Static and Dynamic Deformations of a Reed Valve Immersed in Hydraulic Fluid

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Introduction: Metal reed valves (Fig. 1) provide a simple solution for flow rectification in compact electrohydraulic pumps [1]. While the natural frequency of such a valve operating in air is easily calculated [2,3], it is difficult to predict the behavior when the surrounding fluid has considerable inertia and viscosity. Immersing a reed valve in liquid medium e.g. hydraulic fluid, effectively lowers the natural frequency of the valve [4], thus making it unsuitable at high pumping frequencies.
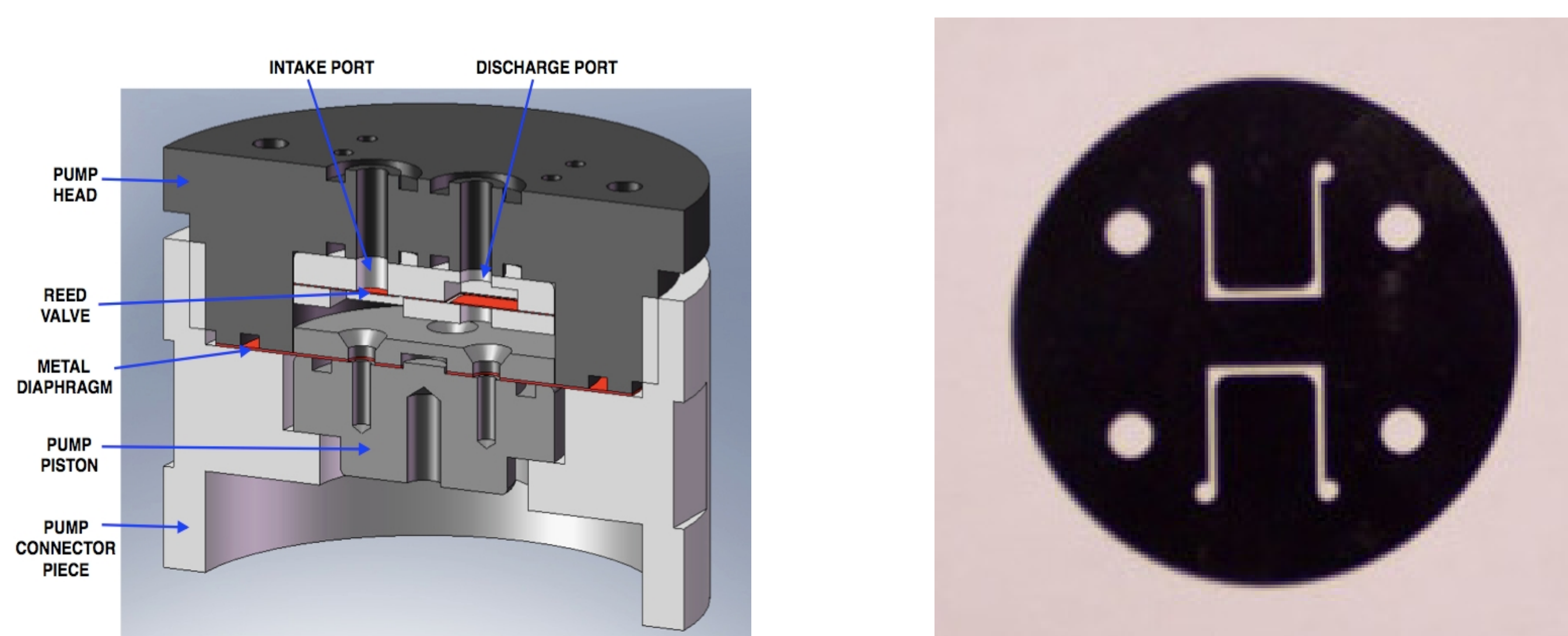

Figure 1. Metal reed valves for fluid flow rectification

Computational Method: Using the Fluid-Structure Interaction (fsi) interface in COMSOL and a 2-D model of the valve geometry (Fig. 2), deformations of the reed valve due to applied pressure gradients were modeled and the corresponding flow velocities calculated. The fluid was assumed to be incompressible and the reed (cantilever beam fixed at one end) was set to follow Linear Elastic behavior; the Fully Coupled solver was chosen to solve the coupled equations.
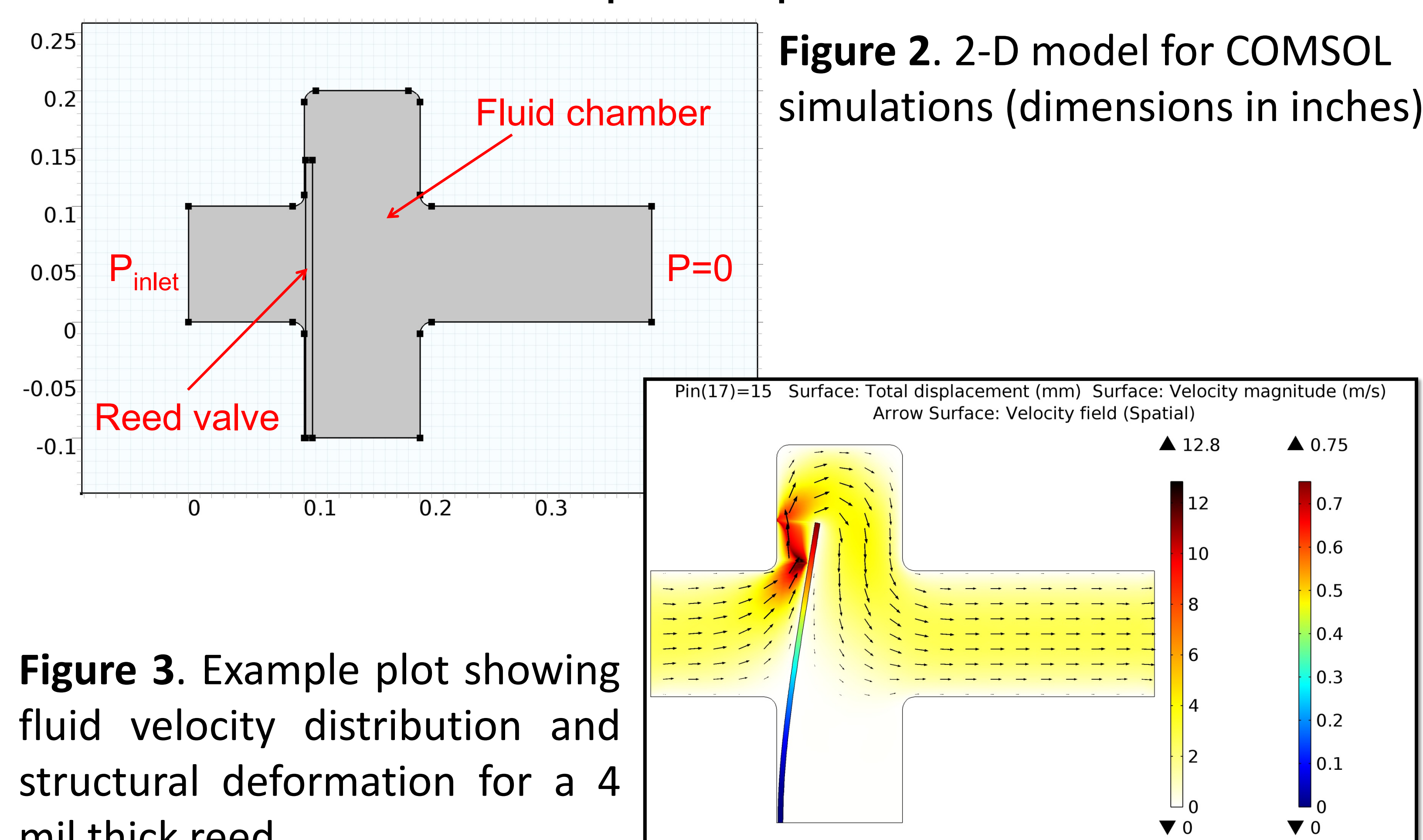

Figure 2. 2-D model for COMSOL simulations (dimensions in inches)

Figure 3. Example plot showing fluid velocity distribution and structural deformation for a 4 mil thick reed

Results – Static deformation: Increasing inlet pressures (P_{inlet}) were applied and the corresponding reed tip displacements (u_{solid}) and fluid velocities (u_{fluid}) were calculated (Fig. 3). The mean outlet flow velocity changes in quadratic manner (Fig. 4a) since minor losses are proportional to flow velocity squared. Pressure gradient required to open the reed increases with thickness (Fig. 4b) due to higher bending stiffness.
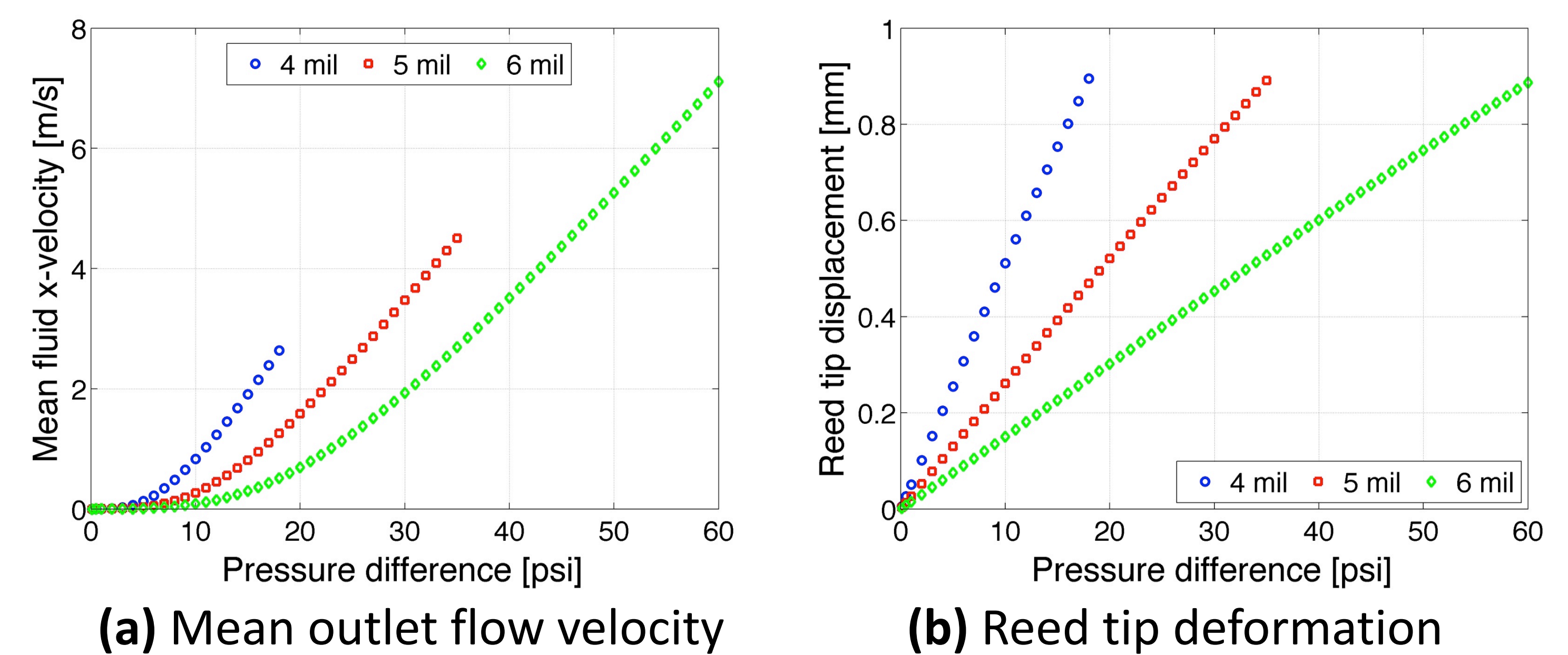

(a) Mean outlet flow velocity   (b) Reed tip deformation

Figure 4. Resulting parameters as a function of inlet pressure for 3 different reed thicknesses

Results – Dynamic behavior: Sinusoidal inlet pressure was applied at different frequencies and the corresponding dependent variables were calculated using the transient solver (Fig 5).
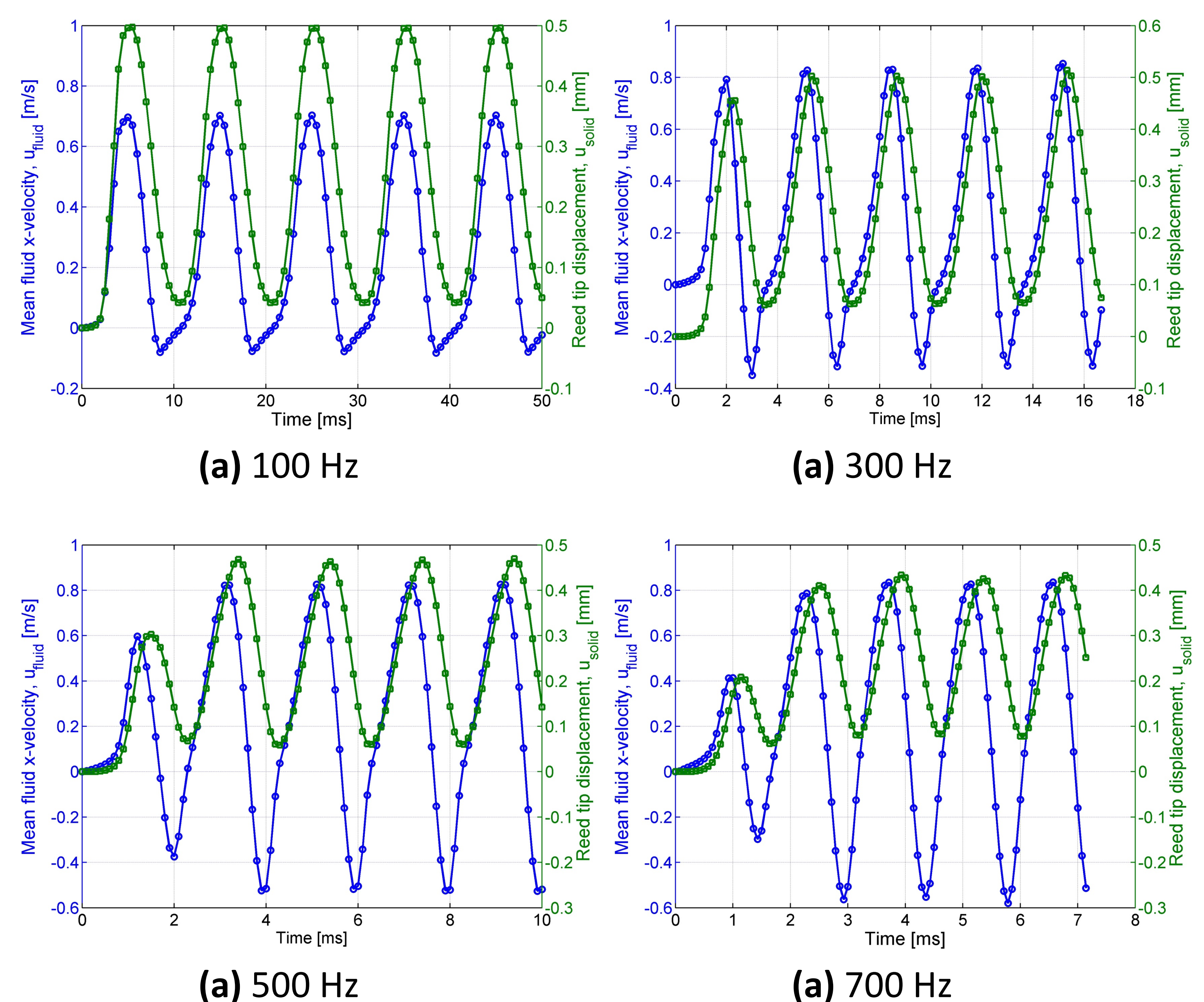

(a) 100 Hz   (a) 300 Hz

(a) 500 Hz   (a) 700 Hz

Figure 5. Transient behavior of a 4 mil reed valve. Simulations show significant reverse flow ($u_{fluid} < 0$) at higher pumping frequencies as the reed fails to close completely ($u_{solid} > 0$ at all times)

Conclusions: A thinner reed valve incurs lower pressure drops but will not be able to close completely under dynamic excitation, thus allowing fluid losses due to flow reversal. Numerical simulations can aid in optimizing the reed valve geometry by accounting for both the minor losses as well as the bandwidth of the device.

References:

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