Lockheed L1011
(Short Body Version – 500)

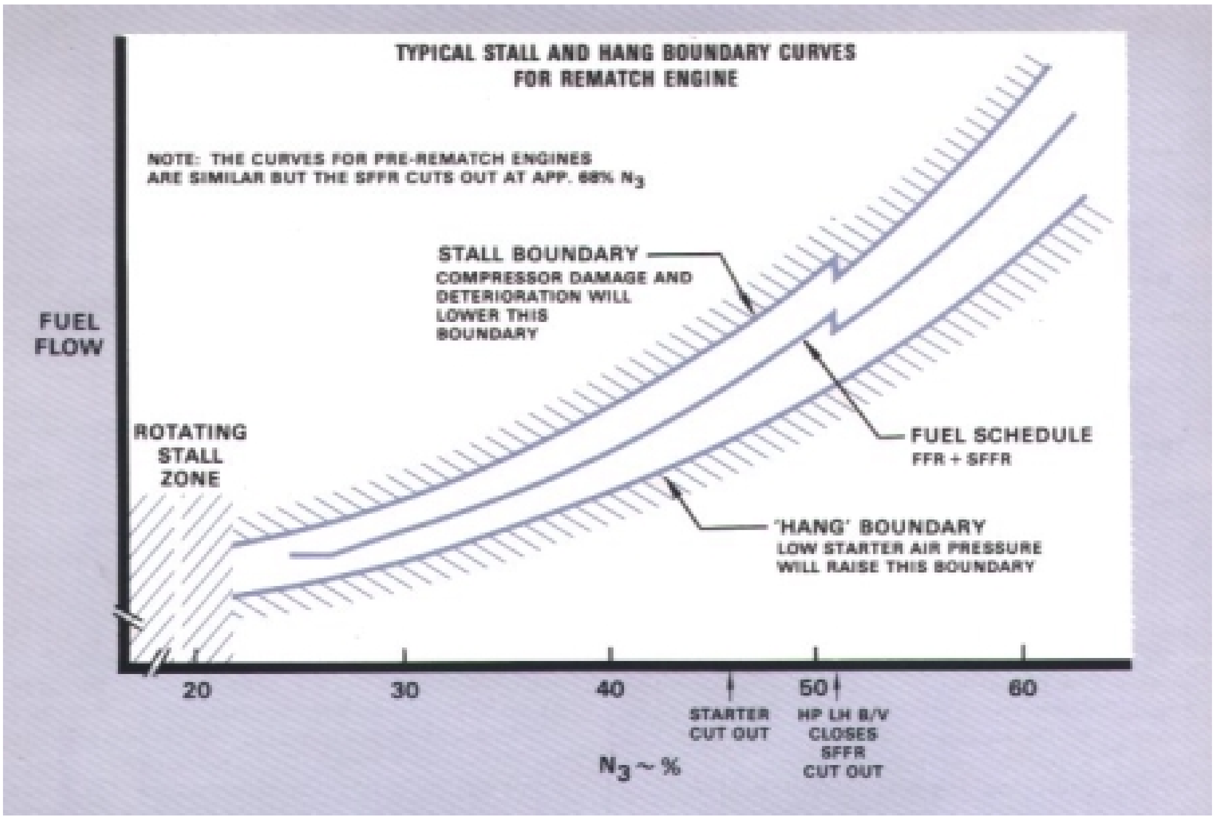
Aircraft Operation Manual
Volume 2 Systems Description
2. Ground starting the RB.211 Engine

Special thanks to Mr. Martin Schwingenheuer

The information presented here is not meant to supersede the Operating or Maintenance Manuals on the RB.211. If any conflict exists, the official publications from Rolls-Royce and Lockheed are the final authority.
This article was written specifically for the Dash 22B engine but is generally applicable to the Dash 524. The basic principles involved in the starting process are similar except that the sequence of events during the starting cycle differ in certain respects. In the Dash 524 engine start, for instance, all of the bleed valves remain open throughout the complete starting cycle and the SFFR, which is controlled by the P_4/P_F switch, remains in operation until just below ground idle. Troubleshooting the Dash 524 engine is fundamentally similar to the Dash 22B.

INTRODUCTION

This article concerns ground starting the Rolls-Royce RB.211 engine. The intent is to provide a better understanding of the boundaries which constrain the starting process, the various systems involved in starting the RB.211, the modifications available for start improvement, and the diagnosis of possible problems.



ACRONYMS USED IN THE TEXT

ACU	Acceleration Control Unit (within the FFR)
APU	Auxiliary Power Unit
BV	bleed valve
CDE	manually controlled "enrich" position of fuel and ignition switch (cold day enrichment)
FFR	Fuel Flow Regulator
F/N	fuel/RPM ratio
gph	gallons per hour
HE	high energy (ignition)
HP	high pressure
HP_1	high pressure compressor, stage 1
HP_3	high pressure compressor, stage 3
HP_6	high pressure compressor, stage 6
HS	high speed
IP	intermediate pressure
LH HP	left-hand HPg bleed valve
LP	low pressure
LUF	light-up flat
MCD	magnetic chip detector
MM	Maintenance Manual
N_1	LP rotor speed
N_2	IP rotor speed
N_3	HP rotor speed
P_4/P_F	discharge pressure ratio (high pressure compressor-to-fan ratio)
pph	pounds per hour psi
psi	pounds per square inch
RH HP	right-hand HPo bleed valve
RPM	revolutions per minute
S/B	Service Bulletin
SFFR	Starting Fuel Flow Regulator (also known as the SCU - start control unit)
SOV	shutoff valve (also known as the Master Shutoff Cock-MSC)
STA	Speed/temperature amplifier (also known as the FCA - fuel control amplifier)
TGT	turbine gas temperature
VIGV	variable inlet guide vanes to IP compressor
VMO	variable metering orifice (in the FFR)

DEFINITIONS

Compressor Stall - A compressor stall occurs when there is a flow breakdown at one or more of the rotating stages in an axial flow compressor. It is basically an aerodynamic stall of the compressor blades/airfoils, similar to an airplane wing in stall. Once a compressor blade or stage stalls, the resulting turbulence can progress downstream causing adjacent blades and stages to stall. When the entire compressor is involved, a flow reversal or surge will occur.

Rotating Stall - A rotating stall occurs when one or more blades in a given compressor stage stall. The stall itself will rotate around the stage at a speed which may be different than the rotor RPM. Crosswinds, or missing or damaged blades may trigger a rotating stall which can progress into a full compressor stall and possible surge.

Hung Start - This is an rpm stagnation during the start cycle, a condition where there is no further N_3 acceleration. Hung starts usually occur just after starter cutout (46% N_3) and are primarily due to lean fuel scheduling (below the hang boundary). Inadequate starter torque can also contribute by raising the hang boundary. The same two factors will cause slow acceleration below starter cutout. TGT is not a factor during the early stages of a hung start although, if the condition is allowed to persist, TGT will climb past the start limit.

Hot Start - This is an overtemp on start. The TGT either exceeds the starting limit or is noted to be climbing so much faster than N_3 that the start must be aborted. If the overtemp condition is not corrected, the HP compressor will go into a stall condition. Hot starts are the result of faulty fuel/air ratios due either to fuel being fed into the engine too early or at too great a rate. The condition can occur at any point in the start cycle, from fuel and ignition ON to ground idle.

Rematch Engine - This is an RB.211 with an increased capacity HP turbine to better match the requirements of the HP compressor (Rolls-Royce SB 72-3722 implemented). This modification increases the stall margin at all N_3 speeds, particularly within the starting range.

Pre-Rematch Engine - The RB.211 engine without SB 72-3722.

"Wet" Motor An Engine - Since the fuel/ignition switch is a single switch, it is necessary to pull the appropriate circuit breaker to isolate either fuel or ignition. Pulling the ignition circuit breaker will allow "wet" motoring an engine without a light-up. In other words, rotation of an engine having a fuel flow but no ignition.

START BOUNDARIES

To fully understand the RB.211 starting system, it is necessary to have some appreciation of the engine operating boundaries present in the sub-idle regime. Figure 1 is a plot of Fuel Flow vs N_3, illustrating the typical areas of stall boundary, hang boundary, and rotating stall boundary relative to a scheduled fuel flow.

During the early stages of a starting cycle, the HP compressor experiences a rotating stall (Figure 1). This is due, in part, to the fact that blade angles and stator angles are optimized for the running range and also that the IP compressor, which is only being rotated by air flow induced by the HP compressor, tends to lag behind thereby obstructing the inlet to the HP compressor. The rotating stall eventually drops out around 22-24% N_3 by which time the N_2 will have reached about 9-10%. It is preferred that the engine does not light-up before the rotating stall drops out, otherwise a hot start may result. This is the reason for the recommendation that fuel and ignition should not be selected ON until N_3 is approaching 25% (or 25 seconds after start of rotation).
Most RB.211 engines will start (and successfully accelerate through the rotating stall range) with fuel and ignition ON at an N_3 as low as 17 or 18%. There is the possibility, however, that a rotating stall may be encountered at these lower HPM's.

Once the engine has lit up, it must be accelerated between the stall boundary and the hang boundary (Figure 1). Fuel must be scheduled to keep the engine operating below the former and above the latter. If for any reason, fuel flow should rise to the level of the stall boundary, a hot start will result. Conversely, if fuel flow were to drop to the level of the hang boundary, a hung start would result.

Damaged or eroded compressor blades will lower the stall boundary and thus make an engine more prone to hot starts. Malscheduled bleed valves can also lower the stall line and cause hot starts.

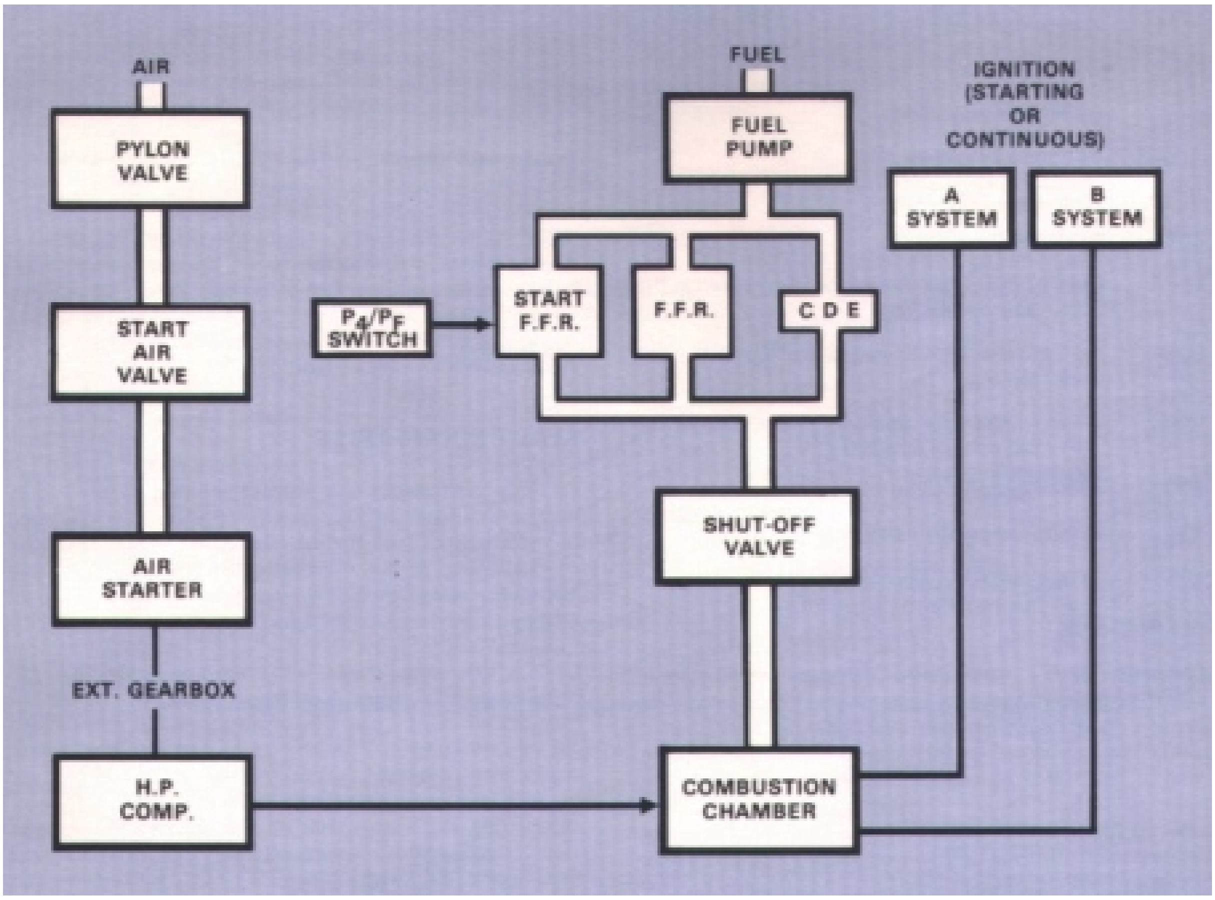
Weak fuel system scheduling which reduces the fuel margin available for acceleration, will cause slow starts and, in severe cases, hung starts. Lack of starter assistance torque (i.e., low starter air pressure) has the effect of raising the hang boundary, which again reduces the available fuel margin for acceleration and can cause slow or hung starts**.** Figure 1.

DESCRIPTION OF SYSTEMS

There are four basic systems which contribute to engine starting.

1. Air starter system
2. Fuel system
3. Airflow control system
4. Ignition system

AIR STARTER SYSTEM

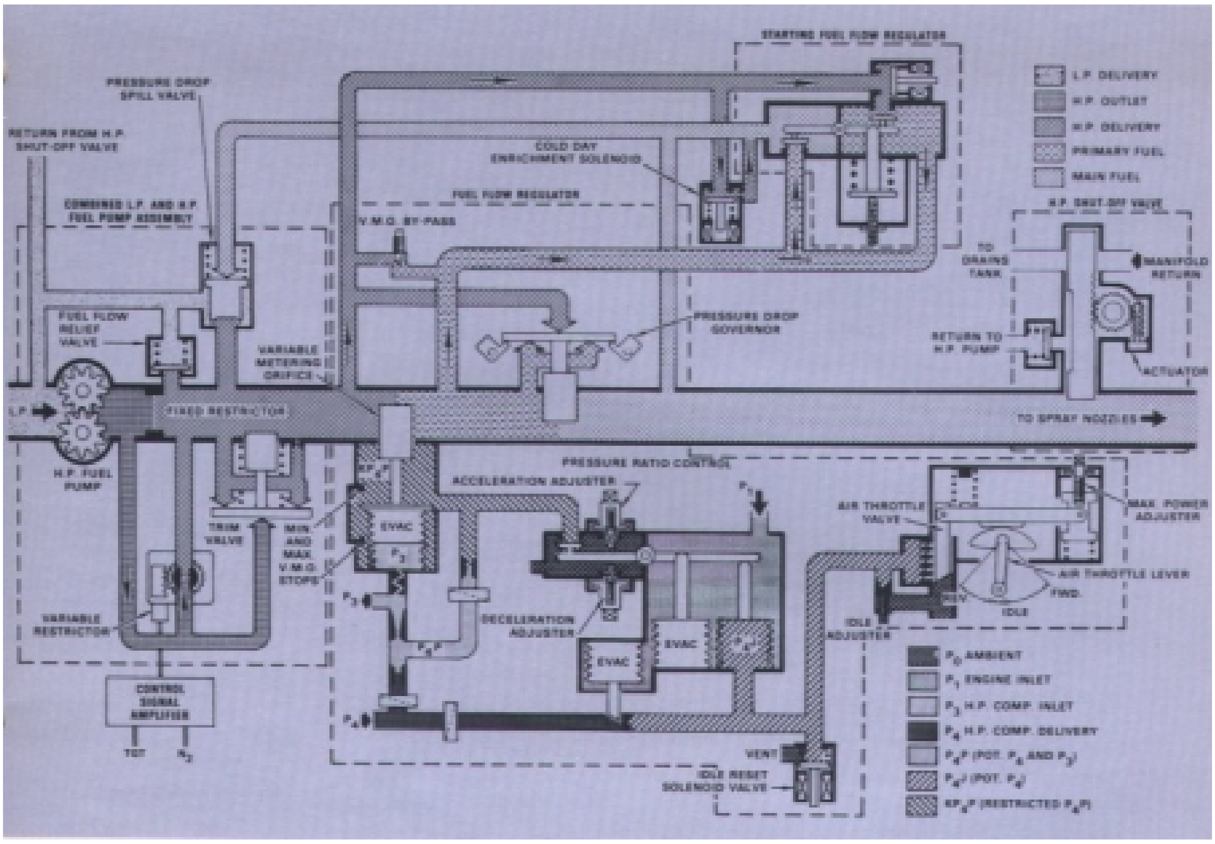


During the starting cycle, air is fed from the aircraft pneumatic system via the engine isolation valve to an air turbine starter motor mounted on the high speed gearbox. The air source can be the APU, a ground cart, or crossbleed from a running engine. The starter motor rotates the high pressure spool and the airflow thus induced through the engine gives the other spools their initial rotation.

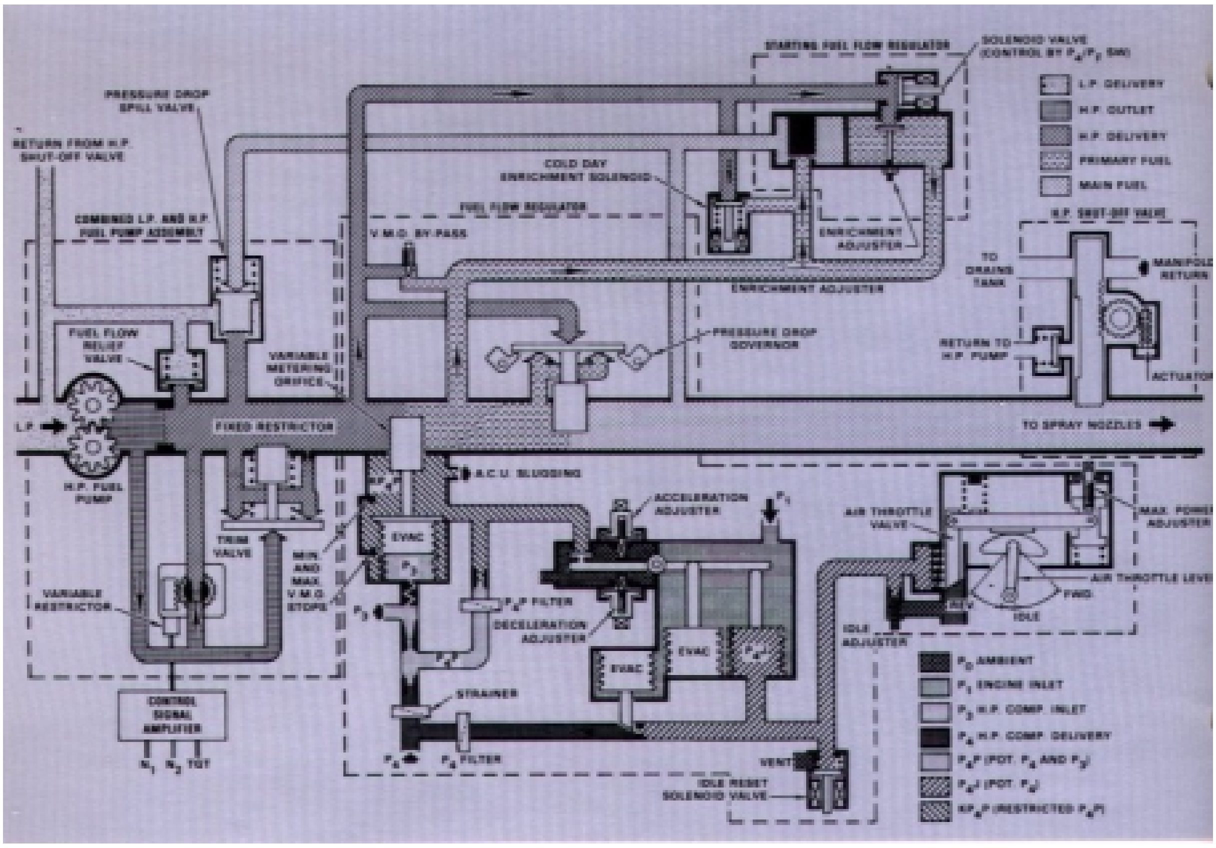
The engine isolation valve in its "normal" mode acts as a non-return valve (check valve) which allows bleed air to flow from the engine to the aircraft pneumatic system, but will not allow airflow in the reverse direction. During the starting cycle the mode of this valve is changed such that air can be fed from the main aircraft pneumatic system to the engine.

At the initiation of the start cycle, the solenoids of the engine isolation valve and the starter air valve are energized, thus opening the valves and allowing air to the starter motor. As the engine accelerates through the starting cycle, the solenoids are de-energized at 46% N_3 via a relay which is triggered by a switch located in the N_3 indicator. The engine isolation valve then reverts to its "normal" mode and the starter air valve closes, cutting off the air supply to the starter motor.

FUEL SYSTEM



Fuel System RB211-22B



Fuel System RB211-524

Fuel is basically scheduled during the starting cycle by two units; the Fuel Flow Regulator (FFR) and the Starting Fuel Flow Regulator (SFFR). In addition, an extra fuel supply can be selected from the cockpit (Enrich — often referred to as CDE) for cold conditions or cases of slow acceleration during the start. The solenoid which controls this "Enrich" flow is located on the HP fuel shutoff valve. A schematic view of the fuel system is shown in Figure 3.

The SFFR has two independent functions:

1. To provide a fixed fuel flow for light-up. This is commonly known as the light-up flat (LUF). At this phase of the start cycle there is no flow from the FFR.
2. To provide an enrichment flow to augment the fuel flow scheduled by the Acceleration Control Unit (ACU) once the transition has been made from the LUF to the FFR. The point at which transition occurs is controlled by centrifugal weights in the FFR as a function of N_3. The SFFR is automatically cut out at approximately 68% N_3 on standard turbine engines (pre-rematch) and 51% N_3 on increased capacity turbine engines (rematch).
   The interaction of the functions of the SFFR and the FFR are shown in Figure 4.

2. When the HP Fuel Shut-off Valve is opened the fuel flow rapidly increases to the light-up flat level scheduled by the SFFR. It remains constant at this value until the action of the centrifugal weights in the FFR brings in the main FFR flow as N_3 increases. This flow is augmented by the enrichment flow from the SFFR.

The flow of the lightup orifice in the SFFR is set during rig calibration *and should never be adjusted in the field.* Adjustment is, however, provided for the SFFR enrichment flow (Figure 5). On early engines this took the form of a square ended adjustment screw, but later engines feature Lucas modification CP 5173 which introduced an indexed "clicker" type adjuster. This modification is available for retrofit. Information on the use of this adjustment is given in the troubleshooting section of this article.

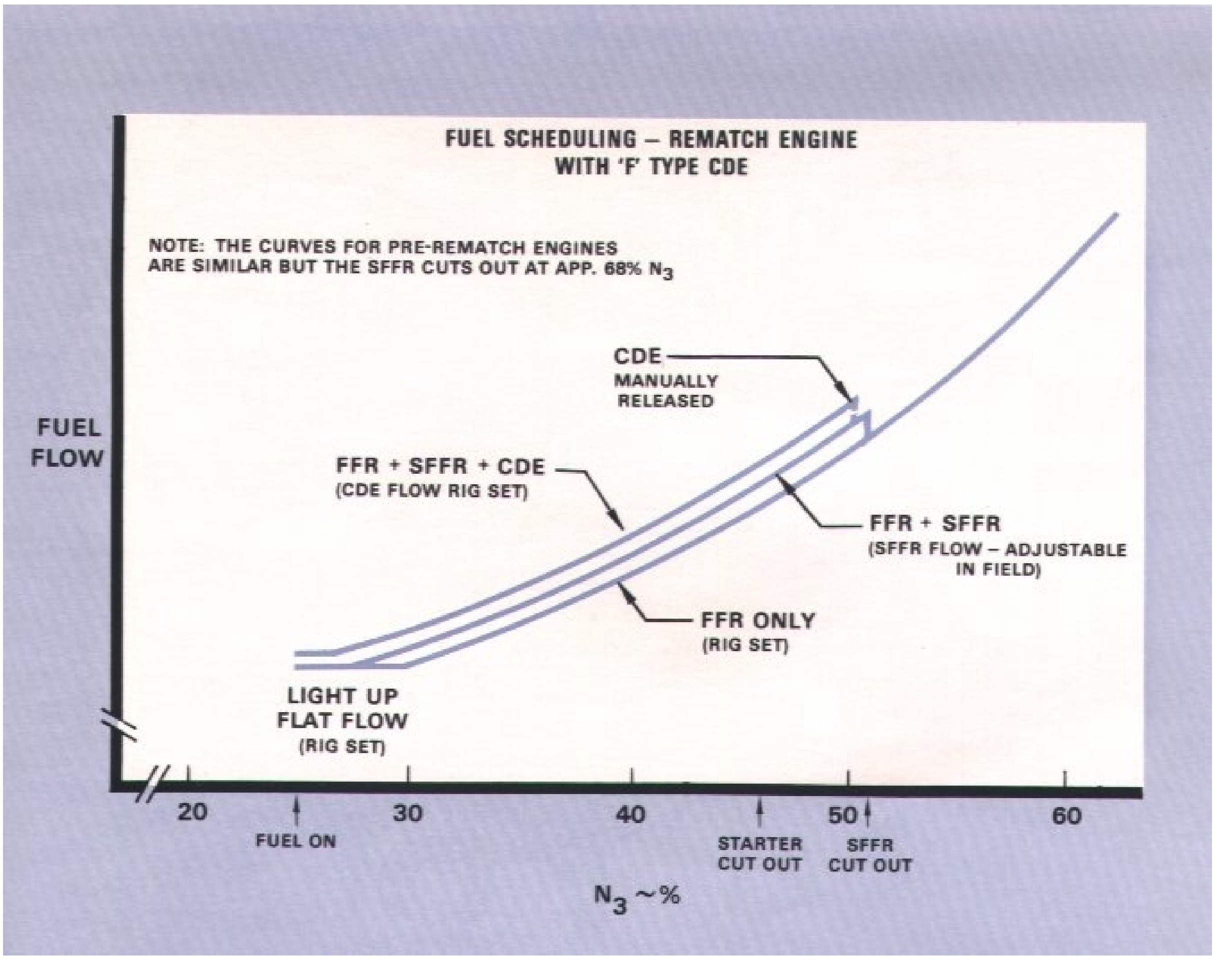
Enrich (CDE)
The effect of the manually controlled "Enrich" device is also shown in Figure 4. There are two standards currently in service: the first, the pre-modification 73-4592 standard, does not increase the LUF but increases the ACU flow by approximately 12 gph at 30% and 24 gph at 60%, whereas the second, the post modification 73-4592 standard ("F" type CDE), increases both the LUF and the ACU flow by a constant 20 gph.

AIRFLOW CONTROL SYSTEM

The airflow control system consists of variable inlet guide vanes at the inlet to the IP compressor and the associated control system, two bleed valves controlling bleed air from stage seven of the IP compressor, and two bleed valves controlling bleed air from stage three of the HP compressor.

During a normal start, the variable inlet guide vanes are positioned at their low-speed stop, and the two IP and two HP_3 bleed valves are open. Both IP and the RH HP., bleed valves remain open throughout the cycle under VIGV ram control. The LH HP_3 BV is controlled by a solenoid valve which receives an electrical signal from the 51% speed switch in the N_3 indicator via a relay, and will close when the engine reaches 51% N_3.

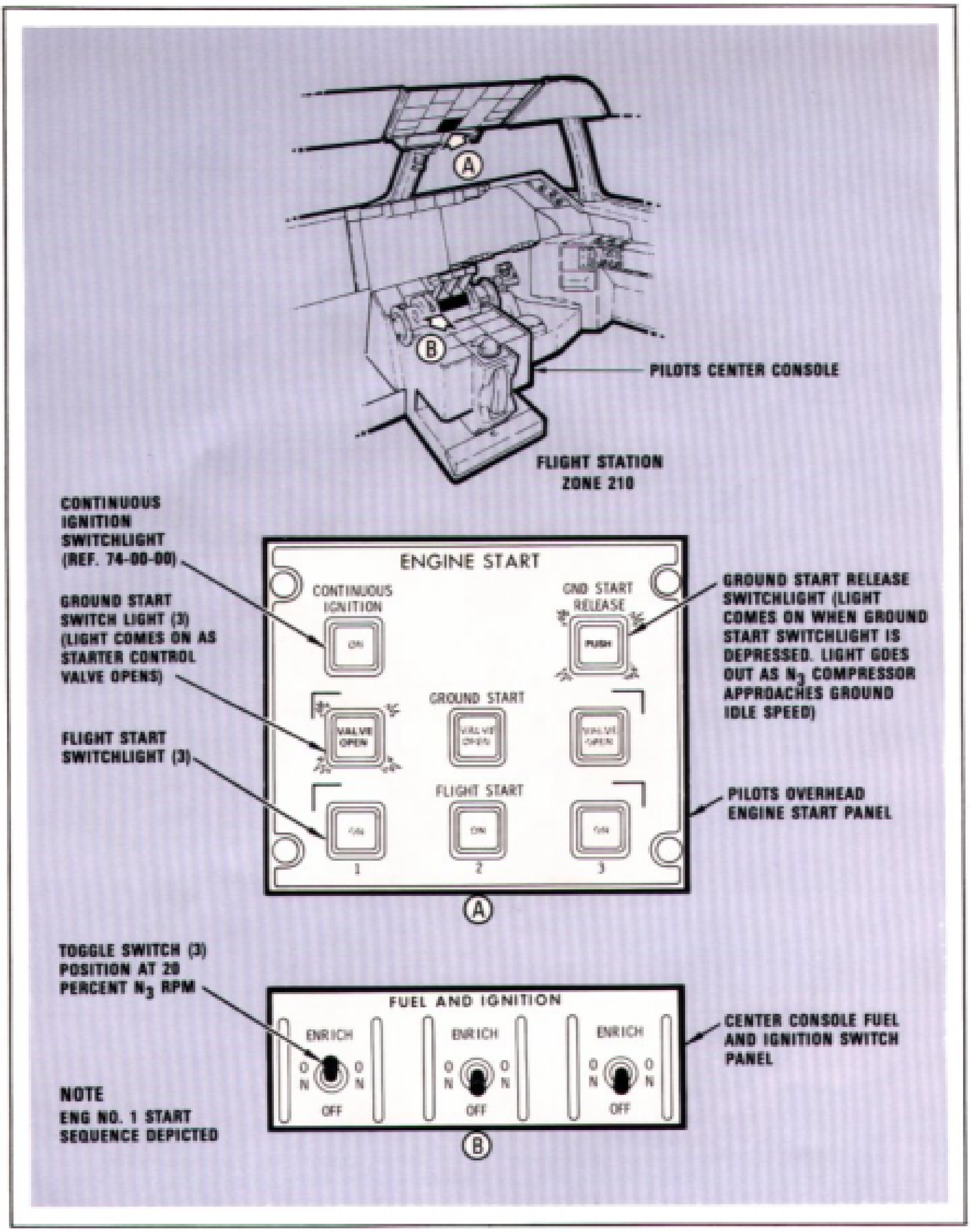
During the early part of a start cycle, the N_3 indicator switch is closed and the HP bleed relay and the bleed valve control solenoid are energized. Thus the left-hand HP_3 bleed valve is held open, initially by spring pressure and later by the combined effect of spring pressure and HP_3 air. When N_3 reaches 51%, the N_3 indicator switch opens de-energizing the HP bleed relay and the bleed valve control solenoid. Spring pressure moves the control valve to vent air from the underside of the left-hand bleed valve piston and HP_3 air moves the piston against spring pressure to close off the outlet ports.

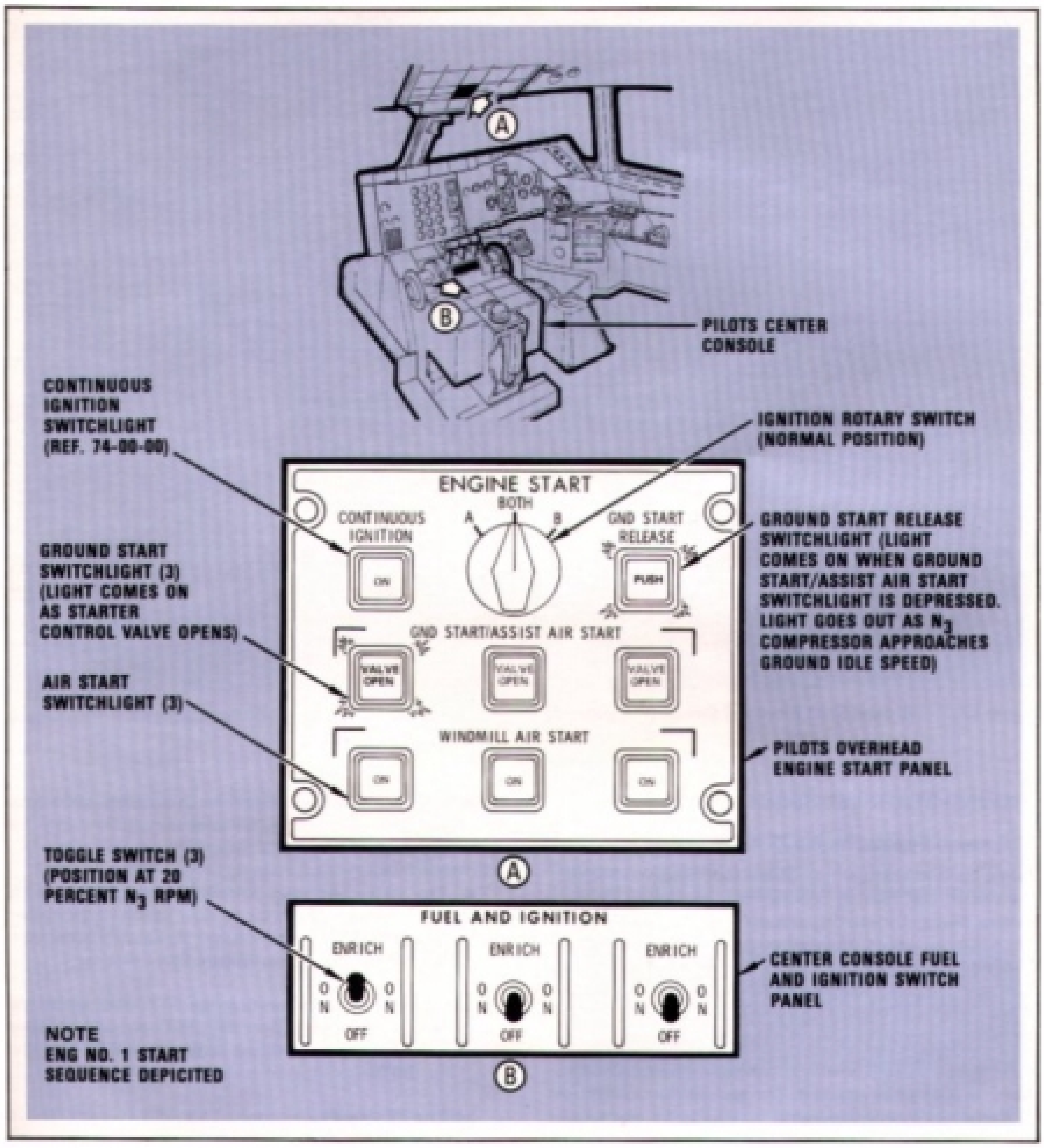


If for any reason the bleed valve control solenoid is not energized during the start cycle, the bleed valve will close at approximately 35-38% N_3. This will lower the stall boundary of the compressor and a hot start will result. Incorrect sealing, or friction of the valve in the control solenoid, can cause the bleed valve to close prematurely at any point between 35% and 51% N_3, and can result in a hot start.

Although, as explained earlier, the variable inlet guide vanes, IP bleed valves, and the right-hand HP bleed valve do not normally operate during the starting cycle, malfunction of any of these systems can give rise to a hot start. The IP bleed valves and the right-hand HP_3 bleed valve are controlled by a shuttle valve mounted on the rear of, and actuated by, the VIGV slave ram. Normally the VIGV system does not move off its low speed stop until approximately 80% N_3. If, however, the system moves off the low speed stop during the start cycle due to a malfunction of the VIGV master ram, the IP bleed valves and the right-hand HP_3 bleed valve will be signalled closed and a hot start will occur.

IGNITION SYSTEM





This system comprises two high-energy ignition units each feeding a surface-discharge type semiconductor igniter plug. The forward ignition unit supplies the left-hand igniter plug and this is designated 'B' system.

The rearmost ignition box supplies the right-hand igniter plug and is designated 'A' system. The plugs, which are located in numbers 8 and 12 fuel-spray nozzle positions, are fed via screened leads. Each igniter unit consists of two independent four-joule stored-energy channels, and during starting, both channels are used to provide an eight-joule output. For continuous ignition, only one four-joule channel from each unit is employed.

During the starting cycle, the eight-joule output commences with the selection of the fuel and ignition switch to ON (or 'Enrich') and is terminated by the 51% N_3 relay. On some aircraft installations, provision is made for manual selection of either 'A' system, 'B' system, or 'Both'. On others, no selection can be made and both 'A' and 'B' systems are employed during all starts.

GROUND STARTING SEQUENCE

Pre-Rematch Engines (Pre S/B 72-3722)

Having covered the function of the four systems which are involved in the starting process, the interaction of these systems during the starting sequence will be examined. As the sequence varies slightly according to modification standard, the pre-rematch engine (pre SB 72-3722) will be discussed first, then the changes introduced on the rematch engine. A ground starting electrical circuit diagram for the pre-rematch engine is shown in Figure 8A.
If the ignition selection switch is fitted, system 'A', 'B', or 'Both' is selected as required. The ground start switchlight on the pilots overhead panel is pressed and is electrically held in. The ground start release switchlight will illuminate. Simultaneously, the following actions occur:

- The solenoid of the engine isolation valve is energized and the valve opens, allowing air to flow into the starter duct.
- The starter air valve solenoid is energized and the valve opens allowing air to flow to the starter motor. The VALVE OPEN legend in the ground start switchlight illuminates.
- On engines incorporating the STA 103 speed and temperature amplifier, the TGT channel redatum circuit is energized which redatums the TGT control to150°C.
- The HP bleed valve control solenoid is energized and closes the vent from the underside of the left-hand HP_3 bleed valve, holding the valve open.
- The minimum Variable Metering Orifice (VMO) stop solenoid in the Fuel Flow Regulator is energized and the stop is withdrawn. This has no effect on ground starting, but during air start (at altitude) it allows the VMO to close further.
- The eight-joule ignition system is armed and the four-joule system is locked out.

At this point the starter motor will begin to rotate the HP spool of the engine. Airflow induced by the rotation of the HP spool will start the IP spool rotating. Eventually the LP spool will begin to rotate as airflow increases.

As N_3 approaches 25%, the fuel and ignition switch is selected to ON. The HP fuel shutoff valve opens and fuel is supplied to the fuel spray nozzles.

The ignition units are energized and the igniters operate.

The Starting Fuel Flow Regulator enrichment solenoid is energized providing additional fuel for acceleration once the fuel system has transferred from the light-up flat to the ACU.

Note: When conditions require it, the fuel and ignition switch can be selected to ENRICH. This energizes a solenoid mounted on the HP fuel shutoff valve and provides additional fuel for starting.

A light-up will normally occur within ten seconds of the selection of fuel and ignition. This is indicated by an increase in observed TGT.

On engines incorporating an STA 103 amplifier, the light-up produces an overdatum signal in the TGT channel once the TGT exceeds 150°C. The amplifier then provides an electrical supply to the fuel trim actuator in the fuel pump which rotates the variable restrictor to maximum trim. This operation is solely to exercise the variable restrictor to prevent sticking or seizure and has no effect on fuel flow during starting.

At approximately 26-27% N_3 the fuel scheduling will transfer from the light-up orifice of the Starting Fuel Flow Regulator to the Fuel Flow Regulator, and the enrichment flow from the Starting Fuel Flow Regulator commences.

As the engine reaches 46% N_3 the speed switch in the N_3 indicator operates and:

- The starter air valve solenoid is de-energized, the valve closes, and the VALVE OPEN legend is extinguished.
- The engine isolation valve reverse-flow solenoid is de-energized and the valve reverts to its normal mode.
- The STA 103 amplifier TGT redatum circuit is de-energized and the variable orifice returns to the minimum trim position.

As the engine reaches 51% N_3, the second speed switch in the N_3 indicator operates and:

- The HP_3 bleed valve control solenoid is de-energized. This vents the underside of the left-hand HP_3 bleed valve causing it to close.
- The minimum VMO stop solenoid is de-energized and the stop returns to the normal setting.
- The ground start release switch is released and the ground-start switchlight extinguishes.
- The ignition system is de-energized.

The engine will continue to accelerate and will stablize atground idle, nominally 57-60% N_3.

The Starting Fuel Plow Regulator solenoid remains energized until the P_4/P_F switch operates at a predetermined pressure ratio corresponding to approximately 68% N_3.

Rematch Engines (Post S/B 72-3722)

On rematch engines the control of the Starting Fuel Flow Regulator solenoid is transferred to the 51% N_3 relay, and control of the minimum VMO stop solenoid is transferred to the P_4/P_F switch.

The effect of this on the starting sequence is that the Starting Fuel Flow Regulator enrichment flow is cancelled at 51% N_3. The minimum VMO stop, however, no longer resets within starting sequence and remains withdrawn right up to the P_4/P_F switch setting which lies between ground idle and flight idle (approximately 68% N_3).

In observing a normal start from the cockpit, the TGT and N_3 indications on a Dash 22B engine start will generally track each other as they both increase. The TGT "outrunning" or leading the N_3 would be a good indication of a hot start or that one could be imminent.

The Dash 524 start will generally show the TGT "outrunning" the N_3 indication. This is a characteristic of a Dash 524 engine start and does not necessarily mean the start should be aborted.

ADDITIONAL STARTING SUGGESTIONS

1. Always make certain there is adequate air pressure for starting.

   - When starting the first engine it may be necessary to off-load all non-essential pneumatics, hydraulics, and electrical to ensure maximum duct pressure.
   - It may be necessary to bypass a troublesome engine and start another, using crossbleed from a started engine at approximately 30 psig manifold pressure to start the other.

2. In the event that no air reaches the starter, both engine isolation valves and the starter control valves possess manual wrenching provisions.

3. Always attempt to head the aircraft into the wind if crosswinds result in stalls.

4. In snow and ice conditions, make certain the fan is free to rotate before attempting a start.

5. Unless a specific fault has been identified, always attempt a second start.

Table 1 lists duct pressures (with starter control valve open) that should be available for consistent starts (assuming a high torque starter is installed).

Ambient temp - °F / °C	-40 / -40	-20 / -28.9	+20 / -6.7	+60 / +15.6	+100 / +37.8	+130 / +54.4
Altitude, ft	Bleed air manifold pressure, psig					
0	31	30	26	24	21	19
4000	27	26	23	21	18	17
8000	23	22	20	18	16	15