Boeing Model 747

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The accelerating demand for both passenger and cargo air transportation dictates a continuing expansion of airport facilities. But the present rate of expansion cannot match the future demand if present size aircraft continue to be operated from these facilities. A much larger transport is necessary to handle the expanding air transportation market of the next 10–15 years. This paper will discuss the development of the new Boeing Model 747, a large capacity, subsonic transport designed to handle tomorrow's market from today's airports.

Introduction

THE need for a much larger jet transport is demonstrated by the projected demand for both types of air transportation: passenger and cargo. Air passenger travel may easily triple in the next ten years, whereas cargo transportation could increase eight times. If present size aircraft were employed to handle this traffic increase, many major airports would become hopelessly congested during peak hours. However, if much larger airplanes such as the Boeing Model 747 were phased into long haul routes, this traffic increase could be held to a manageable level. A comparison of aircraft departure rates indicates how much traffic reduction could be achieved by transports the size of the 747 (Fig. 1). By 1980, about 24,000,000 departures of present size aircraft would have to be scheduled each year to meet the predicted free world demand, but with 747 size airplanes handling long haul routes, annual departures could be reduced to 15,000,000. This represents 37% fewer departures.

Congestion

The importance of this possible reduction in departures can be appreciated when one considers the present traffic levels of many major airports. During peak hours, many airports are already near their ultimate limit in runway capacity. Similarly, congestion in the airways above many airports is an ever-increasing problem. The problem, then, is how to carry more passengers and cargo in the future without increasing the departure rate to the level of acute congestion. The Model 747, which can carry 2.5 times more passengers or cargo than present intercontinental transports, is a promising answer to this problem.

Operating Demands

Besides having greater capacity, the new subsonic transport must meet new operational demands. The volume of future air traffic requires that the new aircraft accept and discharge its increased load of passengers or cargo without increased time. Furthermore, the demands of the traveling public are increasing. Air passengers now want a better flight schedule, faster baggage handling, and a more comfortable ride. Finally, the communities near airports are demanding a better noise environment. All of these needs must be considered in developing a new aircraft capable of handling the future market from present airports with improved efficiency and profitability.

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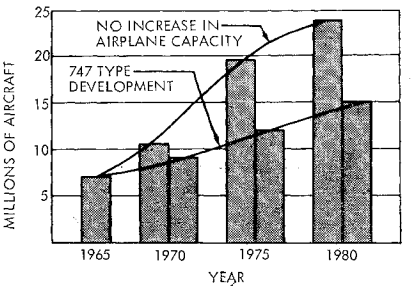

Fig. 1 Aircraft departures.

New Technology Available

Engine

Need alone does not constitute the basis for developing a new airplane. Without technological advances, many of the needs previously cited could not be met. Fortunately, many new advances are now available to an airplane designer. Engines have been greatly improved in thrust and operating efficiencies as a result of both past developmental experience and the recent C-5A and SST programs. New high-bypass-ratio turbofan engines produce over twice the thrust of present turbofan transport engines. Although this new engine has a gas generator not much larger than that of present engines, its high-bypass ratio gives it added thrust and efficiency. Also, the new engine is simpler; it has only 4 main bearings, compared to 7 or 8 bearings on present engines, and only a single combustion chamber instead of a number of combustion "cans." These features will considerably improve the maintainability of the new engine.

The new technology engine offers greatly improved fuel economy. The present low-bypass-ratio turbofan engine represents an advance of 15% in specific fuel consumption over the older, pure jet engine. The new high-bypass-ratio turbofan will reduce fuel consumption another 20–25%. And this new engine will produce three times the thrust of pure jet engines used on earlier transports.

The new engine is also quieter. Inlet guide vanes have been eliminated and noise attenuation lining added. Other engine features which contribute to a better noise environment are a low-speed fan and low-exhaust gas velocities.

Aerodynamics

Aerodynamic development has also advanced considerably in the past few years, particularly in the area of flap design. The newest flap systems have a much greater increment of lift than those of the past. The 747 flaps were designed with the latest technology and experience. They will enable the 747 to take off from a shorter runway and cruise at a higher speed than a proportionally loaded 707.

Because this flap system provides more takeoff lift, the wing sweep and thickness can be optimized for cruising. This

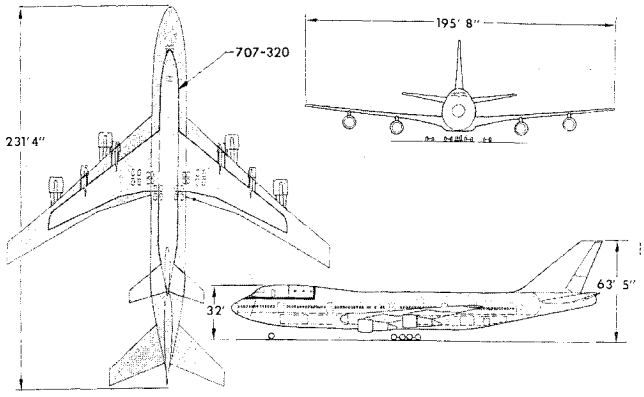

Fig. 2 General arrangement.

wing, combined with engines having better cruise thrust performance, gives the 747 a faster cruising speed than present intercontinental transports.

Design Objectives

The design objectives that are guiding the development of the Model 747 have been determined both by the need for a new transport and by the new technology available. The primary objective of the Model 747 is to provide a capacity capable of matching the market demand during the 1970's. Another objective is to design an airplane that is close to optimum, both as a passenger and as a cargo transport. In the past, commercial airplanes were designed as passenger transports, because the cargo market had not developed sufficiently to require a specialized airplane. However, the cargo market is now becoming important enough to play a major role in influencing the design of an airplane.

Another basic design consideration is to produce an airplane that can take off and land from existing airports without requiring longer or stronger runways. Because the communities' tolerance to airplane noise is reaching a limit with ever-expanding air traffic, this airplane is being designed for minimal takeoff and landing noise.

General Description

Dimensions

The Model 747 (Fig. 2) is much larger than present intercontinental transports. Its great capacity derives from a fuselage that is nearly 80 ft longer and nearly twice as wide as a Model 707 intercontinental transport. Overall, the 747 is 232 ft long compared to 153 ft for the 707, and has a wing span of over 195 ft compared to over 145 for the 707. Figure 2 also illustrates the unusual position of the cockpit, which is placed above the main deck. This feature permits the main payload deck to run the entire length of the airplane. Thus, cargo containers can be loaded directly into the nose of the 747 freighter version to speed up cargo handling. A noteworthy feature of the 747 passenger version is the 10 entry doors which facilitate rapid passenger handling.

General Characteristics

The basic characteristics of the Model 747 can be compared to those of the 707 (Fig. 3) to indicate the size of the new sub-

	707-320	747	747F
MAX TOGW LB	332,000	680,000	680,000
LANDING WT LB	247,000	564,000	564,000
PASS. MIXED/ECON	139/185	366/446/490	-
PAYLOAD LB	90,320	-	217,200
DENSITY LB/CU FT	11.8	-	9.1
VOLUME CU FT	7,640	-	17,640 UP 6,250 DN
		TOTAL	23,890

Fig. 3 Basic characteristics.

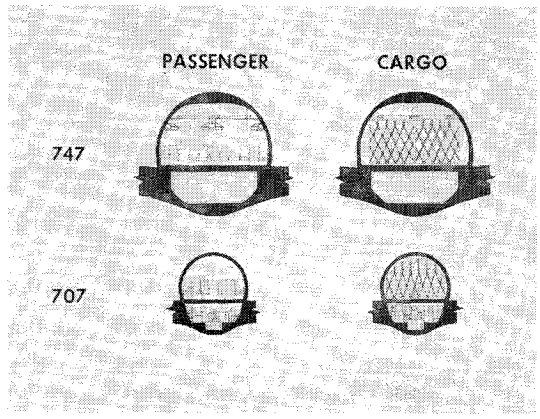

Fig. 4 Cross sections.

sonic transport. The takeoff gross weight of the 747 is about double that of the 707-320 Intercontinental. The 747 is also faster than today's jets. Whereas today's jets cruise at 0.80 Mach, the 747 will cruise at 0.86 Mach. This additional speed will cut off considerable time on long polar flights such as Paris to Los Angeles. In its passenger version, the 747 will carry up to about 450 passengers in a 9-abreast seating arrangement, about 2.5 times as many passengers as today's intercontinental transports. And in its cargo version, the 747 will carry more than 217,000 lb of freight, nearly 2.5 times the payload of today's transports.

Cross-Section Selection

Perhaps the single most difficult design problem in the development of the 747 was the selection of the cross section. Our basic approach was to design a cross section that would be as close to optimum for both a cargo and a passenger airplane. Initially, both a double-deck and a single-deck cross section were considered, but after the advantages and disadvantages of both types of cross sections were exhaustively examined, the single-deck cross section (Fig. 4) was chosen as closer to optimum for both a passenger and a cargo airplane. When both a single- and double-deck passenger airplane are designed for the same capacity, the wide single deck is essentially equal to the double deck in weight, space, and drag. It is superior in passenger loading and unloading, and offers a much better passenger environment with its wide spacious cabin. For a cargo airplane, the single deck with a swing-up nose door offers faster freight handling because of its capability for straight-in loading onto a single deck.

Passenger Compartment

The advantages of the single-deck cross section are readily apparent in the passenger version. With seats 10% wider than present economy seats, the 747 can seat 9 passengers abreast and still have room for two aisles running the length of the fuselage. This seating arrangement enables the 747 to carry up to 450 passengers compared to 185 on present intercontinental transports.

In the first-class compartment of a typical mixed-class arrangement (Fig. 5), 58 passengers can be seated 6 abreast in wide seats at a 42-in. pitch. Carry-on baggage will be stored above the passengers to keep the cabin uncluttered. In the

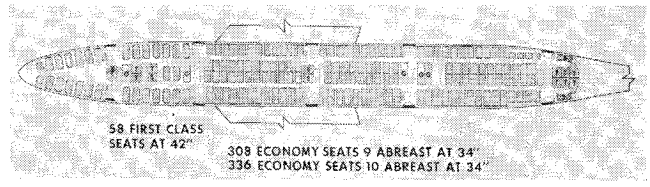

Fig. 5 Mixed-class arrangement.

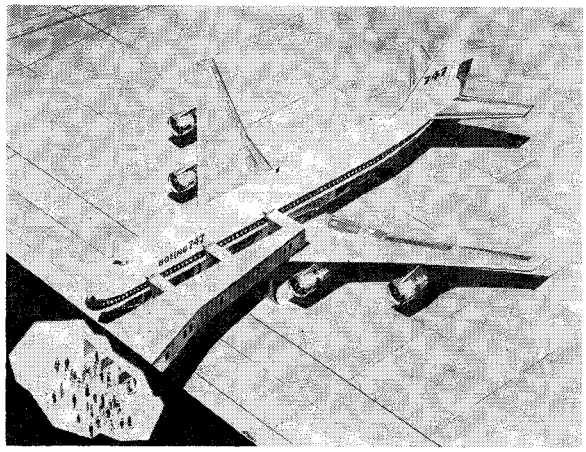

Fig. 6 Passenger loading.

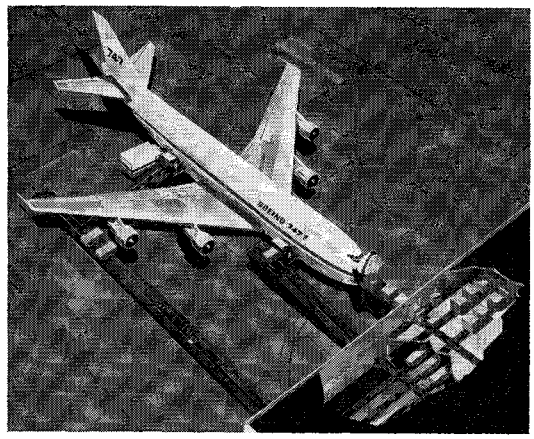

Fig. 8 Cargo loading.

economy section, 308 passengers will be seated 9 abreast at a 34-in. pitch in seats 10% wider than present seats. The double aisles will serve 9 passengers compared to a single aisle serving 6 passengers as in present transports. The double aisles are intersected by 5 lateral aisles that connect the 5 pairs of double doors for unparalleled ease of passenger movement. Finally, the extra space behind the raised cockpit might be used for staterooms or extra lounges.

In a 9-abreast, all-economy seating arrangement, the 747 can carry 447 passengers in seats 10% wider than today's tourist seats. And in a 10-abreast, all-economy arrangement, the 747 can carry 490 passengers in present tourist seats.

Although the Model 747 carries many more passengers than today's jets, it can accept and discharge its passengers in equal time. Figure 6 indicates how three of the double-size entry doors might be used at a suitable terminal to reduce passenger loading and unloading time. With this system, 6 files of passengers can be loaded simultaneously. This is only one of many loading proposals under study.

Cargo Compartment

In an all cargo version of the 747, the wide cross section accommodates two pallets or containers 8 ft wide by 8 ft high, which are carried side by side on the main deck. These 8-ft^2 cross-section containers can be interchanged between trucks and airplanes. This feature will greatly reduce transfer time and, thus, indirectly, operating costs. A typical 747 cargo airplane can carry twenty-eight 96- by 125-in. pallets (or 8 ft by 8 ft by 125 in. containers) on its upper deck, a total of 17,640 ft^3 of cargo (Fig. 7). Below the main deck, 15 belly containers can be stored for an additional 5250 ft^3 of containerized cargo. Room is left for 1000 ft^3 of bulk cargo. The 6250 ft^3 volume of the 747's lower lobe represents 82% of the total payload for a 707-320C. The entire payload volume amounts to 23,890 ft^3, more than 3 times the volume of present intercontinental transports.

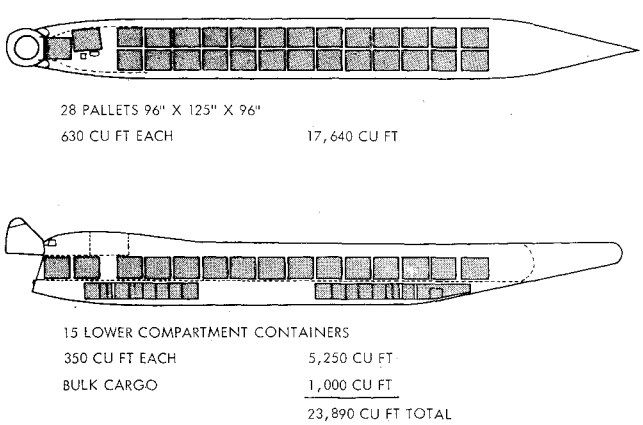

Fig. 7 Cargo arrangement.

Although the Model 747 freighter carries over 2.5 times the cargo of today's transports, it can accept and discharge its cargo in equal time. Consequently, total ground time for an equivalent payload is greatly reduced, producing large gains in cargo economics. Figure 8 indicates how an automated conveyor system can be employed for rapid cargo loading. Once the cargo reaches the airplane, the automated conveyor system of the airplane moves the cargo into final position. Rubber-tired driving wheels in the main deck floor move containers that are supported on casters and roller trays (Fig. 9).

Systems

The avionics system combines the functions of the flight director and the automatic flight controls. The combined system will provide visual guidance for the flight crew through an attitude director indicator and automatic flight control for cruise or approach and landing. The basic 747 will have the capability of fully automatic flight to touchdown under category II conditions.

The inertial navigation system on the 747 will provide the capability of navigating anywhere in the world without dependence on ground-based aids. In addition, the inertial platform provides the primary attitude information for the flight instrumentation and automatic flight control systems, as well as providing the primary heading stabilization reference for the magnetic heading reference system. Updated communication and radio navigation systems will be available to the flight crew to assist in their operation and navigation of the 747.

Extensive use of microelectronic solid-state circuitry in the avionic system permits much greater electronic capability to

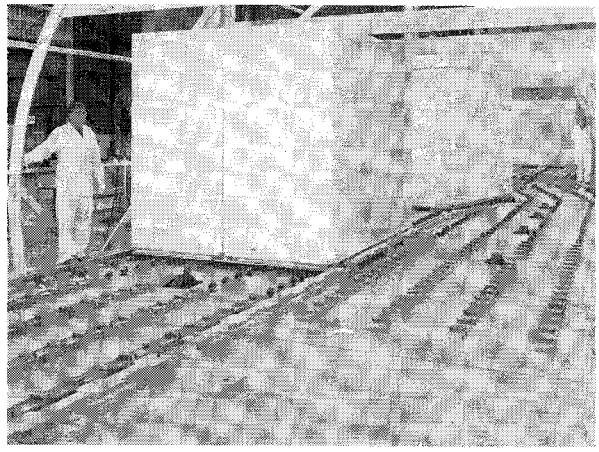

Fig. 9 Airplane conveyor system.

be designed into smaller packages. This increased application of microelectronics will significantly increase airplane availability, because the inherent reliability of the new circuits is much higher.

Improved air-conditioning is planned for the airplane, providing increased capacity and better temperature control. The airplane is equipped with a 1100-hp onboard auxiliary power unit, which will provide conditioned air even during ground loading under hot temperature conditions when no outside power is available to the airplane.

The rudder, elevators, and ailerons are all actuated solely by hydraulic power. For greater system redundancy, rudder and elevator have split control surfaces, powered by dual load path actuators that respond to either electrical or manual inputs.

Four independent hydraulic subsystems provide power for flight control and landing functions such as steering, brakes, and flaps. Each subsystem is pressurized by two pumps in parallel. One pump is engine-driven; the other is pneumatically-driven and operates only when required by high demand or by loss of engine-driven pumps. The four hydraulic systems provide high redundancy, ensuring adequately powered control of the airplane with any two systems.

Airplane Performance

Payload Range

The 747 passenger version is designed for intercontinental stage lengths. With 366 passengers and 7000 lb of cargo, the 747 will fly about 4500 naut miles (Fig. 10). On shorter ranges the full capacity of the lower compartment (6250 ft^3) can be utilized.

The 747 freighter is designed to carry its full payload over transcontinental ranges. On North Atlantic ranges, the 747 will carry about twice the payload of the 707-320C (Fig. 11). When the payload range characteristics of the two airplanes are compared, it should be noted that the 707-320C is a fully developed airplane; whereas the 747 is a newly designed airplane in initial operation.

To insure that the capability of the airplane will increase, an unusually extensive follow-on development test program is planned. Of particular significance are: ground and flight test planned beyond the initial design takeoff weight; performance tests with advanced engine ratings; structural testing for destruction of a complete airframe and all load carrying surfaces; a flight load survey program to verify the data under maximum flight load and maneuver conditions; and a complete airplane fatigue test program estimated to last three years and demonstrate two normal airplane lives.

Takeoff Field Length

The 747's improved engines and flaps give it substantially improved takeoff performance compared to the 707-320 models. There is no necessity to lengthen runways now handling present intercontinental transports. For example, a 707 loaded to fly a range of 4000 naut miles requires about a 9500-ft runway for takeoff. On the other hand, a 747 loaded for the same 4000-mile range requires about 8500 ft. As the 747 powerplant is improved, the 747 will require less takeoff field length, or allow substantial gross weight growth without exceeding today's runway lengths.

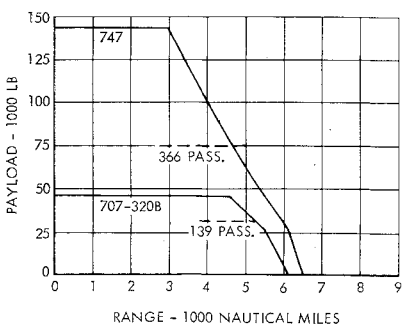

Fig. 10 Passenger payload range.

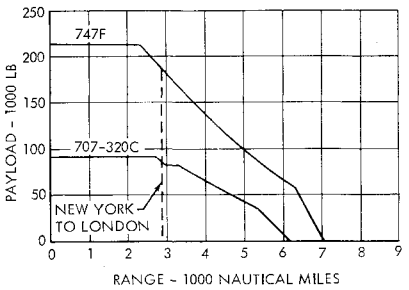

Fig. 11 Cargo payload range.

Landing Performance

Landing gear received considerable attention during the design of the 747, because present heavy-weight airplanes are already approaching the stress limits of some runways. The landing gear of the 747 has been designed to reduce runway stress by distributing the airplane's weight over a very wide area. Two main oleos with four wheels each, as on present transports, extend down from the wing of the airplane (Fig. 12). However, two additional main oleos are attached to the body, putting 16 main gear wheels on the ground for an excellent weight distribution pattern. With this landing gear, the 747 can operate at more than double the gross weight of present transports and still not cause as much runway stress. In fact, the 747 is designed to permit considerable growth before it reaches the runway stress levels of present transports. The advantages of the four main gear are evident. Present airplanes, which have two main gear, are already limited in growth, because they have reached the maximum stress limit of most concrete runways. If two 747 main gear were used on present 707-320 airplanes, their gross weights could be raised to 370,000 lb, an increase of 40,000 lb. If three 747 main gear were used, gross weight could be further increased to 560,000 lb, but because an initial gross weight of 680,000 lb plus the capability of additional growth was desired for the 747, four main gear are provided. This will permit the 747's gross weight to be increased 70,000 lb. Similar comparisons can be made for landing performance on flexible pavement.

The range of approach speeds for both the passenger and freighter versions of the 747 is comparable to proportionally loaded 707-320 versions. Landing field lengths are also comparable to those of 707-320 airplanes.

Noise Levels

Because of its good takeoff characteristics and improved engines, the 747 operates at a considerably lower noise level than

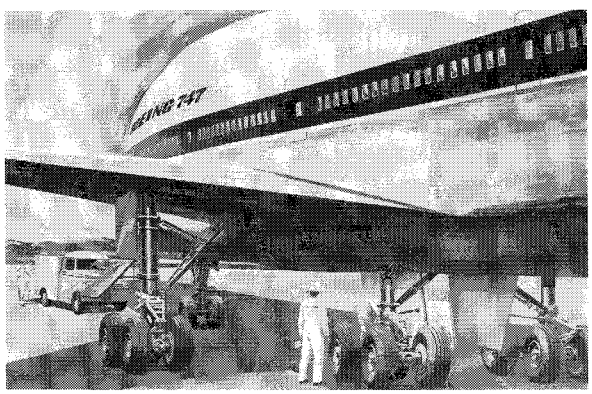

Fig. 12 Landing gear.

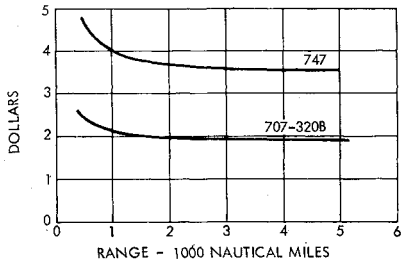

Fig. 13 Direct operating cost per mile.

do today's transports. Under full takeoff power and loaded for a 4500 naut mile range, the 747 will be about 5 PNdb quieter; and, at cutback, the 747 is 10 PNdb quieter. This represents a significant reduction in noise characteristics. Similarly, the 747 is quieter during landing. Approach noise will be 10 PNdb less than today's transports. These lower noise levels should help alleviate the growing community noise problem from increased air traffic.

Economic Analysis

The 747 represents an important advance in operating costs, one of the most important objectives in the characteristics of any new airplane. Present jets owe a great deal of their success to lower operating costs than the propeller-driven airplanes they replaced. Similarly, the 747 further reduces direct operating costs for each pound of payload. Although the 747's payload is 2.5 times that of today's excellent standard, the 707, its direct operating cost per mile is less than twice as much (Fig. 13). On a typical North Atlantic flight, today's 707-320B costs approximately $1.95/mile, whereas the 747 has a direct cost of about $3.60/mile.

The operating efficiency of the 747 passenger version can be appreciated when one examines the reduction in the direct cost of transporting passengers. The 707-320B costs over

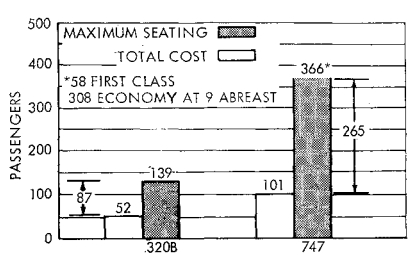

Fig. 14 Capacity vs break-even passengers.

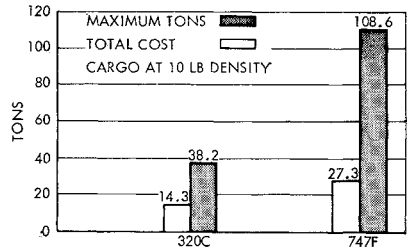

Fig. 15 Capacity vs break-even tons.

1.4¢/seat naut mile on a typical flight. The 747 will reduce direct seat-mile costs about 30%, down to about 1¢/seat mile.

Another measure of the profitability of a passenger transport is the number of profit passengers it can carry (Fig. 14). Today's 707-320B must carry 52 passengers to pay the total cost of a typical flight and, fully loaded, in a mixed-class configuration, can produce 87 profit passengers. Comparatively, a fully loaded 747 can produce 265 profit passengers, with 101 passengers paying the total cost of the flight. A comparison of profit passengers, 265 to 87, reveals the potential profitability leverage of the 747 as a passenger transport. The 747 costs only twice as much to operate, but produces over three times the profit passengers of today's transports.

The 747 promises outstanding economy as a cargo transport. The present 707-320*C* costs about 5.3¢/ton mile. The 747 will reduce costs over 35%, down to about 3.3¢/ton mile.

An important measure of a cargo transport's profitability is also its profit payload (Fig. 15). Today's 707-320C must carry 14.3 tons to pay the total cost of a typical flight and, fully loaded, can produce 23.9 profit tons. On the other hand, a fully loaded 747 can produce 81.3 profit tons, with 27.3 tons paying the total cost of the flight. A comparison of profit tons, 81.3 to 23.9, demonstrates the profitability the 747 offers as a cargo transport. Much like the passenger airplane, the 747 freighter costs only twice as much to operate, but produces over three times the profit payload.

Conclusion

The Model 747 will be the first subsonic transport with sufficient capacity to handle the expanding air transportation market of the next 10–15 years. The latest advances in technology have enabled The Boeing Company to design the Model 747 to carry 2.5 times the payload of today's transports, yet operate from the same airports. The Model 747 offers a new level of comfort for air travelers, an improved environment for airports and nearby communities, and superior passenger and cargo operating economics for airlines.