Fluid Webs: Tearing of Viscoelastic Films

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Figure 1: 3.09 m/s

Figure 2: 4.64 m/s

Figure 3: 5.24 m/s

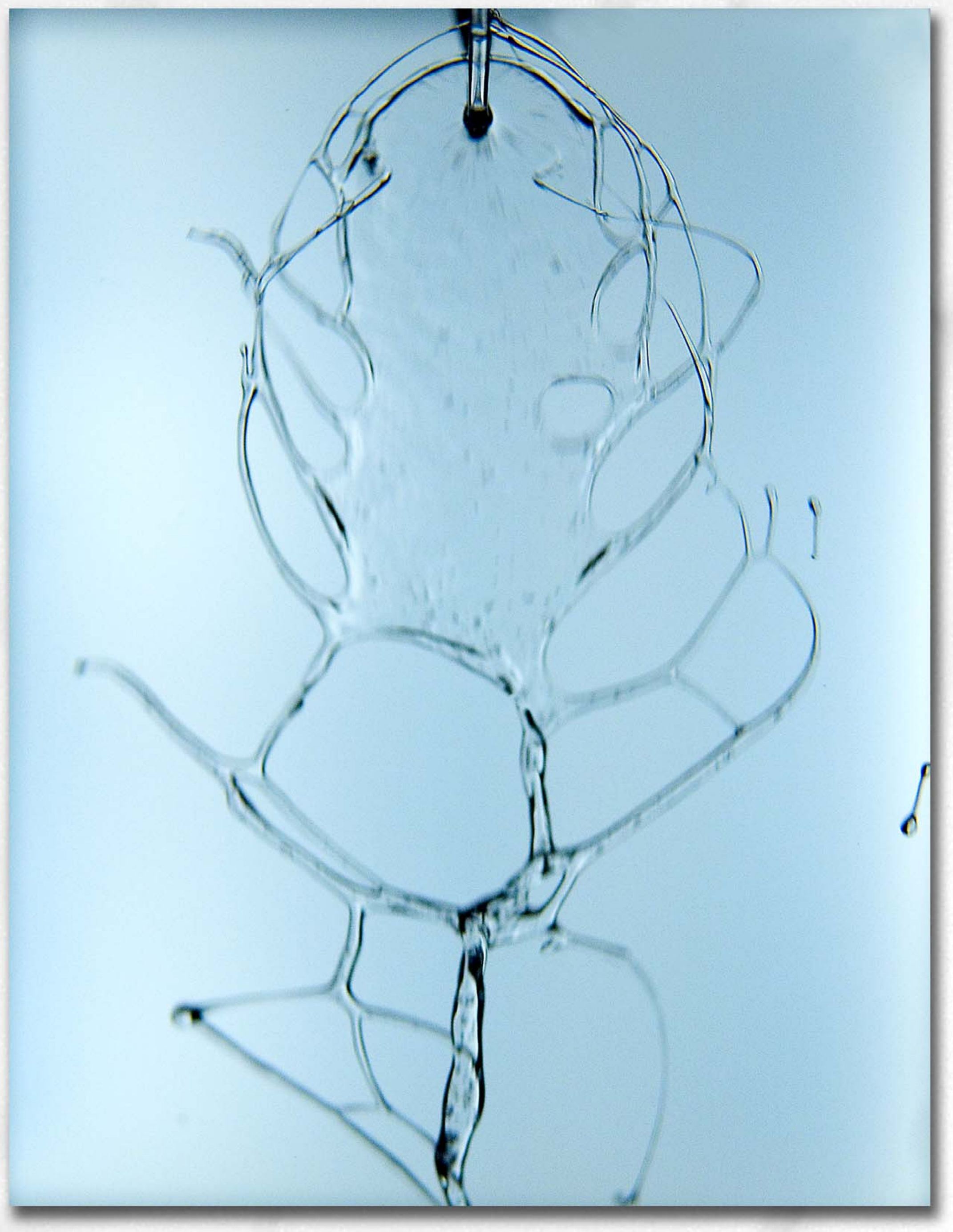

Figure 4: 5.84 m/s

We performed a qualitative exploratory survey of the collision of viscoelastic fluid jets at an oblique angle. Wormlike micelle solutions of 25 mM cetyltrimethyl-ammonium bromide and 25 mM sodium salicylate with a zero-shear viscosity of 70 Pa-s and a relaxation time of 30 s were used. The jet diameter was 1.5 mm through a circular opening and maximum flow speeds approached 7 m/s. All photographs were produced using a digital SLR camera and ambient light.

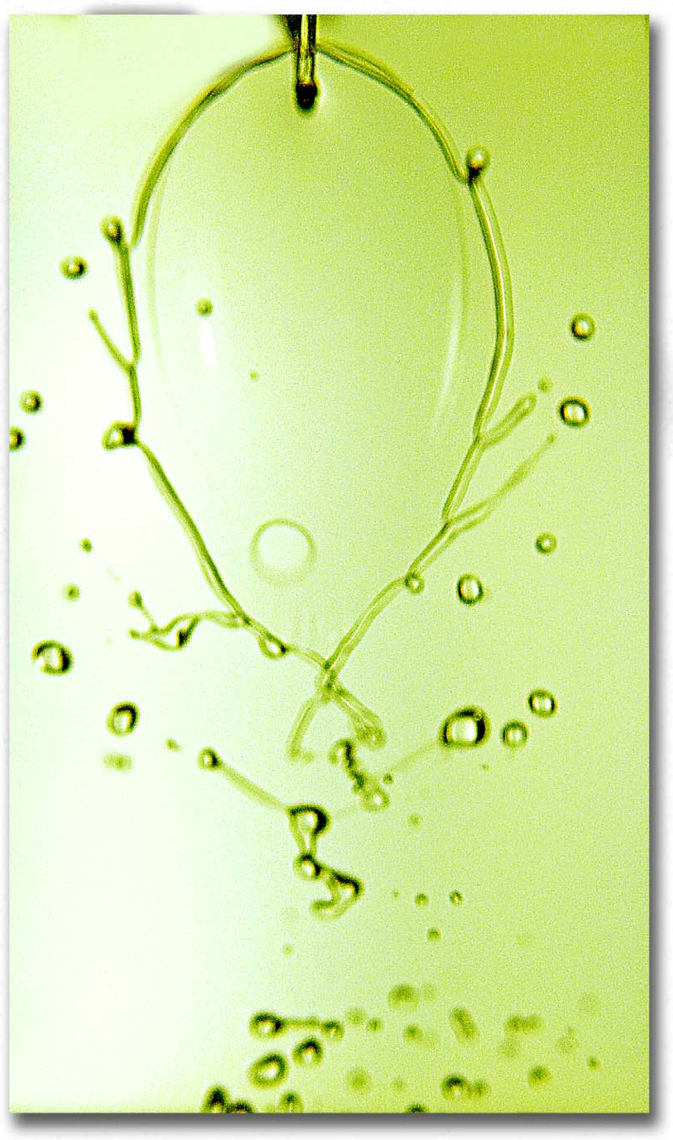

Figure 6: Glycerine + Water

Previous colliding jet studies using Newtonian fluids [1] have shown that the resulting stream has a characteristic succession of forms. At low flow rates, a steady, almost ribbon-like chain of oval links filled in the middle with thin sheets is observed. As the flow rate increases, the initial oval (in a plane perpendicular to that of the colliding jets) increases in size and waves begin to form in the central sheet causing the ring to become unstable. Droplets form on the perimeter of the ring, and remain attached for a short time by thin tendrils. At even higher flow rates (>3 m/s), the impingement becomes similar to a fan-like spray.

When viscoelastic fluids are used, the succession is similar to that of the Newtonian flow, until the higher flow rates. In Figure 1, although somewhat irregular, we see the cascading ribbon. The central ring grows and becomes unstable, shown in Figure 2, and in Figure 3, finger formation around the outer ring becomes apparent. The effects of viscoelasticity and the large extensional viscosity of this fluid become much more noticeable as the outer ring becomes completely unstable and rather than droplets attached by thin tendrils, we see finger-like forms, shown in Figure 4. At the highest flow rates, shown in Figure 5, the outer ring seemingly detaches along with the fingers, and a portion of the central sheet tears away. The torn sheet fragments collapse, and the many fingers create the appearance of a web centered on the initial sheet formed at the colliding jet intersection. High speed video shows that the web-like form taken by the flow is the result of multiple rupture events within the central sheet. As the fluid recedes from the point of rupture, new fluid rims are formed and interact to form the structures seen in Figure 5.

The spray like appearance of a Newtonian fluid at high flow rates (65% glycerine in water solution shown in Figure 6), is attributed to the Rayleigh instability which causes the droplet formation and breakup. In contrast, the extensional viscosities of the non-Newtonian fluids are orders of magnitude greater than shear viscosity, and resist droplet breakup.

[1] A. E. Hasha and J. W. M. Bush, “Fluid Fishbones,” Phys. Fluids 14, S8 (2002).

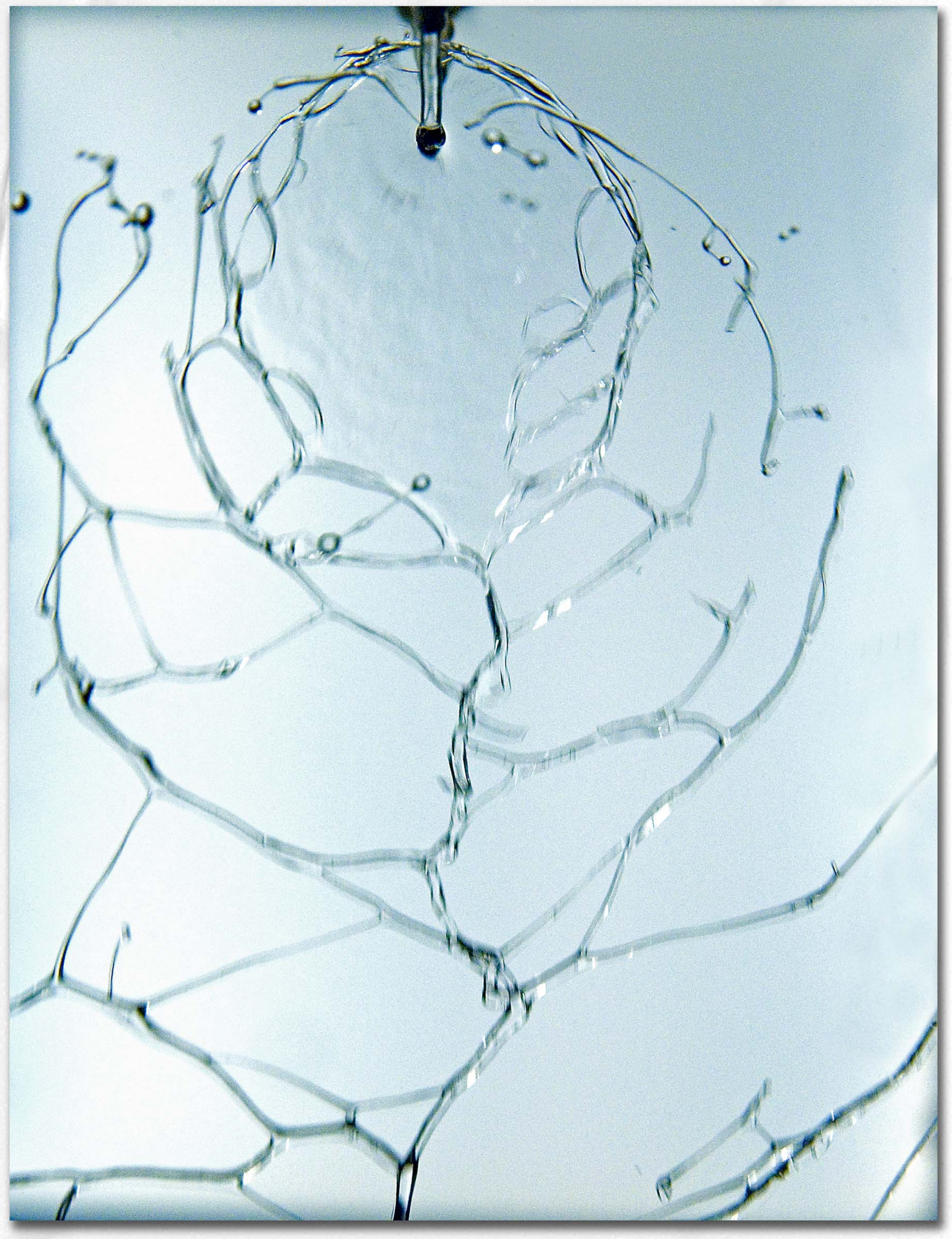

Figure 5: 6.18 m/s