30 Years of Dynamic Modeling

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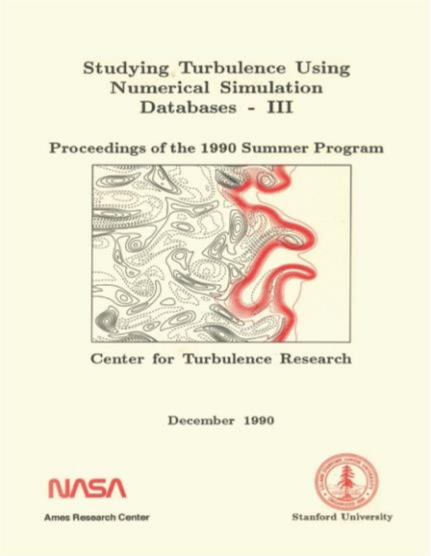

Proceedings of the 1990 Summer Program

July 1990. East and West Germany are re-unified, Italy places third in the FIFA World Cup, Martina Navratilova wins the women's singles title at Wimbledon, and, on the 16th, the 1990 CTR Summer Program begins at Stanford University.

Massimo Germano, from the Politecnico di Torino, is one of the participants. Parviz Moin is the Director of CTR. William Cabot is a Research Associate at Stanford. Ugo Piomelli is Assistant Professor at the University of Maryland. Germano has recently derived an identity involving the subgrid-scale (SGS) stresses at two different scales and is looking for a way to apply it. Piomelli is not, officially, part of the program; being in California for personal reasons, however, he visits his *alma mater*, and Moin invites him to participate in the program, at least until he returns to Maryland.

One of the areas of focus of the Summer Program was the development of improved SGS models. The limitations of the Smagorinsky model, whose coefficient is flow-dependent and requires *ad hoc* adjustments in transitional flows near solid walls, in the presence of rotation etc., were well known. Furthermore, not many of the existing models had been effective in using the frequency and wave- number information contained in the resolved field to extrapolate the behaviour of the unresolved scales. Those two areas were in dire need of improvement.

One morning, during the first week, Germano, Moin, Cabot and Piomelli discuss the possible utility of the identity. The idea is suggested that it might be used to evaluate the coefficient in a Smagorinsky-like SGS eddy-viscosity model. Eventually, a possible formulation is proposed: starting from the identity, the contribution of the smallest resolved eddies to the SGS dissipation is calculated; then, the model coefficient can be extracted by requiring that the dissipation thus obtained is equal to the prediction of an eddy-viscosity SGS model.

The potential of the model to do away with empiricism is immediately apparent. The unresolved- scale behavior is predicted by sampling the smallest resolved eddies, and the only adjustable parameter is the range of eddies that are sampled. Since it senses the energy content of the eddies near the cutoff wave-number, the eddy viscosity turns off in laminar flows. Its near-wall behavior, moreover, is correct without the need for damping functions.

Overflowing with optimism, Piomelli flies back to Maryland, incorporates the model into his channel-flow code, and starts running simulations. The results are disappointing: the transition to turbulence is significantly delayed. After noticing that he had entered too many zeros in the amplitude of the Tollmien-Schlichting waves, he duly berates himself for this lapse of attention, fixes the mistake, and re-runs the calculation. The LES now agrees extremely well with the reference data.

During two sleepless weeks additional calculations are carried out, *a priori* tests are performed, and the results are found to compare favorably with standard models that require *ad hoc* adjustments. Piomelli flies back to California, the group presents their results, and starts writing a report for the Summer-Program Proceedings. Now it is the middle of August. The report is reformatted and submitted to the *Physics of Fluids A* in November. All the results had been gathered in three weeks and, from conception to submission, the research had taken less than four months.

Main picture: 1990 CTR Summer Program group photo taken in front of the intake of the 80x120 wind tunnel at NASA-Ames; Cabot and Piomelli (who was in Maryland on that day) are missing. The photo in the left inset was taken at the 1987 Graduation ceremony, Stanford University. The photo of Bill Cabot was taken during the 1994 CTR Summer Program, when he worked with Charles Meneveau and Tom Lund on the Lagrangian dynamic model.

The article was accepted in March and appeared in the July issue of the journal [1], less than a year after the idea had seen the light. It was only 6 pages long.

The main contribution of Ref. [1] is the way in which the scale information present in the resolved velocity is used. The idea that useful information can be obtained by sampling the smallest resolved scales was not new, but the way in which it was applied was very novel, and the article immediately received significant attention. Since then, its influence on the field has been considerable: the dynamic model has become one of the workhorses for large-eddy simulations and is implemented in commercial and open-source codes. Many variants and improvements have been developed. When a new model is proposed, the dynamic model is commonly chosen as the standard of comparison. Reference [1] has been cited 8000 times (Google Scholar on December 7, 2020). Not a bad outcome for a morning discussion in July. And it was the facilitation of such synergistic collaborations that has been at the heart of CTR's mission since its founding.

[1] M. Germano, U. Piomelli, P. Moin, and W. H. Cabot. A dynamic subgrid-scale eddy viscosity model. *Phys. Fluids A*, 3:1760–1765, 1991.