**Jetting behaviour of ultrasound-driven microbubbles in contact with a soft substrate**

Marco Cattaneo, Gazendra Shakya and Outi Supponen

*Institute of Fluid Dynamics, Department of Mechanical and Process Engineering,*

*ETH Zürich, Sonneggstrasse 3, 8092 Zürich, Switzerland.*

**Abstract**

Phospholipid-stabilised gas microbubbles driven by ultrasound are regarded as highly promising vascular agents for a wide variety of biomedical applications, from blood clots removal to targeted drug delivery, owing to their extraordinary ability to focus acoustic energy and release it in the form of mechanical action. Despite of this route’s success observed in clinical trials involving animals and humans, the underlying physical mechanism leading to microdamage of soft tissues remains under debate owing to the microscopic length scales and nanosecond-time scales of the process. In this work, we characterise the dynamics of single coated microbubbles in contact with a soft polymeric substrate, which mimics the blood vessel wall, across bubble sizes and clinically relevant acoustic amplitudes, by means of time-resolved side-view visualisations.We observe the emergenceof repeated microjets towards the substrate when the acoustic-driven bubble interfacial acceleration exceeds a certain threshold. The large jet speeds measured and the corresponding high water hammer pressures produced suggest that the periodic jetting plays a pivotal role in causing microdamage of soft tissues, as also evinced by electron microscopy images of the soft substrate taken after the experiment. We evidence the existence of three distinct, bubble size-dependent, mechanisms causing the periodic microjet formation. On super-resonant bubbles, the volumetric oscillations induces half-harmonic surface oscillations caused by the Faraday parametric instability, which in turn causes the half-harmonic occurrence of microjets directed towards the substrate. Conversely, sub-resonant bubbles are too small to exhibit shape modes but at sufficiently high ultrasound pressure they produce a jet at every compression phase. Finally, on near-resonant bubbles, large shape deformations cause the pinching-off of daughter bubbles that synergically interact with the main bubble to produce harmonic microjets.