BOEING COMMERCIAL AIRPLANE COMPANY

Airliner

APRIL 1977

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IN THIS ISSUE

ON THE COVER

This issue features an article recommending that Boeing jet airplanes be flown "On the Numbers." A Boeing pilot demonstrates use of the Quick Reference Handbook to determine the bug airspeed value.

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NEW SERIES OF AIRFRAME, ELECTRICAL AND AVIONICS COURSES

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Due to customer interest, Boeing is making available in 1977 a number of special maintenance training courses on airframe, electrical, and avionics systems of current production Boeing jet airplanes. The courses, ranging in length from 12 to 35 days, are based on 707-300C, 727-200, 737-200C, and 747-200C airplane configurations. The courses, which reflect the current typical delivered configuration for these models, will include all new systems.

Although not customized to any particular operator, the courses will include the same basic information provided when a customer buys a new model. They are designed to provide airline personnel technical instruction on system installation, operation, and general maintenance.

All courses will be taught in English. To attain maximum benefits from the courses, students should be proficient in speaking and reading the English language and be experienced in commercial jet airplane maintenance.

Because standard student materials, course graphics, and course enrollment guidelines will be used, the course offerings will allow operators to plan and schedule training for their personnel at significantly reduced costs.

Actual course offerings are detailed in an announcement entitled *Boeing Aircraft Maintenance Supplementary Training Program*, mailed with all-operator letter M-7501-913 to Boeing customers. Enrollment will be on a first-come, first-served basis. Boeing will acknowledge enrollment and confirm schedules when a minimum enrollment has been reached. If an insufficient number of students have enrolled one month before start of a class, the class will be cancelled and an alternate course will be offered enrollees.

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A new Boeing Airliner Index, 1958-1976, is being distributed in limited quantities with this issue.

Jack Waddell – Director Flight Training
Bill Syblon – Flight Operations Engineer
BOEING COMMERCIAL AIRPLANE COMPANY

"FLY THE NUMBERS"

Today's jet transport airplanes are designed to provide safe and efficient air transportation. To meet this objective these airplanes should be flown as recommended by the manufacturer, "On The Numbers." Typical "Numbers" for approach and landing include approach speeds, procedures, approach path control, touchdown point, and flying techniques. A significant reduction in the approach/landing accident rate could be realized if flight crews understood the airplane performance basis for the "Numbers."

A review of worldwide jet transport accidents indicates the importance of the approach and landing phase to the air transport industry. Approximately one half (47 percent) of all recorded accidents between 1959 and 1975 occurred during 4 percent of the total flight exposure time, approach and landing. Cockpit crew error was listed as a probable cause in 80 percent of these accidents.

The accident report data which lists cockpit crew as a probable cause suggests some common threads which tend to tie these accidents together. First, a series of events, such as weather and runway conditions, tend to compound, placing the crew in a position of exposure to an accident. Second, at some point the crew deviates from the recommended "Numbers," thereby placing the airplane in a potentially hazardous position. In many cases, if any one of the separate items were removed the accident might have been avoided.

PROCEDURAL DEVIATIONS

Some of the common procedural deviations during approach and landing are: excessive approach speed, excessive height over the threshold, excessive floating, and incorrect stopping technique. These deviations from recommended procedures have been documented in many approach and landing accident reports.

One of the prime reasons flight crews deviate from recommended procedures during approach is a lack of understanding regarding the airplane performance aspects of the "Numbers." Some common reasons given for doubting the approach and landing numbers include: uncertainty of airplane climb performance at approach speeds, engine thrust response relative to airplane speed stability, and fear of encountering adverse wind conditions on approach.

Boeing stands ready to assist in promoting flight crew understanding of the basic performance factors used to develop the numbers for all phases of flight—with special emphasis on approach and landing. Information in this article is intended as a guide for preparing crew training material which will develop confidence in the "Numbers."

STABILIZED APPROACH

A safe landing begins with a properly executed approach. The stabilized approach is defined as flight on the desired glide path, electronic or visual, at a steady rate of descent, and on the correct approach speed. The approach should be stabilized before reaching 500 feet above the runway. A stabilized approach should be practiced for each landing, maintaining a habit pattern, as it is the pilot's best insurance for completing a safe landing under any set of weather, airport, and runway conditions.

The stabilized approach implies that the airplane is in trim with the proper amount of thrust. Under such conditions, the modern jet transport airplane exhibits inherent stability which frees the pilot from making continual thrust and pitch attitude changes. This freedom allows the pilot to be mentally ahead of the airplane rather than behind it. With less attention required to fly the airplane, the crew is free to monitor the entire approach picture such as changing visibility conditions, other traffic, wind gradients, and runway conditions.

Approach Speed

Boeing recommends a target approach speed of VREF + 5 knots for landing with light and variable wind reported. VREF has a minimum of 30 percent speed margin above stall speed. When landing in higher wind conditions, the recommended approach speed is VREF plus ½ the steady-reported wind plus the full gust value. The target speed should not exceed VREF plus 20 knots.

The "½ steady-reported wind" factor accommodates the decreasing wind gradient likely to be encountered as the airplane nears the runway. The "gust" factor protects the airplane from transient losses in airspeed due to gusty wind conditions.

The 20 knot maximum wind and gust factor is derived from many years of experience with airplane flight testing and monitoring of airline operations. Also, VREF plus 20 knots is adequate to handle known conditions of wind gradient and to provide full airplane controllability under adverse gusts.

Ability of the airplane to withstand banked flight, or to be subjected to adverse gusts without stalling, can be expressed in terms of maneuver capability (Fig. 1). The approach maneuver capability of Boeing airplanes at VREF is approximately 1.6*g* to stall speed. The stall margin increases to approximately 2.0*g* at VREF + 20 knots.

When considering the margins to stickshaker speed while maneuvering at VREF, the 747 has approximately 1.3*g*. These maneuver margins, based on idle thrust stall speeds, are typical of Boeing jet airplanes. Increasing thrust to that required for level flight provides a 3- to 5-knot reduction in stall speed due to thrust vector effect. As shown by the dotted lines, maneuver margins increase 4 to 6 percent.

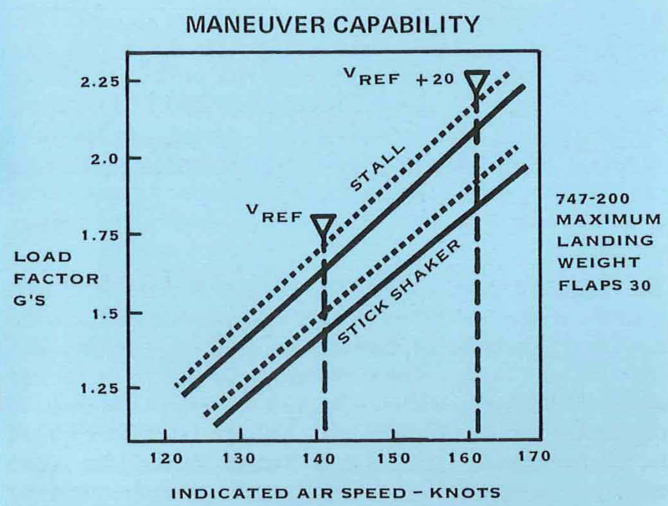


FIG. 1—Airplane maneuver capability during final approach is shown for the 747-200. Note that the dotted lines indicate maneuver capability with thrust set for level flight while the solid lines represent idle thrust stall conditions.

Thrust management is an important part of being able to maintain the proper speed and descent rate relationship for a stabilized approach. The JT8D and JT9D thrust response characteristics (Fig. 2) show that both engines accelerate from flight idle to go-around thrust in approximately 6 seconds. This acceleration time is based on rapid thrust lever movement and is representative of current production jet engines.

Starting from the thrust level required to fly an approach at VREF significantly reduces the time to achieve go-around thrust, as compared to the flight idle case. Conversely, if the approach is flown off speed or glide slope, idle thrust settings may result. Idle settings will increase engine acceleration time, possibly reducing airplane speed response in case of windshear.

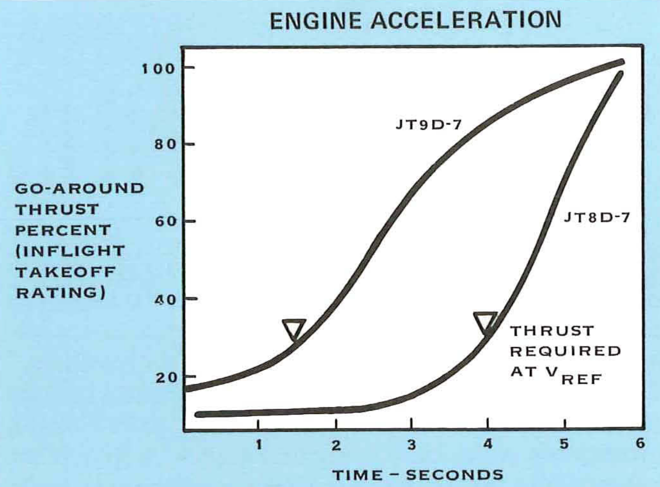


FIG. 2—Current production turbine engine acceleration characteristics minimize the time span from the approach thrust required setting to the full go-around thrust level setting.

Climb capability of the 727 airplane in the landing configuration at go-around thrust (Fig. 3) is typical of modern jet transport airplanes. At VREF and VREF plus 20 knots the rate of climb is slightly below the maximum available. The rate of climb at stickshaker speed is approximately 70 percent of the maximum value indicating the climb performance capability at speeds below VREF.

Note also that operating at speeds exceeding VREF +20 knots will reduce climb performance. A trade-off between climb performance and speed may be accomplished, if desired. However, this maneuver requires bleeding speed and increases workload compared to holding a constant speed.

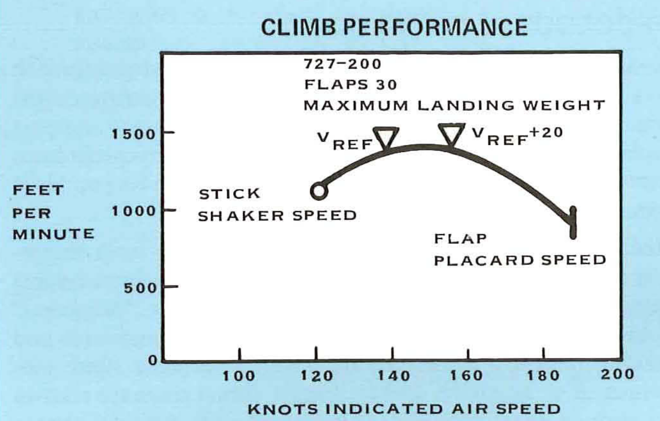


FIG. 3—Airplane climb performance is shown for the approach configuration—from stick shaker to flap limit speed.

An important performance factor to the pilot is the ability to change his flight path once the approach has been established. It is necessary to change both pitch attitude and thrust to transition from a glide slope descent to a positive rate of climb (Fig. 4). At speeds between VREF and VREF + 20 knots, climb rates are maximized.

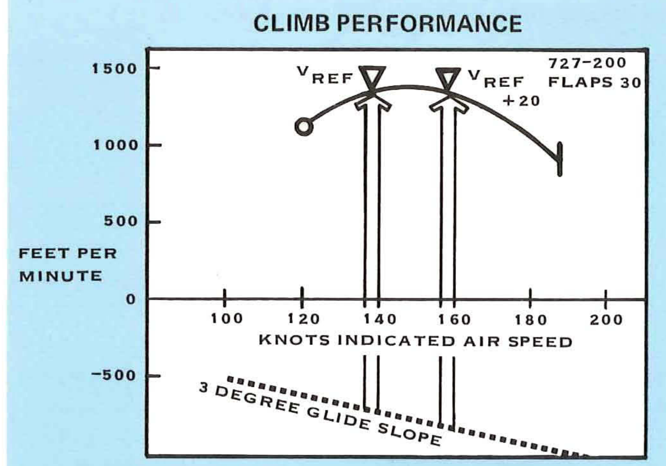


FIG. 4—Performance capability available to transition from an ILS descent to go-around climb is shown for a typical landing configuration. Note that performance is optimized in the recommended speed range.

Approach speed stability is a vital airplane handling characteristic. Speed stability is a direct function of the relationship between approach speed and drag—or thrust required (Fig. 5).

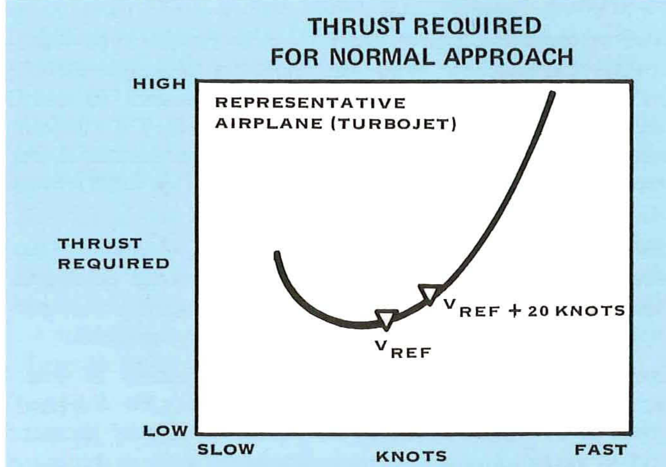


FIG. 5—Thrust required for approach speeds is shown for a typical jet transport. Speed stability is exhibited while minimizing thrust required.

All Boeing models exhibit positive speed stability when flown in trim at their correct approach speed. This characteristic results from the fact that small increases in airspeed will increase aerodynamic drag, which tends to decrease airspeed back to its original value. Conversely, small decreases in airspeed tend to correct themselves when the drag decreases. Therefore, speed excursions will correct themselves with minimum control inputs from the pilot.

WINDSHEAR

The magnitude and composition of low-level windshear has recently come to industry attention. This problem is significant enough to warrant a thorough investigation to determine if present procedures are adequate to cope with the transient flight conditions encountered.

A windshear mathematical model has been developed for use in the Boeing Flight Crew Simulators. This model is, in part, based on the meteorological conditions encountered in the EAL Flight 66 accident at JFK which are documented in "Spearhead Echo and Downburst Near the Approach End of a John F. Kennedy Airport Runway, New York City." This model is designed to assist crews in recognizing windshear conditions and understanding how to fly through them.

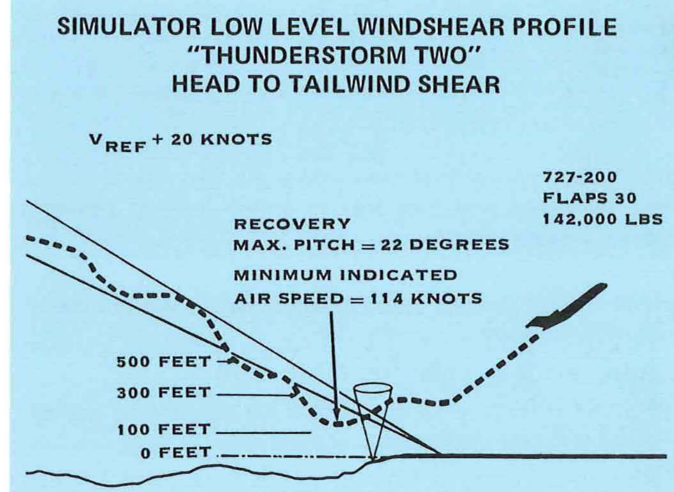


FIG. 6—Severe head to tailwind shear conditions result in approach flight path excursions. Airplane performance capability, however, is adequate as shown if recommended procedures are followed.

Various airline and Boeing pilots have flown and worked on the "Thunderstorm Two" model in the simulator. A representative flight path profile (Fig. 6) shows that windshear conditions are extreme, but they can be handled if the pilot understands and uses the available airplane performance.

Time histories of the recovery techniques (Fig. 7) show that go-around thrust was applied early in the recovery and that a nose-up elevator control input was initiated immediately. Pitch attitudes of up to 22 degrees were reached. Approach speed decayed from 149 knots to a low of 114 knots in approximately 8 seconds.

Altitude recovery was started at 200 feet after rapid application of thrust and a trade of speed for climb performance. The approach was flown at VREF + 20 knots, which provided an adequate margin to trade speed for climb performance.

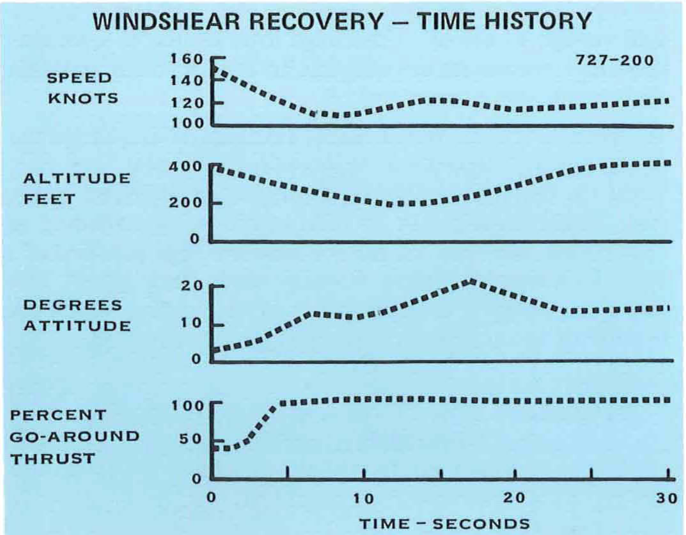


FIG. 7—Pilot recovery from severe head to tail wind shear is detailed. Note the elapsed time from start of airspeed decay to completed recovery and stabilized airspeed.

Several salient points have emerged from the simulator evaluation program:

a) Apply maximum thrust early in the recovery.

b) Fly the attitude required to check descent rate by trading speed for climb performance as necessary.

c) Be prepared to fly at transient speeds down to stickshaker actuation.

A comprehensive article entitled "Hazards of Landing Approaches and Takeoffs in a Windshear Environment" appears in the January 1977 *Airliner*.

APPROACH PATH CONTROL

Proper approach path control places the airplane over the end of the runway at the correct height, in a stabilized condition, and leads to a touchdown at the 1000- to 1500-foot point on the runway. The approach path deviations which most commonly occur in line operation are excessive height over the runway threshold and touchdown short of the target point.

The short touchdown, typically a result of instrument approach errors, will not be covered in this article. The most common approach path error associated with landing overruns is excessive height over the threshold.

Excessive height results in the airplane landing long and consuming excess landing distance. Again, this situation is not a problem on long, dry runways but it leads to bad habit patterns that tend to compound when operating into a short, wet runway under poor visibility conditions.

Excessive height extends the landing distance (Fig. 8). Maintaining a 2-dot-high glide-slope deviation at the middle marker through touchdown will extend the landing distance approximately 1100 feet.

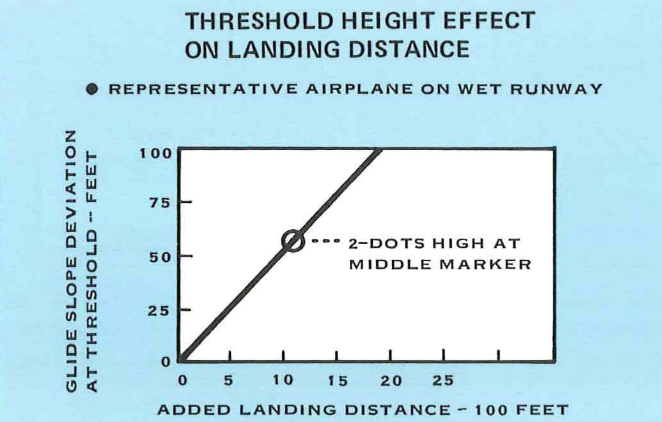


FIG. 8—Threshold height above the glide slope value will increase landing distance as shown.

FLARE

Flare maneuver technique depends upon airplane type. Each airplane has different flying characteristics in ground effect, not to mention landing gear geometry differences. In many cases, pilots who fly various equipment develop a standard technique for flaring all airplanes. A common mistake is the attempt to achieve a soft landing, which often leads to an extended flare or a "float" to touchdown.

The flare maneuver is intended to be brief, minimizing the ground distance to touchdown. A small attitude change is made to check the rate of descent to 100 to 200 feet per minute, which results in a loss of 4 to 5 knots of airspeed.

Excess approach speed will increase the tendency to float, causing touchdown beyond the target point (Fig. 9). A typical jet transport will use an additional 250 feet of runway for each knot of excess approach speed, assuming the airplane is put on the runway at normal touchdown speed. This compares with approximately 50 feet of runway used per knot of excess speed if the airplane is flown onto the runway at the higher speed and a stop is initiated.

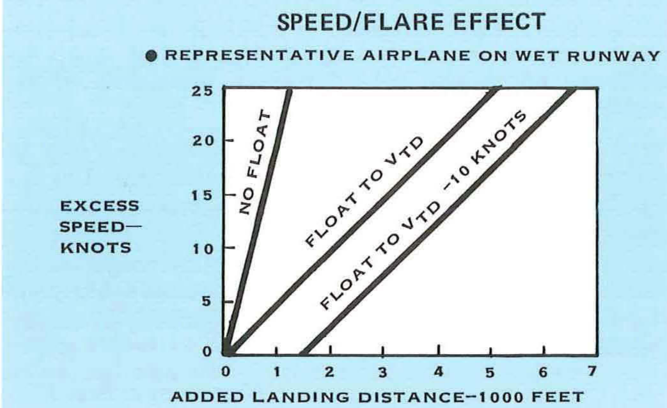


FIG. 9—The effect of incorrect approach speed and landing technique is shown for a wet runway. The penalty for floating to bleed off excess speed for a normal touchdown speed (V_{TD}) is severe.

The deceleration capability on the runway is approximately five times greater than allowing the airplane to float down the runway. This fact emphasizes the importance of approach speed control and proper flare techniques.

TOUCHDOWN

Touchdown should be firm and on the target point, avoiding a bounce. After main gear contact, immediately start to lower the nose gear onto the runway. Nose gear contact increases directional control and puts the airplane in the stopping attitude.

FAA LANDING CERTIFICATION

Before considering the landing rollout, a review of the FAA certification requirements for determining landing field length is in order. This review shows that adequate margins are included to compensate for variations in landing conditions encountered during daily line operation. The requirements are given in FAR 25.125 and form the basis for the certified landing data as well as the manufacturer's recommended procedures and techniques for the entire approach and landing phase (Fig. 10).

The actual landing distances are demonstrated and then multiplied by 1.67 to find the certified FAR landing field length for the dry runway case. Thus, when landing at field length limit weight, a margin of at least 67 percent exists over the airplane's actual capability, not including the contribution of reverse thrust.

The FAR wet runway field lengths can be determined by two methods. The first is to multiply the FAR dry field lengths by 1.15, which gives an overall factor of 1.92 times the actual demonstrated dry runway distances. The second method is outlined in FAA Advisory Circular 121.195(d)-1 and involves actual wet runway testing. The demonstrated wet distances are multiplied by 1.15 to find the FAR wet landing field lengths.

The margin provided by the FAA certification rules will be decreased if the pilot deviates from the recommended speed, glide path, sink rate, touchdown point, and stopping procedures. It is recognized that on long runways and normal landing conditions, maximum stopping capability need not be used. What is important, however, is that crews understand the "Numbers" and do not allow bad habit patterns to develop, which may lead to an accident.

STOPPING SYSTEMS

All Boeing airplanes are equipped with three separate systems to stop the airplane. They are: speedbrakes, wheel brakes, and thrust reversers. These systems must be used together to guarantee stopping performance under all conditions. Before addressing specific airplane systems, a review of the factors which affect runway traction will be accomplished.

A primary measure of runway traction is the tire/runway friction coefficient which is usually designated Mu. Mu is a dimensionless number which indicates the available traction force from a given runway. Values of Mu range from .40 or more for a dry runway to .08 or less for an icy runway.

The average value of Mu for a dry runway is .35 to .40 and is approximately constant over the landing speed range, thereby indicating that wheel braking is effective at both high and low speeds.

For a wet runway, Mu varies from approximately .10 to .35 for high and low speeds, respectively. At speeds of 140 to 150 knots the braking may be the same as on ice. At low speeds, 50 knots or less, braking effectiveness is approximately equal to that available on a dry runway.

For the icy runway, Mu may be as low as .05 to .10 and is approximately constant over the landing speed range.

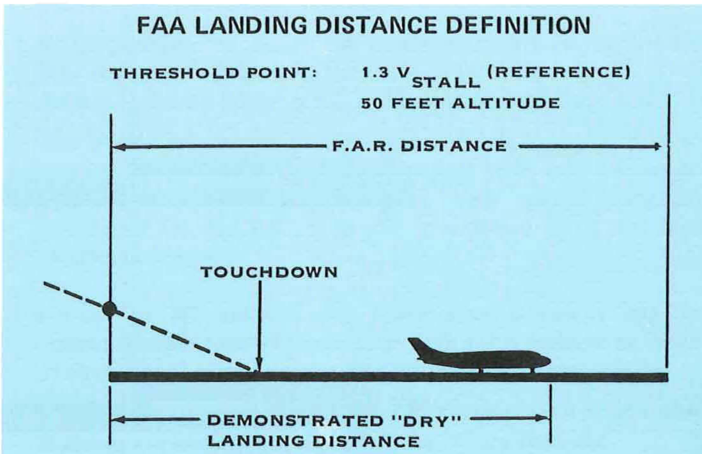


FIG. 10—The FAR Landing Certification Profile is shown for a dry runway. Note that the approach profile crosses the threshold at 50 feet and minimizes the air distance to touchdown.

SPEEDBRAKES

The flight crew's first priority after main gear touchdown is to establish directional control. As soon as possible after main gear contact, speedbrakes should be raised or automatic speedbrake system actuation, verified. The speedbrakes instantly increase airplane drag by up to 50 percent and, by dumping lift from the wing, place 50 percent to 100 percent of the airplane weight on the gear. This shortens wheel spin-up time and increases the braking and directional control forces generated by the tires.

The effectiveness of speedbrakes on high speed stopping performance is significant (Fig. 11). The total retarding forces, without reverse, for wet and icy runways at high speeds are nominally 66 percent and 55 percent, respectively, of the maximum dry retarding force (Fig. 11).

In all cases the retarding force without speedbrakes is only 55 percent of the maximum available with speedbrakes. This is a significant factor to the pilot, as speedbrakes contribute approximately half the total retarding force, because of aerodynamic drag and "dumping" the airplane weight on the wheels at high speeds. Failure to use speedbrakes will increase stopping distance by 2000 feet or more, depending on runway condition.

Please turn to Page 17.

SPEEDBRAKE CONTRIBUTION

- WITHOUT REVERSE THRUST EFFECT
- 747-200, MAXIMUM LANDING WEIGHT

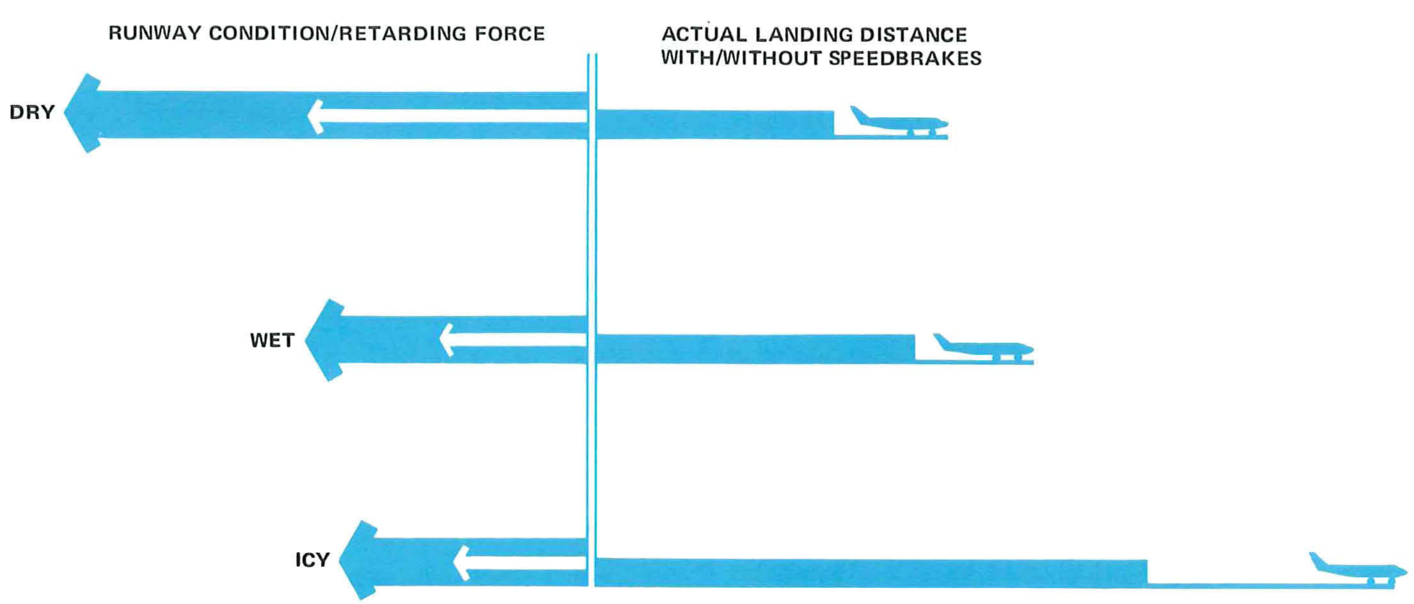


FIG. 11–Speedbrake actuation contributes approximately 50 percent of the retarding force, regardless of runway condition, if reverse thrust effects are ignored. As runway conditions deteriorate, retarding force decreases, making speedbrake actuation increasingly important.

747 Onboard Loader

Boeing has designed an onboard cargo loader which allows 747 Freighter and Convertible airplanes to serve airports with limited cargo handling facilities. The loader, which stows in the forward section of the 747 main cargo deck, can be attached either at the nose of the airplane or at the side cargo door to load or unload pallets and containers.

Special structural provisions are necessary at the nose door to permit loader stowage and deployment. Electrical outlets near the 747 nose and side cargo doors provide 115/200-volts a-c, 400-Hz, 3-phase electrical power for loader operation. Power can be supplied from either the airplane system or directly from a ground power cart.

Estimated time to deploy or stow the onboard loader is slightly less than one-half hour. Time required to deploy the loader, unload 26 pallets from the airplane, reload 26 other pallets, and stow the loader is estimated at two hours and 40 minutes.

The onboard loader is deployed from the nose cargo door in the following sequence through switches on control panels inside the airplane (Opposite and Page 10).

- The nose cargo door is opened.
- The loader is deployed by power drive wheels in the 747 cargo floor to a point approximately 10 feet forward from the front of the airplane main deck. Further outward movement is halted by a mechanical stop.
- Forward legs of the loader are extended electrically, and leg bracing is installed.
- The loader is powered outward to the limit of airplane main deck drive system extension.
- By using a manual drive system in the forward legs, the loader is advanced outward a final few feet to a second mechanical stop.
- Aft legs are extended electrically, and leg supports are installed.
- The loader platform is lowered, and side support cables are installed.

The loader is stowed in a sequence the reverse of the extension cycle.

When operating at the nose of the 747, the loader distributes cargo weight between its forward legs and the nose door sill of the airplane. During cargo loading, the aft legs of the loader, the wheels of which remain approximately five inches above the ground, provide only a guiding and bracing function for the platform.

The loadmaster has an unobstructed view of the cargo loading operation and can control both the loader and airplane cargo handling system. Lower level loading and unloading, however, is usually performed from the ground by using the control panel on the forward left leg of the loader.

The loader and hardware required to adapt it to the airplane nose and side cargo doors weigh approximately 14,600 pounds and when stowed aboard the airplane displace four main deck

pallets. Two reduced height pallets, however, can be stowed on the loader platform during flight.

The loader platform, which has a lift capacity of 30,000 pounds, can be operated from controls on the left forward leg and left upper frame. Hoist speed is 15 feet per minute. The platform is equipped with roller trays and a power drive system similar to the one inside the airplane. Retractable end stops restrain cargo while the platform is being lifted or lowered. Platform transfer speed for cargo is approximately 60 feet per minute. The platform can load cargo up to 96 inches wide by 324 inches long. For example, it can accommodate three 88 by 108-inch pallets/containers or two 96 by 125-inch pallets/containers at any one time.

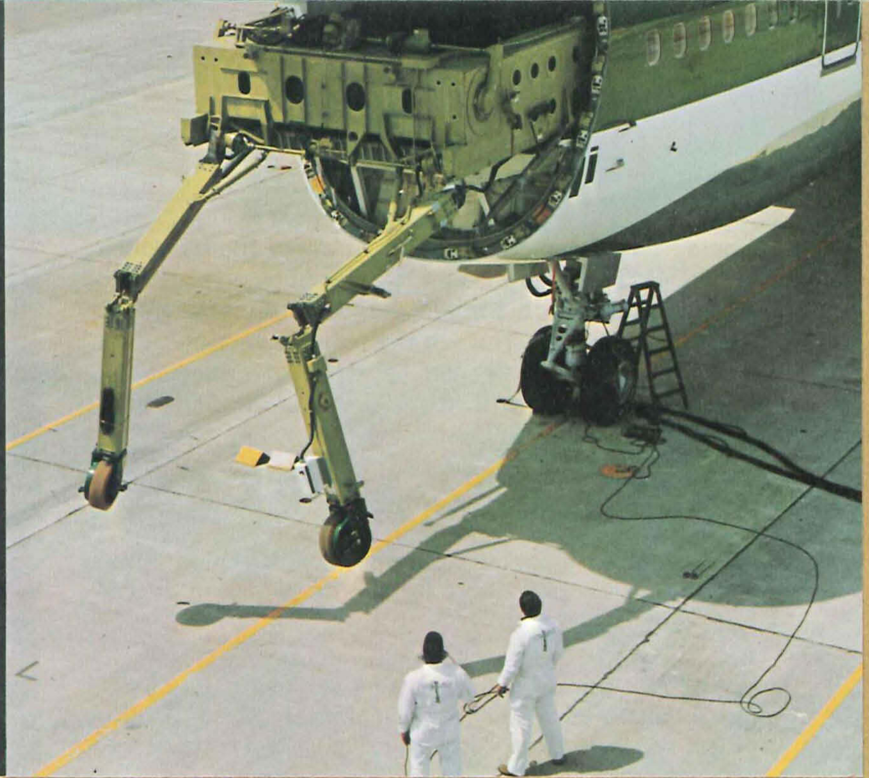
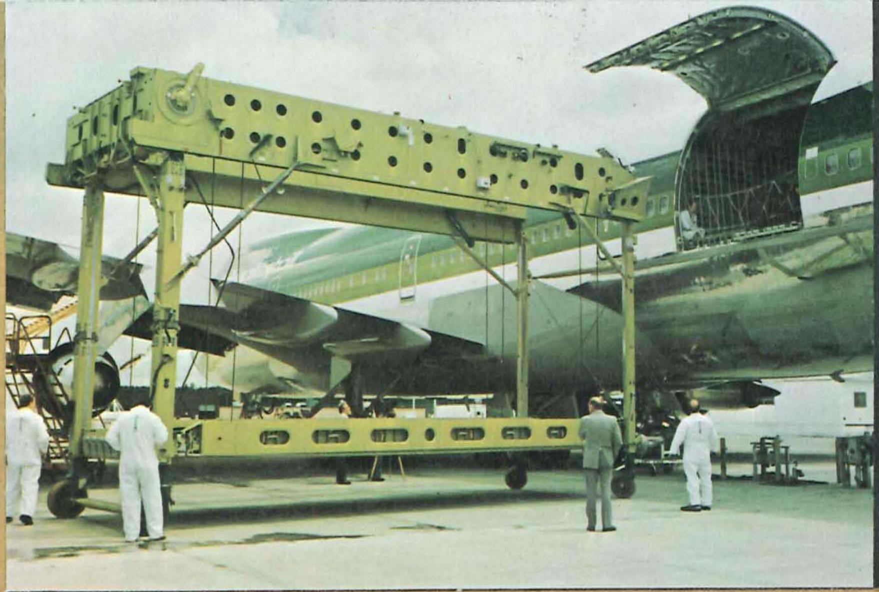
In preparation for loader use at the side cargo door, the aft legs are extended to make the loader a free-standing unit. Two fittings facilitate loader moving and positioning (Page 11).

The loader, which can be offloaded and left at any airport to accommodate schedule cargo operations with any 747 cargo airplane. On 747's not equipped with special electrical provisions for the loader, power is supplied by a standard ground power unit.

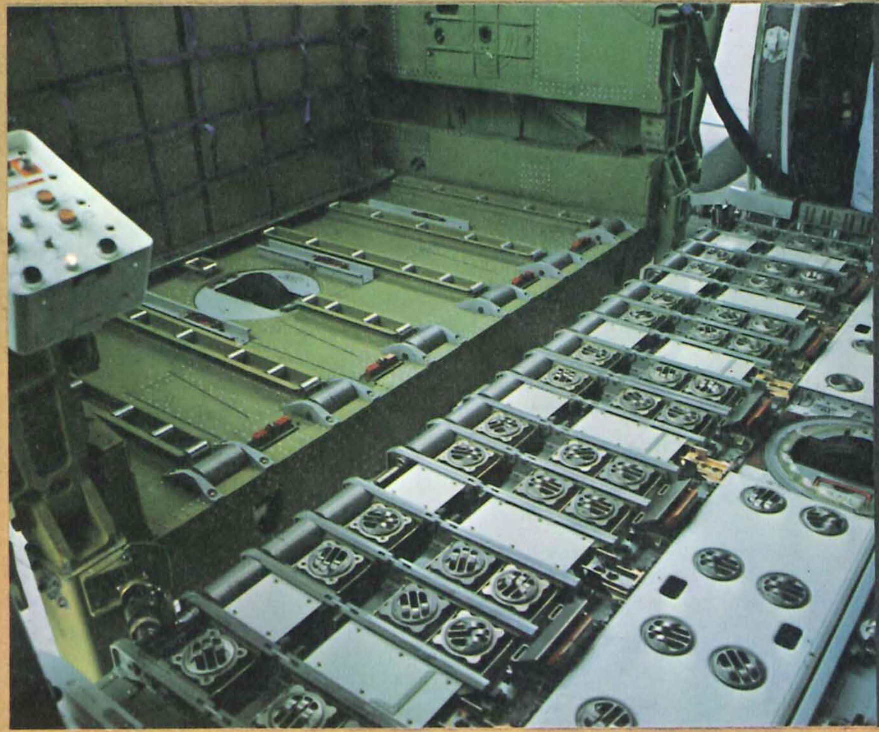
Above–**The 747 onboard cargo loader stows compactly into the forward section of the 747 main cargo deck and is deployed by means of electrical and manual systems. Legs are shown in stowed position.**

Page 10– **The onboard loader deployment sequence and use of loader to unload and load cargo at the nose of the 747 are illustrated.**

Page 11–**The 747 onboard loader can also be positioned at the side cargo door to load or unload cargo. Its positioning, its attachment to the airplane and the unloading of cargo are illustrated.**








747 FULL FLIGHT REGIME AUTOTHROTTLE SYSTEM

This article was prepared in conjunction with L. L. Lundquist, group engineer, and members of the 747 Automatic Flight Controls Group.

An automatic throttle control system which can control engine thrust from takeoff to landing (Fig. 1) has been developed by Boeing for installation on future 747 production airplanes. The first two airplanes with this system installed were delivered to customers in November. Provisions for the system are now being installed in 747 production airplanes, and the system will eventually be available for all 747 airplanes.

The description in this article applies to the autothrottle system installed on 747's with Pratt & Whitney JT9D or Rolls Royce RB211 engines. These engines have Engine Pressure Ratio (EPR) thrust references. General Electric CF6 engines have an N1 thrust reference, but 747 autothrottle system operation is essentially the same. Only significant differences between the EPR and N1 referenced autothrottle systems are mentioned in the description.

SYSTEM OPERATION

The system is a functional integration of a new 747 autothrottle system and a Total Air Temperature (TAT)/EPR Limit system (or TAT/N1 Limit system on airplanes with CF6 engines).

The system provides three primary autothrottle control modes: EPR control, Mach Hold control, and Speed control.

They are selected on the Autothrottle-TAT/EPR mode select panel (Fig. 2).

EPR Control–In EPR control mode the autothrottle system commands the thrust levers so that the engine with the highest EPR indication acquires and maintains the EPR Limit value for the selected EPR limit mode minus any increment of EPR decrease selected. The autothrottle computer continuously compares all four engine EPR's and selects the one with the highest EPR as the controlling unit. The flight crew can adjust thrust levers of individual engines to attain agreement in the EPR reading of the four engines. EPR mode is used for takeoff, climb, cruise, maximum continuous thrust, and go-around regimes of flight.

Mach Hold Control–In Mach Hold control mode, normally used during cruise, the system commands the thrust levers so

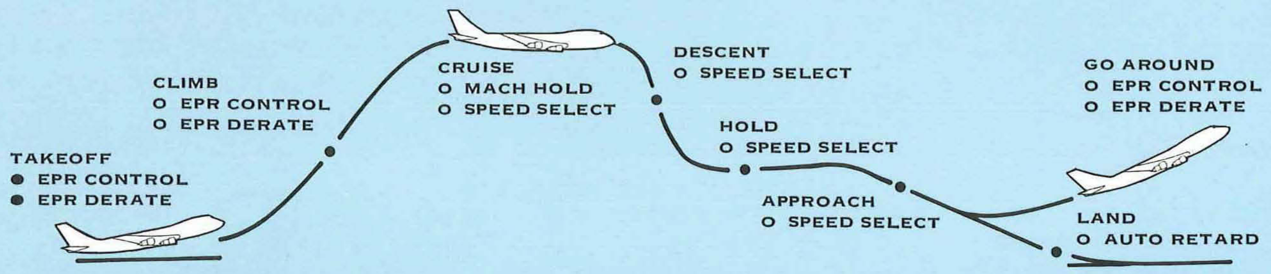


FIG. 1–The new full flight regime autothrottle system provides full-range speed control, Mach hold control during cruise, and EPR control during takeoff, climb and go-around. A 747 flight profile shows the usual autothrottle mode selection for each segment of the flight.

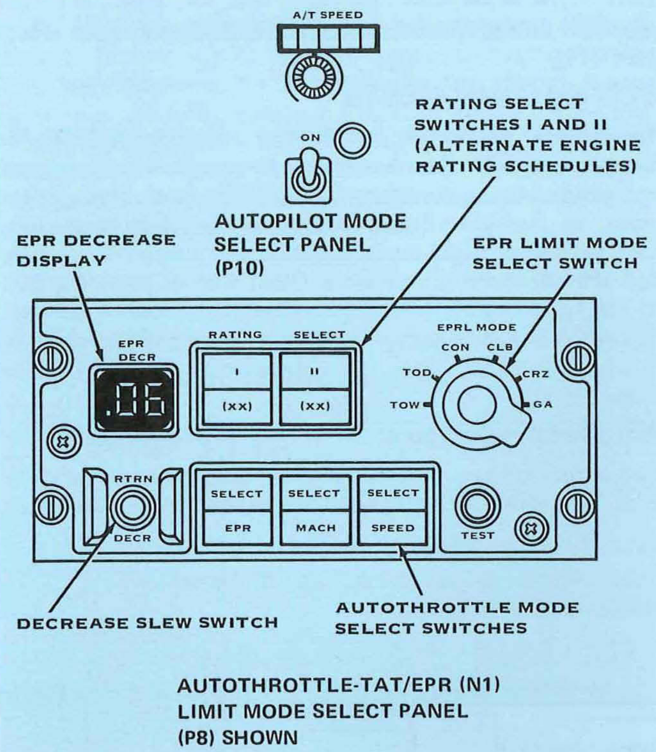


FIG. 2–Select switches for the autothrottle system, TAT/EPR Limit mode select switches, EPR rating select switches, and a display of the increment of EPR decrease selected on the slew switch are located on the TAT/EPR Limit mode select panel. The autothrottle ON-OFF switch and airspeed select control and indicator are on the autopilot-flight director mode select panel.

that the airplane maintains the Mach number existing at the time of Mach Hold mode engagement.

Speed Control–In Speed Control mode, the autothrottle system commands the thrust levers so that the airplane acquires and maintains the selected airspeed. Airspeeds from 100 to 400 knots may be selected. Speed is selected by a control on the autopilot-flight director mode select panel (Fig. 2). The selected value is repeated by the "bug" on the captain's and first officer's airspeed indicators. A bias function is included to compensate for gusts during approach. Speed control mode is typically used for the descent, holding, approach, and landing regimes of flight.

Submodes Available

Several submodes of the above primary modes serve control and/or protective functions. The submodes include takeoff, overboost protection, minimum speed protection, and flap speed limit protection.

Takeoff submode is an EPR mode which depends upon selection of a takeoff TAT/EPR Limit mode. In this mode thrust levers are controlled so that the highest engine EPR acquires the selected reference EPR and maintains that EPR until the airplane attains a speed of 80 knots. At 80 knots the autothrottle system shifts to a throttle hold mode–which inhibits further automatic throttle control activity. The mode is interrupted by the selection of a different EPR Limit system mode.

The overboost protection features operates in all modes–except for the system reversion mode–and functions in two separate paths, one providing a backup for the other. The primary path is EPR Limit override control, which provides thrust limiting by overriding the Speed or Mach Hold control mode if the thrust required to correct for speed or Mach error is greater than the selected EPR reference. The backup to the EPR Limit override control is a path which actuates when the EPR limit is exceeded by a certain value as programmed by the EPR rate of change. When the EPR value is exceeded, electrical power is interrupted to the throttle servomotor to stop thrust lever forward movement.

The minimum airspeed protection feature operates during the Speed and Mach Hold modes and assures a safe airplane angle of attack to avert low speed buffet at high altitudes and at speeds below approximately 1.3 V-stall at low altitudes. Two angle of airflow sensors are installed on the fuselage–one on each side. The autothrottle computer (Fig. 3) uses the average of these two sensor inputs, compares this average with a reference airspeed value, and advances the thrust levers to keep airspeed from becoming too slow.

Below 15,000 feet, the reference airspeed value is programmed as a function of flap position, and the system will provide override control to the appropriate speed for each flap position. The flap placard limit speed protection feature automatically limits the maximum speed that can be commanded by the autothrottle system to a value determined by extended flap position. The steady-state speed limits are slightly below the flap placard speed values.

The system permits selecting an EPR increment below the computed EPR Limit for use as an engine EPR control reference.

Reversion Mode

An autothrottle reversion mode allows the throttle to operate in Speed mode if a TAT/EPR Limit system malfunction is indicated. The system can be used for approach and landing modes only, when EPR Limit protection is lost. Thrust lever forward movement is limited by fixed limit switches set at a thrust lever position of 38 degrees, the same as the current in-service 747 autothrottle.

The EPR Limit system computes the EPR limit for the following conditions or modes available on the TAT/EPR Limit mode select switch (Fig. 1):

Engine Rating	*EPR Limit Mode*
Takeoff Dry (without water injection)	*TOD*
Takeoff Wet (with water injection)	*TOW*
Maximum Continuous	*CON*
Maximum Climb	*CLB*
Maximum Cruise	*CRZ*
Go Around	*GA*

Note: TOW Limit mode is not available on 747's with CF6 or RB211 engines and on some JT9D engine installations.

Two alternate engine ratings, which are engine programs of decreased thrust, are available in each configuration through selection on the Autothrottle-TAT/EPR Limit mode select panel (Fig. 2).

SYSTEM COMPONENTS

The system includes an autothrottle computer, a Total Air Temperature/EPR Limit system, longitudinal and normal accelerometers, an Autothrottle-TAT/EPR Limit Mode Select panel, an Autopilot-Flight Director mode select panel, four EPR indicators, flight mode annunciators, airspeed indicators, and attitude director indicators. Other sources providing data to the autothrottle computer include the central air data computer (CADC), inertial navigation system (INS), angle of incidence (attack) vanes, and flap position transmitters. See Figs. 2, 3, and 4.

Autothrottle Computer

The autothrottle computer (Fig. 3) accepts inputs of EPR limit from the TAT/EPR Limit computer, Mach Hold signals from the central air data computer, selected airspeed error signals from the captain's airspeed indicator, and angle of incidence (attack) signals from the angle of airflow sensors for use as basic references for thrust lever position control. It uses inputs from the EPR indicators, CADC, INS, longitudinal and normal accelerometers, and the engine power lever angle transducers for signal programming and damping. Mode selection logic permits selection of correct combinations of these signals to achieve desired functions.

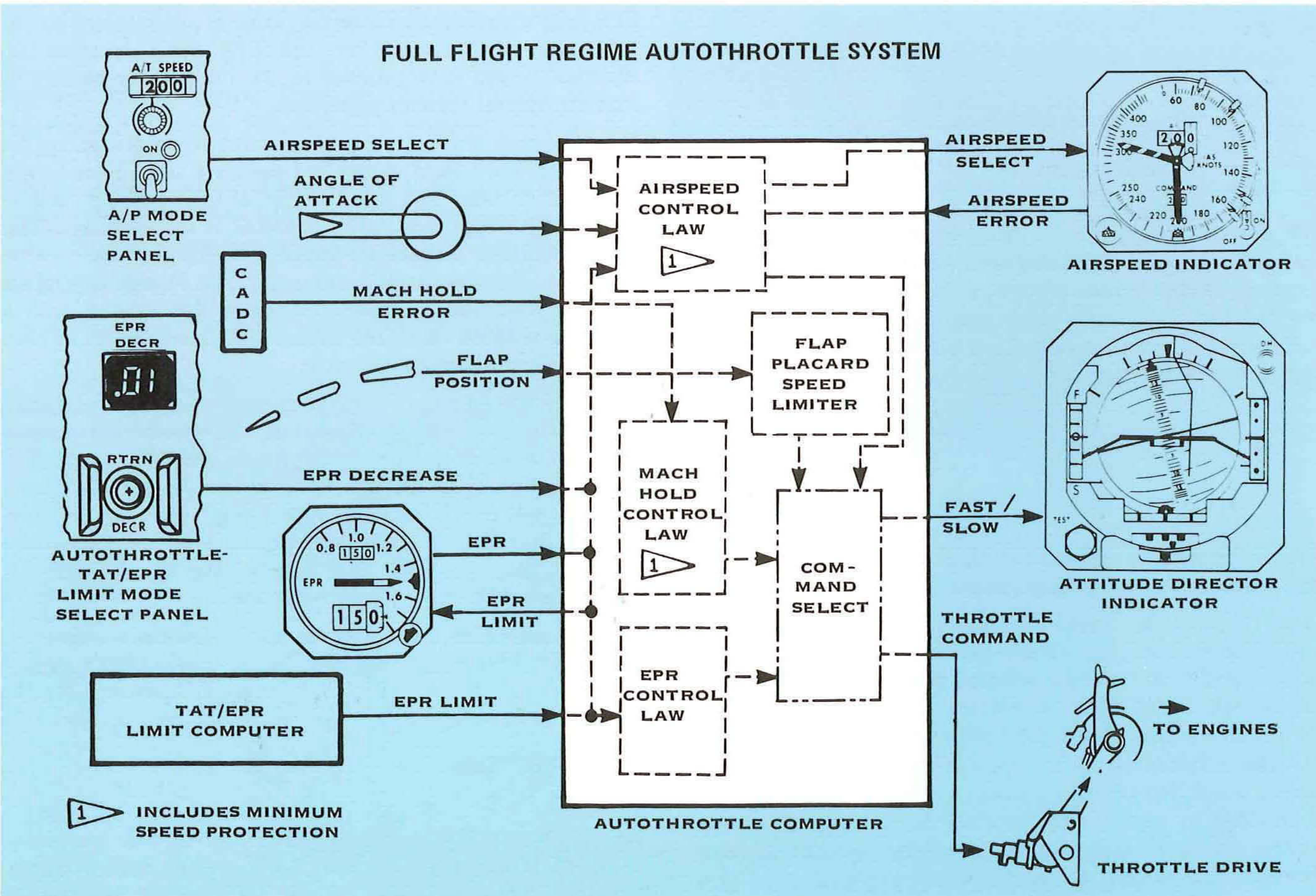


FIG. 3—The autothrottle computer receives inputs from several data sources and provides outputs to the captain's and first officer's airspeed and attitude director indicators and to the thrust lever servomotor.

TAT/EPR Limit Computer

The TAT/EPR Limit computer (Fig. 4) accepts inputs of pressure altitude, Mach number, bleed air use, and total air temperature. These parameters are used with engine data stored in memory to compute the EPR limit for the selected thrust mode. When a limit mode is selected, a signal addresses the computer to calculate the EPR limit and supply a signal to drive the limit counter within the TAT/EPR Limit indicator. The computer can provide at least three different engine rating programs.

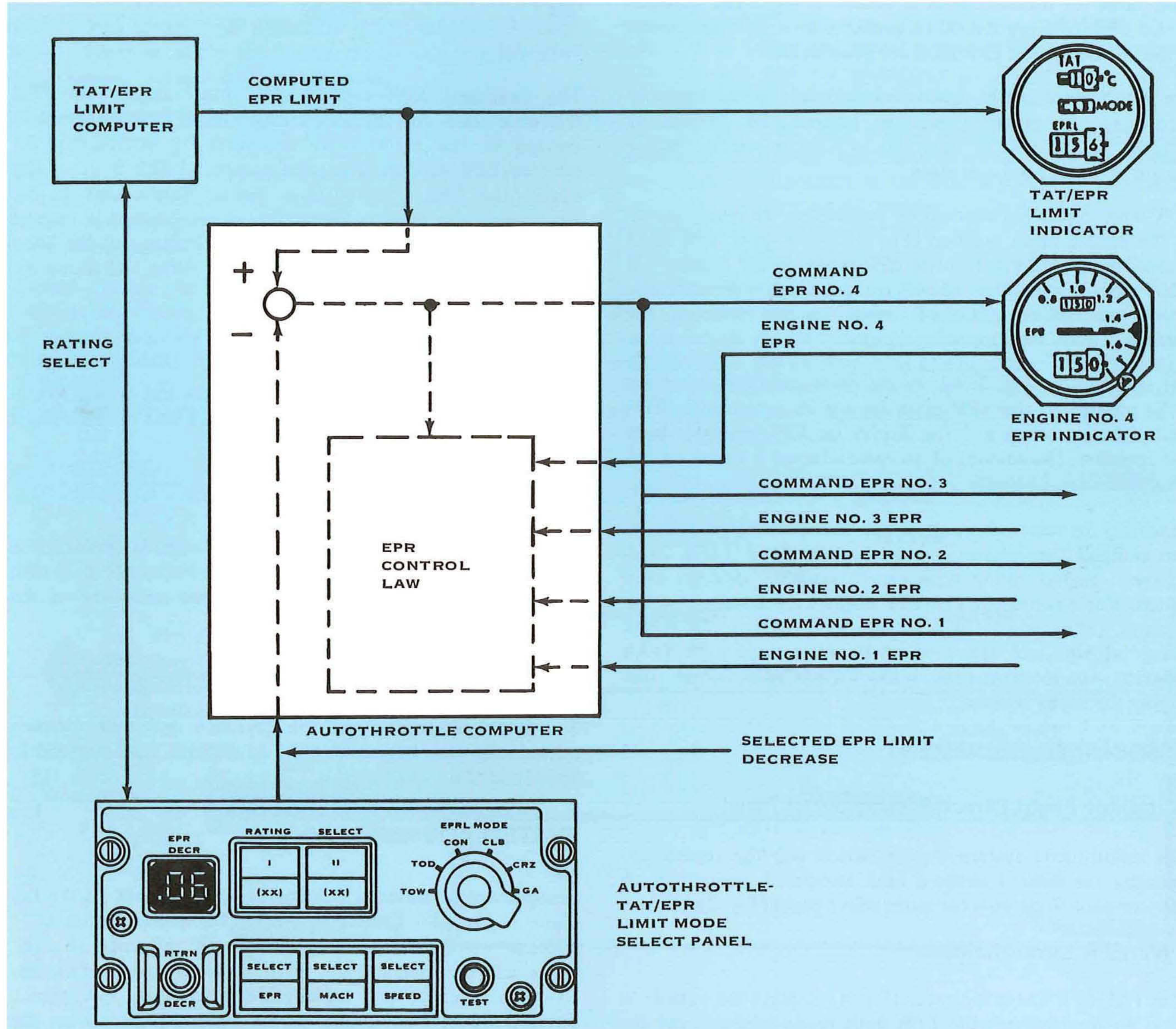


FIG. 4—The computed value of EPR limit is displayed on the TAT/EPR Limit indicator while the command EPR (EPR limit minus selected value of EPR decrease) is displayed on the command bug and counter in the EPR indicators.

Autothrottle-TAT/EPR Limit Mode Select Panel

Switches for selecting the autothrottle control modes and the proper EPR limit mode are on the Autothrottle-TAT/EPR Limit mode select panel (Fig. 2). Also included on this panel are controls for selecting the desired engine rating EPR programs and the desired amount of EPR below the computed limit value for thrust control reference. A maximum decrease of .06 EPR (or 5 percent N1) is available when operating levels below the computed EPR limit are permissible.

The basic autothrottle modes are selected by momentarily depressing one of three switches, labeled EPR, MACH, or SPEED (Fig. 2). One of these modes must be selected before the autothrottle can be engaged.

EPR limit modes are selected by positioning the rotary switch to the desired mode position (Fig. 2). Selection of EPR Limit takeoff mode and autothrottle EPR mode on the ground will select the autothrottle takeoff program upon autothrottle system engagement. If EPR mode is not selected, the autothrottle system cannot be engaged.

The slew switch (Fig. 2) selects the decreased EPR increment to be applied to the EPR limit for use in autothrottle EPR control computation and for display on EPR indicator bugs and counters. The amount of decrease selected is shown on the associated digital counter.

Capability to select alternate lower engine rating programs is also available through rating select switches I and II (Fig. 2). A different engine rating schedule is available through each switch. For example, if JT9D-7F engines are installed on the airplane, rating select I will actuate a JT9D-7 or -7A thrust rating program and rating select II will actuate a JT9D-3A program. Annunciators next to the TAT/EPR Limit indicator display the rating selected.

ASSOCIATED EQUIPMENT

Autopilot-Flight Director Mode Select Panel

The autothrottle system engage switch and the control for selecting the desired airspeed (and associated readout) is on the autopilot-flight director mode select panel (Fig. 2).

TAT/EPR Limit Indicator

The TAT/EPR Limit indicator (Fig. 4) displays the outside or total air temperature, the EPR limit mode selected, and the computed value of the selected EPR limit. An aspirated temperature probe provides the TAT/EPR Limit indicator accurate ambient air temperature (OAT) input before flight and total air temperature (TAT) during flight. The indicated outside or total air temperature is provided to the TAT/EPR Limit computer for EPR limit computation.

EPR Indicators

EPR indicators (Fig. 4) receive a signal from the engine pressure ratio transducers which is proportional to the ratio of engine inlet and exhaust gas pressures. A transmitter is installed in the indicators to provide signals to the autothrottle computer.

The command EPR counter and "bug" display the EPR reference used for the autothrottle. This EPR reference is derived in the autothrottle computer by subtracting the selected EPR decrease from the computed EPR limit. A flag covers the EPR counter if a malfunction occurs in the automatic drive system. The indicator can be used in manual mode by pulling out the EPR set knob. Pulling out the knob removes the flag, overrides the automatic drive, and allows the EPR "bug" to be set for visual reference.

Flight Mode Annunciation

Autothrottle system operating mode status and caution/warning lights are displayed on the captain's and first officer's flight mode annunciator panels.

Airspeed Indicators

Airspeed selected for the autothrottle system is displayed on the captain's and first officer's airspeed indicators (Fig. 3) with a select "bug" which moves around the periphery of the indicator.

Attitude Director Indicators

The fast-slow pointer on the captain's and first officer's attitude director indicators (Fig. 3) displays the command in Speed and Mach Hold modes.

SYSTEM ADVANTAGES

Smooth operation is an outstanding characteristic of the full flight regime autothrottle system. The system responds to airplane configuration changes, selected reference changes, flight path changes, and gust disturbances in a positive manner to avoid excessive and undesirable thrust lever movements. Smooth thrust lever inputs can be expected throughout the full flight regime and minimum cabin noise level changes can be expected on takeoff and approach. Thrust lever positioning closely maintains the desired EPR speed reference—with a potential for fuel saving and increased engine life.

Continued from Page 8.

THRUST REVERSERS

When landing on slippery runways, thrust reversers provide a significant portion of the retarding force. Reverse thrust is most effective at high speeds. Also, it is necessary to apply thrust to generate effective reverse thrust. To obtain the largest benefit from reverse thrust, it is important to initiate reverse early and promptly apply thrust as required up to the limit EPR. Thrust reversers can typically reduce landing distance 500 to 800 feet if used as recommended. On very slippery runways where traction is minimized, reversers can reduce landing distance 2000 feet or more.

BRAKE AND ANTISKID SYSTEMS

Antiskid components were introduced into braking systems to minimize tire skidding and prevent wheel lockups during braking. Antiskid provides optimum braking under dry and slippery conditions.

Antiskid system operation is optimized when it receives a steady input from the pilot. Pumping or cycling pedal pressure will degrade stopping performance by reducing the ability of the antiskid system to modulate brake pressure to the wheels accurately. The pilot making a maximum effort stop should use full pedal pressure until the stop is complete.

STOPPING TECHNIQUE

Procedurally, stopping technique includes speedbrake extension immediately after main gear touchdown followed by brake application and reverse thrust as required. The specific system contributions to stopping vary with runway conditions and will be addressed in the following paragraphs.

TOTAL STOPPING PERFORMANCE

Total stopping performance (Fig. 12) is a combination of airplane drag, brakes and thrust reversers. The total retarding forces for wet and icy conditions are 65 percent and 55 percent respectively of the maximum dry-runway level.

First, airplane drag and reverse thrust contributions are independent of runway condition. The contribution of these components is 80 percent of the total icy runway retarding force while representing 50 percent of the total dry runway capability. This supports the early use of speedbrakes and reverse thrust during slippery runway operations.

Second, the deterioration in available retarding force on wet and icy surfaces is due to reduced braking effectiveness. Note that the brakes do contribute 30 percent of the total stopping capability on a wet runway, even at a high speed. This braking contribution should be considered by a pilot making a landing on a slippery runway because braking effectiveness increases rapidly as speed decreases.

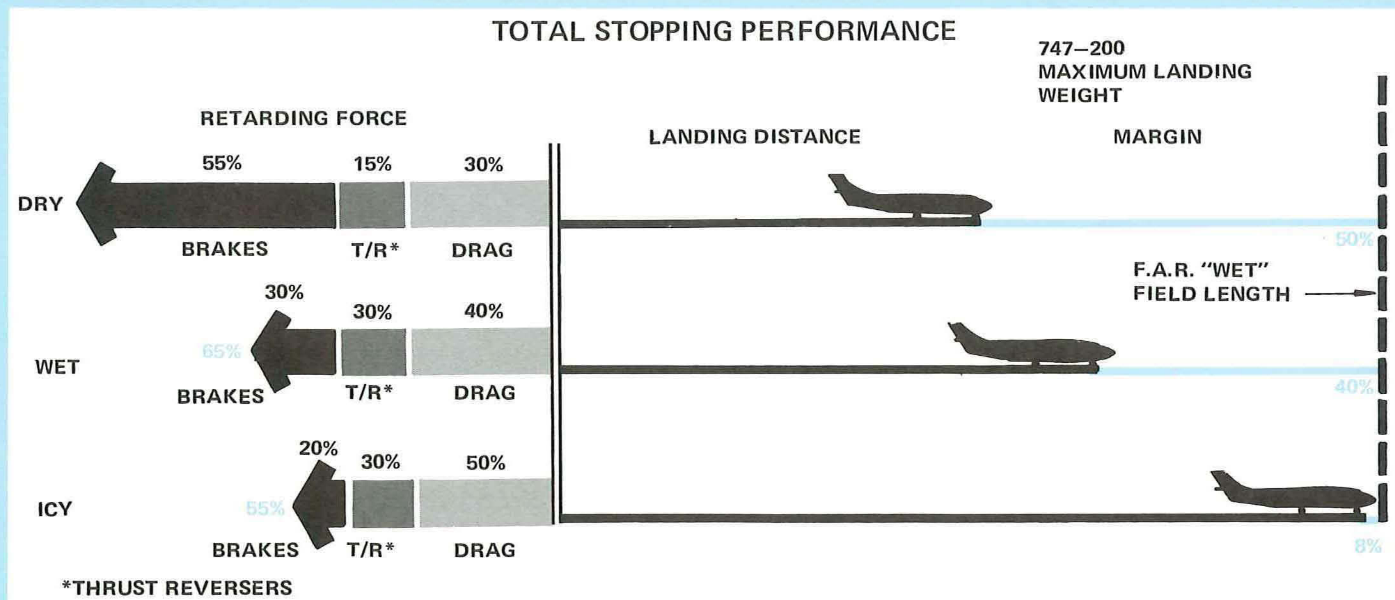


FIG. 12—Total retarding force is shown for several runway conditions, illustrating the relative contributions of airplane drag, brakes, and thrust reversers. Note the margins available compared to FAR wet field length.

Speed and pilot technique deviations will extend landing distance significantly:

DEVIATION	PENALTY
• *Speed*	*50 feet per knot*
• *High*	*20 feet per foot above glide slope*
• *Floating*	*200 to 250 feet per knot*
• *Brakes*	*100 feet per second delay*
• *No reverse*	*500 to 800 feet*

WHAT CAN WE, THE INDUSTRY DO?

Accident causes of the nature discussed in this article are generally a consequence of bad habit patterns which develop over a period of time. Habit patterns are formed and subsequently reinforced in many instances by the environment in which the crew member lives.

Intangible rewards exist for meeting schedules, for soft landings, and for minimizing brake, tire and reverser wear. In daily line operation, the runways are often long and the consequences of high, fast approaches are not immediately apparent. On rollout there is no hurry or need of proper sequence when applying speedbrakes, brakes and reversers. These factors tend to promote individual techniques and personal preferences.

The solution to this problem is obviously complicated. A major first step, however, can be taken now by revising training programs with course material which addresses these problems and by reorienting training philosophy to one which instills the desire to fly the airplane by "The Numbers" on every flight. Considering revised course content, the following is suggested.

- *Reinforce the present training programs with selected airplane certification criteria and related performance information to give flight crews confidence in speeds, techniques and procedures.*
- *Introduce training material reviewing airplane accidents and incidents with associated causes.*
- *Introduce real operational problems into flight simulator training including wind shear, slippery runway operations, variable visibility, etc.*
- *Demonstrate in ground school, simulator, and flight training the adverse effects on landing distances of such items as high, fast approaches, lack of speedbrakes, and other common deviations.*

SUMMARY

The frequency of approach and landing accidents can be reduced with proper training programs. The programs should instill confidence and the desire to fly the recommended "Numbers." This confidence and desire can only be the result of knowledge.

about the authors

Jack Waddell *is Director of Flight Training for the Boeing Commercial Airplane Company. A Boeing test pilot since 1957, Waddell did the initial flight testing on eight new Boeing jet airplanes, from the 707 prototype through the 747 and 747SP. Waddell, as chief project pilot, took the number one 747 on its maiden flight, launching one of the most extensive flight test programs in Boeing's history.*

Waddell, who earned a B.S. degree in Engineering Physics at Montana State University and a M.S. degree in Aero Engineering at Cornell University, is a former naval aviator (WWII) and engineering test pilot for North American Aviation.

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