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Gas Turbine Engine Inlet Flow Distortion Guidelines

RATIONALE

This document provides definitions of stability margin and total-pressure distortion descriptors for gas turbine engines. In addition, guidelines for stability assessments, testing, instrumentation, data acquisition, and data processing are addressed.

This document contains information that is fundamental to the discipline of inlet-engine compatibility and is expected to remain stable for the foreseeable future.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE S-16 Turbine Engine Inlet Flow Distortion Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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1. SCOPE:

The turbine-engine inlet flow distortion methodology addressed in this document applies only to the effects of inlet total-pressure distortion. Practices employed to quantify these effects continue to develop and, therefore, periodic updates are anticipated. The effects of other forms of distortion on flow stability and performance, and of any distortion on aeroelastic stability are not addressed.

The guidelines can be used as necessary to create a development method to minimize the risk of inlet/engine compatibility problems. The degree to which guidelines for descriptor use, assessment techniques, and testing outlined in this document are applied to a specific program should be consistent with the expected severity of the compatibility problem.

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. 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, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP246B	Orientation of Engine Axis, Coordinate and Numbering Systems for Aircraft Gas Turbine Engines
AS681	Gas turbine Engine Steady State Performance Presentation for Digital Computer Programs
ARP755	Turbine Engine Performance Station Identification and Nomenclature
ARP1210	Gas Turbine Engine Interface Test Data Reduction Computer Programs
ARP1257	Gas Turbine Engine Transient Performance Presentation for Digital Computer Programs
AIR1419	Inlet Total-Pressure-Distortion Considerations for Gas-Turbine Engines

2.2 Terminology:

The following terms are given to supplement definitions presented elsewhere in the text of ARP1420.

AERODYNAMIC INTERFACE PLANE (AIP): An AIP is an instrumentation plane used to define inlet distortion and performance (see 8.2.1).

DISTORTION DESCRIPTOR: A distortion descriptor is a non-dimensional numerical representation of the measured inlet pressure distribution (see Section 5).

DISTORTION EXTENT (θ_F): The distortion extent refers to the circumferential arc size of a distorted region (see 5.1.1.2 and Equation A1).

2.2 (Continued):

DISTORTION INTENSITY ($\Delta P/P$): Distortion intensity refers to the amplitude of a distortion pattern. For a circumferential distortion, intensity is defined in 5.1.1.1 and Appendix, A.1.1. For a radial distortion, intensity is defined in 5.1.2 and Appendix, A.1.2.

DISTORTION SENSITIVITY: Distortion sensitivity is the loss in compressor stability pressure ratio, ΔPRS , per unit of numerical distortion descriptor, $\Delta P/P$ (e.g., K_c , and K_r in Equation A9).

INLET FLOW DISTORTION: Inlet flow distortion refers to spatial variations in the total pressure at the inlet/engine interface plane.

LOSS IN STABILITY PRESSURE RATIO (ΔPRS): The loss in stability pressure ratio is the percent change in stability pressure ratio, at constant corrected airflow, between the undistorted stability limit point and the distorted stability point (see 6.2 and Equation A9).

MULTIPLE-PER-REVOLUTION DISTORTION: Multiple-per-Revolution distortion refers to the equivalent number of distorted regions occurring in 360° (see 5.1.1.3 and A.1.1).

OFFSET TERM (C): Loss in stability pressure ratio (ΔPRS) correlated to a distortion sensitivity element of zero (see Equation A9).

OPERATING POINT: An operating point refers to the location on a compressor map that satisfies the matching relationships which govern the engine operation. Operating points may describe either steady or transient operation (see Figure 1).

ROTATING STALL: Rotating stall is a compression component instability that is characterized by a separation-induced flow blockage rotating at a fraction of the rotor speed, resulting in quasi-steady operation at globally reduced mass flow and pressure ratio.

STABILITY ASSESSMENT: Stability assessment is the procedure by which destabilizing effects are accounted for in an engine (see 6.3).

STABILITY LIMIT LINE: The stability limit line is defined as the locus of points on a compressor map that represent a limit above which the compressor should not be operated. These limits are set either by aerodynamic instabilities or aeromechanical limits.

STABILITY MARGIN: Stability margin is the pressure ratio range, at a constant corrected airflow, through which a compressor may be operated between its operating point and stability limit line without stall (see 6.1).

STALL: Stall is the breakdown of flow within a compression component that precedes aerodynamic instabilities such as rotating stall or surge. The occurrence of stall will generally be manifested by the loss in discharge pressure of the stalling compression component.

STALL POINT: A stall point is the last stable point on a throttled compression component speed line just prior to the occurrence of aerodynamic instability.

2.2 (Continued):

STEADY-STATE DISTORTION: Steady-state distortion is the spatial variation in time-averaged total pressure at each location in the AIP.

SURGE: Surge is a system instability that is characterized by large cyclic variations in the global mass flow and pressure ratio, possibly including complete flow stoppage or reversal.

TIME-VARIANT DISTORTION: Time variant distortion is the instantaneous spatial variation of total pressure at each location at the AIP.

2.3 Nomenclature:

AIP	Aerodynamic Interface Plane
ARP	Aerospace Recommended Practice
C	Offset term (Equation A9)
$C(\tau)$	Covariance of time varying pressures
f	Frequency
KC	Circumferential distortion sensitivity (Equation A9)
KR	Radial distortion sensitivity (Equation A9)
L	Characteristic length (cowl lip to compressor face)
MPR	Multiple-per-revolution element
N	Number of instrumentation rings
$\bar{P}$	Total pressure
$\bar{P}$	Time-averaged total pressure
PAV	Ring average total pressure
PAVLOW	Average total pressure of low total-pressure region for a ring (Equations A2 and A5)
PFAV	Face average total pressure (A.1.2)
PR	Pressure ratio of given compression components
PRDS	Stability pressure ratio with distortion
PRO	Operating pressure ratio
PR1	Undistorted stability pressure ratio
$P(\theta)$	Total pressure at any angle θ for a given ring
Q	Number of low-pressure regions
R	Radius
RMS	Root mean square
SM	Stability margin
T	Total temperature
$\Delta PC/P$	Circumferential distortion intensity element (Equations A2 and A5, A.1.1)
$\Delta PR/P$	Radial distortion intensity element (Equation A8, A.1.2)
$\Delta PRMS$	Root mean square of time varying total-pressure fluctuations
ΔPRS	Stability pressure ratio loss (Equation A9)
ΔSM	Stability margin loss (Equation A10)
θ	Circumferential location in degrees
θ^+	Extent of high-total-pressure region

2.3 (Continued):

θ	Extent of low-total-pressure region
τ	Time increment
$\phi(f)$	Power spectral density of time-varying pressure

Subscripts

c	Circumferential
i	Instrumentation ring number
j	Instrumentation rake number
k	Low-pressure region number
MAX	Maximum
MIN	Minimum
r	Radial

3. PURPOSE:

This Aerospace Recommended Practice (ARP) provides guidelines by which gas turbine engine aerodynamic stability and performance, as affected by the quality of the airflow delivered to the engine, can be evaluated consistently. The following subjects are addressed:

3.1 Distortion Descriptors:

Distortion descriptors are presented that permit the representation and evaluation of inlet total-pressure distortion effects on propulsion system stability and performance.

3.2 Stability Assessment:

Guidelines are presented for developing an evaluation method that relates the distortion descriptor levels to engine stability in a form suitable for use in computer simulations.

3.3 Testing:

Guidelines are provided for testing, instrumentation, data acquisition, and data processing.

4. PROVISIONS:

Guidelines are provided to:

- a. Identify the inlet/engine Aerodynamic Interface Plane (AIP) (Section 8).
- b. Express inlet flow distortion data in terms of numerical distortion descriptor elements (Section 5 and Appendix A).
- c. Quantify engine compressor stability margins (Section 6).
- d. Provide an empirical correlation technique for translating distortion descriptors into parameters suitable for stability and performance assessments (see Appendix A).
- e. Provide an inlet distortion procedure, useful for both engine and inlet development, to identify potentially critical stability conditions (see Section 5).
- f. Conduct assessments to quantify the effects of inlet distortion on engine stability and performance (see Section 6).
- g. Recommend inlet and engine tests to evaluate propulsion system stability and to develop engine stability and performance assessments.
- h. Provide the aerodynamic stability and performance information for use by ARP1257 and AS681.

5. DISTORTION DESCRIPTOR FORMAT AND USAGE:

The AIP pressure-probe data are used to describe inlet distortion directly in terms of the probe readings (pattern) and numerically in terms of a distortion descriptor that is related to the severity of the distortion. The distortion descriptor provides a means of identifying critical inlet flow distortions and of communicating during propulsion system development. A universal distortion descriptor is beyond the state of the art; however, distortion-descriptor elements have been identified for use in structuring a distortion descriptor for a particular engine. These elements should be used to define each distortion descriptor system and its associated computation procedure.

5.1 Distortion-Descriptor Elements:

The distortion-descriptor elements are used to describe the distortion at the AIP. The fundamental element is the set of pressure-probe readings that are used to describe the pressure distribution at the AIP. The pressure probes are usually arranged in rake and probe arrays, as described in Section 8 (see Figure 2). Circumferential and radial distortion elements (obtained using the pressure-probe readings) are described on a ring-by-ring basis, as described below and in detail in the Appendix.

- 5.1.1 Circumferential Distortion Elements: Circumferential distortion is described in terms of intensity, extent, and multiple-per-revolution elements.