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Thesis title: Self-similarity in a Boundary-layer Flow over a Dynamic Boundary: Flow of Air Induced by a Falling Soap Film

Research aim: A wide range of dynamical phenomena in nature are self-similar. This remarkable property entails that scaled versions of a phenomenon conform onto themselves. It not only affords simplified mathematical analysis but also reveals the physical underpinnings of the phenomenon. In fluid flows, a textbook example of such phenomena is the boundary-layer flow over a rigid boundary—the Blasius boundary layer flow. In this thesis, we experimentally and theoretically study self-similarity in boundary-layer flow over a dynamic boundary, wherein the flow and the boundary are dynamically coupled.

Material and method: Our experimental setup is a soap film channel, which is essentially a soapy waterfall—a planar film of soap-water solution falling under gravity. This setup has long been used to study quasi- two-dimensional flows in a laboratory setting. Unlike previous experiments, however, where the focus is on the flow in the film, we train attention on what surrounds the film: air. The falling film drags the surrounding air, inducing flow in a thin layer of air adjacent to the film. This flowing air, in turn, resists the motion of the falling film; thus, the film-air interface is a dynamic boundary. We measure the velocity profile of the airflow in the boundary-layer of this interface using super-resolution Particle Image Velocimetry. (To our knowledge, these are the first experiments to measure airflow induced by a soap film.)

Result and Conclusion: The downstream evolution of the air velocity profile manifests self-similarity, which we analyze using the framework of boundary-layer theory. Surprisingly, we find that the conditions of self-similarity of the airflow also shed light on the downstream evolution of the film. Beyond air-film interaction, our findings may bear on a broader class of flows over dynamic boundaries, e.g. air-sea interaction.