Integrating Ground Support for Propulsion Systems on the 747

A.H. Sargent* and W.P. Newell†
The Boeing Company, Seattle, Wash.

Each engine in use and planned for the Boeing 747 presents unique ground support requirements for the airframe manufacturer. Specialized engine installation and removal equipment, transport requirements, procedures, and handling data must be developed and documented. Unique airline customer requirements, like lower lobe cargo bay air transport of engines, must be coordinated by the manufacturer with engine supplier, airline, and ground equipment vendors. Common nacelle programs are a new dimension in ground support integration. All of these aspects, their problems, solutions, and the management process used in integrating propulsion system ground support are discussed.

I. Introduction

THE high bypass trubofan engine has helped the 747 pile up impressive fleet statistics since its introduction in January 1970:

9	hr per day average utilization
41	world-wide airline operators
268	airplanes delivered to date
1,484	mean hr between engine removals
3,335,000	hr fleet time to date
13,340,000	hr engine time to date
1,760,000,000	miles flown in revenue service.

The 747 was initially certified with Pratt and Whitney Aircraft JT9D-3A engines. Since then, the 747 has been equipped with the JT9D-7, 7A, 7F and General Electric CF6-50 engines; and the JT9D-70 common nacelle system is now installed and being tested. In design is the Rolls-Royce RB.211-524 system which will be installed on future British Airways 747s. Figure 1 illustrates the use of the various propulsion systems on the spectrum of 747 models.

The above statistics provide a feeling for the air side or operational side of the topic. Behind the impressive operational statistics and flight hardware is the support system that keeps them flying, the ground side of the picture. Since preliminary design began in 1965 on the basic 747 using the JT9D-3 engine, a new engine configuration has been introduced about every 1.5 years since the JT9D-7 replaced the JT9D-3A in 1970. Each new engine has presented unique ground support requirements for the airframe manufacturer. The various engines from each engine supplier have different Quick Engine Change, "QEC" features, and transport requirements, among other differences. Specialized installation and removal equipment, procedures, and handling data must be developed and documented. Unique airline customer requirements, like lower lobe cargo bay air transport of engines, must be satisfied. Resolution of these requirements is accomplished through an integrated "team" effort.

The four key members of the 747 Propulsion Ground Support System Team are the airframe manufacturer, engine manufacturer, component supplier and the GSE supplier. This paper examines the job of integrating these team members to insure total customer support for the 747 propulsion systems.

The integration management process begins with an early exchange of design data in the development phase and proceeds through to the operational phase with feedback from operators. This process has been repeated and refined on the 747 program through the successive implementation of the four 747 propulsion systems in use or planned.

II. 747/JT9D-3, 7 System

The basic "team" for implementing the first airplane/engine combination, the 747/JT9D-3 system, included Boeing, who designed strut cowling, buildup components, installation, and QEC GSE; the Rohr Corp., who fabricated strut, cowling, thrust reverser, and builtup QEC packages; and of course Pratt & Whitney Aircraft, which was responsible for the basic engine.

The Boeing Flight Test Airplane made its first flight on February 9, 1969 with JT9D-3 engines. The JT9D-3 engine is a second generation turbofan with hi-bypass ratio of 5:1. It featured higher turbine inlet temperatures, low gas exhaust velocity, variable pitch stators, an annular combustion chamber, and improved noise attenuation. But this new engine also presented special ground support problems. The key ones are listed as follows: larger size and weight; new maintenance concept and requirements; and ground and air transport requirements. The impact of these problems will be examined in the order listed.

Figure 2 illustrates the challenge presented by the size of the JT9D series engines. The JT9D-3 is approximately one and a

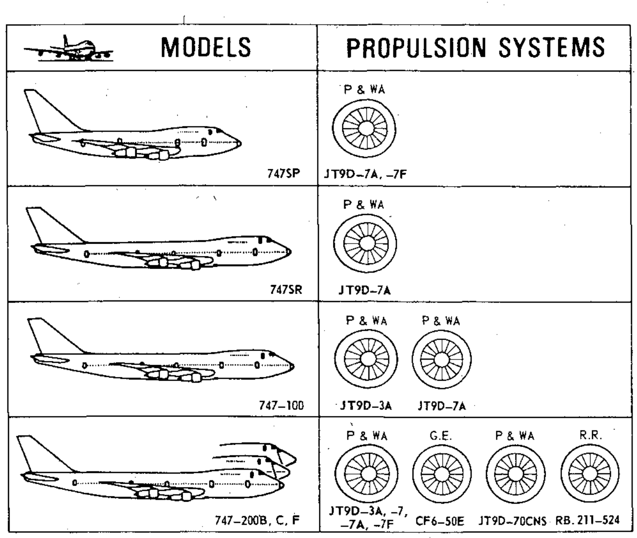


Fig. 1 Propulsion spectrum.

Presented as Paper 75-1329 at the AIAA/SAE 11th Propulsion Conference, Anaheim, Calif., Sept 29- Oct 1, 1975; submitted Nov. 5 1975; revision received Feb. 26, 1976.

Index categories: Ground Support Systems; Airbreathing Propulsion, Subsonic and Supersonic.

*Senior Group Engineer, Customer Support, Boeing Commercial Airplane Company.

†Senior Specialist Engineer, Customer Support, Boeing Commercial Airplane Company.

half times as large as the first generation JT3 and JT8 engines used on the 707/727/737 airplanes, and thrust was up almost three times. These aspects generated ground handling, air transport, maintenance, and test problems which will be discussed further on. The JT9D was the first jet engine to be designed and built to a modular concept allowing independent removal and installation of the major engine sections depicted in Fig. 3. To optimize this concept, Boeing, working with the airlines, conceived and designed a strut configuration to capitalize on the maintainability designed into the JT9D engines. The key steps taken in the process towards resolution of the problems associated with engine size, transport needs, and maintenance were detail definition of requirements; coordination with the airline ATA subcommittee on engine logistics; working group with P & WA; supplier symposium; and equipment demonstration.

Definition of support requirements was the first step in solving the problems associated with this new engine. Work began in 1966 soon after preliminary design. Initial data were in the form of the 747 Facility Planning Document, 747 Illustrated Tool and Equipment List, and the JT9D Fan Engine Ground Handling Document. These documents provide design data for Boeing customers planning to fabricate or to have fabricated GSE peculiar to the engine installation. These data initiated coordination with airlines and were used for introductory support meetings and briefings.

In April 1967, a symposium was held in Seattle for airline customers and GSE suppliers to acquaint them with the technical requirements and to solicit their support in getting ready for the 747 introduction. The next key step in integrating this program was a JT9D Engine Maintenance and GSE seminar conducted by P & WA at Hartford. This seminar provided Boeing, P & WA, and airline people the opportunity to get definitive information on the JT9D and to discuss engine handling. Airlines indicated that access, QEC removal, and installation times and availability of the fifth engine kit were major concerns. Preliminary discussions on the feasibility of on-the-wing maintenance, a concept of particular interest to Trans World Airlines, were also held. These discussions grew into a Boeing and P & WA working group to develop on-the-wing maintenance requirements and equipment definition.

Integration efforts expanded in 1967 with the formation of an Air Transport Association (ATA) Committee on Engine Logistics. The 747 committee grew out of the committees formed to support the SST development and introduction, and when the two programs ran concurrently, it was realized they could also serve a similar and valuable function for 747 introduction. This international team of engine handling experts representing eight airline companies and Boeing met periodically to coordinate and resolve issues related to engine handling, transport, maintenance, air shipment, testing, and review of GSE designs.

In July 1968, Boeing conducted a major symposium in Seattle for airline people covering all aspects of the JT9D power plant installation including design details, maintainability, maintenance plan, GSE handling, and transport. This symposium supplemented continuing ATA Committee meetings, correspondence , and oral communication, all aimed at a smooth introduction, airline equipment commonalty, and adequate planning and support for the 747/JT9D combination. The Boeing Company and Pratt and Whitney Aircraft, recognizing maintainability as a key factor in profitable airline operation, designed the JT9D engine and power plant installation accordingly. Pratt & Whitney's JT9D engine was the first jet engine to be designed and built utilizing the modular concept permitting the independent removal and installation of major engine sections and subsequent sectionalized overhaul.

Extensive coordination and integration of design concepts went into developing the "on-the-wing- maintenance" method (Fig. 4) an outgrowth of a similar concept in use by some airlines on the 707/JT93D. Enhancing and optimizing the modular concept of the JT9D engine, Boeing developed a strut-mounted rail system for 747 on-wing engine maintenance. By employing this support system repairs and replacement of individual engine sections could be made with the engine sections could be made with the engine remaining on the airplane. Some engine modules, which must be separated to gain access to the module to be replaced, could be stored on the rails, allowing for rapid reassembly. Significant cost savings from reduced spares requirement and transportation costs were anticipated. It subsequently turned out that engine removal was most often necessary anyway, and on-the-wing maintenance is practiced only for limited requirements now. The modular concept does return many benefits in overhaul maintenance, however.

All engine handling GSE designs were critiqued by ATA Engine Logistics Committee members. The overhead sling and bootstrap method were selected as the primary removal

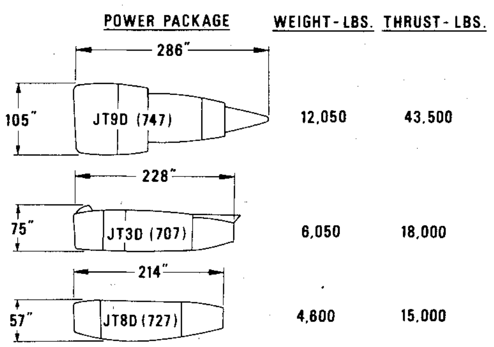


Fig. 2 Size comparison.

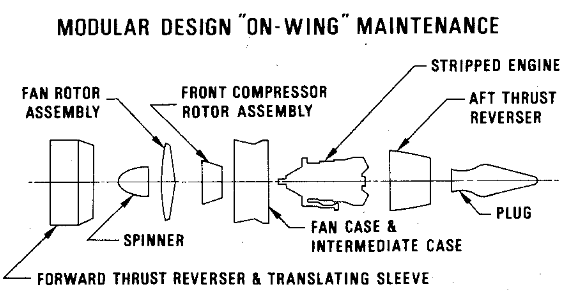


Fig. 3 New maintenance concept.

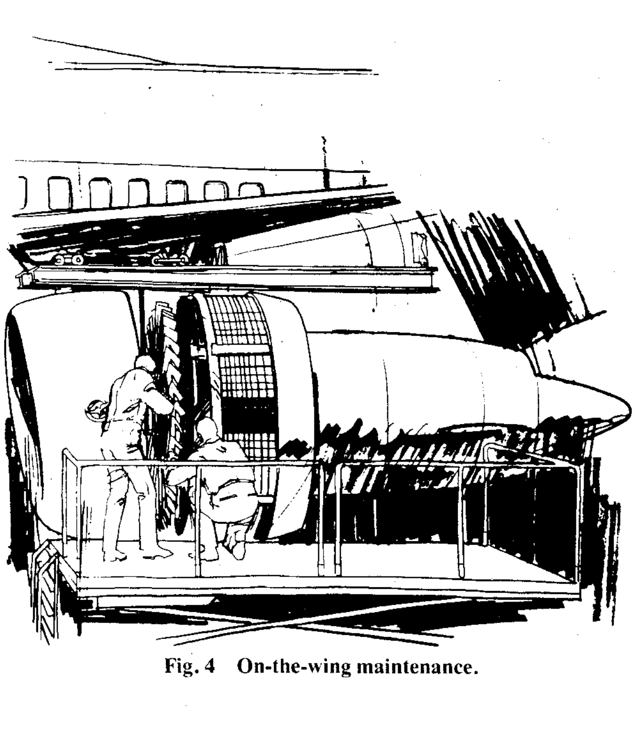


Fig. 4 On-the-wing maintenance.

and installation means. Boeing also designed an inlet sling, an installation tool kit, and transportation dolly. All engine change equipment was fabricated and demonstrated for the ATA committee and changes were incorportated to satisfy operators and to ensure optimum maintenance operations. All GSE purchased by customers was first tried out at Boeing prior to shipment to airlines. The 747/JT9D-3 "Bootstrap" system is shown in Fig. 5.

Early in the determination of support requirements for the 747, it was apparent that a rapid method of shipping spare JT9D-3A and 7 engine pods would be necessary, especially in view of the size of the engine relative to available air cargo carrier aircraft. For Pan American's world-wide routes, the "fifth engine" concept was selected. This external carriage concept, now in use by several airlines, attaches a fifth pod to the left wing of the 747 between the fuselage and inboard engine for air shipment. For fifth pod air shipment, the fan blades are removed from the core engine and packaged separately. Pod size and clearances required a unique method for installation of the pod. The following sequence is followed when preparing the engine for fifth pod shipment:

1) A special strut is attached to the engine.
2)After removal of the fan rotor blades, a deflector dome is mounted on the front compressor.
3) The rear of the engine is covered with a turbine exhaust fairing.
4) The spare engine is ready for transport to the aircraft.
5) The fifth pod is raised into position inboard of the No. 2 engine by means of a special hoist system built into the strut.
6) Cowling is installed to complete the pod.
7) The completed pod is on its way to its destination. (Fig. 6).

The advent of the 747 freighter airplane permitted development of internal carriage equipment and procedures to supplement the external carriage of spare engines. The initial method developed provided for carriage of the engine and its QEC components immediately inside the nose door in the forward position as shown in Fig. 7. Clearances here were extremely close, but by holding the shipping buck dimensions to a minimum, it was possible to carry the complete JT9D-3A and 7 QEC's inside the freighter.

Longitudinal carriage of the JT9D-7 is also possible aft of the position shown if the fan thrust reverser is removed or the engine is tilted to provide a maximum height of 97″. The addition of a side cargo door to the 747 freighter and to modified passenger airplanes has increased the capability of the 747 for engine transport. The JT9D-7 QEC can be carried in the lateral position shown in Fig. 8. Removal of the tail plug is required in this position.

Ground support for the 747 propulsion system has evolved in the 10 yrs. since introduction through the JT9D-7, 7A, and 7F engine revisions. Boeing equipment is in use all over the world serving 100 cities in 50 countries. Proven support was one reason for selection of the 747 for the USAF Command Post requirement. Commercial GSE is supporting the JT9D-7 engines on number 1 and number 2 Command Post airplanes.

III. 747/CF6-50E

The US Command Post airplanes will all eventually use the General Electric CF6-50E engines. The CF6-50E is a third-generation derivative of the TF39 engine used on the USAF C-5 transport and is rated in the 51,000 lb thrust class. These engines are also being offered as alternates to the JT9D on all 747-200 aircraft. With the advent of competitive wide-body aircraft, Boeing, in cooperation with General Electric, in 1971 initiated propulsion system design and then in 1973, a flight test program to certify the 747 with the CF6 engine. Along with the Command Post, 747 airplanes with General Electric engines are or will soon be flying for Royal Dutch Airlines (KLM), Lufthansa German Airlines (DLH), Air France, and Alia, Royal Jordanian Airlines.

Commonality with DC-10 GSE was one of the aims in this program, but engine handling equipment ended up being different and unusable on aircraft other than 747's. Respon-

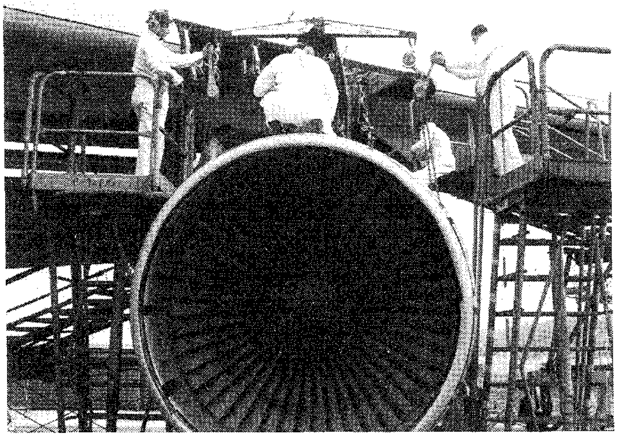


Fig. 5 GSE demonstration.

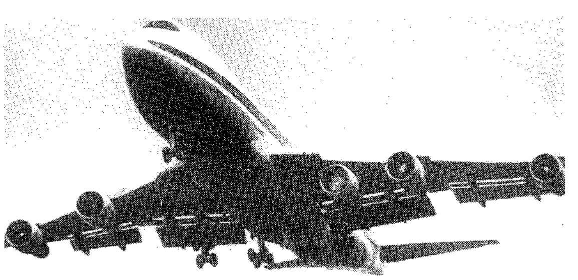
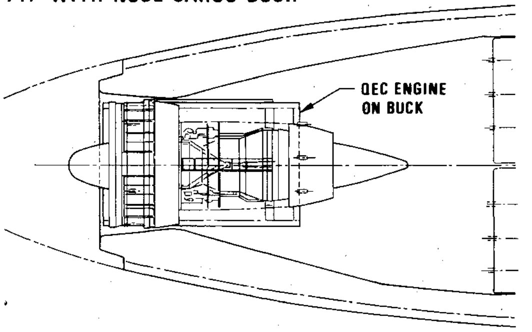


Fig. 6 Fifth engine carriage.

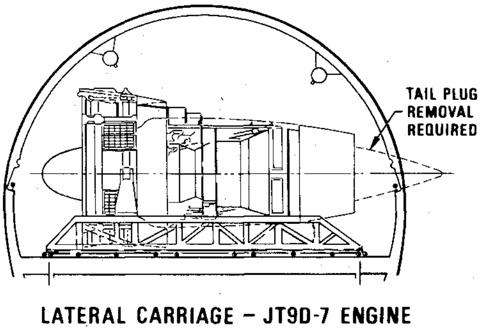
747 WITH NOSE CARGO DOOR



LONGITUDINAL CARRIAGE – JT9D-7 ENGINE

Fig. 7 JT9D air transport.

747 WITH SIDE CARGO DOOR



LATERAL CARRIAGE – JT9D-7 ENGINE

Fig. 8 Internal transport.

siblity for design of strut, cowling, and buildup components was that of The Boeing Company with the exception of the fan and turbine thrust reversers. General Electric was responsible for bare engine, fan thrust reverser, and turbine thrust reverser. Boeing fabricated the strut, cowling, and built up the engines at its Everett facility. Inboard struts are reworked JT9D-7 inboard struts. The outboard struts are new design. Unlike the JT9D-7 program, General Electric shared responsiblilty for power package handling equipment. Boeing was responsible for all installation and removal GSE related to strut, cowling, and build-up components. General Electric provided designs and GSE to handle the turbine, thrust reverser, and on-strut maintenance of the fan thrust reverser.

Ground handling equipment developed for the JT9D-7 engines in most cases was not usable for the CF6-50 engine. The fan thrust reverser, unlike the one on the JT9D-7, was hinged from the strut and remained in place during engine change, restrained by an integral actuator on each side and a backup GSE hold-open device. During engine change, the fan cowling also remained attached to the strut and was held open by an additional hold-open device. The primary method of engine installation/removal due to the aforementioned constraints was determined to be by a bootstrap hoisting system. This system and the CF6-50 cowling array are shown in Fig. 9.

Unlike the JT9D-7 engine, it is necessary to support the CF6-50E engine in a cradle while it is being lifted. The cradle, Fig. 10, developed for the CF6 engine, was able to be used with the JT9D engine transportation dolly; however, due to the 4° upward pitch of the engine and 7° roll due to wing dihedral, a new bootstrap hoisting kit had to be developed.

The maintenance design features of the CF6 engine were developed through the cooperation of General Electric, aircraft manufacturers, and customer airlines. The engine can be disassembled into its major components or engine maintenance units for both sectionalized repair and overhaul. This modular design also enables the engine to be split for shipping. Figure 11 illustrates the CF6 engine fan module separated from the basic engine.

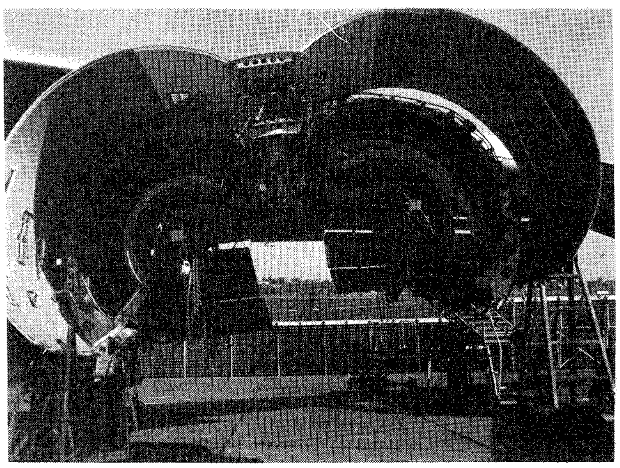


Fig. 9 Ground handling changes.

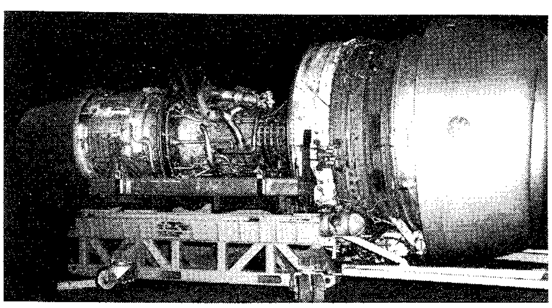


Fig. 10 Engine cradle.

Boeing, General Electric, airlines, and a GSE supplier all participated in the development of the equipment shown here. PF Industries of Seattle designed these integrated disassembly, shipping, and assembly stands. This GSE is now in use by a number of airlines for world-wide engine transport. By coordination with Boeing and the KLM airline, PF was able to design their system to air transport the G.E. engine on two pallets. The handling equipment also performs the tasks of assembling the replacement engine; removing the damaged engine from the airplane; installing the new engine; and disassembly of the damaged engine for transport to the airplane as illustrated in the sequence shown in Fig. 12. Using a standard cargo loader and pallet dollies, the two pallets are compactly stored in the lower lobe of the 747 for transport to repair facility. Ability to carry the engine in the lower cargo hold of a passenger airplane allows an airline to haul a spare engine, engine change GSE, and a change crew all on a regular flight, thereby reducing maintenance costs. Similar GSE has also been designed for the JT9D series engines.

IV. 747/JT9D-70

The recently (Jan. 1975) certified P & WA JT9D-70 engine has installation characteristics similar to the CF6-50. This

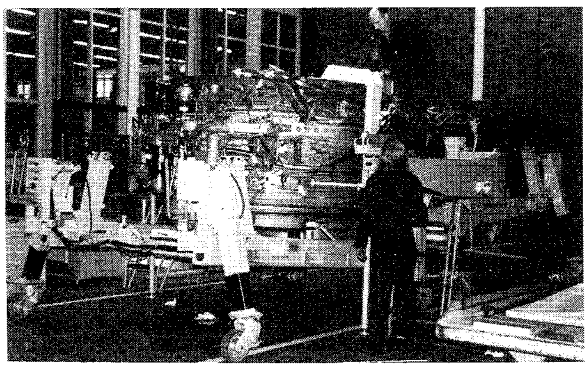


Fig. 11 Split engine shipping.

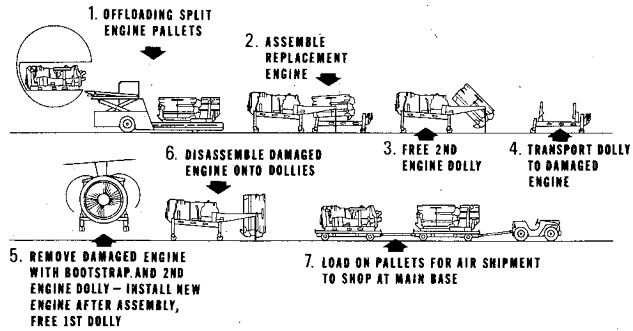


Fig. 12 Engine handling sequence.

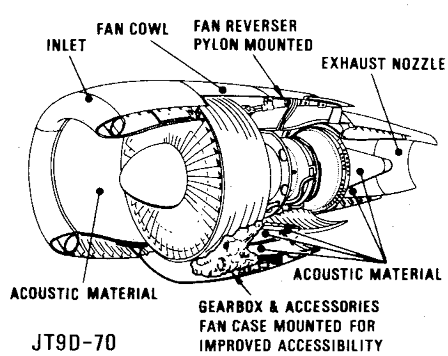


Fig. 13 Common nacelle system.

engine is being housed in a new quiet nacelle provided by the Rohr Corp. The first JT9D-70s have been installed on a Seaboard World Airlines' 747-200 freighter. The JT9D-70 and its counterpart, the JT9D-59 used on the DC-10, are both contained in the common nacelle (Fig. 13) developed by Rohr. This allows airlines to interchange their engines among the DC-10-40 and 747-200, and any other airplane using the nacelle.

The Boeing Company negotiated a contract with the Rohr Corp. to provide a complete propulsion package. Boeing is responsible for the bare strut and its contents, Rohr for pod below the strut, and P & WA is responsible for the bare engine. Design responsibility for GSE is shared between Rohr and Pratt & Whitney. Rohr is responsible for GSE for removal/installation of engine, cowling, fan thrust reverser, and nozzle. P & WA is responsible for GSE related to bare engine. Coordination between P & WA and Rohr insured fixtures and tooling designed for the bare engine will also accommodate the builtup engine. Component overhaul GSE data is covered by a product support agreement negotiated between Rohr and Boeing. Rohr will provide this data for airline customers.

The JT9D-70 is similar to CF6-50E so far as ground handling characteristics are concerned. It includes a fan thrust reverser hinged to the strut that remains in palce during engine change. A fan cowling is also hinged from strut and held open during engine change. There is no core or side cowl since the fan thrust reverser extends all the way to the nozzle. In place of a turbine thrust reverser, only a nozzle or tail pipe is required.

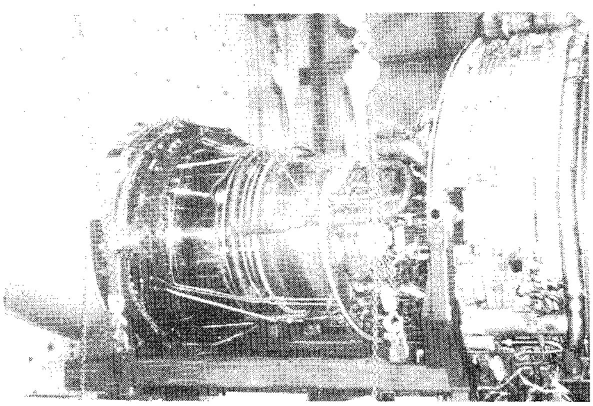


Fig. 14 Engine lift—JT9D-70.

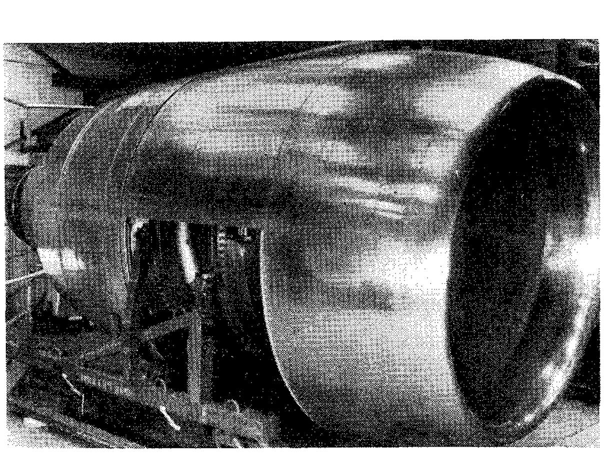


Fig. 15 RB.211 GSE.

The JT9D-70, like the CF6-50E, must be supported by a cradle during installation and removal. The engine ground handling provisions on the engine are different from the CF6-50 and JT9D-7 necessitating a separate handling cradle. Since the buildup is common in many respects to JT9D-59 could be used. However, the 4° pitch and 7° roll of the engine installation eliminated a good bit of the commonality. The support cradle is common to both the JT9D-59 and 70. The bootstrap hoist (Fig. 14) and hold-open equipment for cowling required a separate design.

This equipment tryout was observed by Rohr, Seaboard World Airlines, and the GSE supplier, representative as well as Boeing. The supplier, Stang, was on contract to Rohr and Seaboard. Boeing being initially interested in knowing that GSE equipment for the 747 will function satisfactorily, works closely with GSE suppliers retained by customers to ensure compatibility. Boeing is also in the process of concluding licensing agreements with GSE suppliers to insure the best customer support possible.

V. 747/RB.211

The next engine to be included on the versatile 747 will be the RB.211-524 (Fig. 15). This engine, to be installed on the long range L1011, is also approved for future installation on British Airways 747s. Adapting it to the 747 provides advantages to airlines already possessing the L1011. The British Government is assisting in development and announced approval of the 747/RB. 211-524 combination in June 1975. With approval, Boeing and R-R design work is underway to support a flight test in late 1976.

Technical integration of GSE requirements is also underway, and is documented through formal coordination memos. Engine handling requirements are unique since the fan thrust reverser stays attached to the engine during installation/removal. There is no core or side cowl and or turbine thrust reverser, only a nozzle, making these aspects common with JT9D-70, During engine change it is necessary to support the engine by means of a cradle. A bootstrap hoisting kit is being developed that requires removal of the fan cowling before engine change can be accomplished. An overhead sling that straddles the strut may also be able to be used. This proposal is presently being evaluated.

Design responsiblity for the propulsion pack is divided between The Boeing Company and Rolls-Royce. Boeing is responsible for the design of the strut and its contents. R-R is responsible for the bare and built-up engine as well as associated cowling, fan thrust reverser, and nozzle.

Design responsiblility for GSE is split between The Boeing Company and Rolls-Royce. The GSE related to the strut, i.e., bootstrap hoisting kit, engine installation tool kit, and strut hoisting will be the responsibility of TBC. All other GSE including transportation, installation/removal of components will be the responsiblity of Rolls-Royce.

VI. Summary

When the RB. 211-254 development is completed and certified, the 747 will be the only wide-body airplane which can be procured with any one of four available high by-pass engines. This progressive "Engine" ering gives the 747 great flexibility to adapt to customer requirements for performance and commonality. The ground support requirements generated by this flexibility have been an interesting challenge to Boeing. But by integrating efforts with the engine manufacturers, GSE suppliers, component suppliers, and the airlines, and through the outstanding cooperation of all involved, the problems have been solved.