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Reply by Authors to M.S. Raju, M.J. Creed, and L. Krishnamurthy

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WE appreciate the commentors' interest in our work and their diligence in examining the critical issues they raised. As they have noted, it is indeed not a trivial task to achieve a numerical simulation of self-sustained oscillations in fluid flow. However, it is apparent that the commentors misunderstood the conclusions of the work presented in Ref. 1. Evidently, they overlooked our statements which emphasized that the reported work was the first-phase solution of a difficult problem and that additional work is needed to simulate such complex flows accurately. In order to avoid any further confusion or misinterpretation we would like to reiterate the statements made in the conclusions of our original paper. "As the first phase of a numerical computation of flow in a combustor, this paper demonstrates the feasibility of modeling the self-excited oscillation involving vortex shedding in axisymmetric flow. It should be emphasized that the computed results are for cold flow only and that certain questions remain unanswered concerning the formulation of the boundary conditions. Although the numerical results are preliminary in nature, they provide insight into the mixing process and can help guide further research in the combustion field." Furthermore, as stated elsewhere in the text of the paper, "caution must be exercised in examining the numerical vorticity data because certain features may not truly represent the physical combustion flow"; and "it must be emphasized that the present numerical simulation does not completely model the combustor experiment since the computational configuration does not include the flow from the central jet, combustion, nor identical air flow rate." In view of these statements, it is most perplexing how the commentors determined that the cold-flow model presented in the paper was intended to represent the reactive flowfield of an operating combustor, and thereby state that the comparison made in the paper was a "gross misrepresentation."

The issues of boundary conditions, turbulence modeling, and extension to three dimensions are areas that have long since been identified as pacing items in advancing the computational capability for complicated flow situations.[2-4] Current computer storage and speed limitations impose restrictions that do not permit realistic three-dimensional computations. However, the computer capability to compute three-dimensional flows will be available with the introduction of the CRAY 2 computer, which will be operational sometime in late 1985.

In their investigation,[5] the commentors employed the k and ϵ turbulence model of Jones and Launder in their attempt to simulate an unsteady flow. It has been reported in the literature[6-8] that the use of a steady-state turbulence model accounts for part of the Reynolds stresses twice in a time-dependent calculation and destroys the basic physical process. The currently accepted procedure is to include only a portion of the turbulence model (only for the high frequencies) and compute the self-sustained oscillation by first principles (see Ref. 9).

A major goal in the advancement of computational fluid dynamics is the development of an unsteady turbulence model.[10] Since this does not exist, it is recommended that one first attempt to compute a known self-sustained oscillation without a turbulence model using the necessary time step and grid size, which will capture the axial waves and represent the transverse eigenfunction adequately. These values may be deduced from linear stability theory.[11-13] After successfully demonstrating the existence of a self-sustained oscillation, a small portion of the turbulence spectrum may be added; recalling, however, that numerical dissipation is already present. Existing circumstantial evidence shows that this approach can be made successful and indicates that the turbulent dissipation apparently is not an essential ingredient in a violent self-sustained oscillation.[14-20]

In order to improve the present state of the art in the area, the following investigations are required in order to advance the capability to numerically simulate self-sustained oscillations.

1) Conduct controlled experiments of oscillating flow in short test sections isolated by choke plates or with well-defined end conditions so that the entire length may be simulated efficiently.

2) Obtain experimental measurements of Reynolds stresses over a wide frequency range to permit the development of an "unsteady" turbulence model.

3) Perform a series of numerical simulations of these experiments and investigate the influence of boundary conditions and numerical resolution.

We are in the process of conducting investigations along these lines and hope that in this manner we may further add to the impressive work in self-sustained oscillations that already exists. We would encourage the commentors to continue their efforts in this area with the hope that, eventually, they too may realize the success others have achieved in simulating complex unsteady flow phenomena.[1,7,15-22]

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