Technical Comments

Comment on "Induced Side Forces at High Angles of Attack"

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IN their recent paper, Wardlaw and Morrison[1] apply linear regression techniques to available experimental data for side forces on bodies of revolution at high angles of attack. In view of the inconsistencies and discrepancies in the data which have been published, their approach is fully justified and they are to be congratulated on their efforts to extract significant trends from the confusion of the published measurements.

In their paper, Wardlaw and Morrison correctly point out that the side forces are apparently very sensitive to small irregularities in model geometry and seemingly insignificant changes in test conditions, such as roll angle; this leads them to adopt their statistical approach. They conclude that a large number of further measurements, giving a more comprehensive data base, are required. Since a very large number of parameters are known or believed to be involved, the amount of testing implied by this approach is very great indeed. It may be helpful, therefore, to consider an alternative point of view.

In a recent paper (published after the acceptance of Wardlaw and Morrison's paper) Lamont and Hunt[2] have presented the results of an extensive experimental study of local side force distribution using a pressure-tapped model. They measured both time-averaged and fluctuating pressures. One of their conclusions is that serious unsteadiness of the flow pattern is a common occurrence and is a result of the flow switching from one of its bistable states towards and sometimes into the other state. They demonstrate that a major cause of such switching is freestream turbulence and that the resulting time-averaged force can be considerably less than the force corresponding to the unswitched state. From observations of models mounted on various balances, it seems likely that vibration of the model on its mounting can also be a cause of flow switching. Lamont and Hunt's time-averaged pressures (and hence forces) exhibited an irregular variation with roll angle, similar in nature to that observed in many overall force studies. However, their unsteady pressure measurements showed that this variation was due to variations in the unsteady flow behavior and that the inferred unswitched levels were independent of roll angle.

Confirmation of these findings is desirable but they do suggest that it is the switching behavior which is sensitive to model geometry and flow conditions and, further, that it may be possible to avoid the occurrence of flow switching by working with rigidly mounted models in low turbulence level environments. Some support for this view can be obtained by a careful examination of the published results.[3]

A conclusion from this discussion is that there is an alternative to the approach of conducting large numbers of overall force measurements and applying statistical methods to the accumulated data. The alternative is to work with rigidly clamped models in low turbulence level flows and to monitor the unsteady behavior so as to ensure that measurements only correspond to the unswitched state. Values obtained in this way should always be larger in magnitude than the values obtained in less ideal conditions, where flow switching is occurring. Once the unswitched behavior is understood, the effect of flow switching can be studied as an unsteady phenomenon. Such an approach gives more detailed information than do statistical methods and seems to stand a better chance of providing the physical understanding which is rightly seen as essential by Wardlaw and Morrison.

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References

[1] Wardlaw, A.B. Jr., and Morrison, A.M., "Induced Side Forces at High Angles of Attack," *Journal of Spacecraft and Rockets*, Vol. 13, Oct. 1976, pp. 589-593.

[2] Lamont, P. J. and Hunt, B. L., "Pressure and Force Distributions on a Sharp-Nosed Circular Cylinder at Large Angles of Inclination to a Uniform, Subsonic Stream," *Journal of Fluid Mechanics*, Vol. 76, Oct. 1976, pp. 519-559.

[3] Lamont, P. J. and Hunt, B. L., "Prediction of Aerodynamic Out-of-Plane Forces on Ogive-Nosed Circular Cylinders," *Journal of Spacecraft and Rockets*, Vol. 14, Jan. 1977, pp. 38-44.

Reply by Authors to B. L. Hunt and P. J. Lamont

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IN their comment on our paper, Hunt and Lamont raise the question of unsteadiness in the high-angle-of-attack flowfield. In the past this type of consideration has been ignored and their concern is well justified. However, it is not clear that flowfield unsteadiness is the only factor leading to the extremely sensitive nature of side forces and moments. Another explanation is that there exist a number of possible steady vortex patterns behind a particular type of model, each producing a different level of side force. The precise pattern adopted depends on the particular idiosyncracies of the model and wind tunnel arrangement. There is evidence to support both points of view. Lamont and Hung have presented unsteady pressure measurements lending credence to the importance of unsteadiness and have found good agreement in a few instances between their discerned unswitched side force levels and measurements made at other facilities.[1,2] Support for the existence of multiple stable vortex pattern comes from flow visualization studies.[3-5] In particular, Clark and Nelson[5] have filmed vortex patterns switching during a static test from a steady symmetric one to a steady asymmetric arrangement for no discernable reason.

In our view both unsteadiness and multiple stable vortex patterns contribute to the erratic nature of side forces and it remains to be determined what the relative importance of each of these two mechanism is. Also, the influence of these two mechanisms may vary with angle of attack and Mach number.

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