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Readers' Forum

Brief discussion of previous investigations in the aerospace sciences and technical comments on papers published in the AIAA Journal *are presented in this special department. Entries must be restricted to a maximum of 1000 words, or the equivalent of one* Journal *page including formulas and figures. A discussion will be published as quickly as possible after receipt of the manuscript. Neither the AIAA nor its editors are responsible for the opinions expressed by the correspondents. Authors will be invited to reply promptly.*

Comment on "Counter-Rotating Structures over a Delta Wing"

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RECENTLY, Hubner and Komerath[1] reported on the periodic nature of velocity fluctuations and streakline patterns near the suction surface of a delta wing. Although they speculate that these fluctuations are related to counter-rotating structures between the surface and the vortex core, there is no clear evidence of that in their paper. Instead, they do not seem to realize that these periodic fluctuations are due to a well-known phenomenon, vortex breakdown.[2] It is well known that flow downstream of vortex breakdown exhibits a well-documented hydrodynamic instability.

Although Hubner and Komerath[1] did not report the location of vortex breakdown in their experiments, vortex breakdown is expected to occur over the wing for the range of angle of attack that they studied. This is shown in Fig. 1a by using reported breakdown locations from the literature[3–7] for sweep angle $\Lambda = 60$ deg. At angle-of-attack $\alpha = 20$ deg, the location of breakdown is expected to be around midchord $x/c \approx 0.5$. In Fig. 1b, which is taken from Hubner and Komerath,[1] streaklines near the surface are shown for the same angle-of-attack $\alpha = 20$ deg. They point out that the upstream streaklines appear very steady while the downstream streaklines show fluctuations. This is not surprising because the flow upstream of breakdown is steady while the flow downstream of breakdown is unsteady due to the hydrodynamic instability. They also point out that the origin of the fluctuations moves upstream with increasing angle of attack. It is well known that vortex breakdown location also moves upstream with increasing angle of attack. Therefore, there is direct evidence that the source of the fluctuations is the breakdown phenomenon. In spite of the clear relationship between the fluctuations and vortex breakdown, the authors state that "The phenomenon clearly does not originate in the core region, postburst or otherwise"[1] with no evidence.

Periodic oscillations were observed in a variety of swirling flows that exhibited vortex breakdown, as summarized in Ref. 2: swirling jets, swirling flow in a tube, tip vortices, and leading-edge vortices. It is well known that these velocity/pressure fluctuations correspond to the most unstable normal modes of the time-averaged velocity profiles of the vortex (downstream of breakdown) based on the linearized, inviscid stability analysis.[8] The disturbances are represented as $\exp\{i(kx + n\phi - \omega t)\}$, where ω is the frequency, k the wave number in the axial direction, and n the wave number in the angular direction. Experiments showed that these fluctuations are due to the first helical mode ($n = 1$). This hydrodynamic instability induces strong pressure fluctuations on the suction surface of delta wings, as measured and computed by several investigators.[2,9,10] The existence of the helical mode instability was demonstrated by two-point pressure measurements in the axial and spanwise directions.[2] The waveform of the helical mode instability was concluded based on the surface pressure measurements, not based on hot film data, as incorrectly stated by Hubner and Komerath.[1] Also, all of the findings regarding the nature of pressure oscillations[2] were the same for $\Lambda = 60$ deg and $\Lambda > 60$ deg. Their statement in Ref. 1 regarding this point is incorrect.

Hubner and Komerath[1] carried out measurements of streamwise and vertical fluctuating velocities in a small domain in a $y = \text{const}$ plane and claim that they found counter-rotating structures whose orientation was essentially spanwise. Fluctuating velocity in a plane for a three-dimensional flow does not mean much. Because the authors carried out velocity measurements in the breakdown wake where the helical mode instability exists, it is not surprising that the fluctuating velocity showed reversals, if one considers the waveform of the disturbances. Also, because they have not measured the lateral velocity component, their conclusion regarding the orientation

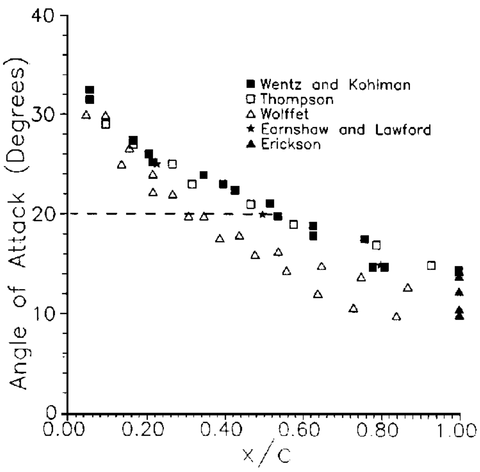

Fig. 1a Location of vortex breakdown.

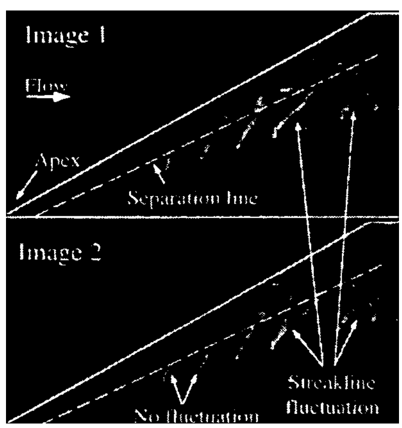

Fig. 1b Streakline pattern near the surface of delta wing[1] for $\alpha = 20$ deg.

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of structures is not valid. How do "spanwise structures" have "a helical geometry of propagation"?

In summary, the origin of the reported fluctuations of velocity and streakline pattern is the helical mode instability, as indicated by the authors' own data. It is the same phenomenon that is responsible for wing and tail buffeting. The evidence of any other phenomenon is yet to be offered.

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Reply by the Authors to I. Gursul

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PROFESSOR Gursul insists that the generation, evolution, or methods of suppression of fluctuations in vortex flows have been completely defined by the helical mode theory of Gursul.[1] This is as interesting as his statement that "fluctuating velocity in a plane for a three-dimensional flow does not mean much."

Gursul's objections can be removed by reading previous work, referenced in our original Note. We agree that the flow over a delta wing goes round and round and downstream, generally within a conical envelope. Disturbance structures in this flow, away from its axis, should take a helical trajectory, regardless of the precise mechanism of their generation. Linear stability analysis should show a mode of propagation that is helical, and this may amplify. This does not provide any information on the nature of these disturbances. For this, Gursul cites surface pressure data (scalar) and single-hot-wire data (also scalar) as proof of the orientation, shape, etc., of these disturbance structures, and asks readers to ignore our quantitative flowfield visualization and phase-locked velocity measurements, tied to hot-film spectra, which unambigously resolve the shape and orientations of the structures.

We take no issue with the obvious fact that we are dealing with postburst vortex flow, so Fig. 1a of the Comment is a nonissue. However, we do maintain that the fluctuations do not originate in the core region. We have studied this problem as follows.[2] First, we tried finding strong cores and burst phenomena over an F-15 scale model at 20-deg angle of attack. No unburst vortex region (and therefore no explicit bursting) is observed over wings with sweep much below 60 deg for $\alpha > 20$ deg, and so explanations that depend on burst locations and core phenomena are inadequate for the various aircraft configurations with moderate sweep where we showed the same phenomenon. Next we accumulated hot-film spectra with different film orientations and showed that the quasiperiodic fluctuation originated over the wings and amplified toward the tails. We then studied the flow over 60-deg wings where bursting could be observed. We tracked the fluctuations upstream to the wing surface by coherence maximization of space-separated sensors. The coherence of the fluctuations is quite low in the postbreakdown core region, and the frequency is different from that in the outer annulus. This is quantitative evidence that the fluctuations do not originate in the core region at all. Let us think beyond the result that linear stability theory gives a frequency in the right ballpark. This would happen equally well if the generation mechanism is due to centrifugal instability near the surface, as we have postulated. Note that this applies as well to other experiments on vortices near surfaces. The disturbances would still go helically around the periphery of the swirling flow. Gursul's question: "How do 'spanwise structures' have a 'helical geometry of propagation'?" is answered in textbooks.[3]

We visualized the phenomenon using laser sheets at different orientations and confirmed their frequency by counting using video frames, compared with hot-film data. We used laser velocimetry, with a surface hot-film providing the sync pulse, to measure the periodic velocity field in two planes, both cutting across the spanwise-oriented structures, which the laser sheet images showed. The phenomenon was confirmed. Measurements of lateral velocity, whose lack is cited by Gursul, are irrelevant to the issue.

Because Gursul spends considerable space requoting Gursul,[1] we draw attention to the data behind his conclusions. Figure 11 of Ref. 1 shows that the helical mode explanation performs poorly for sweep of 60 deg; no lower sweep is considered. The straight line drawn in Fig. 12 ignores the other features of the data. We thank Gursul for his comments. Unfortunately, the flow continues to exhibit phenomena that go beyond his descriptions. This is not unexpected: shear layer transition, for example, was not fully explained with the discovery of the Orr–Sommerfeld equation.

Finally, the helical mode theory offers little guidance on how to suppress these fluctuations, which is the whole point in studying them. We have shown how to do this[4] using surface-mounted devices that do not perturb the core region or the wing global characteristics and yet reduce the fluctuations by over 50%. This is strong and useful evidence for the correctness of our interpretation of the flow.

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