Low airplane maintenance costs and high dispatch reliability are key to the financial success of any airline. Both these performance measures are central to the design of the 717-200, the newest Boeing twinjet airplane for the short-haul, high-frequency, 100-passenger market. Airline experience to date indicates that the 717 is exceeding its economic performance targets.
HIGH DISPATCH RELIABILITY
In the competitive airline industry, low direct operating costs (DOC) are key to airline profitability. The five elements of DOC are ownership costs, flight and cabin crew costs, fuel costs, maintenance costs, and other costs (fig. 1). Maintenance costs are a significant part of DOC. In fact, the world’s airlines spend more than $40 billion on airplane maintenance each year. Depending on airplane age, type, and range, maintenance costs typically represent 10 to 20 percent of DOC. Understanding how the 717-200 provides operators with low maintenance costs and high dispatch reliability requires a discussion of the following:

1. Industry definition of maintenance costs.
2. Airplane maintainability and reliability by design.
3. In-service support.
4. 717 operator experience to date.

**INDUSTRY DEFINITION OF MAINTENANCE COSTS**

The air transportation industry describes airplane maintenance costs as the expenditures required to restore or maintain the systems, components, and structures of an airplane in an airworthy condition. These costs include expenses for direct airframe and engine maintenance and maintenance overhead.

Direct airframe and engine maintenance costs are the costs of the labor and materials required to perform servicing, repair, modification, restoration, inspection, test, and troubleshooting tasks during on-airplane and shop maintenance activities. Maintenance overhead costs are unallocated labor costs and the expenses for maintenance supervision, training, and planning; equipment rental; and utilities. Overhead costs do not include capital expenses for facilities, spares, test equipment, maintenance tooling, and ground-support equipment.

To help operators and manufacturers understand the relative maintenance costs of airplane features and the factors that influence those costs, the total cost of maintaining a specific airplane model can be subdivided several ways. One method...
is to divide maintenance costs according to airplane systems, as defined by Air Transport Association (ATA) chapters (fig. 2). Cost data at the ATA chapter level are used to analyze the effects of design choices and project maintenance costs for new and derivative airplanes.

Another approach is dividing total direct airplane maintenance costs according to routine and nonroutine activity (fig. 3). Routine maintenance comprises scheduled tasks outlined in airline maintenance programs. Nonroutine maintenance involves unscheduled on-airplane repairs and the removal and restoration of components. Nonroutine labor and material costs are the primary causes of increasing maintenance costs as an airplane ages. Operators and manufacturers strive to reduce nonroutine maintenance because of its effect on schedule reliability and airplane downtime.
2 AIRPLANE MAINTAINABILITY AND RELIABILITY BY DESIGN

During design of the 717, Boeing focused on the interrelated aspects of maintainability and reliability. The design team sought to reduce part counts, reduce the number of maintenance and inspection tasks, minimize downtime, increase ease of access, increase commonality of components and procedures among 717 systems, consider human factors related to maintenance tasks, and improve fault-isolation capability.

The design team implemented the following key steps to ensure continuous focus on its design goals:

- Establishment of maintenance cost and reliability baselines and targets.
- Involvement of airline advisory groups (AAG).
- Assignment of a chief mechanic.
- Continuous focus on maintainability and reliability targets.

**Establishment of maintenance cost and reliability baselines and targets.**

Because dispatch reliability and maintenance costs are directly related and can be improved through increased component and system reliability, the 717 design team reviewed the dispatch reliability of another Douglas-designed twinjet airplane, the MD-80, whose design was based on that of the DC-9. The MD-80 fleet represented a mature airplane program from which to draw reliable data. With 1.5 million dispatches annually, the MD-80 had a 98.9 percent dispatch reliability at the time that the 717 was designed. Using this information, the 717 design team established targets of a 0.2 percent improvement in dispatch reliability (99.1 percent, later revised to 99.17 percent) and a related 20 percent reduction in maintenance costs. Engine manufacturer Rolls-Royce also adopted these reliability and maintainability goals for the 717 power plant, the BR715.

**Involvement of AAGs.**

Unlike AAG participation in earlier airplane programs, the 717 AAGs not only reviewed airplane designs but also made design recommendations during the airplane design phases. The most important considerations were airplane maintainability, reliability, and maintenance costs. AAG meetings focused on numerous improvements to flight deck, interior, and airplane system designs, many of which were expected or had been shown to reduce maintenance costs and improve reliability in service. For example, the wheel brake mounting was redesigned to significantly reduce removal and installation time. A new design for the potable water system incorporates integrally heated hoses that eliminate cold-weather cracking and resultant leaks in the cargo compartment. A new, sealed flap-position transmitter on the wing protects electrical contacts from exposure to the corrosive environment.

**Assignment of a chief mechanic.**

A chief mechanic was assigned to the 717 design team to serve as an airline advocate during the design process, specifically in the areas of maintenance and operations. As a peer of the chief engineer on the design team, the chief mechanic ensured that all design decisions considered maintenance costs, dispatch reliability, and the perspective of airline mechanics, and he was able to increase the team’s awareness of fleet problems experienced on previous Douglas-designed twinjet airplanes. The chief mechanic also monitored changes made during the design process to ensure that they had a neutral or positive effect on dispatch reliability, focusing on the master minimum equipment list and the configuration deviation list.

**Continuous focus on maintainability and reliability targets.**

To help ensure that established goals would be met, the design team focused on airplane design, system design, power plant design, and scheduled maintenance program development.

**Airplane design.** The first step in the airplane design process was to examine the causes of nonroutine maintenance on previous Douglas-designed twinjet airplanes. MD-80 dispatch delays were attributed to 1,699 components (i.e., 1,699 six-digit ATA chapter classifications). Of these, 116 components caused 50 percent of the delays, and their improvement was given the highest priority by the 717 design team.

The team also focused on retaining airplane design elements that had proved successful on previous Douglas-designed twinjet airplanes, including the 100,000-cycle airframe structural design and the simple, reliable, low-maintenance primary flight control system. Figure 4 shows some of the significant 717 airplane design improvements made to lower maintenance costs and improve reliability.

**System design.** System designs on 717 predecessors were revised to improve component-level design and ease of maintenance on the 717:

- The environmental control system uses three-wheel air-cycle machines, which eliminate the need for air-cycle machine ground cooling fans and reduce scheduled maintenance. The system has 27 percent fewer line-replaceable units (LRU) than the DC-9 and MD-80 design.
- The integrated electrical system reduced the number of major components from 60 to 9, which eliminated 150 wires compared with the DC-9 and MD-80 design. The 717 system features an integrated drive generator, no-break power transfer, and interchangeable power conversion distribution units.
- The airplane interior features removable window escutcheons that permit inner and outer windowpanes replacement without the removal of seats or sidewall panels.
Electrically controlled aileron trim, rudder trim, and spoilers simplified the flight deck pedestal, or aisle stand, and eliminated many cables compared with the DC-9 and MD-80 design.

The in-line (i.e., straight-shaft), engine-driven hydraulic pumps have higher reliability than the bent-axis (i.e., articulated-shaft) pumps on earlier airplanes. The flareless fittings in the hydraulic lines significantly improve reliability because they are less prone to cracking and leakage.

The integrated flight deck has state-of-the-art displays, communication and navigation equipment, and digital flight guidance system, which cumulatively reduce the number of flight deck LRUs by 57 percent, compared with the DC-9 and MD-80 design.

The landing gear system incorporates steel brakes that are attached with 10 pins rather than traditional fasteners, which reduces installation time by 60 percent, compared with the DC-9 and MD-80 design.

The vacuum waste system, which features modular lavatories, permits single-point aft servicing and is designed for corrosion prevention.

Built-in test equipment is an integral element of many 717 digital components, reducing troubleshooting and inspection times. In addition, the integrated centralized fault display system (CFDS) receives inputs from more than 30 LRUs and presents information on the flight deck multifunction control and display units for ease of line maintenance.

The auxiliary power unit, based on a proven design, requires no specialized ground-support equipment for transport.

The 717 structures are based on the proven design of its predecessors, with improved corrosion protection and appropriate material choices.

**Power plant design.** Rolls-Royce focused on power plant maintainability, low maintenance costs, and high reliability throughout the design of the BR715 engine.

The wide-chord fan is highly resistant to damage from foreign object debris.

The engine modules are prebalanced, which allows for quick replacement.

The use of digital and hardware mockups early in the design process helped ensure LRU accessibility.

The use of lock wire on engine LRU installations was minimized.

With the exception of integrated drive generator servicing, only standard hand tools are required to perform engine maintenance.

Repair of the all-aluminum cowling requires no specialized materials or skills. To expedite line maintenance tasks, the cowling is designed for use as a mechanics’ stand and can support two mechanics and a toolbox (fig. 5, p. 24).

The majority of the LRUs are located on the bottom of the engine for ease of access.

To prevent contamination, the pneumatic elements are located on the top of the engine, away from fluids on the bottom.
The fan blades have been designed to allow on-wing replacement within 60 min.

The full-authority digital electronic control isolates and annunciates faults and interfaces with the CFDS. Unambiguous NO DISPATCH and TIME-LIMITED DISPATCH messages are displayed to the flight crew on the engine alerts display.

The latest generation engine vibration system permits data sampling for use in balancing blades.

Extending replacement intervals for life-limited parts (LLP) reduces the materials costs of engine maintenance. LLPs on the BR715 engine have target cycle limits of 25,000, 30,000, and 50,000 cycles, compared with 19,000 cycles for LLPs on the DC-9 Pratt & Whitney (PW) JT8D-15/-17 engine and 20,000 and 25,000 cycles for LLPs on the MD-80 PW JT8D-219 engine.

Scheduled maintenance program development. The scheduled maintenance program for the 717 significantly reduces maintenance labor-hour requirements (figs. 6 and 7), thereby lowering total maintenance costs. The labor-hour reduction results from improved scheduled maintenance programs and new design initiatives.

The 717 scheduled maintenance programs were developed using a process established by the Maintenance Steering Group (MSG), a committee of airframe manufacturers, airlines, and U.S. Federal Aviation Administration representatives. Through the MSG Level 3, Revision 2 (MSG-3 Rev. 2) process, maintenance programs are developed using a top-down, systems-level approach, rather than the bottom-up, component-level approach used in the development of MSG-2 maintenance programs. Only tasks deemed applicable and effective are included in the maintenance programs, which reduces scheduled maintenance activities by extending maintenance intervals and eliminating some tasks required by earlier maintenance programs. (This process also was used during development of the 777 and 737-600/-700/-800/-900 maintenance programs.) In addition, the MSG-3 Rev. 2 process integrates aging airplane maintenance programs, such as the Corrosion Prevention and Control program, which eliminates some duplication of tasks (e.g., entry and access tasks).

The time needed to conduct scheduled maintenance tasks also was reduced on the 717 compared with its predecessors through several design features:

- A single point of entry for maintenance inspections.
- Time-saving CFDS inspection procedures (e.g., checking the proper rigging of all 14 landing gear, 4 slat, and 8 door proximity sensors is accomplished from the flight deck in moments, rather than inspecting each at its location).
- Single-switch activation and reset of all cabin reading and call lights during service inspections.
Figure 8 illustrates the time-saving improvements in the 717 scheduled maintenance programs. The conversion of an MD-80 maintenance program to the MSG-3 approach results in a 35 percent reduction in cumulative MD-80 scheduled maintenance labor-hours during a 10-year period. In addition, because of airplane design improvements, the 717 requires 45 percent fewer cumulative labor-hours than does an MD-80 on an MSG-3 maintenance program.

The scheduled maintenance of the 717 power plant is similarly efficient. The BR715 engine features an on-condition maintenance program rather than a scheduled engine overhaul program, thereby allowing extended intervals between shop visits. Engine condition analysis includes monitoring of exhaust gas temperature, engine vibration, and spectrometric oil analysis program parameters. Internal engine borescope inspections can be
accomplished quickly through numerous access ports.

**IN-SERVICE SUPPORT**

By providing in-service support, Boeing helps 717 operators to attain low maintenance costs. Support programs for all Boeing commercial airplanes include on-site service representatives, a business-to-business web portal, and maintenance services. Boeing also offers services that support operators’ airplane maintenance programs, including engineering support; program management; quality support; recovery and modification; repair, overhaul, and exchange; and worldwide spares distribution.

In addition to the standard services available to all Boeing operators, Boeing offers an integrated services program for 717 customers in Europe. Customer Operation Support (COS) supports 717 customers’ daily operations with a pool of high-value rotatable spare parts, inventory management, and the repair and overhaul of the COS program parts.

Rolls-Royce supports the BR715 power plant at its Dahlewitz, Germany, facility, which is the coordination point for all in-service issues and spare parts provisioning. The engine manufacturer’s field service representatives coordinate with the Dahlewitz team.

**717 OPERATOR EXPERIENCE TO DATE**

To date, 717 operators are experiencing dispatch reliability and maintenance costs that meet or better program targets.

**Dispatch reliability.**

According to statistics reported to Boeing, 717 fleet dispatch reliability is exceeding the final design target of 99.17 percent for on-time departures (fig. 9). Dispatch reliability has exceeded 99.2 percent, and several operators are experiencing reliability greater than 99.5 percent. One operator is experiencing a 717 dispatch reliability 1.37 percent greater than that of its DC-9s. Another operator reported its 717 dispatch reliability was 1.10 percent greater than that of its MD-80s during the latest six months.

**Maintenance costs.**

Early data indicate that operators with both 717s and DC-9s are experiencing significantly lower maintenance costs on their 717s (fig. 10). Because reported maintenance costs for first-year operations are excluded from any maintenance cost analysis, maintenance data reported to the U.S. Department of Transportation are just becoming statistically significant. (The inclusion of first-year data skews reported costs because of the variable effect of airplane newness on maintenance activity.)

In addition, reports from one 717 operator, who also operates DC-9s, indicate that in-service experience is exceeding Boeing forecasts:

- The operator’s 717 in-service checks require significantly fewer labor-hours than for its DC-9 fleet. During a period of 550 flight-hours, the
cumulative total of labor-hours for 717 in-service checks is 200 less than that of the DC-9.

- Out-of-service time for the operator’s 717s is 80 percent less than for its DC-9s. Extensive maintenance inspections performed on a periodic basis (e.g., C-checks) average 3 days for the 717 compared with 21 days for the DC-9.

- The operator’s intervals between 717 C-checks are more than 8 percent longer than those of its DC-9s.

- C-check costs for the operator’s 717s are only 10 percent of those for its DC-9s.

- Regulatory authorities extended the operator’s check intervals based on the operator’s in-service experience with the 717. The A-check interval increased from 450 flight-hours to 500 flight-hours, and the C-check interval increased from 3,600 flight-hours (15 months) to 4,500 flight-hours (18 months).

- The operator’s BR715 power plant sustains far less damage from foreign object debris than the PW JT8D on its DC-9s. Another 717 operator has found that the 717 allows it to reduce maintenance costs several ways.

For example, the operator uses reduced engine power settings on takeoff (i.e., derate) to extend engine life considerably, thereby lowering engine maintenance costs.

In addition, the digital technology allows the operator to know how each system and each component within a system are operating. As a result, the operator anticipates problems before they occur and replaces units before functionality or performance is degraded. This proactive maintenance capability increases reliability and lowers the cost of line maintenance staffing and inventory requirements associated with unexpected part failures.
Maintenance costs for the 717 are the lowest of any 90- to 120-seat airplane operating today. Lower costs were achieved through a concentrated focus during airplane design on maintainability and reliability and through in-service support following airplane delivery. The 717 design team focused on the correlation between airplane dispatch reliability and nonroutine maintenance costs, which led to many system improvements and also validated the incorporation of the best features of 717 predecessors. Specific considerations during airplane design included airplane accessibility and ease of troubleshooting, inspection, and repair.

The 717 scheduled maintenance program was developed using the MSG-3 Rev. 2 maintenance process, which minimized tasks and maximized the intervals between inspections. Boeing in-service support helps ensure that airlines minimize 717 maintenance costs while maximizing reliability. To date, 717 operators report that they are experiencing high airplane dispatch reliability and relatively low maintenance costs.