were reproduced in Ref. 2: The model is locked to the balance by means of a set screw. The principal objection to using zero-spin data as a tare is that a nonspinning body develops a side force and yawing moment which is roll-angle-dependent.[4] I would suggest rather that the wind-tunnel balance, with spinning model mounted, serve as a flow angularity probe [viz Eq. (7)] to obtain $\{\alpha_0, \beta_0\}$. It should also be pointed out in Platou's correction equations that the use of the Magnus coefficient, C_{N_p}, with its implied linearity of force with spin rate is probably inappropriate for fin-stabilized configurations. Although bodies of revolution may evidence linearity of load with spin rate over a broad range of interest, finned bodies, in general, do not. Even if linearity were justified, the derivative, C_{Y_p}, would be required for consistency with his implied Y-axis direction.

References

[1] Platou, A. S., "Wind-Tunnel Magnus Testing of a Canted Fin or Self-Rotating Configuration," *AIAA Journal*, Vol. 10, No. 7, July 1972, pp. 965–967.

[2] Regan, F. J., "Magnus Measurements on a Free-Spinning Stabilizer," AIAA Paper 70-559, Tullahoma, Tenn., 1970.

[3] Benton, E. R., "Supersonic Magnus Effect on a Finned Missile," *AIAA Journal*, Vol. 2, No. 1, July 1964, pp. 153–155.

[4] Regan, F. J., "Roll Induced Force and Moment Measurements of the M823 Research Store," NOLTR 68-195, Nov. 1968, Naval Ordnance Laboratory, White Oak, Md.

Reply by Author to F. J. Regan

Anders S. Platou*

U.S. Army Ballistic Research Laboratories, Aberdeen Proving Grounds, Md.

I WISH to thank F. J. Regan for his comments on my paper.[1] I feel that Regan agrees with my main finding that there is a normal force interaction term in the Magnus data presented in Ref. 2. The main disagreement appears to be in how to eliminate the interaction from the data. I still feel that the most accurate way to do this is to subtract the zero spin measurement from the spin measurement at the same angle of attack. This is difficult or impossible to do when the zero spin data are roll dependent. The zero spin data measurement is not impossible if it is not roll dependent.

In the case where one wishes to or is forced to correct spin data for a normal force interaction then one has the choice of my technique or Regan's technique—both have their difficulties.

In my technique one must estimate the Magnus force center of pressure or in the case of a finned body where both fin and body are rotating one must also contend with the produced Magnus couple. However, my technique does take into account the variation of average flow inclination over the body at each angle of attack.

Regan's technique eliminates the need to estimate the Magnus center of pressure, but it does assume that the flow inclination is constant in the wind-tunnel flow region traversed by the model. Since the normal force interaction in the Magnus measuring direction is very sensitive to the exact flow inclination one must be very careful in evaluating the results of this corrective technique. I would suggest that anyone evaluating wind-tunnel Magnus data where normal force interactions are suspected should attempt correction of the data using both techniques.

In closing, I would like to say that my main reason for publishing Ref. 1 was to make the reader aware that Magnus data on a self-rotating configuration can contain a normal force interaction and that a careful study of the data is necessary before one can use these data as free flight Magnus data.

The other points of disagreement are minor and need only a short comment. My sentence referred to in Regan's third paragraph should be changed to read, "The existence of a moment at zero force is indicative of a couple and in this case (Ref. 2) is due to the normal force interaction term ($N \sin \varepsilon$) acting opposite to the fin Magnus force." Also, Eq. (8) in Regan's comment is correct rather than my Eq. (2).

Received October 10, 1972.

Index categories: Uncontrolled Rocket and Missile Dynamics; Rocket Vehicle Aerodynamics.

* Aerospace Engineer.

References

[1] Platou, A. S., "Wind-Tunnel Magnus Testing of a Canted Fin or Self-Rotating Configuration," *AIAA Journal*, Vol. 10, No. 7, July 1972, pp. 965–967.

[2] Regan, F. J., "Magnus Measurements on a Free-Spinning Stabilizer," AIAA Paper 70-559, Tullahoma, Tenn., 1970.

Reply by Authors to A. G. Kurn

Darshan S. Dosanjh*

Syracuse University, Syracuse, N.Y.

AND

James C. Yu†

George Washington University, Washington, D.C.

IN the comments (see Ref. 1) on the authors' paper entitled, "Reduction of Noise from Supersonic Jet Flows,"[2] Kurn has drawn attention to his interesting experimental results on pressure fluctuations at the base of a bluff afterbody containing a sonic nozzle with the jet flow submerged in an external free-stream of a transonic wind tunnel.[3] He points out that at certain ratios of the total head of the jet flow to that of the surrounding uniform flow, a sudden reduction of discrete spectral components of the base-pressure fluctuations was observed. Based on schlieren photographs of the flow, he attributes this behavior of the base-pressure fluctuations to the modification or elimination of the periodic shedding of vortices from the bluff base of the afterbody. Since no direct noise measurements were undertaken by Kurn, the deductions about any possible changes in the radiated "far-field" noise from this flow configuration are based entirely on the corresponding behavior of the measured base-pressure fluctuations. Since the periodic vortex shedding observed by Kurn[3] and also by many others in supersonic free jet flows[4–6] has often been shown to generate discrete sound emissions, it therefore seems to be a reasonable deduction that either the disappearance or the modification in strength or periodicity of the vortex shedding in Kurn's experiments may lead to an elimination, modification, or reduction of discrete component of the related noise emission. Kurn, however, assumes similarities between his experiments and those described by the authors.[2] He then advances an alternate hypothesis that the elimination of the vortex shedding at the interface (mixing region; Fig. 7b; Ref. 2) of the inner and outer coaxial jets may be responsible for the observed noise reductions reported in Ref. 2.

The authors submit that the flow characteristics of a sonic jet exhausting into a bluff base submerged in a much larger uniform

Received September 12, 1972.

Index categories: Aerodynamic and Powerplant Noise (Including Sonic Boom); Jets, Wakes, and Viscid-Inviscid Flow Interactions; Supersonic and Hypersonic Flow.

* Professor, Department of Mechanical and Aerospace Engineering. Associate Fellow AIAA.

† Graduate Student, Department of Mechanical and Aerospace Engineering; now Assistant Research Professor of Engineering, George Washington University. Associate Member AIAA.

flow stream are not quite similar to those of the two interacting coaxial supersonic jet flows, and that thus Kurn's assumption of similarity seems to be of doubtful validity. Moreover his hypothesis of periodic vortex shedding in the interface of the two jets and vortex disappearance or modification as the main source for substantial noise reductions observed from two coaxial supersonic interacting jets[2] is an oversimplification. Therefore some clarifying remarks may be helpful.

The ratio of the inner to outer sonic nozzle exit areas for the coaxial-jet experiments by the authors[2,7] were systematically varied from 1.65 to 0.31. The inner annular wall thickness of the coaxial jet configurations was approximately $\frac{1}{32}$ in., yielding a ratio of sonic nozzle exit area to total base area of 0.74, and a ratio of the inner annular solid base to inner nozzle exit area is 0.36. After extensive far-field noise measurements, it was concluded that the maximum noise reduction is achieved when the exit areas of the inner and outer coaxial sonic nozzles are about equal. On the other hand, in Kurn's experiments[3] the ratio of nozzle to total base area is 0.42 and the ratio of the annular solid base to nozzle exit area is 1.38, which suggests that Kurn's experiments were conducted comparatively with a more blunt base. The total head-pressure ratios of the inner (jet) to the outer (tunnel) flows for which Kurn observed the elimination of the base-pressure fluctuations were greater than one, whereas in the experiments by the authors[2] with coaxial jet flows, at minimum noise condition the total head pressure of the outer supersonic jet was invariably somewhat higher than that of the inner supersonic flow. It is pertinent to point out that in some of the experiments by the authors where the total head pressure of the inner jet was higher than that for the outer jet (similar to Kurn's case), the characteristic composite shock structure just downstream of the nozzle exists (see Fig. 7, Ref. 2) did not develop, and the observed noise reductions in this mode of operation were rather minimal. Moreover the pressure along the interface of the coaxial interacting supersonic jet flows varied with the downstream distance because of the presence of complex expansion and compression regions in both the inner and the outer jet flows. However in Kurn's experiments with the jet exhausting into the external uniform supersonic stream, the cellular shock structure does not develop and the external flow appears to exert a nearly constant pressure along the boundary of the jet flow, except in the region of the base flow and the associated single trailing shock.

The two types of periodic vortex shedding reported by Kurn seem to be direct consequence of the oscillation of the shock cell. This shock oscillation is induced by the in-phase and/or out-of-phase pressure fluctuations on the opposite sides of the sonic jet in the base of the bluff afterbody. The in-phase base-pressure fluctuation is responsible for the symmetrical shock oscillation which induces toroidal vortex shedding, whereas out-of-phase pressure fluctuation results in asymmetric shock oscillation and hence helical vortex shedding. Since only a single shock exists in Kurn's flow configuration, the simple phase relation between the base and the shock cell could also favor flow resonance by acoustic feedback.[6] Similar shock oscillations and flow instabilities have been reported by Westley and Wooley[4] for moderately under-expanded sonic jets issuing into quiescent air, and by the authors[6] for radially impinging under-expanded jets. These types of flow instabilities were found to be the source of intense discrete sound emissions recorded in the far field. However, the type of shock structure encountered in Refs. 4 and 5 is more complex, and usually more than one dominant frequency was recorded.

Preliminary experimental data gathered by the authors for coaxial jets with nearly a knife-edge as the inner wall (thereby for all practical purposes eliminating any bluff-base cavity) still revealed the characteristic modifications of the shock structure and the associated noise reductions essentially similar to the ones observed with coaxial jets with finite inner nozzle wall. The near-zero bluffness in this case would not have caused the base-pressure fluctuations similar to the ones observed by Kurn. Therefore to explain the observed substantial noise reductions in the experiments reported by the authors,[2] one must carefully consider other possible mechanisms.

The steplike over-all noise power reduction observed by the authors (Ref. 2) was confirmed by subsequent detailed near- and far-field measurements conducted with a typical coaxial jet configuration where the bandwidth of the acoustic equipment was extended to 200 kHz. It was concluded that the observed far-field noise reduction was mainly broad-band in nature (see Fig. 6 in Ref. 2 and also experimental results in Ref. 8) and the contributions to the over-all noise power reduction owing to the elimination of the discrete noise components was found to be comparatively minor. Moreover the near-field results[8] indicated that the sources of the discrete noise components were located in the repetitive shock cells with each cell emitting a different discrete component. Since an extension of noise investigations of similar coaxial supersonic interacting jet flows but using larger model jets has been recently undertaken at Syracuse University,‡ some of the limitations imposed by the small scale of the experiments, as also pointed out by Kurn, upon a detailed interpretation and analysis of the optical records of the interacting coaxial jet flows, will be rectified. Hopefully the effective noise sources, their emission mechanisms, and their modifications will then be more thoroughly examined, and any acoustic role of the possible vortical nature of the interface between the inner and outer jet flows, if present, may become more apparent. However on the basis of the experimental studies to date, the important mechanisms for the noise reductions observed with coaxial interacting cold turbulent supersonic jets as reported and explained in Ref. 2, and subsequently further elaborated in Ref. 8 are mainly attributed to 1) the substantial modifications and/or the elimination of the repetitive shock structure in the interacting supersonic jet flows, because of which the broad-band noise radiation resulting from shock-turbulence interaction is reduced and the shock-induced discrete components of noise are weakened and/or eliminated. It has been shown[2,6,8] that changes in the broad-band noise emissions 2) are the dominant contributors to the noise reductions achieved downstream of the composite standing shock structure located near the jet exits. The mean velocities of the jet flows reduce, the velocity profiles change, and the mixing between the inner and outer jet flows is modified. The outer annular jet flow 3) acoustically shields any flow-submerged noise sources, should these be located in the inner turbulent jet flow or in the slipstreams originating at the intersections of shock fronts of different strengths or in the interface between the outer and inner jet flows.

References

[1] Kurn, A. G., "Comment on 'Reduction of Noise from Supersonic Jet Flows'," *AIAA Journal*, Vol. 11, No. 2, Feb. 1973, pp. 254–255.

[2] Dosanjh, D. S., Yu, J. C., and Abdelhamid, A. N., "Reduction of Noise from Supersonic Jet Flows," *AIAA Journal*, Vol. 9, No. 12, Dec. 1971, pp. 2346–2453.

[3] Rossiter, J. E. and Kurn, A. G., "Wind Tunnel Measurements of the Effect of a Jet on the Time Average and Unsteady Pressures on the Base of a Bluff Body," Current Paper 903, Aug. 1965, Aeronautical Research Council, Royal Aircraft Establishment, Farnborough, Hants, England.

[4] Westley, R. and Wooley, J. H., "An Investigation of the Near Noise Fields of a Choked Axisymmetric Air Jet," *Proceedings of Aerodynamic Noise Symposium*, University of Toronto Press, 1968, pp. 147–167.

[5] Dosanjh, D. S. and Yu, J. C., "Noise from Underexpanded Axisymmetric Jet Flows Using Radial Jet Flow Impingement," *Proceedings of Aerodynamic Noise Symposium*, University of Toronto Press, 1968, pp. 169–188.

[6] Powell, A., "On the Mechanism of Choked Jet Noise," *Proceedings of the Physics Society*, Vol. B66, 1953, pp. 1039–1056.

[7] Farassat, Fereidoun, "Noise from High Speed Coaxial Interacting Jets," master's thesis, Sept. 1970, Mechanical and Aerospace Engineering Dept., Syracuse Univ., Syracuse, N.Y.

[8] Yu, J. C. and Dosanjh, D. S., "Noise Field of Coaxial Interacting Supersonic Jet Flows," AIAA Paper 71-152, New York, 1971.

‡ Supported by DOT under Grant OS-20094.