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RICH HIGGINS  The Boeing Enterprise One maintenance management software system has a modular design that optimizes major airline support functions, improves fleet utilization, decreases maintenance costs, and better manages inventory.

NEW ETOPS REGULATIONS  Regulatory changes are coming to airplane operations because of a data-driven paradigm shift that has occurred since ETOPS flying began 18 years ago.


MAINTENANCE OF HIGH-STRENGTH ALLOY STEEL COMPONENTS  Airline personnel need to follow proper maintenance procedures and rework practices, checklists, and guidelines during the maintenance and overhaul of landing gear and flap components made of high-strength alloy steel.

Boeing 777-300ER
Enterprise One is an ERP tool specifically tailored to the air transport industry. It’s a set of integrated software modules that can help you optimize major support functions such as maintenance planning and scheduling, engineering operations, logistics management, document management, and configuration control. Enterprise One allows you to improve fleet utilization, decrease maintenance costs, and manage inventory better.

The beauty of Enterprise One is that the modules are designed to integrate seamlessly, forming a comprehensive, digitally based management system. At the same time, the modular design makes it easy for you to select just the portions you need to meet your specific requirements.

For example, Royal Brunei has opted to install four portions of Enterprise One:

- Maintenance modules to streamline regulatory compliance reporting and tailor maintenance programs for each airplane in the Royal Brunei fleet.
- Engineering modules to track airworthiness directives and service bulletins more efficiently.
- Logistics modules to support heavy volumes of spare parts procurement and inventory transactions.
- The Portable Maintenance Aid™, a document management product to help mechanics troubleshoot airplane maintenance.

The modularity of Enterprise One gives you the ability to use the software system in the best way for your particular operation. You also have the flexibility to expand your information technology capabilities in the future.

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

We are committed to your success.

This month marks Boeing’s official entrée into the enterprise resource planning (ERP) market as we begin the installation of our Enterprise One maintenance management software system at launch customer Royal Brunei Airlines. The installation also exemplifies our continued commitment to your success.
Extended-range operations with two-engine airplanes (ETOPS) rank among the safest and most reliable of all flight operations. Pending rulemaking by the U.S. Federal Aviation Administration may expand these reliability enhancements and operational protections to all extended-diversion-time operations (i.e., flying on routes with the potential for an extended diversion), not just those performed with two-engine airplanes.

As airplane range capabilities continue to increase, flights across remote regions of the world are becoming more common. The global aviation community—which collaboratively defined and proposed this U.S. rulemaking—believes that applying ETOPS rules to all extended-diversion-time operations will raise the industry to a higher and uniform standard.
In December 16, 2002, the Aviation Rulemaking Advisory Committee (ARAC)—an advisory committee of the U.S. Federal Aviation Administration (FAA)—presented to the FAA its findings and recommendations on extended operations (i.e., operations on routes with the potential for an extended-duration diversion). Initiated by the FAA tasking statement of June 14, 2000, this proposed U.S. rulemaking marks the culmination of more than two years of global collaboration to review current requirements for extended-range operations with two-engine airplanes (ETOPS) and propose updated and standardized requirements that will embrace all extended-diversion-time operations, not just those performed with two-engine airplanes.

The ARAC ETOPS Working Group comprised expert representatives from many of the world’s airlines, airframe and engine manufacturers, pilots’ associations, regulatory authorities, and nongovernmental organizations. In keeping with its proposal that the extended-operations protections be applied broadly to protect all airplanes, regardless of the number of engines, the ETOPS Working Group further recommended that the term ETOPS itself be redefined to simply mean extended operations. (See “ARAC ETOPS Working Group Participants,” p. 7.)

The FAA will evaluate the proposed ARAC findings and recommendations, make whatever changes it deems appropriate, and publish the results in a Notice of Proposed Rulemaking (NPRM) for public review and comment. Following comment resolution, the FAA is expected to enact new extended-operations rules, perhaps as soon as late 2004.

This article discusses the reasons behind this global activity and describes the specific regulatory changes that the ARAC has proposed.

THE ETOPS PARADIGM SHIFT
When the conservative ETOPS program began in 1985, its intent was to ensure that the safety of two-engine airplanes would match that of three- and four-engine airplanes on long-range transoceanic routes. Implicit in the ETOPS rules was the initial assumption that turbine-powered airplanes with

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**FIGURE 1**

**BOEING ETOPS ROUTES THROUGH SEPTEMBER 2002**

- 29,000 ETOPS flights per month
- 2,626,000 cumulative ETOPS flights
- 94 current ETOPS operators
two engines were inherently less safe than those with three or more engines. As a result, a separate set of more stringent requirements was deemed necessary for operating two-engine airplanes on routes with the potential for an extended-duration diversion.

Since then, however, extensive ETOPS service experience has brought about a profound revision to that initial thinking. After nearly two decades of highly successful ETOPS around the world, the global aviation community today views ETOPS in a different light. Characterizing this profound data-driven paradigm shift are the present-day industry perceptions that

1. ETOPS is the state of the art in intercontinental air travel.
2. Engine reliability is no longer the single focus of safety concerns.
3. A uniform standard is desirable for all extended operations.

ETOPS is the dominant mode of transatlantic flight operations today and accounts for a rapidly growing component of transpacific and other operations as well. Since 1985, more than 3 million ETOPS flights have been logged using the twinjets of several manufacturers. Today, about 125 operators worldwide log an additional 1,100 ETOPS flights each day. Of this industry total, Boeing twinjets alone have performed more than 2.6 million ETOPS flights, and 94 Boeing operators fly nearly 1,000 more each day (fig. 1).

This vast service experience reveals that ETOPS ranks among the safest and most reliable of all flight operations. This success results from the preclude and protect philosophy of ETOPS, which enhances flight operations in two ways:

- ETOPS-related design improvements and maintenance practices increase airplane systems and engine reliability, making it less likely that an airplane will need to divert from its intended course and land at an alternate airport.

- ETOPS operational requirements introduce proactive measures that protect the airplane, passengers, and crew should a diversion occur.

This philosophy has indirectly benefited the entire industry. All commercial operations today—including those performed with three- and four-engine airplanes—benefit from gains in the reliability and robustness of airplane engines and systems initially achieved through ETOPS programs.
Operators flying three- and four-engine airplanes are not currently required to meet the high ETOPS standard. Nevertheless, some operators already comply with key ETOPS safety enhancements on a voluntary basis. This elective application of ETOPS best practices suggests that the maintenance and operational benefits of ETOPS are well recognized by the global industry and that operators find them cost effective.

ENGINE RELIABILITY IS NO LONGER THE SINGLE FOCUS OF SAFETY CONCERNS

In the past, concerns about flight safety focused first and foremost on the reliability of propulsion systems. When ocean-spanning commercial flight operations began after World War II, that narrow focus was appropriate in light of the limited reliability of piston engines. During the 1940s and 1950s, in fact, piston engine-related events were the predominant cause of airliner accidents and contributed to a worldwide fleet hull-loss accident rate that was some 60 times higher than today’s.

The limited reliability of piston engines led to an operating restriction being placed on two-engine airplanes 50 years ago. The intent of the so-called 60-Minute Rule of 1953 (U.S. Federal Aviation Regulation [FAR] 121.161) was to bar two-engine propeller airplanes, such as the Douglas DC-3, from flying extended routes then more safely served by four-engine propeller types, such as the DC-4. That piston-era operating restriction remains in effect at the time of this writing.

During the late 1950s, however, the transition to turbine power brought about a quantum leap in propulsion system reliability. Engine reliability has continued to improve in the jet age, so much so that today’s high-bypass-ratio fanjet engines are at least 50 times more reliable than the large piston engines that inspired the 60-Minute Rule.

By the 1970s, advancing technology had set the stage for two-engine, turbine-powered airplanes to safely exceed the 60-min operating restriction. The result was ETOPS, which began in 1985 with 120-min diversion authority and the requirement for an average engine in-flight shutdown (IFSD) rate of just 0.05 per 1,000 engine-hours. With 180-min ETOPS authority, which followed in 1988, an even more stringent reliability target of just 0.02 IFSDs per 1,000 engine-hours was specified.

In this way, ETOPS drove manufacturers and operators alike to pursue dramatic gains in propulsion system reliability. The industry met this challenge and bettered it. During the past few years, in fact, the average IFSD rate of the worldwide 180-min ETOPS fleet has typically been at or below 0.01 IFSDs per 1,000 engine-hours—twice the reliability required for such operations. So profound has this trend been that propulsion reliabilities unachievable just 15 years ago are today routine in the modern twinjet fleet.

In light of these advances, and because the safety and reliability of two-engine airplanes equal or exceed those of three- or four-engine airplanes, the industry no longer views propulsion system reliability as the primary safety and reliability concern in extended operations. Instead, current rulemaking recognizes that a variety of airplane systems and operational issues (e.g., cargo fire suppression capability, weather conditions and facilities at alternate airports) are relevant to overall safety and reliability on routes with the potential for an extended diversion.

A UNIFORM STANDARD IS DESIRABLE FOR ALL EXTENDED OPERATIONS

All airplanes flown on extended-diversion-time routes face similar operating challenges in terms of weather, terrain, and limitations in navigation and communications infrastructure. Given that the operating environment is common to all extended operations, and that all categories of jetliner are safe, the global aviation community believes a uniform standard is desirable for extended operations. The global community further recognizes that applying ETOPS requirements to all airplanes—not just those with two engines—will raise the industry to a higher and uniform standard.

Although diversions are rare, any airplane might someday need to divert to an airport other than its intended destination for various reasons (e.g., passenger illness, smoke in the flight deck or cabin, turbulence, adverse winds, weather, fuel leak, cargo fire, in-flight engine failure or shutdown). Thus, the dual ETOPS philosophy of precluding diversions and protecting the passengers, crew, and airplane on those rare occasions when diversions do occur is applicable to all extended operations, not just those performed with two-engine airplanes.

As a result of ETOPS, the industry has achieved significant improvements in the reliability and robustness of airplane engines and systems. However, such efforts can never entirely prevent diversions because most are unrelated to the airplane, its systems, or its engines. In fact, fewer than 10 percent of all diversions during extended operations are airplane related, and fewer than 3 percent are the result of an in-flight engine failure or shutdown. In general, of course, engine failures tend to occur during takeoff and initial climb rather than during the cruise phase of flight where ETOPS is flown.
PROPOSED ARAC RULEMAKING AND GUIDANCE

ETOPS authorization
Modify existing rule FAR 121.161 to codify ETOPS in the U.S. federal aviation regulations; describe the redefinition of ETOPS and the updated requirements being proposed for the authorization of all extended operations.

Definitions
Add a new rule, FAR 121.7, to add the definitions of ETOPS-applicable terms to ensure understanding of and compliance with the updated ETOPS requirements now being proposed.

Communications
Add a new rule requiring voice communications, where available, and the most reliable communications technology, voice based or data link, for all extended operations beyond 180 min; require that another form of communications be available in case communication is not possible with the most reliable technology.

Dispatch
Add a new rule specifying dispatch or flight-release requirements for weather at ETOPS alternate airports; further require that weather be updated at the start of the ETOPS phase of flight to verify the continuing availability of a valid ETOPS alternate.

Propulsion-related diversions
Issue new guidance clarifying the requirements for twinjet diversion in the event of an in-flight engine failure or shutdown; specify what factors shall and shall not be considered sufficient justification for the crew to fly beyond the nearest suitable alternate airport.

Fuel reserve
Add a new rule specifying the reserve fuel to be carried to protect the airplane in the event of a cabin depressurization following by an extended diversion at low altitude to an alternate airport.

Maintenance
Add a new rule making ETOPS maintenance standards applicable to all airplanes flown in extended operations.

Passenger recovery plan
Modify existing rules FARs 121.135 and 121.97 to require all extended operators to develop a plan that ensures the well-being of passengers at diversion airports and provides for their safe retrieval without undue delay.

Modify existing rule FAR 121.415 to require training for crew members and dispatchers in their roles and responsibilities in the operator’s passenger recovery plan.

Cargo fire suppression
Add a new rule requiring that ETOPS diversion times shall not exceed the time limit, minus 15 min, specified in the Airplane Flight Manual for that airplane’s most time-limited system, which is typically cargo fire suppression.

Performance data
Modify existing rule FAR 121.135 to require all ETOPS operators to have the applicable performance data available to support their extended operations.

Polar operations
Modify existing rule FAR 121.161 to define polar-area zones of ETOPS applicability in which ETOPS requirements apply at all times. This requirement applies to all operations north of 78°N latitude (North Pole) and south of 60°S latitude (South Pole).

Rescue and fire fighting
Modify existing rule FAR 121.106 to require rescue and fire-fighting equipment to be available at any airport designated as an ETOPS en route alternate.

Other proposed changes
Modify the rules governing transport-category airplane and engine design to incorporate ETOPS enhancements that reduce the rate of airplane diversions and protect airplanes when they divert.

ARAC ETOPS WORKING GROUP PARTICIPANTS

AIRLINES
Non-U.S.— All Nippon Airways, along with British Airways, KLM Royal Dutch Airlines, and Scandinavian Airlines System, representing the Association of European Airlines (AEA)

INDUSTRY ASSOCIATIONS
European Association of Aerospace Industries (AECMA), General Aviation Manufacturers Association (GAMA), International Civil Aviation Organization (ICAO), National Business Aviation Association (NBAA), Air Transport Association (ATA), National Air Transportation Association (NATA), National Air Carriers Association (NACA), and International Federation of Airline Dispatchers’ Associations (IFALDA)

MANUFACTURERS
Airframe — Airbus Industrie, The Boeing Company, Bombardier, Cessna, and Gulfstream
Engine — GE Aircraft Engines, Pratt & Whitney, and Rolls-Royce

PILOTS’ ASSOCIATIONS
Air Line Pilots Association (ALPA), Independent Association of Continental Pilots (recently merged with ALPA), Allied Pilots Association (APA), Coalition of Airline Pilots Associations (CAPA), International Federation of Airline Pilots’ Associations (IFALPA)

REGULATORS
U.S. Federal Aviation Administration (FAA), Transport Canada, Joint Aviation Authorities (JAA) of Europe as represented by the U.K. Civil Aviation Authority (CAA), Direction Générale de l’Aviation Civile (DGAC) France, and Civil Aviation Safety Authority (CASA) Australia

OTHER PARTIES
Air Crash Victims Families Association (ACVFA)

PROPOSED U.S. REGULATORY CHANGES
This paradigm shift created growing awareness around the world that the regulatory framework currently governing twinjet and other extended operations should be reviewed. Consequently, the FAA — which meets its responsibility to update regulations through the proven ARAC process — initiated the collaborative ARAC activity previously described.

The ARAC-proposed regulations (table 1) might change as a result of the current FAA review and pending NPRM comment processes. We at The Boeing Company are proud to have participated in this global ARAC effort, which will make flying even safer and more reliable in the coming years. Pages 8 through 10 detail the proposed changes.
ETOPS Authorization
The ARAC has recommended that FAR 121.161 (the 60-Minute Rule) and associated guidance and advisory material be revised to

■ Establish the basis and requirements for operating twin-engine, turbine-powered airplanes beyond 60 min of flying time (at single-engine cruise speed with no wind and in standard conditions) of an adequate alternate airport.

■ Apply this same regulatory framework to the operation of turbine-powered airplanes with more than two engines beyond 180 min (at one-engine-inoperative cruise speed with no wind and in standard conditions) of an adequate alternate airport, and also make it applicable to all operations in polar areas (see Polar Operations, p. 10).

■ Make the designed and certified operating capabilities of the airplane type the basis for determining the maximum diversion authority of that type.

■ Define allowable diversion authorizations for different regions of the world based on the overall operational needs of each region.

■ Apply current ETOPS best practices to all extended operations.

It should be noted that, although these proposed ETOPS requirements are consistent for all jetliners, the threshold varies at which they would take effect. For two-engine airplanes operating under FAR Part 121, ETOPS will be in effect — as is currently the case — on routes where the airplane is at some point more than 60 min flying time from an alternate airport. For FAR Part 121 operations by airplanes with three or more engines, these new ETOPS rules will apply on routes that are at some point more than 180 min from an alternate airport. They also will apply to all operations in the polar regions (i.e., the areas north of 78°N latitude and south of 60°S latitude).

Definitions
The ARAC has proposed that ETOPS-applicable definitions be added to FAR Part 121. Many of the terms used in the new regulations and guidance material for ETOPS are unique to extended operations and demand precise definition to ensure common understanding and proper compliance.

To encompass all extended-diversion-time operations, not just those flown with two-engine airplanes, the term ETOPS would be redefined as extended operations (as used in this article) and shall no longer mean extended-range operations with two-engine airplanes. Another noteworthy change is the addition of the term ETOPS alternate, which is an airport that meets stated requirements for planned diversion use and at which the weather conditions are at or above the operating minimums specified for a safe landing. This new term would replace the current ETOPS term suitable, which denotes an alternate airport that is both above required weather minimums and available for diversion use. Under the new rules, suitable would no longer have an ETOPS-specific meaning; where it appears in the new regulations and associated guidance material, therefore, it should be interpreted only according to its broadly accepted, everyday definition.

It should be noted that long-range operations (LROPs) is not proposed as an ETOPS term. Although used by some segments of the global industry, LROPs currently does not appear or have legal standing in the FARs. The ARAC ETOPS Working Group did not propose adding LROPs because the term would be misleading — extended operations are defined by distance to an alternate airport, not by overall length of flight — and because it invites confusion with the similar but unrelated term ultra-long-range operations, which deals primarily with flight crew duty time, crew rest, and other human-factors issues.

Communications
Current regulations require reliable communications. Recognizing that advances in technology occur and that verbal communications can be particularly valuable, the proposed rule promotes the adoption of voice communications for extended operations.

This proposed rule states that the most reliable communications technology — voice based or data link — shall be installed in all airplanes operating beyond 180 min from an alternate airport. Alternative means of communication must also be available in the event the most reliable means is not available for any reason (e.g., lack of satellite coverage). Examples of these communications technologies (e.g., SATCOM voice link, SATCOM data link, HF data link) are given in the associated guidance material.

The proposed rule is not intended to require operators to continually upgrade existing installations on an incremental basis. Rather, the rule is meant to further the adoption, as appropriate, of new technologies that significantly enhance the quality and reliability of communications. One example of such innovation is today’s transition from HF radio to satellite-based technologies.

Dispatch
The ARAC has proposed a new regulation specifying airplane dispatch requirements for ETOPS alternate airports. The operator would have to select en route alternate airports that meet the weather requirements set forth in its operations specifications.

Because alternate airport weather is checked before airplane departure, and weather conditions can vary over time, the conservative weather minimums required for dispatch are higher than those that would be required to perform an instrument approach at that alternate airport. As proposed, this dispatch rule further requires the crew to verify the continuing availability of a valid alternate airport by means of en route weather updating at the beginning of the ETOPS phase of flight. For this en route updating, the crew would be required to ascertain only that the planned alternate is
above normal landing minimums, not above the higher minimums applied before dispatch.

One of the distinguishing features of ETOPS is the identification of and reliance on alternate airports to which airplanes can divert should an unscheduled landing become desirable or necessary. Under this proposed regulation, operators flying three- and four-engine airplanes in extended operations would be required to designate ETOPS alternate airports within 240 min, or if beyond 240 min, designate the nearest available ETOPS alternate.

**Propulsion-Related Diversions**

The ARAC has proposed no substantive change to the rule that governs diversion following an in-flight engine failure or shutdown. However, the committee did offer guidance to further clarify existing diversion requirements for two-engine airplanes in the event of engine failure or shutdown.

To aid flight crews, the proposed guidance lists factors (e.g., airplane condition and systems status, weather conditions en route, terrain and facilities at the alternate airport) that the pilot in command should consider when deciding which alternate airport to divert to. To ensure that safety always remain paramount, the ARAC further identified factors that shall not be considered sufficient justification for flying beyond the nearest available alternate airport (e.g., additional range capability based on remaining fuel supply, passenger accommodations beyond basic safety, maintenance and repair facilities at the available alternate airports).

**Fuel Reserve**

The ARAC has proposed that all airplanes flown in extended operations shall carry an ETOPS fuel reserve to protect the passengers, crew, and airplane from a cabin depressurization followed by a low-altitude diversion.

Cabin depressurization is a very rare event that can occur on any jetliner and is largely unrelated to the number of engines. If it does occur, the flight crew must immediately descend to an appropriate altitude, as defined by oxygen availability or oxygen systems capability. A diversion is then generally required because of the increased fuel consumption of turbine engines at low altitudes and the corresponding reduction in range.

This ETOPS fuel reserve requirement assumes that decompression would occur at the most critical point along the route in terms of total fuel consumption (a concurrent engine failure is further assumed if it would add to the total). The reserve thus calculated would ensure sufficient fuel for an extended low-altitude diversion followed by a descent to 1,500 ft at the alternate airport, a 15-min hold, and an approach and landing. Further allowance is made for possible airframe icing and wind forecasting error.

Following extensive review of data related to the accuracy of wind forecasting, as well as review of the icing scenario based on the Canadian Atlantic Storms Program (CASP II), the ARAC proposed revising the ETOPS fuel reserve requirement. Under this proposed rule, two-engine airplanes on extended operations would carry somewhat less reserve fuel than in the past. Airplanes with more than two engines would be required to carry an ETOPS fuel reserve for the first time, although many three- and four-engine operators do currently carry a depressurization fuel reserve as a matter of internal airline policy.

**Maintenance**

The ARAC has proposed making current twin-engine ETOPS maintenance standards applicable to all airplanes flown in extended operations. This would require three- and four-engine operators to also have an ETOPS maintenance program in place before flying routes with the potential for an extended diversion.

ETOPS maintenance requirements have significantly reduced the incidence of in-flight engine failures. Such events can be enormously costly and disruptive for airlines, which is why some operators of three- and four-engine airplanes have already voluntarily raised their maintenance standards to ETOPS levels.

**Passenger Recovery Plan**

The ARAC has proposed that all extended operators shall develop a plan to ensure the well-being of passengers and crewmembers at diversion airports. This plan should address their safety and comfort at that airport in terms of the facilities and accommodations and their retrieval from that airport.

Currently, passenger recovery plans are required only for cross-polar operations. Because diversions can occur anywhere, however, the ARAC has proposed that every operator flying routes over remote areas of the world should anticipate the possibility of a diversion within those regions and devise a plan outlining how it would recover the passengers, crew, and airplane.

**Cargo Fire Suppression**

To further ensure safety, the ARAC has proposed that all time-critical systems aboard airplanes flown in extended operations shall have sufficient capability to protect the airplane throughout the longest potential diversion for that route. In particular, each flight shall have continuous fire suppression capability for a period equivalent to the maximum planned diversion time plus an additional 15 min to cover approach and landing at the alternate airport.

Two-engine airplanes flown in extended operations have met this requirement since 1985. In contrast, although all jets have fire suppression systems, those with more than two engines are not currently required to carry sufficient fire suppressant during extended operations to protect the airplane continuously throughout a maximum-duration diversion.

The ARAC has proposed that three- and four-engine airplane operators that do not currently comply with this requirement shall have six years after ETOPS regulations take effect to bring their existing fleets into compliance with this new rule.

Many airplane systems enhance safety during flight. Of these, cargo fire suppression is generally the most time-limited.
**Proposed changes (continued)**

Applying ETOPS cargo fire suppression requirements to all extended operations can thus further protect passengers, crews, and airplanes on routes with extended diversion times.

**Performance Data**

The ARAC has proposed that existing regulations be modified to require that performance data be available to support all phases of extended operations. Flight crews and dispatchers must have data available that describe the specific performance of the airplane in normal and non-normal situations, including those that might be encountered during an extended diversion.

**Polar Operations**

The ARAC has recommended that the North Polar area (i.e., everything north of 78°N latitude) shall be designated an area of ETOPS applicability. The same designation shall be applied to the South Pole and surrounding region (i.e., everything south of 60°S latitude).

Within these areas, ETOPS requirements shall apply to all airplanes, regardless of the number of engines or distance from an adequate airport. This proposed requirement recognizes the challenges associated with these areas and sets forth steps to protect diversion.

Polar operators require training and expertise to support airplane diversions and their subsequent recovery. These operators must consider requirements for en route alternate airports, a strategy for and monitoring of fuel freeze, a passenger recovery plan, and reliable communications capability.

**Rescue and Fire Fighting**

The ARAC has proposed a rule specifying rescue and fire fighting (RFF) requirements at ETOPS en route alternate airports. If adopted, this rule will further ensure the safety of all airplanes when flying extended operations, regardless of how many engines an airplane has.

Before dispatch, ETOPS operators have always had to designate alternate airports that are above ETOPS-specified weather minimums. In addition, these designated alternates must provide the necessary facilities and equipment to ensure the safety and well-being of the passengers and crew throughout an extended diversion, after landing at the alternate airport, and for as long as they remain at that airport before being retrieved. RFF capability is a key element of this protection.

During nearly two decades of ETOPS and more than three million ETOPS twinjet flights around the globe, there has been a single landing accident following an extended diversion from the ETOPS phase of flight. The fact that RFF services have not been needed does not mean that such an event will never happen. Therefore, the ARAC finds it prudent to formalize RFF requirements for alternate airports in the regulations.

**Other Proposed Changes**

The proposed regulatory changes described above would affect FAR Part 121, the section of the FARs governing the operation of transport-category airplanes. In response to the FAA tasking statement, the ARAC ETOPS Working Group also has proposed changes to other parts of the FARs.

In particular, the ARAC has proposed changes to FAR Part 25, which governs the design and testing of transport-category airplanes, and FAR Part 33, which governs engine design and testing. If adopted, these regulatory modifications will benefit the development of future transport airplanes — regardless of the number of engines — by formalizing ETOPS-inspired improvements that have been shown in service to further protect airplanes and reduce the likelihood that they will need to divert.

The ARAC has further recommended that operators must comply with all rules within FAR Parts 25 and 33 when considering the longest flight and longest diversion time for which approval is sought. The rigor of this practice will ensure that all airplanes designed to these requirements will have the necessary redundancy and reliability to ensure safe extended operations.

To further protect airplanes during extended operations, the ARAC has identified the factors that ensure high levels of safety on flights with the potential for a long diversion. In the case of two-engine airplanes, the most significant element is propulsion system reliability.

Using several methods to assess risk, the ARAC concluded that diversion time can be significantly increased without added risk if the IFSD rate is sufficiently low. An IFSD rate of 0.01 per 1,000 engine-hours — or twice the engine reliability level required for 180-min ETOPS — has been determined to allow unconstrained operations with two-engine airplanes. Currently, the world-fleet average IFSD rates for the 767 and 777, which together perform the majority of ETOPS, are both below this threshold.

Other key elements that support extended diversion times are proper testing and validation of an airplane type (i.e., airframe-engine combination) to ensure ETOPS safety at service entry. The Boeing 777 Early ETOPS program processes provided a successful template on which to base future such programs. Consequently, the design, analysis, and test features from the 777 Early ETOPS program are incorporated in the proposed ETOPS regulations.
About the Authors

Capt. Chester “Chet” Ekstrand
is vice president in charge of Regulatory Affairs for Boeing Commercial Airplanes. He is responsible for issues and initiatives related to operational safety and serves as the company’s focal for ETOPS. Capt. Ekstrand’s expertise in working with the industry and regulatory authorities worldwide contributed significantly to the precedent-setting early ETOPS certification of the 777. Former positions include vice president of Communication, Navigation, Surveillance/Air Traffic Management and Extended-Range Twin-Engine Operations; vice president of Government and Industry Technical Affairs; director of Flight Crew Operations; chief pilot, flight training; and chief pilot, technical.

Mohan Pandey, senior manager of Operational Regulatory Affairs, has played a key role in almost every ETOPS operational issue. He led Boeing participation in the ARAC ETOPS Working Group and currently serves as a member of the JAA and ICAO ETOPS committees as well as the JAA Operational Steering Team. Mr. Pandey is a 30-year veteran of the aviation industry and has held a variety of positions since joining Boeing in 1980.

SUMMARY
As airplane range capabilities continue to increase, and flights become more common in remote regions of the world, expanding ETOPS to embrace all extended-diversion-time operations—not only those involving two-engine airplanes—will raise the industry to a higher and uniform standard.

The proposed U.S. ETOPS regulations reflect broad recognition within the global aviation community that ETOPS-related practices can further enhance the safety and reliability of all operations on routes with extended diversion times. The proposed rules recognize the high standard of safety that has been achieved during nearly two decades of highly successful twinjet operations worldwide and are the next logical step in enhancing aviation safety.

The FAA will evaluate these ARAC-proposed regulations, make whatever changes it deems appropriate, and publish the results in an NPRM for public review and comment. After comment resolution, the FAA is expected to enact the new ETOPS rules, perhaps as soon as late 2004.
Boeing will soon offer a suite of new integrated flight deck navigation options that enhance the proven approach capability of 737-600/-700/-800/-900 airplanes. Available in 2003, these options enable pilots to fly precise three-dimensional paths that smoothly intercept a variety of final approach legs. The Category IIIB Autoland, Global Navigation Satellite System Landing System, Integrated Approach Navigation, and Navigation Performance Scales options work together or separately to improve safety and performance while decreasing operating costs.
Operators will be able to enhance the approach capability of their 737-600/-700/-800/-900 airplanes this year with a suite of new flight deck navigation options: Category IIIB Autoland, the Global Navigation Satellite System (GNSS) Landing System, Integrated Approach Navigation, and Navigation Performance Scales.

Together with the excellent existing approach capabilities of the 737, these options offer a flexible navigation solution for airlines that want to increase their competitive advantage by improving airplane safety and performance, decreasing operating costs, and reducing flight crew training requirements through advanced technology.

The new navigation options work together or separately to enable pilots to fly safe, stable, and precise three-dimensional paths that smoothly intercept a variety of final approach legs. The options improve landing capability in adverse weather conditions, in areas of difficult terrain, and on existing difficult approach paths. It addition, they will allow crews to take advantage of emerging air traffic control technologies designed to improve airport operations.

To help operators understand these navigation options and their features, this article describes
1. Category IIIB Autoland.
2. GNSS Landing System.

The article also discusses how the options and procedures are compatible with current and emerging approach navigation technologies such as the Instrument Landing System, mixed-mode, and constant-angle nonprecision approaches.

The new 737-700/-800/-900 Category IIIB Autoland option (fig. 1) provides the same all-weather, precision approach autopilot guidance currently available on other Boeing airplane models.

This option, which is in flight test, will be offered with the 737-700/-800/-900 over-under engine format. The over-under format provides the display space necessary for Category IIIB Autoland system messages. (The 737-600 is not currently being certified for Category IIIB operation.)

The initial 737-600/-700/-800/-900 GNSS Landing System (GLS) option uses Global Positioning System navigation satellites and a Ground-Based Augmentation System (GBAS) to provide signals similar to Instrument Landing System (ILS) signals (fig. 2). Ultimately, the GLS could replace the ILS as the primary means for guiding airplanes to the runway in low visibility. The GLS also might be expanded to support curved approaches. (See “Global Navigation Satellite System Landing System,” Aero no. 21, January 2003.)

Retrofit for the 737-600/-700/-800/-900 GLS requires new multimode receiver (MMR) hardware and software, a navigation control panel with GLS capability, and hardware and software upgrades for the enhanced ground
proximity warning system (EGPWS), flight management computer (FMC) U10.5 software, and common display system (CDS) Block Point 2002 software. A future curved GLS approach capability might require autopilot and CDS software changes.

The U.S. Federal Aviation Administration (FAA) plans to deploy GLS ground stations in Memphis, Chicago O’Hare, Juneau Alaska, Seattle, Phoenix, and Houston to support operational evaluation testing. The program calls for the purchase and deployment of as many as 40 ground stations per year after the initial phase. The FAA projects a total of 160 GBAS ground stations are needed in the United States. Europe also plans to develop and install GBAS ground stations.

**INTEGRATED APPROACH NAVIGATION**

Integrated Approach Navigation (IAN) is an approach option designed for airlines that want to use ILS-like pilot procedures, display features, and autopilot control laws for nonprecision (Category I) approaches. This option does not require additional ground facility support.

The FMC transmits IAN deviations to the autopilot and display system. The pilot procedures for IAN are derived from current ILS pilot procedures and are consistent for all approach types:

- Select the approach on the FMC control display unit, tune the appropriate station, and arm the autopilot approach mode. The IAN function supports the ILS for glideslope inoperative, localizer only, and backcourse approach types.
- The IAN function will alert the crew to approach selection or tuning inconsistencies. For example, if an ILS station is tuned and an area navigation (RNAV) approach also is selected on the FMC, the flight crew will be alerted and the ILS approach mode will take precedence automatically, with the appropriate display format.
- While the IAN display (fig. 3) is similar to an ILS display, there are sufficient visual differences to ensure that the crew does not confuse a nonprecision IAN approach for a precision ILS or GLS approach (fig. 4). As on all nonprecision approaches, the altimeter is the primary method of ensuring that altitude constraints are honored.
- Retrofit of this option involves software updates for the FMC, CDS, flight control computer, and digital flight data acquisition unit (DFDAU) and hardware and software updates for the EGPWS.
Navigation Performance Scales (NPS) is a new display feature that integrates the current lateral navigation (LNAV) and vertical navigation (VNAV) with actual navigation performance (ANP) and required navigation performance (RNP). The primary display format of the NPS (fig. 5) can be interpreted easily, thereby allowing the crew to monitor flight path performance relative to flight phase requirements and airplane system navigation performance.

NPS can be especially valuable for approaches with tight airspace restrictions because of terrain, traffic, or restricted areas. LNAV and VNAV with NPS supports Category I approaches down to 0.10-nmi RNP. NPS also is designed to smoothly transition to an ILS, GLS, or IAN approach. (For a detailed description of NPS, see “Lateral and Vertical Navigation Deviation Displays,” Aero no. 16, Oct. 2001.) Retrofit of this option involves software updates for the FMC, CDS, and DFDAU.

This year, operators will be able to enhance the approach capability of their 737-600/-700/-800/-900 airplanes through a suite of new flight deck navigation options: Category IIIB Autoland, GLS, IAN, and NPS. These options enable pilots to fly paths that smoothly intercept various final approach legs. This integrated, flexible approach navigation solution improves safety and performance and decreases operating costs. The options are designed to meet the current and future approach requirements of Boeing customers worldwide.
Capt. Ray Craig has been with Boeing Commercial Airplanes since 1990. Currently chief pilot for the 737, Capt. Craig has served as senior project pilot for 737 Engineering Flight Test and 737 Production Flight Test.

Drew Houck is an Associate Technical Fellow with 10 years of experience in the Boeing Flight Crew Operation Integration and Avionics System Display groups. Key projects include flight deck display software development and test for the 777, 737-600/-700/-800/-900, and 767-400 airplanes.

Rolan Shomber is an Associate Technical Fellow with 19 years of experience in flight management system design and development, with expertise in navigation, guidance, and displays. He is active in the development of required navigation performance concepts and Boeing flight management systems capability.
New Navigation Approach Options Complement Instrument Landing System Capability

<table>
<thead>
<tr>
<th>Approach option/capability</th>
<th>Description</th>
</tr>
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| Category IIIB Autoland                         | ■ All-weather, autoland capability  
■ Matches Category IIIB capability available on other Boeing airplane models  
■ Not currently offered for 737-600                                                                                                                                                                      |
| GNSS Landing System                            | ■ New augmented satellite landing system  
■ Does not require a dedicated ground station for each runway  
■ Proposed as potential follow-on to current ILS stations  
■ Supports Category I operation in initial implementation  
■ Retrofit requires MMR and EGPWS hardware and software, FMC and CDS software, and a new navigation control panel  
 ■ Nonprecision Category I capability with display similar to current ILS  
■ FMC-generated glidepath and final approach course  
■ Integrates with ILS localizer and backcourse approaches  
■ Retrofit requires EGPWS hardware and software and FMC, CDS, flight control computer, and DFDAU software  
 ■ Supports RNAV Category I procedures  
■ Integrates ANP and RNP capability with current LNAV and VNAV capability  
■ Supports curved approaches  
■ Integrates with ILS, GLS, or IAN final approach capabilities  
■ Retrofit requires only software changes  
 ■ Currently available on 737-600/-700/-800/-900  
■ Well-established procedures  
■ Supports Category I and II operations  
■ Integrates with IAN  
■ Many ILS ground stations may be deactivated in the future |

FMC Enhancements to Improve LNAV and VNAV Operations

Additional FMC enhancements are being studied or developed to further improve LNAV and VNAV approach operations, including:

■ LNAV missed approaches, which enable the crew to arm and engage an LNAV missed approach by pressing the takeoff/go-around button. This option reduces crew workload during a busy period in the flight deck.

■ Branching missed approaches, which allow one of several preplanned missed approach procedures to be engaged for the applicable approach leg.
Safety Benefits of Stabilized Approaches

The safety benefits of stabilized final approaches, both nonprecision and precision (fig. A), have been recognized for years. The Global Positioning System makes stabilized approaches possible at many airports around the world. NPS, IAN, and GLS all take advantage of this technology to provide consistent, intuitive displays and associated procedures that support stabilized approaches.

The following excerpt (source: The Boeing Company, copyright 1997) is from Controlled Flight Into Terrain Education and Training Aid, section 3:

Unstable approaches contribute to many incidents/accidents. Pilots should establish a stabilized approach profile for all instrument and visual approaches. A stabilized approach has the following characteristics:

- A constant rate of descent along an approximate 3-deg approach path that intersects the landing runway approximately 1,000 ft beyond the approach end and begins not later than the final approach fix or equivalent position.
- Flight from an established height above touchdown should be in a landing configuration with appropriate and stable airspeed, power setting, trim, and constant rate of descent and on the defined descent profile.
- Normally, a stabilized approach configuration should be achieved no later than 1,000 ft AGL in IMC. However, in all cases if a stabilized approach is not achieved by 500 ft AGL, an immediate missed approach shall be initiated.
New Approach Navigation Option Displays and Procedures Dovetail With Current and Emerging Technologies

Displays and Procedures Are Similar to ILS

The current ILS remains the basic approach capability. To minimize training requirements, new 737-600/-700/-800/-900 approach options use displays and pilot procedures that are similar to those used with the ILS (fig. B). For example, the new options involve the established fly-to convention, where a lateral pointer on the right of the center scale reference indicates a lateral path to the right of the current aircraft position (fig. C).

The 737-600/-700/-800/-900 displays include an explicit annunciation at the top of the attitude indicator that clearly defines the source of the displayed deviation scales and pointers. The approach data block, which includes the selected station and course and distance measuring equipment distance, is retained in the GLS and IAN approaches although modified to support their unique characteristics.

The 737-600/-700/-800/-900 procedures have been human engineered to ensure that, although their appearance and operation are consistent with an ILS, aircrews easily can differentiate among approach types (fig. 4, p. 16).
Mixed-Mode Approaches

Under certain circumstances, pilots may choose to mix modes (fig. D). For example, figure E shows an Instrument Landing System localizer (ILS LOC) approach with vertical navigation path (VNAV PTH) vertical guidance. The procedures for mixed-mode approaches are straightforward, and the display formats are consistent and easy to interpret.

Constant-Angle Nonprecision Approaches

Many airlines are moving away from the traditional “dive and drive” step-down procedures and are introducing new constant-angle nonprecision approaches (CANPA). In conjunction with the autopilot, lateral navigation, and vertical navigation, CANPAs decrease workload during approach by allowing the flight crew to load most required data before beginning the approach.

The new 737-600/-700/-800/-900 navigation displays allow the flight crew to easily and intuitively evaluate the status of the entire approach against an objective flight technical error scale and pointer. Flight technical error is a measure of the accuracy with which the airplane is being controlled relative to the defined flight path. Deviations can be caused by the autopilot, crew response to the flight directors, or external environmental conditions such as a wind gradient or turbulence.
Many landing gear, flap supporting, and flap actuating components on Boeing airplanes are made of high-strength alloy steels. Operational advantages are realized when these high-strength, high-heat-treated materials are used in limited-space envelopes. To reap the benefits of high-strength alloy steel components and avoid potential safety issues resulting from damage, airline maintenance and overhaul personnel need to follow proper maintenance procedures and rework practices, checklists, and guidelines during component maintenance and overhaul.
ALLOY STEEL
Any landing gear, flap track, flap carriage, and other flap actuating components on Boeing airplanes are made of high-strength alloy steels, such as 300M, Hy-Tuf, 4340M, and 4330M. These components provide structural benefits (e.g., reliable, durable design) and strength characteristics that permit an efficient use of available airframe space. Other steels in use, including 9Ni-4Co-0.3C, AerMet 100, and precipitation-hardened stainless steels, have similar maintenance and overhaul requirements. (Note: High-strength alloy steels referenced in this article generally have been heat-treated above 180 ksi [180,000 psi]; most have been heat-treated above 220 ksi.)

Airline personnel should follow proper maintenance procedures and Boeing-provided rework practices, checklists, and planning guidelines during maintenance and overhaul of these components. This will help operators achieve the benefits associated with high-strength alloy steels and avoid potential safety issues resulting from damage caused by stress concentrations, detrimental surface conditions, corrosion, improper processing, or other factors.

This article discusses some factors that cause damage in service or during overhaul. Most can be attributed to a lack of familiarity with high-strength alloy steels. Operators usually recognize the benefits of using these steels; however, certain characteristics of the steels are not always given proper consideration during component maintenance or overhaul. These characteristics, including sensitivity to corrosion pitting, susceptibility to microstructural damage resulting from embrittlement, and notch sensitivity, can lead to rapid crack growth in some load environments.

This article describes

1. Benefits of high-strength alloy steel.
2. Importance of proper inspection and rework.
3. Guidelines for reworking high-strength alloy steel components.
**1 BENEFITS OF HIGH-STRENGTH ALLOY STEEL**

Components made of high-strength alloy steel generally weigh less and require less space to house than components made of lower strength alloys. Using high-strength alloy steel for component design provides an opportunity to do the same job with less material. When properly maintained and overhauled, high-strength alloy steel components demonstrate high levels of service reliability.

The decision to use high-strength alloy steels is based on weight and economic factors. Airframe space for gear components may be reduced because of smaller diameter shock strut components, smaller pins (reduced space for joints), smaller diameter trucks and axles, and, in some instances, smaller drag brace, side brace, and attach fittings. By reducing the space required for these components, the wheel well size can be minimized and aerodynamic surfaces can be optimized, which allow an increase in fuel tank size (optimal wing spar location) or additional space for other uses.

The use of high-strength alloy steel parts is economical because it reduces weight, thereby allowing for more efficient aerodynamic surfaces and providing the potential for increased payload and fuel.

For example, the trailing edge of the wing is relatively shallow. Using high-strength alloy steel flap tracks, flap carriages, and flap actuating components reduces the profile and decreases spatial envelope requirements while meeting or improving aerodynamic requirements. This also optimizes wing shape and reduces the potential need for bulging aerodynamic surfaces, which in turn reduces drag and increases airplane performance.

**2 IMPORTANCE OF PROPER INSPECTION AND REWORK**

Following proper rework practices and using Boeing-provided documents during maintenance and overhaul are necessary to achieve the benefits associated with high-strength alloy steel components and help ensure safe airplane operation.

Airline personnel who participate in component rework, maintenance, and overhaul tasks should be familiar with the properties of high-strength steels and understand the negative effects that can result from:
- Sensitivity to stress concentrations (notch sensitivity).
- Microstructural damage from embrittlement or overheating.
- Detrimental surface conditions.
- Corrosion.
- Improper processing.

Improper rework practices can result in unscheduled maintenance or surface damage that causes crack initiation. Maintenance efforts focus on corrosion prevention and removal in addition to normal checks for wear and free play.

High-strength alloy steels can experience rapid crack propagation from stress corrosion under certain loading conditions. Therefore, surface damage detection is important during overhaul and on components in service. Removing visible surface corrosion before pitting begins (such as during a C-check) helps prevent conditions that can lead to crack initiation. The best safeguard against corrosion is to ensure that finishes conform to the design and that design improvements are incorporated as minor changes whenever possible.

Components manufactured from steel alloys heat-treated above 180 ksi (180,000 psi) should be reworked in accordance with guidelines in Component Maintenance Manuals (CMM) 32-00-05, 32-00-06, and 32-00-07. Although these guidelines apply directly to landing gear components, they can be used to plan the overhaul rework of all high-strength steel components. Standard Overhaul Practices Manual (SOPM) 20-10-01 generally is specified in each CMM section for the rework of wing components (e.g., flap tracks, flap carriages). For repair of high-strength, 300M steel parts on DC-10 and MD-11 airplanes, use CMM 20-11-02; for DC-9, MD-80, MD-90, and 717 airplanes, use CMMs 20-10-18 and 20-10-06.

In addition, airline personnel need to understand the importance of maintaining component finishes while in service (in situ, or on the airplane). This includes repairing damaged finishes to prevent corrosion and ensuring that solvents and materials that come in contact with the finishes do not result in premature degradation and unscheduled component removal.

Boeing documentation describes the methods for detecting base metal damage while in service and during overhaul. Common techniques include detailed visual inspections and other nondestructive inspection methods, such as magnetic particle inspection (MPI) and fluorescent penetrant inspection (FPI). (See SOPMs 20-20-01 and 20-20-02.) Ultrasonic or eddy current inspections also may be useful for in situ inspections.

Boeing also is developing supplemental, specialized techniques, such as the Barkhausen inspection, to detect base metal heat damage under chrome plating or other protective finishes. This technique can be used successfully to screen components with suspect damage. For example, if an axle fractures as a result of chrome-grinding heat damage during manufacture or overhaul, the Barkhausen inspection allows other suspect components to be screened without first performing a chrome strip and temper etch (e.g., nital etch) inspection on all suspect axles.
GUIDELINES FOR REWORKING HIGH-STRENGTH ALLOY STEEL COMPONENTS

This section provides guidelines for reworking high-strength alloy steel components and describes some of the implications of improper rework procedures.

- Stress concentrations.
- Overheating components.
- Hydrogen embrittlement.
- Cadmium embrittlement.
- Improper finishing.

STRESS CONCENTRATIONS

During component design, eliminating or minimizing areas of stress concentrations is a key objective. Special attention is given to protective finish runouts adjacent to stress concentration details. In addition, all stress concentration details are subject to extensive testing and/or analysis to ensure that no detrimental effects are introduced into a part. Any rework or repair must not increase stress concentrations that degrade component durability.

High-strength alloy steel components, when shot-peened to create a shallow layer of compressive residual stress at the surface. This layer helps to:

- Minimize the effects of stress concentrations in transition areas.
- Impede crack initiation and initial crack growth caused by fatigue or stress corrosion.
- Create a surface that will have minimal adverse effects from the residual stresses of plating.

When a surface is machined or ground to remove damage, the reworked area should be shot-peened with proper overlap onto the existing shot-peened surface. During overhaul, personnel must observe the plating runouts specified in the CMM sections and SOPMs 20-10-01 and 20-42-03.

For example, when a coating such as chrome or nickel plating is applied to surfaces to prevent wear or corrosion, the coating must exhibit proper runouts that terminate before the tangent of fillet radii, edges, or other shape changes. Boeing SOPM guidelines should be followed for the rework of any component and for all types of plating or coating.

Rework or overhaul of components should not introduce stress concentrations, or otherwise increase stresses, which can reduce the service life of a component below that of the original design configuration.

Stress concentrations can lead to initiation of cracking by fatigue, stress corrosion, or hydrogen-assisted stress corrosion. These cracks may result in a fracture or scrap of a component when found while in service or during overhaul. The following are examples of stress concentrations that can lead to cracking.

Transitions or radii that are sharper than original design. When removing damaged material from part surfaces during rework, the new transitions or radii should not cause an unacceptable increase in stress concentration at the location or degrade the original design features. When locally machining out corrosion or damage during overhaul, a gradual transition into the reworked depression is necessary.

The intent is to remove the least amount of material possible while ensuring that all discrepant material is removed and the original design strength and durability are maintained. There are few options to restore these machined depressions to meet interface requirements. One type of rework or overhaul, sulfamate-nickel plating, is common on shock strut cylinder diameters and is used to repair lug faces to design dimensions as follows:

- Local blends on inner cylinder outer diameter surfaces and outer cylinder inner diameter surfaces are filled with sulfamate-nickel plating to restore them to dimensions that are suitable for subsequent chrome plate application.
- Spot facing on lugs is controlled to have a generous radius at the transition to the adjacent surface and usually is kept at the minimum depth necessary to clean up the damaged surface. Spot face depressions typically are not filled with plating to restore the dimension but instead are finished in the same manner as the original design. Spot face transition radii need to be such that they can be shot-peened to the requirements of the adjacent surfaces.

When the entire face of a lug must be machined to remove damage, the new lug transition radii should be shaped and positioned in accordance with CMM requirements. Surface transitions into the lug hole and at the lug edges must have design transitions that will allow restoration of shot-peening on all reworked areas and permit complete seating of bushings without contacting hole edges.

Abrupt changes in sections, holes, and sharp-cornered keyways should be avoided. Proper design will reflect generous fillets, gradual changes of shape, and the use of relief grooves in areas of high stress. Finer surface finishes also may be needed to eliminate unnecessary stress concentrations, especially in areas of machined radii or undercuts. Overhaul should reflect the same careful, detailed review that occurred during the original design.

Plating conditions and runout controls that are not in accordance with design standards. During overhaul, many landing gear components are completely stripped to replace nickel and chrome plating. In most instances, these repairs involve rework of the base metal. The new plating deposits frequently are thicker than the original design configuration.

In all cases, it is important to adhere to the SOPM recommendations. This will ensure that the restored plating is of high quality and that it does not terminate with an abrupt edge. Through-thickness cracks in chrome plate (generally present where there is evidence of chicken-wire cracking) can lead to corrosion at the base metal interface.
and deterioration of the plating adhesion. Through-thickness cracking also can lead to fatigue or stress corrosion cracking of the base metal beneath the plating.

Visual evidence of chicken-wire cracking after chrome grinding indicates poor chrome quality and also may indicate the possibility of base metal heat damage. Chicken-wire cracking noted in SOPM 20-10-04 indicates that the chrome should be stripped and replated.

If the plating runouts are blended or machined to remove the abrupt plating edge, the techniques must be well controlled to avoid damaging the adjacent base metal. Improper blending can remove the required shot-peened layer or create undercuts or grooves at the edge of the plating that can cause cracking in service.

Several in-service fractures have been attributed to improper plating technique, poor-quality plating, improper runout conditions, and base metal damage caused by poor blending or machining control.

Proper use of special plating techniques, such as conforming anodes and robbers, can control plating thicknesses and runouts. This can reduce the possibility of chrome chicken-wire cracking and poor runout details.

Plating into a transition (radius transition or undercut) will create a stress concentration that can cause crack initiation. For example, figure 1 shows an outer cylinder clevis plated into the lug transition. In service, fatigue cracking initiated at the plating runout led to lug fracture.

**Corrosion and pitting.** Corrosion pits are stress concentrations. As the pit forms, it damages the shot-peened layer locally at the surface. The pit then grows through the compressive layer, and the change in residual stress state and the pit geometry initiate stress corrosion cracking. This type of cracking most often occurs on surfaces that are both prone to corrosion and exposed to sustained tensile stresses while in service, such as the lower surface of landing gear trucks, axles, and the surfaces of forward and aft trunnions.

Corrosion pitting also can lead to fatigue crack initiation depending on the component, the location of pitting, and cyclic loading conditions. In these cases, the cracks can propagate to the critical length and result in ductile fracture of the component. The degree of cracking tolerated before fracture varies by component, crack location, and component loading conditions.

To prevent excessive corrosion, thorough visual inspections should be performed on a regular basis to evaluate the condition of the protective finishes. Damage should be repaired soon after it is found. Touching up damage to accessible enamel and primer in a timely manner can prevent the formation of corrosion pits and reduce the need for excessive rework during overhaul. Rework that requires low-hydrogen-embrittlement (LHE) cadmium stylus plating should be performed when the component is not loaded.

When the component is removed for overhaul, all evidence of corrosion must be removed and finishes restored to design requirements or better. The sequence of rework operations is provided in CMMs 32-00-05, 32-00-06, and 32-00-07.

Landing gear truck fractures have occurred in service because of corrosion on the inner diameter of the main gear truck beam (figs. 2 and 3). These fractures may be caused by a combination of degraded protective finishes on the truck inner diameter, poor drainage, and contact with the corrosive chemicals in washing solutions or deicing compounds. Truck fractures most often occur at maximum ground loads such as after fueling or during preflight taxi.

Figures 4 and 5 show a drag brace from which corrosion was not removed completely during overhaul. The part was subsequently shot-peened, and new protective finishes were applied over the residual active corrosion. This resulted in crack initiation and propagation while in service and the eventual fracture of the component.

**Mechanical damage.** Stress concentrations can be created by mechanical damage that compromises the protective finishes and alters the compressive shot-peen layer. This
damage often is caused by improper maintenance practices such as jacking adjacent to a jack pad or an inadvertent impact with tools or ground-support equipment (e.g., tow vehicles). Although high-strength alloy steels are hard and resist dents, scratches, and nicks, stress concentrations caused by mechanical damage can dramatically reduce the service life of a component.

High-strength alloy steel components also can be damaged by mishandling during shop rework (e.g., dropping, impact), and in some circumstances, by foreign object debris. Possible mechanical damage to a high-strength alloy steel component should be evaluated by the operator and repaired as needed.

If the damage is local and widespread deformations are not evident, repair may be similar to that required for corrosion and pitting. All deformed material must be removed before refinishing; deformed high-strength steel alloy components must not be straightened. Contact Boeing for assistance, if needed.
OVERHEATING COMPONENTS

Overheating of components can change the original steel temper and mechanical properties of the affected area. Overheating damage can be caused by:

- Frictional heating while in service.
- Abusive machining and grinding operations during manufacture or overhaul.
- Exposure to high temperatures during overhaul bake cycles.
- Unusual conditions such as refused takeoffs and local fires.

The degree to which the mechanical properties are changed depends on the temperature and duration of exposure.

Overheating can result in overtempered martensite (OTM) or untempered martensite (UTM) formations in the base metal. Both conditions can be detected by a temper etch (i.e., nital etch) inspection of the base metal. UTM indications show white during temper etch inspections and often are found within patches of OTM, which show dark gray to black during temper etch inspection. SOPM 20-10-02 provides details about the inspection process and interpretation of the results.

Heat damage generally is removed by carefully machining the base metal. Afterward, another temper etch inspection is done to ensure that the machining did not create more heat damage.

UTM formations may be accompanied by heat-induced cracking within these overheated areas that, if left in place, can propagate while in service. Figures 6 and 7 show service-induced heat damage on the inside diameter of a main gear outer cylinder. This component developed extensive frictional heat damage in the upper bearing contact area as a result of improper clamp-up. The heat damage led to cracking through the cylinder wall. Salvage was not possible.

Less severe friction-induced heat damage can be found on inner cylinders during component overhaul. This damage, which occurs on a more frequent basis, is caused by vertical motion against the lower bearing surfaces. This damage generally is shallow and can be removed by machining. After overhaul operations are completed, the component is returned to service in accordance with CMM requirements.

When grinding chrome to finish dimensions, overheating the base metal can create UTM and OTM formations under the chrome. Figures 8 and 9 show a severe grinding burn on a main landing gear axle that resulted in a fracture. Similar grinding burns also have led to the fracture of flap carriage spindle journals (figs. 10 and 11).

Any visible evidence of chrome plate distress can indicate the likelihood of base metal heat damage. Figures 12 and 13 show a grinding burn that led to the fracture of a pivot pin. SOPM 20-10-04 and CMMs 32-00-05, 32-00-06, and 32-00-07 provide guidelines that indicate when chrome must be removed during overhaul.

Some heat damage is so severe that the heat-treat condition of material is altered in adjacent areas. This widespread reduction in metal hardness (Rockwell-C hardness readings) may indicate that the component cannot be salvaged. Axle heat damage caused by a wheel bearing fracture may lead to such a condition.

Shop procedures such as magnetic particle inspection and LHE cadmium stylus plating can cause arc burns if appropriate precautions are not maintained during processing. Figures 14 and 15 show a fracture resulting from an arc burn that developed during LHE stylus cadmium plating. (Note: In this article, cadmium plating means cadmium-titanium or LHE cadmium plating.)

Overheating will not alter the heat-treat conditions of the base metal if the temperatures are below the original tempering temperature. However, the component still may require special...
consideration (or rework) because
■ Shot-peening may be compromised (heated above 400°F).
■ Cadmium embrittlement may occur (heated above 450°F with cadmium plating present).
■ Chromate conversion coating may be degraded (heated above 400°F).
■ Organic coatings or sealants may crack or become brittle or discolored (wide range of temperatures).

These situations often occur when components are
■ Inadvertently overheated in an oven.
■ Exposed to elevated temperatures with some finishes intact or bushings installed.
■ Exposed to fire.

Residual cadmium often is left on a part during overhaul processing to protect it from corrosion. The part is then stripped of all cadmium and re-plated near the end of overhaul. Parts with residual cadmium should not be heated over 400°F during overhaul.

Bushings should not remain installed during overhaul unless retained by specific CMM requirements. Bushings must be removed to permit a thorough inspection of the base metal and to avoid bushing-to-bore interface degradation during bake cycles. Design finishes are restored and new bushings with design interferences and dimensions are installed because bushing wear limits do not apply during overhaul.

Wheel bearing fractures or high-energy refused takeoffs often result in high local heat on an axle. Discoloration of the enamel, primer, or chrome or evidence of cadmium damage on the inner diameter of the axle may require the heat-damaged component be removed from service.

Overheating affects components to various degrees; in some instances, only finish durability is degraded. This may result in a shorter than planned time between component overhauls. Contact Boeing for assistance with questions about repairing or salvaging high-strength alloy steel components that appear to have been damaged by overheating.

**HYDROGEN EMBRITTLEMENT**

Hydrogen embrittlement occurs when a high-strength alloy steel component absorbs hydrogen, which is not removed in a timely manner in accordance with the SOPM (e.g., embrittlement relief baking).

When hydrogen remains in a component for an extended time, the microstructural damage that develops significantly degrades the mechanical properties of the steel. The infused hydrogen migrates to areas of high stress (e.g., material internal stresses) and creates local microstructural damage. When the component is installed on an airplane, this internal damage can lead to crack initiation and propagation, resulting in component fracture.

The elevated temperatures reached during hydrogen embrittlement relief baking, which is performed directly after stripping or plating operations during overhaul, effectively remove hydrogen generated during these operations. Processes that must be followed with relief baking include chrome, sulfamate-nickel, and LHE cadmium plating; stripping operations; and many nital etch inspections. After hydrogen-generating operations, relief bake delay time limits must be observed to ensure complete hydrogen removal. In general, the best practice is to initiate baking as soon as possible following a plating operation.

The delay time between plating completion and baking start typically is observed. However, when thick plating deposits or multiple plating operations are performed on a single component, the total time between initial plating start and baking start is a key factor when determining the maximum delay time allowed. For example, embrittlement relief baking must begin 10 hr after sulfamate-nickel plating is completed or within 24 hr after plating.
begins, whichever results in the shortest overall bake delay.

Figure 16 shows a flap track that cracked because of hydrogen embrittlement 149 flight cycles after overhaul. Figure 17 is a scanning electron microscope view of a typical hydrogen embrittlement crack where separation occurs along grain boundaries. Typically, hydrogen embrittlement cracks propagate rapidly once loads are applied to the part. In some cases, internal residual stresses are sufficiently high to cause cracking even before the part is installed.

**Cadmium Embrittlement**

Overheating LHE cadmium or cadmium-titanium plated components causes embrittlement of high-strength alloy steel by cadmium, resulting in cadmium diffusion into the steel grain boundaries. Solid-metal embrittlement by cadmium can occur at temperatures below the cadmium melting point. These effects on the base metal can begin to occur at 450°F, whereas the cadmium melting point is generally 610°F. The microstructural anomalies resulting from cadmium embrittlement can lead to component fractures in service.

Determining whether cadmium has migrated into the grain boundaries of cadmium-plated, high-strength alloy steel components requires destructive testing of the components. If these components have been overheated, salvage may not be possible. However, if high-temperature exposure was short and discoloration of the enamel or primer was minimal, the component may be a candidate for salvage. Slight or no discoloration of the enamel or primer may indicate the cadmium plating was not heated to the extent that cadmium embrittlement would be suspected. Boeing can assist in this determination.
Improper Finishing

Improper application of protective finishes during manufacture or overhaul can lead to finish degradation, corrosion, and corrosion pitting, which can result in component fracture while in service (figs. 2 and 3, pp. 27–28). Some cleaners and chemicals may accelerate finish degradation and lead to corrosion. Operators should ensure that cleaners and chemicals are tested before use in accordance with Boeing document D6-17487, Evaluation of Airplane Maintenance Materials. Testing to these requirements will determine whether a cleaner or chemical is detrimental to protective finishes or base metal. However, long-term exposure to the solution or material still may adversely affect finishes.

During overhaul (including removal of bushings and bearings in all structural components). This allows a thorough inspection of the base metal (a primary component overhaul requirement) and ensures that all finishes, including the LHE cadmium plating and conversion coating, are restored to the original design requirements. This is addressed in an all-model Boeing service letter dated April 23, 2002, Overhaul of High Strength Steel Components–Cadmium Strip Required (e.g., 757-SL-20-036-A, 767-SL-20-038-A, 747-SL-20-062-A).

Restoration of the shot-peened layer during overhaul is important to ensure that the shot-peen compressive residual stresses are maintained or restored. Removing or damaging the shot-peened layer can reduce the protection that this compressive layer provides against fatigue and stress corrosion crack initiation. Discontinuous shot-peening can lead to crack initiation at the tensile surface stresses adjacent to edges of abrupt compressive layer runouts (no fade-out). All reworked surfaces must be shot-peened after removing material damaged by corrosion, heat, and deformation.

As a rule, if material removal exceeds 0.0015 in (or 10 percent of the Almen strip intensity), the surface should then be shot-peened to CMM requirements. Exceeding shot-peen requirements is better than leaving areas without shot-peening. All portions of a component that are to be shot-peened should first be completely stripped; no cadmium residue should remain on the surface.

Personnel must ensure that materials used for activities such as cleaning and deicing conform to Boeing document D6-17487 requirements and will accomplish the intended task (verified by the material provider or operator). Refer to the Aircraft Maintenance Manual for materials specified for aircraft cleaning and deicing. The CMM specifies the materials for use in repair.

High-strength alloy steel components should be stripped completely during overhaul (including removal of bushings and bearings in all structural components). This allows a thorough inspection of the base metal (a primary component overhaul requirement) and ensures that all finishes, including the LHE cadmium plating and conversion coating, are restored to the original design requirements. This is addressed in an all-model Boeing service letter dated April 23, 2002, Overhaul of High Strength Steel Components–Cadmium Strip Required (e.g., 757-SL-20-036-A, 767-SL-20-038-A, 747-SL-20-062-A).

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High-strength alloy steels are used widely in landing gear, flap track, flap support carriage, and flap actuating components on Boeing airplanes. These high-strength materials provide significant structural benefits and can result in a weight savings. These parts often are selected for placement in limited-space envelopes (e.g., wheel wells and wing trailing-edge support structures) because of their reduced profile or smaller diameters.

With these benefits comes a need for airline personnel to exercise precise care when reworking high-strength alloy steel components during scheduled maintenance and overhaul. They need to understand the importance of maintaining component finishes while in service, follow proper rework practices, and use Boeing-provided maintenance procedures, planning guidelines, and checklists during scheduled maintenance and overhaul processes.

Improper rework and overhaul practices may result in loss of finish, corrosion, and damage to or alteration of the base metal, which may require unscheduled maintenance between overhauls. The resulting damage also could precipitate crack initiation and removal of the part from service. Removing corrosion and restoring worn interfaces on a periodic basis are the main emphases of high-strength alloy steel component overhaul rework.

Key benefits of proper rework and maintenance practices include the possibility of extending the gear or component overhaul intervals (time between overhaul). Operators also will benefit from the enhanced reliability and durability of high-strength alloy steel components on their airplanes.

Operators should ensure that proper SOPM and CMM documentation is used during overhaul and rework of high-strength alloy steel components. The planning flowcharts in CMMs 32-00-05, 32-00-06, and 32-00-07 are value-added guidelines for planning the rework of any high-strength alloy steel component on a Boeing airplane.

Editor’s note: The SOPMs and CMMs identified in this article can be ordered through the Data and Services Catalog.
About the Authors

Ralph M. (Mike) Garber has been a structures engineer in the aircraft industry for 38 years, including 28 years as lead engineer and the past 7 years as an Associate Technical Fellow. His primary responsibilities have involved design and certification analysis of the wing, empennage, nacelle struts, and landing gear with a focus on airline workshops and identifying design improvements to increase durability and fatigue resistance. He is a licensed professional engineer and has assisted in NTSB investigations and Boeing- and FAA-recommended structural changes.

Craig Dickerson has been a metallurgical engineer in the aerospace industry for 18 years. As lead engineer for the Boeing Materials Technology Landing Gear Design Center support group and former lead engineer for the Fracture Analysis group, he is involved with all aspects of landing gear structure materials and processes, including detail part manufacture, in-service performance, component overhaul, analysis of parts returned from service, and accident and incident investigations.
INCREASED USE OF TITANIUM ALLOYS AND TUNGSTEN-CARBIDE COATINGS

Boeing and the industry are working together to develop thermal spray coatings to replace chrome plating. These coatings, which currently are used in some production and repair applications, can be applied using the high-velocity oxygen fuel (HVOF) process. The two coatings primarily in use are tungsten-carbide-cobalt and tungsten-carbide-cobalt-chrome.

These tungsten-carbide coatings can be applied to steel and titanium alloys. Steels can be either chrome plated or coated with tungsten-carbide. Titanium alloys cannot be chrome plated but can be coated with tungsten-carbide through the HVOF process. With this coating, the lighter weight titanium can be used in more landing gear and flight control applications where high-strength alloy steels would have been used in the past, resulting in a weight savings.

Titanium alloys are being used more often in the design of new landing gear and flight control support structure. These materials, which are becoming more readily available, exhibit higher strength-to-weight ratios than do steel alloys. Titanium alloy components require less finishing, are more easily maintained, are less prone to corrode in service, and require less overhaul processing than most high-strength alloy steel components. The durable, HVOF-applied tungsten-carbide coatings broaden possible titanium alloy applications. HVOF-applied tungsten-carbide coatings also provide multiple process benefits when compared with chrome plating:

- Embrittlement baking is not needed after application because hydrogen does not infuse into the base metal.
- When grinding the coating to the desired finish, overheating the base metal is less likely.
- Applying coatings using the proper HVOF procedures and equipment can save shop processing and flow time.

These benefits are driving more tungsten-carbide applications to be identified for both steel and titanium alloy components in production and as a substitute for chrome plating during component overhaul. Some repair agencies and airlines are purchasing equipment and preparing facilities for HVOF coating application during overhaul as an alternative to chrome plating.

MAINTAIN FINISH DURABILITY THROUGH PROPER WASHING, CLEANING, AND FREQUENT RELUBRICATION

Properly restoring the finish of high-strength alloy steel components to original design conditions during overhaul minimizes the effects of washing and cleaning solutions, solvents, and compounds on the structure. Design-quality finishes are less likely to degrade in service. In addition, frequent relubrication of these components soon after washing protects finishes at lubricated interfaces. Relubrication intervals are specified in the Aircraft Maintenance Manual (AMM) but generally are adjusted based on operator experience.

Boeing continues to receive reports of premature corrosion from operators that use pressure-washing techniques on their airplanes. The following guidelines will help operators maintain the finishes of their high-strength alloy steel components through heightened awareness and knowledge about key aspects of airplane washing processes.

Washing and Cleaning Techniques

- Operators should avoid using high-pressure washing.
- When cleaning landing gear and other mechanical, electrical, or hydraulic components, operators must follow the requirements in the AMM procedure Remove Material Around Sensitive Components (e.g., 747-400 AMM 12-25-01, p. 301, 2.A.2[J]).
- After washing landing gear and control surfaces, operators should complete rinsing within the specified time period. Rinsing must not be delayed.
- Operators should cover joints without relubrication fittings to avoid contamination from water and cleaning solutions.
- If washing is done at the beginning of a scheduled maintenance period, operators should not wait until the end of the period to perform lubrication—the elapsed time may not be acceptable.
- When flushing or rinsing landing gear assemblies, operators should reduce spray pressure, ensure that the nozzle is at least 12 in from the joints, and replace the corrosion preventative compound after washing. (See the multimodel maintenance tip, “Airplane High Pressure Washing,” May 18, 1999.)

Impact of Aggressive Washing on Finishes and Lubrication

- Short-term exposure to materials that normally contact properly restored finishes, such as solvents, should not cause premature degradation or loss of finish requiring repair or unscheduled removal between overhaul. However, premature corrosion and deterioration can occur in service when water or foreign material enters joints as a result of spraying cleaning solutions directly into joints. This aggressive washing technique displaces grease and negatively affects lubricated joints even though immediate relubrication will purge most contaminants from the lubricated cavities.
- Most corrosion-related cracking and fractures in service are aggravated by aggressive washing techniques and corrosive solutions. To help ensure that finishes do not degrade prematurely between overhaul, operators should lubricate all greased bearings and cavities no later than 12 hr after airplane washing. Relubrication and replacement of corrosion preventative compounds within this time period minimizes finish exposure to corrosive cleaning agents following airplane washing.

High-pressure washing is detrimental and should not be used under any circumstances.
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