TERMINAL LEARNING OBJECTIVE

ACTION: Identify the operational characteristics, malfunctions, appropriate emergency procedures, and describe immediate actions pertaining to the UH-60 power plant systems.

CONDITIONS: In a classroom environment.

STANDARDS: Without references and in accordance with (IAW) TM 1-1520-237-10, TM 1-1520-237-CL, TC 1-237, and the student handout, correctly answer nine (9) out of twelve (12) questions from this scorable unit. If four (4) or more questions are answered incorrectly, the student will receive a No Go for this section of the criterion examination.

SAFETY REQUIREMENTS: Classroom: Use care when operating training aids or devises and handling components.

RISK ASSESSMENT: Low

ENVIRONMENTAL CONSIDERATIONS: None. However, it is the responsibility of all Soldiers and DA civilians to protect the environment from damage.

EVALUATION: Each student will be evaluated on this block of instruction during UH-60 Aircraft Systems Examination, Part 1. You must correctly answer Nine (9) out of twelve (12) questions to receive a GO.

1. LEARNING STEP 1: Identify the operational characteristics of the T-700 Engine.
   a. Operational Description.
      (1) The General Electric T-700 engine is a front drive turboshaft type engine utilizing a gas generator, Gas Generator Speed (Ng), section consisting of a five stage axial and a single stage centrifugal flow compressor, an air cooled two stage axial flow high pressure turbine (44,700 rpm = 100% Ng speed), and a free or independent two stage un-cooled axial flow power turbine, Power Turbine Speed (Np).
      (2) The power turbine shaft, which has a rated speed of 20,900 rpm, 100% Np / Main Rotor Speed (Nr), is coaxial and extends to the front end of the engine where, via a splined joint, it is connected to the output shaft assembly for airframe engine power extraction.
   b. Operational Sections.
      (1) A thorough understanding of Ng and Np is key to understanding the cockpit controls, instruments, operational characteristics, and malfunction analysis of the T-700 engine.
      (2) Ng and Np are synonymous with N1 and N2; these abbreviations generally represent two operational sections common to all turboshaft engines, regardless of the manufacturer.
         (a) Ng Section. The Ng section is the part of the engine that generates power in the form of gas pressure. The volume/pressure of this gas is varied to meet the power needs of the helicopter. The Ng section can be thought of as "the engine".
         (b) Np Section. The Np section is the part of the engine that converts power generated by Ng into shaft rotation, and delivers it to the main rotor (Nr) via the input and main transmission modules. The Np section can be thought of as a "drivetrain component".
      The relationship between Ng, Np, and Nr can be explained as follows: Ng makes power and drives Np, which is connected to Nr; Nr must rotate at a constant speed so the power turbines connected to it must be driven at a constant speed; the Nr load does not remain constant because the collective pitch is frequently adjusted; the gas pressure output of the Ng section acting upon the power turbine must be varied to match the main rotor load; Ng, and anything mechanically connected to it, is a variable; the Np/Nr are a constant.
Combustion pressure acting upon the Gas Generator Turbine Rotors is what powers the engine (Compressor & Accessory components).

Combustion pressure acting upon the “FREE” Power Turbine Rotors is converted into rotational shaft energy to power the drivetrain system. NP’s largest power user is the Main Rotor, other loads include: Tail Rotor, Hydraulic Pumps, AC Generators, and the Transmission Oil Cooler.

c. Mechanical Link.

(1) To have a better understanding of the T-700 operational characteristics, you need to understand the mechanical link between the engines, main rotor system, and the gauges associated with this link. Each power turbine is mechanically connected to the main rotor system through shafting and gearboxes. This mechanical connection is a one-way connection. The power turbine drives the main rotor system, but when the main rotor speed exceeds power turbine speed (as in autorotation), the power turbine will decouple from the drivetrain via the freewheeling unit.

(2) The disengagement of the engine from the main rotor system is accomplished by over running clutches (free-wheeling unit) in the input module. The free-wheeling unit allows for engine disengagement during autorotation, or in the case of a non-operating engine, from the main rotor system.

   (a) Engaged: The free-wheeling unit is engaged by the input drive gear of the engine and a compression spring. As the engine drive gear turns the spring, it assists in forcing the rollers out of their cage, which forms a coupling between the engine input drive gear and transmission cam.

   (b) Disengaged: When the engine input drive gear slows down below the speed of the transmission cam, the rollers are forced back into their cage. This disengages the engine drive from the transmission drive in the input module and allows the main rotor to continue to drive the accessory and main modules during autorotation or single-engine operation.

(3) The mechanical link between the engine and the helicopter drivetrain can be explained in three different examples.
(a) The first example is pushing a car. Your leg power (Np) is mechanically transferred through your arms to the car (Nr). The connection is one way, you may push the car, but the car cannot pull you. If your foot speed is constant at 3 mph, then the car speed is a constant 3 mph. This explains the statement that if the Np is constant, then the Nr is constant.

(b) The second example of the mechanical link between the engine and helicopter is peddling a bicycle. The leg power (Np) is transferred to the wheel (Nr) via the chain (highspeed shaft). This connection is a one-way connection, your legs can drive the rear wheel, but when coasting down a hill, the rear wheel will not drive your legs. If your leg speed is constant at 100%, then the wheel speed will be a constant 100%. Again, this is an example of the mechanical link between Nr and Np.

(c) The last example is called a mechanical loop. Due to the mechanical interaction of both power turbines, if one power turbine speeds up, driving the Nr up, the other engine power turbine becomes unloaded. An example of this would be Person No. 1 pushes harder on the car than Person No. 2. Person No. 2 senses the speed of the car increasing and instead of increasing speed with it he maintains the constant speed of 3 mph.

(4) Np Arrangement-Each power turbine is driven at 100% rpm (by it's own Ng section), which yields 100% Revolutions Per Minute Rotor (RPM R). Use the % RPM 1-R-2 Vertical Instrument Display (VID) on the Pilots Display Unit (PDU) to visualize the mechanical connection between Np and Nr. Scan the % RPM R VID to identify which power turbine (normally both) is mechanically connected to the main rotor system. Next, use the % TRQ 1 and 2 VID to identify how much torque (work) each power turbine is delivering to the main rotor. In this situation, both power turbines are hooked to the main rotor, and delivering equal amounts of power as indicated on the PDU.

(a) The Nr directly affects the Np, should the main rotor load demand increase to the point that the main rotor load exceeds the power capabilities of the engines; the Nr will push the Np down. An example of this is observed during a main rotor droop, the % RPM 1 and 2 are slowed down by the main rotor load as shown on the PDU.

(b) During an autorotation, the main rotor speed (Nr) may build to a point where the power turbines decouple from the drivetrain. The % RPM R rises above the % RPM 1 and 2. The Nr won't pull the Np up due to the free-wheeling units in the drivetrain system.

(c) When experiencing a high speed shaft failure, the RPM of the affected engine will increase to the Np over speed limit of 106±1%. Since the affected engine is no longer coupled to the Main Module, the affected engine torque will reduce to 0 %. The Rotor RPM will be dependant on the remaining engines ability to provide sufficient power to maintain speed. If the remaining engine has insufficient power capability to maintain 100 % due to reaching max torque available, the rotor will slow and maintain the same speed as the remaining engine and possibly result in a DECREASING % RPM R situation. If this occurs, pilot corrective action from memory is required.

NOTES:
Figure #2

PDU & the mechanical link between Np & Nr

258 RPM = 100% RPMR

CAR PUSH SCENARIO:

Two People pushing a car is analogous to two Power Turbines pushing the same rotor system. Constant twist speed yields constant car speed. A Power Turbine driven at a constant speed will yield constant main rotor rpm.

The mechanical connection between hands & cars is the same as flight, the people may pull the car, the car won't pull the people. The Power Turbines "push" the main rotor, main rotor won't "pull" Power Turbines.

EX. #1
3 mph

EX. #2
1 mph

EX. #3
3 mph

EX. #4
1 mph

20,900 RPM = 100% RPM 1

100% RPM 1-R-2
NORMAL FLIGHT INDICATION, BOTH POWER TURBINES HOOKED TO THE MAIN ROTOR, BOTH DELIVERING EQUAL AMOUNTS OF POWER.

DROP
MTA OF BOTH ENGINES EXCEED MAIN ROTOR PUSHING DOWN TWO POWER TURBINES.

AUTOROTATION
BOTH POWER TURBINES DECOPLED, NR WON'T "PULL" NP'S UP.

#1 HIGH SPEED SHAFT FAIL
MTA OF #2 ENGINE EXCEEDED, ROTOR PULLING DOWN #2 POWER TURBINE.
d. Engine Correlation.

(1) Understanding the engine correlation factor is critical knowledge that must be fully understood. You will use the correlation factor to identify normal operation of the engine, or to analyze engine malfunctions. Indications observed inside the cockpit such as ENG OIL TEMP/PRESS, TGT, Ng, and %TRQ of both engines will correlate up and down, while the % RPM 1-R-2 will remain constant at 100%. During normal operation, brief transient fluctuations are normal.

*** To insure equal sharing of the main rotor load, a torque matching system keeps the engines within 5% torque of each other. This effectively synchronizes the engine power outputs and the result of torque matching is a relative balance between all No. 1 and No. 2 engine instruments.

(2) When one engine changes its power output, the other engines governing system, the Electrical Control Unit (ECU), makes an opposing power change to maintain the % RPM R at 100%. Retarding the No. 2 Power Control Lever (PCL) will cause the No. 2 engine instruments to correlate down indicating a power reduction in the No. 2 engine. Automatically, and simultaneously, the No. 1 engines instruments correlate up indicating a power increase to maintain % RPM R at 100%.

(a) Engine Malfunction Identification. With the UH-60 being a dual engine aircraft, correcting power plant related malfunctions begins with identifying the malfunctioning engine. This skill is critical and must be mastered. After the malfunctioning engine has been positively identified, corrective action is taken on that engine by manipulating the corresponding controls. With this in mind, it should be noted that mishaps have occurred due to the misidentification of the malfunctioning engine, and/or manipulating the wrong engine controls. Take your time and get it right the first time.

(b) Engine Malfunction Identification General Rules: An accurate method of identifying which engine is malfunctioning is summarized in the following general rules: LO-LO-LO and HI-HI-HI. The first rule mentioned is the LO-LO-LO, which refers to the following indications and symptoms.

The first LO is a low RPM R, or a % RPM R below 100%. This is indicated on the PDU.
The second LO refers to the engine power, specifically, the malfunctioning engine power. This information is verified using the engine correlation factor to properly identify the malfunctioning engine.
The last LO is referring to a low side failure of the ECU (or a power loss), which is most likely the cause, and is pilot correctable. Other causes of a power loss could be the catastrophic failure of an engine or the drivetrain, which is not pilot correctable.

HI-HI-HI, the second rule applies to a high % RMP R (greater than 100%), which is the first HI.
The next HI is obtained using the engine correlation factor, based on the cockpit indications the malfunctioning engine is the high power engine.

Finally, the last HI refers to a high side failure of the ECU, which would be the most likely cause, and is pilot correctable by retarding the PCL of the high power engine. If the power increase is caused by an internal malfunction of the HMU and the PCL has no authority, the pilot action is to perform an emergency engine shutdown.

CAUTION: Key points to remember, whenever applying the LO-LO-LO (decreasing RPM R) or the HI-HI-HI (increasing RPM R) general rules are to, always verify the engine correlation prior to taking action. Identify the low or high power engine by checking all available engine indications.

CAUTION: During certain catastrophic failure conditions, (failure of the gas generator turbine or compressor), the Turbine Gas Temperature (TGT) for that engine may indicate high, while that engines remaining indications correlate low. Do not misinterpret the high TGT as an indication of the engine making power. Check all available engine indications, and thoroughly analyze the malfunction using the engine correlation factor.

e. Best Cockpit Indications.

(1) TGT and RPM R can be the best cockpit instruments used for identifying, and reacting to engine malfunctions. Instrument scans begin with the RPM R, the pilot on the controls takes immediate and instinctive action to keep the %RPM R in acceptable operational range. Engine TGT is the most reliable
indication of engine power if there is a failure of the engine alternator, directly or indirectly, causing a loss of the Ng, Np, and TRQ signals. This leaves only a TGT signal available for indications of a malfunction.

(2) The presence of TGT, in normal conditions, indicates the presence of combustion pressure available to act upon the power turbine to drive the main rotor. However, some engine failures show a high TGT indication (i.e., a failure of the gas generator turbine rotors or compressor), leading you to believe the engine is making power when it is not. Do not use one engine instrument to analyze an engine malfunction, such as TGT by itself. Always use the engine correlation factor, using all available cockpit instruments to identify the malfunction prior to taking any corrective actions.

NOTES:

(2) Engine instruments are correlating low as low side failure of ECU trims #2 engine power low, #1 engine’s governing system (ECU) senses decaying RPM R via droop of it’s power turbine, it compensates by increasing it’s power until TGT limiting is reached, RPM R then decays. Initial action is to reduce collective to regain RPM R, next action is to reclaim lost #2 engine power by locking out the malfunctioning #2 ECU and setting #2 engine power manually.

(both power turbines are hooked up to the M/R and are being drooped by M/R load, #1 P/T is delivering 88% TRQ to M/R, yet #2 P/T is delivering 20% TRQ. Reducing collective will reduce M/R load and bring %RPMR back into the normal range)
2. LEARNING STEP 2: Identify abbreviations used in discussing the T-700 engine.

a. The T-700 and its systems function are very similar to other Army turbine engines. The abbreviations listed in this section are common abbreviations used when discussing the operational characteristics of the T-700 engine.

   (1) Nr (Main Rotor Speed): Main Rotor speed (Nr) is the largest power user and must be driven at a constant speed, it normally rotates at 100% (258 rpm). Both engines through a direct mechanical connection of the two power turbines supply power to the main rotor. The power turbines also rotate at 100% (20,900 rpm).

   (2) Np (Power Turbine Speed): Power Turbine Speed (Np) drives the main rotor. Two power turbines are mechanically linked to one main rotor via the drivetrain. Power turbine operational components consist of a two-stage power turbine rotor, a power turbine shaft, a splined adapter, and a highspeed shaft assembly.

   (3) Ng (Gas Generator Speed): The purpose of the Gas Generator speed (Ng) is to drive the Power Turbine's speed (Np). The Ng section generates power in the form of gas pressure by continuously combusting a fuel/air mixture. The Ng sections main parts are a six-stage axial/centrifugal compressor, and a two-stage Gas Generator turbine (GG) rotor assembly.

   (4) AGB (Accessory Gear Box): A gearbox that mechanically drives engine accessory components, every AGB component is driven relative to NG speed via the Power Take Off (PTO).

   (5) PTO (Power Take Off): The Power Take Off (PTO) is a gear that drives a radial drive shaft, which mechanically links the AGB and Ng. Simply, the Ng section powers all of the AGB components through the PTO.
(6) IPS (Inlet Particle Separator): The Inlet Particle Separator (IPS) is an AGB driven pump that suctions dirty air from the collector scroll, and blows the dirty air overboard.

(7) AC (Alternating Current): Alternating current (electrical power) is produced by the engine alternator, which is driven by the Accessory Gear Box (AGB). The AGB supplies AC power to the engine electrical systems and generates a Gas Generator Speed (Ng) tachometer signal for the cockpit. Some engine systems get electrical power from other airframe sources.

(8) A/I (Anti-Ice): Each engine has two anti-icing systems; the first is the engine anti-ice system, the second is the engine inlet anti-ice. Both systems are activated by one switch for each engine, the ENG ANTI-ICE No. 1 and No. 2 switches. Both systems have dedicated advisory lights (#1 and #2 ENG ANTI-ICE ON, and #1 and #2 ENG INLET ANTI-ICE ON).

AISBV (Anti Ice Start Bleed Valve): The Anti Ice Start Bleed Valve serves as both an engine anti ice valve and as a compressor bleed valve. It is HMU controlled for the bleed function and pilot controlled for anti icing. The bleed function aids in the rapid acceleration or deceleration of the compressor to allow stall free operation.

(9) P3 (Compressor Discharge Pressure): Pressure at the 3rd Engine Stage (P3) represents Compressor Discharge Pressure (CDP), which is used to cool the hot section engine components and support the combustion for power production. Other uses of P3 air include purging, oil control, and bleed air powered accessories.

(10) T2 (Compressor Inlet Temperature): Temperature at the 2nd Engineering Stage (T2) represents the Compressor Inlet Temperature (CIT). T2 is used by the engine fuel metering systems to compensate for changes in air temperature. A T2 sensor passes inlet air temperature information directly to the HMU for use in adjusting the metered fuel. Inlet Air Temperature information from the T2 sensor is also used for Ng limiting.

(11) HMU (Hydromechanical Unit): The Hydromechanical Unit (HMU) is a fuel control unit with 9 functions; these functions will be discussed later in this lesson. During normal conditions, the HMU meters fuel to the combustion chamber in accordance with three main control inputs: Power Control Lever (PCL) position, collective position, and the ECU input. During abnormal conditions, the pilot, placing the HMU in the manual mode, can lock out the ECU.

(12) PCL (Power Control Lever): The Power Control Lever (PCL) sets the maximum power that may be called upon by the collective, or ECU. The PCL has four settings: OFF, IDLE, FLY, and LOCKOUT. The PCL is mechanically linked to the Power Available Spindle (PAS) through a cable. The PAS changes the linear cable movements into rotary inputs to the HMU.

(13) LDS (Load Demand Spindle): The Load Demand Spindle (LDS) is a spindle that changes linear cable movements into rotary motion. This mechanical link between the collective and the HMU makes fuel-metering adjustments in a proactive attempt to match engine power to rotor load.

(14) ECU (Electrical Control Unit): The ECU is an electronic engine governor that reduces pilot load by maintaining a constant power turbine speed of 100%. Due to the power turbine speed mechanical link to the main rotor speed, this yields a constant main rotor rpm of 100%. The ECU also provides Turbine Gas Temperature limiting, (limits the TGT to 843 °C), load sharing (which keeps the torques of both engines matched within 5%), and power turbine overspeed protection (limits the power turbine speed to 106 ±1%). The ECU also processes power turbine speed and torque signals for the cockpit and feeds data to the history recorder.

(15) POU (Pressurizing and Overspeed Unit): The Pressurizing and Overspeed Unit (POU) is a fuel-controlling unit with four functions. The POU sequences metered fuel between the start and main fuel nozzles/injectors. The POU also purges the fuel nozzles with P3 air, preventing the fuel nozzles from clogging. An overspeed solenoid in the POU reduces the fuel flow to Ng, an ECU circuit activates the solenoid when the Np speed reaches 106 ±1%, once activated the solenoid actuates a valve inside the POU to reduce the fuel flow. This reduces the Ng output acting upon the Np. The reduction in fuel flow will continue to cycle until the cause of the overspeed is removed or %RPM is reduced manually.
(16) VG (Variable Geometry): The HMU mechanically positions Variable Geometry (VG) linkage that actuates four items: the IGV, 1st and 2nd stage variable stator vanes, and the Anti-Ice and Start Bleed Valve (AISBV) for engine bleed functions. The pilot controls the AISBV for engine anti-ice functions.

(17) IGV (Inlet Guide Vane): The Inlet Guide Vanes (IGV) precedes the first stage of axial compression. The IGV's work together with the 1st and 2nd stage variable stator vanes, which precede the 2nd and 3rd stages of axial compression. IGV's and variable vanes (stage 1 and 2) are positioned by the HMU, and operate in accordance with the gas generator speed and engine inlet air temperature. Use of the IGV's and the variable stators facilitates rapid stall-free accelerations, optimizing fuel consumption at partial power conditions.

(18) Q (Power Turbine Torque): Power Turbine Torque (Q) is an engineering term used to express engine torque, #1 represents the engine being discussed, and #2 represents the other engine. Both engines function independently, with one exception. The torque signals are relayed between each others ECU's for load sharing functions.

(19) T4.5 (Power Turbine Inlet Temperature): The Power Turbine Inlet Temperature (T4.5) is the temperature at the engineering stage 4.5 and Turbine Gas Temperature (TGT) is identical. Seven turbine gas temperature probes are positioned between the Ng and Np, and measure the temperature of combustion gases produced by the Ng that are about to drive the Np. The maximum temperature at station 4.5 of the power turbine is 843º C, which is monitored/limited by the ECU.

(20) TGT (Turbine Gas Temperature): The Turbine Gas Temperature (TGT) and T4.5 are identical, as they are the measurement of combustion gasses produced by the Ng that are about to drive the Np. There are seven TGT probes positioned between the Ng and Np of the power turbine of the combustion section of the engine.

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Ng generates gas pressure to drive Np. (Ng and anything mechanically connected to it will be a "variable" BUM item.)

ELECTRICAL POWER UNIT

100% RPM R = 100% RPM 1 or 2

T-2

Engine and control system overview

STC WILIAM A. MILLER 1996
3. LEARNING STEP 3: Identify the operational characteristics of the T-700 modules and components.

a. Engine Modules and Components—Under the modular maintenance concept, the T700 series turboshaft engines are divided into four modules: Accessory Section Module (Accessory Gearbox), Cold Section Module (Compressor Section), Hot Section Module (Combustion Section), Power Turbine Module (Power Turbine). The engine can be disassembled into the four modules.

   The four modules consist of several major components. The T700 engine major components consist of the swirl frame, front frame, main frame, and scroll case which comprise the inlet section of the engine; a vertically split compressor stator casing which provides a housing for the variable and fixed stator vanes, a 6-stage (5 stages axial, 1 centrifugal) compressor rotor; the diffuser case, diffuser and midframe. The components are part of the cold section module. The accessory gearbox is top mounted to the main frame and, together with the various accessories mounted on the forward and aft casings, is the accessory section module.

   The combustion liner and stage one turbine nozzle is housed in the midframe, which also provides a mounting provision for the gas generator turbine stator. The combustion liner, stage one turbine nozzle, gas generator turbine stator, and rotor, comprise the hot section module. A two-stage power turbine rotor is housed in the power turbine casing, which also contains the No. 3 and No. 4 power turbine nozzles. The exhaust frame is bolted to the power turbine casing. The power turbine rotor, casing and exhaust frame comprise the power turbine module.

b. Engine Modules—The four modules of the engine can be associated with two sections, Ng and Np. The Ng section (Gas Generator) is the part of the engine that makes the power: the cold, hot, and accessory modules make up the gas generator. The Np section (Power Turbine) converts the Ng's gas pressure into rotational shaft energy that is transferred to the helicopter drive train. The power turbine is represented by it's own module. Keep in mind that operational knowledge of the engine and its instruments revolves around the understanding of the two main operational sections of Ng and Np, which operate within the four modules.
(1) Cold Section Module-The cold section module includes the inlet particle separator, compressor, diffuser and midframe case (surrounds the combustion chamber), the output shaft assembly, and various Line Replacement Units (LRU). The cold section has mounting points: a forward support tube secures the engine in its fore-aft axis to an elastomeric gimble on the input module. Aft mounts secure the engine in its radial axis to the deck through spherical bearings that allow the engine to move fore and aft as the forward mount flexes. This mounting arrangement makes the engine to the airframe connection flexible, which dampens vibrations and compensates for the flex of the airframe.

(a) Output Shaft Assembly-The output shaft assembly (highspeed shaft) is splined into the engine and bolted to the input flange of the input module. A flexible coupling and balance studs are attached to the highspeed shaft and input flange to minimize vibrations and provide centering of the shaft. The highspeed shaft delivers engine power (from the power turbine) to the helicopter. The highspeed shaft rotates at 20,900 rpm when Np is 100%, and there is no gear reduction in the engine.

(b) Swirl Frame-The inlet section includes the components forward of the compressor. The components are the swirl frame, mainframe, output shaft, front frame, and scroll case. These, together with the inlet duct and blower, make up the engine inlet particle separator. Air enters the separator through the swirl frame. Swirl vanes direct the air into a rotating or swirling pattern to separate sand, dust and other foreign objects by centrifugal action. These particles are carried to the outer section of the main frame, through a series of scroll vanes and into the scroll case. The particles are sucked from the scroll case by the blower and are blown out through an airframe supplied overboard duct. Air that remains after particle separation is carried to the front frame deswirl vanes, straightened and directed to the compressor inlet. Relatively clean air (approximately 85% of total) from the center of the rotating air mass is directed into the axial compressor. The inlet particle separator blower (IPS) evacuates the remaining dirty air (15% of total) from the collector scroll and discharges (blows) it overboard.
(c) Inlet Particle Separator Blower-The particle separator blower removes sand, dust, and other foreign material from the engine inlet air. Engine inlet air passes through the swirl vanes, spinning the air and throwing dirt out by inertial action into the collector scroll. The foreign material is drawn into the blower and discharged overboard around the engine exhaust duct. Pilot considerations about the IPS blower are: during start-up and shut-down, when the Ng speed is low, the IPS blower is not effective. Also, it is not effective against sheet ice shed from the windshield, which is due to the shape of the ice.

![Diagram of Inlet Particle Separator Blower](image)

The inlet particle separator removes particles from the inlet air flow. The inlet air is drawn into the swirl frame and the swirl vanes direct the air into a swirling pattern. Centrifugal action then removes dust, sand, and foreign objects. The foreign objects are carried to the outer section of the main frame and collected in the scroll case. The inlet particle separator blower draws the objects from the scroll case and discharges them overboard.

(d) Compressor Section-The compressor section is a 6 stage air pump that continuously pressurizes the combustion chamber, supporting combustion, and cooling the hot section components. The compressor is arranged in a 5 and 1 combination. This means, it is a 5 stage axial compressor and a 1 stage centrifugal impeller. P 2.5 air is also used for: seal pressurization, engine and engine inlet anti-ice, pressurization of the pneumatic manifold for crossbleed engine start, pressurization of the Auxiliary Fuel Management System (AFMS), and cockpit heat.

1. Compressor Stator-The burning of the unpressurized fuel/air mixture yields very little power, a continuous supply of compressed air is needed so the engine can produce large amounts of power. A large amount of energy is required to drive the compressor. Approximately 75% of the combustion energy is consumed by the GG rotors as they self sustain the engine by driving the compressor and AGB components. The remaining 25% of the combustion energy passes beyond the GG rotors, and acts upon the power turbine. The 25% combustion pressure acting upon the power turbine rotors equates to a potential of 1,546 SHP.

2. Diffuser Section-The axial compressor raises the air pressure approximately 7 times above atmosphere, with the air slowing as it reaches the 5th stage. A dual entry centrifugal impeller raises the speed of the compressed air and becomes supersonic as it leaves the centrifugal impeller entering the diffuser. The diffuser reduces velocity and increases pressure, and then directs the air into and around the combustion chamber. At the combustion chamber, about 33% of the P3 air supports combustion, with the remaining 66% used for cooling and other purposes.

3. Compressor Rotor-The combined 6 stages of the compressor yield a total compression ratio of about 17:1. The product of the compressor is referred to as Pressure at 3rd Engineering Stage (P3), or CDP. Compressor speed varies depending on the PCL and collective positions, increasing as the collective is raised and decreasing as the collective is lowered. Speed ranges of the compressor are between 29,000 rpm (minimum idle 63% Ng) and 44,700 rpm (maximum continuous 99% Ng).
Compressor Variable Geometry Actuation System—The variable geometry actuation system of the T700 high performance compressor permits optimum performance over a wide range of operating conditions. Use of variable stator vane angles facilitates rapid stall-free accelerations and optimizes fuel consumption at partial power conditions. The variable geometry components include the stage 1 and stage 2 variable vanes of the compressor casing, Inlet Guide Vanes (IGV’s) in the main frame, lever arms attached to the individual vanes, and three actuating rings (one for each stage). The three actuating rings, levers, and vanes are actuated and synchronized by the crankshaft assembly, which is positioned by an actuator within the Hydromechanical Unit (HMU). This actuator is in turn, positioned by a servo system with feedback, which responds to compressor or gas generator speed (Ng), compressor inlet temperature (T2), and physical position of the variable geometry actuator.

The "bleed function" of the AISBV is controlled solely by the HMU, due to the fact that the bleed function is occurring through use of the anti-ice valve and associated ducting, the engine anti-ice on advisory lights will illuminate (with engine anti-ice switches off) when the HMU opens the AISBV for bleed functions. The AISBV opening/closing point occurs typically at about 30% torque or between 88-92% Ng. Actual valve opening/closing point varies depending on T-2 and Ng speed.

The "engine anti-ice function" of the AISBV is controlled by the pilot. When the #1 or #2 engine anti-ice switch is placed "ON" the AISBV opens to direct 5th stage (P-2.5) air to the front of the engine for anti-ice purposes, the respective engine anti-ice advisory light will illuminate.
(e) Anti-Icing Airflow-The 1st three stages of axial compression are preceded by variable pitch vanes, which control air flow characteristics in the front portion of the compressor to facilitate rapid stall-free accelerations and optimize fuel consumption at partial power conditions. The inlet guide vanes precede the 1st stage of axial compression, and the stage 1 and 2 variable vanes precede the next two stages of compression. The HMU varies the pitch of the IGV's and stage 1 and 2 variable vanes IAW Ng speed and T-2 as necessary to optimize compressor function.
The AISBV is HMU controlled and serves as both an engine anti-ice valve and as a compressor bleed valve. A compressor bleed function is required during starting so the compressor can accelerate (stall free) from static to engine idle. A compressor bleed function is also required in flight modes of operation because compressor speed varies as power changes are called upon by collective movements, power reductions require less P-3 air at the combustion chamber and the compressor must "spool down", power increases require more P-3 air at the combustion chamber so the compressor must "spool up".

AISBV-Problems arise when a low rpm compressor is asked to rapidly increase in rpm, the laws of physics allow a maximum "spool up" rate, if the acceleration rate is excessive, air within the compressor stops flowing aft (as the compressor blades stall) and the supply of P3 air to the engine fluctuates, this phenomenon is called compressor stall or surge. The side effects of compressor stall are three fold, stalling rotating airfoils within the axial compressor are subjected to excessive stress as the air abruptly reverses and surges forward, interruption of pressurized air to the hot section causes an immediate loss of power, and hot section components are subjected to excessively high temperatures.

(2) Hot Section Module-The hot section module consists of the following components: combustion liner, stage one nozzle assembly, stages one and two gas generator turbine rotor, and the gas generator stator. The gas generator turbine consists of the gas generator stator assembly and a two-stage air cooled turbine rotor assembly. The combustion liner is a ring type combustor cooled with secondary airflow from the diffuser case. The stage one nozzle contains 12 air cooled nozzle segments and directs gas flow to the gas generator turbine. The GG rotors are hot section components, which convert gas pressure into shaft rotation to power the engine (compressor and AGB components).

(a) Hot Section Module Components-The hot section module consists of the following components: combustion liner, stage one nozzle assembly, stages one and two gas generator turbine rotor, and the gas generator stator.

1. Combustion Liner-The combustion liner is where combustion occurs and energy, in the form of gas pressure, is directed aft to act upon two separate turbine sections (Ng and Np). It also houses twelve fuel injectors, two primer nozzles, and two igniters. Two counter rotating air vortexes swirl over each injector. The injectors spray preheated fuel at high pressure in a 32 degree duplex cone pattern that rotates fuel spray opposite the vortex air. This process yields nearly complete atomization, ensuring excellent fuel economy and a low smoke level in the exhaust.

2. Stage 1 Nozzle-The stage 1 nozzle directs gas pressure upon the stage 1 GG rotor, a second nozzle, located within the stator, directs gas pressure onto the stage 2 GG rotors. The GG rotors drive the compressor and engine AGB components as driven by the PTO gear and radial drive shaft. About 75% of the total combustion energy is extracted by the GG rotors to self sustain the engine. The remaining combustion energy powers the helicopter through the power turbine. The GG rotors operate in an extreme environment of high temperature and centrifugal loads. It is critical to respect the engine operating limits to prolong the life of the GG rotors. Due to the nature of the environment in which the GG rotors operate, permanent stresses accumulate within the rotors and they are replaced at established intervals in accordance with history recorder data.

3. Stage 1 Rotor-Overall power production is limited mostly due to thermal reasons. A thermal barrier exists within the confines of current metals and cooling technology, and engineers strive to produce maximum power without damaging the engines components. Cooling air must be present prior to starting the engine, and remain present during engine operation. Primary air enters the combustion chamber to support combustion for power production (approximately 33% of the total CDP). Secondary air is used to cool hot section components (approximately 66% of the total CDP).

4. Gas Generator Turbine Stator-P3 air protects the hot section components from heat destruction by diluting combustion gasses to reduce heat, and by maintaining a protective boundary layer between the flame and the metal. P3 air is also directed inside the hot section components to conduct heat away from the components. The interruption of P3 air (as in a compressor stall) can stress or damage the hot section components. TGT/T4.5 represents the temperature at the gas generator output, which is the same as the power turbine temperature. This temperature is limited to 850 °C by the ECU. 850° C at T4.5 equates to about 1700° C - 1800° C within the combustion chamber. A malfunction of the
ECU (high side failure) or operation in ECU lockout renders TGT limiting inoperative, enabling the possibility of exceeding 850º C at T4.5 and thermally stressing the hot sections components. This is only one example of how the TGT could exceed 850º C.

(b) Hot Section Airflow-P-3 air protects hot section components from “heat destruction” by diluting combustion gasses to reduce heat, and by maintaining a protective boundary layer between the flame and the metal (P-3 air is also directed inside hot section components to conduct heat away). The interruption of P-3 air (as in compressor stall) can stress or damage hot section components. TGT/T4.5 represents the temperature at the Gas Generator output (same as P/T input temp.); this temperature is limited to 850º C by the ECU. 850º C at T-4.5 equates to about 1700-1800º C within the combustion chamber. Malfunction of the ECU (high side failure) or operation in ECU lockout renders TGT limiting inoperative, enabling the possibility of exceeding 850º C at T-4.5 and thermally stressing hot section components.

(3) Power Turbine Module-The power turbine module converts gas pressure into rotational shaft energy to power the drive train. Power Turbine Rotor and Drive Shaft Components-The power turbine is
comprised of a two stage power turbine rotor, each prefaced by nozzles, and a power turbine drive shaft. The power turbine shaft passes through the center of the Ng section, but has no mechanical link with the Ng. A splined adapter mates the power turbine shaft to the high speed shaft. The high speed shaft transfers engine power to the input module and it rotates at the same speed as the power turbine rotors. Reductions in rpm occur in the input and main module.

Np Operational Overview-Expanding gases produced by the Ng section attempt to drive the power turbine at 20,900 rpm, which is equal to 258 RPM R, 100% Np/Nr.

Np to Nr Output-Np, the power turbine, is mechanically connected to the Nr, a variable load. Due to this mechanical connection, changes in the main rotor load, the collective pitch, affect the power turbine load. Changes in the power turbine load necessitate changes in the Ng output. The Ng is trimmed by the collective movement through the LDS and the engine governing system, the ECU.

(a) Overspeed Protection-The power turbine is protected from damaging overspeed conditions by the Np overspeed system. If the Np speed reaches 106 ± 1%, the Np overspeed system activates and reduces the Ng output to slow down the Np. Two magnetic pickups are housed in the power turbine section. The Np sensors relay magnetic pulses to the ECU for Np governing purposes and for cockpit indications of % RPM 1 or 2. A torque and Np overspeed sensor forwards Np speed and torque signals to the ECU for torque matching and Np overspeed functions. The ECU also conditions the signal for cockpit torque indications.

(b) Temperature Sensors-Seven thermocouple probes are placed just prior to the power turbine, station 4.5. These sensors measure the temperature of the gasses between the two turbine sections. The thermocouple probes feed temperature data to the ECU for the TGT limiting function. The ECU relays the TGT signal to the CDU through the Signal Data Converter (SDC).
(4) Accessory Section Module-The accessory section module, also known as the AGB, is an Ng powered gear box that drives the engine accessories. The AGB mounts across the top of the cold section module with components that are driven by the PTO gear and radial drive shaft. The components on the front and rear face of the AGB are driven relative to the Ng speed so RPM, temperatures, and pressures associated with them will correlate up and down with the Ng speed.

(a) On the front face are pads for the alternator and fuel boost pump. A cavity is provided for the lube and scavenge pump, and chip detector. Pads are supplied for the oil cooler, and fuel and lube filters. Cored passages in the AGB housing convey fuel and oil between components.

1. Oil Temperature Detector-The oil temperature detector, or sensor, transmits oil temperature to the cockpit (CDU via SDC), the "Eng. oil temp" caution light illuminates at 150º C.

2. Oil Pressure Transmitter-The oil pressure transmitter, or sensor, transmits oil pressure to the cockpit (CDU via SDC), the "Eng. oil press" caution light illuminates at 20 psi.

3. Oil Filter-The oil filter has an impending bypass indicator button and a bypass switch, which illuminates the "oil filter bypass" caution light when oil filter is nearly/fully clogged. A relief valve routes cold/thick oil around the filter until the oil heats up.

4. Chip Detector-The chip detector monitors the scavenge oil stream for metallic particles, and illuminates "engine chip" caution light.

5. Oil Cooler-The oil cooler is a liquid-to-liquid heat exchanger that uses fuel to cool engine oil. A relief valve routes cold/thick oil around the cooler until oil heats up.

6. Fuel Filter-The fuel filter has an impending bypass indicator button and a bypass switch, which illuminates the "fuel filter bypass" caution light when the filter becomes fully clogged.

7. Fuel Boost Pump-The engine driven fuel boost pump is designed to suction fuel from selected fuel cell and feed fuel to the HMU.

8. Oil Pump-The oil pump is a seven element pump that pumps/scavenges engine oil.
Alternator-The alternator forwards an Ng signal to the cockpit (PDU via SDC), and supplies electrical power to the engine ignition and Electrical Control Unit (ECU).

(b) The rear face provides drive pads for the engine starter, hydromechanical unit, inlet particle separator blower, and a face ported pad for the overspeed and drain valve.
1. POU-The pressurizing and overspeed unit provides flow dividing/purging functions between start and main fuel manifolds/nozzles, it also has an ECU actuated, solenoid controlled valve that reduces fuel flow to prevent power turbine overspeed (106 ± 1%).

2. HMU-The hydromechanical unit has numerous functions, 3 main functions include: LDS (collective input), PAS (power control lever input), and the Torque Motor (ECU - engine governor) input.

3. Starter-The pneumatic starter is powered by bleed air, typically from APU, it motors the Ng section via the AGB and PTO. It decouples (via internal clutch) from the AGB when the engine is running. Starter limitations exist because the bleed air powering it is hot (400ºF) and can damage the starter if exposure time is excessive.

4. IPS Blower-The Inlet Particle Separator (IPS) blower suctions dirty air from the collector scroll and blows it overboard, operates at high RPM's (30,000 rpm at 100% Ng) in a Foreign Object Damage (FOD) rich environment.

4. LEARNING STEP/ACTIVITY No. 4. Identify the operational characteristics of the engine start system.

   a. Engine Start System-The UH-60 has an automatic start system that simplifies engine start by controlling various pneumatic and electrical systems during the engine start process. The primary switches and controls associated with engine start include the PCL and the air source heat/start switch. The PCL sets the fuel flow limits and houses the start override and abort switches. The air source heat/start switch selects the air source to be used for the engine start. Of the possible air sources available to start the engine, the APU is the most common. Other available air sources used to start the engine include an external source, or the other engine.

      (1) Automatic Start System-The starter button on the PCL activates the automatic start system when the PCL is in the "OFF" position. When the auto start is activated, a start relay controls and activates several functions. They include:

          • Main function: allows the engine start valve to open, illuminating the starter caution light. The engine start valve directs compressed air to the pneumatic starter and the starter motors the Ng section (AGB to the PTO) for engine start.

          • Additional functions: activation of the ignition and auto prime, deactivation of the cockpit heater and engine inlet anti-ice, closing the APU start/bypass valve (Turboch APU only), and arms the override switch in the PCL.

   b. Engine Start Overview

      (1) While the Ng is being motored by the pneumatic starter, the PCL is advanced to "IDLE", which starts the fuel flow causing the engine to "light off" and accelerate up to idle speed (minimum 63% Ng). During acceleration to idle, a speed sensor on the starter feeds the Ng speed information to the speed switch (auto start circuit). The speed switch commands the starter valve to open until the Ng speed reaches a minimum of 52% Ng. Between 52 - 65% Ng, the start valve will close extinguishing the starter caution light.

      CAUTION: To avoid damage to the engine start switch actuators, do not move the ENG POWER CONT lever from IDLE to OFF while pressing the starter button.

      (2) The pilot may abort the auto start by pulling down on the PCL. This actuates the abort start switch and closes the starter air valve. In the event of an auto start malfunction, the pilot may complete a manual start by pressing, and holding the starter button during the start process, and releasing the button when the Ng speed reaches a minimum of 52% Ng.

   c. Pneumatic System

      (1) The pneumatic system is comprised of a series of tubing and valves that distribute compressed air to bleed air dependant systems. Compressed air originates from four sources: the APU, No. 1 engine, No. 2 engine, or external. The pneumatic system routes the compressed air from the source,
generally the APU, to start the engines, cabin heater, pressurize the Extended Range Fuel System (ERFS), or to export air to another helicopter for buddy start.

(2) Engine Start Valves-The engine start valves are located inside the oil cooler compartment, inboard of each respective engine's firewall. The engine start valves are electrically controlled, and air actuated to allow bleed-air to flow through to the engine starter.

When the starter switch is pressed, the engine start valve is electrically opened by the solenoid valve. Opening the engine start valve allows compressed air from the air source to motor the air turbine starter of the engine being started. The air entering the engine start valve is filtered to remove impurities from the air as it passes through the engine start valve.

(3) Crossbleed Valves-The crossbleed valves are electrically controlled and air actuated to allow bleed-air to flow through to pressurize the entire pneumatic manifold. The actuation of the crossbleed valves is accomplished through the air source heat/start switch and the automatic start system.

The crossbleed valve is electrically actuated and pneumatically opened. An electric solenoid allows the crossbleed valve to open when air is being forced out. The start relays prevent the crossbleed valve and engine start valve from being opened at the same time. There is no cockpit indication of valve position; a mechanical valve position index mark is located on the valve shaft.

(4) APU Start Bypass Valve-The APU start bypass valve is located on the lower left hand side of the APU combustion chamber on the Turbomach APUs. They are not required on the Garret APUs due to a better fuel control. The APU start bypass valve is an electrically actuated valve that allows excess air to be dumped overboard until needed for engine start. The valve, "armed" when the air source heat/start switch is in the APU position, opens to unload the compressor during the start sequence, preventing compressor stalls.

The APU start bypass valve is a solenoid-operated, normally open, pneumatic valve. The valve is open for APU start and energized closed for engine start.

NOTES:                                                                                          
                                                                                              
                                                                                              
                                                                                              
                                                                                              
                                                                                              
                                                                                              
                                                                                              
                                                                                              
                                                                                              
                                                 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STARTER RELAY FUNCTIONS

(E-denotes relay energized)
(D-denotes relay de-energized)
direct or indirect control of the following:

OVERRIDE SWITCH ARM (manual start circuit)
E. Arms override switch.
D. Disarms override switch.

ENGINE IGNITION
E. Ignition is activated (if ignition key is on).
D. Ignition is deactivated.

ENGINE AUTO-PRIME FUEL
E. Activates auto-prime.
D. Deactivates auto-prime.

ENGINE INLET ANTI-ICE
E. Closes eng. inlet Avl valve (if open).
D. Allows eng. inlet Avl to reopen (if active).

APU START/BYPASS VALVE (Turbomach only)
E. Closes valve (if armved), all APU air routed to air manifold.
D. Opens valve, allows a portion of APU air to dump outboard.

ENGINE CROSSBLEED VALVE
E. Closes crossbleed valve on starting eng.
D. Valve operates IAW A/S heat/start switch

ENGINE START VALVE
E. Allows air source to open eng. start valve.
D. Closes eng. start valve.

PCL ELECTRICAL FUNCTIONS:

1. START SWITCH: signals speed switch to energize starter relay, speed switch de-energizes relay IAV Ng speed or abort switch.

2. OVERRIDE SWITCH: (used when speed switch malfunctions) once starter relay is energized by start switch, override switch manually holds relay open.

3. ABORT SWITCH: de-energizes starter relay, all start functions stop.

ENGINE STARTER

Starter caution light illuminates IAV switch contacts within the start valve, indicates start valve is open & all functions of starter relay are activated.

AIR SOURCE

HEAT / START

ERFS

COCKPIT HEAT

"AIR SOURCE"

ENG

OF

OFF

APU

APU start/bleed valve closes when starter button is pressed (Turbovalve only)

D-27
(5) Engine Starter-The pneumatic starter is powered by bleed air, typically from APU, it motors the Ng section via the AGB and PTO. It decouples (via internal clutch) from the AGB when the engine is running. Starter limitations exist because the bleed air powering it is hot (400ºF) and can damage the starter if exposure time is excessive.

The engine starter is an air powered starter that motors the engine for starting. Compressed air acts upon the starter turbine wheel, which motors the Ng section via the AGB/PTO link. When engine RPM is greater than the starter (engine running), the starter disengages from the AGB via a one-way clutch within the starter. A magnetic pickup on the starter feeds an Ng speed signal to the speed switch (auto-start circuit) to effect starter dropout between 52 to 65% Ng. Extended starter operations can cause damage due to the high temperature of the bleed air driving the starter (about 400º F). Refer to TM 1-1520-237-10 for starter limitations.
An illuminated starter caution light that stays on with your thumb off the starter button means:

The start valve is open and the auto-start circuits (speed switch & start relays) are active. (else in Ng confirms air source is physically rotating starter, AGB & Ng section)

NOTE: A starter caution light that won’t remain illuminated when the starter button is released is an indication of an auto-start circuit malfunction (bad speed switch?), complete a manual start.

PROBLEM: If the heater shutoff valve is open during APU start the APU may fail during the start attempt as APU compressor air is vented away from it’s combustion chamber.

SOLUTION: Make sure the heater switch is “OFF” prior to moving the APU control switch “ON”.

NOTE: The heater shutoff valve is energized with DC Primary power, meaning the heater switch is functionless until AC power is applied, also the thermostat setting factors in as well making this failure mode illusive. APU failure won’t occur during initial APU start because heater valve stays closed regardless of heater switch position. During APU start when main generators are on line, the APU may fail if the heater switch is left “ON”.

SCENARIO: APU runs but APU generator switch “ON” stays nothing (APU generator shaft sheared or GCU inop). Air source “AVAILABLE, A/C power "NOT" available. You now have two choices:

1. Troubleshoot & replace defective parts. Then complete a normal engine start.
2. Complete a nonstandard #1 engine start. (electrical/mechanical/pneumatic)

IF AC POWER IS NOT AVAILABLE: Only the #1 engine start circuits will function (assumes battery state of charge sufficient enough to energize DC ESS bus). NO COCKPIT INDICATIONS WILL BE AVAILABLE until #1 PCL is advanced and main generators come on line. (a normal #2 engine start can now be completed with full cockpit instrumentation available).
d. Power Control Lever four Mechanical Functions; OFF, IDLE, FLY, and LOCKOUT.

(1) When the PCLs are in the OFF position, the fuel flow to the engine is stopped. In the OFF position, the fuel shut-off valve inside the HMU is mechanically closed through the linkage to the Power Available Spindle (PAS).

(2) With the PCLs in the IDLE position, the fuel flow begins, the HMU meters the idle fuel flow, and the engine is set at idle speed (63% Ng).

(3) In the FLY position, fuel flow is set to maximum, and the ECU trims the fuel flow in order to maintain 100% Np and Nr.

(4) Placing the engine power control lever in lockout allows the pilot to manually control the fuel flow while bypassing ECU to HMU functions. When the PCL is in LOCKOUT, care must be taken to keep the engine TGT within the operational range.

**CAUTION:** When engine is controlled with the ENG POWER CONT lever in LOCKOUT, engine response is much faster and TGT limiting system is inoperative. Care must be taken not to exceed TGT limits and keeping %RPM R and %RPM 1 and 2 in operating range.

e. Power Control Lever Electrical Functions; START SWITCH, OVERRIDE SWITCH, and the ABORT SWITCH.

**CAUTION:** To avoid damage to the engine start switch actuators, do not move the ENG POWER CONT lever from IDLE to OFF while pressing the starter button.

(1) Start Switch- The start switch function is actuated by pressing the starter button when the PCL is in the OFF (full aft) position. The start switch commands the speed switch to energize the start relay until the engine reaches 52% - 65% Ng.

(2) Override Switch- The override switch is activated by pressing and holding the starter button "IN". The override switch overrides the automatic start system, allowing the pilot to manually hold the start relay closed. The override switch is not "armed" unless the start switch has been actuated first. This prevents accidental activation of the start system with the engine already running.

(3) Abort Switch- Pulling downward on the PCL activates the abort start switch. This deactivates the automatic start functions by deenergizing the start relay.
f. Engine Start with APU- The following scenario is with the APU online, IAW chapter 8 of the TM 1-1520-237-10 engine start procedures up to pressing the starter button with the PCL in the OFF position.

(1) Press the engine start button until a rise in Ng is noted.

(2) Release the engine start button and check the starter caution light remains illuminated. If the starter caution light does not remain illuminated, the automatic start is malfunctioning, and a manual start must be accomplished.

(3) Check the engine TGT to verify it is below 150º C prior to introducing fuel into the combustion chamber. If the TGT is above 150º C, continue to motor the Ng section until the TGT drops below 150ºC.

g. Once the PCL has been slowly advanced to the IDLE position, (fuel flow begins), start the clock and watch for the following indications.

(1) A rise in TGT within 45 seconds.

(2) A rise in Oil Pressure within 45 seconds.

(3) A rise in % RPM 1, 2, or RPM R within 45 seconds.

(4) Starter drop out (starter caution light out) not prior to 52 % Ng.

(5) Monitor TGT below 850º C before IDLE speed is attained (63 % Ng).

h. Malfunctions and Pilot Actions- There are typically, five malfunctions experienced during an engine start sequence with the APU as the air source.

(1) The first malfunction listed references the starter caution light going out when the starter button is released. If this malfunction occurs, the auto-start system is malfunctioning and the pilot should conduct a manual start.

NOTE: If an ENGINE STARTER caution disappears when the starter button is released, and the ENG POWER CONT lever is OFF, the start attempt may be continued by pressing and holding the starter button until 52% to 65% Ng SPEED is reached; then release button.

(2) The second is no rise in TGT, oil pressure, or % RPM 1 or 2 within 45 seconds. If this malfunction is experienced, the pilot is to conduct an emergency engine shutdown. No % RPM 1 or 2 may be caused by starting an engine with the gust lock engaged. The cause of no rise in TGT within 45 seconds may be the ignition key is still in the "OFF" position. If this is the case, do not turn the ignition key on, or you will ignite all of the fuel that has been pumped into the combustion chamber. You must conduct a complete emergency engine shutdown.

(3) For the third malfunction, it is important to understand that during the engine start sequence, TGT limiting is inoperative. Therefore, should the pilot experience an engine TGT rise above 850º C during an engine start sequence, an emergency engine shutdown must be completed, and starter motored until TGT is below 538º C.

CAUTION: If start is attempted with ENGINE IGNITION switch OFF, do not place switch ON. Complete EMER ENG SHUTDOWN procedure.

(4) The fourth malfunction, engine starter drops out prior to 52% Ng. The Ng section of the engine needs the starter to assist until 52% Ng speed. If the starter drops out too soon a hot start may result, complete an emergency engine shutdown.

(5) An engine starter staying engaged past 65% Ng is the fifth, and final malfunction discussed. If the engine starter caution light remains on above 65% Ng, the pilot will pull downward on the malfunctioning engine PCL actuating the abort switch. If this does not cause the starter to drop out, the start valve is stuck in the open position, and hot air will eventually damage the starter. The pilot must then remove the air source as required.

i. Engine Start with other Air Sources-There are three additional air sources available for engine starting. The use of an external air source, for example an Auxiliary Ground Power Unit (AGPU) or another aircraft, is the same as an APU start except the air source is connected to the receptacle on the left side
of the aircraft. To use this air source, the AIR SOURCE HEAT/START switch must be in the "OFF" position.

(1) Ground Source- The Auxiliary Ground Power Unit (AGPU) is one of the external air sources used for engine starting.

(2) Buddy Start- The Buddy Start system (aircraft to aircraft) is another method of starting the engines. Procedures for this method are found in the TM1-1520-237-MTF.

(3) Cross Bleed Starting- Another method of starting the engine is cross bleed starting. Cross bleed starting utilizes the bleed-air shutoff valve to direct air from the operating engine to the opposite engine during the start sequence.

Starting one engine from the other (cross bleed start) is the same as starting an engine using the APU as the air source, except the AIR SOURCE HEAT/START switch will be in the ENG position. Pressure from the running engine compressor is used to start the other engine. To accomplish this, the running engine should be at 90% Ng with the RPM R at 100%, and the ENG ANTI ICE ON advisory light off. The collective may have to be raised to increase the Ng to 90% as an 18% loss of the Maximum Torque Available (MTA) on the air source engine will be experienced during the start sequence.

In order to attempt a cross bleed start, the #1 Ng must be above 90% and the #1 ENG ANTI ICE ON advisories must not appear with the #1 Engine at fly with an RPM R of 100%. A cross bleed start in flight may decrease the maximum torque available from the running engine by as much as 18%. Therefore, the APU should be used for in flight starting of an engine.

Conducting an engine start with no AC power available. If the battery is the sole source of DC power, and an air source is available (i.e. the APU available, but the APU generator is inoperative), only the No. 1 engine may be started. The No. 1 engine start valve is powered by the DC essential bus, and no instruments will operate until the AC power becomes available. The No. 2 engine start valve is powered by the No. 2 DC primary bus, and requires an operational main or APU generator, or an external power source.

Pressing the No.1 engine starter button opens the No.1 engine start valve, allowing air supplied by the APU to enter the No.1 starter and the No.1 engine.

5. LEARNING STEP/ACTIVITY No. 5. Identify the operational characteristics of the engine lubrication system.

a. Lubrication System- The entire engine lubrication system is integral with the engine. A 1.7 gallon oil tank is housed within the cold section and a liquid to liquid heat exchanger cools the oil with fuel. The lubrication system is a dry sump system that lubricates the AGB and 3 sumps containing bearings that support Ng and Np. An emergency lubrication system provides lubrication to the engine should there be an oil system malfunction. The oil filter has a bypass function that routes oil around the filter should it become clogged.

(1) Oil Tank- The oil tank is integral with the engine and has a 1.7 gallon capacity. A visual indication of the oil level is through a vertical sight-glass on each side of the tank.

Oil consumption can be up to 1 quart for every 6.5 flight hours, verify the oil level is far enough above the add marker to complete the planned mission, two quarts are required to service the engine from the ADD mark to the FULL mark. If a flight over 6 hours is to be made the engine oil level must be at the full line of sight glass before the flight.

(2) Oil Pump- The oil pump, located on the front of the AGB, contains 7 elements, 1 pump element and 6 scavenge elements. The oil pump is driven by the AGB, variable IAW Ng, so normal oil pressure varies from 20 to 100 psi.

(3) Oil Filter- The oil filter is located on the forward end of the accessory gearbox. The oil filter consists of a stainless steel bowl with an impending bypass indicator, a throw away filter element, and a bypass valve assembly. The bowl threads into the forward side of the accessory gearbox. The bypass valve assembly threads into the accessory gearbox and supports the aft end of the filter element. If the impending bypass indicator button pops, it means that the filter element is dirty and that it needs to be
replaced. Once the button has popped, it cannot be reset until the bowl and the filter element has been removed. The oil filter bypass sensor switch (located next to the filter) will send a signal to the cockpit and illuminate the #1 or #2 OIL FLTR BYPASS caution lights to let the pilot know the filter is in a bypass condition. When the oil temperature reaches about 38 °C the caution should disappear.

If the oil is cold during engine starting, the pressure will be high which will cause the oil to be bypassed. A thermal lockout prevents the button from popping when the oil temperature is below 38 °C. The bypass valve assembly opens when the oil pressure is too high. This means the filter element is dirty or the oil is still cold. The bypass valve will close when the oil temperature warms up to operating temperature and pressure decreases.

Oil Filter Bypass Indicator Systems (Normal Position): Differential pressure between the filter inlet and outlet act to move a piston against a spring when the pressure reaches 44 to 60 psi. The piston contains a magnet, which normally attracts a red button assembly and holds it seated against its spring. When the piston moves, the button is released and it extends 3/16 inch to visually indicate an impending bypass condition. The button is physically restrained from tripping by a cold lockout bimetallic latch if temperature is less than 100 to 130 °F to prevent a false trip during cold starts.

Oil Filter Bypass Indicator Systems (Tripped Position): As the button is released, a small ball also moves out of position to latch the button and block reset. The internal piston assembly automatically resets on shutdown; however, the indicator remains latched out. When the bowl is removed from the gearbox and the filter element is removed, a spring-loaded sleeve around the indicator moves aft and pulls the piston assembly to a tripped position. This makes the button trip if operation is attempted with no filter in the bowl. To reset the indicator, the bowl is held vertical so that the button latch ball can roll out of the latched position. The button is then manually reset after the filter element has been replaced.

(4) Oil Pressure and Temperature Transmitters- The oil pressure transmitter monitors engine oil pressure and forwards the signal to the CDU through the SDC. Normal oil pressure may range from 20 to 100 psi. Minimum oil pressure is 20 psi below 90% Ng or 35 psi above 90% Ng. The ENGINE OIL PRESS caution light illuminates at 20 psi. The oil temperature transmitter monitors engine oil
temperature and forwards the signal to the CDU through the SDC. When oil temperature reaches 150°C, the ENGINE OIL TEMP caution light illuminates.

(5) Oil Cooler- The fuel-oil cooler is a tube and shell design which cools the combined output of the scavenge discharge oil that is ported through gearbox cored passages to the cooler. The cooler is mounted adjacent to the fuel boost pump on the forward side of the gearbox. The oil cooling process heats the fuel, which improves fuel atomization. A counter parallel flow multi-pass cooler design is used in order to minimize pressure drop while obtaining maximum cooler effectiveness. Fuel flows through the tubes, while the oil flows over the tubes, resulting in the counter-parallel flow arrangement. If the oil cooler pressure becomes too high, the oil cooler relief valve will open to dump scavenge oil directly into the oil tank.

The port plates, eccentric rings, and gerotors are assembled into a surrounding concentric aluminum tubular housing that maintains all elements in proper alignment. The oil suction and discharge passages from the gerotors are brought radially through the housing to match the appropriate locations of the mating passages in the engine gearbox casting. The entire stack of port plates is retained in the housing with retaining rings at the spline end. The outermost end of the housing has an integrally cast cover. The cover bolt holes are so arranged as to properly orient the pump assembly in the gearbox housing during installation.

(6) Chip Detector- The engine diagnostic device most likely to provide the first warning of an impending part failure is the chip detector located on the front of the accessory gearbox. The chip detector has an outer shell with an internal magnet, an electrical connector, and a removable screen. The magnet attracts magnetic particles to the detector. When these particles bridge the gap between the magnet and the outer shell, a circuit is completed which illuminates the CHIP #1 ENGINE or CHIP #2 ENGINE chip detector caution light in the cockpit.

b. Lubrication System Flow- Oil flow is drawn from the oil tank by the lubrication and scavenge pump. From the pump, pressurized oil flows through the oil filter and into the cored passages in the accessory gearbox. Inside of the gearbox, the oil divides and flows to the A, B, and C sumps and to the accessory gearbox. Scavenge oil from the lubrication and scavenge pump then flows through the electrical chip detector. From there, the oil flows through the oil cooler and into the main frame. Scavenge oil enters a manifold at the top of the main frame. The oil then flows through the scroll vanes and back to the oil tank.
6. LEARNING STEP/ACTIVITY No. 6. Identify the operational characteristics of the engine electrical system.

a. Electrical System

   (1) Electrical System Components (Left Side). The T700-GE-700 engine uses electrically operated accessories to control anti-icing airflow, ignite the fuel-air mixture in the combustor, and control the engine power level. In addition, electrical indication and warning devices assist the pilot in engine operation. The electrical system provides: all electrical power required for engine ignition and all electrical control requirements throughout the operating range of the engine without the use of airframe power.

   Interconnecting harnesses between engine electrical and diagnostic components; an accurate and stable trimming signal to the HMU to isochronously govern power turbine speed, limit maximum TGT, and share the load between engines; and a Np overspeed limiting system. Ground checking capability for the Np overspeed system is also provided.

   (2) Electrical System Components (Right Side). The electrical system also provides: engine ignition during starting; cockpit signals of gas generator speed (Ng), power turbine speed (Np), engine shaft torque (Q), power turbine inlet temperature (T4.5), fuel and oil pressure, and oil temperature. Also provided are: history counter signals of Ng and T4.5; and an engine shaft torque signal for use in the load-sharing circuit and hot start prevention.

   (3) Electrical Connection Diagram- Interconnecting wiring harnesses are color-coded to aid the mechanic.

   (a) The yellow harness connects circuits that are dedicated solely to "engine electrical functions".

   (b) The blue harness is dedicated to the "Np Overspeed and torque indication systems".

   (c) The green harness functions as an "engine to airframe interface".

   (d) The black harness is dedicated to "engine ignition".

b. Engine Alternator- The engine-supplied electrical alternator is mounted on the forward face of the Accessory Gearbox (AGB), on the right-hand side. It supplies AC power to the ignition exciter, Electrical Control Unit (ECU), and supplies an Ng speed signal to the cockpit. The alternator powers all essential engine functions. The alternator rotor is mounted on a cantilevered shaft extending from the gearbox. The rotor contains a set of 12 permanent magnets. The stator housing encloses the rotor and is bolted to the gearbox case. It contains three separate sets of windings for its three functions: Ignition power, ECU power, and Ng signal.

   (1) A Gas Generator Ng speed signal originates at the alternator and is forwarded to the CDU through the SDC. When the Ng VID on the CDU indicates 55 % Ng speed, the ENGINE OUT warning light illuminates and the audio warning is also activated. Failure of the Ng winding in the alternator causes a false ENGINE OUT indication, always cross check RPM R and TGT to verify the ENGINE OUT warning.

   (2) A dual ignition exciter (5000 to 7000 volts) is mounted on the right side of the engine, and powers the two igniter plugs. The engine alternator supplies power for the engine ignition. The ignition is activated when three conditions are met: the key is on, the start relay is energized, and the alternator is supplying power (the AGB is being motored by the pneumatic starter). Ignition is only required to light off the fuel air mixture in the combustion chamber and deactivates when the starter caution light goes out. Failure of the ignition winding on the alternator would prevent any further start attempts on that engine.

   (3) The alternator is the primary power source for all ECU functions, although some ECU functions can receive power from airframe sources. When alternator power is removed from the ECU through an alternator failure/loss of rotation, indications of TRQ and % RPM 1 or 2 is lost, and the CDU Ng indication is lost, triggering the ENGINE OUT warning system. The absence of an ECU input to the HMU results in the reset of engine power to maximum (a high side failure), and the TGT indication rises (possibly above limits).
c. Electrical Control Unit- The ECU is mounted below the compressor casing with a heat sink projecting into the collection scroll where it's cooled by the dirty air flow. The ECU functions primarily as an electronic engine governor. The ECU has 7 functions.

1. TGT Limiting prevents the TGT from exceeding 850 °C and protects the hot section components.
2. Np Governing maintains power turbine speed at 100%.
3. Load Sharing matches the TRQ output of both engines within 5%, and balances the power output of both engines.
4. Np Overspeed Protection prevents power turbine speed from rising above 106 ± 1% (Still available during ECU Lockout).
5. Conditioning of Cockpit Signals are forwarded by the ECU from the power turbine speed (Np) and torque (Q).
6. History Data Recorder Feed of TGT and Ng speed is provided for life tracing of the GG rotors and IPS blower.
7. NP reference to the cockpit (96-100% RPM 1 & 2).

The Overspeed Circuit Connector is where the blue cable is connected to the ECU. The blue cable carries signals between the torque and overspeed sensor, the ECU, and the POU. Of these systems, it is important to note that the Np Overspeed Switch has circuits with redundant electrical power sources.

The Control Circuit Connector is where the yellow cable is connected to the ECU. The yellow cable carries signals between the ECU, speed sensor, HMU, thermocouple assembly, history recorder, and alternator. It is important to note, of these systems; the TGT limiting is inoperative and or ineffective during engine start, ECU lockout, alternator failure, and compressor stall. And the data feed to the history recorder contains circuits with a redundant electrical power source.
The (Diagnostic) Interface Connector is used for troubleshooting the engine or electrical control system while the aircraft is on the ground. The (Aircraft) Interface Connector, green cable, transmits information to the cockpit instruments.

d. Electrical Control Unit Input Signals:

(1) Alternator electrical power, which powers all ECU circuits.

(2) Main AC generator to power Np O/S protection function and history data recorder should the engine alternator fail.

(3) T4.5 thermocouple harness for TGT limiting (relayed to cockpit for TGT indication).

(4) Np sensor for Np governing function and Np tachometer signal for the cockpit.

(5) TRQ and Np O/S sensor input for load share, cockpit TRQ indication, and an Np speed signal for Np O/S protection function.

(6) Np reference input from collective INCR/DECR switches to set Np governing speed.

(7) Torque signal from the other engine (Q1 or Q2) for torque matching.

The engine alternator is the primary power source for all ECU circuits. When alternator power is absent (alternator failure) all ECU circuits except Np O/S protection and the history data feed are rendered inoperative. The No. 1 and No. 2 ECU’s accept AC primary bus electrical power as a backup power source (in the event of alternator failure) for Np O/S protection circuits and history data recorder circuits.

The thermocouple harness senses the temperature between the two turbine sections (Ng and Np) at T4.5, the TGT harness provides a direct reading to the ECU for TGT limiting function, the signal is relayed direct to the CDU via the SDC for cockpit TGT indication.

The Np sensor and Torque and O/S sensor contain a permanent magnet and wire coil that senses pulses induced by teeth on the power turbine shaft, these pulses are used to generate a power turbine speed signal that's used for Np governing and for cockpit indication of % RPM 1 or 2.

The torque and O/S sensor references torque by actually measuring power turbine shaft twist. This is accomplished by pinning a reference shaft to the front end of the power turbine shaft and allowing it to rotate relative to the drive shaft. Nr loads the power turbine on the output end while Ng drives the power turbine rotors; this causes the power turbine shaft to twist. This shaft twist causes the teeth on the power turbine shaft to vary in position relative to the reference shaft teeth. A torque circuit within the ECU processes the electronic pulses. At intermediate power (1,543 SHP), the output torque is 403 ft/lb and the twist of the shaft is 7.4º. A torque signal is relayed from each engine to the other engine for the load share function.

Np reference for the Np governor is adjustable via the INCR/DECR switch on the collective sticks, either switch simultaneously controls both ECU’s; individual adjustment of each engine is not allowed. Pilot authority to adjust the Np reference is limited to 96-100% rpm 1 or 2, with the pilot side switch having authority should both switches be actuated at the same time.

A torque (Q1/Q2) signal is exchanged between both ECUs for the load share function.

e. Operation of Electrical Control Unit Circuits

(1) ECU cockpit signal generation, in addition to the speed governing functions, the ECU conditions and forwards the Np signal to the cockpit. An isolation transformer receives Np speed pulses from the Np sensor. These pulses are converted into a power turbine speed signal that is forwarded to the PDU through the Signal Data Converter (SDC). During an alternator failure the cockpit Np signal, % RPM 1 or 2, is lost because the isolation transformer needs alternator power to function.

(2) ECU cockpit signal generation, in addition to the speed governing functions, the ECU conditions and forwards the TRQ signal to the cockpit. A torque circuit receives pulses from the torque and O/S sensor. The timing differential between the pulses is converted into a torque signal to the PDU through the SDC. The torque circuit also forwards the torque information to the load share comparator to both
ECU's. During an alternator failure, the cockpit TRQ signal is lost because the torque circuit needs alternator power to function.

(3) The TGT limiting system protects engine hot section components from stress or damage by limiting the temperature at T4.5 to approximately 843 °C. When TGT limiting is active it reduces fuel flow at the HMU by actuating the torque motor. When the TGT limiter is active it overrides the Np governor and load sharing circuits. The TGT limiter can only reduce fuel flow. TGT limiting is disabled when the system is in ECU lockout. When the system is in ECU lockout care must be taken to keep the TGT within operational ranges.

**WARNING:** TGT limiting does not prevent over temperature during the following conditions:

* Engine start - ECU functions are not fully operational during engine start.
* ECU lockout - Pilot has locked-out the TGT limiting circuit, Np governing, and Load Share circuits.
* Compressor Stall - TGT limiting system can't react quick enough.
* Alternator Failure - TGT limiting, Np governing, and load share circuits have no electrical power.

(4) Np governing circuit maintains Np and Nr at a constant speed, normally 100%. The Np governor compares actual Np speed from the Np sensor to the Np reference set by the pilot. Any time the actual Np speed differs from the reference, the Np governor sends an increase or decrease fuel flow signal to the HMU through the torque motor. The Np governor has authority to increase the fuel flow to maximum, or decrease fuel flow to idle. Np governing is disabled when the system is in ECU lockout.

(5) Torque matching circuit (Load Share Comparator) maintains a 5% match between both engine torques. Load share is active when the engine torques are not within 5%, only the low torque engine load shares. The load share comparator in each ECU monitors Q1 and Q2, any time Q1 is more than 5% less than Q2 the load share circuit temporarily increases the Np reference in Np governor by 3%. The Np governing circuit increases fuel flow, causing Np and Nr to increase, the other engines Np governor reacts to the increasing Nr by reducing its fuel flow. So the low engine increases power as a function of load share, while the high engine reduces power as a function of Np governing. When both engine torques fall back into the 5% range, the load share allows the Np governor to revert to its original governing speed, which is normally 100%. TRQ matching is disabled when the system is in ECU lockout.

(6) The Np Overspeed protection circuit protects the power turbine from overspeed conditions that might cause damage or destruction. Np O/S circuits obtain operating power from two independent sources, the engine driven alternator and the main AC generator(s). The Overspeed switch senses a separate Np signal from the torque and O/S sensor, and is independent from all of the other ECU circuits. The Np O/S protection activates when the Np speed exceeds 22,200 RPM (106 ±1%), the overspeed switch activates a solenoid in the POU, fuel flow to the engine is immediately reduced, Ng output decreases, and the power turbine speed decreases. The reduction in fuel flow will continue until the cause of the overspeed is removed or % RPM is reduced manually.

(7) The history data recorder circuits include a TGT signal that is relayed directly to the history data recorder, and a Ng speed signal originating from the engine alternator which is relayed to the history data recorder as well. History data is used to track the life span of the GG rotors and the IPS blower.

**NOTES:**
**Electrical Control Unit**

- **TGT LIMIT AMPLIFIER**
  - Prevents overtemp; limits TGT to 850°C
- **Np GOVERNING**
  - Maintains constant power turbine speed, which yields constant main rotor rpm
- **LOAD SHARE COMPARATOR**
  - Keeps torques matched within 5% (only the low engine load shares)
- **TGT OVERSPEED SWITCH**
  - Activates overspeed solenoid in POU to limit power turbine speed to 106 ± 1%.
- **TORQUE MOTOR AMPLIFIER**
  - Acts on torque motor in HMU, also receives feedback signal from LVDT for signal stabilization.
- **HISTORY RECORDER**
  - Records TGT data
- **OTHER ENGINE**
  - Np reference to ECU

**Components**

- **Engine driven fuel boost pump**
- **Fuel filter**
- **Hydromechanical Unit (HMU)**
- **Linear Variable Differential Transducer (LVDT)**
- **Turbine**
- **Thermocouple harness (7 probes)**
- **Power Turbine**
  - Shaft rotation: 20,900 RPM = 100% RPM 1 or 2
- **Torque & Np overspeed sensor**
- **Np sensor**
- **Power Turbine shaft rotation**
- **Other collective inc/dec switch**
- **Sets Np reference in both ECUs, 96-100% RPM 1 or 2 (pilot has priority)**
- **Np ref.**
- **To Fuel Injectors**
- **Hydromechanical Unit (HMU)**
- **Pressurizing & Overspeed Unit (POU)**

**Other Relevant Information**

- **OVERSPEED TEST CIRCUITS A & B (upper console)**
- **Oil Cooler**
- **Engine driven fuel boost pump**
- **Submerged boost pump (electric)**
- **#1 Fuel cell**
- **#2 Fuel cell**
- **#3 Fuel cell**
- **#4 Fuel cell**
- **#5 Fuel cell**
- **#6 Fuel cell**
- **#7 Fuel cell**
- **AC Primary Bus**
- **SDC**
- **T4.5**
- **Other collective inc/dec switch**
- **Engine driven fuel boost pump**
- **Fuel filter**
- **Hydromechanical Unit (HMU)**
- **Linear Variable Differential Transducer (LVDT)**
- **Np sensor**
- **Power Turbine shaft rotation**
- **Torque & Np overspeed sensor**
- **Power Turbine**

**References**

- **837-849**
- **115V, 400Hz**
- **96-100% RPM 1 or 2 (pilot has priority)**
- **9.5**

**Version**

- **ver 1.01**
- **10/00**

**Additional Notes**

- **TGT feed to history data recorder**
- **TGT data**
- **Np speed data**
- **Overspeed test circuits A & B (upper console)**
- **To Fuel Injectors**
7. LEARNING STEP/ACTIVITY No. 7. Identify the operational characteristics of the engine fuel system.

a. T700 Fuel System Overview- The UH-60 fuel system is designed to provide the proper fuel flow to the engine under all operating conditions including starting, idle, normal flight, and maximum power.

Components of the engine fuel system include (in order of fuel flow) an engine driven boost pump, fuel filter, fuel pressure sensor, hydromechanical unit (HMU), liquid to liquid cooler (oil cooler), pressurizing and overspeed unit (POU), 12 fuel injectors, and 2 primer nozzles.

The UH-60 fuel system was designed to operate in a "suction mode", meaning the engine driven boost pump suction fuel from the cell to feed the engine. Should a leak occur in the main fuel supply lines no fuel would leak or spray from the hole, air would be drawn in. The draw back to operating "pressurized" verses "suction" is that a break or hole in the main fuel supply line now results in fuel spray.

b. Fuel System Flow- Fuel originates from the fuel cells, each containing an electric submerged boost pump that can pressurize fuel to 25-27 psi. The engine driven boost pump suctions fuel at -3 to -6 psi in the suction mode from the selected fuel cell. If the electric submerged boost pump is "ON", fuel is pumped to the engine driven boost pump in the pressurized mode. The engine driven boost pump raises the fuel pressure to 45-90 psi, and pressurizes the AGB fuel passages. Next are the fuel filter, the fuel pressure sensor (controls the #1 FUEL PRESS and #2 FUEL PRESS caution lights), and the HMU. The HMU has a high pressure vane pump that increases the fuel pressure to 400-832 psi, and varies fuel flow through a main metering valve. Main metered fuel then flows from the HMU through the oil cooler, the POU, and then to either 2 start fuel nozzles or 12 main fuel injectors.
c. Hydromechanical Unit- The hydromechanical unit is mounted to, and driven by the AGB. The HMU also receives filtered fuel through the AGB core passages. The HMU contains a high pressure pump that delivers fuel to the combustion chamber. The vane pump is self priming and is driven directly by the AGB (9,947 rpm); it pressurizes the fuel to about 300 psi at IDLE, or to 400-832 psi at FLY. The HMU Main fuel metering control responds primarily to three main inputs: Collective pitch through the LDS, Power Control Lever through the PAS, and ECU inputs for governing. The HMU also responds to Compressor Inlet Temperature (T2), Compressor Discharge Pressure (P3) and Ng speed. In addition to fuel flow metering the HMU positions variable geometry (VG) linkage through a hydraulic piston extending from the left side of the HMU.

Hydromechanical Unit 9 Functions:

1. Fuel Pumping (high pressure Ng driven vane pump).
2. Fuel flow Metering (main metering valve controlled by the pilot, HMU, and ECU).
5. Ng limiting and Ng shutdown (max. Ng at 103%, shutdown at 110%).
6. Variable Geometry positioning (IGV, variable vanes, and AISBV).
7. Torque motor to trim Ng governor (ECU/HMU interface, pilot override through ECU lockout).
8. PAS override allowing manual control with ECU inoperative (ECU lockout).
9. Open Vapor Vent for fuel system priming (PCL in lockout position opens a HMU case vent, allows pilot to purge fuel system using prime boost, or submerged boost pump).

Ng Limiting- Ng limiting can be a function of Ng governing. The HMU mechanically computes and sets the maximum Ng speed IAW the T2 sensor input, or a physical limitation in which the Ng speed is "Max Fuel Flow limited", the resultant Ng speed with metering valve full open. The type of limiting that is in effect depends on the T2 (engine inlet temperature). Under warm climatic conditions higher Ng speeds are allowed with the maximum Ng limited to 103 % Ng (the fuel flow limited). In warm conditions, TGT limiting will most likely limit the Ng prior to Ng limiting. In extreme cold conditions, less Ng speed is allowed. The Ng limiting (Ng governing) may be entered prior to the TGT limiting. The Ng speed - T2 charts can be found in TM 1-2840-248-23 (Engine, Aircraft Turboshaft Models T700).
(1) Vane Pump- The internal Vane pump is an Ng driven high pressure vane pump located inside the HMU. The vane pump increases fuel pressure to supply internal HMU fuel scheduling systems, and to pressurize metered fuel passages (lines) enroute to the start and main fuel nozzles/injectors. In the unlikely event of a simultaneous failure of both the submerged boost pump and engine driven boost pump, the HMU vane pump can suction fuel from the fuel cell (10,000 ft and below, assuming all fuel passages are intact). The main metering valve controls pressurized fuel from the vane pump to the Ng section.

(2) Three primary HMU functions affecting adjustment of fuel flow via the metering valve:

(a) A LDS input adjusts the load demand schedule. The load demand schedule is manually adjusted by collective movements through the LDS. Raising or lowering the collective increases or decreases the fuel flow. The collective link to this schedule proactively attempts to match engine power output with the main rotor load. The term Proactive is used because power changes are made simultaneously with the main rotor load changes. This attempt to match engine power output to the rotor load is approximate, and requires further adjustment by the ECU circuits through the torque motor. In the event of a LDS cable shear, or a collective bias tube pin shear, an internal spring resets the LDS to a position that equates to full up collective; Np governing will limit back fuel if the engine is in governing with the ECU operating. If such a failure occurs at IDLE, the Ng speed on the effected engine will indicate higher than the other engine.

(b) An ECU input through the Torque motor refers to trimming (fine adjustment) of Ng output that acts upon the power turbine. The torque motor accepts three inputs: TGT limiting, Np governing, and load sharing or torque matching. The torque motor acts as an interface between the ECU and the load demand schedule of the HMU. ECU trimming of the HMU reduces pilot load by automatically keeping Np and Nr constant (Np governing), keeping power outputs of the engines closely matched (load sharing), and preventing TGT from reaching destructive levels (TGT limiting). Torque motor trim of the collective schedule is reactive because schedule adjustments are made after parameters physically change. The pilot not on the controls may sever the ECU to HMU interface by locking out the torque motor using the PAS override function, and then manually trim the collective schedule with the PCL, effectively replacing the three ECU functions that have been locked out.

(c) A PAS input sets the maximum power available schedule. Set by the PCL through the power available spindle. Sets maximum power limits that may never be exceeded by collective movements. PAS has no internal spring to set a default position, if the PAS cable shears (shot in two), power level does not change, however all PAS functions are lost.

(3) Additional fuel flow metering functions/features of the HMU:

(a) Acceleration/Deceleration fuel flow limiting is an automatic mechanical function that prevents flameout due to rapid power changes (power changes called upon by PAS, LDS, or ECU). This limits the metering valve movement rate to prevent engine flameout due to excessively rich, or lean, fuel/air ratios.

(b) The Ng limiting and Ng shutdown occurs when the Ng limiting limits the fuel flow (through Ng governing or maximum fuel flow) to control the rotational speed of the compressor/gas generator turbine rotors (actual limiting speed depends on T2). Keep in mind; TGT limiting may precede Ng limiting depending on the T4.5. As a general rule, more Ng is allowed in warm weather, less Ng is allowed in cold weather. Ng shutdown is engine shutdown (flameout) at 110 % Ng to prevent destruction of the Ng section due to excessive Ng speed. Ng shutdown occurs when a mechanical Ng speed sensing mechanism inside the HMU (centrifugal flyweights) stops all fuel flow to the engine when the Ng speed reaches 110 %.

There is a relationship between Ng limiting and Ng shutdown. There are two types of Ng limiting (Ng governing or maximum fuel flow) that limit the overall Ng speed, a malfunctioning T2 sensor may cause the Ng governing to allow Ng speed to increase well beyond the maximum design parameters. Test cell analysis places catastrophic Ng section failure at approximately 150-160 % Ng, thus Ng shutdown is a fail safe fuel metering function that prevents catastrophic failure in the event the Ng governing fails to properly limit the Ng speed.
(c) The PAS override function is used if an ECU malfunction causes an uncommanded power reduction as low as idle. The pilot can reclaim lost power through ECU lockout. Advancing the PCL to the lockout position mechanically blocks off the torque motors fuel controlling passage within the HMU, effectively disabling all torque motor inputs, engine power saturates to maximum, and the PCL is quickly retarded to set power at the desired level. Full manual control is available while in ECU lockout. Moving the PCL to the IDLE detent reopens the torque motor fuel control passage restoring torque motor (ECU) operation.

(4) HMU functions not affecting fuel flow metering:

(a) Variable geometry positioning- A variable geometry actuator extending from the HMU varies the angle of attack of the IGV's and the variable stator vanes, and opens or closes the anti-ice/start bleed valve. As the Ng speed increases, the IGV and variable vanes are sequenced open while the AISBV is closes. As the Ng speed lowers, the IGV and variable stator vanes are sequenced closed, while the AISBV opens. The pilot has a cockpit indication of the AISBV position, when the AISBV is opened by the HMU (or pilot for A/I) the "engine A/I" advisory light will illuminate. Actual positioning of IGV, variable vanes, and AISBV depends on T2 and Ng speed.

(b) Vapor vent valve- The vapor vent valve allows the pilot to manually prime the fuel system passages from the fuel cell to the HMU case cavity. Holding the PCL in the lockout position with engine not running vents the HMU inner case (normally full of pressurized fuel) to the overboard drain. Activating either the prime boost pump or the submerged boost pump will then purge the fuel system. When fuel is observed exiting the overboard drain, located on aircraft belly, the prime maneuver is complete. Manual priming is required when the fuel system components are changed due to maintenance, or if the TGT rise is not noted within 45 seconds during cold weather operation. See chapter 8 in TM 1-1520-237-10 for current manual priming procedures.

(c) Pressurized Overspeed Unit (POU) - The POU is located on the aft side of the AGB; all main metered fuel from the HMU passes through the POU. P-3 air is supplied to the POU for fuel purging. The POU has three outlet tubes. One leads to the start fuel manifold and two primer nozzles, another leads to the main fuel manifold and 12 fuel injectors, and a third serves as an overboard drain. The POU has four functions: (1) sequences start fuel to two primer nozzles, (2) sequences main fuel to twelve main fuel injectors, (3) purges start and main fuel manifolds and nozzles/injectors, and (4) fuel flow cut back to provide Np O/S protection IAW the ECU input.
8. LEARNING STEP/ACTIVITY No. 8. Identify the operational characteristics of the engine anti-ice system.

a. Engine Anti-Ice System Overview- The engine anti-ice system is comprised of two separate systems, the engine anti-ice and engine inlet anti-ice. Both prevent ice from damaging the engine and are activated by one switch. The engine A/I is controlled, or actuated, through the AISBV. The engine inlet A/I is controlled, or actuated, through the inlet A/I valve and the ambient air sensor. Each system has its own advisory light located on the caution/advisory panel. When the engine and engine inlet A/I is activated, a 16% loss of MTA for that engine is realized; with the cabin heat on an additional 4% reduction of MTA occurs for a total of 20%. This is based on the assumption that both systems are active. Electrical power is required to deactivate both systems, if there is the absence of electrical power; the system has a fail-safe causing the A/I system to be active.
Anti-Ice Airflow- The Engine A/I is pilot activated electrically through the engine anti-ice switch on the upper console. When the switch is placed in the "ON" position, electrical power is removed from a solenoid in the AISBV. The AISBV sequences open to direct hot fifth stage compressed air, P-2.5, through ducting that anti-ices each swirl vane, the nose splitter, and each IGV. A micro switch within the AISBV illuminates the ENG ANTI-ICE ON advisory light. Keep in mind, the AISBV is also actuated mechanically by the HMU for compressor bleed functions; this also causes illumination of the ENG ANTI-ICE ON advisory light.

b. Engine Anti-Ice- The Engine Inlet A/I is also pilot activated via the engine anti-ice switch on the upper console. When the switch is "ON" the engine inlet A/I is "ARMED", meaning it may or may not activate. Activation of engine inlet A/I depends on ambient temperatures detected at the ambient air sensor in the inlet, preventing activation of inlet A/I in hot environments, possibly causing damage to the fiberglass inlet assembly. The inlet A/I valve is connected to its own P-2.5 supply, allowing it to function independent of engine A/I. When active, stage 5 air (P-2.5) is directed through fiberglass ducting and out the gill slits of the engine inlet assy.

Engine Inlet Anti-Ice Airflow- The ENG INLET ANTI-ICE ON light is illuminated via a thermal switch inside the inlet when the inlet temperature reaches 93°C. At ambient air temperatures between 4-13 ºC the valve may be open or closed. At 4 ºC or colder the valve must be open, at 13 ºC or warmer the valve must be closed. This prevents overheating of the fiberglass inlet assembly.

(1) Engine Anti-Ice Activation- At ambient temperatures of 4º C and colder, when the NO. 1 or NO. 2 ENG ANTI-ICE switch is placed in the ON position, the corresponding ENG ANTI ICE ON advisory light will illuminate. Activation of the corresponding ENG INLET ANTI ICE ON advisory light indicates that inlet anti-icing is being provided and the fairing temperature is at 93º C.

(2) By placing the NO.1 ENG ANTI-ICE switch in the ON position, the No.1 Engine Anti-Ice system is activated (#1 ENG ANTI-ICE ON light illuminated), and the No.1 Engine Inlet Anti-Ice system is activated (#1 ENG INLET ANTI-ICE ON light illuminated).

**Engine & Engine Inlet Anti-Ice**
UH-60 PNEUMATIC SYSTEM

AIR SOURCES (4)
- APU
- Engine #1
- Engine #2
- External (GPU or other UH-60)

USE OF BLEED AIR
- Engine start (single or dual engine start)
- Cockpit heat
- Pressurization of external fuel tanks
- Engine & Engine inlet anti-ice
- Export to other helicopter (via buddy hose)

INLET A/I VALVE CONTROL
- When A/I switch is on, valve opens/closes IAW ambient temp:
  - 4 deg. C or colder valve should open, 13 deg. C or warmer valve should close, between 4-13 deg. C valve may be open or closed.
  (protects fiberglass inlet from heat damage)

4% loss of MTA when heater is active. (If only one engine is operating, a 4% loss of MTA will be realized on that engine. With two engines operating the loss is shared between the two engines.)

A 16% loss of MTA is realized when engine & engine inlet A/I is activated (loss is realized only on the engine being anti-iced, there is no exchange of bleed air between engines for anti-ice purposes)

#1 AISBV can be opened/closed by pilot for A/I function.
#2 AISBV can be opened/closed by HMU for compressor bleed function.
When switch is in ENG position, crossbleed valves are armed & will open if P-2.5 is present. With switch off, both valves close.
When switch is in APU position, apu start/bypass valve (turbomach apu only) closes when either start button is pressed (a start relay function). With switch OFF, valve remains open and vents a large portion of apu air overboard. To remove 100% of apu bleed air from the pneumatic manifold system the apu must be shut down. (Garrett type APUs don't have a start/bypass valve)

#2 A/I valve is passing P-2.5 to nLite System.

AIR SOURCES (4)
- APU
- Engine #1
- Engine #2
- External (GPU or other UH-60)

USE OF BLEED AIR
- Engine start (single or dual engine start)
- Cockpit heat
- Pressurization of external fuel tanks
- Engine & Engine inlet anti-ice
- Export to other helicopter (via buddy hose)

INLET A/I VALVE CONTROL
- When A/I switch is on, valve opens/closes IAW ambient temp:
  - 4 deg. C or colder valve should open, 13 deg. C or warmer valve should close, between 4-13 deg. C valve may be open or closed.
  (protects fiberglass inlet from heat damage)

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#2 AISBV can be opened/closed by HMU for compressor bleed function.
When switch is in ENG position, crossbleed valves are armed & will open if P-2.5 is present. With switch off, both valves close.
When switch is in APU position, apu start/bypass valve (turbomach apu only) closes when either start button is pressed (a start relay function). With switch OFF, valve remains open and vents a large portion of apu air overboard. To remove 100% of apu bleed air from the pneumatic manifold system the apu must be shut down. (Garrett type APUs don't have a start/bypass valve)

#2 A/I valve is passing P-2.5 to nLite System.

AIR SOURCES (4)
- APU
- Engine #1
- Engine #2
- External (GPU or other UH-60)

USE OF BLEED AIR
- Engine start (single or dual engine start)
- Cockpit heat
- Pressurization of external fuel tanks
- Engine & Engine inlet anti-ice
- Export to other helicopter (via buddy hose)

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- When A/I switch is on, valve opens/closes IAW ambient temp:
  - 4 deg. C or colder valve should open, 13 deg. C or warmer valve should close, between 4-13 deg. C valve may be open or closed.
  (protects fiberglass inlet from heat damage)

4% loss of MTA when heater is active. (If only one engine is operating, a 4% loss of MTA will be realized on that engine. With two engines operating the loss is shared between the two engines.)

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#2 AISBV can be opened/closed by HMU for compressor bleed function.
When switch is in ENG position, crossbleed valves are armed & will open if P-2.5 is present. With switch off, both valves close.
When switch is in APU position, apu start/bypass valve (turbomach apu only) closes when either start button is pressed (a start relay function). With switch OFF, valve remains open and vents a large portion of apu air overboard. To remove 100% of apu bleed air from the pneumatic manifold system the apu must be shut down. (Garrett type APUs don't have a start/bypass valve)

#2 A/I valve is passing P-2.5 to nLite System.

AIR SOURCES (4)
- APU
- Engine #1
- Engine #2
- External (GPU or other UH-60)

USE OF BLEED AIR
- Engine start (single or dual engine start)
- Cockpit heat
- Pressurization of external fuel tanks
- Engine & Engine inlet anti-ice
- Export to other helicopter (via buddy hose)

INLET A/I VALVE CONTROL
- When A/I switch is on, valve opens/closes IAW ambient temp:
  - 4 deg. C or colder valve should open, 13 deg. C or warmer valve should close, between 4-13 deg. C valve may be open or closed.
  (protects fiberglass inlet from heat damage)

4% loss of MTA when heater is active. (If only one engine is operating, a 4% loss of MTA will be realized on that engine. With two engines operating the loss is shared between the two engines.)

A 16% loss of MTA is realized when engine & engine inlet A/I is activated (loss is realized only on the engine being anti-iced, there is no exchange of bleed air between engines for anti-ice purposes)

#1 AISBV can be opened/closed by pilot for A/I function.
#2 AISBV can be opened/closed by HMU for compressor bleed function.
When switch is in ENG position, crossbleed valves are armed & will open if P-2.5 is present. With switch off, both valves close.
When switch is in APU position, apu start/bypass valve (turbomach apu only) closes when either start button is pressed (a start relay function). With switch OFF, valve remains open and vents a large portion of apu air overboard. To remove 100% of apu bleed air from the pneumatic manifold system the apu must be shut down. (Garrett type APUs don't have a start/bypass valve)

#2 A/I valve is passing P-2.5 to nLite System.

AIR SOURCES (4)
- APU
- Engine #1
- Engine #2
- External (GPU or other UH-60)

USE OF BLEED AIR
- Engine start (single or dual engine start)
- Cockpit heat
- Pressurization of external fuel tanks
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- Export to other helicopter (via buddy hose)

INLET A/I VALVE CONTROL
- When A/I switch is on, valve opens/closes IAW ambient temp:
  - 4 deg. C or colder valve should open, 13 deg. C or warmer valve should close, between 4-13 deg. C valve may be open or closed.
  (protects fiberglass inlet from heat damage)

4% loss of MTA when heater is active. (If only one engine is operating, a 4% loss of MTA will be realized on that engine. With two engines operating the loss is shared between the two engines.)

A 16% loss of MTA is realized when engine & engine inlet A/I is activated (loss is realized only on the engine being anti-iced, there is no exchange of bleed air between engines for anti-ice purposes)

#1 AISBV can be opened/closed by pilot for A/I function.
#2 AISBV can be opened/closed by HMU for compressor bleed function.
When switch is in ENG position, crossbleed valves are armed & will open if P-2.5 is present. With switch off, both valves close.
When switch is in APU position, apu start/bypass valve (turbomach apu only) closes when either start button is pressed (a start relay function). With switch OFF, valve remains open and vents a large portion of apu air overboard. To remove 100% of apu bleed air from the pneumatic manifold system the apu must be shut down. (Garrett type APUs don't have a start/bypass valve)

#2 A/I valve is passing P-2.5 to nLite System.
At ambient temperatures of 4º C and colder, failure of the ENG ANTI-ICE ON advisory to illuminate indicates a system malfunction. With the NO.2 ENG ANTI-ICE switch in the ON position, the No.2 Engine Anti-Ice system failed to function properly (#2 ENG ANTI-ICE ON light illuminated but the #2 ENG INLET ANTI-ICE ON light did not illuminate).

(3) At temperatures between 4º C to 13º C the ENG INLET ANTI-ICE ON advisory may or may not appear. Above 13º C appearance of the ENG INLET ANTI-ICE ON advisory indicates a system malfunction. With both ENG ANTI-ICE switches in the ON position, the No.1 Engine Anti-Ice system is functioning properly (#1 ENG INLET ANTI-ICE ON light extinguished), however the No.2 Engine Anti-Ice system is not functioning properly (#2 ENG INLET ANTI-ICE ON light remained illuminated).

**NOTE:** A malfunctioning engine anti-ice and engine inlet anti-ice system may result in power losses as much as 40% MTA at 30-minute TGT demands. If any part of the engine inlet anti-ice check fails, do not fly the helicopter.

(4) At ambient temperatures of 4º C and colder, when the NO. 1 or NO. 2 ENG ANTI-ICE switch is placed in the ON position, the corresponding ENG ANTI ICE ON advisory light will illuminate. Activation of the corresponding ENG INLET ANTI ICE ON advisory light indicates that inlet anti-icing is being provided and the fairing temperature is at 93º C. At ambient temperatures of 4º C and colder, failure of the ENG INLET ANTI-ICE ON advisory to illuminate indicates a system malfunction. At temperatures between 4º C to 13º C the ENG INLET ANTI-ICE ON advisory may or may not appear. Above 13º C appearance of the ENG INLET ANTI-ICE ON advisory indicates a system malfunction.

9. **LEARNING STEP/ACTIVITY No. 9.** Identify the operational characteristics of the engine controls.

a. Engine Controls- The primary engine controls consist of the PCL and collective stick, with the controlling of the main fuel accomplished by the HMU. The HMU has three main inputs that can affect fuel flow metering, the PAS, the Load Demand Spindle (LDS), and the ECU.

   (1) Engine and Control System Schematic- The engine control system provides for fuel handling, computation, compressor bleed and variable geometry control, speed control, overspeed protection, and over temperature protection. The system also incorporates control features for torque matching of multiple engine installations. Shaft power absorber coordination is provided initially by a mechanical input signal to the control system, proportional to helicopter rotor collective pitch setting, and a final automatic trim of the power setting to precisely equal the rotor needs is provided electrically. The engine control system is self-contained and does not require external electrical power for any controlling functions. Design of the engine control system allows removal of major components from the engine separately from any input components and replacement without calibration or matching.

   (a) HMU Schematic Diagram- The HMU handles all main fuel metering tasks during normal operations. Three main inputs to the HMU, the PAS, LDS, and ECU, affect metered fuel flow, other HMU functions limit fuel flow in support of the main three.

   (b) Power Available Spindle- Fore and aft Power Control Lever movements are changed into rotary HMU inputs through a push-pull cable and the Power Available Spindle. This direct mechanical link between the PCL and HMU allows the pilot to set the engine power lever anywhere from OFF, to maximum (OFF-IDLE-FLY). The FLY setting equates to a max power setting, but during normal operations the engine governor (ECU) trims back the power level to maintain the Np and Nr at a constant 100%. A PAS cable shear will cause a loss of all mechanical PCL functions. The engine can be shut down by fuel cut off using the fuel selector lever.
(c) Collective/Load Demand Spindle- Up/down collective movements are changed into rotary hydromechanical inputs via a push-pull cable and the Load Demand Spindle. This direct mechanical link between the collective stick and HMU allows the pilot to reset the engine power level to match the main rotor load. The amount of power the collective may call upon through the LDS depends on the PCL position, which sets the maximum power limits. If the PCL is in the IDLE detent, collective movements will not reset the power any higher than idle. With the PCL in the FLY detent, collective movements can reset power levels anywhere from idle to maximum. A LDS cable shear (or collective bias tube shear pin failure) allows an internal spring within the LDS to reset the LDS to a position that equates to full up collective, ECU and/or PAS inputs adjust fuel flow to compensate for the loss of LDS function, attempting to maintain the %RPM and %RPM R at 100%.

(d) Electrical Control Unit- The ECU functions primarily as an engine governor endeavoring to maintain power turbine and main rotor speed constant at 100%. The ECU adjusts the engine power level through the HMU, via torque motor inputs. Three ECU functions: TGT limiting, Np Governing, and Load Share, affect engine power levels through the torque motor, HMU link, and one ECU function (Np overspeed protection) effects the engine power level through the overspeed solenoid and POU link. The pilot can disable all ECU/HMU functions by locking out the torque motor authority (ECU lockout); ECU/POU functions (Np overspeed protection) are not affected by lockout. An INCR/DECR switch on each collective stick allows the pilot to set the Np reference within both ECU's between 96% - 100%, which is normally set at 100%.

ECU malfunctions can range from high side or low side failures which can cause increasing or decreasing RPM R scenarios, partial high or low side failures resulting in a torque split, or an oscillation of engine power from low to high continuously. An ECU malfunction will not cause flame out, and all ECU malfunctions can be countered through PCL "lockout" or "retard". The engine controls are designed to retain full engine control in the event of a loss of all electrical systems. Lost ECU inputs can be replaced manually via PCL movements, while mechanical Ng governing systems (within the HMU) remain operational to limit various fuel flow parameters.
b. Switches/Lights/Gauges/Controls- Switches, lights, gauges, and controls located in the cockpit are additional components related to the engine.

(1) Upper Console- The engine related switches located on the upper console are:
   (a) APU Control Switch
   (b) Heater Switch
   (c) Air Source Heat/Start Switch
   (d) Engine Anti-Ice Switches
   (e) Prime Boost Pump Switch

(2) Engine Control Quadrant- On the Engine Control Quadrant, related switches and controls include:
   (a) Start Override Switch
   (b) Start Abort Switch
   (c) Start Switch
   (d) Fuel Selector Lever
   (e) Power Control Lever

(3) Instrument Panel- An engine related switch located on the Instrument Panel is the ignition switch. Additional engine related lights, gauges, and switches are located on the caution/advisory panel, CDU, PDU, and master warning panel.

(4) Caution/Advisory Panel- The Caution/Advisory Panel has advisory and caution lights designated to the engines.
   (a) Advisory Lights include: #1 and #2 ENG ANTI-ICE ON, #1 and #2 ENG INLET ANTI-ICE ON.
   (b) Caution Lights include: #1 and #2 FUEL PRESS, #1 and #2 ENGINE OIL PRESS, #1 and #2 ENGINE OIL TEMP, CHIP #1 and #2 ENGINE, #1 and #2 ENGINE STARTER, #1 and #2 OIL FLTR BYPASS, and #1 and #2 FUEL FLTR BYPASS.

(5) CDU-Engine related lights and gauges on the CDU are: ENG OIL TEMP 1 and 2, ENG OIL PRESS 1 and 2, TGT TEMP 1 and 2, Ng SPEED 1 and 2.

(6) PDU-Related lights and gauges for the engines on the PDU include: % RPM 1-R-2, % TRQ 1-2.

(7) Master Warning Panel-The Master Warning Panel has four lights related to the engines: LOW ROTOR RPM, #1 and #2 ENG OUT, and MASTER CAUTION PRESS TO RESET.

(8) Lower Console- Fuel Boost Pump Control is located on the lower console. There are two switches and two lights (NO.1 PUMP and NO.2 PUMP) related to the engines.

(9) Collective Stick- ENG RPM INCR/DECR Switch is located on the collective stick, which allows either pilot to trim the speed of both engines (96%-100%) simultaneously via the ECU.

10. LEARNING STEP/ACTIVITY No. 10. Correctly identify the malfunctions, determine the appropriate emergency procedures, and describe all immediate action procedures IAW TM 1-1520-237-10, TM 1-1520-237-CL, and the student handout.

a. Emergency Procedures
   (1) Decreasing %RPM R
   (2) Increasing %RPM R
   (3) %RPM Increasing/Decreasing (Oscillation)
(4) % Torque Split Between Engines 1 and 2
(5) Engine Compressor Stall
(6) Oil Filter Bypass
(7) Engine Chip
(8) Engine Oil Temperature
(9) Engine Oil Pressure (LOW)
(10) Engine Oil Pressure (HIGH)
(11) Engine High-Speed Shaft Failure
(12) Lightning Strike