales (NPS) and associated display features, RNP and ANP are digitally displayed on the navigation display. Additionally, and as defined in regulatory guidance, an RNP system should contain both performance monitoring and alerting: a caution alert is initiated by the FMC and annunciated on the display system to draw flight crew attention in the event that ANP exceeds RNP. That alert typically signifies that the performance of an FMC position update sensor has deteriorated, and, subsequently, the computed navigation system accuracy can no longer ensure containment (see fig. 4).

The FMC's LNAV function continually provides guidance to maintain the lateral path centerline and any deviation from the path centerline is displayed as lateral cross-track error. In Boeing airplanes, cross-

track error is displayed on the FMC's "PROGRESS" page or under the navigational display's airplane symbol when NPS is on board. The display provides flight crews with a precise assessment of lateral deviation, particularly important in low RNP environments. Display of cross-track error on the "PROGRESS" page was an original feature in the Boeing FMCs and continues as a fundamental indication of path deviation.

Although RNP operations are increasing in numbers and applications and will provide for the future for PBN, RNAV is also being increasingly implemented for operations where consistent ground tracks are desired. RNAV approaches, standard instrument departures (SID) and standard terminal arrival (STAR) procedures are being produced primarily throughout the United States and in selected areas of the world. RNAV leverages the original path management capability of the FMC and, unlike RNP, lateral containment was not specified. From an operational point of view, RNP is RNAV with containment. If a path is defined and active in the route, the FMC is designed to maintain the centerline of the path. That basic operation has not changed since the original 767 FMC.

#### CONTINUED FMC MODERNIZATION

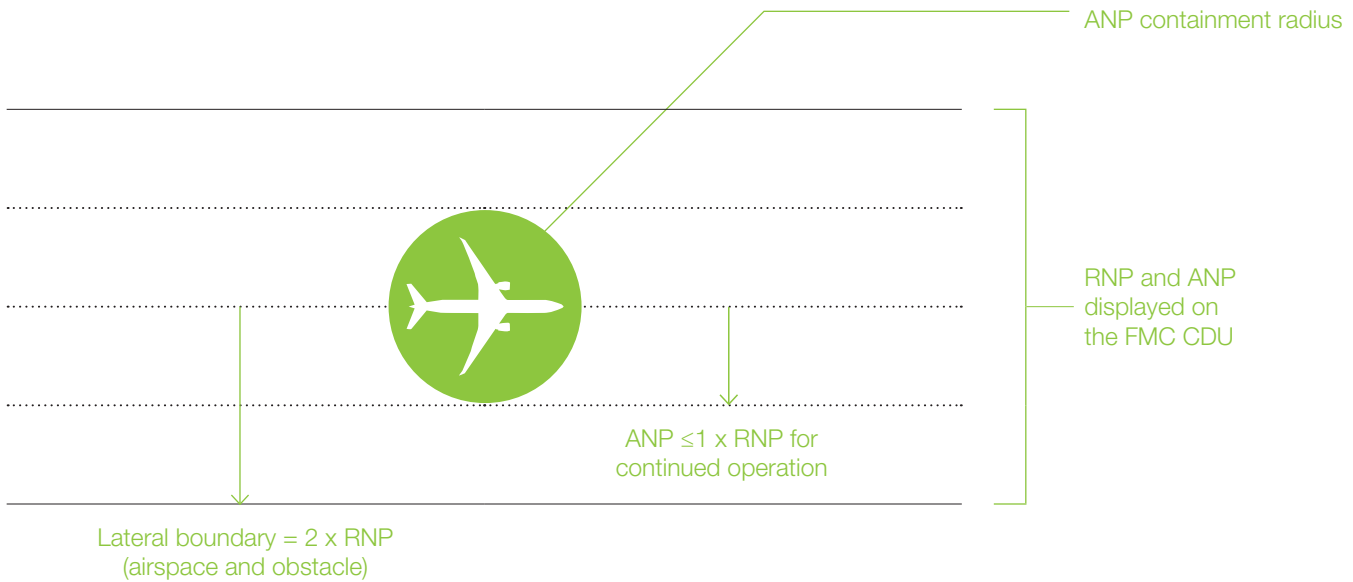
The 737, 747-400, MD-80, and MD-11 FMC functions that enabled RNP were

reasonably robust for the initial RNAV and RNP operations, but each of the Smiths (now GE) and Honeywell FMCs on Boeing airplanes continued to be updated with software improvements and new hardware versions with enhanced processing power and memory. Some enhancements specifically related to RNP include:

- Vertical RNP — Introduced the capability with which to define containment relative to the computed VNAV path (see fig 5).
- Radius to fix legs — Implemented the ARINC 424 leg type that provided a fixed radius ground path (similar to a DME arc but without the required navaid).
- En-route fixed radius transitions — Implemented a fixed radius transition between en-route path segments, to enable the implementation of reduced route spacing in higher-density traffic environments (currently 737 only).
- GPS availability — Refined algorithms that enhanced the navigation performance for very low RNP procedures.
- LNAV tracking — Enhanced the precision and aggressiveness of LNAV path tracking.
- NPS — Provided data to the display system for lateral and vertical path deviation scales, deviation pointers, and sensor performance indications.
- RNP from the NDB — Enabled application of RNP values coded in the NDB for routes and procedures.

#### Figure 4: RNP in practice

RNP defines the path and allowable tolerance for continuous operation (+ 1 RNP). Containment to ensure obstacle clearance is defined as + 2 x RNP. ANP less than the prescribed RNP provides position assurance for continued operation.



As a result of these enhancements and additions to other FMC functions, the modern FMC is well-equipped for RNP operations that will enable future airspace management concepts.

#### THE PROMISE OF PBN

PBN, which comprises both RNAV and RNP specifications, provides the basis for global standardization, which will facilitate future airspace design, traffic flow, and improved access to runways. This change offers a number of operational benefits,

including enhanced safety, increased efficiency, reduced carbon footprint, and reduced costs. To fully realize these benefits, operators may need to make changes to their airplanes and operations.

The primary premise of a PBN system is to move away from restricted, sensor-based operations to a performance-based navigation system that incorporates RNP as the foundation and a system in which operational cost efficiencies are emphasized (see fig. 5). According to the International Civil Aviation Organization Performance-Based Navigation Manual, airspace procedures should be designed

to reduce track miles, avoid noise-sensitive areas, and reduce emissions through the use of efficient descent paths by minimizing terminal area maneuvering (i.e., unwanted throttle movement) and periodic altitude constraints.

#### AIRSPACE MODERNIZATION

The current airspace system of airways and jet routes has not changed significantly since the inception of non-directional beacons and VORs in the middle of the last century. Incremental improvements,



such as RNAV en-route waypoints, RNAV SIDs and STARs, FANS dynamic rerouting, and Q-routes, have been implemented, but the general structure of the airspace still reflects historic ATC methods.

In a direct contrast to the PBN approach, the increased traffic since the early 1990s has necessitated more complex arrival and departure procedures — procedures that frequently inflict a penalty on fuel efficiency with an added consequence of increased potential for flight crew error.

The PBN concept is centered on operational efficiencies. Several successes have already been realized. Procedure and airspace designers in Canada and Australia have worked with operators to plan routes and terminal area procedures that reduce track miles while addressing environmental issues that are receiving increased scrutiny by the public and government. Both Europe and the United States are implementing RNAV and RNP procedures.

#### FUTURE CONCEPTS

Advanced airspace environments include the FAA's Next Generation Air Transportation System, which will transform the current ground-based ATC system to satellite-based, and Europe's Single European Sky ATM Research (SESAR). Migrating to these environments will require fundamental changes to air traffic management methodology. The airspace

structure, procedure design, and traffic control methodology will need to focus on safety *and* efficiency if capacities are to increase at major airports and operators are able to maintain fuel costs within reason.

Concurrent with the airspace evolution, the FMC will continue to require enhancements that either control or participate with other onboard systems for new traffic control methods. These methods include time-based metering, merging and spacing, self-separation during continuous descent arrivals and/or during the final segment, automated dependent surveillance broadcast, and cockpit display of traffic information. New terminal procedures, such as a hybrid RNP procedure that terminates in an instrument landing system or a global navigation satellite system landing system final and autoland, are already in the FMC's repertoire. However, considerations to the associated flight mode annunciator changes during the transition from FMC-based guidance to autopilot guidance on short final and other crew distractions will require attention. The new 787 and 747-8 FMCs are addressing some of these issues and implementing enhancements that position those models for future PBN operations. Additionally, each of the FMC designs has incorporated growth options so that changes to the FMC can be made with minimal impact to the FMC software.


Flight crews will see significant improvements in speed, capability, and operation of the 737 FMC and the new FMCs in the

787 and 747-8 airplanes. Although modern in every respect, each of the FMCs is operationally similar to the original 767 FMC of the early 1980s. To address system complexity and enhance the operational capability of the flight crew for the transition to the Next Generation Air Transportation System, Boeing and its partners are investigating new flight management methodologies that focus on flight path trajectory management and ease of operation. Such new systems will assist the flight crew in managing the trip costs and contribute to a safe conclusion to each flight.

#### SUMMARY

Flight management systems have evolved to a level of sophistication that helps flight crews fly commercial airplanes more safely and efficiently, while enabling PBN through application of RNP and the evolution to future airspace management systems.

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