747 MODERNIZATION

ICAS-86-2.1.3

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INTRODUCTION

The 747 story begins with the great increase in airline traffic growth in the mid-1960s. Revenue passenger-miles (less than 50 billion in 1955) had more than tripled by 1965 on a rapidly rising trend. Air travel was forecast to reach at least 500 billion passenger-miles by the mid-1970s, and almost a tenfold increase in air cargo was predicted for the same period.

At these same rates it was estimated that passenger traffic would approximately double every five years. With airports already congested and jets lined up nose-to-tail on taxiways waiting for takeoff, adding more airplanes to handle traffic growth would only have compounded the problem.

By 1975, about 20 million departures of 707-sized aircraft would have to be scheduled each year to meet the predicted world demand. By contrast, if airplanes of 350-400 passenger capability were phased into the long-haul routes, it was estimated that annual departures could be reduced to about 12 million. Building a larger airplane was the better solution.

Development History

In the summer of 1965 Boeing stipulated four design objectives for the development of a new airplane to meet market projections:

1. To provide a capacity capable of matching the predicted market trend of the mid-1970s.
2. To design an airplane equally suited for passengers and cargo.
3. To design an airplane capable of operating from existing airports with minimum takeoff and landing noise.
4. To design for operating costs (seat-mile costs) 25 to 30 percent below existing averages.

Some of the first investigations toward meeting these goals included stretching the body of the 707. This would have provided greater capacity, but it really offered little improvement from the passenger's standpoint and reduced seat-mile cost objectives could not have been met. Additionally, few airports could have handled such an airplane because of the added weight on the two landing gears. The answer was a large wide-body aircraft with four main landing gears and new advanced-technology engines as shown in figure 1.

Fig. 1. 707/747 Characteristics

Because the airplane was to serve both as a passenger and cargo-carrying aircraft, the wide-body cross section design was heavily influenced by the desire to carry 8- by 8-foot (2.4- by 2.4-meter) cargo containers side by side. For a passenger airplane, the new body width permitted nine-abreast seating (later 10-abreast) at comfort levels higher than previous six-abreast seating. The four-post main landing gear with its 16 wheels was designed to allow operation from all existing runways accommodating 707/DC-8-type aircraft. Designed specifically for the 747, the Pratt & Whitney JT9D high-bypass turbofan engine produced twice the thrust of earlier engines and lowered specific fuel consumption by 20 to 25 percent.

Current Family

When the first 747 flew in 1969, it commanded world attention as the most technically advanced commercial aircraft ever built. Its pioneering technology involved major innovations in airframe design, engines, aerodynamics, avionics and flight control systems. Ushering in the new era of wide-body transportation, the 747 fleet carried over 7 million passengers during the first year of service.

The 747 airplane has become legendary, and over the past 17 years many new models, derivatives and options have emerged; interior designs and comfort levels have set new standards; and literally hundreds of technological improvements have been incorporated to satisfy the ever-changing needs of operators. The direct benefits of this applied technology are embodied in the new 747s with greater range and capacity, reduced fuel burn, lower operating costs and improved reliability statistics. Initial certification covered a maximum takeoff gross weight (MTOW) of 710,000 pounds (322,050 kilograms). Subsequent engine/airplane design changes have increased the capability to 850,000 pounds (385,560 kilograms) (fig. 2). Available engine thrust has grown from 43,500 to 57,900 pounds (194 to 258 kiloNewtons). Fuel capacity has been increased from 47,331 to 57,285 U.S. gallons (179,150 to 216,820 liters). Ranges have been extended from 4600 to 7100 nautical miles (8520 to 13,150 kilometers).

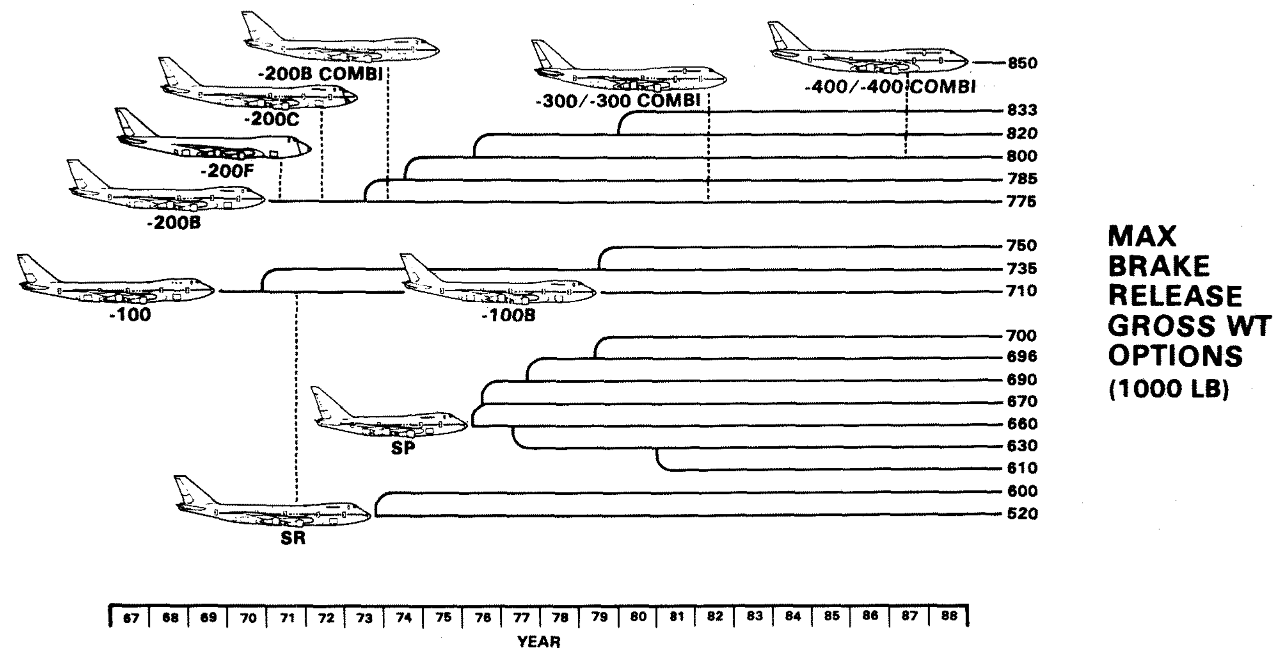


Fig. 2. 747 Airplane Family

Today the world's fleet has over 640 747s with capacities from over 600 passengers to over 120 tons (110 tonnes) of cargo with several intermediate combinations. To date, this fleet has flown over 19 million revenue hours, more than 9.5 billion miles and carried over 670 million passengers.

Each model evolved with specific features to meet and serve specific market needs. The original 747-100 more than doubled passenger and cargo payloads compared to a 707 or DC-8. Increased gross weight and engines with higher thrust ratings allowed the 747-200B to fly longer routes with increased payloads. Strengthening the floor and adding a nose cargo door paved the way for the Freighter and Convertible models. The Convertible can be changed from an all-cargo to an all-passenger configuration to fit particular markets. The 747SR (Short Range) now carries over 600 passengers, and accommodates the demands of frequent takeoffs and landings. The Combi carries passengers forward and cargo aft and adapts to markets with fluctuating demands.

The newest member of the in-service 747 family is the 747-300. Introduced in 1983, its profile is identifiable by the longer Stretched Upper Deck (SUD) shown in figure 3.

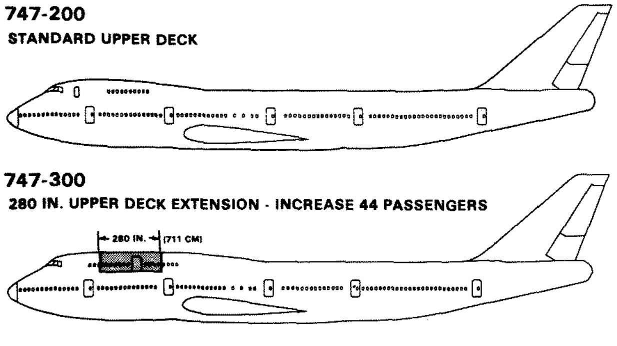


Fig. 3. 747-200/-300 Comparison

This structural change increases the seating capacity by 10% and drives seat-mile costs down by some 5%. Available in all-passenger or Combi versions, the 747-300 has captured 65% of all 747 deliveries since 1983.

By 1984 the world's airlines were issuing yet a new set of criteria for wide-body aircraft to meet their future market needs. Included in this were modifications to modernize the flight deck to require only two crewmembers and to redesign the interior to allow "quick changes," thereby permitting the flexibility for matching configurations to seasonal route requirements. In addition, there was a desire for longer range capability to allow more nonstop operations on key markets, such as the Far East-Europe and transpacific routes (fig. 4).

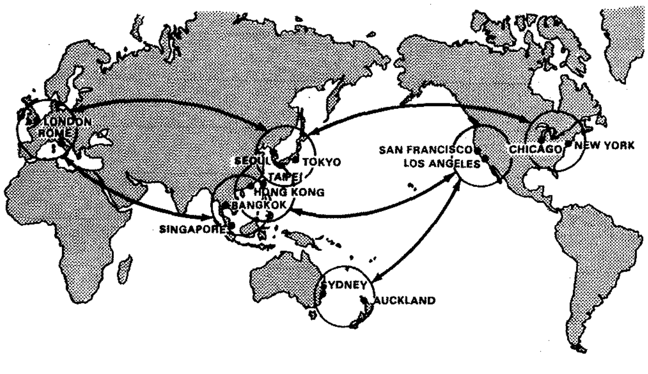


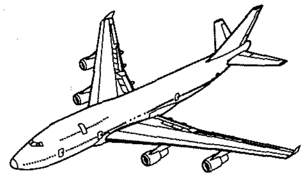
Fig. 4. 747-400 Long-Range Requirements

The New 747-400

The 747-400 development is well underway to meet these new market needs with delivery to its first operator slated for December 1988. The new Boeing 747-400 incorporates evolving technology into what will be the world's largest, most modern airliner in commercial operation. While the new 747-400 will have the same fuselage dimensions as the 747-300, it will deliver more range, better fuel economy and lower operating costs. The 747-400 has a range capability of 7100 nautical miles (13,150 kilometers), an 800-1000 nautical mile (1480-1850 kilometer) increase over the 747-300. It will consume 11 to 15% less fuel than the 747-300 depending on engine selection. An improvement of up to 25% is expected over older 747s currently in service.

To deliver superior airplane operating efficiency, the design for the 747-400 embodies technological advances in several areas outlined in figure 5. These include:

- Engines
- Aerodynamics
- Structural materials
- Avionics
- Interior design



BASELINE DEFINITION

- 800,000 LBS MAXIMUM TAKEOFF WEIGHT
- ADVANCED ENGINES
  - PW4000
  - CF6-80C2
  - RB211-524D4D
- WEIGHT REDUCTION
  - 757/767 ALUMINUM ALLOYS
  - STRUCTURAL CARBON BRAKES
- AERODYNAMIC IMPROVEMENTS
  - WING TIP EXTENSION
  - WINGLET
  - WING TO BODY FAIRING
- NEW INTERIOR
  - INCREASED CONFIGURATION FLEXIBILITY
  - LARGER OVERHEAD STOWAGE
  - VACUUM LAVATORY SYSTEM
- ADVANCED FLIGHT DECK
  - 2-CREW
  - ADVANCED AVIONICS ARCHITECTURE
  - ELECTRONIC INSTRUMENTATION
  - SIMPLIFIED SYSTEM OPERATION
  - REDUCED LRU COUNT
- OPTIONS
  - 850,000 LBS MAXIMUM TAKEOFF WEIGHT
  - 3300 U.S. GAL. HORIZONTAL TAIL FUEL TANK
  - OVERHEAD CREW REST

Fig. 5. 747-400 Baseline Definition

The following sections will address each technology area by describing the technical studies, testing and evaluation that led up to the development of the 747-400.

ENGINES

High-Bypass Turbofans

A major contributor to airplane performance is, of course, the engine. Engine manufacturers have made considerable improvements in thrust and thrust specific fuel consumption (TSFC) since the inception of the turbojet engine. The high-bypass ratio turbofan used on the 747 airplane is a typical example delivering an initial 15% improvement in TSFC compared to the low-bypass ratio turbofan engines initially used on the 707, 727, and 737 airplanes.

As shown in figure 6, cumulative engine performance improvements totalling 10% in TSFC have been realized on the 747 airplane since its introduction, along with the required thrust increase to support the 747 airplane gross weight growth. Figure 7 summarizes many of the advances in engine technology which are responsible for these improvements. The most recent advances in the high-bypass ratio engines which are being incorporated on the 747-400 airplane result in a fuel burn improvement of up to 10% over today's 747 engines as depicted in figure 8.

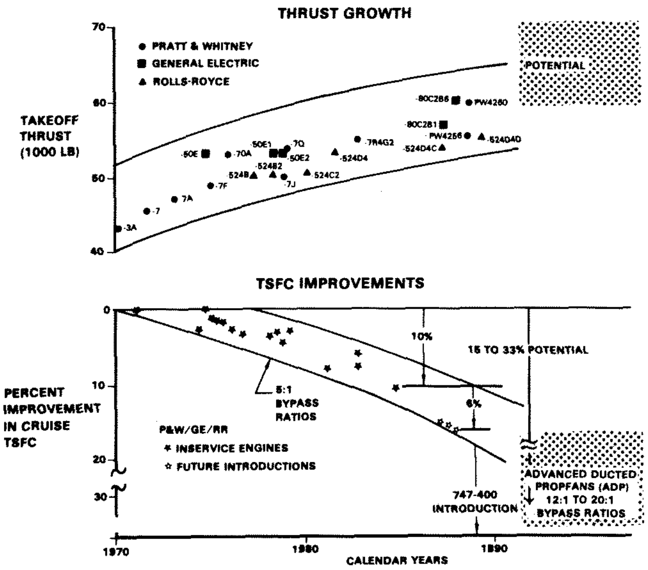
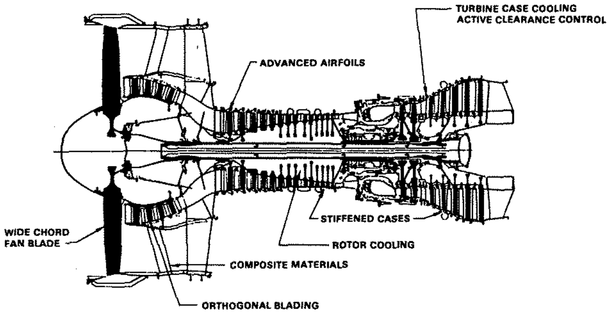


Fig. 6. 747 Engine Development



- IMPROVED MATCH OF ENGINE CYCLES
- HIGHER CYCLE TEMPERATURES
- HIGHER PRESSURE RATIOS
- REDUCED COOLING AIR FOR TURBINE AND HOT SECTION
- HIGHER ROTOR SPEEDS AND SMALLER DIAMETERS
- ALLOYS FOR BEST THERMAL EXPANSION
- FULL AUTHORITY DIGITAL ENGINE CONTROLS

Fig. 7. Engine Technology Improvements

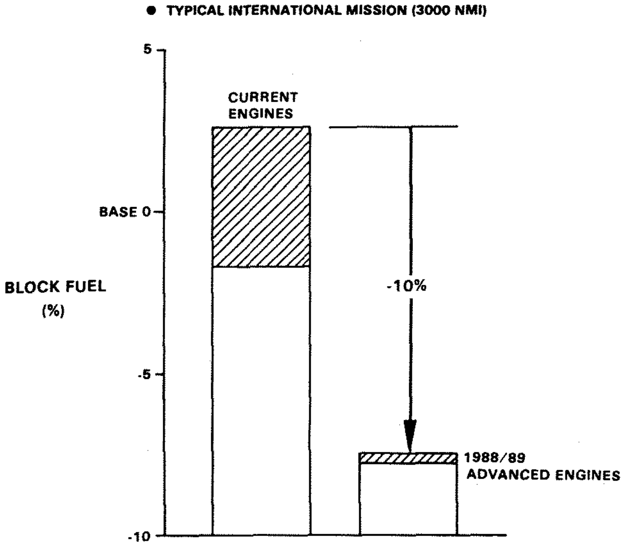


Fig. 8. 747 Fuel Burn Improvement (Engine Change Only)

Engine Control System

To achieve the desired performance improvements, engine technology advancements place greater demands on engine control systems to provide increased control accuracy, and to accommodate more variables for protecting engine stability margins. More accurate thrust management is required to minimize engine overboost conditions (operations at high turbine temperatures) and, therefore, minimize impact on engine life. These requirements resulted in the development of Full Authority Digital Engine Controls (FADEC) by the engine manufacturers. FADEC will meet the performance and accuracy requirements for all engine control functions and will also integrate the engine control functions with the airplane digital flight management and thrust management systems. The advantages of the electronic engine contol system are summarized in figure 9.

- REDUCES PILOT WORKLOAD
  - CABLE SYSTEM & HYDROMECHANICAL CONTROL SYSTEM HYSTERESIS ELIMINATED
  - ALLOWS A SINGLE SERVO AUTOTHROTTLE SYSTEM TO ACHIEVE UNIFORM THRUST SETTINGS ON ALL ENGINES
  - PROVIDES CONSISTENT THROTTLE SETTING SENSITIVITIES & FULL USE OF AISLE STAND THROTTLE LEVER TRAVEL AT ALL ALTITUDES & TEMPERATURES
  - PROVIDES ENGINE OVERBOOST PROTECTION AND ALLOWS CREW TO ACHIEVE MAXIMUM RATED THRUST BY ADVANCING THROTTLE LEVER TO FORWARD STOP
- PROVIDES IMPROVED INTERFACES WITH BOTH AIRCRAFT AND ENGINE MONITORING SYSTEM
- PROVIDES IMPROVED OPERATION/INTERFACES WITH AIRCRAFT AUTOFLIGHT SYSTEMS
- HAS POTENTIAL FOR ACHIEVING REDUCED FUEL BURN

Fig. 9. 747-400 Engine Control System (FADEC)

New Nacelles and Struts

New-design nacelles and struts will support the new advanced engines, the Pratt & Whitney PW4000, General Electric CF6-80C2, or Rolls-Royce RB211-524D4D, all rated at 56,000 pounds (249 kiloNewtons) or more thrust. Considerable wind tunnel model testing for aerodynamic and structural dynamic assessments has been carried out on each of the new engine variants. The goal of the aerodynamic evaluation is to provide an installation that minimizes installation drag effects. Structural wind tunnel model testing has been aimed at understanding aerodynamic load and engine mass effects on each installation, so that the airplane will continue to be flutter-free within its design envelope.

AERODYNAMICS

Because of the popularity of the 280-inch extension to the upper deck cabin on the 747-300 model, the decision was made to maintain this fuselage geometry as a baseline for the new 747-400. With the fuselage configuration estabished, the task of the aerodynamicists was to develop an aerodynamic configuration around the following constraints:

1. Maintain existing 747 tooling for major wing, fuselage and empennage components.
2. Keep airplane wing geometry compatible with the majority of existing airline/airport facilities.
3. Select changes that are cost-effective to both Boeing and its airline customers.

With these constraints in mind, the aerodynamics department set about establishing recommendations for the derivative airplane which would meet the airlines' needs. In the case of the 747-400, airlines' desires for extra long-range flight capability were well established, making structural weight associated with any aerodynamic improvements more significant. For example, the amount of weight that degrades fuel burned by 1% on a normal mission will degrade the maximum range by more than 2%.

Several other design considerations and constraints were examined during this development process. One consideration was airline/airport compatibility. The wing extension had to provide for proper airport gate and maintenance hangar clearances. Surveys of current airline and airport facilities show a marked increase in facility modification would be required if the wing span measured greater than 215 feet (65.5 meters). This was one of the primary reasons for choosing a winglet over additional increased wing span.

Another set of constraints can be grouped under aerodynamic loading. Trade studies were performed to tailor the wing design by taking into consideration the wing twist and camber, aeroelastics, winglet cant angle, and local section characteristics. Variations of these parameters were studied with the goal of simplifying structure, while maintaining current low speed capability and maintaining drag improvement. However, one of the most significant factors was the overall system weight. The tailoring of the aerodynamic loading as it translated to wing loads was very important in this respect. In the final configuration over half of the increase in wing weight is manifest in other parts of the main wing rather than in the tip extension or winglets.

Manufacturing constraints also "burdened" the optimum design. Manufacturing costs dictated a certain minimum spanwise radius of curvature of the basic wingtip extension, not to mention certain constraints placed on the winglet manufacturing process. Other small items, yet none the less significant in the overall design, included the provision for navigation lights in the wingtip and relocation of the HF antenna.

These factors have been balanced against the potential improvement for many candidate modifications, such as a new aft body tail cone and section changes on the basic wing. Three aerodynamic improvements providing optimum benefits are being incorporated on the 747-400 – a revised wing-to-body fairing, a wingtip extension, and a unique winglet.

Wing-to-Body Fairing

Drag improvement has been attained in the region of the wing-to-body juncture by enlarging and recontouring the fairing. (See fig. 10.) High speed flow visualization evaluation in the Boeing Transonic Wind Tunnel was used to select the optimum design. This modification is particularly effective because 1) the structural implications are minimal since it is external to primary structure, and 2) it replaces a current fairing with minimal increased weight.

Wingtip Extension/Winglet

The design goal for the wingtip extension and winglet was to provide an improvement in cruise performance, while retaining good handling qualities at low speed. Extensive low-speed and high-speed wind tunnel testing was performed to ensure that all the design objectives were attained. Two lift/drag curves, depicted in figure 11, show that the high-speed design objectives were met. The newly configured airplane was tested in the low-speed wind tunnel as shown in figure 12.

A major concern item in the design of the winglet was to ensure against premature flow separation and buffet during low-speed, high angle-of-attack operation. Figure 13 is a schematic showing the final design leading edge sweep angle of 60 degrees. This configuration was found

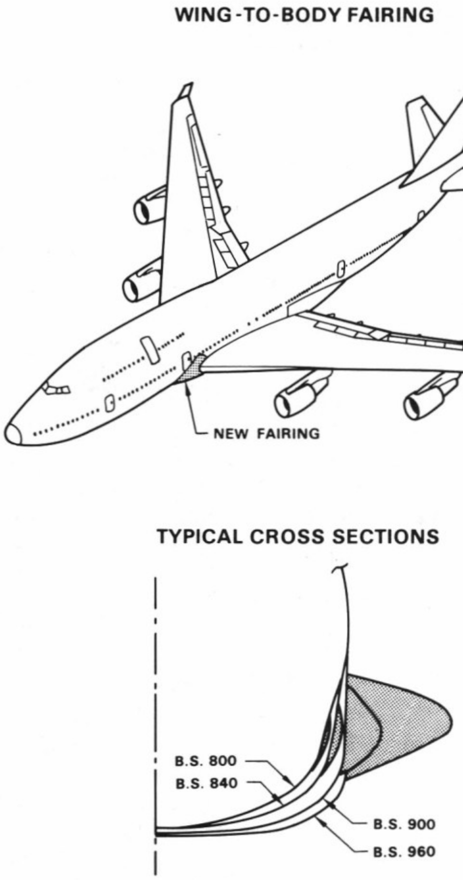


Fig. 10. Wing-to-Body Fairing Modification

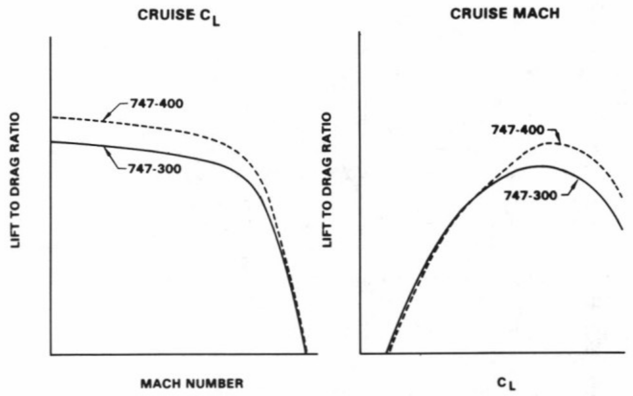


Fig. 11. Lift-to-Drag Ratio Comparison

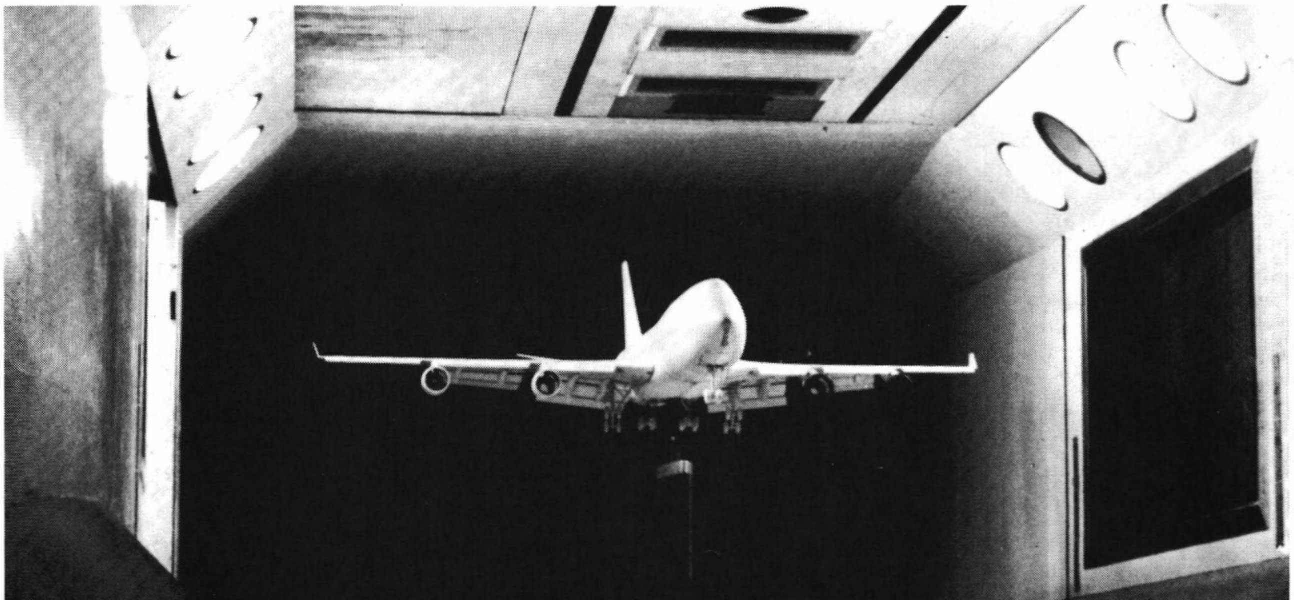


Fig. 12. Low-Speed Wind Tunnel Model Testing

to provide good low-speed capability by inducing a stable vortex at high angles of attack, which delays winglet flow separation/buffet until after wing stall. An additional variable camber Kreuger flap panel was required, however, to provide adequate leading edge stall protection for the wingtip extension.

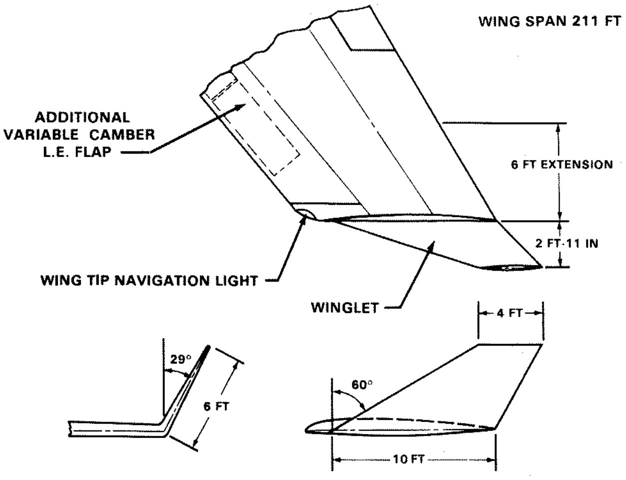


Fig. 13. 747-400 Outboard Wing Change

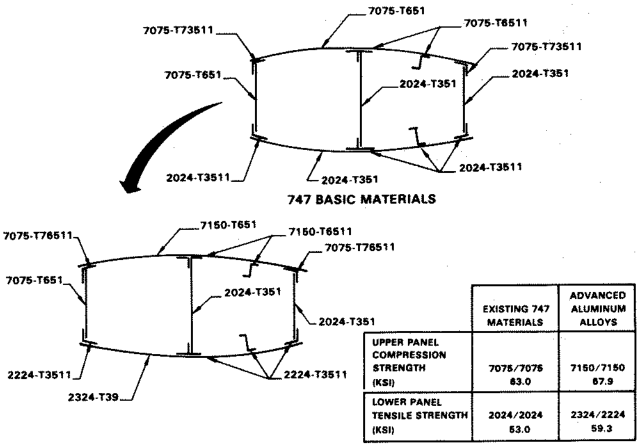
The winglet geometry arose from requirements common to other winglet designs and represents a good compromise between structural constraints and low-speed and high-speed performance. Specific winglet geometry and wingtip extension length are functions of the integration of these modifications into an existing wing design and the nature of the performance improvement goal. The design range requirement placed a premium on weight, requiring a careful blend of aerodynamic improvement versus weight increase to achieve its performance goal.

STRUCTURES AND MATERIALS

Advanced Aluminum Alloys

There are many constraints limiting the design in order to maintain a cost-effective product. It was originally envisioned that a new family of aluminum-lithium alloys would be available for the 747-400 in all forms – sheet, plate, exrusions and forgings – to support the manufacture of an airplane ready for service in 1988. Properties of the new aluminum lithium alloys promised the same strength as existing alloys used on the 747s, but with an approximate 8 to 10% reduction in density (a cumulative saving of several thousand pounds of structural weight). An added benefit would have been no change to basic 747 assembly tools. However, industry capability in the development and scale-up of aluminum lithium alloys has not kept pace with the 747-400 production schedule. Future development might allow incorporation into the 747-400 at a later date. Currently an aluminum-lithium landing gear tow fitting has been incorporated on several 747 in-service airplanes in a proof-of-concept program.

Higher strength aluminum alloys have been utilized on the Boeing model 757 and 767 airplane wings in the plate and extrusion forms. Since the change in wing loading effected by the wingtip extension and winglet required a change in structural material gages in the primary wing box an opportunity was presented to incorporate these higher strength alloys in the 747-400 wing. Figure 14 shows new alloys incorporated in the 747-400 wing, along with a comparison of the mechanical properties of existing alloys. A weight saving of approximately 5000 pounds (2270 kilograms) has been achieved in the wing with the application of the new aluminum alloys, which offset the weight increase of the wingtip extension/winglet.



	EXISTING 747 MATERIALS	ADVANCED ALUMINUM ALLOYS
UPPER PANEL COMPRESSION STRENGTH (KSI)	7075/7075 63.0	7150/7150 67.9
LOWER PANEL TENSILE STRENGTH (KSI)	2024/2024 53.0	2324/2224 59.3

Fig. 14. 747-400 Aluminum Wing Alloys

Carbon Brakes

Carbon brake technology has progressed so that applications to commercial transports are viable. Carbon brakes are used on Boeing 757s and are being implemented on the Boeing 767 wide-body airplanes. The technical advantages offered by carbon brakes include excellent heat characteristics and improved wear resistance. In brake applications this allows a lighter weight yet longer life brake system to be offered.

In the case of the 747-400 with 16 main landing gear wheels, the estimated weight saving is 1800 pounds (820 kilograms). Figure 15 shows a schematic cross section of today's 747 wheel and brake compared to a 747-400 design. One design constraint was to keep as much of the existing main landing gear and wheelwell design as possible unchanged. This required the design of a new wheel and tire to accommodate the larger volume

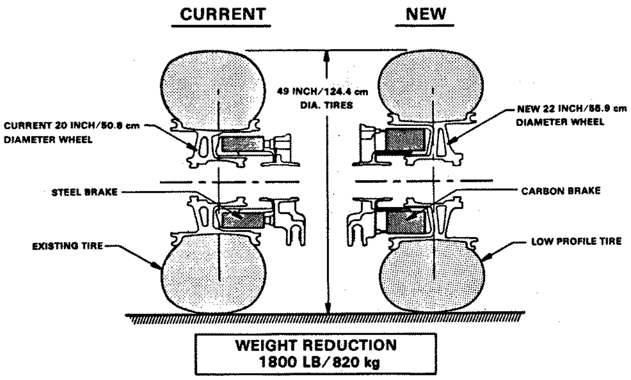


Fig. 15. 747-400 Carbon Brake Application

required for carbon brakes, yet keeping the overall outside tire diameter constant. The result is a landing gear that is stowable in the existing wheelwell cavity during flight.

Winglet Construction

The newly designed winglet offered an excellent opportunity to incorporate advanced composite materials. The winglet construction is of a conventional multi-cell torque box. Graphite-epoxy laminate is used for the spar chords, while graphite-epoxy honeycomb is used for the skin panels, spar webs, rib chords and rib webs. The leading edge and the fittings that attach the winglet to the wingtip are aluminum (fig. 16). The graphite-epoxy materials used are an industry standard and are presently used on the 737-300, 757 and 767. This system uses a 350° F (177° C) cure process that will assure maximum environmental durability in the winglet. The utilization of graphite-epoxy materials with known structural characteristics has resulted in a winglet that is durable, lightweight, and cost-effective. Compared to conventional aluminum structural concepts, the composite winglet saves 60 pounds (27 kilograms) per airplane.

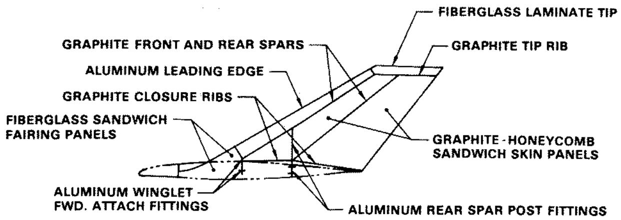


Fig. 16. 747-400 Winglet Construction

Fuel Tank Option

The significant increase in range capability of the 747-400 dictated the need for higher brake release gross weight and additional fuel capacity. Considerable study has been carried out on the 747 to locate a useable volume where additional fuel may be carried to achieve long-range mission requirements. Figure 17 shows a summary of fuel tank locations evaluated for 747-400.

All locations (except the horizontal stabilizer and the vertical fin) required building a separate container for the additional fuel. A separate container requires more structural weight per unit volume of fuel contained than modifying existing structure for fuel containment. For example, the flat-sided tank studied in the aft lower bulk cargo hold had a capacity of 1620 U.S. gallons (6130 liters) of fuel, but required almost 2000 pounds (905 kilograms) of added structural weight. By using the horizontal stabilizer internal volume, 3300 gallons (12,490 liters) of fuel volume was achieved with an increase in structural weight of only 300 pounds (136 kilograms).

The relatively low-cost alternatives of installing fuel tanks in the cargo bays was overwhelmingly rejected by our customers. The cargo revenue contribution from the 747 lower hold is too valuable to consider using the space for fuel storage. And, design trade studies pointed towards using the cavity volumes of either the vertical fin or the horizontal stabilizer for the added fuel capacity. The vertical fin tank alternative was discarded because of the local structural weight increase associated with having to design for fluid hydrostatic pressure effects. Thus, the horizontal stabilizer was selected. Its volume limit is dictated by structural load effects on the aft fuselage and by the rotor-burst pattern of the tailcone-mounted auxiliary power unit.

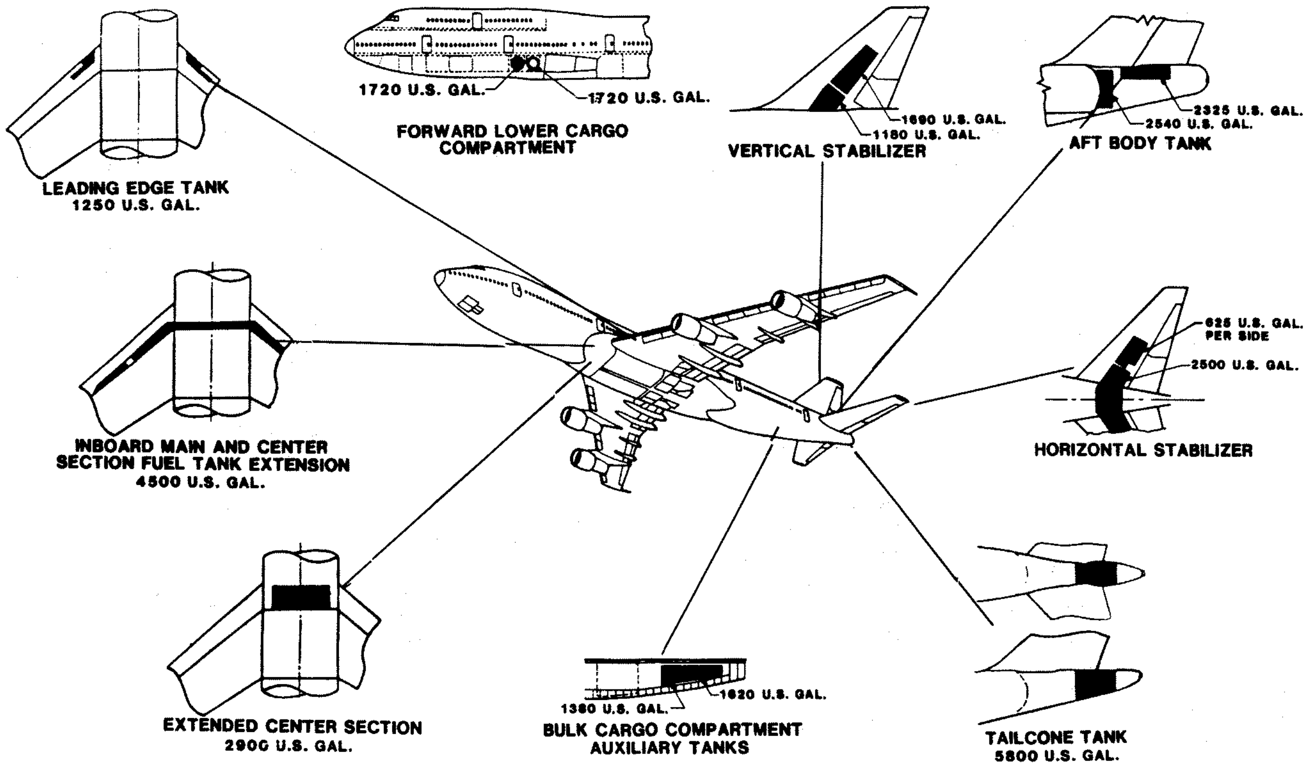


Fig. 17 Potential 747 Fuel Tank Locations

Wind tunnel model testing was carried out to verify that the added mass associated with the 3300 U.S. gallons (12,490 liters) in the horizontal stabilizer fuel tank created no additional structural dynamic modes that could not be structurally accommodated by the 747-400 configuration. Figure 18 shows details of the fuel tank option in the horizontal stabilizer.

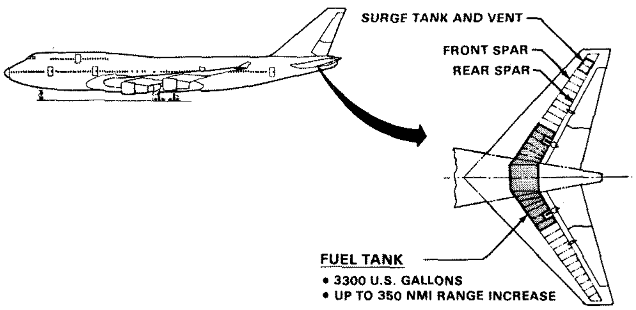


Fig. 18. Horizontal Stabilizer Fuel Tank

AVIONICS

Digital Systems

Digital microprocessor technology has had a major impact on the aerospace industry in the last fifteen years. During the conception of the Boeing 757 and 767 airplanes in the late 1970s, the advantages of digital technology for application to the avionics and systems areas were recognized. These advantages were:

- Lower costs
- Increased reliability
- Increased capability
- System automation

Both 757 and 767 designs incorporated digital technology. The primary result was an improvement in the flight deck of the airplane with a two-crew complement established as a new standard for operation. After three years of successful operation in the new twinjet airplanes, the digital technology has proven out. Figure 19 displays comparative reliability data between analog and digital equipment.

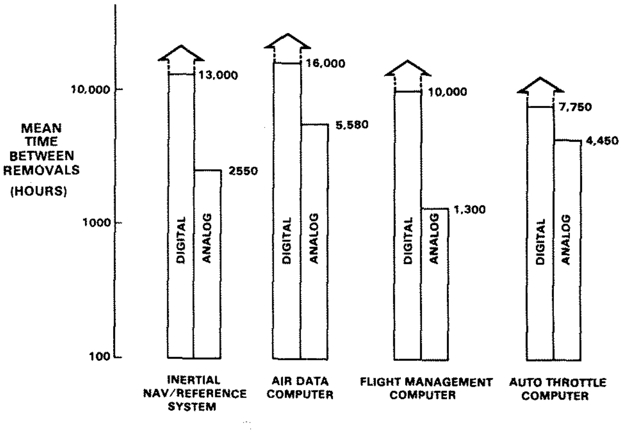
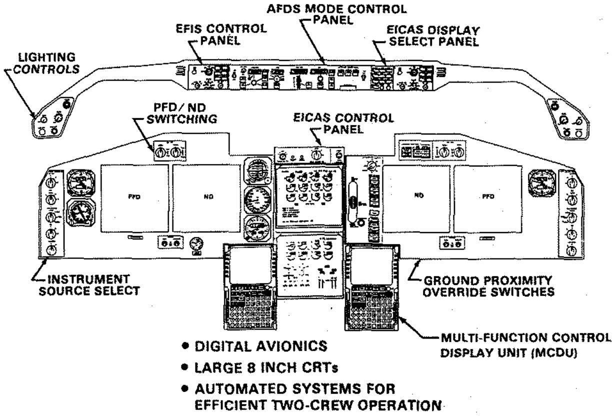


Fig. 19. Digital Equipment Reliability

Two-Crew Flight Deck

The 747-400 flight deck design is patterned after the successful 757 and 767 design and takes it one step further to provide even more capability. Boeing, in concert with present 747 operators, has developed a flight deck configuration which embodies improvements available since the 757 and 767 introductions. These improvements provide further redundancy, increased capability, and further simplification of systems. The most obvious improvement is visible in the display system in the six large 8- by 8-inch (20- by 20-centimeter) cathode ray tubes (CRTs) used to display airplane flight control, navigation, and engine and crew alerting functions. Figure 20 illustrates the pilots' main forward panels with the new displays.



- DIGITAL AVIONICS
- LARGE 8 INCH CRTs
- AUTOMATED SYSTEMS FOR EFFICIENT TWO-CREW OPERATION

Fig. 20. 747-400 Flight Deck

The CRTs which make up the display system have identical part numbers, which means that the units can display basic airplane data (primary flight display [PFD]), or the navigation information (navigation display [ND]), or the engine/crew alerting information (engine indicating and crew alerting system [EICAS]), depending on panel location. The display system includes all data processing in itself, whereas, the previous design required separate line replaceable units to carry out this function. In addition, automatic and manual display switching is built into the design in the event of an individual CRT failure.

The larger CRTs allow more information to be displayed with a reduction in the number of conventional instruments. Figure 21 shows a comparison between an existing 747 and the newly designed 747-400 forward panel. The simplification is apparent and is numerically illustrated in figure 22. The number of flight deck lights, gages, and switches has been reduced by approximately 600. Also shown are the total number for flight deck lights, gages and switches for the two-crew twin-engine 737, 757 and 767 airplanes. It is interesting to note that the number of indicators is fewer for the four-engine 747 than for the twin-engine airplanes.

The modern design of the two-crew 747-400 will provide safe and efficient aircraft operation. This design also allows for replacement of the CRTs with flat panels, when that technology becomes available and ready for commercial aircraft application. In this way the 747-400 flight deck will be kept modern, up-to-date and competitive into the next century.

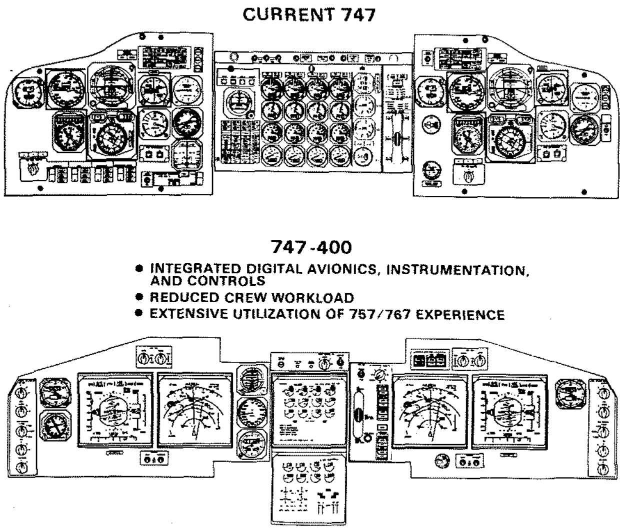


Fig. 21. Flight Deck Comparison

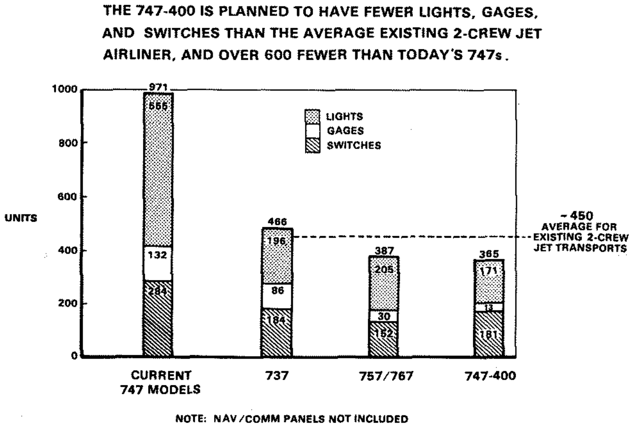


Fig. 22. Simplicity in Controls and Indicators

PASSENGER ACCOMMODATIONS

New-Look Interior

Compared to other 747 models and derivatives, the interiors of the 747-400 will reflect a new look; the result of significant redesigning aimed at improving passenger conveniences and interior appeal. Figure 23 shows the comparative interior seating arrangements of the 747-200 and the 747-400. Ceiling and sidewall panels have been recontoured (fig. 24) with new, lighter weight materials that are noticeably different and easier to clean and maintain. The overhead stowage volume has been dramatically increased both at the side and center bin locations.

Quick-Change Features

Interior arrangement flexibility (fig. 25) will permit operators to quickly relocate class dividers and galley and lavatory modules to better serve particular market requirements. Airlines will be able to respond more quickly in its market mixes, whether they be for first-, business-, or economy-class seating. Servicing, too will be much more efficient – faster and less costly.

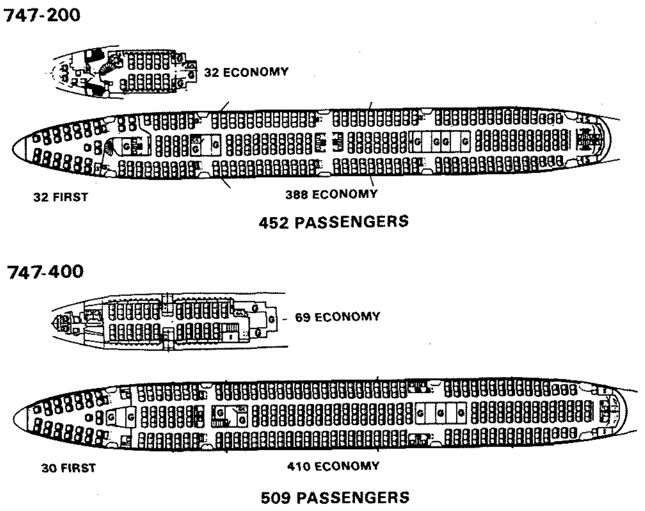
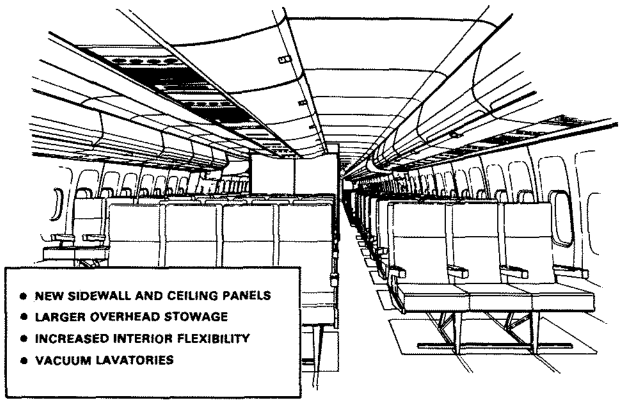


Fig. 23. 747 Interior Arrangement Comparison



- NEW SIDEWALL AND CEILING PANELS
- LARGER OVERHEAD STOWAGE
- INCREASED INTERIOR FLEXIBILITY
- VACUUM LAVATORIES

Fig. 24. 747-400 "New Look" Interior

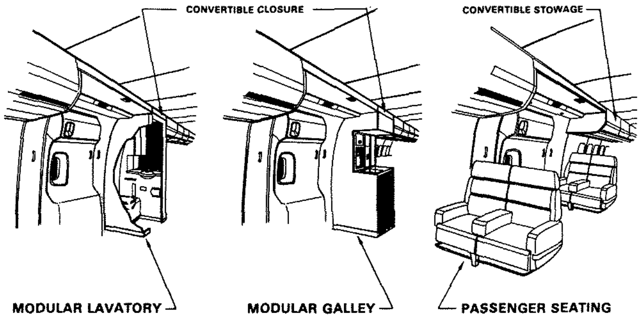


Fig. 25. Sidewall Reconfiguration Flexibility

Upper Deck Alternatives

The upper decks of both the 747-300 and 747-400 (fig 26) offers those extra benefits not found on any other aircraft. Seating alternatives on this premium deck, for example, can range from 26 large and luxurious sleeper seats for the high-yield passenger to the other extreme of carrying up to 91 passengers in the tourist-class arrangement at a comfortable 34-inch (84 centimeter) seat pitch.

Fig. 26. 747-300/-400 Upper Deck

The stretched upper deck also houses 19 additional windows, two or three lavatories depending on configuration, and a large galley with 20 food and beverage carts, Two new large gull-wing doors replace existing 747-200 upper deck exits. An aft straight stair replaces the original 747 forward circular stair. Upper deck passengers can now board through the main-deck door no. 2; economy-class passengers need not be boarded through the forward first-class zones.

PERFORMANCE SUMMARY

Long-Range Capability

The 747-400 is the result of an intensive research and development effort. The design changes which have been incorporated can be quantified in the form of performance improvements. The 747-400 occupies the long-range end of the performance spectrum with a design range of 7100 nautical miles (13,150 kilometers) (fig. 27). This increase of about 800 nautical miles (1480 kilometers) allows the 747-400 to fulfill requirements of several customers for these extreme ranges.

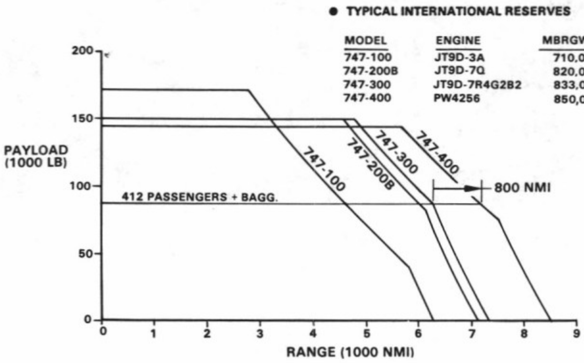


Fig. 27. Payload-Range Comparison

The achievement of this range objective was made possible by 1) fuel burn improvement resulting from more efficient engines, lightweight structure and improved aerodynamic configuration and 2) a higher gross weight plus an optional horizontal tail fuel tank which provides 3300 gallons (12,490 liters) of additional fuel.

Fuel Burn Improvements

These improvements also produce benefits for customers on more typical stage lengths. Figure 28 shows that the 747-400 burns 37% less block fuel per seat than the original 747-100. This comparison, based on specification interiors, shows total improvement due to interior changes, aerodynamic improvements and engine improvements.

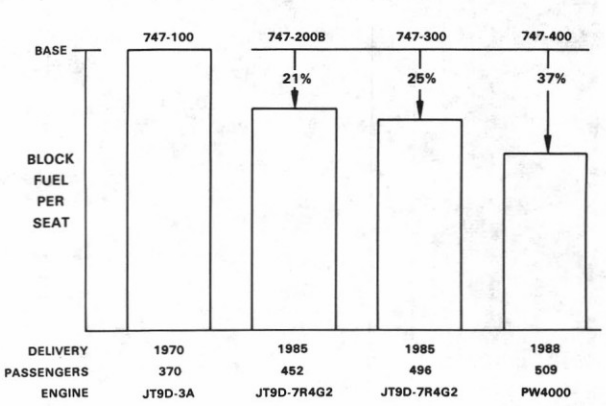


Fig. 28. 747 Increased Fuel Efficiency

Based on typical airline configurations, a fuel burn improvement of about 13% is estimated (fig. 29) for the 747-400 relative to its predecessor, the 747-300. A large part of this evolution in airplane efficiency is the engine fuel consumption improvement. On the 747-400, about 7.5% of the block fuel improvement is due to the new generation engines, with the remaining 5.5% provided by the configuration changes such as winglets and wingtip extensions.

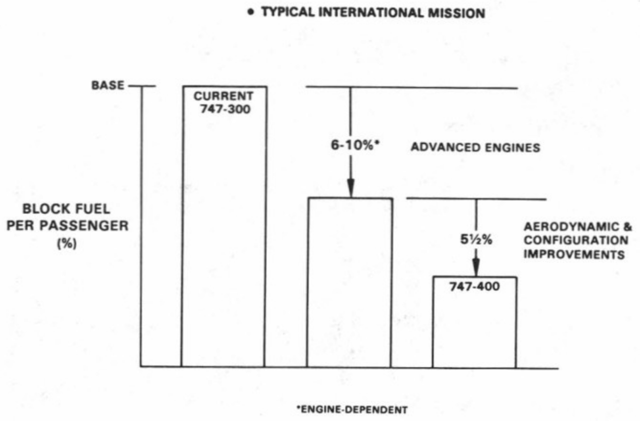


Fig. 29. 747-400 Fuel Burn Improvement

CONCLUSIONS

Certainties and Future Possibilities

The design, engineering and marketing of a new airplane model such as the 747-400 is always exciting and demanding, as we strive to meet the airline's future requirements with applications of the latest technology available. An added challenge lies in the necessity and in our ability to lower the costs of producing these new aircraft.

Our approach to meeting airline requirements for future equipment is two-fold: First, to deliver the most technically modern, cost-effective derivatives of our current family of 747s as the world markets demand. Second, to introduce all-new, higher technology aircraft when such developments make sense.

The Boeing Company is totally committed to listening to its customers. Our objective is to continually improve our product line with appropriate technology applications that will specifically solve not only our customers' operational current needs, but also projected plans, as well.