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Readers' Forum

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Comment on "Self-Excited Wire Method for the Control of Turbulent Mixing Layers"

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IN a recent paper by Vandsburger and Ding,[1] the effect of perturbations produced by a musical wire placed in a turbulent mixing layer were investigated. I find no fault with this study; however, I would like clarification on a few items, as well as comment on several points.

Within the original text, the amplitude of the wire displacement is stated as ~6 mm. Such a statement would normally be taken to indicate the peak value. In the discussion section, the wire is said to traverse an elliptical path, with the length of the major axis specified as 6 mm, therefore implying a peak to peak value. If 3 mm is the peak displacement, an excitation intensity can be approximated as v_{rms}/U_c, where v_{rms} is the rms velocity in the y direction and U_c is the convection velocity. Estimating v_{rms} from the peak amplitude of the displacement and period of the disturbance, excitation intensities of 0.123 and 0.247 were determined for the 200 and 400 Hz excitations, respectively. Fiedler and Mensing,[2] while investigating an acoustically disturbed single stream mixing layer, considered strong excitation to exist when the excitation intensity v_{rms}/U_0 was greater than 0.0156. Accounting for U_c, one would still categorize the present disturbance levels as strong excitation.

If one digitizes the original Fig. 4, it becomes apparent that the momentum thickness θ at 40 mm is something other than 3.0 mm, as quoted in the original paper. Using the digitized data, θ was estimated to be approximately 1.3 mm at the end of the splitter plate. This produced $Re_\theta = 2 \times 10^3$, based on the velocity difference and θ. A boundary layer at the trailing edge of a splitter plate is said to reach transition around $Re_\theta \approx 10^3$, so one may wonder if the present separating boundary layer was laminar or turbulent. Comparing the spread rate ($d\theta/dx$) of the present work to that of other researchers leads one to question the initial conditions and possible facility abnormalities.[3] Specifically, $d\theta/dx$ for the unexcited case was plotted against published spread rates appearing in Ho and Huerre,[4] as a function of velocity ratio. This process indicated that the present $d\theta/dx$ was at least 50% higher than the closest data point. A possible cause for this difference is a combination of the boundary-layer state and the presence of a pressure gradient. The pressure gradient resulting from the confined test section may also be responsible for the overshoot in the presented normalized velocity profiles (original Fig. 3). If one examines the width of the mixing layer as presented in the turbulent kinetic energy (TKE) maps, interactions between the test section wall layers and the mixing layer are not unexpected. Using the digitized θ data, it was also noted that the agreement between the original Figs. 4 and 5 is poor. Calculated differences between θ at $x = 155$ mm varied between 7% at $f_e = 200$ Hz and 33% at $f_e = 0$ Hz (see Fig. 1).

An examination of the unexcited power spectra (i.e., naturally excited, without the presence of the music wire) shows several interesting features. Four peaks whose amplitudes are within 1.0% of each other are apparent in the original Fig. 2a. The corresponding frequencies are 361, 478, 537, and 659 Hz. The third peak (at 537 Hz) corresponds to the natural shedding frequency f_n of vortices shed from a laminar boundary layer, computed[4] from the Strouhal number (St). For a laminar boundary layer initial condition, $St_n = f_n\theta_0/U_c = 0.032$. When the boundary layer is turbulent, the St lies between 0.044–0.048. Based on this St, f_n of 529 and 761 Hz were determined for laminar and turbulent boundary layers, respectively. Good agreement between the f_n calculated using $St = 0.017$ and the peak at 537 Hz in the unexcited power spectrum (Fig. 2a) is noted. This suggests that the boundary layer may be laminar or transitional but probably not fully turbulent. Also apparent is the subharmonic at 268 Hz and a peak at 361 Hz that is approximately two-thirds of the 537 Hz peak.

At $X = 200$ mm (Fig. 2b) the attenuation of the 537 Hz peak is observed as is the strengthening of the 353 Hz peak, which may be associated to the 361 peak at $X = 40$ mm. Likewise there is a subharmonic (at 181 Hz) and two-thirds harmonic at 244 Hz. Also noted is a relatively strong peak at 206 Hz. All spectral information was obtained through digitization of original data. The uncertainty in the frequency is ~7 Hz. All four energy peaks were within 2.5% of the maximum frequency at 353 Hz.

Although, the shear layer appears to lock onto the f_e (i.e., based on the power spectrums), the passage frequency f_p of the vortical/organized motions, which can be observed in the TKE maps, provide limited support for this condition. The f_p obtained from the

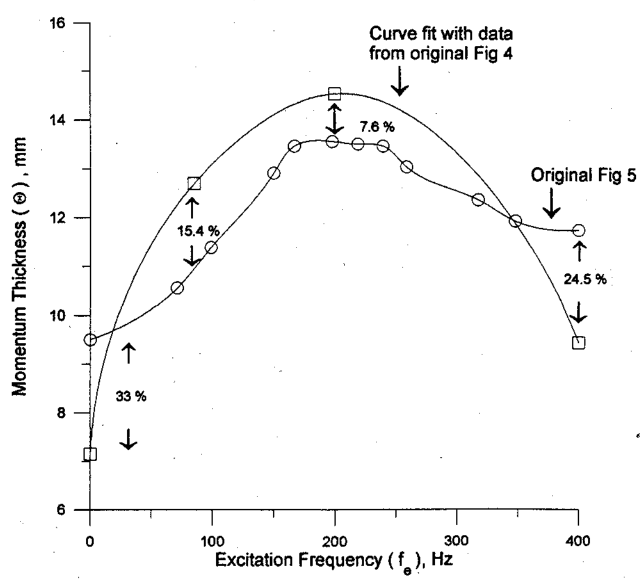

Fig. 1 Comparison of momentum thickness variations.

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TKE maps and power spectrum agree for $f_e = 400$ Hz. In addition, the organized motions appear fairly consistent throughout the mixing layer. However, if one examines the TKE maps for $f_e = 200$ Hz, the f_p of the organized vortical structures is nominally 300 Hz. This may be a result of the smearing that can occur when phase locking is employed.[5] For the most part f_p estimated from the TKE maps lie within a band of frequencies from 270 to 350 Hz.

References

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Reynolds Number Effects on the Prediction of Velocity Profile in Compressible Flows

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In a recent article, Huang et al.[1] presented an algorithm for the prediction of skin friction and velocity profiles for compressible turbulent boundary layers. Their method relies on the use of an analytical expression for the mean-velocity profile of compressible turbulent boundary layers, based on the van Driest formulation[2] and the Coles' law of the wake[3]:

$$\frac{u^*}{u_\tau} = \int_0^{y^+} \frac{2}{1+\sqrt{1+4k^2(y^+)^2[1-\exp(-y^+/A^+)]^2}}\,dy^+ + \frac{\Pi}{k} w\left(\frac{y}{\delta}\right) \tag{1}$$

In the above relation, A^+ is the damping factor, k the slope for the law of the wall, $y^+ = yu_\tau/v_w$, Π the wake parameter as suggested by Cebecci and Smith[4] $\{\Pi = 0.55[1-\exp(-0.243z_1^{0.5} - 0.298\, z_1)]$, in which $z_1 = Re_\theta/425 - 1\}$, $w(y/\delta) = 1 - \cos[\pi(y/\delta)]$ the wake function, $u_\tau = \sqrt{(\tau_w/\rho_w)}$ the friction velocity, and the transformed velocity is defined by

$$u^* = (u_\delta/b)\sin^{-1}\left\{\left[2b^2(u/u_\delta) - a\right]/(a^2+4b^2)^{0.5}\right\} \tag{2}$$

in which

$$a = (T_\delta/T_w)\left[1 + r(\gamma-1)M_\delta^2/2\right] - 1 \tag{2a}$$

$$b^2 = r(\gamma-1)M_\delta^2(T_\delta/T_w)/2 \tag{2b}$$

where T is the temperature, r the temperature recovery factor, γ the specific heat ratio, M the Mach number, and the subscripts w and δ refer to the conditions at the wall and at the edge of the boundary layer. Then, for a given flow condition with a specific boundary-layer momentum thickness θ (or boundary-layer displacement thickness δ^*) as the only known parameter and by using Eq. (1) and the inverse of the van Driest transformation [Eq. (2)] in an iterative procedure, they demonstrated that a unique solution for the skin friction coefficient and, hence, the velocity profile can be obtained. Although their analysis is based on the validity of the van Driest transformation for general compressible flows and direct extension of the wake-function concept from incompressible turbulent boundary-layer data to compressible flows, it does produce, as was stated by Huang et al.,[5] satisfactory results when applied to a series of experimental data for different freestream Mach numbers, both in terms of skin friction and velocity profile. The speed at which the solution is converged in mathematical sense was also very satisfactory. However, as it will be shown for a given flow Mach number, this method fails to correctly predict the effect of Reynolds number on the mean flow distribution in the boundary layer, and it appears that the accuracy of the method is Reynolds-number dependent. As examples, the effect of Reynolds number on the accuracy of the results can be observed in Figs. 1–6 for three different flow Mach numbers. Experimental data examined here are taken from Winter and Gaudet[6] for $M_\delta = 1.4$ and $Re_\theta = 17\times10^3 \to 130\times10^3$ (Figs. 1 and 2), $M_\delta = 2.2$ and $Re_\theta = 14\times10^3 \to 90\times10^3$ (Figs. 3 and 4), and Stalmach[7] for $M_\delta = 3.68$ and $Re_\theta = 2\times10^3 \to 10.5\times10^3$ (Figs. 5 and 6). As can be seen, there exists strong Reynolds number influence on the prediction of mean-velocity profiles. For all the cases, their method fails to correctly predict the velocity profiles at

Table 1 Percent error (ΔC_f) in the prediction of skin friction coefficient by the method of Huang et al.,[1] $\Delta C_f = (1 - C_{f,\text{calc}}/C_{f,\text{exp}}) \times 100$

	Experimental data			Predicted
Profile	Ref.	M_δ	Re_θ	ΔC_f, %
10	6	1.394	17,914	0.2
11	6	1.395	39,333	1.7
12	6	1.400	60,234	2.0
13	6	1.400	113,948	2.0
14	6	1.400	128,035	2.2
JPL-A112	8	1.314	19,880	2.0
JPL-A113	8	1.321	21,236	2.3
JPL-A114	8	1.320	21,971	2.9
JPL-A115	8	1.315	23,580	2.6
JPL-A122	8	1.308	34,560	2.7
65020301	7	2.865	225,909	2.8
65020401	7	2.897	167,222	2.3
65020501	7	2.908	50,857	2.8
65020601	7	2.910	49,261	3.2
74021801	7	4.517	10,134	−5.4
74021802	7	4.510	15,882	−7.2
74021803	7	4.510	19,789	−5.8
74021804	7	4.500	25,001	−6.1
74021805	7	4.493	28,447	−7.5
58020201	7	2.735	2,011	7.7
58020203	7	2.731	3,834	5.4
58020207	7	2.739	12,228	−5.2
18	6	2.186	14,640	−2.3
19	6	2.197	30,865	−2.3
20	6	2.201	48,223	−2.7
21	6	2.206	88,907	−0.5
39	6	2.198	19,939	−1.9
40	6	2.199	24,993	−2.5
41	6	2.200	30,300	−2.5
42	6	2.201	35,014	−2.2
43	6	2.202	39,867	−2.1
44	6	2.204	46,899	−2.3
45	6	2.205	53,841	−1.5
46	6	2.206	63,569	−1.8
47	6	2.207	73,310	−1.1
48	6	2.208	84,259	−0.4
JPL-A132	8	2.172	23,938	3.5
JPL-A133	8	2.166	24,409	3.3
JPL-A134	8	2.164	25,782	3.2
JPL-A135	8	2.172	25,891	3.0

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