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ORIGINAL ARTICLE

# Strip distortion generator for simulating inlet flow distortion in gas turbine engine ground test facilities

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**Abstract** A methodology has been developed to generate a non-uniform/distorted inlet flow field to test a gas turbine engine in ground test facilities. The distorted flow field is generated by positioning radial and circumferential strips of varying widths upstream of the Aerodynamic Interface Plane. The interacting wakes from these strips are used to generate a given target flow field. The approximate superposition of these wakes is investigated and used to construct the strip arrangement which is subsequently validated by computing the flow field by solving the Navier–Stokes equations. The strip geometry designed using the present methodology is able to produce the target Mach number distribution with a root-mean-square error of 5.06%.



## 1. Introduction

The performance of a gas turbine engine is adversely affected by the non-uniform or distorted flow in the aircraft inlet duct. The engine compression system is particularly vulnerable to the distorted flow. The compressors are designed for uniform flows and suffer from performance degradation due to distorted inflow conditions leading the compressor to aerodynamic instabilities like rotating stall and surge. Inlet flow distortion also lowers the surge margin of the compressor with surge occurring at much lower pressure ratios. The distortion in the inlet flow field can be in static or total pressures, or temperatures, or velocities. The total pressure distortion is the most common type and also has the most deleterious effect on the performance of the compressor. The total pressure distortion can be either in circumferential or

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## Nomenclature

| | |
|---|---|
| $A$ | constant |
| $AIP$ | Aerodynamic Interface Plane |
| $b$ | width of strip (unit: m) |
| $C_D$ | drag coefficient |
| $C_{p,b}$ | average base pressure coefficient |
| $d$ | diameter of inner circle (unit: m) |
| $D$ | diameter of duct (unit: m) |
| $GCI$ | grid convergence index |
| $k$ | turbulence kinetic energy (unit: m$^2$/s$^2$) |
| $M$ | Mach number |
| $(M_{min})_i$ | minimum Mach number in each ring |
| $(M_\theta)_i$ | Mach number at a circumferential $\theta$ location in the $i$th ring |
| $MPR$ | multiple-per-rev parameter |
| $M_u$ | unaffected Mach number |
| $n$ | total number of strips |
| $p_{0,low,ave}$ | average of the total pressures below the ring average total pressure (unit: Pa) |
| $p_{0,ring,ave}$ | average total pressure in the ring (unit: Pa) |
| $(\Delta PC/P)$ | circumferential distortion intensity |
| $(\Delta PR/P)$ | radial distortion intensity |
| $Re$ | Reynolds number |
| $RMSE$ | root-mean-square error |
| $s$ | separation distance between strips (unit: m) |
| $S$ | Mach number function |
| $T$ | function of the circumferential coordinate $\theta$ |
| $Tu$ | inlet turbulence intensity |
| $u_0$ | velocity of the unaffected stream (unit: m/s) |
| $\Delta u$ | decrement in velocity caused by the strip (unit: m/s) |

### Greek letters

| | |
|---|---|
| $\varepsilon$ | turbulence dissipation rate (unit: m$^2$/s$^3$) |
| $\theta_c$ | half-limit angle of influence (unit: degree) |
| $\theta^-$ | circumferential distortion extent (unit: degree) |
| $\lambda$ | circumferential separation between strips (unit: degree) |

radial directions and such total pressure patterns are called 'classical' distortion patterns. The total pressure distortion profiles such as those occurring at flight conditions are termed 'complex' (or 'composite') distortion patterns and can have both circumferential and radial non-uniformities.

The general subject of inlet flow field distortion and its adverse consequences on the performance and stability of the compression systems were reviewed in Longley and Greitzer [1], and Sivapragasam and Ramamurthy [2]. The distorted flow field ahead of the compressor is simulated in ground test facilities by various methods. Several such techniques were examined by Beale et al. [3]. Of the various methods of distortion simulation in ground test facilities the distortion screen and the air jet distortion system are deemed most satisfactory.

The distortion screens have been commonly employed for simulating total pressure distorted inlet flow field in test facilities. The screens are simply wire meshes of various porosities secured to a frame and placed ahead of the engine/compressor. The screen porosities are chosen to produce the required pressure drop. The distortion screens are the most preferred method of distortion simulation by virtue of their simplicity. The design of screens to simulate a desired distorted flow field was discussed by Overall [4], Anderson [5], Sankaranarayanan et al. [6] and Ramamurthy et al. [7]. Apart from distortion screens other types of aerodynamic blockages can also be introduced, like, for example, strips used by Zhang and Gao [8] and Cousins et al. [9], or split-airfoil employed by Beale et al. [10], or round bars used by Hirschmann et al. [11], to achieve total pressure distortion.

In the present study we develop a methodology for the design of strip arrangement to generate the target distortion pattern. This methodology is closely based on the method of [8]. The general strategy, in Ref. [8] and in the current work, is the linear superposition of the wake fields from individual strips to achieve the required distortion pattern. The present paper is arranged as follows. The computational procedure for computing the flow field behind the strips is described in Section 2. The flow field due to a single full-length strip spanning the diameter of the confining duct, and the flow field due to two such adjacently positioned strips are discussed in Sections 3.1 and 3.2, respectively. In Section 3.2 we also introduce the idea of linear superposition of the wake fields. In Section 3.3 the flow field due to a single short-length strip is discussed, and in Section 3.4 we extend the linear superposition principle to two angularly positioned short-length strips. The methodology developed to generate a target distortion pattern is described in Section 4, and an example flow case is considered to demonstrate the application of this methodology. In Section 5 the total pressure distortion parameters are evaluated and presented as per current industry standard. The conclusions from the present work are given in Section 6.

## 2. Computational procedure

Consider a strip of width $b$ placed diametrically in a duct of diameter $D$ as shown in Figure 1. The flow field at a distance $1D$ behind the strip is to be investigated; this plane is identified as the Aerodynamic Interface Plane ($AIP$) which is the station used to define the distorted field between the inlet and engine. At this plane the velocity or Mach number (or total pressure) distribution is to be evaluated on six rings: ring 0, which is the innermost ring, to ring 5, which is the outermost ring as shown in Figure 1. The presence of the strip produces a wake field behind the strip. The Mach number outside of the wake remains uniform and this unaffected value is denoted as $M_u$. The extent of influence of the wake in a downstream plane is schematically illustrated by vertical dashed lines in Figure 1. The angle subtended by this extent of influence

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