



AEROSPACE RECOMMENDED PRACTICE

ARP1702™

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Superseding ARP1702A

(R) Defining and Measuring Factors Affecting Helicopter Turbine Engine Power Available

RATIONALE

ARP1702B has been revised as part of the SAE Five-Year Review policy. Most sections contain minor changes for improved clarity and consistency of language and terminology throughout the document, including Figures 1 and 2. More significant technical changes have been made in several sections. Consideration of inlet swirl distortion and its influence on installed power available have been added in 3.1.5 and 5.2.3. Effects of altitude, airspeed, and ambient temperature conditions have been added in 3.3.3. Effects of crosswind or tailwind conditions have been added in 3.3.4. Finally, additional considerations for instrumentation used for measuring inlet pressure distortion have been included in 5.2.1.

ARP1702B has been reaffirmed to comply with the SAE Five-Year Review policy.

A reaffirmed status is given to technical reports that have been reviewed by the technical committee and deemed to be current with no need for immediate revision. No changes have been made to this document as a result of this review.

INTRODUCTION

The very nature of the engine installation on most helicopters inevitably results in some loss of power when comparing the installed performance of the engine with the specification level for an engine run on a test bench. This loss of installed power is clearly detrimental to the overall performance of the aircraft and it is in the aircraft manufacturer's interest to minimize it. The rotorcraft flight manual (RFM) is based on the engine manufacturer's performance specification for an uninstalled engine and the airframe manufacturer's allowance for the installation power losses. Therefore, careful and accurate determination of the installation effects is essential to ensure safe operation of the aircraft.

The engine manufacturer, having set the specification performance level, will add operating margins to allow for the effects of in-service deterioration and to ensure satisfactory installed lives. In addition, the known effects of such things as bleed extraction, anti-icing selection, and accessory power extraction, will be declared so that the aircraft manufacturer can make appropriate allowance for these penalties. An in-service power assurance check procedure will be defined which takes account of installation power losses when assessing the measured performance of the engine in the aircraft against the minimum uninstalled specification level. Any overestimate or underestimate of the aircraft installation power losses will make the installed performance of the engine appear different than it truly is and so can lead to inaccurate RFM performance and variation in installed engine life. It is, therefore, also in the engine manufacturer's interest to ensure that installation losses are accurately measured.

The determination of the installation power losses and the RFM validation for a particular aircraft/engine combination is the responsibility of the aircraft manufacturer and/or the manufacturer of any equipment which, when installed, impacts available power. However, accurate measurement of installation effects is not easy and is best achieved through careful cooperation between aircraft, engine, and equipment manufacturers. While the individual concerns of each party may differ, they share the common goal of accurately determining installation power losses and, wherever possible, ensuring that these are minimized and properly accounted.

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1. SCOPE

This SAE Aerospace Recommended Practice (ARP) identifies and defines a method of measuring those factors affecting installed power available for helicopter powerplants. 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 RFM. It is intended that the methods presented herein prescribe and define each factor as well as an approach to measuring said factor. Only basic installations of turboshaft engines in helicopters are considered. Although the methods described may apply in principle to other configurations that lead to more complex installation losses, such as an inlet particle separator, inlet barrier filter (with or without a bypass system), or infrared suppressor, specialized or individual techniques may be required in these cases for the determination and definition of engine installation losses. Some rotorcraft may use an alternate source of propulsion system power to supplement engine output shaft power delivered. If RFM performance includes the contribution of a Supplemental Power Unit (SPU), then the installed power available of the SPU should also be defined and measured, for which the power loss factors and methods described in this document may be applicable.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR1419	Inlet Total-Pressure-Distortion Considerations for Gas-Turbine Engines
AIR1678	Uncertainty of In-Flight Thrust Determination
AIR4083	Helicopter Power Assurance
AIR5642	The Effect of Installation Power Losses on the Overall Performance of a Helicopter
AIR5686	A Methodology for Assessing Inlet Swirl Distortion
ARP1217	Instrumentation Requirements for Turboshaft Engine Performance Measurements
ARP1420	Gas Turbine Engine Inlet Flow Distortion Guidelines
ARP4056	Engine Exhaust System Design Considerations for Rotorcraft

2.1.2 Other Publications

AEDC-TR-73-5 Handbook	Uncertainty in Gas Turbine Measurements
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2.2 Definitions

GAS GENERATOR: The rotating assembly of compressor(s) and their driving turbine(s) connected by shaft(s) in a gas turbine engine.

POWER AVAILABLE: The power delivered via the engine output shaft to the rotorcraft.

POWER TURBINE: The rotating assembly of turbine(s) that extract power to drive the output shaft in a gas turbine engine. Also known as a free turbine.

2.3 Symbols and Abbreviations

CFD Computational Fluid Dynamics

EIM Engine Installation Manual

P_{STD} Standard Pressure at Sea Level

P_{ti} Inlet Total Pressure

RFM Rotorcraft Flight Manual

SPU Supplemental Power Unit

T_{STD} Standard Temperature at Sea Level

V_h Maximum Speed in Level Flight with Maximum Continuous Power

δ Corrected absolute pressure (pressure / standard sea level pressure)

θ Corrected Absolute Temperature (temperature / standard sea level temperature)

3. FACTORS AFFECTING POWER AVAILABLE

Power available is the power delivered via the engine output shaft to the rotorcraft. Factors affecting power available at the engine output shaft are described in this section. Impacts of many of the installation factors can be quantified using the engine performance computer model, also known as a customer deck, but analytical predictions for installed power loss should be verified by measurement techniques when possible. AIR5642 contains additional reference information regarding installation power loss mechanisms and their effect on engine performance.

3.1 Installation Losses

3.1.1 Engine air inlet total pressure loss is best defined as that head loss incurred by the air flowing from the atmosphere to the engine/aircraft inlet interface plane. It is normally attributable to friction, turbulence, diffusion, and turning losses. Its effect is manifested by a reduction in total pressure at the compressor inlet plane, which results in a reduction in power produced by the power turbine at any given gas generator speed. In forward flight the degree of freestream total pressure or “ram” recovery achieved by the aircraft intake must also be considered.

A good rule of thumb for gas turbine engines stipulates that intake pressure loss, expressed as a percentage of the total pressure available multiplied by two, is an approximation of the power loss (i.e., 1% delta P_{ti} = 2% power).

- 3.1.2 The air inlet temperature rise is the increase in compressor intake air temperature above freestream total temperature. This increase can be the result of exhaust gas ingestion, anti-icing air discharge from the intake, 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 as an increase of 1 °C (2 °F) represents approximately a 1/2 to 1% power loss when operating at limit turbine temperature. Good duct design and location can usually prevent temperature rise from exceeding 2 °C (4 °F) in the hover condition with headwind. However, for small helicopters where the engine inlet flow may be used for cooling the main rotor gearbox, higher levels of temperature rise will inevitably be suffered. A tailwind condition may be the critical condition for inlet temperature rise, which should comply with any limitations listed in the Engine Installation Manual (EIM) created by the engine manufacturer.
- 3.1.3 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 gas turbine engines is 1% increase in total exhaust back pressure loss results in approximately 1% power loss. ARP4056 contains additional reference information on engine exhaust system design considerations and their physical, functional, and performance interfaces.
- 3.1.4 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. AIR1419 and ARP1420 should be consulted for a wider appreciation of inlet distortion effects. Inlet distortion effects are primarily considered for characterizing engine compression component stability; however, excessive levels of inlet distortion that persist could have aeromechanical as well as performance implications for the engine compressor. The EIM should be consulted for any limitations.

Inlet pressure distortion will tend to reduce engine air mass flow for a given gas generator speed. Because power is directly related to air mass flow for a given engine speed or temperature, it follows that such an effect will reduce power available for a given value of either parameter. The presence of inlet pressure distortion, even within prescribed limits, may result in a loss of power on both a temperature and speed basis.

Inlet temperature distortion will cause the engine compressor to operate at values of corrected gas generator speed ($speed/\sqrt{\theta}$, where θ is computed using the temperature at the compressor inlet station) which can vary in both a circumferential and radial sense. Because both compressor air mass flow and efficiency are functions of corrected speed, it is possible for inlet temperature distortion to adversely affect both of these parameters. Reductions in air mass flow and efficiency will both result in a loss of engine power available.

Inlet temperature distortion can result in an erroneous inlet temperature measurement (either high or low) due to the limited measurement locations. This may cause the control to set off-optimum conditions of stator vanes or other control schedules, or may unnecessarily limit the output power.

It is possible, in extreme cases, for inlet distortion to affect the outlet temperature profile of the engine combustion system. As gas temperature is measured at a limited number of positions, it is possible for this change in profile to result in an apparent change of measured temperature. Such an effect can lead to an apparent power penalty or improvement by raising or lowering, respectively, the mean measured gas temperature at a given running condition. This type of effect is not readily discernible and if suspected may require the assessment of individual thermocouple readings or the use of a special multi-point harness.

- 3.1.5 Inlet airflow angularity, or swirl, may also exist in the engine inlet flowfield as a result of the external flowfield and/or the air intake configuration. Although limitations on swirl may not be included in the EIM, swirl can affect the aerodynamic performance of the compressor through changes in incidence angle of the air relative to the compressor blades. Depending on the type of swirl and the compressor design, swirl can lead to either positive or negative impacts on compressor stability and installed power available. Either influence on power available can be detrimental to the accounting of installed performance. AIR5686 contains additional information regarding characterization of inlet swirl and its impacts on compressor stability.