some general remarks are in order. The von Kármán approximant (VKA) method is *not* a stand-alone turbulence simulation model, but should be used with models for gust standard deviations and integral length scale. These parameters have considerable influence on simulation realism. The VKA method is intended for real-time simulations, and the designation "real time" imposes severe restrictions on computational complexity. Dr. Treviño has made several points, each of which I will consider in turn.

Dr. Treviño refers to the emulation of physical forces in turbulence acting on aircraft. Strictly speaking, the only hope of achieving a totally realistic simulation of turbulence with all physical mechanisms accurately modeled is by large-eddy or direct simulation of turbulence using the unmodeled, time-varying, Navier-Stokes equations. Large-eddy simulation provides exciting results, however, with present computer limitations is can model only relatively simple, low-Reynolds-number flows. Some of the simulations at NASA Ames Research Center require more than 100 h of supercomputer time. Alternatives are to use real measured turbulence for simulations or to use Monte Carlo methods to capture most of the phenomena affecting the response of the aircraft. The use fo real turbulence presupposes measurements at high resolution over a two- or three-dimensional field (for realistic simulations).

Dr. Treviño refers to the Gaussian nature of the VKA and other simulation methods as unrealistic and provides figures showing highly skewed distributions, which he claims are more characteristic of atmospheric turbulence. He believes that Gaussian analyses do not even provide a viable limiting-case analysis of the phenomenon. No one will argue that turbulence is Gaussian, but, in some instances, one-point statistics closely approximate Gaussian behavior (see, for example, Ref. 2, p. 170, Fig. 8.1). In many instances, turbulence has a larger than Gaussian value of kurtosis, and almost none of the skewing indicated in Dr. Treviño's figures.[3-5] These higher values of kurtosis can be simulated by modulating the turbulence with a stochastically varying gust standard deviation.[6-8] Modulation techniques should be applied to VKA turbulence.

Dr. Treviño implies that the nonlinear convection term is ignored in Monte Carlo turbulence simulation, and states that without it, "...turbulence is nothing more than diffusion." His statement is remarkable for three reasons: first, the fundamental physical basis for a $-5/3$ fall off with frequency is the predominance of inertial forces,[3] hence, the genesis of the phrase *inertial* subrange; second, all turbulence simulators require the frozen turbulence hypothesis, which excludes diffusion; and third, the creation of a chaotic process from the linear diffusion equation is difficult to accept. The destruction terms in the turbulent kinetic energy equation arise from the diffusion terms in the Navier-Stokes equations. Dissipation is predominant in the dissipation subrange at frequencies of little interest for most simulations.

Dr. Treviño refers to pilots' complaints that Gaussian simulated turbulence does not have the right "feel" to it, and lacks the element of "surprise." The element of surprise can readily be added by modulating the Gaussian turbulence. Although Gaussian turbulence may be "bland," Etkin[9] points out that pilot ratings on the Cooper-Harper scale show the expected trends with increasing turbulent intensity. Physical processes other than the stochastic nature of turbulence may contribute to its "feel." In a conversation some years ago, Carl Terry, an engineer with United Airlines, pointed out that the "feel" of turbulence may be in large part due to airframe vibrational response. Airframe ringing is difficult to build into a simulator.

Dr. Treviño suggests that third-order moments strongly influence aircraft turbulence response and should be added to turbulence simulations. Unfortunately, he does not offer a means for doing this. To my knowledge, no one has done this yet, especially not for a real-time simulation. A simpler but similar application illustrates some of the problems that may be encountered in attempts to improve simulation models; a problem of filter overspecification was encountered and overcome, but the resulting filters were not realizable.[10] Dr. Treviño's problem is easier said than done.

References

[1]Campbell, C. W., "Monte Carlo Turbulence Simulation Using Rational Approximations to von Kármán Spectra," *AIAA Journal*, Vol, 24, Jan. 1986, pp. 62–66.

[2]Batchelor, G. K., *Theory of Homogeneous Turbulence*, Cambridge, University Press, London, 1967.

[3]Dutton, J. A., "Effects of Turbulence on Aeronautical Systems," *Progress in Aeronautical Science*, Vol. 11, edited by D. Kuchemann, Pergamon Press, New York, 1970, pp. 67–109.

[4]Campbell, W., Camp, D. W., and Frost, W., "An Analysis of Spanwise Gust Gradient Data," Ninth Conference on Aerospace and Aeronautical Meteorology, American Meterological Society, June 1986, pp. 303–309.

[5]Frost, W., Lin, M-C., Chang, H-P. and Ringnes, E., "Analysis of Data from NASA B-57B Gust Gradient Program," Final Report under NASA Contracts NAS8-36177 and NAS8-35347, Sept. 1985.

[6]Reeves, P. M., "A Non-Gaussian Turbulence Simulation," AFFDL-TR-69-67, Nov. 1969.

[7]Reeves, P. M., Campbell, G. S., Ganzer, V. M., and Joppa, R. G., "Development and Application of a Non-Gaussian Atmospheric Turbulence Model for Use in Flight Simulators," Sept. 1974, NASA CR-2451.

[8]Reeves, P. M., Joppa, R. G., and Ganzer, V. M., "A Non-Gaussian Model of Continuous Atmospheric Turbulence for Use in Aircraft Design," NASA CR-2639, Jan. 1976.

[9]Etkin, B., "Turbulent Wind and Its Effect on Flight," *Journal of Aircraft*, Vol. 18, pp. 327–345.

[10]Campbell, C., "Adding Computationally Efficient Realism to Monte Carlo Turbulence Simulation," NASA TP 2469, May 1985.

Comment on "The Role of Damping on Supersonic Panel Flutter"

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LOTTATI[1] has analyzed the effect of a form of viscoelastic damping on the flutter speed of a two-dimensional simply supported panel in supersonic flow, employing piston theory for the aerodynamic forces. The results obtained indicate that even for infinitesimally small values of the damping coefficient, there is a value of the speed (or Mach number) parameter above which the system becomes unstable. This result is similar to the one obtained by Zisfein and Frueh[2,3] for "structural" damping as typically used in flutter analyses in this country. "Structural" damping is rigorously defined only for motions harmonic in time but can be used to determine the boundary between stable and unstable motions. On the stability boundary, an equivalence, which is flutter-frequency-dependent, can be established between the "structural" damping and any form of linear viscoelastic damping. Thus, it is not surprising that similar characteristics are found for the effects of viscoelastic and structural damping on panel aeroelastic stability.

Zisfein and Frueh[2,3] arrived at a relatively simple criterion for the onset of panel instability in terms of the shape of the frequency-velocity curve for the undamped system, corresponding to Lottati's Fig. 1. The validity of this simple criterion was established by intricate calculations of the mo-

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tion of a panel system in discrete modal form. Their results, established initially for two- and three-degree-of-freedom systems, were extended to any finite number of degrees of freedom by Fonda.[4] A much more direct and simple approach based on small-perturbation theory can be applied directly to the partial-differential equation [Eq. (1) of Ref. 1] for plate aeroelastic stability. The criterion for instability at infinitesimal values of the viscoelastic damping coefficient that is found is identical to the result of Zisfein and Frueh for "structural" damping, namely, that instability occurs when

$$\frac{\partial \omega}{\partial v} > \frac{1}{2}\frac{\omega}{v}$$

where the frequency ω and velocity v refer to the curve of frequency vs velocity for the undamped system. A simple geometric construction on Lottati's Fig. 1 suffices to demonstrate this point.

The stabilizing effect of uniform viscous damping (i.e., force proportional to plate transverse velocity) is also well known, having been expounded by Movchan,[5] Bolotin,[6] and others. For small values of combined viscous and viscoelastic damping, the real parts of the root of the stability equation are algebraically additive.

In Lottati's Note, viscoelastic damping was shown to be destabilizing for all values of the viscoelastic damping coefficient for which data were given, and this effect was also specifically noted in the text. In fact, in exact analogy to Parks'[7] determination of values of viscous damping sufficient to stabilize against panel flutter at any velocity using Liapounov's direct method, it can be shown that a panel becomes aeroelastically stable for any velocity with sufficiently large viscoelastic damping. This phenomenon also occurs in many nonconservative systems with unequal modal damping, as demonstrated by Bolotin[6] for two degrees of freedom.

References

[1]Lottati, I., "The Role of Damping on Supersonic Panel Flutter," *AIAA Journal*, Vol. 23, Oct. 1985, pp. 1640–1642.

[2]Zisfein, M. B. and Frueh, F., "A Study of Velocity-Frequency-Damping Relationships for Wing and Panel Binary Systems in High Supersonic Flow," AFOSR TN 59-969, Oct. 1959.

[3]Zisfein, M. B. and Frueh, F., "Approximation Methods for Aeroelastic Systems in High Supersonic Flow," AFOSR TR 60-182, Oct. 1960.

[4]Fonda, A. G., "Decay-Damping Relationships for Highly-Coupled Systems with Many Degrees of Freedom," AFOSR 1317, Aug. 1961.

[5]Movchan, A. A., "On the Stability of a Panel Moving in a Gas," Translation, NASA RE-11-21-58W, Washington, DC, Jan. 1959.

[6]Bolotin, V. V., *Nonconservative Problems of the Theory of Elastic Stability*, Macmillan, New York, 1963, pp. 79–85, 137–138, 244.

[7]Parks, P. C., "A Stability Criterion for Panel Flutter via the Second Method of Liapunov," *AIAA Journal*, Vol. 4, Jan. 1966, pp. 175–177.

Reply by Author to A. H. Flax

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I WOULD like to acknowledge the interest that Prof. A.H. Flax has shown in my recent Note.[1] The effect of damping on the stability of systems has been the subject of many previous published works, some of which are referred to by Flax and Ref. 1. It is a well-known fact[2,3] that the stability determinants obtained for the undamped system and the very lightly damped one are not compatible and thus it is not surprising that a light damping may change the flutter speed of the system remarkably. Nevertheless, most of the results referred to by Flax were obtained by applying the modal analysis assuming a finite number of degrees of freedom to simulate the infinite number of degrees of freedom of the continuous structure. The results reported in Ref. 1 were obtained by solving exactly the differential equation of the supersonic panel with the associated boundary conditions, obtaining the critical speed at which the panel will undergo flutter, subjected to different types of damping. It is satisfactory to observe that the results of Ref. 1 are in very good agreement with the results obtained by other researchers applying different methods of solution for dynamic systems that are not specifically related to supersonic panel flutter.

References

[1]Lottati, I., "The Role of Damping on Supersonic Panel Flutter," *AIAA Journal*, Vol. 23, Oct. 1985, pp. 1640-1642.

[2]Nissim, E., "Effect of Linear Damping on Flutter Speed, Part I: Binary Systems," *The Aeronautical Quarterly*, Vol. XVI, May 1965, pp. 159-178.

[3]Lottati, I. and Kornecki, A., "The Effect of an Elastic Foundation and of Dissipative Forces on the Stability of Fluid Conveying Pipes," Technion, Haifa, Israel, TAE Report 563, Feb. 1985.

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