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Mean Wake Characteristics of an Aerodynamically Loaded Fan

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Abstract

ONE of the main mechanisms responsible for the generation of turbofan noise in flight is the interaction of the unsteady rotor wake field with the fan stators. Analysis of the strength of this interaction noise source requires a knowledge of the rotor-produced flow disturbances as a function of radius and downstream distance. Thus the validity of noise-related design choices such as rotor-stator spacing and the determination of the position of the blade span most responsible for noise generation depend on the rotor wake flow field characterization. The parameters usually described are the magnitude of the wake defect and its width. The purpose of the present experiment is to determine these parameters along with the harmonic content of the rotor wakes in order to provide wake parameters of interest to acousticians and fan designers.

Contents

Existing rotor wake data were primarily obtained from low-speed laboratory fans.[1,2] The present study was conducted to measure wake properties under conditions that are more representative of practical turbofan operation. The experiments were performed on a 0.5-m-diameter fan with a 1.2 pressure ratio in the NASA Lewis 9×15 ft anechoic wind tunnel.[3] The fan was tested at a tip speed of 197 m/s, equal to 96% of the design speed (8020 rpm.)

Rotor wake properties under static ($U=0$) and forward velocity conditions ($U=41$ m/s) were measured with a stationary cross-film anemometer circumferentially located midway between two stator vanes and oriented to measure the streamwise and upwash components of the velocity downstream of the rotor, as indicated in Fig. 1. The anemometer signals were analyzed in a Fast Fourier analyzer, utilizing an ensemble averaging technique in which the analyzer was triggered by a once-per-revolution signal. Data from radial locations at the midspan and near the fan tip are presented for three downstream locations ranging from 0.54 to 1.77 rotor chords.

For noise and other purposes, one is interested in the decay characteristics of the wake as a function of downstream distance. As Fig. 2 indicates, in the midspan region the amplitude of the wake streamwise and upwash components decreases with downstream distance. The streamwise wake defect magnitude is larger than the magnitude of the wake upwash by nearly a constant amount. The effect of forward velocity ($U=41$ m/s) on the change in velocity in the wake is minimal.

A second parameter commonly used to describe the wake, the wake width, is shown in Fig. 2b. The wake width is measured at the point where the wake velocity is half of its extreme value. The width of the streamwise wake deficit increases with downstream distance corresponding to the spreading of the wake. The upwash width also increases with downstream distance but appears to pass through a minimum at the intermediate distance. As in the case of the velocity defects, the wake widths show little effect of forward velocity.

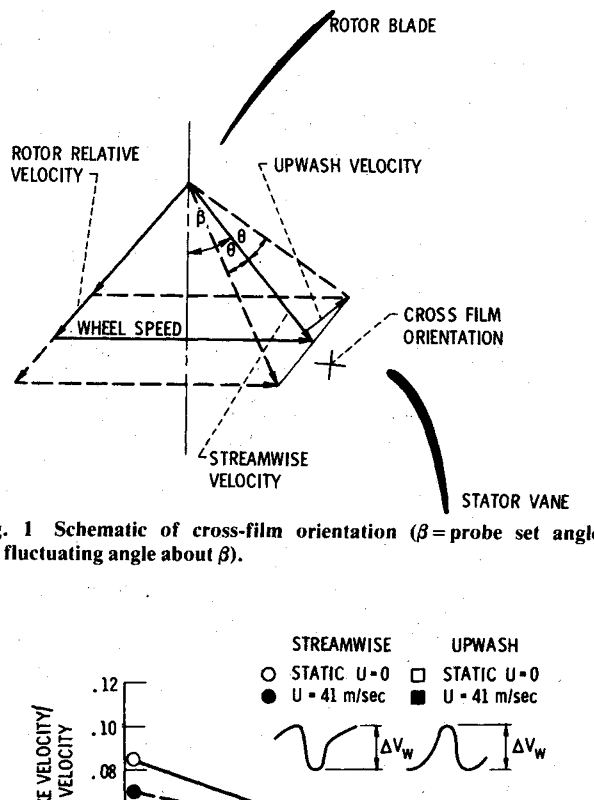

Fig. 1 Schematic of cross-film orientation (β = probe set angle, θ = fluctuating angle about β).

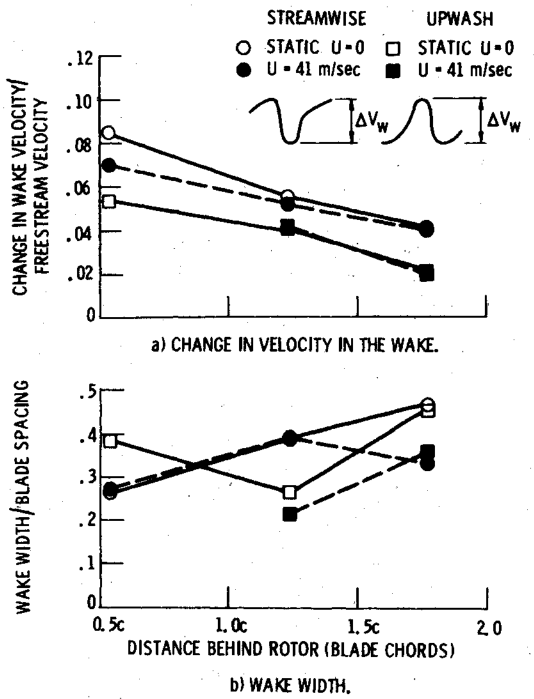

Fig. 2 Effect of downstream distance and forward velocity on wake parameters, midspan position, 96% of design rpm. Streamwise Mach number = 0.49.

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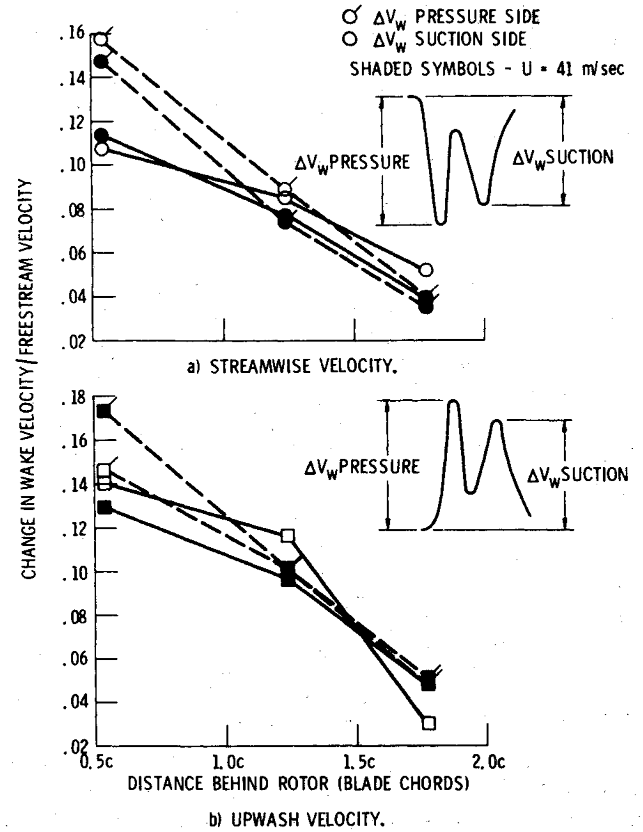

Fig. 3 Effect of downstream distance and tunnel flow on the change in velocity in the wake in the near tip region. Streamwise Mach number = 0.43.

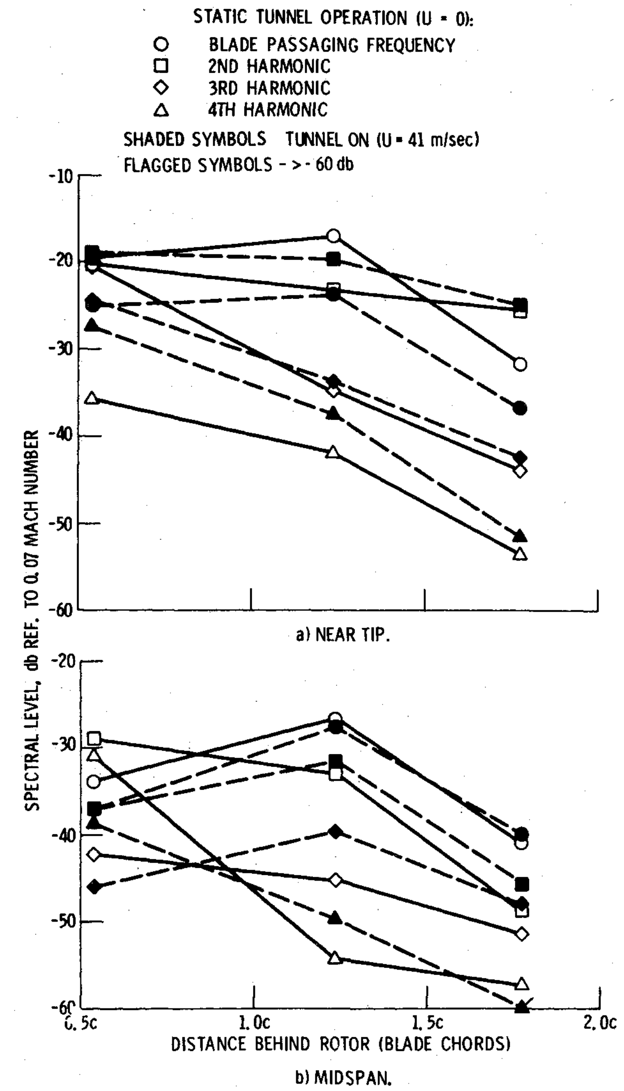

Fig. 4 Harmonic levels from signal enhanced spectra, upwash component, 96% of design rpm.

The rotor wake in the near tip region has a more complicated shape than in the midspan region, as can be seen by comparing the schematics in Figs. 2 and 3. Near the tip, the simple wakes and potential flows are complicated by interaction with the casing boundary flow as well as a number of secondary flows. A tip vortex can be generated because of the clearance between the blade tip and outer wall which allows communication between the pressure and suction side of the blade. It could also be generated by relative motion of the blade scraping the wall boundary layer and rolling it into a vortex. Since the radial component of the velocity field behind the blade was not measured it is not possible to determine which feature of the wake velocity in the tip region can be attributed to a tip vortex. As an indicator of what occurred with downstream distance, the wake region was characterized by measuring the magnitude of the velocity change on the pressure side and suction side of each waveform.

Figure 3 indicates that the magnitude of the change in velocity on the pressure side of the waveform has a linear decay rate that is considerably greater than the decay rate of the midspan wakes. The suction side wake magnitude shows the same decay rate as do the midspan wakes over the first two stations but then decays at about the same rate as the pressure side magnitude. At the farthest downstream position both the suction and pressure side magnitudes of both the streamwise and upwash components are nearly equal and approximately at the same values as for the midspan wakes at this location.

Because of the differences in shape of the rotor wakes in the near tip and midspan region, the typical parameters of velocity defect and wake width are not adequate descriptors of the rotor wake field. Therefore the ensemble averaged waveforms were analyzed by the fast Fourier transform method to determine their harmonic content. Figure 4 indicates the change in harmonic content of the waveforms with increasing downstream distance for the upwash component. The high levels of the second harmonic together with the fundamental levels indicate that the upwash component of the rotor wake has a complicated shape. This complexity is not adequately described by the magnitude of the velocity change through the wake (Fig. 2) and its width (Fig. 3). Although forward velocity had minimal effect on the other wake parameters, it does affect the harmonic content of the wake in the tip region at the closest spacing.

Although only two components of the velocity were measured in the present experiment, the data reveal the complex nature of the velocity components of the rotor wake of a highly loaded rotor in the stationary reference frame. The analysis of the rotor wake waveforms in terms of their harmonic content will aid in understanding the complex nature of the fan noise generated by the fluctuating velocity field surrounding the stator vanes.

References

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[3] Heidmann, M. F. and Dietrich, D. A., "Simulation of Flight-Type Engine Fan Noise in the NASA Lewis 9×15 Anechoic Wind Tunnel," NASA TMX-73540, Nov. 1976.