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# DEFINING AND MEASURING FACTORS AFFECTING HELICOPTER TURBINE ENGINE POWER AVAILABLE

1. PURPOSE: The purpose of this Aerospace Recommended Practice (ARP) is to define a method of measuring those factors affecting installed power available for helicopter power plants. These factors are installation losses, accessory power extraction, and operational effects. Accurate determination of these factors is vital in the calculation of helicopter performance as described in the flight manual. It is intended that the methods herein prescribe and define each factor as well as an approach to measuring said factor.

2. DEFINITIONS: Factors affecting power available at the engine output shaft are defined as follows:

2.1 Installation Losses:

(a) Air intake total pressure loss
(b) Air intake total temperature rise
(c) Exhaust gas back pressure

2.2 Accessory Power Extraction:

2.2.1 Gas Generator and/or Power Turbine Accessory Power Extraction:

(a) Accessory pad power, blowers, pumps, compressor, etc.

2.2.2 Compressor Bleed Air Extraction:

(a) De-Icing, environmental control, etc.

2.3 Operational Effects:

(a) Power turbine output shaft speed off optimum effects

3. DISCUSSION:

3.1 Engine air inlet total pressure loss is best defined as that loss incurred by the air flowing from the atmosphere to the front of the engine compressor inlet housing. It is normally attributable to friction, turbulence, diffusion and bend losses. Its effect on net power output is manifested by a reduction in engine mass flow and pressure available at the power turbine.

A good rule of thumb for all turbines stipulates intake total pressure loss expressed as a percentage of the total pressure available multiplied by two, is an approximation of the percentage power loss (i.e. 1% $\Delta$ Pti = 2% power). Each engine manufacturer, in the model specification or computer program gives the best estimate performance loss which is calculated by inputing the appropriate pressure loss.

3.2 The air inlet temperature rise is that increase in compressor intake air temperature above free stream stagnation temperature. This increase can be the result of exhaust gas recirculation, leaks in the inlet ducting allowing hot zone air to be ingested, and/or heat transfer through the intake ducting. This can be a significant loss since 1°C (2°F) represents approximately a 1/2% to 1% power loss when operating at limit turbine temperature. Good duct design and location usually prevents temperature rise from exceeding 2°C (4°F).

3.2.1 Air intake total pressure and total temperature distortion can affect compressor performance and surge margin. The effect can be estimated but is generally measured from an engine test which simulates radial and circumferential inlet distortion of total pressure and temperature. Installed pressure and temperature distortion is measured during flight testing of the aircraft with instrumentation specified by the engine manufacturer. Levels of distortion are calculated by procedures defined by the engine manufacturer. ARP 1420 should be consulted for other aspects of inlet distortion evaluation.

3.3 Bleed air extraction power effects occur when compressor air is utilized for cabin heating, air conditioning, engine inlet de-icing, etc. It becomes a true power loss only when operating at a limit turbine inlet temperature. At part power conditions the loss manifests itself as an increase in fuel flow. On most engines, bleed air extraction is quite costly, i.e. 1% bleed flow extraction costs approximately 2-3% power at limit turbine temperature.

3.4 Mechanical power can be extracted from several sources such as the compressor rotor or power turbine drive train. Power extracted from the compressor rotor is generally more expensive than that taken from the power turbine. Power extracted from the compressor rotor changes the thermodynamic match of the compressor and power turbine which requires the gas generator speed to be reduced to maintain the engine reference temperature.

3.5 Exhaust gas back pressure power loss is due to the increased back pressure in excess of that imposed by the engine manufacturer's diffuser (datum) tailpipe resulting from additional bends, a different effective exit area and/or the incorporation of an exhaust ejector. A good rule of thumb for all turbine engines is 1% increase in total exhaust back pressure loss results in approximately 1% power loss.

3.6 Off Optimum Power Turbine Speed Power Effect: This power loss/effect is the result of operating the power turbine at some speed other than that which maximum internal engine efficiency is achieved. It is calculated by using the engine manufacturer's performance program for the specific speed at which the helicopter rotor system is operated.

## 4. MEASUREMENT METHODS TO DETERMINE INSTALLATION LOSSES:

Several methods have been developed to measure installation losses with advantages for each technique.

4.1 The gross measurement technique involves comparison of helicopter turbine engine measured parameters against those same parameters recorded in the reference engine test cell calibration. The referral technique is used to normalize any temperature and pressure differences between the flight test (hover or tie down) and test cell ambient conditions. Installation loss is usually considered to be an engine run line shift at a discrete turbine inlet temperature or in some cases gas generator speed. These data normally involve stabilized readings of ambient temperature, pressure altitude, compressor speed, power turbine speed, turbine inlet temperature, fuel flow, and engine torque. If there were no appreciable errors in measuring the above parameters this gross technique would be very accurate. However, in practice it has been shown to be inaccurate due to accumulated measuring tolerance of the power parameters. The method serves as a quick check to get a rough idea of the installation losses. In certain cases with special accurate instrumentation setups, it is possible to achieve adequate results of the installation loss by this gross technique. See Figure 1 for a plot of installation losses.

4.2 Individual Loss Measurement Technique: The appropriate approach to determining installation losses is to measure each discrete item/loss and input their respective values into the appropriate engine performance computer program for the total loss. Calculating each loss separately will not account for the interaction among the loss parameters.

4.2.1 Engine air inlet total pressure loss is derived from a compressor inlet pressure survey conducted on a flight vehicle. The sampling techniques normally utilized for this survey provide more than adequate data to calculate an average inlet total pressure. This inlet loss with due consideration given to ram effects, is then converted to horsepower by using the appropriate engine performance computer program. For some high performance engines high inlet distortion causes additional power loss.

4.2.2 Engine air inlet temperature rise can be extracted from the inlet temperature distortion survey. However, if these data are not available air inlet temperature instrumentation must be installed and a minimum of 8 to 12 thermocouples (or a number specified by the engine manufacturer) averaged to compute the inlet temperature rise. Due to inherent problems with thermocouples, this type of testing produces a fairly wide scatter in test data. Usually many data points are acquired and the results averaged. Some high performance engines suffer performance penalties due to inlet temperature distortions.



4.2.3 Accessory Power Extraction and/or Accessory Drive Losses: These losses are usually in the form of power to drive blowers, fuel pumps, generators, etc. Direct measurement of this loss usually involves insertion of a load cell between the drive pad and accessory or strain gages on the power supply shaft. It is often more convenient to utilize the accessory manufacturer's bench power consumption data, if it is of a credible nature. If the accessory drive power consumption is reasonably low, small errors in the bench data are not significant. (Note: If the power is extracted from the compressor rotor the value must be put into the engine computer deck to determine the output loss. Power extracted from the power turbine system is directly subtracted from the net engine output power.)

4.2.4 Compressor Air Bleed Extraction Losses: Measurement of bleed extraction is usually accomplished by means of a calibrated venturi meter placed in the pneumatic supply line between the engine and the distribution system. However, another approach where flow limiting devices are used is to calculate the bleed flow using the appropriate bleed air temperature and pressure. Flow limited devices (converging-diverging nozzles) normally lend themselves to reasonable analytical prediction. Upon determination of the proper bleed flow, it is then possible to determine the loss from the engine computer program.

4.2.5 Exhaust back pressure is seen as an increase in pressure on the downstream side of the power turbine and thus for a given upstream pressure, less power can be extracted. Because of the swirl of exhaust gases, measurement of this back pressure when the engine is installed is difficult with standard total pressure probes. Directional probes offer some help, but high swirl angles can exceed the capability of these total probes. The most desirable measurement technique is to establish the referred engine mass flow versus referred gas producer speed relationship in the test cell, with the referee tailpipe, while measuring exhaust static pressure with several wall statics at the interface of the engine exit.