The Pratt & Whitney 4060: Power for the Future

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Gregory Sumner, having been admitted to the Carl and Winifred Lee Honors College in 1992, successfully presented the Lee Honors College Thesis on April 24, 1997.

The title of the paper is:

"The Pratt & Whitney 4060: Power for the Future"

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The Pratt & Whitney 4060:

Power for the Future

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22 April 1997
Lee Honors College Thesis

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Executive Summary

The Pratt & Whitney 4000 engine platform is considered the most economical turbofan engine in its class. Pratt & Whitney advertises the 4000 series to provide the most efficient service “on the line”, as well as the most reliability for air carriers. United Airlines, a strong Pratt & Whitney customer, utilizes the company’s next-generation engines for its 757, 767-300, 747-400, and 777 fleets, providing a great commonality of service. The Pratt & Whitney 4060 engine is the power plant used on United’s 767-300 and 747-400 fleets.

From my internship at United Airlines from May 1996 until August 1996, I learned a great deal about airline operations. As a result, my understanding of air operations has truly moved from the classroom to real-world situations. This research project attempts to synthesize this acquired knowledge, bringing together the maintenance and flight officer perspectives of the Pratt & Whitney 4060.

The paper begins with basic turbine engine theory and moves on to engine classifications. Here, the Pratt & Whitney 4060 power plant is introduced. The systems are covered in fairly good detail, with operational aspects emphasized throughout. The maintenance areas of service and inspections are described to show how airline personnel may interact with the powerplant’s computers.

The realm of flight operations is explored during the section on performance, with examples from the 767-300, 757, and 777 aircraft. Consequently, these are the aircraft types with which I had the most experience flying from Miami with United Airlines. Finally, a description of activities during the internship describe the interesting facets of the semester with United.

The report has many diagrams incorporated throughout its pages, without which the descriptions would be bland. Many of the engine component diagrams come from a Pratt & Whitney training manual acquired from a maintenance technician at United Airlines, with his notes written on the illustrations from training sessions in Connecticut. Where
possible, these handwritten notes were maintained in the diagrams to give a more “real-world”, operational aspect to the research project.

It is hoped the reader understands that this was truly a research experience, with many events of having to correlate ideas from one source to another. In several instances, for example, I had to define and interpret areas of turbine technology and aircraft performance schedules independently. These were both frustrating and enlightening events during my research. It is these very events that provide the realization that the goal of the Senior Thesis has been accomplished: to create a culminating product that synthesizes the knowledge learned at Western Michigan University and United Airlines, and the independent research conducted to prepare this work.
Jet Propulsion Theory

Operating Cycle

Jet engines produce propulsive forces by drawing in, burning, and expelling gases. Although they have basically the same four-cycle process as a reciprocating engine—intake, compression, power, and exhaust—jet engines operate as a continuous flow of expanding gases. This translates into more efficiency than their reciprocating counterparts.

The core engine of a turbine consists of an intake attached to a spinning compressor. The compressor forces the air into a combustion chamber where fuel is being sprayed. Once the ignition has begun, the chemical reaction between the air and fuel remains continuous. The expanding gases are then used to drive a turbine; this turbine is connected through a shaft to rotate the compressor. The high-pressure gases are expelled through an exhaust nozzle.

Major Components

The major engine components are illustrated in the figure below. They are the intake lip, spinner, compressor, accessory drive, combustor section, shafts, igniters, fuel nozzles, turbine section, and exhaust nozzle. Most modern turbine engines incorporate a
dual spool design in which there is a low-pressure spool and a high-pressure spool; both spools, consisting of a compressor and turbine, rotate freely of each other.

The low-pressure spool’s rotational speed is described as "N₁". The low-pressure compressor is the forward-most compressor, and its accompanying turbine is the rearmost turbine. The high-pressure compressor, located behind the low-pressure compressor, is driven by the high-pressure turbine. The high-pressure, or N₂, shaft counter-rotates around the N₁ shaft. The rotational speed of the high-pressure spool is known as "N₂". The N₁ and N₂ values are extremely important for engine start and operation as discussed later.

Thrust

Thrust is produced when a mass of air is taken in the front of the engine and expelled through the exhaust at a much higher speed. The amount of thrust produced by the engine is equal to the mass flow rate times the change in velocity. The basic thrust equation is summarized:

\[ F_n = W_a/g(V_2 - V_1) + W_f/g(V_f) + A_j(P_j - P_{am}) \]

where

- \( F_n \) = Net Force
- \( W_a \) = Weight of Air (lb/s)
- \( g = 32.2 \text{ ft/s}^2 \)
- \( V_2 \) = Velocity of air at exhaust nozzle (ft/s)
- \( V_1 \) = Velocity of airplane (ft/s)
- \( W_f \) = Weight of fuel (lb/s)
- \( V_f \) = Velocity of fuel (ft/s), the same as \( V_2 \)
- \( A_j \) = Area of exhaust nozzle (ft²)
- \( P_j \) = Static pressure of exhaust nozzle (lb/ft²)
- \( P_{am} \) = Ambient static pressure (lb/ft²)

Within a turbine engine, both forward- and rearward-acting forces are being produced during operation. For example, forward forces are produced when fuel is burned and heat energy is increased. Also, an increase in total pressure energy by
compression or changing kinetic to pressure energy will give the result of forward forces. These forward forces propel the body forward.

Rearward forces are produced, however, whenever heat or pressure energy are decreased, or when heat energy is changed into kinetic energy. The net forces acting at any point in an engine may be calculated if one has the known area, the pressure acting on that area, air flow velocity and mass air flow. Thus, the sum of the forces is calculated by the formula:

\[ F_n = Ma + PA \]

where \( M = \) mass
\( a = \) acceleration
\( P = \) pressure
\( A = \) area

The effects of fuel flow are typically discounted due to equivalent, calculated air leakage through the engine; as a result, fuel flow effects on thrust distribution will not be included in this simplified "\( F_n \)" equation.

The area where maximum pressure occurs in the engine is the compressor discharge outlet, whether that is at a diffuser or the final stage of an axial compressor. This is to allow a pressure drop in the combustion chamber and subsequently the gases to expand as combustion occurs. The airflow will continue, then, to flow toward the exhaust nozzle.

The highest air temperature produced in the engine is of course in the combustion section. The temperatures are above melting point for the majority of metals, so there is a boundary layer of air designed to act as a cooling film within the chamber.

The maximum velocity is quite dependent on the pressure and temperature changes occurring within the engine. According to the universal gas law, the velocity is directly proportional to the temperature change of the gas and inversely proportional to the pressure change, as shown in the following equation:
\[
P_1 V_1 = P_2 V_2
\]
\[
\frac{T_1}{T_2}
\]

The maximum air flow velocity occurs as the air passes through the converging turbine nozzle. The velocity increase is a result of the large pressure drop as the air drives the turbine section. Another important aspect of velocity as related to gas turbine design is the inlet air velocity. This value must remain subsonic, which means that the inlet design must slow the airflow of a high subsonic transport aircraft engine down to an acceptable speed for the compressor to function properly. In conclusion, the velocity of the air exiting the turbine engine, through pressure and temperature changes, must be a higher value than the airflow entering the front.
Engine Classifications

Turbine engines are classified into several groups, each having its unique advantages and disadvantages for the operator. The engines may be classified by the type of compressor used, the airflow through the engine, and the power usage. The three types of compressors are the centrifugal flow type, axial flow type, and the axial-centrifugal flow type. The mixed-flow compressor provides an alternative method of directing the airflow through the engine. Finally, engines may be classified according to power usage; they may be a turbojet, turbofan, or turboprop.

Centrifugal-Flow Compressors

Engines that use centrifugal-flow compressors are more durable, lower in weight and cost, simple and have a high compressor ratio per stage. The number of stages is limited, however, so typically compression ratios of only 10:1 may be attained. They are typically found in the turboprop and executive jet markets.

As shown in the figure above, the intake air enters the compressor and is accelerated outward to increase its pressure. This air is directed into the diffuser which slows the airflow, further increasing its pressure before the air reaches the combustion chamber.

The centrifugal-flow compressor may be single-stage, two-stage in series, or two-stage in parallel.
Axial-Flow Compressors

Axial-flow compressors are more efficient than their centrifugal counterpart, reaching compression ratios of 25:1 and better. They are therefore more fuel efficient and produce more thrust for the same engine weight (better specific weight); large transport aircraft typically use axial-flow turbines.

The air maintains a longitudinal flow to the engine, as shown above. Rotor blades spin and deflect the air while fixed stator vanes located right behind each stage of blades direct the airflow back to a linear direction. Each stage of rotor blades and stators compresses the air more and more until the air reaches the combustion chamber.

A spool is a group of axial stages mounted on the same shaft driven by a turbine.

Axial-Centrifugal Compressor

This type of compressor is simply a combination of an axial compressor mounted either on the same or a different shaft as a centrifugal compressor. These compressors are ideal in some situations such as in a turboprop operation or where there is a need to keep the engine short such as on the Cessna Citation.

Mixed-Flow Compressor

This type of compressor has blades designed to change the discharge air from a centrifugal flow to an axial flow or from an axial flow to an angled flow. It is no longer used in compressor designs.
Turbojet Engines

Turbojets produce their thrust by the high acceleration of a small mass of air passed through and combusted in the core engine. They are extremely loud and very inefficient at low altitudes and airspeeds. Of the three classifications based on power usage, turbojets have the lightest specific weight. The figure on page 1 is considered a turbojet.

Turbofan Engines

The majority of jet engines produced today are turbofan engines, with a core similar to the pure jet but with an additional shrouded fan in front. The shrouded fan is a very sophisticated group of fan blades with a close-fitting nacelle around them. The purpose of the shrouded fan is to accelerate a mass of air without burning it, greatly increasing the efficiency of the entire engine. The fan is driven by one of the engine's turbine sections as shown in the figure below.

![Turbofan Engine Diagram](image)

Once the intake air passes through the shrouded fan, it either is sent through the core engine or bypassed around the core engine. The bypass ratio is therefore the ratio of air that passes around the engine core to air sent through the core and burned. High-bypass turbofan engines are more fuel efficient, because most of the thrust produced is from the shrouded fan bypass air.
The turbofan engine uses the best aspects of a turbojet engine, appropriate for fast, high-altitude flying, and the turboprop engine's efficient operation at lower altitudes and airspeeds. In addition, the turbofan has a reduction of 10 to 20 percent of noise level over the turbojet. The cool bypass air is mixed with the hot exhaust gases, decreasing the noise drastically. Turbofans perform much better than turbojets in high, hot and humid environments.

Turboprop Engines

As previously stated, turboprop engines are very efficient at lower altitudes and airspeeds due to the use of a propeller. Propellers can accelerate large masses of air without forward airspeed. The turboprop (shown below) uses a core engine to turn either a drive gear or a free turbine power section; therefore, turboprops may be classified as either direct-drive or free-turbine types. Very little of the accelerated gases from the turbine engine are used for forward thrust; the burning of fuel and air is done simply to turn a propeller.

Of the three power usage types, turboprops have the lowest thrust specific fuel consumption (TSFC) but are the most complicated. Reverse thrust is achieved by changing the pitch angle of the propeller blades.
The Pratt & Whitney 4060 Engine

United Airlines utilizes the PW4060 engines on its 767-300 aircraft and its 747-400 fleet. The 4060, the mid-range version of the "4000 Platform" and predecessor to the 777's PW4084 engine, is an excellent, versatile engine. It is flat-rated up to 86°F ambient temperature and produces up to 60,000 pounds of thrust at sea level. The flat rating concept will be discussed later. The power plant has a bypass ratio of approximately 5:1.

The engine is an axial-flow turbofan consisting of six areas that make up the gaspath configuration illustrated below.

GASPATH CONFIGURATION

The low-pressure compressor (LPC) and the low-pressure turbine (LPT) make up the low-pressure spool. This spool consists of a five-stage, low-pressure compressor, including the first-stage 94-inch diameter fan, and a four-stage, low-pressure turbine. The 11-stage, high-pressure compressor (HPC) and the two-stage high-pressure turbine (HPT) are the components of the high-pressure spool. The final two items that makeup the gaspath construction are the diffuser/combustor and the turbine exhaust case (TEC).
The “core” of the engine is actually the high-pressure section and the diffuser/combustor section. As described previously, the high-pressure shaft, rotating at speed $N_2$, spools around the low-pressure shaft.

These six major power plant areas are also part of the engine's major assemblies. The major assemblies in turn are divided into build-group items and non-build-group items. A build group is the largest group of engine parts that can be removed or installed as a unit, or that can be disassembled or preassembled independently of the other build groups. The PW4060 is divided into the ten build groups and four non-build groups depicted below.
**PW 4060 Build Groups**

- LPC
- Fan Cases
- Intermediate Case
- HPC
- Diffuser and Combustor Case
- Turbine Nozzle
- HPT
- LPT
- TEC
- Main Gearbox (MGB)

All of these assemblies are supported directly or indirectly by bearings and flanges and are housed within a nacelle. Although the power plant has an inlet cowl as well as an exhaust nozzle and plug, the nacelle is actually just the fan cowl, reverser cowl, and the core cowl. These three structures are the only mounts to the engine pylon and thus are considered the nacelle. A discussion of the inlet and exhaust must accompany the nacelle section to keep continuity.

The cold section of the PW 4060 consists of the compressor inlet cone, fan blades, the LPC, the LPC/LPT coupling, the fan cases, the intermediate case, and the HPC. The hot section of the 4060 consists of the diffuser and combustor, the turbine nozzle, the HPT, the LPT, and the TEC.

**PW4060 Non-Build Groups**

- Inlet Cone
- Fan Blades
- Angled Gearbox (AGB)
- LPC/LPT Coupling
Bearings and Flanges

The engine has five main bearings shown on the next page that are located at various points of the power plant. Generally, there are two basic bearing types used on turbine power plants. The ball bearing can support both radial and axial loads, while the roller bearing can only bear radial loads. A radial load is a load at right angles to the shaft. The axial, or thrust load is in a direction parallel to the shaft. In the compressor section, there must be a ball bearing present to absorb the radial and axial loads due to heat-induced engine growth; there must also be a roller bearing to allow the axial movement caused by changing dimensions in the engine.

The No. 1 bearing is a single ball bearing supported by the intermediate case. It is a thrust bearing for the LPC and has a dry-face spring-loaded carbon seal. The bearing itself consists of split-inner-race, angular-contact ball. It is lubricated by oil supplied under
the inner race; the oil is directed to the bearing through the inner race split. No. 1 is
pressurized by station 2.5 LPC bleed air.

The No. 1.5 bearing, a non-preloaded single roller bearing, is also supported by the
intermediate case. No. 1.5 functions as the radial support for the front of the LPC drive
shaft as well as an additional LPC rotor support. It, too, has dry-face spring-loaded
carbon seals; however they are pressurized by ninth-stage HPC bleed air. To lubricate the
No. 1.5 bearing, a single jet is directed at the front of the seal plate and an axial scoop is
used to lubricate the rear seal plate.

The thrust bearing for the the HPC is the No. 2 bearing, a bearing very similar to
the No. 1 bearing. It is also a split-inner-race, angular-contact bearing, has a dry-face
spring-loaded carbon seal, and is supported by the intermediate case. Its method of
lubrication is similar to the No. 1 bearing; the No. 2 bearing is also pressurized by station
2.5 LPC bleed air. Its distinguishing feature is its oil damping shutoff valve due to the
bearing being oil-damped.

The No. 3 bearing acts as a radial support for both the HPC and the HPT. It is a
pre-loaded, single roller bearing supported by the diffuser case. Unlike the first three
bearings, the No. 3 has a wet face spring-loaded carbon seal. It uses 12th-stage HPC
bleed air that has passed through a heat exchanger in the forward intermediate case for
pressurization. Lubrication is accomplished by directing splash oil from the seal plates and
scop, while cooling oil is fed under the race.

Finally, the No. 4 bearing, the radial support for the aft LPC drive shaft and the
LPT. This oil-damped, single roller bearing is mounted to the turbine exhaust case and
utilizes a dry face ring-type carbon seal. Lubrication and cooling are very similar to the
No. 3 bearing. The No. 4 is not pre-loaded and is pressurized by station 2.5 LPC bleed
air; this air enters the LPT shaft forward of the the No. 1 bearing.

The following page shows the engine flanges and engine stations, as reprinted from
the Pratt & Whitney PW4000 Line and Base Training Manual.
ENGINE CONSTRUCTION
ENGINE SPECIFICATIONS AND CONFIGURATION

ENGINE FLANGES
- A: Inlet cowl attachment
- A1: Stiffness and bracket attachment
- B: Front fan case to fan exit outer case
- B1, B2: Stiffness and bracket attachment
- C: Fan exit outer case to intermediate case
- D: "V" ring groove - cowl load sharing
- D1: "V" ring groove - cowl load sharing
- E: Intermediate case to HPC front case - forward engine mount provision
- H: HPC front case to HPC rear case
- J: Stiffness and bracket attachment
- K: HPC rear case to diffuser case
- M: Diffuser case to HPT case
- N: HPT case to LPT case
- P: LPT case to turbine exhaust case
- R, S: Aft mount attachment at 11:00 and 1:00 locations, ground handling attachments at 3:00 and 9:00 locations
- T: Exhaust nozzle attachment
- T1: Exhaust plug attachment

ENGINE STATIONS
- 2: Engine Core Inlet
- 2.5: LPC Exit
- 2.9: 9th Stage Exit
- 3: HPC Exit
- 4: Combustor Exit
- 4.5: LPT Inlet
- 4.95: LPT Exit (at turbine exhaust case rear flange)
- 12: Fan Inlet
- 14: Fan Exit

ENGINE FLANGES AND STATIONS
Nacelle Configuration

The cowl panels' function is to protect the internal sections of the engine.

The first cowl panel, the inlet cowl, is attached to the engine at the A flange and has a leading edge anti-icer. The exhaust nozzle is mounted on the engine at the T flange, and the exhaust plug is attached at the T₁ flange. The thrust reverser door is mounted to the pylon, and will be described later in the thrust reversing section.

The fan cowl covers the engine fan case, fairing the inlet cowl to the thrust reverser doors and protecting the electronic engine control (EEC). The two panels are
hinged at the top of the engine and latch at the bottom with three flush-mounted tension latches. The fan cowl utilizes a hinged pressure relief door on the left door which opens automatically in case of thermal anti-ice duct failure. Both doors contain a static port and tubing for the full authority digital electronic control (FADEC). (See next page.)

*Note: Pratt and Whitney has coined the term "FADEC" specifically for the PW4056/60 engines used on the 767/747-400 to describe the EEC. For reader ease in understanding, the electronic engine control for the 767-300 PW4060 will be referred as "FADEC/EEC" and described later.*

The core, or primary, cowl shown below protects the turbine sections of the engine. The two panels are hinged to the pylon strut and fair with with the inner barrel of the thrust reverser. On the aft edge of the cowl, the panels rest against the engine exhaust sleeve. The panel doors each contain two pressure relief doors hinged to relieve high pressures due to a duct failure. The primary cowl has several access doors, including oil servicing, integrated drive generator (IDG) and starter servicing, overboard breather exhaust port, and pre-cooler exhaust. All the access ports are located on the left panel.

**NACELLE CONFIGURATION – BOEING**
An important feature of the PW4060 nacelle is the cowl load-sharing characteristics via the thrust-reverser doors. Aerodynamic loads caused by a high inlet-air AOA and large secondary airflows cause the engine to bend and the cases to deflect. This causes fan blades to come in contact with their casings and increases blade-tip clearances. The reverser doors form a stiff case, integrating the engine, the pylon, the exhaust nozzle, and the reverser doors in a rigid structure. Load-sharing "V" grooves on the fan and intermediate cases and an aft load-sharing "T" ring on the exhaust nozzle match the reverser doors to the engine in order to maintain proper blade-tip clearances.
Major Assemblies
Compressor Inlet Cone

The first major assembly on the PW4060, a non-build group item, is the compressor inlet cone, illustrated below. This is simply an aerodynamic fairing that ensures a smooth intake airflow. The inlet cone, also known as the nose cone or spinner, incorporates an anti-ice feature of 12 vent holes equally spaced around the rear cone segment. This bleed air passes through a .3 inch hole in the shaft from the stage 4 compressor. The vent holes themselves are .1 inch in diameter.

The spinner is constructed of Kevlar and epoxy resin with a polyurethane coating. The pre-balanced assembly is actually constructed of two cone segments, the rear segment bolted to the front of the LPC hub, and the front segment bolted to the rear piece. The inlet cone is a line replaceable unit.
Fan Blades

The first stage of the LPC, the fan blades shown below compress the air entering the engine, producing both a primary core flow and a fan gaspath. On the 4000 series, there are 38 fan blades. The blades are titanium-forged and incorporate a single part-span shroud. Although the shroud is not located at the mid-point of the fan radius, it is considered the mid-span shroud. The individual blades are held radially in the dovetail slots of the LPC hub. Axial support is obtained by a split-ring blade lock that incorporates an anti-rotation pin and a lock removal hole. In addition, the unit uses a rubber seal below the blade platform.

Each blade's moment weight is marked on the concave surface. They are line-replaceable units and may be replaced as pairs or individual units if the replacement blade is with the required moment weight.
Low Pressure Compressor

The low pressure compressor increases the pressure of the primary airflow. The engine's first build group, the LPC includes a five-stage rotor assembly known as stages 1, 1.6, 2, 3, and 4. It also incorporates a four-stage stator assembly (stages 1, 1.6, 2, and 3) and the compressor blades for stages 1.6, 2, 3, and 4. The entrance to the primary gaspath is the first stage stator assembly located just aft of the fan blades. There is a fan exit fairing in place to divide the primary and secondary paths. This fairing is attached to the fan exit inner case assembly (see "Fan Cases" build group section).

As previously described, the LPC rotor is supported by the No. 1 ball bearing on the front compressor hub. The LPC stator assembly is supported by the fan exit inner case assembly. Again, the rotors are driven by the LPT.

The 2.5 bleed valve is located at stage 4 for spinner anti-ice and to bleed 4th-stage air for various functions (see "LPC/LPT Coupling" section).
LPC/LPT Coupling

The low-pressure compressor/low-pressure turbine coupling connects the LPC rotor to the LPT shaft and is supported by bearing No. 1.5. The coupling is splined to the LPC rotor hub and to the LPT shaft. It provides improved support for the LPC because of the No. 1 and No. 1.5 bearings. The $N_1$ transducer senses the rotational speed of the LPC via the 60 teeth on the coupling's pickup wheel. The transducer transmits the $N_1$ value to the FADEC/EEC.

LPC/LPT COUPLING

The LPC/LPT coupling is continuously filled with bleed air from stage 4. The air enters the coupling through holes located aft of the front splines. The stage 4 bleed air has various functions, including pressurization of the No. 1 and No. 4 bearing carbon seals. The air passes through a .3 inch hole in the turbine shaft plug, also referred to as the cover plate, and anti-ices the spinner. In addition to filling the coupling's internal space, the fourth stage bleed is used to cool the LPT.
Fan Cases

The fan front case, fan exit guide vanes, and the fan exit case all make up the 4060’s fan case structure. The fan cases make a flowpath for the fan discharge air and support the nacelle’s inlet cowl.

The fan front case itself actually supports the inlet cowl and contains fan blade-tip rubstrips. Fan blade containment, preventing the blades from exploding radially out of the engine in case of failure, is accomplished by the front case.

The fan exit case consists of an inner case, an outer case, and the fan exit guide vanes. The exit case structure causes the fan discharge air to be straight before it enters the thrust reverser fan air duct (See "Thrust Reverser" section). There are 84 fan exit guide vanes made of graphite epoxy with metal screen mesh on their leading edges. The vanes connect the fan exit inner and outer cases.
Attached to the fan exit inner case at the LPC exit is the 2.5 bleed valve, allowing the 2.5 bleed air to exit the inner case through 14 slots into the secondary airstream. In addition, the top eight bleed slots for the 2.5 bleed valve have screens.

Intermediate Case

The primary structural component of the power plant is the intermediate case, another build group item. Many components are mounted to the intermediate case (depicted on the following page). The intermediate case, for example, supports three main engine bearings: No 1, No.1.5, and No. 2 bearings. The makeup of the case includes nine struts, the fourth stage compressor stator assembly, and the towershaft drive gear. The tower shaft is driven by the HPC and turns the angle gearbox.

The intermediate case rear section remains 950°F for up to two hours after shutdown. A complete discussion of the components attached to the rear section follows.
Starting at the 12:00 o'clock position, the forward mount pad is a puck and gimbel type and can take torque, vertical, and growth loads.

At the 1:00 position is one of three 4-way solenoid valves. The 1:00 valve controls the right HPC secondary flow control valve. It also acts as an override switch for the IDG air/oil heat exchanger valve.

The second solenoid valve is located at the 5:00 position and controls the right 2.9 start bleed valve and the left 2.9 stability bleed valve.

At 10:30 is the third 4-way solenoid valve, controlling the left HPC secondary flow control valve. This valve also controls the two turbine vane and blade cooling air (TVBCA) valves.

The forward mount thrust brackets at the 1:30 and 10:30 positions take the torque and thrust loads.

At the 2:00 position is the No. 3 bearing buffer air cooler. It precools the No. 3 bearing compartment cooling air with stage 12 air. Pratt & Whitney gives a special warning to not touch the cooler or its associated tubing for at least three hours after engine shutdown to prevent serious burns.
• Next is the IDG air/oil heat exchanger and valve at the 4:00 position. Fan air is used here to cool the IDG system oil.
• The N₁ speed transducer is located at the 5:00 position on the intermediate case aft section.
• The angle gearbox at the 6:00 position is driven by the tower shaft.
• At 7:00 is the 2.5 bleed valve actuator. Also attached to the fan exit case, it is a hydraulic actuator for the 2.5 bleed valve.
• The engine air/oil heat exchanger and valve at the 8:00 position uses fan air to cool the engine oil. The valve opens when the shaft turns through the 121° position.

High Pressure Compressor

The high pressure compressor has an 11-stage rotor and stator assembly and is driven by the HPT. The HPC in turn compresses primary air from the LPC and sends it to the diffuser. The HPC also turns the towershaft to drive the AGB and supplies various bleed air sources.
The first set of stator vanes is known as the inlet guide vane (IGV) assembly. The first four stages of stators are actually variable vanes and have a related unison ring assembly.

As previously stated, the HPC is supported by the No. 2 bearing at its front, and at its rear by the No. 3 bearing.

The various bleed air stages provided by the HPC are the 8th, 9th, 12th, and 15th stages. The eighth is for aircraft use, while the ninth stage is used for engine stability, rotor cooling, and No. 1.5 bearing seal pressurization.

The twelfth stage bleed air cools and pressurizes the No. 3 bearing and seal. This bleed also cools parts of the turbine. The fifteenth stage balances the thrust load on the No. 2 bearing and pressurizes the No. 3 bearing seal. It is also used to supply aircraft air, to cool parts of the turbine, for sensing airflow, and finally for muscle pressure. (Muscle pressure is pneumatic air pressure used to close certain system valves that are spring-loaded open.)
Diffuser/Combustor Unit

The diffuser case, located just aft of the HPC, contains the compressor exit stator which straightens the primary airflow when it enters the diffuser. This stator is also the last HPC stator stage. The diffuser itself increases the air pressure by slowing the primary airflow. This section supports the No. 3 bearing and also directs 15th stage bleed for use by the engine and the aircraft.

Attached to the diffuser case are the eight fuel injector manifolds which transmit fuel to the injectors. Also attached around the case are the 24 fuel injectors; to complete the diffuser section are the two ignitor plug bosses which provide ignition (See "Igniter and Starter System" section).

The combustion chamber uses 25% of the total intake air to burn with the Jet-A fuel and accelerate the primary gaspath. The chamber consists of two distinct sections, the
outer chamber that is part of the diffuser/combustor build group, and the inner chamber that is within the turbine nozzle build group. These two parts form the annular design.

The chamber walls are segmented to allow air to enter for combustion, dilution, and cooling. First, the combusted air enters through large holes toward the front of the chamber. To decrease the temperature of the exhaust gases, dilution air enters smaller holes near the rear of the chamber. And finally, small holes at each segment allow the cooling air to enter and then flow against the inner surface of the chamber, acting as the previously described cooling film necessary at the 3500°F chamber temperature.

The combustion chamber is held by doweled end bolts known as "combustion chamber retaining bolts".

Turbine Nozzle

The turbine nozzle guides the exhaust gases from the combustion chamber to the 1st-stage turbine blades. The nozzle section consists of the inner combustion chamber, the 1st-stage cooling duct, and 17 HPT nozzle guide vane cluster assemblies, with two
vanes per cluster. The guide vanes ensure that the primary airflow enters the HPT at the correct angle and speed. The cooling duct is for the 1st-stage rotor and blades.

The inner combustion chamber walls are constructed in welded segments, with holes that, again, allow air for combustion, dilution, and cooling. The cooling air from the diffuser flows through several paths around the inner and outer combustion chamber walls. As described in the previous section, air enters the chamber through the segment holes to act as a cooling film. In addition, air enters the internal passages and exits out of each guide vane for a protective film on the vane surfaces. The air passes through the annular cooling duct, the duct being a metering nozzle. The air is metered and flows against the turbine rotor.

Honeycomb seals are installed at the interfaces with the 1st-stage turbine rotor, minimizing the leakage of this 1st-stage cooling air.

High-Pressure Turbine

Contained in the high-pressure turbine build group (see following page) are a case and vane assembly; two disk and blade rotor assemblies; and one rotating inner airseal. The air-cooled parts in the turbine are the 1st- and 2nd-stage disk and blade assemblies; the 2nd-stage vanes; and the inner airseal. The turbine, thus, has only two stages.

The first stage of turbine blades are constructed through a single crystal casting process. The second stage, however, is made through a directional solidification casting process. Around the blade tips are abradable ceramic outer airseal segments, resistant to the high temperatures of the HPT.

There are 21 vane cluster assemblies, with two vanes per cluster, within stage 2. The inner airseal is located at the inner diameter of the 2nd-stage vanes. The 2nd stage is cooled internally by 12th stage HPC bleed air entering through ports into the turbine vane cooling air annulus.
Attached to the HPT are the turbine case cooling (TCC) components not classified as any build group. The TCC components include the cooling air manifolds attached to brackets on the outside of the HPT case. They control fan airflow through the manifolds to cool the HPT case; this reduces the HPT diameter and, hence, bladetip clearances. The TCC components will be described in more detail in a later section.

Low-Pressure Turbine

While the HPT has turbine stages 1 and 2, the low-pressure turbine shown on the following page has four stages numbered consecutively three to six. All the LPT stages incorporate nozzle guide vane clusters with three vanes per cluster. The 3rd stage uses 39 nozzle guide vane clusters and 128 turbine blades. Stage four has 44 vane clusters and 130 blades. Stages five and six have 38 clusters with 118 blades and 36 clusters with 128 blades, respectively.
The fifth stage disk provides the support for the other three units; the 3rd and 4th stages are cantilevered from the front and the 6th stage is attached to the rear.

Like the HPT, the LPT has turbine case cooling components incorporated into the assembly. These cooling air manifolds are also attached to brackets on the turbine case outer shell and control the flow of fan air to decrease the case's diameter and blade tip clearances.

Bleed air from the 4th-stage LPC is used to cool the inner seal area of the 6th stage stator and disk. The HPC's 9th stage cools the inner wall of the transition duct, as well as the disks and stator inner seal areas of the 3rd, 4th, and 5th stages. Finally, 12th-stage HPC bleed cools the 2nd-stage HPT vanes, and helps to cool the outer areas of the transition duct.
Turbine Exhaust Case

The turbine exhaust case houses the No. 4 bearing compartment, holds the exhaust nozzle and plug, and sends the turbine discharge gases through the TEC struts to the exhaust nozzle and plug. These struts straighten the primary airflow before it enters the exhaust plug and nozzle.

The TEC has attachment points for both the rear engine mount and ground handling equipment. The case also has openings and attachment points for four probes. Two are $Tt_{4.95}$ probes, while two are combination $Pt_{4.95}/Tt_{4.95}$ probes.
Gearboxes

The final two items that are part of the PW4060's major assemblies are the two gearboxes: the main gearbox, and the angle gearbox that drives it. This MGB drives all the accessories for the engine and the aircraft. Both the AGB and the MGB housings are alluminum casting, and both gearboxes are line-replaceable units.

ANGLE AND MAIN GEARBOXES

The AGB, driven by the HPC towershaft, is installed at the rear of the intermediate case at the 6:00 position; it lies between the primary and secondary gaspaths. The gearbox is supported by two mount lugs at the front and the layshaft housing at the rear. The AGB actually turns the horizontal layshaft, or gearbox driveshaft, to drive the MGB.

The MGB is installed under the HPC case, also at the 6:00 position. It is supported by the layshaft link at its front, two side mounts connected to the HPC rear case,
and an antisway bracket preventing lateral movement. Unlike the AGB, the MGB has a chip detector.

The accessory drives are all easily installed on, or removed from, the MGB. They have replaceable carbon seals and permit seal drain leakage to be collected by engine build unit (EBU) components and transmitted overboard. Except for the starter drive, all the accessory drives are wet-spline types. The following is a list of accessory drives located on the front and rear of the MGB:

**Front of Gearbox**
- Fuel Pump Drive Pad
- N₂ Crank Pad
- Layshaft Housing
- Deoiler

**Rear of Gearbox**
- Gearbox Oil Storage Cavity
- Oil Tank Mount Pad
- Breather Air Discharge Port
- IDG Drive Pad
- FADEC/EEC Alternator
- Lubrication and Scavenge Oil Pump
- Rear Hydraulic Pump Drive Pad
- Starter Drive Pad

The locations of these accessories are shown on the following page. Finally, the gearbox oil stage cavity allows more volume to keep the oil and contains an oil check valve.
MAIN GEARBOX – FRONT

MAIN GEARBOX – REAR
Major Systems

The following two pages illustrate the external components located on the left and right sides of the PW4000 platform and provide a good introduction to the discussion of major systems. Since the FADEC/EEC is the "brain" of the 4000 operation, this is explained in detail first. If the FADEC/EEC is the brain, the fuel and oil systems are the heart and are appropriately discussed next. This section concludes with a discussion of supporting systems and introduces systems/crew interface.
PW4000/B747/767 EXTERNAL COMPONENTS
RIGHT SIDE
FADEC/EEC

The FADEC/EEC is a dual channel, full authority unit without any hydromechanical backup. It is the primary interface between the cockpit and the power plant. The PW4000 FADEC/EEC is a tremendous advance for turbine engine technology, improving the engine's efficiency, basic control functions, engine protection, operational reliability, maintenance, and the actual flight deck interface.

FULL AUTHORITY DIGITAL ELECTRONIC CONTROL SYSTEM

Engine Efficiency

The FADEC/EEC controls the compressor bleeds, variable stator vanes, cooling airflows, engine oil cooling, IDG oil cooling (override function only), nacelle cooling, and fuel heating.

Basic Control Functions

The FADEC/EEC improves the following operational functions of the 4060: starting, idle, acceleration and deceleration, stability, and thrust control.
Engine Protections

The control unit limits critical speeds ($N_1$ and $N_2$), burner pressure ($P_b$), thrust, and overboost; as a result these limitations protect the power plant.

Reliability

The FADEC/EEC has several features that improve the reliability of the 4060 in line operations. It uses two-channel control, automatic fault detection and compensation, and redundant inputs and outputs.

Maintenance

The FADEC/EEC monitors the engine, isolates faults, and initiates self-tests in order to ease maintenance inspection.

Engine Interface with Crew

To improve the pilot/engine interface, the FADEC/EEC uses an automatic engine pressure ratio (EPR) control feature as well as an automatic agreement feature between the thrust lever position and the engine thrust setting. EPR will be discussed in detail in a later section.

Description

The PW4060's FADEC/EEC is located on the fan case at the 1:30 position and is cooled by convection. The unit weighs 27.5 pounds, with dimensions of 13.5 inches (width) x 18.6 inches (length) x 4.35 inches (height). It is a line-replaceable unit.

There are four shock/vibration connectors, an EEC programming plug receptacle, and four pressure ports on the FADEC/EEC. The unit also has a ground strap and a handle for removal and installation.

Its inter-channel communication feature consists of two channels, the "A" channel and the "B" channel. The two channels will alternate which is in command during each progressive start.
FULL AUTHORITY DIGITAL ELECTRONIC CONTROL (FADEC/EEC)

FADEC/EEC PNEUMATIC CONNECTORS
DEP (EEC PROGRAMMING PLUG)

FADEC/EEC “A” CHANNEL CONNECTORS

FADEC/EEC “B” CHANNEL CONNECTORS
Electrical Harness

The harness is made up of bundled wires attached to the exterior of the engine with brackets and clips.

ELECTRICAL HARNESSSES

FADEC/EEC interface with Engine

The FADEC/EEC receives inputs from engine sensors and then compares and checks those inputs for validation (SEE FIG 6-15). First, the $N_1$ value comes from the FADEC/EEC speed transducer; $N_1$ is used for limiting, for scheduling systems, and for an alternate mode. Next, $N_2$ and power are input from the FADEC/EEC alternator. The computer uses $N_2$ for limiting, scheduling systems, and setting engine speeds.

Compressor exit temperature ($T_{t3}$) is sensed in the diffuser case and is used to calculate starting fuel flow. $T_{t4,95}$ is the exhaust gas temperature in the exhaust case; it is used simply as a cockpit indication. Fuel temperature ($T_{fuel}$) is used to schedule the fuel heat management system; the fuel pump has a temperature probe for this purpose. Oil
temperature ($T_{oil}$) is detected in the MGB; it is also used to schedule the fuel heat management system as well as the IDG oil cooling system.

$T_t$ gives the inlet total temperature from the inlet cowl; the FADEC/EEC uses this value to calculate fuel flow and rotor speed. The inlet total pressure ($P_{t}$) and the exhaust pressure ($P_{t,95}$) from the exhaust case are used to calculate EPR. A sensor in the diffuser case gives burner pressure ($P_b$) to aid in limiting pressure and for surge detection. Finally, ambient pressure ($P_{amb}$) from the inlet cowl is used to validate altitude and $P_t$.

Critical to the interface is an internal mating connector between Channels "A" and "B"; it allows for a crosstalk link for data transmissions.

![Diagram of FADEC/EEC interface with engine](image-url)
FADEC/EEC ALTERNATOR — N2 AND POWER
FADEC/EEC SPEED TRANSDUCER — N1
Tt3
Tl4.95
Tfuel
Toll
Toll NO.3 BEARING
Tl2
P12
P14.95
FADEC/EEC SPEED TRANSDUCER — N1
FADEC/EEC ALTERNATOR — N2 AND POWER

CHANNEL A

CHANNEL B

INTERNAL MATING CONNECTOR

FADEC/EEC INPUTS FROM ENGINE SENSORS

CHANNEL A

THROTTLE INTERFACE

DISCRETES OUT

• ALTERNATE MODE LIGHT

• THRUST REVERSER INTERLOCK

ARINC IN

ENGINE PARAMETERS AND STATUS INFORMATION TO EICAS

DISCRETES IN

MAINTENANCE INFORMATION TO CMCS (747) OR PIMU (767-200, 300)

ANALOG IN

POWER SUPPLY

INTERNAL MATING CONNECTOR

CHANNEL B*

N1 TO AVM AND BACKUP
N1 TO FLIGHT DECK

*NOTE: CHANNEL B SAME AS
CHANNEL A EXCEPT AS NOTED

FADEC/EEC INTERFACE WITH AIRCRAFT
**EEC Programming Plug**

The programming plug has a crucial function for the FADEC/EEC interface with the engine. It selects the applicable schedules for the engine thrust rating (to be discussed later), EPR modification data, the engine performance package, the variable stator vanes, and the 2.9 bleed valve thermocouple selection.

The plug is on the "A" channel housing with the data input to the "A" Channel and crosstalked to the "B" Channel. Each engine individually receives a correct programming plug during its test cell initialization when the EPR/thrust relation is compared. The plug is specific for the particular engine. If the plug is not installed at the time of engine start, the FADEC/EEC reverts to the N₁ mode; if the plug disconnects during flight, operation continues as normal.
Idle Speed

There are two idle speeds used during the operation of the 4060: minimum idle and flight idle. Both are accomplished by putting the throttle lever in the idle position. Also known as ground idle, minimum idle speed is selected based on several parameters. These include enough N_2 to prevent IDG cutout; a corrected high-pressure rotor speed (N_2c_2) derived from T_{t_2} for constant taxi thrust; enough N_1 for engine icing protection; a P_b high enough to support service and anti-ice air bleeds; a rate of fuel flow (W_f) to burner pressure ratio that will prevent burner blow out; and a minimum W_f for safe operation.

The flight, or approach, idle speed occurs when the weight is off the landing gear or the slats are extended. It is selected with an N_2c_2 that will provide for constant approach thrust and sufficient takeoff/go around (TO/GA) power as regulated by the FAA.

Fuel Metering

There are nine components to the fuel distribution system of the 4060. They are the FADEC/EEC, fuel pump, bypass valve on the fuel pump, fuel/oil cooler and bypass valve, metering unit, flow transmitter, distribution valve, injector supply manifolds, and injectors. The fuel path is illustrated on the next page and described below.

- From the aircraft fuel tanks (left, right, center) via a common crossfeed manifold to the fuel pump boost stage inlet;
- Pump boost stage discharge to the fuel/oil cooler;
- Fuel/oil cooler to the fuel pump; at the pump, the fuel is filtered and sent through the main stage;
- Main stage discharge to the fuel metering unit (FMU);
- FMU to one of three areas: "servo fuel" (P_f) to the interface components, "bypass fuel" to the pump interstage, and "metered fuel" through the fuel flow transmitter to the fuel distribution valve;
- Fuel distribution valve to fuel manifolds and injectors
The FADEC/EEC uses its electronic interface with the FMU to schedule the fuel flow based on aircraft and power plant information. In addition, servo supply fuel is used in the FMU and in the interface components as an actuation pressure; these components include the selected compressor airflow control, turbine case cooling air flow control, and oil system components. Non-metered or non-servo fuel is bypass flow, joining the boost stage outlet fuel at low power or, when selected, bypassing the IDG section of the engine fuel/oil cooler at high power. The fuel distribution components are shown below, and their locations on the engine are shown on the following page.
**Fuel Pump**

The boost stage of the pump is of the centrifugal type, while the main stage is a gear-type displacement pump. The fuel pump is driven by the MGB. Attached to the fuel pump are the FMU, and the fuel filter differential pressure switch that closes at 5.5 psid (pressure increasing) and opens at 3.5 psid (pressure decreasing). The fuel pump also has a seal leakage drain that allows for overboard fuel and/or oil drainage for the fuel pump/MGB.

**Fuel Bypass Valve**

The fuel bypass shown on the next page prevents high fuel and oil temperatures during high power operations. It diverts the FMU fuel either upstream or downstream of the IDGS core of the fuel/oil cooler. The IDGS oil temperature is also lowered by transferring the heat energy to the boost stage exit fuel; this improves the IDGS durability.
**Fuel/Oil Cooler and Bypass Valve**

This assembly heats the fuel coming from the fuel pump boost stage. It prevents fuel system icing, cools the engine and IDGS oil, and prevents excessively high fuel temperatures. The fuel flow is continuous, and thus there is a pressure-relief valve incorporated into the IDGS cooler core. The FADEC/EEC controls the engine oil bypass valve with a 28 volts direct current (VDC) solenoid. This bypass allows the engine oil to bypass the cooler core and prevents high outlet fuel temperatures to the fuel pump filter.
Fuel Metering Unit

The FMU is controlled by the FADEC/EEC through inputs from the cockpit. The FADEC/EEC inputs electronically control a dual coil torque motor that closes or opens the valve. During engine starting, the FADEC/EEC commands a minimum pressure of 300 psig for controlling the engine system's actuators. One safety feature is the internal fuel flow cutback solenoid. At 116.4% N₁ or 109% N₂, the solenoid is energized, causing the metering valve to move to the minimum fuel flow stop. Another safety item is the dual channel overspeed solenoid that becomes energized if the "redline" of N₁, N₂, or Pᵇ is exceeded by 5%.
FADEC/EEC "B" CHANNEL CONNECTOR (J1)

BYPASS FUEL TO FUEL PUMP
MAIN STAGE DISCHARGE FROM FUEL PUMP

FADEC/EEC "A" CHANNEL CONNECTOR (J2)

METERED FUEL TO FUEL FLOW TRANSMITTER

FADEC/EEC CONNECTORS

AIRFRAME CONNECTOR (J3)

LEFT SIDE

RIGHT SIDE

METERED FUEL TO FUEL FLOW TRANSMITTER

FUEL METERING UNIT INPUTS AND OUTPUTS
Fuel Distribution Valve

The fuel distribution valve allows metered fuel to flow to the fuel injector supply manifolds. The valve has an integral metal screen fuel filter housing. Spring-loaded closed, the valve is opened by fuel pressure at approximately 20 psid.
Fuel Injector Supply Manifolds and Injectors

While the supply manifolds transmit fuel to the fuel injectors, the injectors themselves atomize the Jet-A fuel for combustion. The eight manifolds supply fuel to a total of 24 air blast fuel injectors. The "air blast" description means that the injectors are pressurized with 15th stage bleed air.
Engine Oil System

The system is a pressurized tank system in which the oil pump's output pressure is proportional to N₂. It consists of three subsystems, known as the pressure, scavenge, and breather subsystems. Below are the oil system components and their locations on the power plant. The following schematic depicts the flow of oil through the system.
Pressure Subsystem

The expansion space in the ten-gallon tank is pressurized to 6 psi, with excess pressure vented through a check valve. The oil flows from the tank, via the tank pressure, to the pressure stage in the lubrication and scavenge oil pump. This pump further pressurizes the oil and transmits the oil to the 15-micron oil filter. When the oil pressure at the pump increases beyond 540 psi, some oil will pass through a pressure-relief valve and back to the tank.

From the filter, the pressurized oil moves to the engine air/oil heat exchanger, without mixing with the IDGS oil. The heat exchanger has an internal bypass valve that opens if pressure exceeds 60 psid. The oil may then bypass the exchanger if it is too cold or the exchanger is clogged. To control the fuel temperature, the FADEC/EEC decreases or increases the flow of cooling air through the exchanger's valves. For example, the amount of cooling air is decreased if the fuel temperature is below a certain value; This increases the oil temperature and gives off more heat to the fuel in the exchanger.
OIL TANK

LUBRICATION AND SCAVENGE OIL PUMP
PRESSURE OIL TO ENGINE AIR/OIL HEAT EXCHANGER
BEFORE FILTER PRESSURE TAP
AFTER FILTER PRESSURE TAP
FILTER BYPASS VALVE AND PACKINGS
MOUNT BOLT (4 LOCATIONS)
BOLT (3 LOCATIONS)
PRESSURE RELIEF VALVE AND PACKINGS
TRANSFER TUBES AND PACKINGS
HOUSING
PRESSURE OIL FROM PUMP

MAIN OIL FILTER AND HOUSING

NOTE:
FUEL LINES GO TO ENGINE AIR/OIL HEAT EXCHANGER VALVE

ENGINE AIR/OIL HEAT EXCHANGER
AIR/OIL HEAT EXCHANGER VALVE
The oil passes on to the fuel/oil cooler and bypass valve, with the bypass valve operating similarly to the heat exchanger bypass valve. The purpose of the fuel/oil cooler is to heat the fuel and cool the oil. From the fuel/oil cooler, the pressurized oil is either sent back to the oil tank for flow-rate control via the oil pressure trim orifice, or it is sent to the externally-mounted "last chance oil strainers". These strainers are necessary if the oil filter is bypassed. From here, the oil goes to the metered oil nozzles in the main bearing compartments and gearboxes; the oil accomplishes the functions of lubrication, cleaning, and cooling.
**FUEL/OIL COOLER**

- Oil to No. 1, 1.5, and 2 Bearings
- IDGS Cooler Core Pressure Relief Valve
- Overboard Drain Port
- Fuel from Fuel Pump
- IDGS Oil from Fuel/Oil Cooler Bypass Valve
- Oil to No. 3 Bearing and Trim Orifice
- Oil to AGB, MGB, Front Hydraulic Pump Drive and No. 4 Bearing
- Last Chance Oil Strainer
- Oil Pressure to Oil Pressure Transmitter and Low Oil Pressure Switch
- Fuel to Fuel Pump Filter
- Overboard Drain
- Overboard Pump Filter
- Engine Oil from Fuel/Oil Cooler Bypass Valve
- Oil to AGB, MGB, Front Hydraulic Pump Drive and No. 4 Bearing
- Oil Outlet Fitting
- New Type

**LAST CHANCE OIL STRAINERS**

- Oil to No. 1, 1.5, and 2 Bearings
- Oil In
- Strainer
- Packing
- Fuel/Oil Cooler Oil Outlet Fitting
- Oil In
- Packing
- Strainer
- Oil In

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Scavenge Subsystem

There are five stages of the scavenge subsystem, pulling oil from the main bearing compartments and the gearboxes. The pumps associated with these stages pressurize the oil to the deaerator in the oil tank. This separates the air from the oil, sends the air into the pump’s "expansion space" to be vented to the MGB, and allows the hot, deaerated scavenge oil to fall back into the oil tank.

Also classified within the scavenge subsystem are the magnetic chip detectors. There are six magnetic chip detectors, or magnetic plugs, that catch any ferrous particles in the scavenge and supply oil. There is a master plug at the bottom of the oil tank, a main gearbox plug at the front of the MGB, and four plugs on the oil pump housing. The chip detectors are regularly removed and inspected.
**Breather Subsystem**

The purpose of the breather subsystem is to vent the air from the bearing compartments after the air is separated from the oil. The air is either separated from the oil in the oil tank deaerator or it is separated in the gearbox deoiler. Both sources of air are vented overboard through the deoiler and the nacelle cowl.

**Oil System Data**

The PW4060 consumes .04 to .05 quarts per hour. The indicated oil system pressure is found by calculating the difference between the pressure of oil at the fuel/oil cooler and breather air from the No. 1, 1.5, and 2 bearing compartments. The minimum limit for indicated pressure is 70 psid, with typical values at idle, cruise, and takeoff of 100 psid, 200 psid, and 260 psid, respectively.
$T_{oil}$ is taken from the scavenge oil in the MGB. The maximum continuous limit is 163°C, while the transient limit of fewer than 20 minutes is 177°C. Typically, this scavenge oil temperature is 120 to 125°C in cruise.

Differential oil temperature, known as DOT, is the difference between No. 3 bearing scavenge oil temperature, and the MGB scavenge oil temperature. Its maximum limit is 44°C; however, the typical range for the DOT is 15 to 25°C.
IDGS Oil System

The integrated drive generator temperature is limited by its own oil cooling system. The IDGS flows from the IDG to the IDGS air/oil heat exchanger. After the heat exchanger, the oil passes to the IDGS fuel/oil cooler before returning to the IDG. The air through the heat exchanger is solenoid-controlled by generator control unit (GCU) logic during normal operation. The IDGS oil cooling solenoid is normally energized, allowing high-pressure compressor discharge flow known as $P_3$ (static pressure at station 3) to flow to the system's pressure switch and closing it; closing the pressure switch completes the 28 VDC circuit for the IDGS air/oil heat exchanger valve control. The IDG oil temperature is regulated to 80-125°C.

The FADEC/EEC allows for the fail-safe operation of the IDG oil cooling system. When the computer recognizes an increasing oil temperature ($T_{oil}$) more than 160°C or $N_2$ below 73 percent, the FADEC/EEC de-energizes the IDGS oil cooling solenoid, allowing...
the P3 to vent from the pressure switch and opening it. This of course opens the circuit for the heat exchanger valve solenoid and opens the heat exchanger valve. The override protection allows for full cooling of the IDG oil. The following page also has illustrations of the IDG cooling system components.
IDG OIL COOLING SYSTEM COMPONENTS

AIRCRAFT POWER (28 VDC) —

IDGS FUEL/OIL COOLER

IDGS AIR/OIL HEAT EXCHANGER AND VALVE

IDGS OIL COOLING/HPC SECONDARY FLOW CONTROL VALVE SOLENOID

PRESSURE SWITCH

PA3 FILTER

IDG OIL COOLING SYSTEM

FADEC/EEC COMMAND

FAIL SAFE
FULL OPEN

IDG OIL COOLING SYSTEM

HIG

CT1217/1.19001191

CT1217/1.19000000
Ignition/Starting Systems

Introduction

Unlike a reciprocating engine, ignition for turbine engines is relatively difficult given their operating conditions. To begin, the fuel/air mixture in the combustion chamber is very cold and overlean. The mixture also moves past the igniter plugs at a very high velocity. The igniters must raise the temperature of the low-volatile jet fuel and thin, cold air within an instant, enough to ignite the mixture. Spark plug fouling is also a challenge due to non-continuous ignition operation—preventing self-cleaning.

Description/Operation

The PW4060’s ignition system consists of two ignition exciters, two exciter-to-igniter plug cables, and two igniter plugs. All of these components are located on the right side of the power plant. In addition, ignition switches are located on the flight deck.
In addition to the electrical requirements during startup, there is a pneumatic requirement to turn the high-pressure spool. Bleed air is supplied to the air turbine starter, or starter drive unit for this purpose. The air turbine starter drive pad is connected to the rear of the MGB. It engages to turn the engine until a certain $N_2$ speed is reached and "starter cutout" occurs.

*Ignition Excitors*

The exciters are of the capacitor discharge type and transform aircraft electrical power to a high voltage for ignition. The input voltage is normally 115 volts alternating current (VAC) with an operating limit of 90 to 124 VAC. The alternating current is normally at 400 cycles, with an operating limit between 360 and 440 Hz. The system allows a maximum input current of 2.0 amperes and a spark rate between 1.0 and 2.0 sparks per second. Finally, the system gives 4 joules of stored energy.

The upper exciter sends electricity to the igniter plug located at the 4:00 position, while the lower exciter sends current to the 5:00 position igniter plug. These capacitor-type exciters provide both high voltage and a very hot spark that can cover a large area.
They increase the reliability of ignition even at high altitudes. The exciters are fan-air-cooled and have an anti-shock mounting. In addition, they are on a continuous duty cycle.

Exciter-To-Igniter Plug Cables

The two interchangeable plug cables are coaxial-type cables and transfer current from the ignition exciters to the igniter plugs. The cables have sheet metal cooling shields to ensure that the fan air is sufficiently cooling them. They also have ceramic-insulated terminals with rubber busings and sealing washers.

Igniter Plugs

The igniter plugs, located in the diffuser case at the 4:00 and 5:00 positions, have shielded center electrodes. They each allow an electrical spark to pass across their gap to ignite the mixture. Like the cables, fan air is used to cool the plug's outer ends. To control immersion depth in the diffuser case, the plugs utilize classified spacers.
IGNITER PLUG CONNECTOR

CERAMIC INSULATED TERMINAL

CLAMP (1 LOCATION)

COOLING AIR DISCHARGE

FAN COOLING AIR

CLAMP (2 LOCATIONS)

IGNITION EXCITER CONNECTOR

COOLING SHIELD (4 LOCATIONS)

EXCITER-TO-IGNITER PLUG CABLE

CLASSIFIED SPACERS

MOUNTING BOSS

KEYWASHER

IGNITER PLUG

OUTER END
**Starter Drive**

The starter drive converts the energy from compressed air into shaft power, powerful enough to turn the MGB and then the HPC. The pneumatic sources for start-up are the auxiliary power unit (APU), a ground power source, or 9th-stage high pressure (2.9) bleed air from the other engine. The compressed air drives the turbines, and reduction gears convert the high speed and low torque of the rotors to a lower-speed, higher-output torque. The start valve automatically closes when N₂ reaches a certain speed, disengaging the starter from the engine.

**Ignition Switches**

The ignition switches in the cockpit consist of the Ignition Select Switch, the Engine Start Selectors, and the Fuel Control Switches. The Ignition Select Switch selects either number "1", "2", or both ignition systems for operation when the Start Selectors are in the GND, AUTO or CONT settings and the Fuel Control Switches are out of CUTOFF. There is only one Ignition Select Switch for both engines on the 767-300.
The Engine Start Selectors command the start valves and the ignition systems during engine operation. A VALVE light for each respective start valve illuminates when the valve position disagrees with the position called for by the Start Selector as described below.

- **GRD:** This opens the start valve, closes the bleed valve, and arms the ignition system for the designated engine. The selector must be pushed to rotate from AUTO to GND. The selector will be solenoid-held in the GND position until 45-50% N₂ rpm when the selector will spring back to AUTO. This is known as "starter cutout".

- **AUTO:** This setting closes the start valve, allows the engine bleed valve to open if bleed is available, and deactivates the associated ignition system. In the AUTO selection, the ignition system will run continuously if the trailing edge flaps are not in the full up position or engine anti-ice is turned on as long as the Fuel Control Switch is in the RUN position.

- **OFF:** This closes the start valve and opens the bleed valve if bleed is available. OFF also deactivates the ignition for the particular engine.

- **CONT:** This setting selects continuous operation of the designated ignition system when fuel is flowing to the engine. This setting is used by United pilots during encounters with heavy precipitation and turbulence to prevent possible flameout.

- **FLT:** To bypass the ignition selector and cause both ignition systems to operate continuously, the pilot selects the FLT mode. Both ignition systems will operate as long as the associated engine fuel control is set to RUN.

### Engine Start

The following is a reprint of the Normal Engine Start checklist that United Airlines uses for the PW4060 engine on the 767-300. A normal engine start implies that the APU bleed air is being used to turn the turbine air starter and the APU generator is supplying power to the ignition exciters.
Normal Engine Start

Capt: Engine Start..........................................................Announce
F/O: Engine Start Selector.................................................GND
F/O: Duct Pressure...........................................................Check
Capt, F/O: Engine Indications.............................................Monitor

At 25% N₂ or maximum motoring of N₂, whichever is less, but not less than the N₂ start radial:
F/O: Fuel Control Switch..................................................RUN
Capt, F/O: Engine Indications/EICAS.................................Monitor

At approximately 50% N₂:
F/O: Engine Start Selector..............................................Verify Movement to AUTO

After starter cutout and N₂ rpm stabilization of the first engine:
Capt, F/O: Second Engine.................................................Repeat Procedure

The alternate methods of starting the 4060 engine include a battery start, crossbleed start, or ground pneumatic start. With the battery start, an external pneumatic supply is required. With a crossbleed start, one engine is started using the pneumatic air from the operating engine after verifying the running engine's Bleed Switch is on and the APU Bleed Switch is off. The operating engine should be accelerated to 70% N₂ to increase the duct pressure to 30 psi. To start the engine with external pneumatic supply and APU operational, the APU Bleed Switch must be off and the isolation valve open.

Abnormal Starts

The 757/767 Flight Manual lists the following conditions as abnormal starts. All are considered emergency conditions.

- No EGT rise within 20 seconds after moving Fuel Control Switch to RUN
- High initial fuel flow or EGT rapidly approaching start limit
- Hung start: stabilized idle of approximately 60-63% N₂ not achieved by 120 seconds after moving the Fuel Control Switch to RUN
- EGT exceeds start limit
- No N₁ increase by 40% N₂
- No oil pressure increase before Fuel Control Switch to RUN
- Engine fuel valve or spar valve fails to open
- Pneumatic or electrical supply interruption
- EICAS engine display interruption

If these conditions occur, the immediate action of the crew is to select CUTOFF on the Fuel Control Switch and GRD on the Engine Start Selector. If the first three conditions listed occur, then a restart attempt is allowed; if the second attempt fails, however, the engine start selector must be turned to OFF and the crew must contact Maintenance.

**Engine Shutdown**

To shutdown the powerplants the F/O simply brings the Fuel Control Switch on each engine to CUTOFF. The F/O will then observe the ENG VALVE and SPAR VALVE lights cycling on and off. He shall then verify the shutdown sequence by observing decreasing fuel flow, $N_1$, and EGT. If the engine does not shut down after 45 seconds, the pilot will pull the necessary Fire Shutoff Handle and then call Maintenance.

![Typical Start Graph](CT39814.19929908)

**TYPICAL START**
IMPEDEING HOT START

UNSUCCESSFUL START
Compressor Airflow Control System

Compressor Stall

Any time that the velocity of the airflow is decreased or the engine's rotor speed is increased, the angle of attack (AOA) of the compressor blades is increased. As this AOA is increased and the pressure zones produced by the rotors are increased, the compression ratio increases, as well. Compression ratio is the amount of pressure rise across the compressor stages. Increasing the compressor ratio too much will produce a stalled condition, decreasing the total compression and airflow through the compressor. In essence, decreasing the airflow relative to engine rotor speed will increase the AOA and hence, the stalling tendencies. Compressor stalls are also known as engine surges.

On the ground at idle speeds, the stall may occur due to choking. At lower-than-design engine speeds, the compression ratio is decreased, allowing for a greater quantity of air in the compressor rear. This larger volume of air "chokes" the compressor rear with a decreased airflow, lowering air flow velocities in the front of the compressor.

In flight, excessive fuel-flow schedules during engine acceleration may cause compressor discharge pressure to increase; this condition decreases the compressor airflow and increases the chance of stall. Also, ram effect causes inlet air temperature to increase, which in turn causes compression ratios to decrease. This also causes a choking effect in the rear stages. The basic Compressor Map below, and the N₁ and N₂ Compressor Maps on the next page, graphically depicts when surges are likely to occur.
Pt2.5/Pt2
Pt3/Pt2.5
SURGE ZONE
SURGE MARGIN
FULL OPEN
FULL CLOSED
2.5 BLEED MODULATION
STEADY STATE OPERATION
AIRFLOW
N1 COMPRESSOR MAP

N2 COMPRESSOR MAP
The 4060 uses a compressor airflow control system to help prevent compressor stalls. The system consists of three subsystems: the hydraulically-actuated 2.5 bleed subsystem; the pneumatically-controlled 2.9 bleed; and the hydraulically-powered variable stator vane control. The FADEC/EEC is the "mind" of all three subsystems.
COMPRESSOR AIRFLOW CONTROL SYSTEM – LEFT SIDE

COMPRESSOR AIRFLOW CONTROL SYSTEM – RIGHT SIDE
2.5 Bleed Subsystem

The 2.5 bleed valve and actuator are located in the fan exit case at the 7:00 position. This subsystem aids in compressor stability during starting, transient situations, and reverse thrust operation (to be discussed later). The FMU sends pressurized fuel (P_f) to the 2.5 actuator as commanded by the FADEC/EEC. The FADEC/EEC schedules the valve position based on TRA (thrust lever resolver angle, or thrust lever position), N_1, N_2, Tt_2, Mach number (M_n), and altitude.

The valve is commanded full open during engine start, allowing 4th stage air into the fan airstream. The FADEC/EEC begins to close the valve at 70% N_2 and closes the valve entirely at 84% N_2. During reverse thrust condition, the valve is 50% open. If a compressor stall condition is sensed in an engine by the FADEC/EEC, the 2.5 bleed valve is opened completely. A rotary valve differential transformer (RVT) transmits the actuator’s position to the FADEC/EEC.

The valve itself is a 360 degree, translating ring-type valve, connected to the actuator by a bellcrank. The valve moves forward to open. In addition to preventing surges during deceleration, the valve acts as a dirt separator, sending any unclean air into the secondary airstream. With the bleed in the open position, LPC discharge air from stage 2.5 exits the 2.5 bleed slots into the fan airstream. In the closed position, the discharge air will simply continue through the intermediate case to the HPC.
2.5 BLEED SUBSYSTEM

2.5 BLEED VALVE ACTUATOR
2.9 Bleed Subsystem

There are two 2.9 bleed valves (Left and Right) in this subsystem which are spring-loaded open, and are closed by \( P_3 \) HPC discharge air. The left valve is used primarily for stability control, while the right 2.9 bleed valve acts as the start bleed valve. Both valves, however, are spring-loaded open for engine start and close at 2% \( N_2 \) below idle speed. Both valves communicate to the FADEC/EEC a change in temperature as a measure of airflow. The stability valve temperature is sent to Channel A, and the start valve temperature to Channel B.
2.9 BLEED SUBSYSTEM

Key to the position of both 2.9 valves are the two start/stability valve solenoids that are energized by the FADEC/EEC alternator. The solenoids are powered by 28 VDC and mounted to a common valve housing. Each solenoid has dual independent coils, one being for Channel A and the other for Channel B. The solenoids have three modes of operation: initial start; approximately two percent before idle or steady state; and shutdown, deceleration, or surge detection.
At engine start, the right solenoid becomes energized and blocks the P_s3 bleed air to the solenoid valves. Hence, both 2.9 bleed valves remain open and are vented to the nacelle area.

When the engine reaches about two percent before idle or a steady state, the right solenoid becomes de-energized and the left becomes energized. The effect of the right solenoid is to supply P_s3 to the start valve in order to close it. The left solenoid in this condition supplies P_s3 to the pneumatic relay valve (discussed below) and closes the stability valve.

With engine shutdown, surge condition or deceleration, both solenoids are de-energized as commanded by the FADEC/EEC. During shutdown, both 2.9 bleed valves open automatically as P_s3 equals P_amb. The FADEC/EEC opens the stability valve--again allowing 9th stage bleed airflow--if a surge is detected. Depending on the aircraft altitude, the valve is also opened if the engine is decelerated below 81% N_2. Above Flight Level (FL) 200, the valve opens for three minutes. Between 16,000 feet and FL 200, the valve ranges open from zero to 180 seconds. Below 16,000 feet the valve will not open.

Unlike the start valve, the ninth stage stability bleed valve receives P_s3 air from the bleed valve solenoid housing via a pneumatic relay valve. The function of this valve is to ensure rapid movement of the stability valve to the open position. When the left solenoid coil is energized, P_s3 is transmitted to the servo port. An important feature of the relay valve is the continuous supply of P_s3 to the inlet port. At 35 psi above inlet pressure, the servo pressure shifts the pneumatic relay valve, sending P_s3 through the outlet port and to the stability valve. This muscle pressure closes the stability valve. When the left coil is de-energized, the P_s3 air is allowed to bleed rapidly to the nacelle through the solenoid valve vent; this feature allows the stability valve to open very quickly and improves the engine's stability.
STABILITY BLEED PNEUMATIC RELAY VALVE

(BLEED OPEN)

(BLEED CLOSED)
**Variable Stator Vane Control Subsystem**

This subsystem is crucial to providing maximum performance while preventing compressor surge. The variable stators also improve engine starting. The variable stator subsystem commands the movement of the HPC inlet guide vanes and the 5th, 6th, and 7th stage vanes according to the FADEC/EEC schedule from $N_1$, $N_2$, and $T_2$. The variable stator vane actuator moves the stator bellcrank, which in turn moves the unison ring adjustor links. The bellcrank allows the vanes to move a total of 2.5 inches.

The schedule for engine start is vanes open until 15% $N_2$; the vanes are then closed. They begin to open again at 40% $N_2$, modulating open as $N_1$ and $N_2$ increase. The vanes are full open at high thrust conditions, modulating according to the FADEC/EEC schedule. If a surge condition occurs, the FADEC/EEC will close the vanes a few degrees.
Stall Indications/Cockpit Response

Several indications are evident during a compressor stall condition. In a mild case, the engine may rumble or buzz. More serious, however, is a rapid EGT increase or fluctuation, rotor speed fluctuation, EPR decrease or fluctuation, severe vibration, or abnormally slow engine response to power-lever movements. Flames, vapor, or smoke may appear at the inlet and/or exhaust in these more severe stalls.

My supervisor, the chief pilot at MIAFO, experienced a compressor stall in a 757 PW2037 engine climbing through FL 310 in August. The compressor stall caused severe vibrations and very loud banging. The crew was forced to shut the engine down and return to Miami International. Even engines with systems designed to prevent compressor stalls experience them during line operations. In fact, the 2037—like the 4060—has a variable-stage HPC.
United considers a compressor stall to be an emergency event, calling for the "High Engine EGT/Compressor Stall" procedure in the flight manual. The condition is described as either RPM being at or below idle and not responding to throttle movement or an increasing EGT.

### HIGH ENGINE EGT/COMPRESSOR STALL

**Condition:** Disrupted airflow results in engine stall on the ground or in flight. RPM is at or below idle and does not respond to throttle movement. EGT is increasing.

**IMMEDIATE ACTION**

AFFECTED ENGINE THROTTLE ................. IDLE
Monitor EGT indicator 30-60 seconds to determine trend. EGT increase may be very gradual.

A/T ARM SWITCH ................. OFF

**REFERENCE ACTION**

If EGT decreases and remains below the limit:

THROTTLE ................. ADVANCE
Advance throttle slowly and observe rpm and EGT follow throttle movement. (Under some conditions, rpm may increase very slowly.)

If stall does not recur and throttle response is normal:

Operate engine normally.

If engine does not accelerate and EGT is normal:

ASSOCIATED ENG BLEED AIR SWITCH ................. OFF
Improves engine acceleration.

If engine accelerates:

ASSOCIATED ENG BLEED AIR SWITCH ................. ON

If engine does not accelerate:

THROTTLE ................. IDLE

ASSOCIATED ENG BLEED AIR SWITCH ................. ON

If stall recurs or if EGT is rapidly approaching or exceeds the EGT limit:

ENGINE FAILURE/SHUTDOWN PROCEDURE ........ ACCOMPLISH
Shut down the engine using the appropriate procedure:

- INFLIGHT ENGINE FAILURE/SHUTDOWN (7-18)
- HIGH ALTITUDE ENGINE FAILURE/SHUTDOWN (7-20)

If engine indications appear normal after shutdown:

ENGINE ................. RESTART

**NOTE**
Exceeding engine EGT limit does not preclude an attempt to restart. However, the engine should be closely monitored after restart and for the remainder of the flight.

Complete a FLAMEOUT/COMPRESSOR STALL/THRUST LOSS REPORT and place in the log book.
Turbine Case Cooling System

The turbine case cooling system (TCCS) is controlled by both FADEC/EEC channels and, according to the P&W Customer Training Manual, "controls fan airflow onto the exterior of the turbine cases to thermally affect the size and cycle life for performance enhancement and increased service life." The FADEC/EEC schedules fuel muscle pressure (Pf) based on N<sub>2</sub> and altitude to actuate a piston. This piston in turn positions air valves to meter fan airflow onto the turbine cases.
This system improves fuel efficiency by decreasing blade tip clearances; the cooling air actually shrinks the HPT and LPT cases and even increases the life of the LPT case. The TCC air valve actuator, controlled by the FADEC/EEC and hydraulically actuated by fuel pressure, sets the TCC air shutoff valves through the TCC air valve control cable. To prevent straining of the control cable during engine expansion, the actuator is attached to mount rails.
The TCC air shutoff valves are spring-loaded to the closed position as a fail-safe if the cable or actuator fails. The aft valve functions as the LPT cooling air valve, while the forward valve is the HPT cooling air valve. During takeoff, the aft valve begins to open and cool the LPT. Cruising above FL 145, the forward valve begins to open to cool the HPT. During shutdown and low power, the two valves are closed, although the LPT valve is constructed to allow some cooling air even in the closed position.

The TCC air valves transmit secondary air to the LPT and HPT air manifolds. They are hollow tubes that surround the turbine cases. The tubes are split and individually replaceable.
TCC AIR SHUTOFF VALVES (LPT), (HPT), AND DUCT

HPT AND LPT CASE COOLING AIR MANIFOLDS
Turbine Vane and Blade Cooling Air System

With six cooling air ducts and two valves, the TVBCA system supplies 12th-stage compressor air to the 2nd-stage turbine stator vanes and rotor blades for cooling during all operating conditions. The vanes are continuously cooled by 12-stage air flowing through two ducts. The vanes receive additional cooling air through two other ducts and two TVBCA valves. The 2nd-stage HPT blades and disks, internally cooled by 15th stage bleed, receive additional 12th-stage cooling air through two more ducts as controlled by the TVBCA valves.

Similar to the 2.9 bleed subsystem, the TVBCA's valves are controlled by FADEC/EEC inputs to the 28 VDC TVBCA solenoid. The valves are spring-loaded open, so the FADEC/EEC must energize the left solenoid to send $P_3$ muscle flow to the valve to close them. When the left solenoid is de-energized (the right controls the left HPC/SFC valve), the $P_3$ is prevented from flowing; the solenoid then bleeds both TVBCA valve pneumatic chambers to the nacelle area.
TURBINE VANE AND BLADE COOLING AIR SYSTEM

HPC SECONDARY FLOW CONTROL VALVE
SOLENOID/TURBINE VANE AND BLADE
COOLING AIR VALVE SOLENOID

TURBINE VANE AND BLADE COOLING AIR SYSTEM

COMPONENTS
TURBINE VANE AND BLADE COOLING AIR VALVES

TURBINE VANE AND BLADE COOLING AIR VALVE SOLENOID
The left and right TVBCA valves require 10 psi of (the right controls the left HPC/SFC valve) muscle pressure to close them. The right valve communicates position information to Channel A of the FADEC/EEC via the valve position switch. Both valves have a position switch that acts as a visual position switch.

HPC Secondary Flow Control System

The HPC/SFC system, using the left HPC/SFC valve solenoid attached to the TVBCA valve solenoid assembly and the right HPC/SFC valve solenoid attached to the IDGS oil cooling solenoid, sends 9th stage air to the HPC rotor and turbine areas. This cools the inner HPC aft section and the forward LPT. The left HPC/SFC solenoid communicates with the "B" channel and the right solenoid communicates with the "A" channel of the FADEC/EEC.

HPC SECONDARY FLOW CONTROL SYSTEM

The FADEC/EEC schedules the secondary flow system based on N₂ and altitude. During cruise, the valves are closed by spring action. 28 VDC is supplied by the FADEC/EEC alternator to energize the left and right solenoids; this allows P₃ to flow through a filter and to close the secondary flow control valves. Like the TVBCA system,
with the solenoids de-energized, the $P_3$ flow is stopped and the solenoid valves bleed the SFC valves' pneumatic chambers to the nacelle area. A muscle pressure of 10 psi will close the HPC/SFC valves.

Position switches on both valves feed the FADEC/EEC valve position information and provide a visual position indication.

Following the diagrams of the HPC secondary flow control system is a reproduction of a Pratt & Whitney training poster entitled, "PW 4000 Secondary Flow and Lubrication Systems". I obtained the poster from a maintenance technician at United Airlines' O'Hare Maintenance Station. The poster is an incredible summary of several major systems on the 4060 engine.
HPC SECONDARY FLOW CONTROL SYSTEM COMPONENTS

HPC SECONDARY FLOW CONTROL VALVES

IDGS OIL COOLING/HPC SECONDARY FLOW CONTROL VALVE SOLENOID

HPC SECONDARY FLOW CONTROL VALVE SOLENOID/TURBINE VANE AND BLADE COOLING AIR VALVE SOLENOID

LEFT SIDE

HPC SECONDARY FLOW CONTROL SYSTEM COMPONENTS

RIGHT SIDE

HPC SECONDARY FLOW CONTROL VALVES

9TH STAGE AIR TO HPC DRUM AREA

ELECTRICAL CONNECTOR (FADEC/EEC FEEDBACK)

FAN AIR COOLING

PA3 FROM SOLENOID

PA3 FILTERS

POSITION SWITCH

FAN AIR COOLING

POSITION INDICATOR

ELECTRICAL CONNECTOR (FADEC/EEC FEEDBACK)

9TH STAGE AIR SUPPLY

PA3 FROM SOLENOID

POSITION SWITCH

PA3 FILTER

HPC SECONDARY FLOW CONTROL VALVE

IDGS OIL COOLING/HPC SECONDARY FLOW CONTROL VALVE SOLENOID

HPC SECONDARY FLOW CONTROL VALVE SOLENOID/TURBINE VANE AND BLADE COOLING AIR VALVE SOLENOID

LEFT SIDE

HPC SECONDARY FLOW CONTROL SYSTEM COMPONENTS

RIGHT SIDE

HPC SECONDARY FLOW CONTROL VALVES

PA3 FILTER

HPC SECONDARY FLOW CONTROL VALVE

IDGS OIL COOLING/HPC SECONDARY FLOW CONTROL VALVE SOLENOID

HPC SECONDARY FLOW CONTROL VALVE SOLENOID/TURBINE VANE AND BLADE COOLING AIR VALVE SOLENOID

LEFT SIDE

HPC SECONDARY FLOW CONTROL SYSTEM COMPONENTS

RIGHT SIDE

HPC SECONDARY FLOW CONTROL VALVES

PA3 FILTER

HPC SECONDARY FLOW CONTROL VALVE

IDGS OIL COOLING/HPC SECONDARY FLOW CONTROL VALVE SOLENOID

HPC SECONDARY FLOW CONTROL VALVE SOLENOID/TURBINE VANE AND BLADE COOLING AIR VALVE SOLENOID

LEFT SIDE

HPC SECONDARY FLOW CONTROL SYSTEM COMPONENTS

RIGHT SIDE

HPC SECONDARY FLOW CONTROL VALVES

PA3 FILTER

HPC SECONDARY FLOW CONTROL VALVE

IDGS OIL COOLING/HPC SECONDARY FLOW CONTROL VALVE SOLENOID

HPC SECONDARY FLOW CONTROL VALVE SOLENOID/TURBINE VANE AND BLADE COOLING AIR VALVE SOLENOID

LEFT SIDE

HPC SECONDARY FLOW CONTROL SYSTEM COMPONENTS

RIGHT SIDE

HPC SECONDARY FLOW CONTROL VALVES

PA3 FILTER

HPC SECONDARY FLOW CONTROL VALVE

IDGS OIL COOLING/HPC SECONDARY FLOW CONTROL VALVE SOLENOID

HPC SECONDARY FLOW CONTROL VALVE SOLENOID/TURBINE VANE AND BLADE COOLING AIR VALVE SOLENOID

LEFT SIDE

HPC SECONDARY FLOW CONTROL SYSTEM COMPONENTS

RIGHT SIDE

HPC SECONDARY FLOW CONTROL VALVES

PA3 FILTER

HPC SECONDARY FLOW CONTROL VALVE

IDGS OIL COOLING/HPC SECONDARY FLOW CONTROL VALVE SOLENOID

HPC SECONDARY FLOW CONTROL VALVE SOLENOID/TURBINE VANE AND BLADE COOLING AIR VALVE SOLENOID

LEFT SIDE

HPC SECONDARY FLOW CONTROL SYSTEM COMPONENTS

RIGHT SIDE

HPC SECONDARY FLOW CONTROL VALVES

PA3 FILTER

HPC SECONDARY FLOW CONTROL VALVE

IDGS OIL COOLING/HPC SECONDARY FLOW CONTROL VALVE SOLENOID

HPC SECONDARY FLOW CONTROL VALVE SOLENOID/TURBINE VANE AND BLADE COOLING AIR VALVE SOLENOID

LEFT SIDE

HPC SECONDARY FLOW CONTROL SYSTEM COMPONENTS

RIGHT SIDE

HPC SECONDARY FLOW CONTROL VALVES
LEFT HPC SECONDARY FLOW CONTROL VALVE SOLENOID

LEFT HPC SECONDARY FLOW CONTROL VALVE SOLENOID

RIGHT HPC SECONDARY FLOW CONTROL VALVE SOLENOID

Ps3 INLET

Ps3 TO LEFT HPC SECONDARY FLOW CONTROL VALVE

Ps3 TO RIGHT HPC SECONDARY FLOW CONTROL VALVE

HPC SECONDARY FLOW CONTROL VALVE SOLENOIDS
Thrust Reversing

Thrust reversing is accomplished on the 4060 with left and right thrust-reverser doors, blocker doors, and cascade vanes. During the rollout, the reverse levers in the throttle quadrant should be raised to the interlocks and held there until the interlocks release; the reverse levers are moved aft upon interlock release and control the amount of reverse thrust produced. Reverse thrust is used once the aircraft has touched down on the runway; the reversers are then stowed at 60 knots (after the levers have been set to reverse idle).
During reverser deployment, the reverser doors are hydraulically moved aft. The left and right doors are powered by the left and right hydraulic systems, respectively. When the levers are raised to the interlock stop, an isolation valve is opened to release hydraulic pressure and extend the reverser. The cowl doors are held closed by hydraulic pressure. The 4060 has an autostow feature that applies hydraulic pressure if an unscheduled thrust reverser unlock is sensed.

When the reverser cowl doors are opened, blocker doors rotate across the fan cowl exhaust airstream. This forces secondary fan airflow to flow through 32 fixed cascade vanes and flow forward as reverse thrust.
Integrated Drive Generator

A discussion of the PW4060 engine would not be complete without a brief explanation of the AC-supplying integrated drive generator. The IDG is made up of the generator and the constant speed drive (CSD). The CSD provides a constant generator speed of 12,000 rpm, maintaining the 120 VAC at 400 Hz needed for the aircraft systems. The generator is of the permanent magnet generator (PMG) type. The permanent magnet, connected to a rotor and driven by the MGB, induces the alternating current.

The IDG is divided between left and right channels for AC supply. Through rectifiers, the IDG also supplies left and right channels of DC power. The 767-300 APU utilizes an identical IDG as the 4060 power plant. As described previously, the IDG is cooled by the IDGS oil cooling system through the air/oil heat exchanger.
Thrust Rating

Engine Rating

The PW4060 is flat-rated to produce 60,000 pounds of thrust up to an ambient temperature of 86°F. Maximum continuous thrust, maximum climb thrust, and cruise thrust are also flat-rated up to standard temperature plus 18°F. Pratt & Whitney uses the flat rating concept of maintaining a constant exhaust gas temperature instead of rating the engine to a constant compressor speed. In using the flat rating concept, compressor speed and ambient temperature are related.

Ambient air temperature and air density vary inversely, while compressor airflow varies directly with compressor speed and air density. Compressor speed is also directly related to the energy available to the turbine driving it (measured by EGT). As a result of these relationships, when the EGT is maintained at a constant level, the compressor speed becomes a function of ambient temperature at a given pressure altitude.

FLAT RATING CONCEPT
Below 86°F the 4060 produces maximum rated thrust with decreased fuel flows, EGT, and compressor speeds; at decreased EGT values, the turbine life is prolonged with no thrust penalty. Above 86°F the FADEC/EEC maintains a constant EGT, resulting in longer turbine life and sufficient thrust capabilities. In other words, at sea-level standard temperature (59°F) the 4060 produces 60,000 pounds of rated takeoff thrust at part throttle; the 4060 can maintain this amount of thrust at ambient temperatures up to 86°F through throttle advancement. Above 86°F, thrust is EGT-limited, with thrust decreasing proportionally as ambient temperature decreases.

**EPR/N1 COMMAND VS TRA**

*Engine Pressure Ratio*

Thrust is normally controlled through the engine pressure ratio, or EPR, mode on the 767-300. Engine pressure ratio is defined as the ratio of the total pressure at the front of the compressor to the total pressure at the rear of the turbine. EPR varies directly with the amount of thrust produced by an engine. On the 4060, the FADEC/EEC calculates
EPR values as a percentage of maximum limits. This percentage is varied according to the throttle position as shown on page 101, so that at full throttle position, the percentage is 100%. The maximum EPR setting during takeoff for the 4060 is 1.61 in standard conditions.

Actual takeoff thrust settings are based on airport pressure altitude and an assumed temperature provided by Dispatch for reduced EPR. If this assumed temperature is above 86°F, the temperature value is accompanied by the letter "C", denoting that the takeoff is limited by climb thrust (because of EGT). The 767's flight management computer (FMC) automatically computes the reduced takeoff thrust any time the assumed temperature is above the outside ambient temperature (OAT).
ENGINE MODEL PW4060

<table>
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<th>Station</th>
<th>2</th>
<th>2.5</th>
<th>14</th>
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<th>4</th>
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<td>Tt °C</td>
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ENGINE MODEL PW4000

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<td>15</td>
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PERFORMANCE DATA

CRUSE 35.000 FT. 0.8 Mn

ENGINE MODEL PW4060

<table>
<thead>
<tr>
<th>N1</th>
<th>97.5 %</th>
<th>3506 rpm</th>
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<tbody>
<tr>
<td>N2</td>
<td>99 %</td>
<td>9800 rpm</td>
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<tr>
<td>Wf</td>
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ENGINE MODEL PW4000

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<th>86 %</th>
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<tbody>
<tr>
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<td>8700 rpm</td>
</tr>
<tr>
<td>Wf</td>
<td>~5300 pph</td>
<td></td>
</tr>
<tr>
<td>EGT</td>
<td>340 °C</td>
<td></td>
</tr>
<tr>
<td>EPR</td>
<td>~1.3</td>
<td>THRUST</td>
</tr>
</tbody>
</table>

OPERATING LIMITS

<table>
<thead>
<tr>
<th>N1 RED LINE</th>
<th>111.4 %</th>
<th>4012 rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>N2 RED LINE</td>
<td>105.5 %</td>
<td>10450 rpm</td>
</tr>
<tr>
<td>EGT RED LINE</td>
<td>MAX TO-650 (5 MIN.) °C</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: N1 @100% = 3600 rpm
NOTE: N2 @100% = 9900 rpm

TAKE-OFF

N1 RED UNE
NOTE: N1 ©100% =
N2 RED UNE
NOTE: N2 ©700% =
EGT RED UNE
MAX CONT 625 rpm
Thrust Management Computer

The FADEC/EEC's thrust management computer (TMC) computes the EPR value by dividing $P_{4,9}$ by $P_2$. The FADEC/EEC uses either Channel A or Channel B inputs for thrust management. If the operating channel cannot provide EPR information, the non-operating channel automatically provides the input. If both EPR inputs should fail, the FADEC/EEC automatically switches to the alternate $N_1$ mode (provided by either channel). If both $N_1$ inputs fail, $N_1$ is synthesized by the operating channel using Mach number and $N_2$.

In the alternate $N_1$ mode, either selected automatically or manually by the crew, a "L or R EEC MODE" message appears on the primary EICAS and the ALTN light illuminates on the related ENG ELEC CONT switch. There is no overboost protection in the $N_1$ mode; thus maximum EPR may be achieved with less than full throttle. The FADEC/EEC still provides $N_1$ and $N_2$ overspeed protection—maximums of 111.4% and 105.5%, respectively—in the alternate $N_1$ mode.

If failure occurs in both FADEC/EEC channels, the affected engine decelerates to and remains at minimum fuel flow.
Cockpit Indicators

The figure below shows the location of the flight deck components necessary to collecting engine data. In addition, the propulsion interface and monitor unit is located in the main equipment center underneath the main deck.
Primary EICAS Display

Primary engine indications are displayed on the upper engine indication and crew alerting system (EICAS) display. These include EPR, N₁, and EGT. Alert messages are displayed on the left side of the primary display. A WARNING, a Level A alert, is displayed in red and requires immediate action. CAUTION is a Level B alert calling for immediate awareness/future action and is shown in amber. Also shown in amber but indented is an ADVISORY message (Level C) simply calling for awareness to the situation. These alert messages are arranged by their urgency and by when they occurred.

The upper screen also displays information to crew concerning the thrust mode, total air temperature, assumed temperature, reverser operation, engine anti-ice, and inflight engine start. A row of arrows at the bottom left-hand part of the CRT indicates that secondary engine data is displayed on the lower EICAS CRT.

Secondary EICAS Display

The lower EICAS display shows secondary engine indications which include N₂, fuel flow, oil pressure, temperature, and quantity, engine vibration level, status displays, and maintenance displays. All of the engine indications from the secondary EICAS can be displayed in digital form on the primary EICAS. The status display and maintenance display are also shown on the secondary EICAS screen.

If either CRT fails, the EICAS will automatically switch to a compacted mode. The remaining display unit displays all the data displayed when both screens are functional; however, all the information is presented in alpha-numerical form except N₁ and EPR.

The following pages describe and show how the indications reach the EICAS displays.
**Location:** Upper EICAS Display

**Location:** Lower EICAS Display
EPR DISPLAY

Assumed Temperature Annunciation
Indicates assumed temperature selected from either the thrust mode select panel or from FMS CDU TAKEOFF REF page.

TAT +15°C
Indicates total air temperature.

Max EPR Limit Radial
Indicates the maximum EPR limit as calculated by the EEC, or the TMC if the EPR mode of the EEC fails. The limit is not affected by the active thrust mode, and varies with existing ambient conditions.

Thrust Mode Annunciation
Indicates in green the mode for which the reference thrust limits are calculated by the TMC or FMC. Possible annunciations are:

- TO Maximum takeoff
- TO 1* Maximum takeoff, derated climb preselected
- TO 2* Maximum takeoff, derated climb preselected
- D-TO Assumed temperature (reduced) takeoff
- D-TO 1* Assumed temperature (reduced) takeoff, derated climb preselected
- D-TO 2* Assumed temperature (reduced) takeoff, derated climb preselected
- CLB Climb thrust
- CLB 1 Derated climb is active (green numeral)

* Numeral displays in white to indicate derated climb is selected

Reference Bug and Display
Indicate the EPR reference and value for the thrust mode. The reference bug is magenta when indicating a target EPR (VNAV SPD during a climb or VNAV PTH with autothrottles off).

The reference bug is green when indicating a limit EPR (all other TMC modes).

With the THRUST REF SET knob pulled out, EPR value is set manually by the knob.

Actual EPR Pointer and Display
Indicate the actual EPR. Not displayed until associated engine reaches approximately 10% N₂ during start.

Commanded EPR Band
Indicates the difference between EPR called for by throttle position and existing EPR. As the engine accelerates or decelerates, the actual EPR pointer moves to the commanded value and erases the band.

REV Annunciation
Indicates in amber that reverser is in transit. Changes to green when reverser is fully deployed, and thrust mode, reference EPR and EPR bug displays are inhibited.

Location: Center Instrument Panel - Upper EICAS CRT
**N₁ DISPLAY**

- **Maximum N₁ Limit Radial**
  Indicates the maximum allowable N₁.

- **TAI Annunciation**
  Indicates in green that engine anti-ice switch is on. Changes to amber if N₁ drops below the minimum required for anti-ice operation.

- **Actual N₁ Pointer and Display**
  Indicate actual N₁. Change to red upon reaching the maximum limit. Not displayed until associated engine reaches approximately 3% N₁ (28% - 30% N₂) during start.

- **Anti-Ice Reference Bug**
  Indicates the minimum N₁ for satisfactory anti-ice operation. Displayed when engine is supplying bleed air, engine anti-ice is on and the opposite engine bleed air source is inoperative. Changes from green to amber if actual N₁ drops below this value.

**Location**: Center Instrument Panel - Upper EICAS CRT

---

**EGT DISPLAY**

- **Cautionary EGT Range**
  Indicates the five minute limit cautionary range.

- **Maximum EGT Limit Radial**
  Indicates the maximum allowable EGT.

- **Start Limit Radial**
  Indicates the maximum starting EGT. Displayed when associated fuel control switch is in CUTOFF, and until engine reaches idle.

- **Actual EGT Pointer and Display**
  Indicate actual EGT. Change to amber or red upon reaching the cautionary range or maximum limit respectively. The change to amber is inhibited for five minutes after amber range is entered during takeoff or go-around. Not displayed until associated engine reaches approximately 10% N₂ during start.

- **Overtemp Display**
  Appears and displays the highest EGT reached when EGT exceeds the maximum limit. Can be erased by pushing the MAX IND RESET switch on the EICAS control panel, but is stored in the computer for maintenance recall.

- **INFLIGHT START Display**
  Indicates inflight start envelope speeds for the three closest odd flight levels below airplane altitude. Displayed only when the full up engine display is selected on EICAS with an engine shutdown in flight.

**Location**: Center Instrument Panel - Upper EICAS CRT
**N2 DISPLAY**

**Maximum N2 Limit Radial**
Indicates the maximum allowable N2.

**X-BLD Annunciation**
Indicates cross-bleed start is recommended for inflight engine start.

**N2 Pointer and Display**
Indicate N2 when the full up engine display is selected on the EICAS control panel or when an N2 overspeed occurs in either engine. When displayed, indicate overspeed by color change in the same way as the N1 displays.

**Fuel On Command Bug**
Indicates minimum fuel on selection point during starter cranking. Displayed when engine is shut down on the ground, or in flight when X-BLD is displayed.

**Overspeed Display**
Indicates the highest N2 reached when N2 exceeds the maximum allowable limit. Can be erased by pushing the MAX IND RESET switch on the EICAS control panel, but is stored in the computer for maintenance recall.

**FF (FUEL FLOW) DISPLAY**

**Fuel Flow Pointer and Display**
Indicate fuel flow when full up engine display is selected on the EICAS control panel.

**Location:** Center Instrument Panel - Lower EICAS CRT

---

**ENGINE OIL AND VIBRATION DISPLAY**

Indicates the respective parameters in digital and vertical scale format. Normally white displays change to amber or red if the values reach cautionary or warning levels.

Entire display appears when the full up engine display is selected on the EICAS control panel or automatically when oil temperature, pressure or quantity is outside normal tolerances.

**OIL PRESS Display**
Displays oil pressure in pounds per square inch (psi). Oil pressure is unregulated and the pressure scale does not include an amber range or red line for high oil pressure. Max oil pressure display is 200 psi, however actual oil pressure may be higher.

**OIL TEMP Display**
Displays oil temperature in °C. The oil temperature signal comes from the EEC. Therefore, oil temperature is not displayed until there is N2 rotation. Oil temperature can vary considerably with thrust changes since it is not thermostatically controlled.

**OIL QTY Display**
Displays oil quantity in quarts. After shutdown, some oil may drain from the tank into the gearbox. The most accurate engine oil quantity readings are obtained within 2 hours after engine shutdown or after motoring the engine.

**VIB Display**
Indicates the rotor (N1 or N2) with the higher vibration level for each engine. Indicates BB if unable to detect which rotor has higher vibration.
STANDBY ENGINE INDICATOR

ENGINE SPEED CARDS

AVM SIGNAL CONDITIONER

FADEC/EEC

FADEC/EEC ALTERNATOR

LOWER EICAS DISPLAY

N2 INDICATION

LOWE EICAS DISPLAY

FUEL FLOW INDICATION
OIL SYSTEM INDICATION

VIBRATION INDICATION
Pilots' EICAS Control Panel

The 767-300 has two Engine Indication and Crew Alerting System computers that communicate with the FADEC/EEC, acting as the interface between the FADEC/EEC and the crew. The crew may select either the left or right EICAS computer, but normally AUTO is chosen for automatic takeover if one of the computers fails.

The pilots may view the engine displays as described above, or they may display the status page on the lower EICAS display unit. When STATUS is pushed, the following information is displayed on the lower CRT: hydraulic quantity; APU EGT and RPM; crew oxygen system pressure; flight control positions relative to neutral position; brake temperatures; and status messages. These status messages make the crew aware of equipment conditions that are necessary at the time of dispatch.

The remaining controls on the pilots' EICAS control panel are described in the figures from the 757/767 Flight Manual that follow. In addition, the Compacted Display and the Status Display are shown.

Warning/Caution Lights

On each end of the glareshield are two master warning lights that illuminate during any warning condition. Two caution lights, next to the master warning lights, illuminate when any cautionary event occurs. Both sets of lights remain illuminated while the condition exists but may be reset by pushing them.
**BRT Knobs**

Inner Knob - Set brightness of upper CRT.
Outer Knob - Set brightness of lower CRT.

Turning either knob adjusts brightness level of both CRTs by the same amount. To adjust brightness of a single CRT, one knob must be held stationary while the other knob is rotated.

**EICAS DISPLAY STATUS Switch**

Selects status display on lower CRT if blank or in secondary engine mode. If lower CRT already displays status information and additional messages are waiting, pushing switch advances message list; otherwise it blanks the lower CRT. Status display cannot be selected in flight if one CRT has failed. Secondary engine parameters exceeding normal range move to upper EICAS CRT in partial compacted display when status page is displayed.

**EICAS DISPLAY ENGINE Switch**

Selects secondary engine display on lower CRT if blank. If lower CRT already displays engine information, pushing switch blanks CRT, if no limits have been exceeded.

**EVENT RECORD Button**

Records in computer memory system data as of time pushed in flight. On the ground, records data as selected on the EICAS maintenance panel. If pushed more than once, erases previous data and records new data. Computer retains only data from most recent push.

**COMPUTER Selector**

L/R - Selects associated EICAS computer for operation.
AUTO - Selects left EICAS computer for operation and right for backup. Right computer takes over automatically if left fails.

**THRUST REF SET Knob**

Inner Knob - Establishes manual control of reference EPR for engines selected on outer knob. When pulled, causes thrust mode indicator to display MAN and reference EPR indicator to indicate 1.55 EPR. Rotating after pulling sets desired EPR. Autothrottle does not control to manually set EPR, rather to the limit for the thrust mode selected.

Outer Knob - Selects either or both engines for manual EPR control by inner knob.

**MAX IND RESET Button**

Resets overtemp and overspeed system and displays. Associated data is stored in computer memory.

**Location:** Forward Control Pedestal

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**12-20 ENGINES**

**Primary Engine Display - Compacted**

**EPR and N. Displays**
Indicate the same information in the same format as the normal mode.

**OIL PRESS, OIL TEMP, OIL QTY and VIB Displays**
Indicate respective parameters in digital form only. Color does not change for abnormal values.

**EGT, N₂ and FF Displays**
Indicate respective parameters in digital form only.

**Location:** Center Instrument Panel - Operative EICAS CRT

---

**12-21 ENGINES**

**Status Display**

**Upper CRT**
Displays EPR, N, and EGT information.

**Lower CRT**
When STATUS switch pushed on pilots' EICAS control panel, displays:
- Hydraulic quantity
- APU EGT and RPM
- Crew oxygen system pressure
- Flight control positions relative to faired (neutral) position
- Status messages

**Location:** Center Instrument Panel
**Standby Engine Indicator**

The figure below shows the standby engine indicator and its digital format.

**STANDBY ENGINE INDICATOR**

**Standby Engine Indications**
Provide backup indications for engine EPR, N1, EGT, and N2. Value adjacent to associated digital readout is maximum limit.

**ENG OIL PRESS Light**
Indicates associated engine oil pressure is below 70 psi. Causes all oil related indications for both engines to appear automatically on EICAS.

**AUTO/ON Selector**
AUTO - Allows indications to be displayed automatically when any one of the following occurs:
- AC power is lost
- EICAS fails
- Both CRTs fail
- Either CRT fails on the ground and STATUS mode is selected.

ON - Indications are displayed full time.
**Thrust Mode Select Panel**

The following figures taken from the 757/767 Flight Manual illustrate the functions of the thrust mode select panel. The thrust mode select panel is located in front of the pilots above the EICAS displays, below the glareshield. As a special note on the Climb Thrust Derate Switches, selecting 1 gives approximately 90% of climb thrust while 2 selects 80% of climb thrust. Between 10,000 and 12,500 feet, the reduced thrust increases until it is the same as CLB power. By the time the aircraft climbs through 12,500 feet, the reduced climb thrust is terminated and the annunciation ("1" or "2") is extinguished.

**THRUST MODE SELECT PANEL**

**Thrust Mode Select Switches**

Select the thrust mode to be used by the thrust management computer for reference EPR computation. The active thrust mode and reference EPR are indicated on EICAS. With VNAV engaged, the flight management computer automatically selects the thrust mode, except when the takeoff mode is active, and manual selection of GA, CLB, CON and CRZ is inhibited. In a VNAV climb, CON (continuous) thrust can be selected and the autothrottle controls to the CON limit. In VNAV cruise, either CON or CLB thrust can be selected to provide a higher upper thrust limit in cruise. The reverse mode is activated automatically when the reverse levers are in the reverse range.

**TO/GA** - Selects TO (takeoff) mode on the ground or GA (go-around) mode in flight. Cancels selected assumed temperature and preselected CLB 1 or CLB 2. Inhibited with GA mode displayed.

**CLB** - Selects CLB (climb) mode. Selects CLB 1 or CLB 2 if 1 or 2 preselected. Deactivates TO mode to flight directors and autothrottle. If selected prior to takeoff, only climb power is available when EPR switch is pushed.

**CRZ** - Selects CRZ (cruise) mode.

**CON** - Selects CON (max continuous) mode.
Climb Thrust Derate Switches
Select either of two derate values for climb thrust computation.

TEMP SEL Knob
Selects the assumed temperature for reduced takeoff thrust. Initial movement of the knob causes the flat rated temperature to be displayed on EICAS and on the FMC CDU TAKEOFF REF page. Further clockwise rotation increases the assumed temperature 1°C per click. When the assumed temperature exceeds ambient, D-TO is displayed on EICAS. The thrust management computer uses the higher of assumed temperature or the flat rated temperature to compute takeoff thrust. If an assumed temperature is not selected, the computer uses the higher of TAT or flat rated temperature to compute takeoff thrust. Counterclockwise rotation of the knob reduces the assumed temperature 1°C per click.

Assumed temperature takeoff thrust is limited to a 25% reduction of maximum takeoff thrust or selected climb thrust whichever is the greater thrust value. When the limit is reached, further clockwise knob rotation does not change the displayed temperature or reference thrust value. The knob is only active in the takeoff mode.

EICAS Maintenance Control Panel

The EICAS maintenance mode may only be accessed while on the ground. The EICAS automatically records the parameters of the environmental control system (ECS), electrical and hydraulic systems (ELEC/HYD), performance (PERF), APU, and the electronic propulsion control system (EPCS). This "auto event" occurs based on EICAS parameters. The manual recording, or "manual event", is initiated by either the flight crew or the maintenance crew on the ground. When the flight crew initiates the manual event, ECS, ELEC/HYD, PERF/APU, and EPCS are recorded. If the maintenance crew initiates
this on the ground, all parameters of the currently displayed maintenance system are recorded.

**EICAS MAINTENANCE CONTROL PANEL**

The DISPLAY SELECT switches show systems information on the lower EICAS display. Examples of some maintenance mode displays are shown on the next page.

- **ECS/MSG**: Environmental Control System and Maintenance Messages. Displays in real time, manual event, or auto event mode for ECS; also displays maintenance messages for all systems except EPCS when ECS/MSG display or Auto Event Read is selected.
- **ELEC/HYD**: Electrical and Hydraulic Systems. Displays in real time, auto event or manual event modes.
- **PERF/APU**: Performance and Auxiliary Power Unit. Displays in real time, auto event or manual event modes.
- **CONF/MCDP**: Configuration and Maintenance Control/Display Panel. Displays real time information.
- **ENGINE EXCD**: Engine Exceedances. Displays in the real time mode any data accumulated since the last erasure of the ENGINE EXCD page.
- **EPCS**: Electronic Propulsion Control System. Displays in real time, auto event or manual event modes.
EICAS MAINTENANCE MODE DISPLAYS

ECS/MSG Display
Provides environmental control system data and messages.

ECS/MSG

<table>
<thead>
<tr>
<th>FLTK</th>
<th>FWD</th>
<th>AFT</th>
<th>FWD EQUIP FAN 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>28</td>
<td>26</td>
<td>ZONE TEMP BITE</td>
</tr>
</tbody>
</table>

| TRIM VALVE | 0.01 | 0.26 |
| L          | R    |

| PACK OUT   | 21   | 19  |
| DUCT PRESS | 33   | 27  |
| PACK FLOW  | 56   | 79  |
| TEMP VALVE | 0.21 | 0.18 |
| RAM IN DOOR | 0.58 | 0.91 |

Location: Lower EICAS CRT

ELEC/HYD Display
Provides electrical and hydraulic system data.

ELEC/HYD

<table>
<thead>
<tr>
<th>STBY /BAT</th>
<th>L</th>
<th>R</th>
<th>APU /BAT</th>
<th>GND PWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOAD</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.95</td>
</tr>
<tr>
<td>AC-V</td>
<td>115</td>
<td>115</td>
<td>114</td>
<td>0</td>
</tr>
<tr>
<td>FREQ</td>
<td>400</td>
<td>402</td>
<td>398</td>
<td>0</td>
</tr>
<tr>
<td>DC-A</td>
<td>3</td>
<td>99</td>
<td>41</td>
<td>4</td>
</tr>
<tr>
<td>DC-V</td>
<td>28</td>
<td>28</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>IDG OUT</td>
<td>75</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDG RISE</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HYD QTY</td>
<td>.76</td>
<td>1.25</td>
<td>.25</td>
<td>RF</td>
</tr>
<tr>
<td>HYD PRESS</td>
<td>2930</td>
<td>3010</td>
<td>2940</td>
<td></td>
</tr>
<tr>
<td>HYD TEMP</td>
<td>50</td>
<td>47</td>
<td>38</td>
<td></td>
</tr>
</tbody>
</table>

Location: Lower EICAS CRT

ENG EXCD Display
Provides engine exceedance data.

ENG EXCD

<table>
<thead>
<tr>
<th>109.7</th>
<th>N₁</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2 BB</td>
<td>VIB</td>
</tr>
<tr>
<td>2.6 BB</td>
<td></td>
</tr>
<tr>
<td>1:37</td>
<td>EGT</td>
</tr>
<tr>
<td>95:23</td>
<td>825</td>
</tr>
<tr>
<td>104.2</td>
<td>N₂</td>
</tr>
<tr>
<td>400</td>
<td>56</td>
</tr>
</tbody>
</table>

Location: Lower EICAS CRT

ENGINE CONFIGURATION Display
Provides airplane configuration data and maintenance panel control display.

ENGINE CONFIGURATION

<table>
<thead>
<tr>
<th>PART NO. S242W701-101</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGINE CONFIGURATION</td>
</tr>
<tr>
<td>EICAS PW 2037 PW 2037</td>
</tr>
<tr>
<td>TMC PW 2037 PW 2037</td>
</tr>
<tr>
<td>FMC PW 2037 PW 2037</td>
</tr>
<tr>
<td>EEC PW 2037 PW 2037</td>
</tr>
<tr>
<td>PROGRAM PINS 8625 3Z MCDO OFF</td>
</tr>
<tr>
<td>EICAS ON DSP ON</td>
</tr>
<tr>
<td>ADC ON RA ON</td>
</tr>
<tr>
<td>TMC ON FMC NCOD</td>
</tr>
<tr>
<td>MCDO OFF FUEL OFF</td>
</tr>
<tr>
<td>ON EEC ON</td>
</tr>
</tbody>
</table>

Location: Lower EICAS CRT

PERF/ APU Display
Provides APU and performance data.

PERF/ APU

| 47 OIL PRESS | 45 | 1.015 | EPR CMD |
|             |    | 1.014 |
| 47 OIL TEMP | 94 | 1.015 | EPR ACT |
|             |    | 1.014 |
| 47 OIL QTY  | 20 | 25.2  | N₁     |
|             |    | 25.3  |
| .05 VIB     | .04 | 408   | EGT    |
|             |    | 420   |
|             |    | 63.9  | N₂     |
|             |    | 62.6  |
|             |    | 1.245 | FF     |
|             |    | 1.191 |

Location: Lower EICAS CRT

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Propulsion Interface Monitor Unit

The 767-300 has two PIMU's located in the main equipment center, one for each 4060 engine. The monitor unit displays FADEC/EEC fault messages. During a five second period when the aircraft has landed, the PIMU receives low-speed ARINC (Aeronautical Radio Incorporated) engine fault data from the FADEC/EEC's two channels. The PIMU allows maintenance technicians to recall faults for all flight legs since the most recent resetting of the system. It also allows them to ensure that the faults have been corrected. The PIMU will be discussed more in the "Engine Inspections and Servicing" section.
**Propulsion Interface Monitor Unit**

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Thrust Settings

*Throttle Quadrant*

The diagram below describes the functions of the throttle quadrant's components. Notice that the Fuel Control Switches and valve lights are located at the bottom of the control pedestal.

**THROTTLE QUADRANT**

- **Reverse Levers**
  Control reverse thrust output of the associated engine. Can be raised only when the associated throttle is closed. Reverser can operate if hydraulic pressure is available whether or not the associated engine is running.
  
  Raising the lever to the interlock causes the associated engine reverser mechanism to operate, ground spoilers to extend if other logic is satisfied, the autothrottle to disengage, and the EEC to compute the maximum N\(_i\) limit for reverse thrust.
  
  When the interlock releases and the reverse lever is moved to the aft limit stop, the EEC controls the engine to the limit without overboost.

- **THROTTLES**
  Control forward thrust output of the associated engine. Locked in closed position during reverse thrust operation.

- **Autothrottle Disengage Switches (Both Sides)**
  Disengage the autothrottle.

- **Go-Around Switches (Both Throttles)**
  Activate the go-around mode of the autothrottle and autopilot/flight director systems, provided the go-around mode is armed.

*Location:* Center Control Pedestal
Takeoff

The takeoff thrust is initially set by the pilot flying (PF) at the beginning of the takeoff roll. The throttles are advanced by the PF to a stabilized EPR of 1.10; he will then smoothly advance throttles to the target EPR setting. The pilot-not-flying (PNF) then brings the throttles to the appropriate, exact EPR position when the PF calls out, "Set takeoff thrust." The EPR switch should be pushed once takeoff thrust is set. The crew should use slow and steady throttle movement while also monitoring the EICAS displays to avoid exceeding operating limitations. In addition, the rate at which thrust is applied is directly related to the EGT value obtained when applying the takeoff thrust.

The Planned Takeoff Data Message that the crew receives from Dispatch gives the maximum EPR setting for the temperature and pressure altitude when the report is generated. If the actual temperature varies from that forecast, the maximum EPR is obtained from the "Takeoff Thrust--EPR" table in the Flight Handbook. The Data Message also gives a reduced EPR setting if possible for that takeoff. This information is used to program the reference EPR cue on the EICAS display via the Thrust Mode Select Panel.

Reduced thrust is critical to daily engine operations because it minimizes several factors in power plant deterioration and failure: tip clang and spatter; creep, intergranular oxidation (IGO), and thermal stress. Tip clang and spatter describes two conditions in which the compressor rotors can contact the case at high RPM and molten metal "splatters" aft engine components. This reduces efficiency of the airfoils and blocks internal cooling ports. Tip clang and spatter has caused catastrophic engine failure on one United Airlines aircraft.

Creep is the stretching of metal components due to inertial effects of spinning rotors resulting in progressive metal deformation. IGO is the oxidation process that occurs on the metal components at high temperatures. Finally, thermal stress is the expansion and contraction of metal parts as the temperature is constantly increased and
then decreased. Thermal stresses have the most profound effect when setting takeoff thrust and then reducing to climb power. Again, using reduced thrust settings when possible decrease the effects of these four items.

Climb

At 800 feet AGL, the aircraft transitions into the climb mode. The PNF will push the VNAV switch and verify CLB is displayed on the EICAS as the thrust limit. With VNAV engaged, the FMC automatically selects the thrust mode. When climbing through 10,000 feet, the FMC will activate the Economy (ECON) climb mode.

Cruise

The FMC will transfer to the ECON cruise mode and automatically compute the cruise speed and the EPR setting that will give that speed. The FMC will set the EPR based on the optimum cruise altitude, best fuel consumption, gross weight, and the best cost index of 40.

Descent

The FMC again will set the EPR during the VNAV mode descent. During the approach, the throttle is set to maintain the reference airspeed based on the aircraft's gross weight. The amount of fuel flow is used as a reference for where to keep the throttle quadrant during the approach.
Engine Inspections and Servicing

Air Carrier Maintenance Program

I did not gain access to the specific maintenance schedule that United Airlines uses. The following summarized information was obtained in AVS 327 class ("Airline Administration") during the fall semester of 1996 at Western Michigan University and describes US Airways' approved maintenance program. US Airways' maintenance program is probably very similar in structure to that used by United. The carrier's inspection schedule consists of seven types of aircraft checks.

The "Daily Check" consists of a basic walk-around of the aircraft by a maintenance technician. This check emphasizes the tires and oil pressure and is usually accomplished once a day between two flights.

The "Overnight Check" includes the Daily Check items; technicians make additional checks on the power plants, brake wear, and water in the fuel. The Overnight occurs whenever the aircraft sits overnight at a maintenance station.

The "Transit Check", accomplished every 50 flight hours, is similar to the Overnight, emphasizes the interior of the plane to check safety items and interior asthetics.

Every 120 to 200 flight hours, the aircraft undergoes the "A-Check". The technician has more time to make more detailed inspections of more items. The flight data recorder (FDR) and cockpit voice recorder (CVR) are also checked.

Next is the "B-Check" done every six months. Known as the main servicing check, Maintenance replaces, cleans, lubricates and services the aircraft. All aircraft lights are inspected and batteries are replaced.

The "C-Check" done about once a year includes the B-Check items, detailed inspection of the fuselage skin and structure, and any time-controlled tasks needed. The aircraft is parked for several days during the C-Check.

Every 11,000 flight hours the aircraft undergoes the "D-Check", the highest level inspection. The aircraft is parked for three to four weeks and is completely torn down.
The maintenance technicians inspect for structural problems as mandated by the FAA, take X-rays, replace components, refurbish the interior, and polish, paint, and placard the aircraft's exterior.

The highest-level, or comprehensive check done on United's 4060-equipped 767-300's is accomplished in Oakland, California. The 4060-equipped 747-400 receives this inspection in San Francisco.

**Borescope Provisions**

The PW4060 has 16 access ports to examine the internals of the engine using a borescope without necessitating engine disassembly. The access ports are named AP-1 thru AP-11. There are actually six AP-8 access ports surrounding the diffuser case that bring the total number to 16. To inspect the LPC and the LPT, the fan can be turned manually. The HPC and HPT may be turned manually with an N₂ crank pad on the MGB; however, it is recommended to use a motor-driven unit to turn the high-pressure spool. The figures that follow show the location of engine areas inspected by borescope.
10TH STAGE VANE

14TH STAGE VANE

ENGINE AREAS VIEWED BY BORESCOPE
API
4TH STAGE
COMPRESSOR

AP10
3RD STAGE TURBINE

AP9
1ST STAGE TURBINE

AP11
REAR COMPRESSOR
DRIVE TURBINE

AP8
COMBUSTION
CHAMBER

AP7
14TH STAGE
COMPRESSOR

AP6
12TH STAGE
COMPRESSOR

AP5
10TH STAGE
COMPRESSOR

AP4
8TH STAGE
COMPRESSOR

AP1
4TH STAGE
COMPRESSOR

AP2
5TH STAGE
COMPRESSOR

AP3
6TH STAGE
COMPRESSOR

APS
COMBUSTION
CHAMBER

BORESCOPE ACCESS PORTS – LEFT SIDE

BORESCOPE ACCESS PORTS – RIGHT SIDE
Control System Components Inspection

The PW4060's engine control system (ECS) components consist of the FADEC/EEC, wiring harness, and engine system actuators, solenoids, switches and valves. The wiring harnesses are the electrical connections between the FADEC/EEC and the aircraft, as well as the FADEC/EEC and the engine systems. The harnesses are actually individual single shielded cables bundled together. The actuators, solenoids, switches, and valves not only activate the engine's systems but also communicate system component positions to the FADEC/EEC. When any engine system or flight deck input fails, the FADEC/EEC will detect and transmit the failure to the PIMU.
The troubleshooting procedure for engine control system failures begins with checking the affected system harness connectors simply for tightness. Then remove the connector from the FADEC/EEC to check for bent or loose pins or pushed-in sockets. A loop resistance check should then be done. The harness connector on the affected system itself should then be disconnected to check for bent or loose pins or pushed-in sockets. The wiring harness should then be checked. If none of these previous items have discovered the malfunction, replace the affected system component, harness, and FADEC/EEC in that order as needed.

Although the FADEC/EEC is a relatively easy component to replace, Maintenance should not hastily remove and replace it in the case of a system failure. According to Pratt & Whitney, the FADEC/EEC is extremely reliable, and very often not the cause of a control system failure.

In the loop resistance check, both the circuit and the shielding (insulation) should be checked for acceptable resistance values. The technician is searching for any open circuits or short circuits that lead to replacement of the defective section. If the continuity check reveals a closed circuit, then there could be an intermittent fault. This practice is similar when checking the wiring harness section and the individual component.

Intermittent faults are most likely due to the wiring harness opening or shorting because of heat and vibration from power plant operation. If an intermittent fault is suspected, a continuity check should be performed while wiggling the wiring harness where possible.

*Maintenance Use of PIMU During Post-Flight Check*

The normal post-flight check the maintenance technicians perform begins with a PIMU interrogation; this is accomplished by pressing the BIT Switch to recall any faults that occurred during the flight and reasons for EICAS messages/engine anomalies. Next, a PIMU ground test is initiated (with the engine not running) to observe which faults are
currently being reported by the FADEC/EEC. If the first line on the PIMU displays "FADEC/EEC-CHA/B CONTROL", the engine may not be dispatched.

To find the cause of an EICAS message or engine anomaly that occurred after touchdown, the maintenance mode is used. After maintenance is actually performed, the technician verifies that the fault is corrected by using the PIMU ground test and the PIMU maintenance mode.

The following spreadsheet shows troubleshooting tips for ECS fault isolation.
The following information has been assembled to assist 767-200, -300 operator and Pratt & Whitney Field Representatives in understanding how to use the PIMU to isolate and correct PW4000 control system problems.

<table>
<thead>
<tr>
<th>PIMU Function</th>
<th>What Used For</th>
<th>Fault Stored In PIMU Non-Volatile Memory?</th>
<th>Requires FADEC/EEC Test Power ON if Engine Not Running</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;PIMU INTERROGATION&quot;</td>
<td>Used after a flight to see what faults were reported by the FADEC/EEC at the moment the aircraft touched down.</td>
<td>YES. Must erase via &quot;RESET&quot; switch after viewing.</td>
<td>NO.</td>
</tr>
<tr>
<td>(PIMU BITE Procedure Blocks 1–3 In Chapter/Section 77–35–00, Figure 103, of 767 Fault Isolation Maintenance Manual)</td>
<td>(All faults which occurred at some point in the flight cycle prior to aircraft touchdown will be found. Any which occurs at some point after last aircraft touchdown will not be found.)</td>
<td>(767 PIMU faults do not erase automatically)</td>
<td></td>
</tr>
<tr>
<td>&quot;PIMU GROUND TEST&quot;</td>
<td>Used to see what faults are currently being reported by the FADEC/EEC.</td>
<td>YES. Must erase via &quot;RESET&quot; switch after viewing.</td>
<td>YES. FADEC/EEC must be powered by engine running OR by Test power.</td>
</tr>
<tr>
<td>(PIMU BITE Procedure Blocks 11,12 in Chapter/Section 77–35–00, Figure 103, of 767 Fault Isolation Maintenance Manual)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;PIMU GROUND TEST&quot;</td>
<td>Used &quot;PIMU GROUND TEST&quot; to verify if maintenance action has corrected a fault. &quot;PIMU GROUND TEST&quot; also appears in Test 6 and Test 7 In Chapter/Section 71–00–00.</td>
<td>YES. Must erase via &quot;RESET&quot; switch after viewing.</td>
<td>YES. FADEC/EEC Test power must be turned off when finished.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(767 PIMU faults do not erase automatically)</td>
<td></td>
</tr>
</tbody>
</table>
### 767-200, -300/PW4000 ENGINE CONTROL SYSTEM FAULT ISOLATION

<table>
<thead>
<tr>
<th>PIMU Function</th>
<th>What Used For?</th>
<th>Fault Stored In PIMU Non-Volatile Memory?</th>
<th>Requires FADEC/EEC Test Power ON if Engine Not Running</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;PIMU MAINTENANCE MODE&quot; (MAINTENANCE RECALL)</td>
<td>Used during troubleshooting to see what faults are stored in the permanent memory of the FADEC/EEC.</td>
<td>NO. These faults are put into volatile memory and will be lost when the PIMU turns off.</td>
<td>YES. Function not available with the engine running.</td>
</tr>
<tr>
<td>Steps specified in EPCS Maintenance Practices in 767 Fault Isolation/Maintenance Manual.</td>
<td>This function is used to see the history of faults which have occurred since last aircraft touchdown.</td>
<td></td>
<td>(FADEC/EEC Test power turned off when finished.)</td>
</tr>
<tr>
<td></td>
<td>This function is used to see what caused an EICAS message which appears during ground running of the engine, since the PIMU will not have recorded anything.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&quot;FL 0&quot; means the fault occurred during the last engine spooldown or during the last engine ground run.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&quot;FL 1, FL 2, etc.&quot; means the fault occurred last flight, two flights ago, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&quot;FL 0&quot; followed by &quot;END&quot; means the memory of that FADEC/EEC Channel has no more faults to view.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NOTE: Channel A and Channel B will probably be reporting different FL numbers.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**EPCS Fault Isolation Procedure**

This EPCS Fault Isolation Procedure is the actual post-flight standard operating procedure for identifying and correcting faults stored in the PIMU. The fault sources include the EICAS display to the pilots, flight crew recordings of EICAS displays in the Flight Log, and routine maintenance interrogations on the PIMU. Maintenance then uses the B767 Fault Isolation Maintenance Manual for corrective action as described above in the "Control System Components Inspection" section. The aircraft may be dispatched once the fault does not get repeated during follow-up interrogations of the PIMU.

**Fuel Hydraulic External Tubes**

The engine's (fuel) hydraulic external tubes should be inspected for nicks, chafing, scratches, and pitting, with any damage being no greater than .002 inch in depth. No dents in the tubes are allowed within .250 inch of the metal material. Tube dents without sharp edges or corners will pass inspection if they permit the free passage of a ball having a diameter of 80 percent of the tube's inner diameter (ID). Rust corrosion and stain are allowed if they're removable by light polishing with crocus cloth. The tubes must be pressure tested at 1500 psi and replaced if there are any leaks.

**Oil System and External Tubes**

No damage in the form of nicks, chafing, scratches, and pitting greater than .003 inch is acceptable. The tubes should be inspected for dents with the same tolerances as the hydraulic external tubes. Again, Maintenance must inspect for corrosion and staining of the tubes. Finally, technicians will pressure test the tubes at 200 psi, replacing the tube if it leaks.

**Fuel System External Tubes**

Damage no deeper than .002 inch is permitted in any location of tube length (including bend areas). The fuel system tubes allow dents of no less than .250 inch from ferrules. Unlike the other external tubes, tube dents must allow free passage of a ball
having a 90 percent diameter of the tube ID. The tubes shall be inspected for rust and
stain and pressure tested to 1500 psi.

*Air System External Tubes*

The air system tubes have the same inspection requirements and tolerances as the
oil system and external tubes.

*Visual Maintenance Checks*

Pratt & Whitney distributes an excellent notebook titled *PW4000/B747-400/B767 Visual Check Prior to Cowl Closing* to airline maintenance departments. The compilation
of maintenance inspections was prepared by Pratt & Whitney's Line Maintenance &
Troubleshooting Department; the notebook has been reprinted in almost its entirety for
this report to guide the reader through the PW4060's inspection and service requirements.
The notebook is self-explanatory.
PW4000/B747-400/B767
VISUAL CHECK PRIOR TO COWL CLOSING

#1
IN RELIABILITY
OUR CONTINUING GOAL

PW4000
PW4000/B767/B747-400
LEFT SIDE VISUAL CHECKS PRIOR TO COWL CLOSING

GENERAL ITEMS:
1. ELECTRICAL CABLES: CHAFING, LOOSE CONNECTIONS, BURNED SPOTS, DETERIORATION
2. TUBES: BREAKS, CHAFING
3. BRACKETS: DEFORMATION, BREAKS
4. DISCOLORATION: INDICATES HOT AIR LEAK
5. CLAMPS: WORN GROMMET MATERIAL, LOoseness, BROKEN BANDS
6. LEAKS: FUEL, OIL
7. VSV ARMS & UNISON RINGS: BENT, LOOSE, FOREIGN OBJECTS

2) OIL PRESSURE TRANSMITTERS
4) OIL FILTER BY-PASS SWITCH
5) MAIN OIL FILTER COVER
7) NO. 3 BEARING SUPPLY LINE
8) OIL SYSTEM SERVICING
10) CHIP DETECTOR (*)
6) MAIN OIL PRESSURE SUPPLY LINE
1) ELECTRICAL CONNECTORS (2.5 BLEED, AIR/OIL HEAT EXCH, PMA)

* ADDITIONAL CHIP DETECTORS LOCATED ON RIGHT SIDE OF ENGINE
PW4000/B76///B747-400
- VISUAL CHECKS PRIOR TO COWL CLOSING -

1) ELECTRICAL CONNECTORS (LEFT SIDE)

Electrical connectors and their backshells have a history of loosening. A simple check of a connector and its backshell can be performed on every component. The following components on the left side of the engine would have the most impact on engine operation if the connector was loose:

1) 2.5 BLEED VALVE ACTUATOR
2) ENGINE AIR/OIL HEAT EXCHANGER VALVE
3) PERMANENT MAGNET ALTERNATOR (PMA)

A visual inspection of the following should be made:

1) CHECK ELECTRICAL CONNECTOR FOR TIGHTNESS.

Note: Connector tightness can be checked as follows: hold the connector backshell and push the connector towards the component while turning the connector nut in the tightening direction.

2) CHECK THE BACKSHELL FOR TIGHTNESS.

Note: Backshell tightness can be checked as follows: hold the rear of the backshell and attempt to move the backshell up and down or side to side directions. The backshell should not feel loose.
CONNECTORelage NUT
CONNECTOR BODY
BACKSHELL COUPLING NUT
SADDLE BARS (STRAIN RELIEF)
BACKSHELL COUPLING NUT
CONNECTOR COUPLING NUT
BACKSHELL
SADDLE BAR
2 REQD.
BACKSHELL STRAIN RELIEF
COUPLING NUT
COUPLING NUT

910805
PW4000/B747-400
- VISUAL CHECKS PRIOR TO COWL CLOSING -

2) OIL PRESSURE TRANSMITTER SWITCH AND TUBING
(OIL PRESSURE TRANSMITTER AND LOW OIL PRESSURE SWITCH)

Broken oil pressure sense tubes have been the cause of (4) IFSD's. Boeing has provided changes to the tubing brackets to solve the problem.

A visual inspection of the following should be made:

1) Check oil pressure sense tubes for cracking.
2) Check tube clamps for wear and/or looseness.
3) Check tubing "B" nuts for evidence of leakage.
4) Check the transmitter housing for leaks.
5) Check the transmitter electrical connector and connector backshell for proper tightness.
6) Check wiring harness for chafing and damage.
3) 2.5 BLEED VALVE ACTUATOR

A FRACTURED 2.5 BLEED ACTUATOR HYDRAULIC SUPPLY LINE HAS CAUSED (1) IFSD. HIGH VIBRATION LEVELS CAUSED THE FRACTURE OF THIS HYDRAULIC SUPPLY LINE.

SB'S 75-45 & 75-52 PROVIDE HYDRAULIC PRESSURE AND RETURN TUBE ASSEMBLIES THAT HAVE GREATER FLEXIBILITY. THESE BULLETINS ADD A NEW BRACKET AND ADDITIONAL CLAMPS WHICH INCREASE DURABILITY BY REDUCING VIBRATORY STRESSES.

CHAFING OF THE INTERNAL WIRING OF THE 2.5 BLEED ACTUATOR HAS CAUSED (1) IFSD. VENDOR (HAMILTON STANDARD) GTA 42-2-75-2 PROVIDES A TEFLOM SLEEVE FOR THE TORQUE MOTOR AND TRANSUDER LEAD WIRES.

NOTE: WHENEVER A 2.5 BLEED MESSAGE IS INTERMITTENT REPLACE THE ACTUATOR. THE INTERMITTENT SETTING OF MESSAGES IS AN INDICATION OF INTERNAL SHORTING.

A VISUAL INSPECTION OF THE FOLLOWING SHOULD BE MADE:

1) FUEL CONNECTIONS AT THE ACTUATOR AND THE TUBES FOR LEAKAGE.
2) CHECK ELECTRICAL CONNECTORS/BACKSHELLS TO THE ACTUATOR FOR TIGHTNESS.
3) CHECK THE 2.5 BLEED LINKAGE FOR PROPER OPERATION BY FEELING FOR 2.5 BLEED RING MOVEMENT THROUGH THE BLEED SLOTS.
PW4000/B787/B747-400
- VISUAL CHECKS PRIOR TO COWL CLOSING -

4) OIL FILTER BY-PASS ELECTRICAL SWITCH

A VISUAL INSPECTION OF THE FOLLOWING SHOULD BE MADE:

1) CHECK THE ELECTRICAL SWITCH CONNECTOR AND CONNECTOR BACKSHELL FOR MOVEMENT.
2) TUBING "B" NUTS FOR EVIDENCE OF LEAKAGE.
3) CHECK THE ELECTRICAL SWITCH HOUSING FOR LEAKS.
Oil filter by-pass switch
5) MAIN OIL FILTER COVER

OIL LEAKAGE FROM THE MAIN OIL FILTER COVER HAS CAUSED (1) IFSD. THE OIL FILTER COVER "0" RING WAS DAMAGED DURING THE INSTALLATION OF THE COVER. SB 79-35 PROVIDES FOR A SMALLER DIAMETER "0" RING THAT IS LESS SUSCEPTIBLE TO DAMAGE DURING COVER INSTALLATION.

A VISUAL INSPECTION OF THE FOLLOWING SHOULD BE MADE:

1) THE MAIN OIL FILTER COVER FOR LEAKS.
6) MAIN OIL PRESSURE SUPPLY LINE

Chafing of the main oil pressure supply line has caused (4) IFSD's. SB 79-36 was issued to install "snap-on" wear sleeves to prevent chafing caused by the clamps.

A visual inspection of the following should be made:

1) Check condition of the clamps and for the presence of wear sleeves at the required location.

2) Check for signs of clamp motion.
   Note: A fine, light red powder in the clamp area indicates clamp motion.

3) Check for leakage.
Main oil pressure supply line
7) NO. 3 BEARING SUPPLY LINE

A CRACK IN THE NO. 3 BEARING OIL SUPPLY LINE HAS CAUSED (4) IFSD'S. REDESIGN OF THE SUPPLY LINE AND ITS CLAMPING CONFIGURATION IS BEING INCORPORATED.

A VISUAL INSPECTION OF THE FOLLOWING SHOULD BE MADE:

1) CHECK THE SUPPLY LINE FOR LEAKAGE.
2) CHECK THE SUPPLY LINE TUBING CLAMPS FOR SECURITY AND PROPER INSTALLATION.
3) CHECK THE SUPPLY LINE FITTING ON THE FUEL OIL COOLER FOR CRACKS, LEAKAGE.
HIGH OIL TEMPERATURE DUE TO OIL SYSTEM OVER-SERVICING HAS BEEN THE CAUSE OF (1) IFSD. SERVICING THE OIL TANK TO THE TOP OF THE FILLER NECK RAISES THE OIL ABOVE THE TRIM HOLE AND CAUSES A REVERSE FLOW OF THE OIL FROM THE TANK, THROUGH THE OIL PRESSURE TRIM LINE, AND INTO THE MAIN GEARBOX AFTER ENGINE SHUTDOWN.

ALERT-SB A79-39 PROVIDES PW4000 OIL TANK SERVICING PROCEDURES TO REDUCE THE POSSIBILITY OF OVER-SERVICING.

SB 79-47 REMOVES THE REMOTE FILL OPTION BECAUSE CRACKS WERE OCCURRING IN THE WELD JOINING THE OIL FILLER NECK TO THE OIL TANK.


A VISUAL CHECK OF THE FOLLOWING SHOULD BE MADE:

* FOR ENGINES AFTER PW SB 79-43 AND 79-47:
  THE OIL SHOULD BE TO THE TOP OF THE FILLER NECK. SEE FIG. 1.

* FOR ENGINES BEFORE PW SB 79-43 AND 79-47:
  RIGHT HAND ENGINES SHOULD HAVE OIL TO THE TOP OF THE FILLER NECK. SEE FIG. 1.
  LEFT HAND ENGINES SHOULD HAVE OIL TO THE FLAPPER VALVE. SEE FIG. 1.

NOTE: MEASURE THE OIL LEVEL BETWEEN (5) MINUTES AND (2) HOURS AFTER ENGINE SHUTDOWN. IF THE (2) HOURS HAS PASSED, DRY MOTOR THE ENGINE UNTIL THE OIL PRESSURE STABILIZES.

NOTE: IF THE OIL IS COLD IT SHOULD BE JUST BELOW THE FLAPPER VALVE. SERVICING TO THIS LEVEL WITH COLD OIL WILL AVOID OVER-SERVICING.
FIGURE 1. ENGINE OIL SERVICING

OIL TANK CAP

HANDLE IN THE LOCKED POSITION

PRESSURE FILL OUTLET

PRESSURE FILL INLET

DUST COVER (2 LOCATIONS)

OIL TANK CAP

ENGINE BEFORE PW SB 79-43 AND 79-47

SCUPPER DRAIN

FWD

OIL TANK

ENGINE AFTER PW SB 79-43 AND 79-47

OIL LEVEL GAGE

SCUPPER DRAIN

MAXIMUM FILL LEVEL ON THE LEFT ENGINE
(ENGINES WITHOUT PW SB 79-43 AND PW SB 79-47)

MAXIMUM FILL LEVEL ON THE RIGHT ENGINE
(ENGINES WITHOUT PW SB 79-63 AND PW SB 79-47)

MAXIMUM FILL LEVEL ON THE TWO ENGINES
(ENGINES WITH PW SB 79-43 AND PW SB 79-47)
PW4000/B767/B747-400
RIGHT SIDE VISUAL CHECKS PRIOR TO COWL CLOSING

GENERAL ITEMS:
1. ELECTRICAL CABLES: CHAFING, LOOSE CONNECTIONS, BURNED SPOTS, DETERIORATION
2. TUBES: BREAKS, CHAFING
3. BRACKETS: DEFORMATION, BREAKS
4. DISCOLORATION: INDICATES HOT AIR LEAK
5. CLAMPS: WORN GROMMET MATERIAL, LOOSENESS, BROKEN BANDS
6. LEAKS: FUEL, OIL
7. VSV ARMS & UNISON RINGS: BENT, LOOSE, FOREIGN OBJECTS

12) ELECTRICAL CONNECTORS (FMU, SVA, IDG AIR/OIL COOLER, EEC)

9) NO. 4 BEARING SCAVANGE TUBE

10) CHIP DETECTORS(*)

11) FUEL FILTER

13) STATOR VANE ACTUATOR

* (1) ADDITIONAL CHIP DETECTOR LOCATED ON LEFT SIDE OF ENGINE
PW4000/B767/B747-400

- VISUAL CHECKS PRIOR TO COWL CLOSING -

9) NO. 4 BEARING SCAVENGE TUBE

A FRACTURED NO. 4 BEARING OIL SCAVENGE TUBE HAS CAUSED (1) IFSD. SB 79-46 WAS ISSUED TO PROVIDE BETTER SUPPORT FOR THE #4 SCAVENGE TUBE BY IMPROVED CLAMPING.

A VISUAL INSPECTION OF THE FOLLOWING SHOULD BE MADE:

1) CHECK TUBE FOR LEAKAGE.
2) CHECK TUBE CLAMPS FOR SECURITY AND PROPER INSTALLATION.
PW4000/B767/B747-400
- VISUAL CHECKS PRIOR TO COWL CLOSING -

10) CHIP DETECTORS:

A CHIP DETECTOR FALLING OUT OF ITS HOUSING BECAUSE OF IMPROPER INSTALLATION IS COMMON AND
COULD CAUSE OIL LEAKAGE AND POSSIBLE IFSD.

A VISUAL CHECK OF THE FOLLOWING SHOULD BE MADE:

1) CHECK FOR LEAKAGE.
2) CHECK FOR PROPER INSTALLATION.

NOTE: TWIST EACH CHIP DETECTOR CLOCKWISE TO INSURE PROPER LOCKING. PULL ON EACH
DETECTOR.

THERE ARE (6) CHIP DETECTORS:

** 1) MASTER   2) MAIN GEARBOX   3) ANGLE GEARBOX
4) NO. 1, 1.5 AND 2 BEARING   5) NO. 3 BEARING   6) NO. 4 BEARING

** MASTER CHIP DETECTOR IS ON THE OIL TANK (LEFT SIDE OF ENGINE).
No. 3 bearing chip detector

Angle gearbox chip detector

No. 4 bearing chip detector

No. 1, 1.5 & 2 bearing chip detector
CLEAN CHIP DETECTOR HOUSING

PACKING

MAGNETIC CHIP DETECTOR PROBE

PORT (REF)

PERMITTED

NOT PERMITTED

CLEAN

USUAL QUANTITY OF METAL

SMALL QUANTITY OF METAL

LARGE QUANTITY OF METAL

J43142-47
910805
PW4000/B767/B747-400
- VISUAL CHECKS PRIOR TO COWL CLOSING -

12) ELECTRICAL CONNECTORS (RIGHT SIDE)

ELECTRICAL CONNECTORS AND THEIR BACKSHELLS HAVE A HISTORY OF LOOSENING. A SIMPLE CHECK OF A CONNECTOR AND ITS BACKSHELL CAN BE PERFORMED ON EVERY COMPONENT. THE FOLLOWING ARE COMPONENTS ON THE RIGHT SIDE OF THE ENGINE THAT WOULD HAVE THE MOST IMPACT ON ENGINE OPERATION IF THE CONNECTOR WAS LOOSE:

1) FUEL METERING UNIT (FMU)
2) STATOR VANE ACTUATOR (SVA)
3) INTEGRATED DRIVE GENERATOR (IDG) AIR/OIL COOLER
4) ELECTRONIC ENGINE CONTROL (EEC)

A VISUAL INSPECTION OF THE FOLLOWING SHOULD BE MADE:

1) CHECK ELECTRICAL CONNECTOR FOR TIGHTNESS.

2) CHECK THE BACKSHELL FOR TIGHTNESS.
   NOTE: BACKSHELL TIGHTNESS CAN BE CHECKED AS FOLLOWS: HOLD THE REAR OF THE BACKSHELL AND ATTEMPT TO MOVE THE BACKSHELL IN THE UP AND DOWN OR SIDE TO SIDE DIRECTIONS. THE BACKSHELL SHOULD NOT FEEL LOOSE.
EEC connectors
PW4000/B767/B747-400
- VISUAL CHECKS PRIOR TO COWL CLOSING -

13) STATOR VANE ACTUATOR

CHAFFING OF THE INTERNAL WIRING OF THE STATOR VANE ACTUATOR HAS CAUSED (1) IFSD. VENDOR (HAMILTON STANDARD) GTA 41-1-75-2 PROVIDES FOR IMPROVED WIRE MANAGEMENT AND FIELD INSPECTION OF TORQUE MOTOR WIRES.

NOTE: WHENEVER A STATOR VANE ACTUATOR MESSAGE IS INTERMITTENT, REPLACE THE ACTUATOR. THE INTERMITTENT SETTING OF MESSAGES IS AN INDICATION OF INTERNAL WIRE SHORTING.

A VISUAL INSPECTION OF THE FOLLOWING SHOULD BE MADE:

1) FUEL CONNECTIONS AT THE ACTUATOR AND THE TUBES FOR LEAKAGE.
2) CHECK ELECTRICAL CONNECTORS/BACKSHELLS AT THE ACTUATOR FOR TIGHTNESS.
Pilot's Preflight Inspection

The F/O performs the preflight walk-around of the 767-300—I learned during the internship that this is known as the "walk-about" in Australia. The figure below shows the first officer's recommended sequence for the exterior inspection. The two engines are visually inspected by the crewmember of the following items. The F/O is instructed to check for proper position of items, damage, fluid leakage, and security of access panels.

- Engine Cowling and Fasteners
- Fuel Control Temperature Probe
- EEC Probe
- Forward Fan Blades
- Blocker Doors
- Tail Cone

- Reverser
- Engine Cowl Lip
- Acoustical Material
- Spinner
- Aft Fan Blades

![Engine Inspection Diagram]
Also important to note during ground operations is the engine hazard area for the PW4060 shown below. The diagram below illustrates the dimensions of the hazard area during takeoff and minimum idle power. I have actually seen a truck be overturned by passing behind a taxiing 757 powered by PW2037 engines!
Pilots' Cruise Report

The pilot-not-flying (PNF) will send engine performance data via the ACARS system as well as record it via the Pilot's EICAS Control Panel if an irregularity occurs. The crewmember will also send and record the data if requested to do so by the San Francisco Maintenance Center, very commonly referred to as "SAMC". If either engine vibration indicates more than 2.5, the PNF must make an entry in the aircraft's Flight Log. If oil consumption on an engine is excessive, or more than one quart per hour, during flight, there should also be an entry made in the Flight Log. The APU Hours Utilization Report is also sent to SAMC via the ACARS system during cruise.
Aircraft Performance

The following is a detailed discussion on performance characteristics of commercial air transports. Since most of my operational experience during the internship was with the Boeing 767-322 and 777-222 aircraft at United Airlines, the majority of the examples come from line operations of these airliners. The majority of my flights as observer-member-of-the-crew (OMC) and as a passenger were in the 767 and 777.

To begin the discussion, several ideas must be communicated about United Airlines' training regarding performance. Each flight officer, when he initially enters the Denver Flight Training Center, receives the Standard Performance Reference Handbook from the coordinator of Airplane Performance Programs. This handbook gives a foundation of knowledge for every pilot to use throughout his career, as United has standardized the system of defining, calculating, and using performance data for its entire fleet. The following is background information to make the specific flow-charts more comprehensible.

"V" Speeds and Other Reference Speeds

The following speeds are used to calculate runway length requirements and are applicable to daily line operations.

- \( V_{mcg} \): The lowest speed that airplane directional control may be maintained on the ground after failure of an engine without the pilot using brakes or nosewheel steering. \( V_{mcg} \) is the minimum speed for control surface effectiveness on the ground. In calculating this speed, the remaining engine is operating at maximum thrust and the takeoff is continued.

- \( V_{mca} \): The lowest speed that directional control may be maintained in the air after failure of an engine. This speed is determined with a five degree bank toward the operating engine, the operating engine is at maximum thrust, and the takeoff is continued.

- \( V_{mbe} \): Velocity, Maximum Brake Energy. This is the highest speed the brakes can absorb the energy required to stop the airplane at a specified weight. When determining this velocity at certain weights, the brakes are heated up by taxiing and
stopping frequently, and then are applied fully from the proposed $V_{mbe}$ value. The brakes are allowed to catch fire during this testing, but the fire must be contained in the wheel area for at least five minutes.

- **$V_1$ minimum**: This is the minimum control speed on the ground, or $V_{mco}$. $V_1$ is always less than $V_{mbe}$. $V_1$ is also very crucial to understanding the takeoff roll in a United Airlines transport. Operationally, it is determined with the assumption that the aircraft accelerates with all engines operating from a standing start to the point where an engine fails. With the airplane continuing to accelerate, the crew recognizes one engine is inoperative at $V_1$. If the crew elects to continue the takeoff, the airplane can continue to $V_2$ at 35 feet above the end of the runway, with only aerodynamic controls and "average" piloting skills. If not, maximum braking is applied at $V_1$, throttles are brought to idle, and spoilers are deployed. Reverse thrust is not taken into account for the $V_1$ determination. Most important to the flight crew, $V_1$ is the "brakes-on" speed, not the decision speed. The captain must decide to abort, and the abort must be initiated, at or below $V_1$ for adequate runway stopping distance.

- **$V_r$ minimum**: This is 1.05 $V_{mca}$. Rotation to the normal takeoff attitude must begin at Rotation Speed to reach $V_2$ by 35 feet with one engine inoperative. This value accounts for a normal rate of rotation, as well as an adequate margin above the minimum unstick speed and $V_{mca}$.

- **$V_2$ minimum**: This is 1.10 $V_{mca}$. It is also known as the "Takeoff Safety Speed." At this speed, the aircraft may be flown at the minimum climb gradient required with an inoperative engine.

- **$V_{mu}$**: Minimum Unstick Speed. This is the lowest speed the airplane can lift off, keeping the control yoke full aft from the beginning of the takeoff roll. This speed helps determine $V_r$.

- **Tire Limit Speed**: It is the maximum speed of the tire as certified by the tire manufacturer. This speed is based on ground speed, and thus may be exceeded in hot and high conditions. United’s takeoff runway limit weights prevent a heavy condition from causing exceedence of the tire limit speed. An interesting note on this speed learned during the internship is that the tire limit speed is actually the one limiting factor for long-haul international operations from Denver International Airport. No matter how long the runways are constructed, a 747-400, for example, would not be able to takeoff safely from Denver because of dangerous tire conditions. Yet, the DOT still insists on spending money, amidst opposition from United, to construct a 16,000 foot runway at DIA!
- **VLO/VLE:** Landing Gear Limit Speeds. VLO gives the speed for maximum operation of the landing gear (extension and retraction), whereas VLE is the maximum aircraft speed while the gear is extended.

- **Rough Airspeed:** Turbulent Air Penetration Airspeed. Above this speed, full or abrupt movement of the controls during maneuvers or turbulent conditions results in an overloaded wing condition. The 767 has two rough airspeed values depending on the aircraft's altitude.

- **VFE:** Maximum Flaps Extended Speed. This speed varies depending on the given flap setting.

- **Flap Retraction Speed:** As depicted on the aircraft's performance Takeoff and Landing Data Card, the flap retraction speeds are minimum speeds that optimize engine-out acceleration by minimizing drag, maintain adequate stall margins, minimize the distance required to accelerate to climb speed, protect against flap asymmetry during retraction, and assure FAR-required climb performance.

- **Vx/Vy:** Best Angle of Climb Speed/Best Rate of Climb Speed.

- **Optimum Climb Speed:** The speed that gives best overall fuel economy. It takes the following factors into account: arriving at cruising altitude as quickly as possible; lowest possible fuel consumption; and best angle of climb speed in order to travel the farthest distance over the ground. The flight management computers on the 767 and 777 automatically calculate this speed.

- **LRC Speed:** Long Range Cruise Speed. This speed provides approximately the greatest no-wind specific range, or distance in nautical miles per 1000 pounds of fuel burned. It is used instead of the maximum range cruise speed because the LRC speed is much more stable to maintain.

- **ECON Climb/Cruise/Descent Speed:** Based on cost index (CI), they are the best speeds for minimizing total operating costs. ECON climb is based on a CI derived from block hour operating cost, maintenance costs, and hourly crew costs; these are all known as time costs. ECON cruise is based on CI, weight, altitude, and wind. ECON descent is simply based on CI. At a CI of zero, ECON is approximately optimum climb speed or cruise maximum range speed. As time costs increase, the CI increases and ECON speeds increases.

- **Maneuvering/REF:** Minimum Maneuvering Speed and Landing Reference Speed. Also depicted on the aircraft Data-or Flip-Card, these speeds are minimum operating speeds at the specified flap configuration. The "VREF" speeds maintain an adequate buffet margin for an inadvertent bank angle of up to 40 degrees.
• **Target Speed:** Speed at which approach should be flown. This is $V_{REF}$ plus one-half the steady-state headwind component plus the full gust component. A maximum correction of 20 knots is allowed to find the target speed. Also, target speed must always be at least $V_{REF}$ plus five.

• **Threshold Speed:** Speed at which airplane should cross the runway threshold. This is $V_{REF}$ plus the full gust component up to a maximum 20 knots of gust correction.

Important Aircraft Weights

The following is a description of important weight figures during the takeoff, cruise, and approach/landing phases of flight.

**Takeoff**

• **Allowable Takeoff Gross Weight (ATOG):** The lowest value of structural limit weight, runway limit weight, performance limit weight, and landing limited takeoff weight.

• **Structural Limit Weight:** The weight that ensures that the aircraft meets maximum in-flight weight restrictions and is the lower weight of certified maximum takeoff weight or maximum taxi weight minus the planned taxi fuel.

• **Runway Limit Weight:** The most restrictive of FAR field length limit weight, obstacle clearance limit weight, brake energy limit weight, and tire speed limit weight.

  The **FAR field length limit weight** is determined by the longest of the all-engine-takeoff field length, accelerate-go distance, and the accelerate-stop distance; these distance will be discussed later. The **obstacle clearance limit weight** is the maximum at which the airplane is able to clear all obstacles in the takeoff path. The **brake energy limit weight** is the limit at which the airplane can be stopped from $V_1$ and not exceed the allowable brake energy. The **tire speed limit weight** prevents the airplane from exceeding tire limit speed at the liftoff speed.

• **Performance Limit Weight:** At or below this limit, the airplane can maintain the minimum FAR-mandated climb gradient depending on the number of engines on the aircraft.

• **Landing Limited Takeoff Weight:** The maximum landing weight allowed at the destination plus the planned trip fuel burn.

Runway Distances
The longest of the following field lengths determines the FAA-regulated field length limit weight: all-engine-takeoff field length, accelerate-go distance, and the accelerate-stop distance. The all-engine-takeoff field length (shown below) is 115% of the all-engine-takeoff distance, or the total distance required to accelerate with all engines, rotate at \(V_r\), and reach 35 feet AGL with at least a speed of \(V_2\). The accelerate-go distance is the total needed to accelerate from a standing start to \(V_1\), recognize the critical engine failure at \(V_1\), continue the takeoff, and reach \(V_2\) at 35 feet AGL using only aerodynamic controls and average piloting skills. Finally, the accelerate-stop distance is the total required to accelerate from a standing start to \(V_1\), recognize the critical engine failure at \(V_1\), abort the takeoff, and reach a full stop using brakes, spoilers and idle thrust.

United Airlines utilizes the balanced field length concept to determine takeoff performance, in which the accelerate-stop distance is equal to the accelerate-go distance. A specific \(V_1\) speed for a given weight and density altitude will determine the minimum runway length required for takeoff. Decreasing the \(V_1\) below this benchmark will decrease the accelerate-stop distance, but increase the accelerate-go distance. The opposite is true if the \(V_1\) is increased. Thus, the \(V_1\) found in the aircraft flip cards is this benchmark or "Balanced \(V_1\)."

Since most takeoffs occur with excess runway and/or climb performance available because the aircraft weight is less than runway or performance limit weight, crews may
use this excess margin to compensate for inoperative equipment and runway conditions, or use it for reduced thrust capability.

The figure below illustrates the balanced field length concept. Balanced field length is also described in the graph on the following page.

**BALANCED FIELD LENGTH**

A balanced field condition exists when Accelerate–Stop Distance equals Accelerate–Go Distance. This is determined by selection of V1 speed. For a given set of ambient conditions and airplane weight, only one V1 speed would cause these distances to be equal. The associated runway length is called the “Balanced Field Length,” and is the minimum runway length required for takeoff. Selecting a lower V1 decreases Accelerate–Stop Distance, but increases Accelerate–Go Distance. Conversely, selecting a higher V1 decreases Accelerate–Go Distance, but increases Accelerate–Stop Distance. Either increases required Takeoff Field Length. (See V1 – ADDITIONAL INTERESTING FACTS, page 14.)
The figure below illustrates Balanced Field Length in another way. It is readily apparent that increasing and decreasing V1 from the Balanced V1 increases runway required.

**BALANCED FIELD LENGTH**

- All engine operating acceleration distance to V1
- One engine inoperative acceleration distance from V1 to V2 at 35°
- Distance to stop from V1

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Speed Limitations

To begin the discussion of 767-300 performance, the following two pages are used to depict the speed limitations of the aircraft. \( V_A \), \( V_{FE} \), \( V_{m cg} \), landing gear limit speeds, maximum operating limit speeds and other operating speeds are all listed for different variables.
### SPEEDS

When both an airspeed and a Mach number are shown as a limit or a specification, use whichever is slower for the particular flight condition.

#### DESIGN MANEUVERING SPEEDS - \( V_A \) (KIAS/Mach)

<table>
<thead>
<tr>
<th>Pressure Altitude (Feet)</th>
<th>10,000</th>
<th>20,000</th>
<th>29,000</th>
<th>30,000</th>
<th>34,000</th>
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<tr>
<td>757</td>
<td>280</td>
<td>283</td>
<td>286</td>
<td>294</td>
<td>295</td>
<td>302/.86</td>
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<tr>
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<td>263</td>
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<td>278</td>
<td>279</td>
<td>285</td>
</tr>
<tr>
<td>767-300</td>
<td>302</td>
<td>315</td>
<td>327</td>
<td>336/.86</td>
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#### FLAPS EXTENDED SPEEDS (MAXIMUM) - \( V_{FE} \) (KIAS)

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<tr>
<th>Flaps</th>
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<th>5</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
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<tr>
<td>757, 767-200</td>
<td>240</td>
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<td>210</td>
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<td>250</td>
<td>230</td>
<td>210</td>
<td>210</td>
<td>180</td>
<td>170</td>
</tr>
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</table>

#### LANDING GEAR LIMIT SPEEDS - \( V_{LO}/V_{LE} \) (KIAS/Mach)

<table>
<thead>
<tr>
<th>Retraction (( V_{LO} ))</th>
<th>Normal System</th>
<th>Alternate System</th>
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</thead>
<tbody>
<tr>
<td>Extension (( V_{LE} ))</td>
<td>270</td>
<td>-</td>
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<tr>
<td></td>
<td>270/.82</td>
<td>250/.75</td>
</tr>
</tbody>
</table>

Maximum Tire Speed 196 Knots Ground Speed

#### MAXIMUM OPERATING LIMIT SPEEDS - \( V_{MO}/M_{MO} \) (KIAS/Mach)

The maximum operating limit speed (\( V_{MO} \) pointer/overspeed warning) shall not be deliberately exceeded in any phase of flight.

<table>
<thead>
<tr>
<th>Pressure Altitude (Feet)</th>
<th>20,000 &amp; Below</th>
<th>26,000</th>
<th>27,500</th>
<th>30,000</th>
<th>35,000</th>
<th>42,000</th>
<th>43,000</th>
</tr>
</thead>
</table>

### MINIMUM CONTROL SPEED GROUND - \( V_{MCG} \) (KIAS)

United refers to \( V_{MCG} \) as \( V \): Minimum (\( V \): & \( V \): Minimum, \( 767-200 \)).

#### 757

<table>
<thead>
<tr>
<th>Pressure Altitude (Feet)</th>
<th>Up To 50 (10)</th>
<th>60 (15)</th>
<th>70 (21)</th>
<th>80 (27)</th>
<th>90 (32)</th>
<th>100 (39)</th>
<th>110 (43)</th>
<th>120 (49)</th>
<th>130 (54)</th>
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#### 767-200

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<th>60 (15)</th>
<th>70 (21)</th>
<th>80 (27)</th>
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<th>100 (39)</th>
<th>110 (43)</th>
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#### 767-300

<table>
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<th>60 (15)</th>
<th>70 (21)</th>
<th>80 (27)</th>
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<td>107</td>
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### Operating Speeds (KIAS/Mach) (UA Limit)

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<th></th>
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<th>767-300</th>
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<tr>
<td>Standard Climb (FMC Operative) 10,000 feet and above</td>
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<tr>
<td>Standard Climb (FMC Inoperative) 10,000 feet and above</td>
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<td></td>
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<tr>
<td>Best Climb Rate 400.0</td>
<td>304/78</td>
<td></td>
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</tr>
<tr>
<td>360.0</td>
<td>298/78</td>
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<tr>
<td>320.0</td>
<td>292/78</td>
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<td>360.0</td>
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<td>202/76</td>
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<td>160.0</td>
<td>201/76</td>
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<tr>
<td>Turbulent Air 15,000 feet &amp; above</td>
<td>290/78</td>
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</tr>
<tr>
<td>Below 15,000 feet</td>
<td>250</td>
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</tr>
<tr>
<td>Standard Cruise (FMC Operative) 10,000 feet and above</td>
<td>330/81</td>
<td>ECON</td>
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<tr>
<td>Standard Cruise (FMC Inoperative) 10,000 feet and above</td>
<td>330/81</td>
<td>300/80</td>
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<tr>
<td>Standard Descent (FMC Operative) 10,000 feet and above</td>
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<tr>
<td>Standard Descent (FMC Inop) 10,000 feet and above</td>
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</table>

### Stall Speeds (KIAS)

The stall speeds listed are applicable to takeoff and landing altitudes only.

#### 757

<table>
<thead>
<tr>
<th>Flap Pos</th>
<th>Gear Pos</th>
<th>Gross Weight (1000 Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>150.0</td>
</tr>
<tr>
<td>0</td>
<td>UP</td>
<td>129</td>
</tr>
<tr>
<td>1</td>
<td>UP</td>
<td>108</td>
</tr>
<tr>
<td>5</td>
<td>UP</td>
<td>102</td>
</tr>
<tr>
<td>15</td>
<td>UP</td>
<td>97</td>
</tr>
<tr>
<td>20</td>
<td>UP</td>
<td>94</td>
</tr>
<tr>
<td>25</td>
<td>DN</td>
<td>89</td>
</tr>
<tr>
<td>30</td>
<td>DN</td>
<td>87</td>
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</tbody>
</table>

#### 767-200

<table>
<thead>
<tr>
<th>Flap Pos</th>
<th>Gear Pos</th>
<th>Gross Weight (1000 Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>200.0</td>
</tr>
<tr>
<td>0</td>
<td>UP</td>
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<td>102</td>
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<tr>
<td>5</td>
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<td>98</td>
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<tr>
<td>15</td>
<td>UP</td>
<td>93</td>
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<td>20</td>
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<td>DN</td>
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</tr>
<tr>
<td>30</td>
<td>DN</td>
<td>90</td>
</tr>
</tbody>
</table>

#### 767-300

<table>
<thead>
<tr>
<th>Flap Pos</th>
<th>Gear Pos</th>
<th>Gross Weight (1000 Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>220.0</td>
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<tr>
<td>0</td>
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<td>137</td>
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<tr>
<td>1</td>
<td>UP</td>
<td>113</td>
</tr>
<tr>
<td>5</td>
<td>UP</td>
<td>104</td>
</tr>
<tr>
<td>15</td>
<td>UP</td>
<td>102</td>
</tr>
<tr>
<td>20</td>
<td>UP</td>
<td>99</td>
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<tr>
<td>25</td>
<td>DN</td>
<td>97</td>
</tr>
<tr>
<td>30</td>
<td>DN</td>
<td>97</td>
</tr>
</tbody>
</table>

9519  757/767 FLIGHT MANUAL OPERATIONS  JUL 4/95

9519  757/767 FLIGHT MANUAL OPERATIONS  JUL 4/95
Determining Takeoff Performance

Allowable Takeoff Gross Weight

The crew receives the ASMD ATOG and ATOG on the "Planned Takeoff Data Message" and the final weights on the ACARS during taxi. The "Temperature Variances" table (shown below) depicts the factors in deciding the thrust setting when the actual temperature at departure differs from the forecast temperature.

**TEMPERATURE VARIANCES**

The following table indicates thrust options for an individual runway/flap combination when the actual temperature at departure differs from the forecast temperature. "If none of the runway/flap combinations provide acceptable takeoff weights, contact Dispatch or obtain a new EPR/ATOG message.

| IF THE ACTUAL WEIGHT IS: | IF THE ACTUAL TEMPERATURE IS: |  
|-------------------------|--------------------------------|---
| Less than or equal to ASMD ATOG | Less than or equal to forecast | Reduced EPR may be used  
| Greater than ASMD ATOG but less than or equal to RWY and PERF ATOGs | 1 to 10°F greater than forecast | If actual temperature is below assumed temperature, takeoff may be made at weights up to the ASMD ATOG with maximum or reduced EPR.  
| Greater than RWY or PERF ATOG | More than 10°F greater than forecast | Obtain new takeoff data via Company Comm or, if a Special OGW page exists for the runway or, telemeter weight information is available, the runway/performance limits weights may be determined by computing the weight corresponding to the current OAT or, contact Dispatch.  

* If the actual temperature is 1 to 10°F greater than forecast, it is permissible to interpolate between lines 21 and 22 to determine RWY and PERF ATOGs. If interpolation is not desired, compare the weights in lines 21 and 22, and use the lower as the applicable ATOG.

**NOTE**

When the actual altimeter differs from the forecast altimeter by more than .15"Hg or 5 mb, obtain a new EPR/ATOG message for the actual altimeter setting. If obtaining a new message is not feasible, weight
The following is a set of variables used on a 767-300 flight from Chicago-O'Hare to Miami International. These values reflect a typical flight between the two cities. Flow charts will be used to determine whether the actual takeoff weight is less than the allowable takeoff gross weight for both maximum thrust and reduced thrust takeoffs.

**Chicago-O'Hare International Airport**

- Altimeter: 29.85
- Field Elevation: 668
- FLAPS: 5
- ASMD ATOG: 345.0
- LB/KT HW: 500

**Miami International Airport**

- Pressure Alt: Sea Level
- FLAPS: 30

Note: All weights are in thousands of pounds, except the HW/TW corrections. The runway and performance limit weights are given for 77°F(25°C). Since the airport data was taken 40 minutes from departure, the data is extremely accurate. The temperature, altimeter, and winds have not changed at "wheels-off", or the beginning of the takeoff roll. The takeoff will be performed with the packs off for less weight restriction. All equipment is operating properly, and the runway is dry.
### ALLOWABLE TAKEOFF GROSS WEIGHT (767-300)

Follow this flow chart to determine the ALLOWABLE TAKEOFF GROSS WEIGHT (ATOG) using the indicated procedures. Specific weight data for each procedure is obtained from the planned takeoff data message, ACARS, Flight Manual, bulletins, or telemeters. Data is based on normal engine bleed and pack configuration (engine bleeds on, packs on) unless otherwise indicated. All Runway Limit Weights are based on full runway length including lineup distance unless a note allows less and identifies a taxiway intersection, displaced threshold or other point where the takeoff may be started. Except where a specific procedure is provided, MEL and CDL weight reductions must be applied to the associated weight limits. Corrections for tailwind and altimeter settings lower than that used in determining the weight data are mandatory. Corrections for headwind and altimeter settings higher than that used in determining the weight data are optional. If actual weight exceeds ATOG select an alternate flap position or runway and repeat the process.

<table>
<thead>
<tr>
<th>STRUCTURAL LIMIT WEIGHT</th>
<th>PERFORMANCE LIMIT WEIGHT</th>
<th>RUNWAY LIMIT WEIGHT</th>
<th>ALLOWABLE LANDING WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>407.0</td>
<td>413.1</td>
<td>409.6</td>
<td>320.0</td>
</tr>
</tbody>
</table>

Planned Fuel Burn

Use Lowest

**ALLOWABLE TAKEOFF GROSS WEIGHT**

### ADJUSTED PERFORMANCE LIMIT WEIGHT (767-300)

**Performance Limit Weight Altimeter Vs Actual Altimeter Correction (1000 lbs)**

<table>
<thead>
<tr>
<th>Altimeter Diff (mb)</th>
<th>-5</th>
<th>-3</th>
<th>-2</th>
<th>+2</th>
<th>+3</th>
<th>+4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correction</td>
<td>-2.4</td>
<td>-1.6</td>
<td>-0.8</td>
<td>+0.8</td>
<td>+1.2</td>
<td>+1.8</td>
</tr>
</tbody>
</table>

**Packs Off Correction (1000 lbs)**

(Do not apply if limit weight entered above was obtained from PACKS OFF EPR/ATOG data)

+3.1

**ADJUSTED PERFORMANCE LIMIT WEIGHT**

(Use in ATOG computation)
ADJUSTED RUNWAY LIMIT WEIGHT
(767-300)

Takeoff Restrictions
- All wheel brakes operative
- Antiskid system must be operative
- No clutter on operational portion of runway

Step 1 of 1

**RUNWAY LIMIT WEIGHT**

Wind Correction
(+30/-10 kts max)

**SUBTOTAL**

**Runway Limit Weight Altimeter Vs Actual Altimeter Correction (1000 lbs)**

<table>
<thead>
<tr>
<th>Altimeter Diff (mb)</th>
<th>-5</th>
<th>-3</th>
<th>-2</th>
<th>+2</th>
<th>+3</th>
<th>+5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altimeter Diff (Hg)</td>
<td>-0.15</td>
<td>-0.10</td>
<td>-0.05</td>
<td>+0.05</td>
<td>+0.10</td>
<td>+0.15</td>
</tr>
<tr>
<td>Correction</td>
<td>-2.1</td>
<td>-1.4</td>
<td>-0.7</td>
<td>+0.4</td>
<td>+0.8</td>
<td>+1.2</td>
</tr>
</tbody>
</table>

**SUBTOTAL**

**Packs Off Correction (1000 lbs)**
(Do not apply if limit weight entered above was obtained from PACKS OFF EPR/ATOG data)

+ 1.1

**SUBTOTAL**

**ADJUSTED RUNWAY LIMIT WEIGHT**
(Use in ATOG computation)
**ADJUSTED ALLOWABLE LANDING WEIGHT**

*(767-300)*

**Step 1 of 1**

**Landing Restrictions**
- Antiskid system must be operative
- All wheel brakes operative

**PERFORMANCE LIMIT WEIGHTS**

*(767-300)*

**FLAPS 30**

Condition:
Values valid for engine anti-ice on or off.

<table>
<thead>
<tr>
<th>OAT °F/°C</th>
<th>Station Pressure Altitude (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120/49</td>
<td>366.7 365.5 354.3 341.6 NA NA NA NA</td>
</tr>
<tr>
<td>115/46</td>
<td>379.2 372.7 366.1 353.0 339.9 326.8 NA NA NA</td>
</tr>
<tr>
<td>110/43</td>
<td>391.6 384.6 377.8 364.2 350.9 337.7 324.8 NA NA</td>
</tr>
<tr>
<td>105/41</td>
<td>400.0 396.2 389.0 375.0 361.3 348.0 335.0 322.4 NA</td>
</tr>
<tr>
<td>100/38</td>
<td>400.0 399.7 385.2 371.1 375.4 344.2 331.5 313.2 307.3</td>
</tr>
<tr>
<td>95/35</td>
<td>400.0 400.0 394.5 380.0 366.1 352.5 339.5 320.8 314.8</td>
</tr>
<tr>
<td>90/32</td>
<td>400.0 400.0 400.0 388.0 373.7 359.8 346.5 327.3 321.2</td>
</tr>
<tr>
<td>85/29</td>
<td>400.0 400.0 400.0 394.9 380.3 366.1 352.4 328.2 326.5</td>
</tr>
<tr>
<td>80/27</td>
<td>400.0 400.0 400.0 399.1 385.7 371.3 357.4 337.5 331.0</td>
</tr>
<tr>
<td>75/24</td>
<td>400.0 400.0 400.0 399.2 387.6 375.4 361.6 341.6 335.1</td>
</tr>
<tr>
<td>70/21</td>
<td>400.0 400.0 400.0 399.3 387.7 376.1 364.8 345.2 338.9</td>
</tr>
<tr>
<td>65/18</td>
<td>400.0 400.0 400.0 399.3 387.7 376.1 364.8 345.2 338.9</td>
</tr>
<tr>
<td>60/16</td>
<td>400.0 400.0 400.0 399.4 387.8 376.2 364.9 349.8 344.0</td>
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<td>55/13</td>
<td>400.0 400.0 400.0 399.5 387.9 376.3 364.9 349.0 344.1</td>
</tr>
<tr>
<td>50/10</td>
<td>400.0 400.0 400.0 399.6 387.9 376.3 365.0 349.1 344.1</td>
</tr>
<tr>
<td>45/7</td>
<td>399.1 393.9 383.0 371.6 360.0 348.4 337.1 321.1 316.2</td>
</tr>
<tr>
<td>40/4</td>
<td>399.1 393.9 383.1 371.7 360.1 348.4 337.1 321.2 316.3</td>
</tr>
<tr>
<td>35/1</td>
<td>399.1 394.0 383.2 371.8 360.2 348.6 337.2 321.3 316.4</td>
</tr>
<tr>
<td>30/7</td>
<td>399.2 394.0 383.3 371.9 360.3 348.7 337.3 321.4 316.6</td>
</tr>
<tr>
<td>25/12</td>
<td>399.2 394.1 383.3 372.0 360.4 348.8 337.5 321.6 316.7</td>
</tr>
<tr>
<td>20/9</td>
<td>399.3 394.2 383.4 372.1 360.5 348.9 337.6 321.7 316.8</td>
</tr>
<tr>
<td>15/7</td>
<td>399.3 394.2 383.5 372.2 360.6 349.0 337.7 321.8 316.9</td>
</tr>
<tr>
<td>10/5</td>
<td>399.4 394.3 383.6 372.3 360.7 349.2 337.9 321.9 317.0</td>
</tr>
</tbody>
</table>

Adjustment:
Engine and wing anti-ice on:

See applicable Allowable Landing Weight flow chart

NA = Not Authorized
### FLAPS 25

**Conditions:**
- Manual landing
- Zero wind
- No reverse thrust
- Auto Speed Brakes
- Maximum Braking

#### Station Press Alt (Feet) Conditions

<table>
<thead>
<tr>
<th>Press Alt (Feet)</th>
<th>Conditions</th>
<th>Dispatch - FAR Landing Field Length (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4500</td>
<td>Dry NA</td>
<td>223.0</td>
</tr>
<tr>
<td></td>
<td>Wet or LM</td>
<td>251.8</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>280.6</td>
</tr>
<tr>
<td></td>
<td>5000</td>
<td>309.7</td>
</tr>
<tr>
<td></td>
<td>5500</td>
<td>339.3</td>
</tr>
<tr>
<td></td>
<td>6000</td>
<td>339.3</td>
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<td></td>
<td>6500</td>
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<td>9000</td>
<td>339.3</td>
</tr>
<tr>
<td></td>
<td>10,000</td>
<td>339.3</td>
</tr>
</tbody>
</table>

**Adjustment:**
- If Auto Speed Brakes inop: See applicable Allowable Landing Weight flow chart

**Notes:**
- LM = Low Minimums, visibility less than 4000 RVR or 3/4 mile
- NA = Not Authorized
- To meet the FAA CAT III requirements when performing CAT III autoland, use the Wet or LM weights if the runway is dry, and use the Wet & LM weights if the runway is wet.

---

### FLAPS 30

**Conditions:**
- Manual landing
- Zero wind
- No reverse thrust
- Auto Speed Brakes
- Maximum Braking

#### Station Press Alt (Feet) Conditions

<table>
<thead>
<tr>
<th>Press Alt (Feet)</th>
<th>Conditions</th>
<th>Dispatch - FAR Landing Field Length (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4500</td>
<td>Dry NA</td>
<td>223.0</td>
</tr>
<tr>
<td></td>
<td>Wet or LM</td>
<td>251.8</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>280.6</td>
</tr>
<tr>
<td></td>
<td>5000</td>
<td>309.7</td>
</tr>
<tr>
<td></td>
<td>5500</td>
<td>339.3</td>
</tr>
<tr>
<td></td>
<td>6000</td>
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<td>6500</td>
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<tr>
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<td>9000</td>
<td>339.3</td>
</tr>
<tr>
<td></td>
<td>10,000</td>
<td>339.3</td>
</tr>
</tbody>
</table>

**Adjustment:**
- If Auto Speed Brakes inop: See applicable Allowable Landing Weight flow chart

**Notes:**
- LM = Low Minimums, visibility less than 4000 RVR or 3/4 mile
- NA = Not Authorized
- To meet the FAA CAT III requirements when performing CAT III autoland, use the Wet or LM weights if the runway is dry, and use the Wet & LM weights if the runway is wet.
**Antiskid Inoperative Allowable Landing Weight (767-300)**

**Step 1 of 1**

**PERFORMANCE LIMIT WEIGHT**

- Engine & Wing Anti-Ice On
  - (-) Wind Correction
    - (+/-) Engine & Wing Anti-Ice On Correction

**ANTISKID INOPERATIVE RUNWAY LIMIT WEIGHT**

- Wind Correction (+30/-10 kts max)

**STRUCTURAL LIMIT WEIGHT**

- 320.0

Use Lowest

**Antiskid Inoperative Allowable Landing Weight**

(Use in ATOG computation)

---

**Brake Deactivated Allowable Landing Weight (767-300)**

**Step 1 of 1**

**PERFORMANCE LIMIT WEIGHT**

- Engine & Wing Anti-Ice On
  - (-) Wind Correction
    - (+/-) Engine & Wing Anti-Ice On Correction

**RUNWAY LIMIT WEIGHT**

- Wind Correction (+30/-10 kts max)

**STRUCTURAL LIMIT WEIGHT**

- 320.0

Use Lowest

**Brake Deactivated Allowable Landing Weight**

(Use in ATOG computation)
**FLAPS 25**

Conditions:
- Manual landing
- Zero wind
- No reverse thrust
- Manual speed brakes
- Irregular procedure for antiskid inoperative utilized

<table>
<thead>
<tr>
<th>Station Press Alt (Feet)</th>
<th>Conditions</th>
<th>Dispatch - FAR Landing Field Length (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8000</td>
<td>Dry</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet or LM</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>NA</td>
</tr>
<tr>
<td>7000</td>
<td>Dry</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet or LM</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>NA</td>
</tr>
<tr>
<td>9000</td>
<td>Dry</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet or LM</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>NA</td>
</tr>
<tr>
<td>1000</td>
<td>Dry</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet or LM</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>NA</td>
</tr>
<tr>
<td>11000</td>
<td>Dry</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet or LM</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>NA</td>
</tr>
<tr>
<td>12000</td>
<td>Dry</td>
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<tr>
<td></td>
<td>Wet or LM</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>NA</td>
</tr>
</tbody>
</table>

**FLAPS 30**

Conditions:
- Manual landing
- Zero wind
- No reverse thrust
- Manual speed brakes
- Irregular procedure for antiskid inoperative utilized

<table>
<thead>
<tr>
<th>Station Press Alt (Feet)</th>
<th>Conditions</th>
<th>Dispatch - FAR Landing Field Length (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8000</td>
<td>Dry</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet or LM</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>NA</td>
</tr>
<tr>
<td>7000</td>
<td>Dry</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet or LM</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>NA</td>
</tr>
<tr>
<td>9000</td>
<td>Dry</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet or LM</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>NA</td>
</tr>
<tr>
<td>1000</td>
<td>Dry</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet or LM</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>NA</td>
</tr>
<tr>
<td>11000</td>
<td>Dry</td>
<td>NA</td>
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<tr>
<td></td>
<td>Wet or LM</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Wet &amp; LM</td>
<td>NA</td>
</tr>
</tbody>
</table>

Wind Correction Factors (1000 Pounds/Knot):

- Headwind: +1.0, +1.1, +1.1, +1.1, +1.1, +1.1, +1.1, +1.1
- Tailwind: -1.1, -1.1, -1.1, -1.1, -1.1, -1.1, -1.1, -1.1

LM = Low Minimums, visibility less than 4000 RVR or 3/4 mile
NA = Not Authorized

To meet the FAA CAT III requirements when performing CAT III autoland, use the Wet or LM weights if the runway is **dry**, and use the Wet & LM weights if the runway is **wet**.

---

**TAKEOFF**

**ANTISKID INOP - RUNWAY LIMIT WEIGHTS**

(767-300)

(1000 Pounds)

**FLAPS 25**

Conditions:
- Manual landing
- Zero wind
- No reverse thrust
- Manual speed brakes
- Irregular procedure for antiskid inoperative utilized

<table>
<thead>
<tr>
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<th>Conditions</th>
<th>Dispatch - FAR Landing Field Length (Feet)</th>
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Wind Correction Factors (1000 Pounds/Knot):

- Headwind: +1.0, +1.1, +1.1, +1.1, +1.1, +1.1, +1.1, +1.1
- Tailwind: -1.1, -1.1, -1.1, -1.1, -1.1, -1.1, -1.1, -1.1

LM = Low Minimums, visibility less than 4000 RVR or 3/4 mile
NA = Not Authorized

To meet the FAA CAT III requirements when performing CAT III autoland, use the Wet or LM weights if the runway is **dry**, and use the Wet & LM weights if the runway is **wet**.

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**9518 757/767 FLIGHT MANUAL OPERATIONS JUL 4/95**

**3-43 LANDING**

---

**3-44 LANDING**

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**UNITED AIR**

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**9518 757/767 FLIGHT MANUAL OPERATIONS JUL 4/95**
Takeoff Weight Data
O'Hare Pressure Alt: 738
ALLOW LDG WEIGHT:
320.0
ATOG: 352.0

The following pages show the actual "Planned Takeoff Data Message" and "Flight Plan" used on a 777 flight from Chicago-O'Hare to Miami International. The runway limit weights given are based on normal engine bleed and pack configurations--engine bleeds on and packs on. If there were any configuration deviations and MEL restrictions, the crew would be required to correct the weight limit; corrections would also have to be made for greater tailwind and lower altimeter settings used in determining the weight data on the data message. Correcting for higher altimeter settings and headwinds than those used in determining the data is left up to crew discretion. On this particular flight that I was an OMC, there were no corrections needed for equipment, configuration, or weather.

Also important to note, the runway limit weight must be supplied by Dispatch; performance limit weight for that temperature must also be furnished to the crew. They are in the form of the ASMD ATOG line (the lesser of the two is shown) and the ATOG T lines; on the ATOG T lines, the runway limit weight is depicted under the specific airport runway number and the performance limit weight is shown in its own column on the right side. The allowable landing weight is determinable by crew; as the flight handbook has a structural limit weight listed; however, the adjusted allowable landing weight is shown on the "Flight Plan".
**PLANNED TAKEOFF DATA MESSAGE**

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| **EPA/ATD0/N1 - ALT 2990 TEMP 75°F (23.3) MAX EPA/N1 - 1.30/90** |

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<th>14R</th>
<th>14RD</th>
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**-0-**

**RWY 14R TKOF FR RWY T2 W/ $ 1000/FT AVL (RWY 14R).**

**RWY 32L TKOF FROM RWY T10 W/ N 9700 FT AVL (RWY 32L).**

**RWY 32L TKOF FR RWY T10 W/ N 9700 FT AVL (RWY 32L).**

**IN CASE OF ENGINE FAILURE ON TAKEOFF FROM RUNWAY 27R**

**BEGIN RIGHT TURN TO 320 DEG MAG AT 1000FT MSL.**

**IN PART 2 OF 2 PARTS**

**209**
Flight 983 departed O'Hare's runway "32L" from taxiway "I". The assumed temperature is 120°F(48°C), REDU EPR/N1 is 1.29/85, ASMD ATOG is 464,700 pounds, ATOG T 77(25) is 543,000 pounds, ATOG T 87(30) is 538,400 pounds, PERF T 77(25) is 565,000 pounds, PERF T 87(30) is 564,600 pounds, LB/KT HW is 571 pounds, and LB/KT TW is -3669 pounds. The final weight is approximately 451,239 pounds. (I do not have the final ACARS printout received during taxi, only the Planned Takeoff Data Message's weight figure. It is assumed that these two values are the same.) The crew has planned on using reduced thrust, so the headwind correction is not permitted.

On Flight 983's “Flight Plan”, the ATOG based on allowable landing weight is listed for both flap settings of 25 and 30 as 448,200 and 481,400 pounds, respectively. This includes 36,400 pounds of planned fuel burn. The crew will use a Flaps 30 setting upon landing in Miami, so the corresponding limit weight is used. The allowable landing weight eventually is the limiting factor for the takeoff from O'Hare according to field conditions at the time of the report, so the MTOG is listed as 481,400 pounds. The crew confirms that the ATOG of 481,400 is the lowest of takeoff structural limit weight, performance limit weight, runway limit weight, and allowable landing weight plus planned fuel burn (545,000, 565,000, 543,000, and 481,400, respectively). Finally, the crew confirms that the actual weight of 451,239 pounds is less than the reduced thrust ATOG of 464,700 pounds. The operation will permit the reduced EPR setting of 1.29.
**Takeoff Thrust Settings**

If the crew has to set the takeoff thrust without the aid of the FMC, the "Takeoff Thrust-EPR" and "Takeoff EPR/N₁ Crosscheck" tables will instruct them which EPR setting to use. Using the 767-300 flight from ORD to MIA and the associated conditions at O'Hare, the following takeoff thrust setting is derived:

- **MAX EPR/N₁:** 1.57/95
- **REDUCED EPR:** 1.42

---

### UNITED AIRLINES

#### TAKEOFF THRUST - EPR

- (767-300)

- Enter table with airport pressure altitude and *airport* temperature to find *maximum* EPR.

- Enter table with airport pressure altitude and *assumed* temperature to find *reduced* EPR.

**Conditions:**

Values valid for both packs on, anti-ice on or off, and when set while airspeed is between 40 and 80 knots.

NA = Not Authorized

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**Adjustment:**

- Packs Off: Add .01
Enter the table with the actual OAT and the unadjusted takeoff EPR (reduced or max) that is to be used for takeoff. Actual engine rpm should approximate the table values and should be at or below the maximum limit of 111.4 (% rpm).

This table is to be used only as an EPR error crosscheck and not for setting takeoff thrust. The actual N\(_i\) during takeoff may differ from values tabulated below by ±2 percent.

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Packs Off +.01 +.01 +.01 +.01 +.01 +.01 +.02 +.02 +.03
Wing A/I On -.01 -.02 -.03 -.03 -.03 -.04 -.04 -.04 -.05
Engine A/I On -.02 -.03 -.04 -.05 -.05 -.07 -.07 -.08
**Takeoff Speeds**

Since United cross-utilizes its pilots to fly the 757, 767-200, and 767-300, the flight handbook is standardized for the three fleets. Several sections of the handbook have type-specific information, while others do not (due to the similar presentation of the information). The "Takeoff and Landing Data Card", for example, is shown only for the 757 model; therefore, this report depicts only excerpts of the 757 "Flip Card".

The layout of the "Takeoff and Landing Data Card" is standardized for all of United's fleets. For determining sample takeoff and flap retraction speeds, then, the 767-300 "Takeoff Speeds" table for "Flaps 5" will be used. The reader should understand, however, that this page is for back-up, and that the standard operating procedure for determining "V"-speeds and flap speeds is by use of the aircraft "Flip Card" and the "Takeoff Speeds Adjustment" page of the flight manual. Examples of the "Flip Card" are shown after the "Takeoff Speeds" and adjustments tables.

**Chicago-O'Hare International Airport**

TOG: 332.0

ASMD TEMP: 120(48)

Airport Pressure Alt: 738

TEMP: 77(25)

WINDS: 32010
TAKEOFF SPEEDS (767-300)

FLAPS 5

V1 Adjustments:
- Altitude/Temperature
- Slope
- Wind
See Adjustments page.

Vn Adjustments:
Altitude/Temperature - See Adjustments page.

V2 speed in shaded area:
After applying all required adjustments check that adjusted V2 is not below V Minimum - See Adjustments page.

Weight V1 Vn V2 Flap Retract
440.0 169 174 - - -
430.0 167 172 - - -
420.0 166 171 - - -
410.0 164 169 - - -
407.0 163 168 173 193 236
404.0 162 167 172 192 236
400.0 161 166 171 191 234
396.0 160 165 170 189 232
392.0 159 164 170 189 232
388.0 158 163 169 188 231
384.0 157 162 168 187 229
380.0 156 161 167 185 227
376.0 155 160 167 184 226
372.0 154 159 166 183 225
368.0 153 158 165 182 224
364.0 152 157 164 181 223
360.0 151 156 163 180 221
356.0 150 155 162 179 220
352.0 149 154 161 178 219
348.0 148 153 160 177 218
344.0 147 152 159 176 216
340.0 146 151 158 175 214
336.0 145 150 157 174 213
332.0 144 149 156 173 212
328.0 143 148 155 172 210
324.0 142 147 154 170 208
320.0 141 146 153 168 206
316.0 140 144 153 167 205
312.0 139 143 152 166 204
308.0 138 142 151 165 203
304.0 137 141 150 164 201
300.0 136 140 149 162 199
296.0 135 139 148 161 198
292.0 133 138 147 160 197
288.0 132 137 146 159 195
284.0 130 136 145 157 193
280.0 128 134 144 155 191
276.0 127 134 143 154 190
272.0 126 133 142 153 188
268.0 125 132 141 152 186
264.0 123 130 140 150 184
260.0 121 128 138 148 182
256.0 120 127 137 147 181
252.0 119 126 136 146 180
248.0 118 125 135 144 178
244.0 116 123 134 142 176
240.0 114 121 133 140 174
## TAKEOFF SPEEDS (767-300)

### FLAPS 15

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**V₁ Adjustments:**
- Altitude/Temperature
- Slope
- Wind

See Adjustments page.

**V₂ Adjustments:**
- Altitude/Temperature
- See Adjustments page.

**V₁ speed within shaded area:**
After applying all required adjustments check that adjusted V₁ is not below V Minimum.
See Adjustments page.

### FLAPS 20

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**V₁ Adjustments:**
- Altitude/Temperature
- Slope
- Wind

See Adjustments page.

**V₂ Adjustments:**
- Altitude/Temperature
- See Adjustments page.

**V₂ speed within shaded area:**
After applying all required adjustments check that adjusted V₂ is not below V Minimum.
See Adjustments page.
**TAKEOFF**

**UNITED AIRLINES**

**ANTISK OPERATIVE RUNWAY LIMIT WEIGHT**

*(767-300)*

**Step 1 of 2**

**Takeoff Restrictions**

- Braking action "good" or better
- Use Antiskid Inoperative V Speeds
- No clutter on operational portion of runway
- Use maximum EPR
- Minimum runway length required: 7700 feet (do not use "overruns" or "stopways")
- Do not use Optional V speeds

**Runway Limit Weight Altimeter Vs Actual Altimeter Correction (1000 lbs)**

<table>
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<th>Altimeter Diff (mb)</th>
<th>-5</th>
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<th>-2</th>
<th>+2</th>
<th>+3</th>
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<td>-0.7</td>
<td>+0.4</td>
<td>+0.8</td>
<td>+1.2</td>
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**Step 2 of 2**

**ACTUAL WEIGHT**

1. Antiskid Inop Runway Limit Weight (from Step 1)
2. Adjusted V1 for Antiskid Inop Runway Limit Wt
3. Runway Length (Ft)
4. V1 Adjmt
5. Antiskid Inop V1 Adjustment
6. Adjusted V1
7. Use Lower V1 Minimum
8. Use Higher V1
9. Adjusted Vx
10. Adjusted V2

**Subtotal**

-72.1

**ANTISKID INOPERATIVE RUNWAY LIMIT WEIGHT**

(Use in Step 2 and in ATOG computation)

**NOV 17/95**

757/767 FLIGHT MANUAL OPERATIONS 9551

**JUL 4/95**

757/767 FLIGHT MANUAL OPERATIONS 9516
**BRAKE DEACTIVATED RUNWAY LIMIT WEIGHT (767-300)**

**Step 1 of 2**

- **Takeoff Restrictions**
  - Braking Action "good" or Better
  - Use Brake Deactivated V Speeds
  - No clutter on operational portion of runway
  - Antiskid system must be operative
  - Use maximum takeoff EPR
  - Takeoff with tailwind not authorized
  - Minimum runway length 5000 feet

- **Runway Limit Weight Altimeter Vs Actual Altimeter Correction (1000 lbs)**

<table>
<thead>
<tr>
<th>Altimeter Diff (mb)</th>
<th>Actual Alt Higher</th>
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<td>-0.5</td>
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<td>+0.1</td>
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<td>+0.8</td>
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- **Brake Deactivated V Speeds**

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**Adjustment of Brake Deactivated Weight**

- **Adjusted Runway Limit Weight**

**Technology**

- **Maximum Allowable Brake Deactivated Weight (1000 lbs)**

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<tr>
<th>Pressure Altitude (Feet)</th>
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<th>Flaps 20</th>
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<td></td>
</tr>
<tr>
<td>6000</td>
<td>348.2</td>
<td>337.0</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>354.8</td>
<td>347.0</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>362.2</td>
<td>358.0</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>371.4</td>
<td>367.0</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>377.0</td>
<td>373.5</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>382.6</td>
<td>389.6</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>393.6</td>
<td>394.6</td>
<td></td>
</tr>
<tr>
<td>-1000</td>
<td>393.6</td>
<td>394.6</td>
<td></td>
</tr>
</tbody>
</table>

**Actual Weight**

- **Adjusted V1**

**Brake Deactivated Subtotal**

- **Adjusted V1 Minimum Use Lower**

- **Adjusted V1 Use Higher**

- **Adjusted V2**
**CLUTTERED RUNWAY LIMIT WEIGHT (767-300)**

**Step 1 of 2**

### Runway Clutter Equivalents and Guidelines

<table>
<thead>
<tr>
<th>Standing Water</th>
<th>Level 1</th>
<th>Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8&quot; to 1/4&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/4&quot; to 1/2&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2&quot; to 1&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&quot; to 2&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2&quot; to 3&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3&quot; to 4&quot;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Takeoff Restrictions**
- All reversers operative
- Automatic speed brakes operative
- Antiskid system must be operative
- All wheel brakes operative
- No tailwind
- Use maximum EPR
- Use Cluttered Runway V Speeds
- Do not use Optional V Speeds
- Minimum runway length required (table)

---

### Minimum Runway Length Required (ft)

<table>
<thead>
<tr>
<th>Airport Pressure Altitude (inches)</th>
<th>Actual Weight (1000 pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press Alt (in)</td>
<td>280.0 320.0 360.0 400.0 420.0</td>
</tr>
<tr>
<td>8000</td>
<td>7000 7300 7600 7900 NA</td>
</tr>
<tr>
<td>6000</td>
<td>6700 7000 7300 7600 NA</td>
</tr>
<tr>
<td>4000</td>
<td>6400 6700 7000 7300 7400</td>
</tr>
<tr>
<td>2000</td>
<td>6100 6400 6700 7000 7100</td>
</tr>
<tr>
<td>5000</td>
<td>5800 6100 6400 6700 6900</td>
</tr>
</tbody>
</table>

**Runway Limit Weight Altimeter Vs Actual Altimeter Correction (1000 lbs)**

<table>
<thead>
<tr>
<th>Altimeter Diff (mb)</th>
<th>-0.15</th>
<th>-0.10</th>
<th>-0.05</th>
<th>+0.05</th>
<th>+0.10</th>
<th>+0.15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correction</td>
<td>-2.1</td>
<td>-1.4</td>
<td>-0.7</td>
<td>+0.4</td>
<td>+0.8</td>
<td>+1.2</td>
</tr>
</tbody>
</table>

**Packs Off Correction (1000 lbs)**

<table>
<thead>
<tr>
<th>Packs Off Correction</th>
<th>(+)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Adjusted Runway Limit Weight**

<table>
<thead>
<tr>
<th>Cluttered Runway Correction (1000 lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Flaps:</td>
</tr>
<tr>
<td>Level 1:</td>
</tr>
<tr>
<td>-25.0 -35.0 -45.0 -50.0 -53.0</td>
</tr>
<tr>
<td>Level 2:</td>
</tr>
<tr>
<td>-35.0 -45.0 -55.0 -60.0 -70.1</td>
</tr>
</tbody>
</table>

**Airport Pressure Altitude Weight Correction (1000 lbs)**

<table>
<thead>
<tr>
<th>Press Alt (in)</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-2.4</td>
</tr>
<tr>
<td>4.8</td>
<td>-7.2</td>
</tr>
<tr>
<td>9.6</td>
<td>-12.0</td>
</tr>
<tr>
<td>-14.4</td>
<td>-16.8</td>
</tr>
<tr>
<td>-19.2</td>
<td></td>
</tr>
</tbody>
</table>

---

**CLUTTERED RUNWAY V SPEEDS (767-300)**

**Step 2 of 2**

### ACTUAL WEIGHT

**Flaps**

<table>
<thead>
<tr>
<th>Flaps</th>
<th>Actual Weight</th>
<th>V1</th>
<th>V2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL</td>
<td>4000</td>
<td>8000</td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>140</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Level 2</td>
<td>140</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>5</td>
<td>140</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>15</td>
<td>140</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>20</td>
<td>140</td>
<td>140</td>
<td>140</td>
</tr>
</tbody>
</table>

---

**Adjusted Vn**

- Use Higher
- Adjusted Vn
- Vn Minimum

---

**CLUTTERED RUNWAY LIMIT WEIGHT (Use in ATOG computation)**

**Adjusted Runway Limit Weight**

- Packs Off Correction
- Airport Pressure Altitude Correction

---

**MAR 8/96**

**757/767 FLIGHT MANUAL OPERATIONS**

9516
757/767 FLIP CARDS – DESCRIPTION AND PROCEDURES

Only three items will be needed to solve any performance problem: The cockpit flip card, the planned takeoff data message, which includes the EPR/ATOG message, and the flow charts in the Flight Manual.

The flip cards measure approximately 8 x 7 inches and are laminated in plastic. In two pilot airplanes, it is not recommended that the cards be written on. The cards are assigned an airplane part number and remain in the cockpit. They are designed to fit in the area just forward of the throttles and are color-coded to indicate the applicable airplane model:

White: 757  Yellow: 767-200  Pink: 767-300

The flip cards are tabulated in 2,000-pound increments for the 757 and 4,000-pound increments for the 767. This weight increment was selected to ensure 1 knot V-speed increments. Simply select the card with the weight that is closest to the actual gross weight. Do not interpolate. Each card has all takeoff and landing speeds for the given weight. A convenient tab system is located along the edge of the cards to facilitate the location of key data.

To avoid the inadvertent use of incorrectly set airspeed bugs, squeeze all bugs together after each takeoff and landing.

COVER CARD

The cover card indicates the airplane type, model designation and engine type to which the card set applies.

SPEED CARD

These cards display takeoff V speeds, flap retraction, minimum maneuvering, and landing reference speeds for the specific airplane weight. Note that on the new cards, V speeds are read vertically for a given flap setting.
SPEED CARDS COMPONENT DESCRIPTION

Unadjusted V Speeds Table
This table shows the unadjusted V speeds ($V_i$, $V_r$, $V_2$) for each takeoff flap position.

The crew should consult the V Speed Adjustment tables in the tabbed section to determine if adjustments to the unadjusted V speeds are necessary.

At light weights, speeds may appear in outlined rather than bold print. This indicates that speed is equal to or less than $V_{\text{minimum}}$. Consult $V_{\text{minimum}}$ table in the tabbed section after V speed adjustments have been made and use the higher speed.

### Flap Retraction Speeds Table
This table shows the minimum speeds at which flaps should be retracted. Retraction speeds are selected to optimize airplane acceleration. Retraction in accordance with the depicted schedule minimizes the distance required to accelerate to climb speed in the event of engine failure on takeoff. The speeds also provide adequate stall margin.

<table>
<thead>
<tr>
<th>Flap</th>
<th>V2</th>
<th>Vr</th>
<th>V1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean</td>
<td>214</td>
<td>194</td>
<td>158</td>
</tr>
<tr>
<td>1 to 0</td>
<td>214</td>
<td>194</td>
<td>158</td>
</tr>
<tr>
<td>5 to 1</td>
<td>158</td>
<td>149</td>
<td>149</td>
</tr>
</tbody>
</table>

### Minimum Maneuvering and Reference Speeds Table
This table shows maneuvering and landing reference speeds for indicated flap positions. All speeds provide at least 30% stall margin at the depicted flap setting. For maneuvering, the speeds are minimum for the selected flap setting. If extensive maneuvering is required or turbulence is a factor, speeds greater than the minimum maneuvering speeds shown should be flown. For landing, the speeds are reference for selected flap settings (REF), unless dictated otherwise by an Irregular Procedure. Target speed is always computed by adding the appropriate wind/gust corrections to reference speed. Speeds in outlined typeface indicate an overweight condition for the corresponding flap setting. The standard go-around flap setting is circled.

<table>
<thead>
<tr>
<th>Maneuvering REF</th>
<th>0</th>
<th>1</th>
<th>5</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>214</td>
<td>176</td>
<td>167</td>
<td>161</td>
<td>145</td>
<td>136</td>
<td>134</td>
<td></td>
</tr>
</tbody>
</table>

V SPEED ADJUSTMENT / $V_{\text{MINIMUM}}$ / TRIM CARD
This card, located toward the back of the card set, displays adjustments for $V_i$, $V_{\text{minimum}}$, and $V_2$ plus minimum $V_{\text{r}}$. It is tabbed for easy access.
V-Speed Adjustment / V. Minimum / Trim Card Component Descriptions

V/Vn/V2 Altitude & Temperature Adjustment Graph
Adjusts V1, Vn, V2 for density altitude. The intersection of pressure altitude (ft) (horizontal line) and temperature (°F or °C) (vertical line) defines the appropriate adjustment to V1, Vn, and V2.

If a maximum thrust takeoff is being made, then the actual temperature is to be used to determine the V speed adjustments. If a reduced thrust takeoff is being made, then the assumed temperature is to be used to determine the V speed adjustments.

V1 Tailwind Adjustment Table
Shows V1 adjustment required for a tailwind takeoff.

V. Runway Slope Adjustment Table
Shows V1 adjustment required for runway slope at COS, LAS, and SEA.

V1 Minimum Table
Shows V1 minimum speeds. The table for the 767-200 also shows Vn minimum speeds and is so labeled.

Trim Table
Shows takeoff stabilizer trim ANU for a given MAC and flap setting.

BLANK CARD
This card is for use with irregular or emergency procedures wherein normal speed card values are not valid (i.e., irregular flap procedures). It is the last card in the set and is tabbed for easy access. Both sides are printed for use.
The following speed schedule was determined for this 767-300 takeoff, adjusting for tailwind (which is non-existent), altitude, and temperature.

\[\begin{array}{l}
\text{Takeoff Speeds} & \text{Flap Retraction Schedule} \\
\text{Minimum } V_1: & 109 & 5-1: & 173 \\
V_1: & 143+5=148 & 1-0: & 212 \\
V_R: & 149+3=152 \\
V_2: & 156+0=156 \\
\end{array}\]

Operating Speeds

Since the 767-300 has a flight management computer (FMC) that calculates the most economical thrust settings and operating speeds, the crew simply ensures that the ECON mode is set in the thrust management computer. The flight handbook has a table entitled "Operating Speeds" which aids the crew with airspeed settings during abnormal conditions (such as the FMC being inoperative).

The 767-300 FMC uses a CI of 40 during the climb, cruise, and descent. During any of these phases, the mode control panel (MCP) may be used to input a different speed, such as when ATC gives a speed restriction during descent.

During the initial climb, the crew will put the flight management system (FMS) into the VNAV, or vertical navigation, mode. Once the aircraft has reached the full flap retraction speed, the FMS defaults to a climb speed of 250 knots below FL100 and transfers to the ECON climb speed when flying through FL100.

At cruise, the FMC will calculate an ECON speed of approximately Mach .80, depending on gross weight and winds. The cruise speed may be altered if operational considerations necessitate a change (for example a time-critical flight or unwanted early arrival). The crew may use the "Flight Planning" table and "Cost Index Flight Planning" table (shown on the next two pages) to schedule a different cruise speed and determine a new fuel burn.
### FLIGHT PLANNING TABLE (767-300)

When the trip length line (corrected for wind) intersects between the horizontal time-fuel lines, use the time and fuel shown in the blocks for the flight altitude. When the trip length line (corrected for wind) intersects on a horizontal time-fuel line, interpolate.

#### Pressure Altitude (Feet) / True Air Speed (Knots)

<table>
<thead>
<tr>
<th>Pressure Altitude (Feet)</th>
<th>43,000</th>
<th>41,000</th>
<th>39,000</th>
<th>37,000</th>
<th>35,000</th>
<th>33,000</th>
<th>31,000</th>
<th>24,000</th>
<th>17,000</th>
<th>10,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>True Air Speed (Knots)</td>
<td>458</td>
<td>458</td>
<td>458</td>
<td>458</td>
<td>458</td>
<td>461</td>
<td>465</td>
<td>465</td>
<td>465</td>
<td>465</td>
</tr>
</tbody>
</table>

#### Flight Time (Hours:Minutes) and Fuel Burnout (Pounds)

<table>
<thead>
<tr>
<th>Flight Time (Hours:Minutes)</th>
<th>Fuel Burnout (Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:43</td>
<td>14:01</td>
</tr>
<tr>
<td>12:00</td>
<td>14:12</td>
</tr>
<tr>
<td>10:20</td>
<td>15:10</td>
</tr>
<tr>
<td>8:50</td>
<td>17:00</td>
</tr>
<tr>
<td>7:30</td>
<td>18:30</td>
</tr>
<tr>
<td>6:00</td>
<td>19:30</td>
</tr>
<tr>
<td>4:30</td>
<td>20:30</td>
</tr>
<tr>
<td>3:00</td>
<td>21:30</td>
</tr>
<tr>
<td>1:30</td>
<td>22:30</td>
</tr>
<tr>
<td>0:00</td>
<td>23:00</td>
</tr>
</tbody>
</table>

#### Adjustments:

Table valid only for landing weight of 240,000 pounds. For each 10,000 pounds deviation above (below) 240,000 pounds, add (subtract) fuel burnout correction shown above for each hour of flight time.

---

**575/76 FLIGHT MANUAL**

OPERATIONS

JUL 4/95
COST INDEX FLIGHT PLANNING TABLE
(767-300)

This table shows the difference in elapsed time and fuel burn for selected cost indices (CIs) between 0 and 300, compared to the standard CI. CIs above 300 have a minimal effect on these values.

<table>
<thead>
<tr>
<th>Distance (NM)</th>
<th>Cost Index</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>100</th>
<th>200</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000</td>
<td>12/-5</td>
<td>5/-3</td>
<td>0/0</td>
<td>-3/.3</td>
<td>-8/1.0</td>
<td>-12/2.2</td>
<td>-15/3.2</td>
<td></td>
</tr>
<tr>
<td>2500</td>
<td>11/-5</td>
<td>4/-3</td>
<td>0/0</td>
<td>-3/.3</td>
<td>-6/8</td>
<td>-11/2.0</td>
<td>-13/2.8</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>9/-3</td>
<td>3/-2</td>
<td>0/0</td>
<td>-3/.2</td>
<td>-6/7</td>
<td>-9/1.5</td>
<td>-11/2.2</td>
<td></td>
</tr>
<tr>
<td>1500</td>
<td>8/-2</td>
<td>3/-1</td>
<td>0/0</td>
<td>-2/2</td>
<td>-4/7</td>
<td>-7/1.4</td>
<td>-8/1.9</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>4/-1</td>
<td>2/-1</td>
<td>0/0</td>
<td>-1/1</td>
<td>-2/3</td>
<td>-4/6</td>
<td>-5/1.1</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>2/-1</td>
<td>1/0.0</td>
<td>0/0</td>
<td>0/0</td>
<td>-1/2</td>
<td>-2/4</td>
<td>-2/6</td>
<td></td>
</tr>
</tbody>
</table>

MACH AIRSPEED DIFFERENCES TABLE
(767-300)

This table provides the economy cruise Mach range at standard temperature with zero wind when manipulated by selecting CI=0 and CI=999 for the conditions indicated. The FMC economy cruise speed is limited to Vmo/Mmo, less 5 knots. At some altitudes and gross weights this speed is reached at less than the maximum CI. When the maximum speed is reached at a CI lower than 999, the speed shown is maximum cruise and is marked with an asterisk.

NOTE
These values are for reference only and vary based on actual conditions.

<table>
<thead>
<tr>
<th>Flight Level</th>
<th>Gross Weight (1000 Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI = 0 / CI = 999</td>
<td></td>
</tr>
<tr>
<td>380.0</td>
<td>360.0</td>
</tr>
<tr>
<td>430</td>
<td>-</td>
</tr>
<tr>
<td>410</td>
<td>-</td>
</tr>
<tr>
<td>390</td>
<td>-</td>
</tr>
</tbody>
</table>

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In addition to cruise speeds, when the crew inputs a desired cruise altitude that is higher than the FMC-computed maximum performance altitude, the display will indicate the maximum altitude possible for the aircraft. This allows the crew to know if a step climb is possible to deviate over weather or get better cruise performance based on actual conditions.

The FMC computes an ECON descent speed of approximately 300 knots with a CI of 40, producing a 1250 foot-per-minute cruise descent. The system then defaults to 240 knots below 10,000 feet. The crew then uses the reference speeds on the aircraft's "Flip Card" for the selected flap settings to correct for wind and fly the approach target speed.

Determining Landing Performance

The crew has already determined the adjusted allowable landing weight for the ATOG determination; the crew will verify that the actual landing weight is at or below this weight before touchdown. The following diagrams depict the approach and landing profile of the 767-300.
**ADDITIONAL United Airlines**

### LANDING GEOMETRY
(767)

- **PILOT 138'**
- **ILS ANTENNA 132'**
- **PILOT 58'**
- **ILS ANTENNA 52'**
- **ILS GLIDE PATH**
- **MAIN GEAR TOUCHDOWN POINT (NO FLARE)**
- **GLIDE SLOPE TRANSMITTER**

**Alert Height**
- 109' RA

**Main Gear**
- **109'**

**Main Gear 29'**
- (-300, 28')

**Threshold**
- **3° GLIDE PATH**
- **550'**
- **450'**
- **1000'**

---

**ILS Glide Slope Transmitter**
At 1000 Feet

<table>
<thead>
<tr>
<th>Flaps 30</th>
<th>Glide Path Degrees</th>
<th>Airplane Body Attitude Degrees</th>
<th>Glide Slope Receiver Antenna Feet (M)</th>
<th>Main Gear Level Point Feet (M)</th>
<th>Main Gear Touchdown Point Feet (M) (No Flare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All heights and distances relative to the threshold</td>
<td>2.5</td>
<td>4.25</td>
<td>44 (13.5)</td>
<td>21 (6.5)</td>
<td>480 (146)</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>3.75</td>
<td>52 (16)</td>
<td>29 (9)</td>
<td>550 (167.5)</td>
</tr>
</tbody>
</table>

---

**BODY ATTITUDE AT TOUCHDOWN**
(767-300)

**GLIDE SLOPE**
- **TRANSMITTER**

**30 REF - 5 kts**
- Landing Gear Struts Compressed

**Body Attitude (Degrees)**

- **Gross Weight (1000 Pounds)**

---

**LANDING FLARE**
(767-300)

- **3°**
- **h = 50'**

**Time (Seconds)**
- 0
- 2
- 4
- 6
- 8

---

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---

**JUL 4/95**

757/767 FLIGHT MANUAL OPERATIONS 9522
**Landing Fuel**

The 767-300 must have 600 pounds of minimum fuel at touchdown to ensure sufficient fuel boost pump coverage during reverse thrust and the landing roll. The minimum fuel to execute a go-around is 1100 pounds, ensuring a climb to 1,000 feet AGL and follow a VFR pattern. There must be a minimum of 900 pounds for design error of the capacitor-type fuel quantity indicator. In conclusion, the minimum desired landing fuel at the threshold is **2600 pounds**.

**Reference Speeds**

Like the takeoff, the crew will use the "Flip Card" to supply landing reference speeds. The $V_{ref}$ is shown on the right side of the flip card that matches the aircraft weight. The *Flight Manual* does have a "Minimum Maneuvering and Landing Reference Speeds" table for redundancy. From the table, the crew would use the following reference speeds. Since Miami's winds are calm at the time of arrival, it is not necessary to change the target speed. The flaps should be extended to the next setting before decelerating below the reference speed for that higher flap setting.

<table>
<thead>
<tr>
<th>Flap Settings/Reference Speeds (KIAS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>300,000</td>
</tr>
</tbody>
</table>

The *Flight Manual* also gives the pilots the go-around thrust settings in $N_1$ and EPR based on temperature and pressure altitude. The FMC, however, calculates the go-around thrust automatically when the Takeoff/Go-Around button is pushed on the throttle quadrant.
### MINIMUM MANEUVERING AND LANDING REFERENCE SPEEDS (767-300)

<table>
<thead>
<tr>
<th>Weight</th>
<th>0</th>
<th>1</th>
<th>5</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>392.0</td>
<td>255</td>
<td>212</td>
<td>193</td>
<td>188</td>
<td>172</td>
<td>164</td>
<td>162</td>
</tr>
<tr>
<td>388.0</td>
<td>253</td>
<td>211</td>
<td>192</td>
<td>187</td>
<td>171</td>
<td>164</td>
<td>161</td>
</tr>
<tr>
<td>384.0</td>
<td>251</td>
<td>209</td>
<td>191</td>
<td>186</td>
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<td>125</td>
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</table>

N1 values are provided for use when EPR indications are inoperative.

**Conditions:**
Values valid for both packs on and engine anti-ice on or off.

<table>
<thead>
<tr>
<th>OAT (°F/°C)</th>
<th>Pressure Altitude (Feet)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>SL</td>
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<tr>
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<td>97.8</td>
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<tr>
<td>100/38</td>
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</tr>
<tr>
<td>70/21</td>
<td>99.7</td>
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<tr>
<td>0/-18</td>
<td>92.9</td>
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<tr>
<td>-20/-29</td>
<td>90.3</td>
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**Adjustments:**
- Wing anti-ice on: Subtract 0.6
- Packs off: Add .06
MAX GO-AROUND THRUST - EPR
(767-300)

Conditions:
- Enter table with airport pressure altitude and airport temperature to find maximum go-around EPR.
- Values valid for both packs on and engine anti-ice on or off.

<table>
<thead>
<tr>
<th>OAT (°F/°C)</th>
<th>Pressure Altitude (Feet)</th>
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</thead>
<tbody>
<tr>
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<td>SL 2000 4000 6000 8000</td>
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<td>110/43</td>
<td>1.51 1.51 1.51 1.51 1.51</td>
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</tr>
<tr>
<td>≤50/10</td>
<td>1.57 1.60 1.62 1.63 1.66</td>
</tr>
</tbody>
</table>

Adjustments:
- Below 4500 feet:
  - Wing anti-ice on: Subtract .01
  - Packs off: Add .01
- Above 4500 feet:
  - Wing anti-ice on: Subtract .02
  - Packs off: Add .02
Landing Distances

The "Demonstrated Landing Distance" table on the following page gives the crew an estimate of landing distances under given conditions. Using auto spoilers during the landing roll and maximum effort braking, our 767-300 will expect to use **3220** feet of runway. Maximum effort braking is completely beyond a comfortable landing rollout for the passengers, as this is the braking effort done during certification as described in the definition above of $V_{mbe}$. The next section describes more practical landing distances experienced during normal operations.
This table is intended for inflight use as a guide to evaluate landing options. Landing distance is only one of the parameters along with weather, runway conditions, landing fuel, inoperative equipment, and pilot judgement to determine whether the selected runways available provide an adequate safety margin.

**Conditions:**
- 30 MAN/REF at threshold
- Maximum effort braking (as demonstrated during certification flight test)
- Minimum float
- No reverse thrust
- Threshold crossing height 50 feet
- Up to 10 knots tailwind
- Pressure altitude 3000 feet or below

### Auto speed brakes

<table>
<thead>
<tr>
<th>Gross Weight (1000 lbs)</th>
<th>220.0</th>
<th>260.0</th>
<th>300.0</th>
<th>340.0</th>
<th>380.0</th>
<th>420.0</th>
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<tbody>
<tr>
<td>Demonstrated Landing Distance (Feet)</td>
<td>2720</td>
<td>2970</td>
<td>3220</td>
<td>3520</td>
<td>4120</td>
<td>4840</td>
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### Manual speed brakes

<table>
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<th>Gross Weight (1000 lbs)</th>
<th>220.0</th>
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<th>340.0</th>
<th>380.0</th>
<th>420.0</th>
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<tbody>
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<td>3720</td>
<td>4320</td>
<td>5040</td>
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</table>

### Adjustments:
For each 1000 feet of landing elevation above 3000 feet MSL: Add 240 feet

**ABNORMAL OR IRREGULAR CONFIGURATION**

### Conditions:
- Auto speed brakes (when operable)
- Speed as noted
- Maximum effort braking (as demonstrated during certification flight test)
- Minimum float
- Maximum available reverse thrust
- Touchdown 1000 feet from end of runway
- Up to 10 knots tailwind
- Pressure altitude 3000 feet or below

<table>
<thead>
<tr>
<th>Airplane Configuration</th>
<th>Cond</th>
<th>APP Speeds</th>
<th>Gross Weight (1000 Pounds)</th>
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</thead>
<tbody>
<tr>
<td>One Engine Inop</td>
<td>Dry</td>
<td>20 Man/Ref +10</td>
<td>4310 4640 5200 5750 6410</td>
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<tr>
<td></td>
<td>Wet</td>
<td></td>
<td>5970 6690 7460 8300 9500</td>
</tr>
<tr>
<td>C &amp; L Hydraulic Systems Inop</td>
<td>Dry</td>
<td>20 Man/Ref +10</td>
<td>4310 4640 5200 5750 6410</td>
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<tr>
<td></td>
<td>Wet</td>
<td></td>
<td>5970 6690 7460 8300 9500</td>
</tr>
<tr>
<td>C &amp; R Hydraulic Systems Inop</td>
<td>Dry</td>
<td>20 Man/Ref +10</td>
<td>3710 4030 4470 5200 6100</td>
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<tr>
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<td>Wet</td>
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<td>5690 6370 7040 7950 9090</td>
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<tr>
<td>L &amp; R Hydraulic Systems Inop</td>
<td>Dry</td>
<td>20 Man/Ref +10</td>
<td>3710 4030 4470 5200 6100</td>
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<tr>
<td></td>
<td>Wet</td>
<td></td>
<td>5690 6370 7040 7950 9090</td>
</tr>
</tbody>
</table>

### Adjustments:
For each 1000 feet of landing elevation above 3000 feet MSL: Add 240 feet
**Autobrakes**

The autobrakes on the 767-300 cause a selected airplane deceleration rate without any regard to the use of reverse thrust. Reverse thrust is used to decrease wear on the brake system. A setting of "1" or "2" is typical for most airports, giving a rate of 4 ft/sec² and 5 ft/sec² for the respective setting. The temperature in Miami is approximately 30 degrees above the 60 degree benchmark for the "Autobrake Stopping Distances" table, so 900 feet must be added to the stopping distance. With an approach speed of 141 knots and an autobrake setting of "2", the aircraft will come to a complete stop within **6700 feet**.

**AUTOBRAKE STOPPING DISTANCES**
*(767-300)*

For guidance only. The automatic wheel braking system modulates brake pressure to achieve a selected **airplane** deceleration rate (indicated in parentheses). The stopping distances are valid for either landing flap with or without the use of reverse thrust. Use of reverse thrust with automatic braking does not change the programmed airplane deceleration rate. All data is for a no wind condition, and indicates actual stopping distance from touchdown. Add 115 feet per knot of tailwind. Add 300 feet per 10°F above 60°F.

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<td>Approach Speed (kts)</td>
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<td>7300</td>
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<td>120</td>
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<td>Approach Speed (kts)</td>
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<td>9500</td>
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<td>120</td>
<td>7500</td>
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<table>
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<tr>
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<td>1800</td>
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Internship Activities

My primary internship responsibilities were in the United Airlines Miami Flight Office (MIAFO) at Miami International Airport. The tasks were mostly administrative, but I was given ample opportunity to pursue other airline operations during the summer of 1996. The following is a log of activities completed during the flight operations internship directly applicable to gas turbine technology as applied to transport class aircraft.

Preflight Inspections

The primary purpose of the preflight inspection as related to the engines is to check for blade damage, most importantly checking for cracks. Cracks are normally repaired if they occur around the outer hub. The blades are replaced if there is damage within the inner hub. Blade clearances are also observed during the preflight check. In addition, the fire bottle squibs are checked to ensure they have not been discharged.

The following log lists those preflight inspections during which I accompanied the first officer (F/O) or second officer (S/O).

19 May 1996: 777-222 with F/O Jim Lavore, PW4084 engines
24 May 1996: 767-322 with F/O Byron Fisher, PW4060 engines
01 June 1996: 767-222 with F/O Dennis Jeck, PWJT9D-7R4 engines
02 June 1996: 727-222 with S/O Eric Temple, PWJT8D engines
11 June 1996: 757-222 with F/O Michael Batts, PW2037 engines
23 June 1996: 777-222 with F/O Keith Johnson, PW4084 engines
02 July 1996: 757-222 with F/O Claire Tarantina, PW2037 engines
07 July 1996: 777-222 with F/O Jim McLean, PW4084 engines
04 Aug 1996: 777-222 with F/O Michael Perez, PW4084 engines
On May 19, during my first OMC flight on the 777, Captain Chris Swenson allowed me to climb down into the main equipment center below the forward section of First Class. All of the avionics equipment, engine monitor equipment, and crew oxygen supplies are located in this area. I could also view the nose wheel well from this area.

**Flights as Observer Member of the Crew**

One of the tremendous opportunities given to United flight interns is flying in the cockpit jumpseat as an Observer Member of the Crew (OMC). These flights allowed valuable experience interacting with crewmembers, ATC, and aircraft and engine systems. During numerous flights the flight crews were very open to explaining the details of the systems. By the end of the summer, I had logged over 90 hours of OMC time. The following is a detailed account of that time.

Some of the experiences I had included reporting the maintenance, including engine data, and APU information through the ACARS on numerous flights and writing reports in the Aircraft Flight Log. I observed maintenance troubleshooting using the cockpit maintenance interface in the Boeing 777; I was also allowed to troubleshoot with the system, as well, with the help of technicians. Finally, the captain on several flights asked me to do the ATC radio calls throughout the flight.

<table>
<thead>
<tr>
<th>Date</th>
<th>Aircraft Type/Ident</th>
<th>Route of Flight</th>
<th>Crewmembers</th>
<th>OMC Time</th>
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<tbody>
<tr>
<td>05-08-96</td>
<td>B747-122/4728U</td>
<td>MIA-EZE</td>
<td>Capt. Ed Petrovich F/O Gustavo Yoguel S/O Stephen Cease</td>
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Besides the preflight inspections and OMC flights, I gained knowledge of line operations from some prominent figures at United Airlines. My two supervisors, Capt. Bill Willson, Chief Pilot, and Capt. Alan Pittman, Flight Manager, gave a lot of insight on operational considerations. Capt. Willson experienced a compressor stall in July with the PW2037 engine on a flight to Caracas, Venezuela. The incident occurred just as the crew climbed through FL300. The crew returned to MIA without further incident after shutting the engine down. I accompanied Capt. Pittman twice on OMC flights where he taught me the intricacies of the B757 and PW2037 systems.

Also, Capt. Al Haynes, pilot-in-command of UAL Flight 232 that crashed in Sioux City, IA, spoke to our group of interns about the crash of his crew's DC-10. He described
in detail what happened to the number two engine, a General Electric CF6 series, and how the crew used all available resources to deal with the situation.

Tours

21 June 1996: United Airlines Maintenance Operations Center, San Francisco International Airport. The interns viewed United’s turbine testbed, one of only two airlines in the nation with its own testing facility. In addition, we observed precision cutting of turbine blades using a laser beam to measure to the micrometer how much the grinder had to cut. According to the technician, the blade lengths are under extreme scrutiny due to their effect on engine reliability. I also met and talked with SAMC personnel about their interactions with the flight crews.

19 July 1996: Airbus Training Center Tour, Miami International Airport. An Airbus flight instructor spent two hours with me and two other interns in the flight simulator. We learned about how the computer interacted with the flight crew and about the flow of information related to engine systems.

22 July 1996: Boeing’s Large Aircraft Assembly Facility, Everett, WA. 767-300’s, 747-400’s and 777-200/300’s are all assembled and test flown at the Everett plant. Although mostly an airframes/structures tour, the interns received a VIP walking tour of the entire Boeing 777 assembly plant. It was learned that customers choose the engine option that is best-suited for their needs; Boeing simply installs them. For example, it would make little sense for United to choose the GE90 or Rolls-Royce Trent engines for its Triple Seven fleet, as it has an almost standardized fleet of Pratt & Whitney engines.

I also learned that Pratt & Whitney leased Boeing’s 747 Number One during its testing and certification phases for the PW4084. Unlike the previous certification for the 4060 engine, the 4084 received immediate 180-minute Extended Range Two-Engine Operation (ETOPS) from United’s vocabulary, or Extended-range Twin-engine Operations according to Pratt & Whitney, approval because of the rigorous testing it received.
Flight Simulators

The pinnacle of the internship experience at United is the opportunity to use the full-motion simulators at the Denver Flight Training Center (DENTK). I was able to integrate what I had learned during OMC flights and my studies of computer-based training aids available at MIAFO.

To get the correct EPR settings for takeoff, the 737-300 and A320 computers marked the correct setting on the EPR gauges. The pilot-not-flying (PNF) set the takeoff thrust accurately using these indications. In the 727-200 and 737-200, we used the takeoff thrust charts from the flight manual based on pressure altitude and outside air temperature.

During the approaches, we used a fuel flow setting of approximately 3000 pounds per hour on all of the aircraft. I also experimented with the autothrottle, keeping it engaged until various stages of the approach. On the Boeing aircraft, the throttle quadrant actually moves when the autothrottle is engaged. The A320 throttles on the other hand do not move with the autothrottle engaged. There are much fewer sensory cues as a result on the A320. One must concentrate on the engine gauges alone for engine performance.
Works Consulted


Skarzynski, Michael. Multiple interviews. United Airlines Maintenance--O'Hare International Airport, Chicago, IL: 1996.
