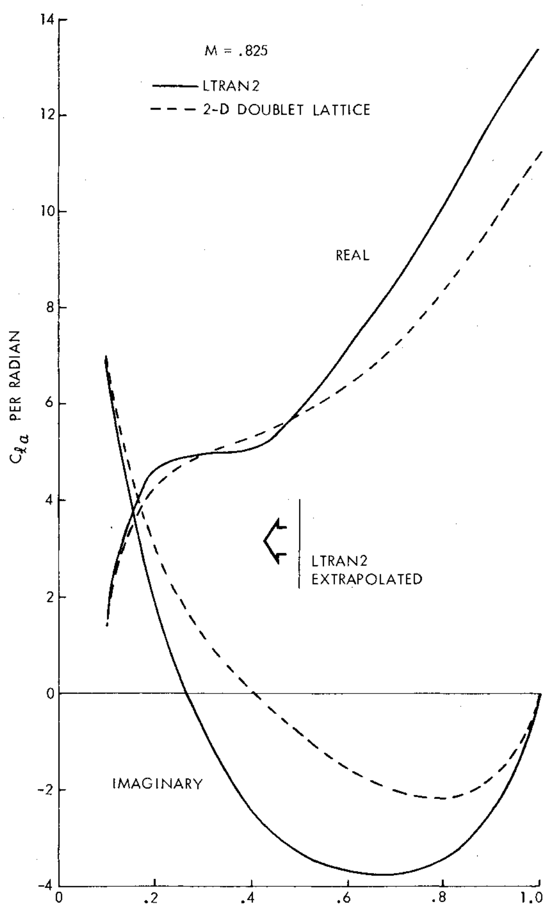

Fig. 4 CFD aerodynamics.

forces may also be precalculated and the required analysis values interpolated using the parameter. Two elements of the modalized air force matrix corresponding to a bending mode and a torsion mode of a large transport are shown in Fig. 3. The aerodynamics are calculated using a lifting surface technique similar to the doublet lattice method of Ref. 3. The complex parameter p is also very useful for representing the modalized aerodynamics for the generalized motion required in active controls analysis.

Computational Fluid Dynamics

As unsteady aerodynamic programs become more sophisticated and costly to use, the parameter p becomes increasingly more valuable. The parameter was used in the first efforts in incorporating the LTRAN2 code of Ref. 4 into the flutter analysis of a three-dimensional wing. Typical aerodynamics, in this case the lift curve slope of the NACA 64A006 airfoil, are presented in Fig. 4. Because LTRAN2 is limited in reduced frequency, the aerodynamics had to be extrapolated to obtain the necessary range. This extrapolation was based on the convergence of the transonic aerodynamics to linear aerodynamics with increasing reduced frequency and is made in terms of the complex ratio of LTRAN2 aerodynamics to two-dimensional doublet lattice aerodynamics. For reference, the two-dimensional linear aerodynamics are also presented in Fig. 4.

Summary

Replacing the reduced frequency with the parameter p allows the entire frequency range to be represented on a finite scale, while expanding the low frequency range which is of most interest. The parameter has proved useful in flutter analysis, active controls analysis, and also in the incorporation of results from computational fluid dynamics (CFD) programs into conventional aeroelastic analyses. Its nature of emphasizing the most critical area in representing the unsteady aerodynamics, leads to an efficient selection of reduced frequencies for precalculating the aerodynamic coefficients and can provide guidelines in selecting the reduced frequencies in unsteady aerodynamic testing.

References

[1] Scanlan, R.H. and Rosenbaum, R., *Introduction to the Study of Aircraft Vibration and Flutter,* The Macmillan Co., New York, 1951.

[2] Edwards, J.W., "Unsteady Aerodynamic Modeling and Active Aeroelastic Control," SUDAAR 504, Stanford Univ., Calif., 1977.

[3] Albano, E. and Rodden, W.P., "A Doublet Lattice Method for Calculating Lift Distributions on Oscillating Surfaces in Subsonic Flows," *AIAA Journal,* Vol. 7, Feb. 1969, pp. 279, 285.

[4] Ballhaus, W.F. and Goorjian, P.M., "Implicit Finite Difference Computations of Unsteady Transonic Flows About Airfoils, Including the Treatment of Irregular Shock Wave Motions," AIAA Paper 77-205, Jan. 1977.

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Propeller Tip Vortex: A Possible Contributor to Aircraft Cabin Noise

Brent A. Miller,* James H. Dittmar,† and Robert J. Jeracki†
NASA Lewis Research Center, Cleveland, Ohio

Nomenclature

D = propeller diameter
C_p = propeller power coefficient = power/[(density) (rpm)^3 $(D)^5$]
J = propeller advance ratio = forward velocity/[(rpm) (D)]
M_0 = Mach number of wind-tunnel flow
M_T = relative Mach number at propeller tip
R = propeller radius
r = radial position of vane microphone

Introduction

THE National Aeronautics and Space Administration, with industry participation, is conducting a broad-based turboprop technology development program that portends a new generation of highly fuel efficient turboprop aircraft with the speed and comfort potential of today's turbofan powered fleet.[1] A key technology area deals with the concern for reducing the passenger cabin noise level in these aircraft to a level comparable to current turbofan aircraft. The assumption is generally made that cabin noise levels are governed by the transmission of propeller generated noise through the fuselage side wall. However, past attempts at reducing turboprop aircraft cabin noise levels by modifications to the fuselage side wall have generally met with limited success, although new analysis and fuselage wall design concepts are currently being developed that may result in significant gains.[2,3]

Others have suggested that propeller induced vibrations may be generated, and transmitted via structural paths to the fuselage structure, to be radiated as noise to the cabin in-

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*Project Engineer.

†Research Engineer.

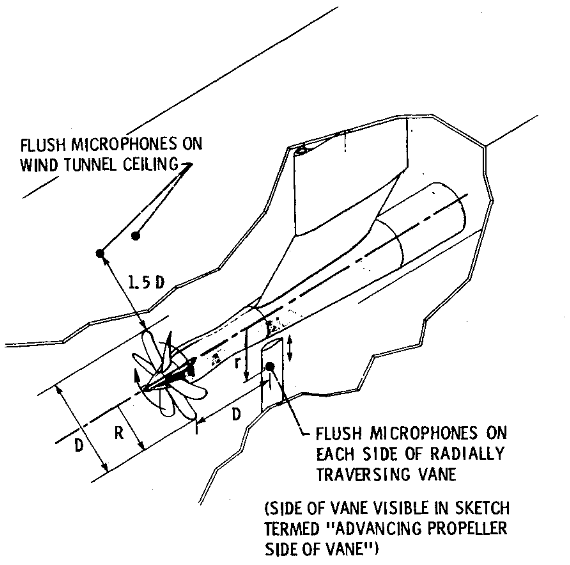

Fig. 1 Installation of propeller, radially traversing vane, and microphones in wind tunnel.

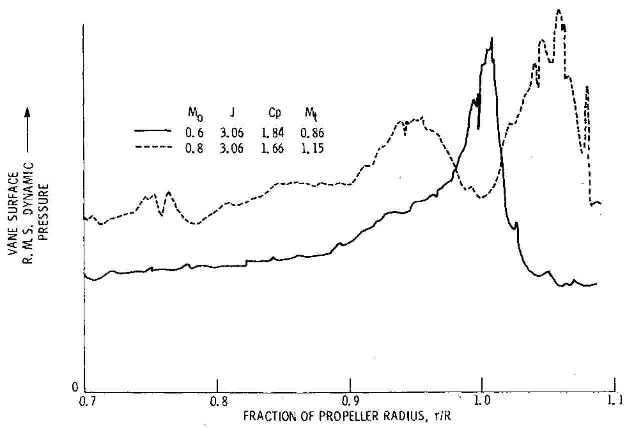

Fig. 2 Radial variation of vane surface rms dynamic pressure measured in propeller wake (advancing propeller side of vane).

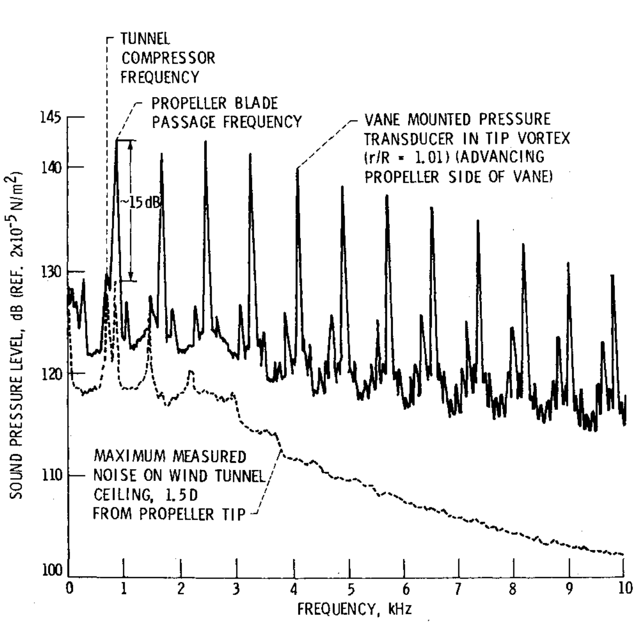

Fig. 3 Comparison of propeller noise spectrum on wind-tunnel ceiling with spectrum measured on vane surface; $M_0 = 0.6$, $J = 3.06$, $C_p = 1.84$, $M_t = 0.86$.

terior.[4] This appears to be a possible explanation for the generally poor success obtained by making modifications to fuselage side walls if a strong source for the propeller induced structural excitations can be identified.

Analysis

It was postulated that the propeller wake striking the wing, in particular pressure disturbances generated downstream of the propeller by the action of the propeller tip vortex, could be the sought after excitation source. A wing surface downstream of the propeller, exposed to the rotating tip vortices, could experience a significant surface pressure fluctuation at the propeller blade passing frequency. A similar phenomena has been suggested for rotor-stator interaction noise in turbofans.[5]

Two simplified approaches were used to estimate the strength of the propeller tip vortex. The first method employed the propeller operating lift coefficient, and local dynamic pressure, to derive the pressure differential generated by the propeller blades. The assumption was made that this pressure differential would be reflected by a like pressure difference across the tip vortex. For the second approach, photographs of the operating propeller showing visible water vapor condensation in the tip vortex, along with the known local temperature and relative humidity, permitted estimates to be made of the static temperature and hence static pressure in the vortex core. In both instances these differential, or fluctuating, pressures, when expressed as acoustic levels, exceeded by more than 20 dB the estimated maximum airborne propeller noise that would strike the fuselage side wall. Thus the propeller tip vortex striking the wing may impart sufficient energy to the aircraft structure to become a significant, or possibly even dominant, factor in governing passenger cabin noise levels. In order to evaluate this hypothesis, tests were conducted to identify the propeller tip vortex and to measure the fluctuating pressures experienced by a simulated wing surface operating in the propeller wake. Significant results of these tests are presented here.

Apparatus and Results

Propeller wake measurements were obtained in the NASA Lewis Research Center's 8 × 6-ft porous wall wind tunnel. The test apparatus and instrumentation are illustrated by Fig. 1. The propeller model, designated SR-3, was 0.61 m in diameter with eight swept blades. Previous tests were conducted to define the aerodynamic and acoustic performance of this model.[6,7] For the present test, pressure transducers were flush mounted in the tunnel ceiling near the plane of the propeller about 1½ propeller diameters from the blade tip. Additional transducers were flush mounted on opposite surfaces of an airfoil-shaped vane located 1 diam downstream of the propeller. This vane was mounted on a traversing mechanism, aligned along a propeller radius, so that measurements in the propeller wake could be obtained over a range of radial positions r. The vane was positioned at an incidence angle of 6 deg relative to the tunnel airflow so as to be approximately aligned with the nominal 6 deg swirl angle anticipated in the propeller wake.

The presence of a strong propeller tip vortex striking the vane is indicated by the vane surface dynamic pressure traces of Fig. 2. At 0.6 tunnel Mach number, a strong peak in dynamic pressure occurs at a radial position corresponding to the propeller tip. At Mach 0.8, where the propeller tip is operating supersonically, the tip vortex appears to shift radially outward to $r/R \approx 1.06$, with a second, lesser peak, occurring at $r/R \approx 0.95$. In all cases, maximum dynamic pressure is confined to a relatively narrow region about the propeller tip. As might be expected, no evidence of the tip vortex or the propeller viscous wake could be detected with the propeller operating at windmill (rotating with no power applied, $C_p = 0$).

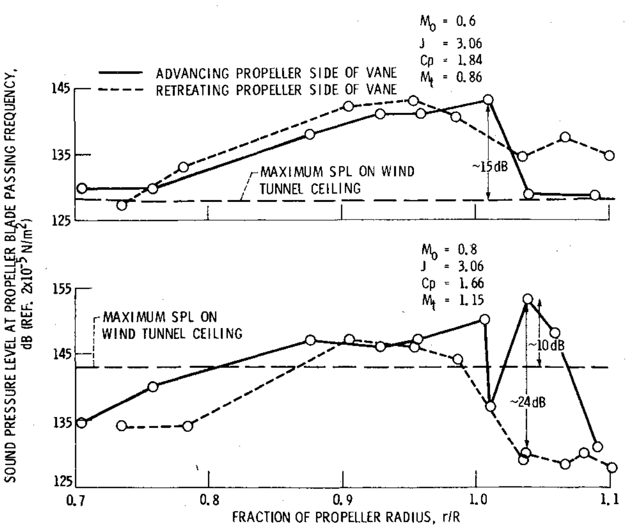

Fig. 4 Radial variation of vane surface sound pressure level at propeller blade passing frequency.

A comparison of the maximum sound pressure level spectra measured on the tunnel ceiling with that obtained by placing the vane transducer in the tip vortex is shown by Fig. 3. At the propeller blade passing frequency of approximately 1000 Hz, the sound pressure level measured on the vane surface due to the action of the tip vortex is about 15 dB higher than the maximum propeller noise measured on the wind-tunnel ceiling. The tip vortex spectra is rich in higher harmonics, showing even larger increases in sound pressure level compared with the ceiling transducer. This suggests that the tip vortex is highly compact and subjects the vane surface to a sharp "slap"—or nearly impulsive excitation—as opposed to a sinusoidal excitation at the blade passing frequency. Somewhat similar results were obtained at Mach 0.8, although the higher harmonics in the tip vortex were usually significantly below the level of the fundamental.

A summary of the blade passing frequency sound pressure level measured in the propeller wake plotted as a function of radial position is shown by Fig. 4. Measurements obtained on both sides, or surfaces, of the vane are shown, as is the maximum blade passing sound pressure level measured on the tunnel ceiling.

At Mach 0.6, the vane surface measurements significantly exceed the wind-tunnel ceiling values for radial positions between $r/R \approx 0.75$ and the propeller tip. Little difference was noted between the two surfaces of the vane, excepting the region beyond the propeller tip. This effect beyond the blade tip may have resulted from the vane being set at 6 deg incidence angle relative to the undisturbed tunnel flow, and thus not aligned with the local flow.

At the Mach 0.8 condition, the advancing propeller side of the vane experienced higher sound pressure levels than the other side of the vane. This is especially evident in the region beyond the propeller tip, where measurements were obtained in or near to the tip vortex. At this radial location the transducers on the advancing propeller surface of the vane experienced a sound pressure level approximately 24 dB higher than the other surface. Maximum vane surface sound pressure levels were about 10 dB greater than the maximum levels measured on the wind-tunnel ceiling.

Concluding Remarks

Model test results support the hypothesis that a well-defined propeller tip vortex exists that can subject a downstream wing surface to a much greater excitation than might be experienced by the aircraft fuselage side wall exposed to propeller generated noise. If the assumption is made that fuselage and wing surfaces are equally responsive to the incident dynamic pressure, and ultimately transmit this response with equal efficiency to the cabin interior, it follows that passenger cabin noise levels may well be governed, at least in some instances, by the action of the propeller tip vortex striking the wing or other portions of the airframe. Indeed, even if structural borne excitations were less efficient than airborne excitations in creating cabin noise, the higher level of the former could still govern cabin noise levels.

Spectral analysis indicates that the vortex may subject the wing surface to a sharp "slapping" excitation rich in high-order harmonics. This maximum excitation exists over a relatively narrow radial extent and could easily be missed or overlooked in a test that relied on microphones at fixed radial positions.

At higher speed, where the blade tip is supersonic, large differences were found in the sound pressure level between the two sides of the vane. This has potential significance relative to preferred directions for propeller rotation, as well as use of the wing or other surfaces to shield the cabin side wall from propeller noise.[8]

The need for more work is clearly indicated to further explore the character of propeller wakes and their potential acoustic interactions with the airframe. Wing surface response to propeller tip vortex induced excitations, and the effectiveness of this response in radiating noise to the cabin interior, must be established to assess the full significance of the results presented here.

References

[1] Dugan, J.F., Miller, B.A., Graber, E.J., and Sagerser, D.A., "The NASA High-Speed Turboprop Program," NASA TM 81561 and SAE Paper 801120, Oct. 1980.

[2] Rennison, D.C., Wilby, J.F., Marsh, A.H., and Wilby, E.G., "Interior Noise Control Prediction Study for High-Speed Propeller-Driven Aircraft," NASA CR-159200, Sept. 1979.

[3] Revell, J.D., Balena, F.J., and Koval, L.R., "Analytical Study of Interior Noise Control by Fuselage Design Techniques on High-Speed, Propeller-Driven Aircraft," NASA CR-159222, July 1978.

[4] Johnston, J.F. and Donham, R.E., "Attenuation of Propeller Related Vibration and Noise," AIAA Paper 81-521CP, April 1981.

[5] Dittmar, J.H., "Interaction of Rotor Tip Flow Irregularities with Stator Vanes as a Noise Source," NASA TM 73706, Oct. 1977.

[6] Jeracki, R.J., Mikkelson, D.C., and Blaha, B.J., "Wind Tunnel Performance of Four Energy Efficient Propellers Designed for Mach 0.8 Cruise," NASA TM-79124, April 1979.

[7] Dittmar, J.H., Jeracki, R.J., and Blaha, B.J., "Tone Noise of Three Supersonic Helical Tip Speed Propellers in a Wind Tunnel," NASA TM-79167, June 1979.

[8] Dittmar, J.H., "Feasibility of Wing Shielding of the Airplane Interior from the Shock Noise Generated by Supersonic Tip Speed Propellers," NASA TM 79042, Dec. 1978.

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Estimate of Human Control over Mid-Air Collisions

J. N. Anno*
Research Dynamics Inc., Cincinnati, Ohio

Introduction

IN the albeit sometimes too complex world of today, it is sometimes refreshing (and sometimes alarming) to stand off at a distance and view the behavior of man and his

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*President.