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DOCUMENT TITLE

GAS TURBINE ENGINES (CASA ATPL)

CHAPTER 9 – ENGINE INSTRUMENTATION AND WARNING SYSTEMS

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INTRODUCTION

The controls of the gas turbine engine have been refined to minimise the workload of the pilot, while still allowing him ultimate control over the engine. Engine parameters require constant monitoring and a full set of instrumentation for the various systems is provided to warn of impending failure. If automatic functions are lost, the pilot can manually control the engine by setting the desired thrust setting and monitoring the engine instruments.

As discussed in Chapter 8, different aircraft manufacturers use differing ways to display information. Until Cathode Ray Tubes were used, engine manufacturers used different presentations.

In larger three crew aircraft (Pilot, Co-Pilot and Flight Engineer), it was common practice to divide the instruments into Primary and Secondary displays.

The Primary Display was usually EPR, N1, EGT and Fuel Flow. These were displayed on the Pilots Center Glare Shield.

The Secondary Instruments, N2, oil system etc, were displayed on the Flight Engineers panel.

These instruments could be broken down into two types, Analogue and Digital. Analogue could be further divided into Radial Dials and Strip Instruments. Refer to Figures 9-1 and 9-2.

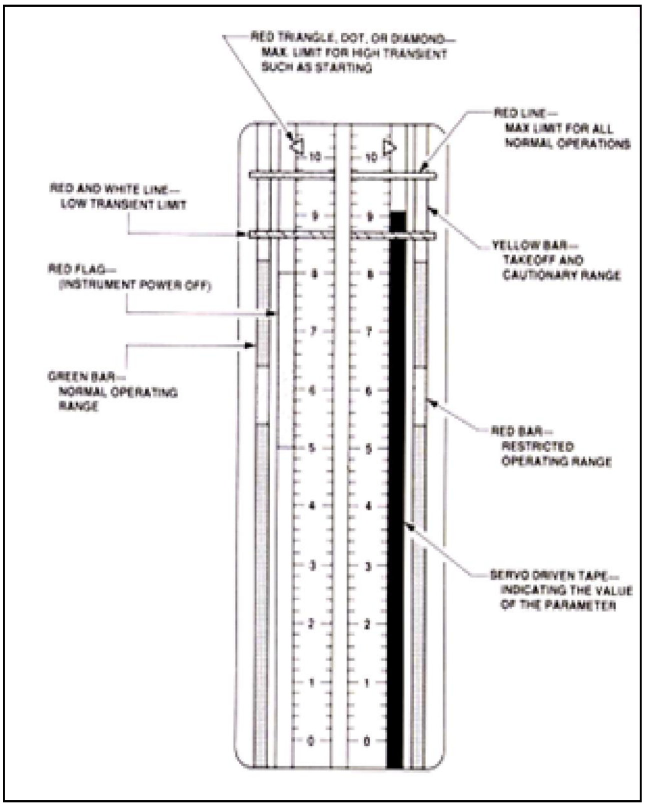

Figure 9-1 Vertical Strip Display

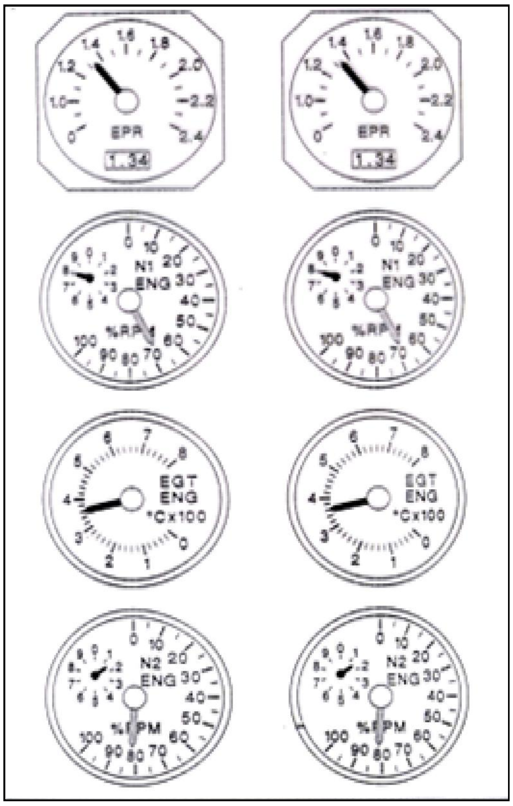

Figure 9-2 P&W Dial Display

Green, amber and red arcs were added to the instruments to aid the crew in identifying problems and parameters that were out of limits. Malfunctions and engine limitations could still be misidentified, sometimes with tragic results. Two examples are detailed;

- British Midland B737 in 1989. On descent through FL280 the crew heard and felt an explosion, followed by a large vibration. Passengers reported seeing smoke coming from the left hand engine. Smoke then entered the cabin. There were no aural or visual warnings except for erratic fuel flow indication on the left hand engine. The pilot retarded both thrust levers and the vibration ceased. Believing the right hand engine supplied the airconditioning, he directed to FO to shut down the right engine. At 2.5 miles from the runway the left hand engine failed and an attempt was made to relight the right hand engine. The aircraft impacted the ground at 110 KIAS one mile from the runway.

- Lockheed C5 Galaxy in 2006. On 3 April 2006, C-5B 84-0059 crashed following a cockpit indication that number two thrust reverser was not locked. The aircraft crashed about 2,000ft short of the runway while attempting a heavyweight emergency landing at Dover Air Force Base, Delaware. The aircraft had taken off from Dover 21 minutes earlier and reported an in-flight emergency 10 minutes into the flight. All 17 people aboard survived, but two received serious injures. The Air Force's accident investigation board report concluded the cause to be human error. Most notably the crew had been manipulating the thrust lever of the (dead) number two engine as if it was still running while keeping the (live) number three engine at idle. The situation was further worsened by the crew's decision to use a high flap setting that increased drag beyond normal two engine capabilities. This incident led to a redesign of the cockpit engine displays, particularly the visual indicators of a non-active engine. Refer to Figure 9-3.

Figure 9-3 C5B Crash in 2006

ELECTRONIC INSTRUMENTATION

Since the demise of the Flight Engineer from the flight deck, the complicated array of gauges and instruments on the instrument panel have been replaced by a more comprehensive display consisting of cathode ray tubes or LCD screens (referred to as a Glass Cockpit), which can display all of the information necessary to operate the engine safely. These screens are part of a system referred to as;

- Engine Instrument and Crew Alerting System (EICAS) Boeing, and
- Electronic Centralised Aircraft Monitoring (ECAM) Airbus.

EICAS

This system consists of two display units, one control panel, and two computers, supplied with analogue and digital signals. Only one computer controls, whilst the other is on standby. Should a failure occur the standby computer can be turned on either automatic or manually. The displays are cathode ray tubes (CRTs) or LCDs and are mounted one above the other.

The upper display is the primary display and displays primary engine parameters (e.g. N_1, EGT, and in some installations EPR). It also displays warning and caution messages. The primary engine parameters are permanently displayed in flight. Refer to Figure 9-4.

The lower display is the secondary display, and displays secondary engine parameters such as N_2, (N_3 which is applicable to Rolls Royce engines), fuel flow, oil quantity, oil pressure, oil temperature, and engine vibration, plus non-engine systems status (e.g. hydraulic system, electrical system, etc.). The secondary display is normally blank in flight, but is selected to indicate secondary engine parameters during start.

Should a display fail, the information automatically transfers to the other screen in a format called compact. If the total EICAS display is lost, a standby LCD engine indicator provides primary engine information.

ECAM

This system was originally developed for the Airbus, and has the same basic components as the EICAS system. The processing and display of information differs quite significantly in that it displays in a checklist and a pictorial or synoptic format. Depending on the aeroplane, the displays can either be mounted one above the other or side-by-side.

The upper or left display is the engine and warning display and displays engine parameters, status of systems, warnings, and corrective action in a sequenced checklist format.

The lower or right display is the Systems Status Display and displays associated information in a pictorial or synoptic format. Refer to Figure 9-5.

Figure 9-4 EICAS Display.

Figure 9-5 ECAM Display.

INSTRUMENTATION INFORMATION

Regardless of the display, the method of generating the information for those instruments has changed very little. Most displays include the following information;

- EPR,
- RPM for each spool,
- EGT,
- Fuel Flow, Fuel Used and Fuel Temperature,
- Oil Quantity , Pressure Temperature, and
- Vibration.

EPR-Engine Pressure Ratio, the ratio of exhaust gas pressure to inlet gas pressure. Refer to Chapter 8.

RPM Regardless of the type of engine, RPM indicators are critical to engine operation.

On a single spool engine one RPM indicator is usually satisfactory. However, as the number of the spools increases, it is necessary to differentiate between the speeds of the individual shafts. Figure 9-6 shows the RPM pick off for N_1 and N_2.

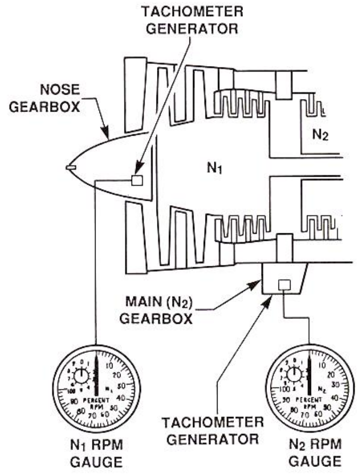

Figure 9-6 Low and High Pressure Compressor Pick Off

There are two methods of producing the indicated RPM. They are;

- Tachometer-generators, and
- Variable reluctance speed probes.

Tachometer-generators are small electrical generators driven by the engine reduction gearbox or drive shaft. They generate a three phase signal, the frequency dependant on engine speed. The frequency controls the speed of the synchronous motor in the indicator which induces rotation to a magnet assembly, causing deflection of the indicator needle. Refer to Figure 9-7.

Variable Reluctance Speed Probes are used where no provision is made for driving a tachometer generator, such as on multi spool engines. A phonic wheel is mounted on the driveshaft and a speed probe is mounted in the compressor casing. The teeth on the phonic wheel induce a current in the speed probe which is transmitted to the indicator. Refer to Figure 9-8.

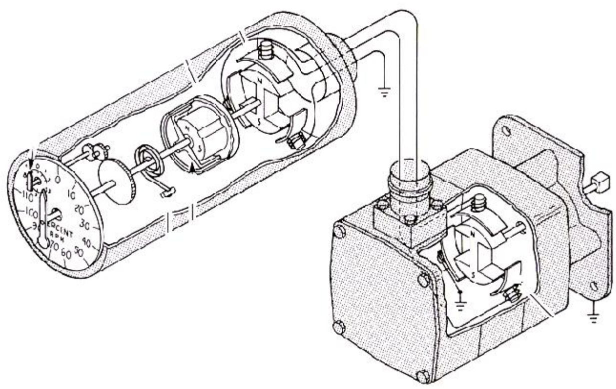

Figure 9-7 Tachometer Generator

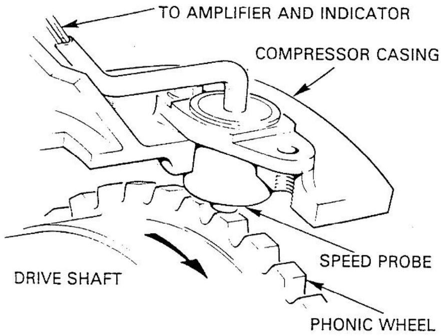

Figure 9-8 Variable Reluctance Speed Probe

EGT or Turbine Temperature Indication can be measured at various locations within the turbine casing and in some installations, from inside the jet pipe. To enable the crew to understand the relevance of the temperature, the location of the detecting device must be clearly indicated. This is normally achieved by using an abbreviation to indicate the location of the probes. Some of the more common abbreviations and meanings are listed below: Refer to Figure 9-9.

- **TIT** Turbine Inlet Temperature,
- **ITT** Inter Turbine Temperature,
- **TOT** Turbine Outlet Temperature, and
- **EGT** Exhaust Gas Temperature.

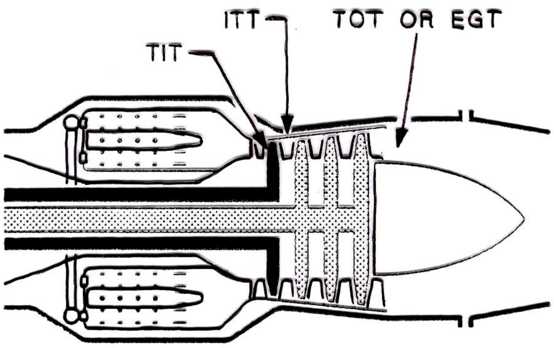

Figure 9-9 Gas Temperature Measurement

The different names reflect the placement of the thermocouples. A stagnation type thermocouple is usually fitted to a turbofan or turbojet engine. A rapid response type probe is used in turboprop installations. It is usual to connect several thermocouples on a parallel circuit to provide an average reading.

It should be pointed out that as the gases pass through the turbine, their temperature decreases. As an example, for a temperature of 1,000°C TIT, the corresponding EGT would be around 600°C. However, the limiting temperature will also decrease. In this example, the limiting EGT may be 640°C and the limiting TIT 1,075°C.

The temperature measuring system normally consists of thermocouple probes consisting of two dissimilar metals joined together inside a metal tube. Holes in the front and rear of the probes allow the hot gases to flow in and out of the probe and across the junction of the two metals. The two metals are normally allumel and chromel. The probes are located in the gas stream so as to generate an average temperature, and are often wired in parallel. The probe is often referred to as the "hot" junction and the indicator as the "cold" junction.

As the temperature increases in the engine, an electromotive force (EMF) equal to the potential difference between the two junctions is generated. The indicator is a millivoltmeter which is calibrated to read in degrees centigrade. As can be seen the thermocouple system generates its own power to drive the temperature indicating system. Refer to Figure 9-10.

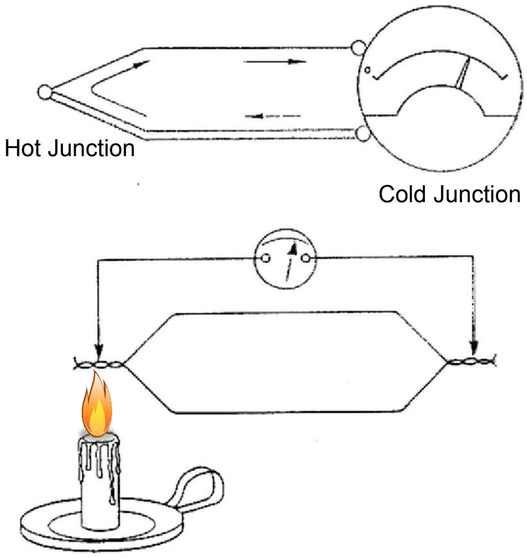

Figure 9-10 Thermocouple Principle

Oil Temperature and Pressure Indicators are critical for the safe operation of the gas turbine engine, and accurate, reliable indications of oil pressure and temperature must be available to the crew.

Oil temperature is measured by a temperature probe located in the oil lines or the oil/fuel heat exchanger outlet as the oil is returned to the tank. The probe causes a change in the resistive value of a bridge circuit, which induces a change in the current flow to the indicator.

Oil pressure can be measured in several ways. One type of system uses a pressure generated electrical signal which is sent to the gauge, causing the indicator to move. The transmitter can be of the direct reading type, or may measure both the supply and return oil pressures, so generating a differential signal which is sent to the indicator. Pressure is generally indicated in pounds per square inch (PSI). Refer to Figure 9-11.

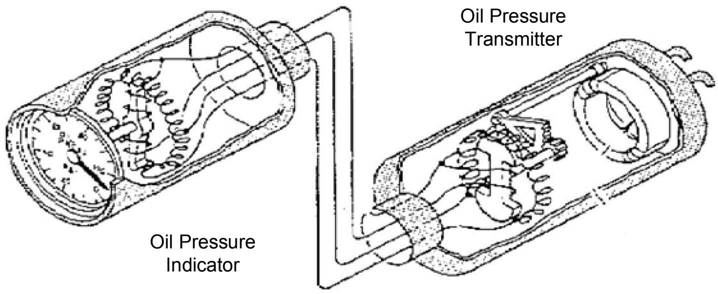

Figure 9-11 Oil Pressure Indicating System

Oil Quantity can be read directly on the oil tank by ground maintenance, usually by a sight gauge. It is also displayed on the oil system page on the lower monitor of the EICAS or ECAM.

Fuel Temperature, Pressure indicators are very important for long range commercial aircraft. The altitudes at which they operate produce temperatures low enough to produce waxing of the fuel and certainly cold enough to freeze any water that may be in the fuel. This will be covered in more detail in Aircraft Systems.

The output of the low pressure engine fuel pump is extremely important, as it ensures that the pump is supplying enough pressure to avoid cavitations of the high pressure pump. It is also normal for the low pressure fuel filters to have a differential pressure switch across the inlet and outlet, which is connected to a caution light on the flight deck, to indicate blockage of the filters. The fuel temperature and pressure indicating system is very similar in operation to the oil pressure indicating system described above.

Fuel Flow is an extremely useful indication in the monitoring of engine operation and aircraft performance.

The system consists of a fuel flow transmitter located in the fuel line after the Fuel Control Unit and prior to the fuel manifold. This provides a positive indication of high pressure cock operation. The transmitter is normally of the synchronous type which relies on a swirling motion previously applied to the fuel, to create a twisting motion to a spring loaded rotor. The applied force results in a signal being generated. The greater the fuel flow, the greater the twisting moment and therefore the greater the reference signal generated. Fuel flow may be indicated in pounds per hour, gallons per hour or in kilograms per hour. On commercial aircraft it is normal for the fuel flow indicator to be connected to a fuel debit system which will indicate the total fuel used. Refer to Figure 9-12.

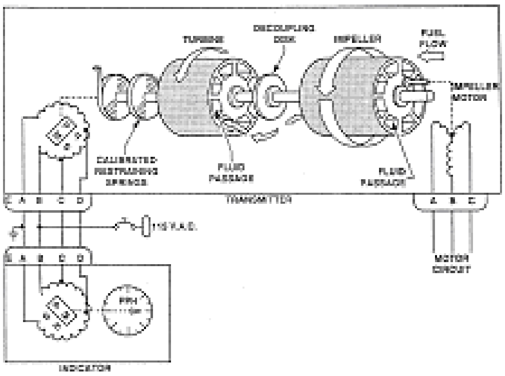

Figure 9-12 Fuel Flow Indicating System

ENGINE VIBRATION

Any engine damage, causing unbalance in a jet engine can lead to serious vibration problems. Early warning permits corrective action before extensive damage can occur. To overcome this situation, vibration monitors which are sensitive to engine vibrations in a radial direction provide early warning signals to the crew.

The type of monitoring unit shown in Figure 9-13, receives inputs from one or two sensors, attached to the engine and also speed inputs from the three rotors N_1, N_2 and N_3. The four position rotary selector allows each rotor to be monitored. The “Normal” position monitors the vibration levels for all three rotors and displays only the highest value of the three. The alarm test/reset switch is used to check and reset the operation of the monitoring unit.

Relative amplitude indicates vibration and if detecting an unacceptable level of vibration, a warning light illuminates on the flight deck. There is also a red line warning on the indicator. Engine-mounted transducers monitor vibration. These can be either electro-magnetic or piezoelectric design. They convert vibration rates into electrical signals that result in the pointer of the indicator moving in proportion to the level of vibration, which is proportional to the amount of rotor imbalance. The signals are amplified, electronically filtered, and sometimes selectable between frequency ranges.

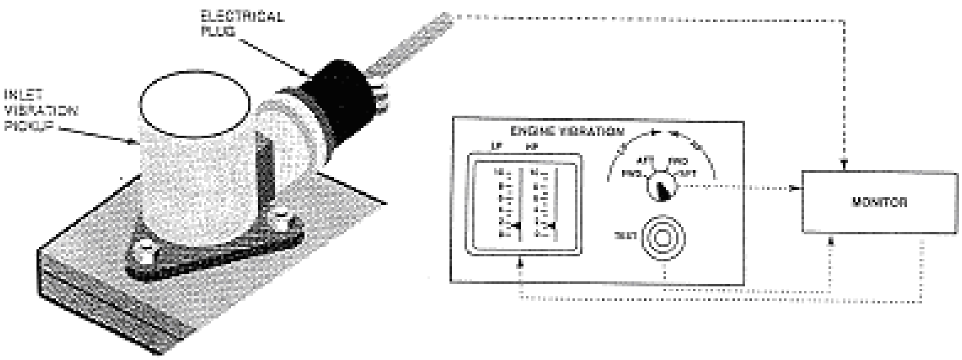

Figure 9-13 Engine Vibration Monitoring

WARNING SYSTEMS

As well as a full set of engine instruments, the modern aircraft may be fitted with a series of warning and caution indicators to indicate visually and aurally to the crew that a system malfunction has or is about to occur. Some of the systems that require visual and/or aural warnings include:

- Oil pressure, temperature and filter by-pass,
- Fuel pressure,
- Low pressure fuel filter blockage,
- Engine overheating, and
- Excessive vibration.

The visual warning normally includes a Master Warning/Caution light to initially attract the crew's attention, and EICAS or ECAM lights to indicate what the problem is.