THE DYNAMICS OF PRESSURE IN PLANAR TURBULENT FLOWS: FLOW STABILITY AND MODELING

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Abstract This investigation examines the role of pressure in the stability of planar, quadratic flows and its subsequent modeling vis-à-vis the second moment closure recourse to turbulence. In the first section, we isolate and analyze the effect of pressure action in the (linear) stability of different regimes of quadratic flows. Pressure effects can be diametric contingent upon the flow regime, wherein for hyperbolic flows, pressure supresses the flow instability, whereas for elliptic flows, pressure engenders and sustains the elliptic flow instability. At the transition between these regimes, for purely sheared flows, pressure does not alter the nature of flow stability. These observations are explicated, from a physics and a mathematical perspective. Thence, we address the question of *whether single point closures can replicate the action of pressure and if so, to what extent*. Each feature of the dynamics of pressure action is examined, systematically and comprehensively, in regard to its amenability to single-point closure modeling. Based on this analysis, we introduce studied compromises in the compass of modeling objectives and allowances in the modeling framework to arrive at a "best-possible" model. Thereupon, the predictions of said model are compared to DNS and experimental results; and contrasted against popular models to exhibit the efficiency of this approach.

OVERVIEW

The effects of pressure action play a pivotal role in determining the nature of a variety of turbulent flows: their stability [6], their structuring [5], etc. Thus, its modeling is a expedient problem in the engineering context. In this vein, various pressure strain correlation models have been developed till date. The nominations available and popular at present, like LRR [4], SSG [7] and the model of Johanssen and Hallback [2], etc, are limited in their robustness and scope. In regimes like closed streamline flows, the predictions of said models are not just inaccurate but also unphysical [1]. Such regimes of flow are fundamentally important to problems such as those regarding wingtip vortices and wake turbulence. There are other models like the PRM of Kassinos and Reynolds [3] that are able to give moderately accurate predictions for a larger set of flows. However, these models require input information that cannot be measured in an engineering context. Thus, there exists a pressing need for a robust yet simple closure for the pressure strain correlation.

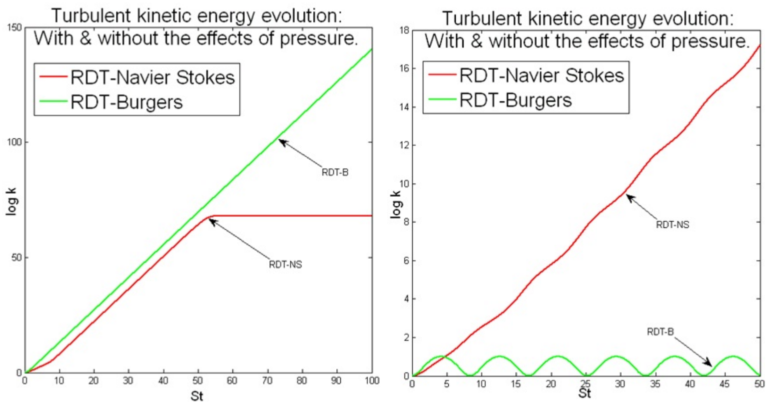

Figure 1. Comparing the evolution of the Burgers and the Navier-Stokes systems, it can be observed that pressure has a stablizing effect on hyperbolic and a destablizing effect on elliptic flows.

Along the maxim of "understanding before prediction", we commence our analysis with investigation of the role of pressure in the stability and structuring of planar quadratic flows, for different flow regimes. To this end, we utilize the tool of Burgulence to isolate the action of pressure, that is the Intercomponent Energy Transfer(IET). The Statistically Most Likely IET behavior is identified, to be incorporated into models. A dynamical systems analysis of the wavevector evolution is carried out and the topology of the most energetic wavevector modes that dominate the turbulence statistics is categorized for each flow regime. Thence, this investigation attempts to resolve the schism between the engineering limitations and the requirements dictated by physics. The individual features of the dynamics of pressure action are examined, systematically and comprehensively, in regard to their amenability to single-point closure modeling. These include (a)flow instabilities; (b)the oscillatory behavior of the statistics in elliptic flows; (c)the bifurcations in the system; (d) non-uniqueness of the modeling problem and Uncertainity Quantification; and (e) realizability requirements predicated upon the models. Based on this analysis, we introduce studied compromises in the compass of modeling objectives and allowances in the modeling framework to arrive at a "best-possible" model. In the final section of this investigation involves the application of these results to develope a pressure-strain correlation model that adheres to the "classical" modeling framework. The predictions of this model are validated with numerical and experimental results and compared against those of popular models such as [4],[7], and [2]. It is exhibited that the new model ensures excellent fidelity in both open or closed streamline flows.

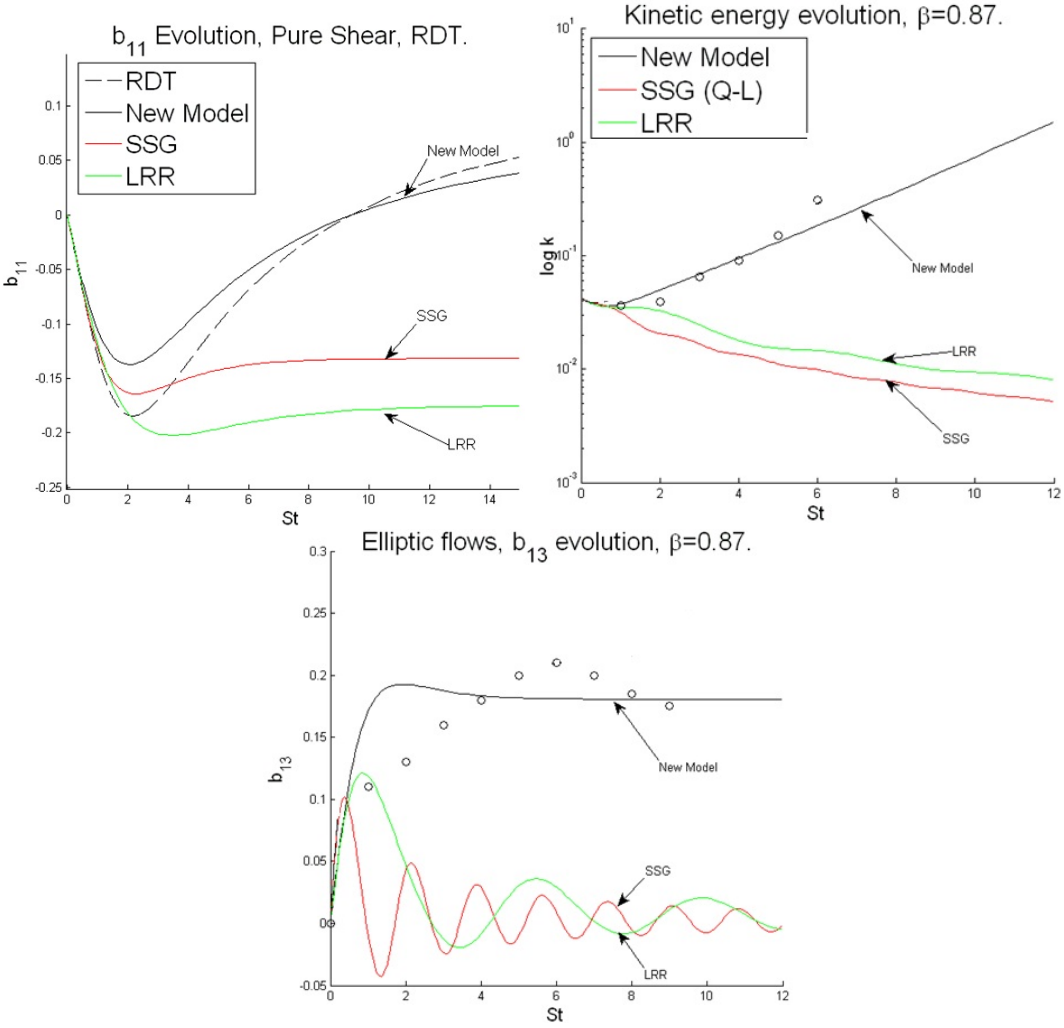

Figure 2. Comparison of the new model's predictions against DNS and other pouplar models. a) RDT of pure shear; b) & c) DNS of elliptic flows from [1].

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