

Ribbing in lubricated contacts : stability analysis & simulations

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Résumé : Friction and wear in moving machine parts affect performance and lifespan, making lubrication essential for efficiency. So, in many applications, thin film lubrication studies help conserve resources, reduce pollution, and save energy.

Lubricated contacts can often be simplified to ball-on-a-plate set-up. Here, the sphere deforms elastically, and lubricant pressure spikes before dropping sharply to ambient pressure, creating conditions for cavitation bubbles. This air/vapor pocket, less viscous than the lubricant, can develop a Saffman-Taylor (ST) instability at the gas-lubricant interface, producing intricate interface corrugations around the bubble and in the wake of the rolling sphere which might perhaps explain oil loss in internal combustion engines.

As part of a joint-effort between two broad themes of wide academic and engineering interest, namely, Tribology studied at the small scale by LTDS (ECL), and Fluid Mechanics of large-scale inertial Two-Phase flows studied at LMFA (UCBL), the intern will study the role of pressure-dependent viscosity in the destabilization of the gas/lubricant meniscus which leads to ribbing. This is key part of a larger tribological puzzle : interface corrugations, and film rupture around the cavitation bubble in complex lubricated contacts. Results will be compared with existing experimental observations and DNS results (Basilisk flow solver).

Scientific description: Lubricating contacts in any moving parts of a machine are widely used as a solution to gain performance and machine life-time. So, investigations on thin film lubrication mechanisms are vital for product sustainability in order to reduce wastes of natural resources, diminish pollutant emissions and save valuable energy consumption. For example, in internal combustion motors, oil leakage in the neighborhood of the piston/ring/liner lubrication results in oil burning in the combustion chamber, or wasted oil in the exhaust chamber. In both cases, there is not only an increase in oil consumption but also in air pollution, which is correlated to oil droplet production in the contact outlet zone. Hence, it is extremely important to predict and control film rupture and lubricant loss in journals and bearings at various mechanical and thermal operational conditions. An Elasto-Hydrodynamic lubrication (EHL) point contact is commonly realized in

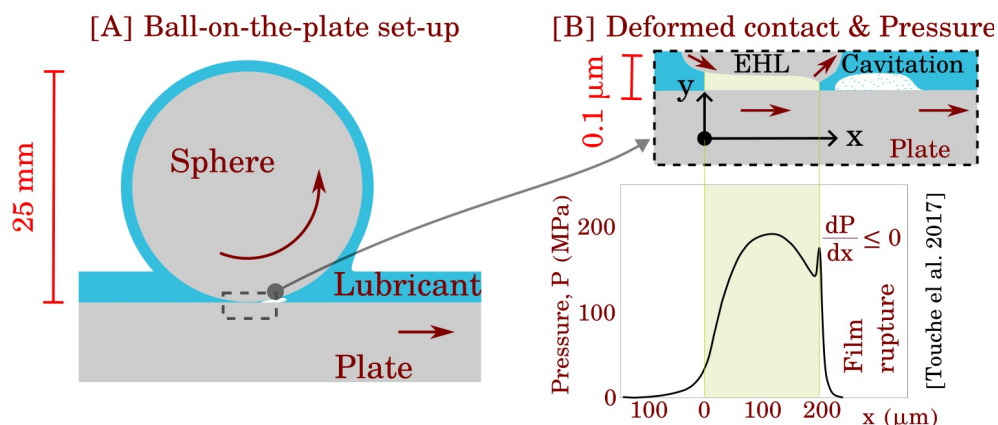


Fig.1 : [A] - [B] Elasto-Hydrodynamic Lubrication contact and lubricant pressure therein.

laboratory using ball-on-a-plate experiments wherein a controlled and measured normal force is applied to both the ball and the plate which move at the same speeds at the contact center [see Fig. 1]. In these experiments, a complex air-vapor-oil flow occurs in the contact wake where the lubricant film ruptures. The extent and content of this zone is crucial for good lubrication performance. For example, Fig. 1 presents schematics from such a configuration. The lengthscales involved in an EHL can range from about a few decades in millimeters (at the level of the entrained flow over the sphere) and up to as small as 10 nm (at the scale of the EHL film flow near the point contact). Here, the sphere undergoes an elastic deformation, and the lubricant pressure in the contact shoots up before it suddenly drops within 10 μm to the ambient pressure at the contact exit. Note that the mechanisms controlling lubrication involve both solid mechanics (sphere deformation) and thermodynamics (lubricant flow). Thereby, a very rich fluid phenomena occurs. At the contact exit, one or more bubbles (oil vapor or air, or both) might form due to cavitation [Dowson & Taylor 1979]. The bubbles might then collapse to form a single large and stable cavitation bubble when the rolling speed is increased. This air/vapor pocket is less viscous than the lubricant and so, in the immediate vicinity downstream of the EHL contact, the gas-lubricant interface is susceptible to a directional Saffman-Taylor (ST) instability [Hakim et al. 1990]. And this could be at the origin of the tiny intricate interface corrugations ($\sim 10 \mu\text{m}$) in Fig. 2 which is termed as ribbing in this proposal. Moreover, finger-like patterns which resemble percolation are also visible at the periphery of the bubble cavity and further downstream in the wake of the rolling sphere in Fig. 2. Also, in applications with fast moving parts, fragmentation of these downstream structures is expected to occur due to inertial entrainment.

The objective of the internship is to develop a mechanical model, based on linear stability analysis, to the fragmentation process of the gaz-lubricant interface. The present intern work will benefit from some recent advances in high-speed rotary entrainment flows [Jerome et al. 2021, 2024], and flow visualizations in thin lubricating films [Nault 2024, Delory et al. 2023] at both LMFA and LTDS, respectively. The onset of ribbing and the most-dominant ribbing wavelength in the neighborhood downstream of the EHL contact, as a function of the relative speed, liquid viscosity, and the contact elasticity, or the imposed gap between the sphere and the flat plate will be analyzed. Using observations and models from recent experiments [Nault 2024, Delory et al. 2023] and the knowledge about the diverging lubrication flow over the sphere, a stability analysis will be conducted. Note that the viscosity evolution with pressure will be taken into account. This will unveil a key part in the large tribological puzzle to understand interface corrugations, and film rupture around the cavitation bubble in more complex lubricated contacts. Results will be compared with existing experimental observations and DNS results (Basilisk flow solver).

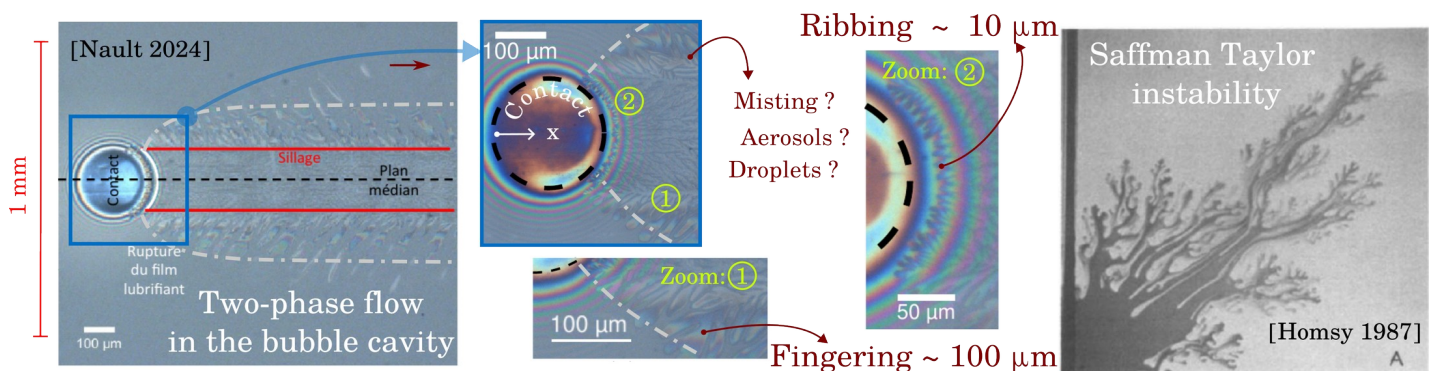


Fig.2 : Film rupture in the cavitation bubble downstream of an EHL contact via ribbing & viscous fingering.