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Thrust-fault dynamics and frictional resistance response inferred though laboratory earthquakes

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Observational and numerical studies have shown that the asymmetric geometry of thrust faults with respect to the Earth's surface leads to a complex dynamic behavior of updip ruptures. Here, we use an experimental technique that combines ultrahigh-speed photography and digital image correlation to characterize the dynamics of transitioned supershear laboratory thrust earthquakes near the free surface with coherent full-field maps of dynamic displacements, velocities, and stresses associated with the ruptures at intervals of one microsecond. The experimental measurements visualize how the free surface breaks the symmetry in the velocity field with a larger velocity magnitude at the hanging-wall and significant rotations into a nearly vertical motion of the hanging wall and footwall motion at a dip angle much shallower than that of the fault. As indicated by the evolving stress maps, these rotations lead to significant normal stress reductions, with a temporal complete release in experiments that were conducted under small initial compressive load. The method enables us to measure the evolving on-fault friction in real time and to unravel the history dependent nature of friction on slip, slip rate as well as fast variations in normal stress. We show that the shear frictional resistance exhibits a significant lag in response to normal stress variations and identify a predictive frictional formulation that captures this effect. Our findings provide guidance to theoretical earthquake source mechanics models by furnishing the necessary on-fault physics needed for the numerical simulation of the rupture process.