The Boeing 7J7 Advanced Technology Airplane

Keynote Speech to the 1986 American Control Conference

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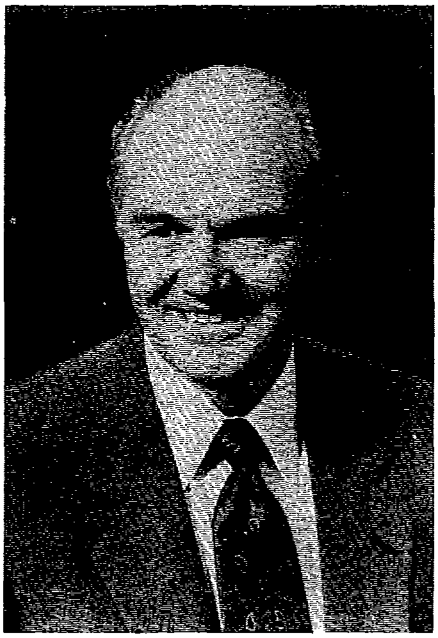
This paper discusses the background of the new Boeing 7J7 airplane that currently is in the preliminary design phase. The advanced technologies under development for application to this 150-passenger, short-to-medium-range airplane design are described, together with their impact on the operational costs of the airplane. Specific areas of interest include the ultrahigh-bypass engines, advanced structural materials, electrical flight control signaling, active controls, advanced flight-deck displays, very high reliability avionics, and comprehensive onboard maintenance reporting.

The preliminary design, technology development, and production development program leading to first deliveries in 1992 are described. The expected operational benefits offered by this advanced technology airplane are presented and compared to today's state-of-the-art designs. The paper also presents the approach being taken to improve significantly the maintainability of the airplane and its systems.



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Background

Introduction

After several years of careful study, The Boeing Company has made a decision to develop an all-new, advanced technology 150-passenger airplane for delivery in the early 1990s. This airplane, designated the 7J7, will be the first of a future Boeing family of new-generation commercial transport designs covering a broad spectrum of payload and range applications that will offer to the world's airlines unprecedented improvements in fuel efficiency and operating costs.

This decision was the culmination of broad-ranging studies that evaluated the market requirements and timing for a 150-passenger airplane, analyzing many potential aircraft designs, including all-new and derivatives. These studies also included the assessment of the status of major technical advances that are under development today and could be incorporated into an airplane delivered in the 1991–1992 time period.

Among those improvements are lightweight structural components constructed of advanced composites and aluminum-lithium alloys; laminar flow and other techniques for reducing skin friction; flat-panel flight-deck displays to reduce weight, cost, and power requirements; fly-by-wire controls; and dramatic improvements in propulsive efficiency from new engine designs such as the advanced propfan. In addition, the cabin cross section and interior features will provide the passenger with new standards of comfort in the short-to-medium-range market sector, and innovative design concepts will provide the airlines with maximum flexibility in configuring interior layouts to meet changing market demands. This emphasis on cabin interiors should provide the airline operator with an opportunity to enhance market share and operating revenues.

Economic Improvement

Overall, Boeing believes that by packaging this diversified new technology, we can offer a 150-passenger airplane in the early 1990s that will provide approximately a 45 percent improvement in fuel efficiency (passenger miles per gallon) and a reduction in direct operating costs (cents per seat-mile) approaching 10 percent when compared with the V2500-powered A320 scheduled for delivery in 1989. Never before in the history of jet transport design have improvements of this magnitude been possible without a significant increase in capacity.

During the next two years, Boeing, in conjunction with customer airlines, will optimize the cost performance of the aircraft. Development costs vs. manufacturing costs, engine total specific fuel consumption (TSFC) vs. maintenance costs, and weight savings vs. production costs represent typical areas where trade-offs will be closely examined. Boeing recognizes that the ever-escalating cost of ownership represents a key airline concern with respect to the economic feasibility of future high-technology aircraft designs. Boeing shares that concern and is placing emphasis on reducing production costs equal to the attention being given to the incorporation of new technology. For some time, Boeing proprietary studies have been under way in an attempt to develop

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design and manufacturing processes that would substantially lower development and production costs. The results of these studies, in which our suppliers are participating, are highly encouraging. In summary, Boeing is committed to making advanced technology affordable, and the key to this is emphasis on cost avoidance during the definition and preliminary design phase.

Program Timing

Initial delivery of the advanced technology airplane is scheduled for 1992, with engine availability the pacing item. Following full-scale engine ground tests in 1985 and a flight-test program in 1986, a General Electric (GE) production go-ahead is scheduled for early 1987, with certification in late 1990. The Boeing development schedule calls for an engineering go-ahead in mid-1987, with a firm production commitment in early 1988. Rollout would occur in early 1991, followed by first flight in mid-1991, and certification in March 1992. A summary program schedule is presented in Fig. 1. The general arrangement of the airplane is shown in Fig. 2.

Because General Electric is the first engine manufacturer to undertake full-scale development of a demonstrator engine, we have been working closely with GE in the initial development of our proposed design. It is important to note, however, that Pratt & Whitney, Rolls-Royce, and Allison also are aggressively pursuing highly competitive advanced technology engine concepts that should be available in the same time period.

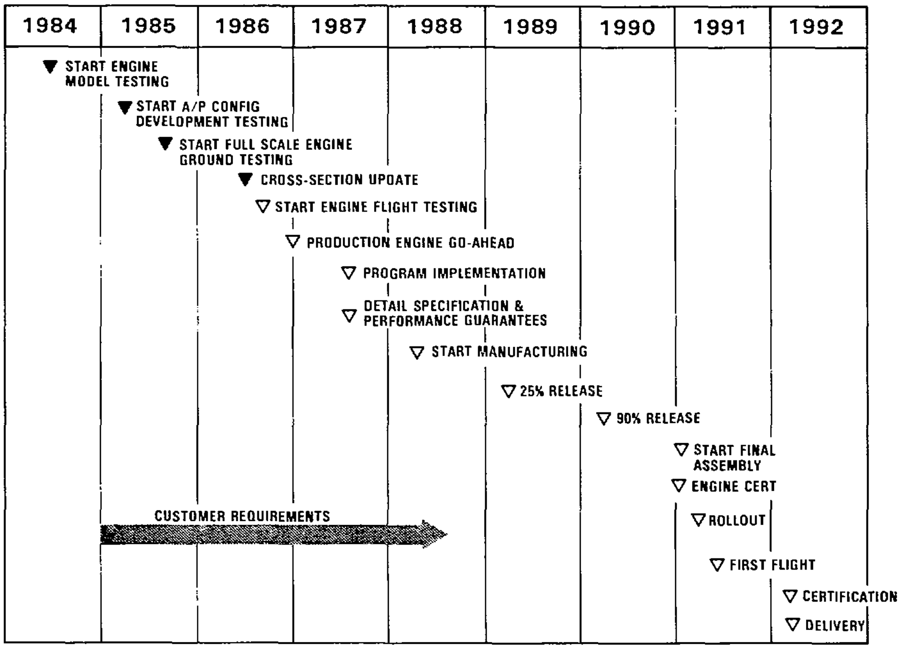

Fig. 1. 7J7 airplane development.

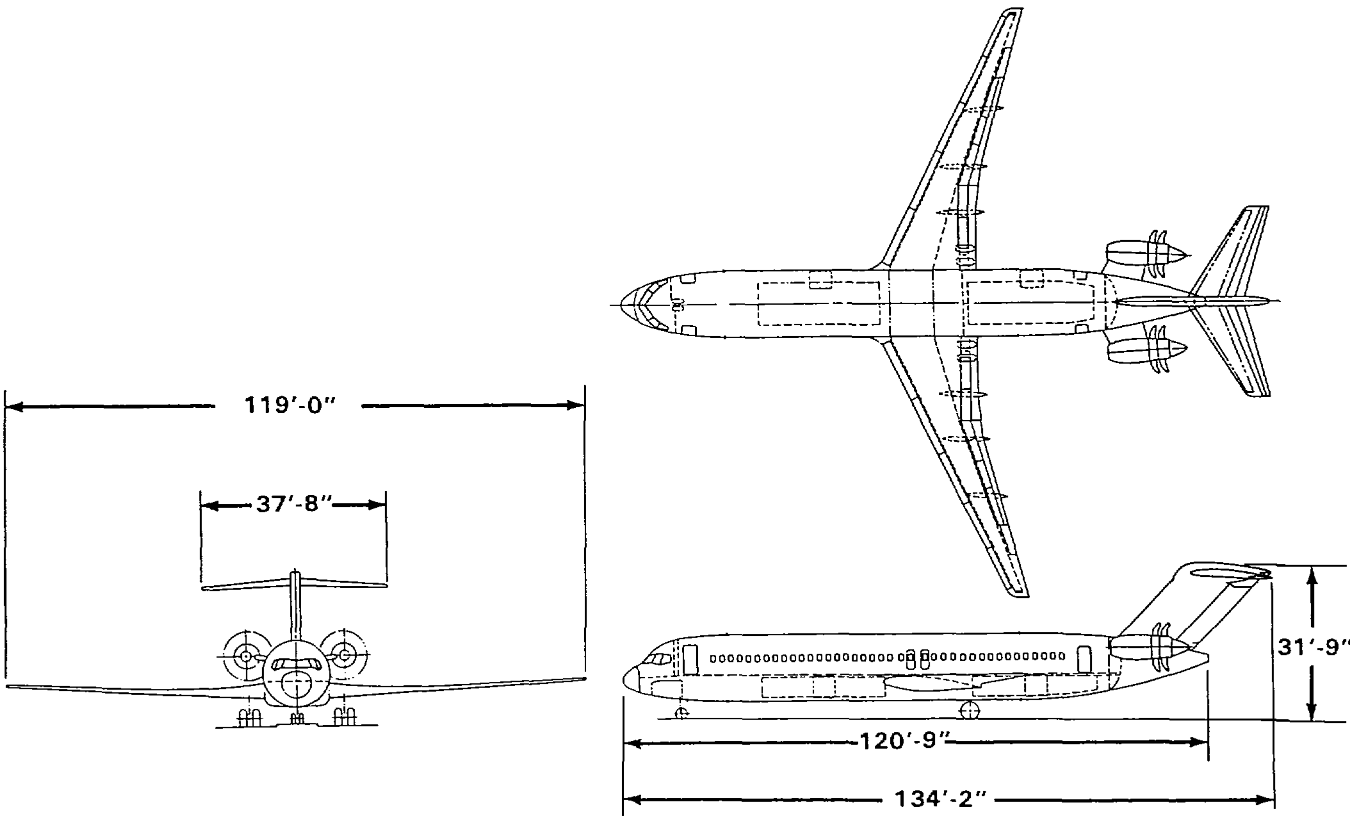

Fig. 2. General arrangement.

Accordingly, Boeing fully anticipates that a vigorous engine competition will develop.

The Boeing Company believes the development schedule outlined is reasonable and has a high degree of confidence that the target dates will be met.

Technology Development and Design Elements

The Boeing Company has consolidated its research and development activities into integrated work packages aimed at technology readiness by the end of 1987.

Propulsion Technology

Significant progress has been made in reducing the specific fuel consumption of conventional high-bypass-ratio turbofans. There is consensus in the industry that a large increase in effective bypass ratio is required if further significant improvements in propulsive efficiency are to be realized. Research and development activities over the last 10 years have led each of the major engine manufacturers to unique engine design concepts that employ counterrotating fans having a very high effective bypass ratio with minimum installed weight and drag.

Boeing has been working diligently with each of the major engine suppliers since early 1980, examining a wide variety of engine design alternatives. The most promising concepts have been incorporated into new airplane configurations to maximize the combined benefit of the engine and airplane technology improvements available in the early 1990s time frame. This work culminated in the selection of an advanced technology 150-passenger airplane incorporating counterrotating pusher engines mounted on the aft fuselage.

The General Electric Company is the first among the engine manufacturers to undertake full-scale development of a demonstrator engine of this type, known as the GE-36 unducted fan. It features a gearless arrangement in which counterrotating turbines drive the unducted fans. This demonstrator engine is part of an established development plan that will result in certified engines in late 1990. It made its first run on schedule on August 29, 1985 (Fig. 3).

Fig. 3. GE-36 unducted fan demonstrator engine.

Pratt & Whitney has teamed with Allison to conduct aggressive development of a counterrotating propfan concept that, unlike the General Electric design, employs a gearbox to transmit power from the power turbine to the counterrotating fans. Large-scale development and test programs for all the high-technology components, including the gearbox, are in place. This schedule calls for complete technology readiness for engine go-ahead by the end of 1987. They are targeting engine certification in 1992.

Rolls-Royce also has a development program in place to develop a geared propfan engine. They, like Pratt & Whitney, are concentrating on gearbox and other advanced technology issues. Allison also has announced that it has a propfan configuration program based on an existing core engine.

Following is a brief description of the development program that is in place to resolve technical issues.

Model Propulsion Simulators

Boeing has designed and built three 2-ft-diam counterrotating unducted fan simulators for General Electric to provide scale data on performance and noise characteristics of the GE-36 design. Initial high- and low-speed tests were conducted in Boeing and General Electric facilities in late 1984, and an extensive series of additional tests was conducted. The initial focus of this test program was to explore a range of fan blade geometric shapes, blade number, loading, spacing, and rotational speeds aimed at optimizing blade performance, structural design, and noise signatures both with respect to near-field cabin noise and far-field community noise. Test results to date are highly encouraging, and we are confident that performance and acoustic requirements are achievable.

The Pratt & Whitney/Allison team is testing a similarly sized propulsion simulator, and Rolls-Royce has a simulator under construction.

To measure the aerodynamic integration effects of the engine on the airframe, Boeing also is developing smaller 1-ft-diam propulsion simulators for airplane wind-tunnel model testing. These airframe/engine integration tests began in 1986.

Full-Scale Ground and Flight Tests

In late 1982, General Electric committed to full-scale development testing of their GE-36 unducted fan demonstrator engine. Key milestones in the GE program are ground testing the engine, which began August 29, 1985, and flight testing the engine, commencing in mid-1986. The objectives of the full-scale ground-test program include demonstration of mechanical and structural integrity, engine controllability, static performance, and noise characteristics. Posttest engine teardowns and inspections will be used to validate mechanical and structural engine design, to assess component reliability, and to evaluate maintainability characteristics.

In August 1986, the GE demonstrator engine was flight-tested in the number three position on a Boeing-owned 727 airplane. The objectives of the flight test are to demonstrate satisfactory engine operating characteristics over the full flight regime and verify achievement of engine performance, structural and mechanical integrity, and noise goals. The 727 airplane was delivered to GE in August 1985.

Boeing has assigned a dedicated team of highly qualified personnel to monitor and audit design development of demonstrator and production engine activities, with specific attention given to component efficiencies, power turbine integrity, propeller blade integrity, engine control systems, engine installed weight, aircraft/engine accessories, and reliability and maintenance.

Noise

Boeing requires cabin noise levels to be equal to or quieter than current turbofan-powered airplanes. Community noise goals include meeting FAR 36, Stage III, and permitting operation in noise-sensitive airports such as Hamburg and Washington National. The acoustic test program under way will provide design verification by late 1985 at model scale, with full-scale verification in 1986.

Aerodynamics

Advanced aerodynamic technologies are emerging that will result in further improvements in aerodynamic efficiency for a 1992 airplane. These advancements are the following.

- Improved computational and testing methods that will allow better aerodynamic refinement and lower development costs at the same time.
- Improved airfoil section and wing designs that allow higher span wings with minimal increase in structural weight.
- Utilization of CAD/CAM to result in a smoother airplane with reduced excrescence drag.
- Application of natural laminar flow airfoils and surface treatment to minimize viscous drag are being considered.

Structures Technology

Significant airframe weight and cost reductions can be achieved by incorporating advanced technology materials and structural design. Prime examples of advanced material systems include the application of aluminum-lithium and advanced composites in the primary structure. Advanced design concepts are aimed at further improvements in structural efficiency and reduced manufacturing costs consistent with new configuration definitions and application of advanced material systems. Development of the design concepts and material systems to a point of technical readiness is consistent with a program go-ahead in the 1987–1988 time period.

Aluminum-Lithium Development

An intensive joint aluminum-lithium development program has been under way at Boeing/Alcoa since 1982. Activities over the past year have concentrated on ingot casting scale-up, rolling of large plate, manufacturing of extruded shapes, and producing full-scale forgings. To date, over 65 production-size ingots (up to 10,000 lb) have been produced, exceeding a half-million pounds of aluminum-lithium. Current research and development activity is fully funded to bring the new material to a point of technical readiness.

Technical advances achieved to date relative to current aluminum alloys include:

- Fracture toughness equivalent to 2024 and 7050 baseline aluminum alloys at current strength levels,
- Significant reduction in crack growth rates,
- Equivalent fatigue initiation threshold cycles, and
- Equivalent general corrosion and stress-corrosion resistance.

Candidates for aluminum-lithium usage include major wing components, extensive usage in fuselage monocoque structure, and airframe major fittings and forgings.

Structural weight reduction of approximately 8 percent relative to current technology alloys is expected.

Advanced Composite Development

Advanced composite materials (graphite-epoxy thermoset materials) have been successfully introduced in Boeing's latest aircraft. Significant weight savings up to 25 percent have been achieved through density reduction and stiffness increases. Application has been on secondary structures and primary flight control surfaces to gain manufacturing and operational experience.

Incorporation of these materials on primary structure has been a long-standing goal throughout the industry. Introduction of these materials in the empennage and floor structure of a new-generation airplane is a logical next step. Five shipsets of graphite-epoxy stabilizers have been designed, fabricated, tested, certified, and placed in service for evaluation in airline operations.

Thermoplastics (polymeric materials) are currently emerging as a possible alternative to the current graphite-epoxy thermoset materials (Fig. 4). Advantages include:

- Increased impact resistance, allowing higher strain design capability in the presence of surface damage,
- Reduced manufacturing cost relative to thermosetting resins, and
- Improved environmental resistance to moisture absorption, thereby increasing design allowables.

Avionic/Flight-Deck/Systems Technology

Aircraft systems have grown in complexity to meet the demanding requirements of improved performance and reduced crew workload. Fortunately, refinements are being developed that can reduce substantially the cost, weight, and complexity of airplane systems while improving performance and reliability. These capitalize on large-scale integrated circuits and include new technology and techniques in data bus configurations, integrated avionics, and control/display devices. A common higher order software language (Ada) that facilitates multiple-use modules will be used. In addition, developments such as the global positioning satellite system, the microwave landing system, and 4D (time) navigation are being integrated into the design.

Data Bus

The advanced data bus (DATAC) is a high-speed bidirectional system with multi-

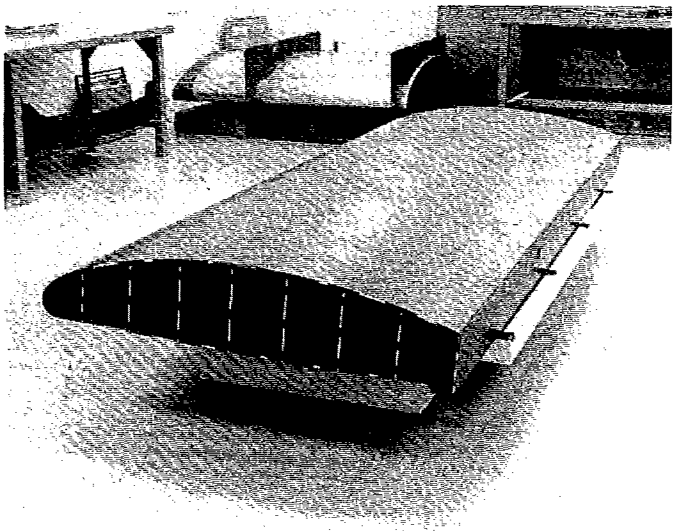

Fig. 4. Thermoplastic wing.

ple transmitters, used for avionics and airplane system communications. Both electrical and optical data buses are being developed to allow the advantages of each to be utilized and one to act as the dissimilar backup to the other in critical systems. These new data bus methods result in large weight reductions in wire, connectors, and associated equipment (Fig. 5). In addition, identical data bus transmission/receiving methods for all equipment simplifies computer I/Os, allows ease in data collection for maintenance and displays, and provides a simplified way to pass information between unrelated systems. The DATAC terminal has been developed as a single large-scale integrated circuit that is now in test. Earlier versions of the DATAC terminal are currently flying on the NASA ATOPS test vehicle, being used for communications between sensors, autopilot, actuators, displays, and test instrumentation.

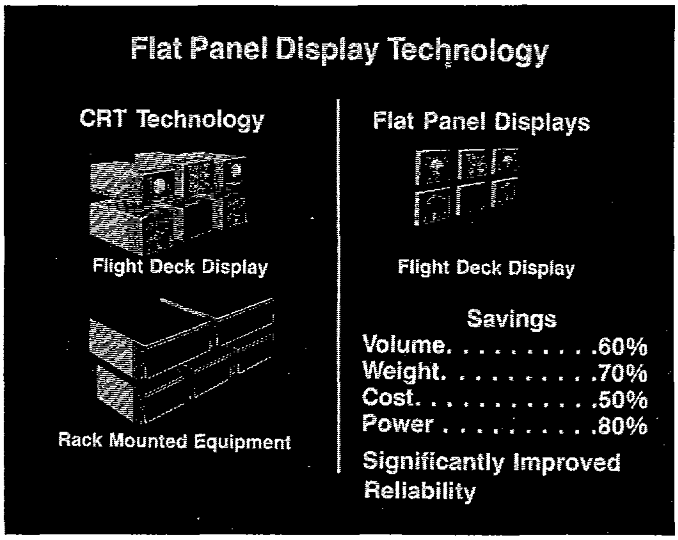

Fig. 6. Flat-panel display technology.

Advanced Avionics

Technology development in electronics continues to provide denser and larger memory packages, miniaturized components, and improved reliability. These technologies are being utilized in large-scale integrated circuit avionics that provide both multiple functions capability and very high reliability systems. Radios will integrate several of today's independent functions, symbol generators and drivers will be built in the display devices, and airplane subsystem logic will be built into the control panels. This will result in 30–50 percent reductions in the number of LRUs compared to existing technology airplanes, allowing electronic bays to be less than half their present size. Power, weight, wiring, and cooling requirements are likewise reduced by 50 percent using this technology. Simplified architectures for a total fly-by-wire/light airplane are being developed, utilizing these new improvements in electronics. Active controls, aerodynamic enhancements, and flight envelope protection logic are incorporated into this system. Spares cost reductions of 20–50 percent and mean time between failure (MTBF) of 3–20 times better than today's equipment are expected. An onboard maintenance computer is being developed for a totally centralized BITE system for both flight management and airplane subsystem components. This area of improvement will be discussed in more detail later in this paper.

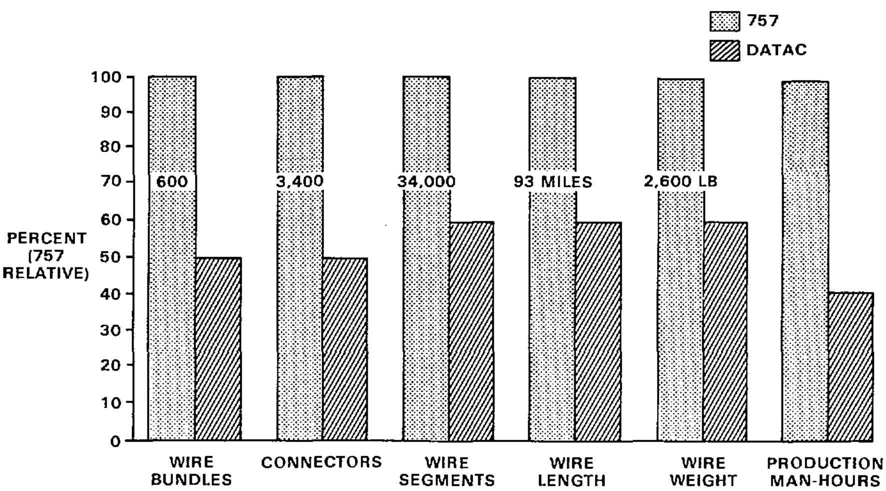

Fig. 5. DATAC benefits.

New Technology Control/Displays

Solid-state displays utilizing large, multicolor flat-panel devices are under development. They provide reduced volume, allowing more efficient installation in the flight deck, over 50 percent reduction in weight and power, and an order of magnitude improvement in MTBF (Fig. 6).

Display formatting is being developed for both conventional flight and engine instrumentation as well as for wind shear, 4D navigation, vertical navigation, and MLS. Solid-state pushbutton switches and panel lighting will provide major improvements in reliability, maintainability, and weight and power reduction.

Improved modular electronic flight controls and throttle devices are under development. These plug-in modules allow easy access and removal for maintenance while providing the flexibility of better placement and operation for the flight crews.

Flight Controls

Trade studies are being performed to determine the final electronic flight control signaling, or fly-by-wire (FBW), system. Cost-benefit analyses have shown that the higher nonrecurring costs of an FBW system compared to the conventional mechanical system are more than offset by reduced recurring costs. The current baseline 7J7-FBW system comprises full digital FBW on all primary and secondary surfaces. The system, as shown in Figs. 7 and 8, provides three levels of pilot control.

- "Core" manual mode provides conventional attitude command/hold as in today's

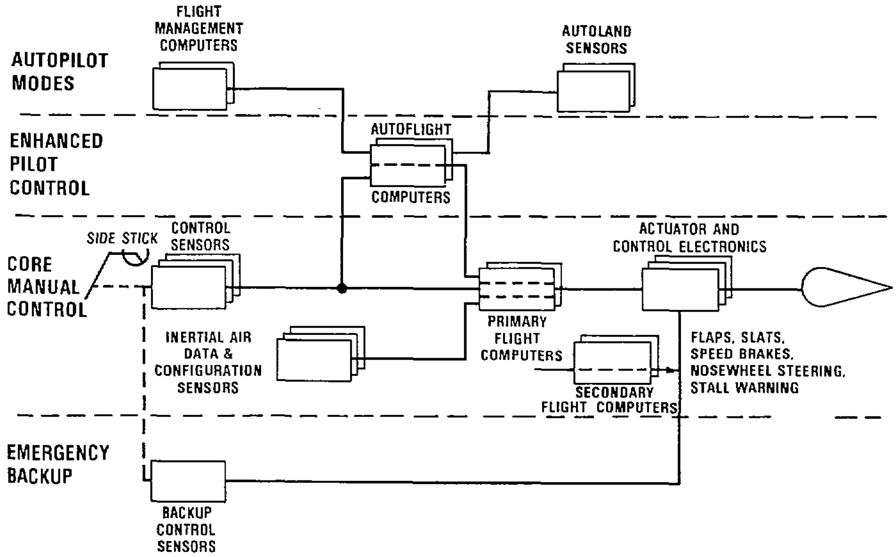

Fig. 7. Candidate fly-by-wire architecture.

airplanes, with full-time stability augmentation and critical envelope protection as required.

- "Enhanced" manual mode provides flight-path angle command/hold, or control-wheel steering, over the full flight envelope. Autothrottle is also provided.
- "Autoflight" mode provides conventional climb/cruise/descent autopilot modes, with or without flight management computer commands, and CAT III B takeoff and landing capability.

The "core" mode computation is performed in two identical, triple-lane computers, each having hardware and software dissimilar from that in the other two lanes. This provides fail operational capability even after a common-mode fault that could fail the identical lane in each computer.

The "enhanced" and "autoflight" mode computations are provided by two identical

AUTOFLIGHT SIMILAR TO TODAY'S -
- AUTOLAND WITH ILS MICROWAVE ILS
- LNAV
- VNAV

MANUAL "HANDS ON" ENHANCED
- FLIGHTPATH HOLD
- FLIGHT ENVELOPE LIMITING
- FULL-TIME AUTOTHROTTLE

MANUAL "HANDS ON"
- SELECTABLE SIMPLE CORE MODE
- SIMILAR TO BOEING 757 HANDLING QUALITIES
- EXTREMELY RELIABLE

EMERGENCY BACKUP
- PROVIDE SAFE LANDING

Fig. 8. FBW modes of operation.

dual-lane computers, with dissimilar hardware and software in each lane. Flight management functions are provided by two identical, single-channel computers.

Because this airplane will be the first to have full digital signaling on all surfaces, Boeing believes it prudent to provide a dissimilar backup. This is a simple analog control surface angle command link directly from the pilot's controls to the surface actuation electronic units. This backup will provide get-home and land capability should an extremely improbable event occur that shuts down both primary flight computers.

Pilot Controllers

Several types of pilot controller for the elevator and aileron are possible with the provision of FBW. These include a conventional wheel/column, a "slider" wheel with which there is no column ahead of the pilot, a large displacement center stick, and a small displacement center stick or side stick.

All these options are being evaluated, initially in flight-deck mockups and then in cab simulators. Finally, there will be flight evaluation of small displacement controllers in the Calspan Total Inflight Simulator (TIFS) airplane at the end of this year. The final choice of controller will be made as a result of these tests and trades of cost, flight-deck access, display visibility, access to system controls, and so forth. This decision is scheduled for early in the second quarter of 1987.

Airframe and Payload Systems

Electrical power for the flight controls system is provided by dedicated, isolated buses, with redundant engine generators, a ram-air turbine generator, and an inflight-operable auxiliary power unit. In addition, there will be a dedicated on-line battery for each flight control bus.

Recent advances in variable-speed constant-frequency (VSCF) electrical generating systems are being utilized in a new electrical system for the fly-by-wire/light airplane. Dedicated power conditioning units for avionics equipment are being studied and will provide high-quality, uninterruptable power. This will eliminate the requirement for independent power supplies in avionics equipment, a major source of problems today.

Technology developments in electrically powered actuators have resulted in both electromechanical (EMA) and electrohydraulic (EHA) power transmission actuators. Electrohydrostatic actuators are being considered on the elevators, ailerons, rudder, and spoilers. Electromechanical actuators are being studied for the secondary flight control surfaces. The choice of an actuation system will be based on considerations of initial cost, life-cycle cost, reliability, etc.

Substantial gains in passenger comfort levels will be achieved in the areas of seat and aisle geometry, carry-on baggage provisions, and environmental control systems that will provide positive smoke removal and will address individual requirements of the passenger. Greater carry-on baggage capabilities will also be provided. New individual passenger entertainment systems are being evaluated, including use of flat video screens to provide increased passenger appeal. It appears highly probable that seat-to-seat wiring and connectors can be eliminated (Fig. 9).

Improvements in interior components will provide airlines with greater modular flexibility for relocation of galleys, lavatories, stowage units, and class dividers, to allow easy reconfiguration of interior arrangements to meet changing needs.

Improved Maintenance Capabilities

Avionics

The proliferation of digital microprocessors in navigation, guidance, control, and other parts of today's airplane has greatly increased its operation envelope and reduced the crew workload. At the same time, the cost of electronic components has become a significant portion of the total cost. Maintenance of these electronic black boxes becomes an important issue from both the technical and the economic viewpoint.

Due to the high cost of the modern air-

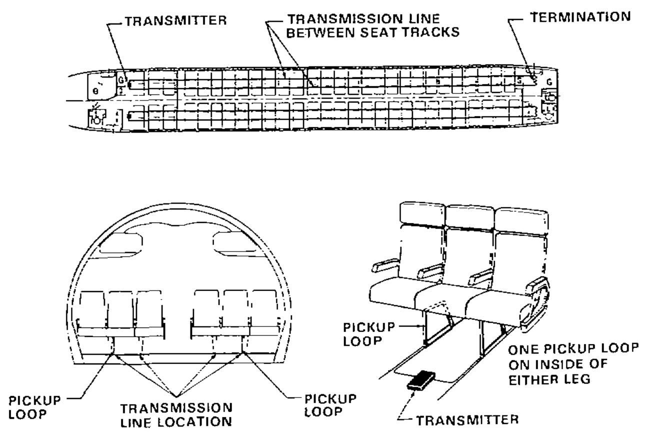

Fig. 9. Connectorless passenger entertainment system.

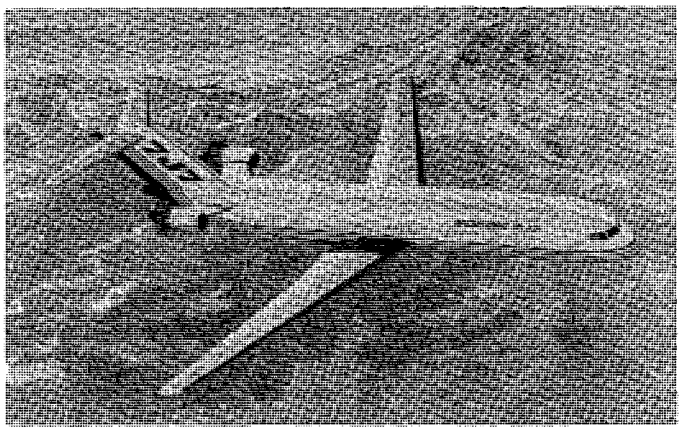

Fig. 10. Boeing 7J7.

plane and the demand of high productivity, very little ground time between flights is available for the ground crew to isolate the problem when an equipment malfunction is recorded on the airplane. The practice of shotgun maintenance is widespread. This practice not only drives up the airline direct operation cost, but neither does it usually fix the problem. Boeing has worked with the airlines and industry to build the new specification ARINC Report 604 that defines the functional requirement of BITE in the LRU and a central fault display system for future new airplanes. The new BITE will be much more accurate in isolating faults on the airplane, and it will be easy to access and operate.

Isolating the fault on the airplane is only the first half of the maintenance action. The ground crew has to locate the faulty LRU, remove it, install a new unit, and execute a verification test to complete the maintenance action. The ground crew often requires assistance to carry out the second half of the maintenance action. The information on LRU location and removal/installation instructions, both in graphic and text formats, will be available on the Boeing 1992 airplane, together with the BITE display. The information will be displayed on the screen with a simple request. There will be no need for the ground crew to go back to the maintenance station to search through the maintenance manuals (or microfilm). This onboard maintenance information system will save precious time on the flight line to protect dispatch reliability. The traditional BITE function will be combined with the onboard maintenance information system to form the new onboard maintenance system (OMS) on the Boeing 1992 airplane. The OMS will provide complete maintenance assistance to the ground crew on the flight line, which can accomplish the maintenance action in the most efficient manner without outside help.

Most of the major airlines have their own electronic shops to test the electronic equipment removed from the airplane. The various automatic test equipment (ATE) used to test the array of LRUs can be very expensive to buy and maintain. With the advancement of electronic technology, the reliability of the LRU used on the new airplane will again be increased several fold, and the LRU failure will occur much less frequently. Because of the advanced capability of the new BITE, the number of unconfirmed LRU removals will be reduced to a minimum. With improved logistic and LRU turnaround time, it may be more economical to send the removed LRU to the supplier for repair and reduce dependence on the airline shop operation. The need for airlines to buy additional test equipment will be reduced, and the cost for electronic equipment maintenance will stay in check.

Payload

Maintenance cost reduction for the payload system will be achieved through the following improvements. New sidewall panels will be designed without shock mounts, which will improve access. Also, sidewall lighting tube access will be improved. Stowage bin doors will be simplified by deleting the snubbers. Attendant seats will be designed with more emphasis on durability. In-service experience with current vacuum toilet systems will be used to refine the design of a second-generation system. Detailed design improvements to the potable water system and bulk cargo door nets are expected to reduce the maintenance requirement of those systems.

Propulsion Systems

Maintenance will be reduced on the fuel system by a reduction from three to two main fuel tanks, resulting in fewer components and a less complex system. There will also be a reduction in maintenance on the APU, utilizing a design with a less complex high-speed rotating assembly, and on the nacelle because it is significantly smaller and has fewer operating panels than the current turbofan installation.

Structures

Structures maintenance costs will be reduced by three methods. First, detailed discussions with airline maintenance personnel will provide data that will allow the design of moving structures (flaps, slats, flight control surfaces, and doors) to be simpler and easier to rig. Second, innovative designs such as the new cabin entry door type will have fewer parts and require less maintenance. Third, application of new technology (glass cabin windows, polycarbonate windshields, radial tires, and carbon brakes) will result in reduced maintenance cost.

Summary

The Boeing 7J7 airplane (Fig. 10) is the affordable new-technology airplane for the 1990s. It is the first of a future Boeing family of new-generation commercial transport designs covering a broad spectrum of payload and range applications. The 7J7 will offer unprecedented improvements in fuel efficiency and operating costs to the world airlines. We hope you will watch our progress and check the results. We are sure that, when you have done this, you will agree that the 7J7 is a revolutionary concept that really does provide affordable high technology with major improvements in operating costs to the airlines.