Fluid Leakage Across a Pressure Seal

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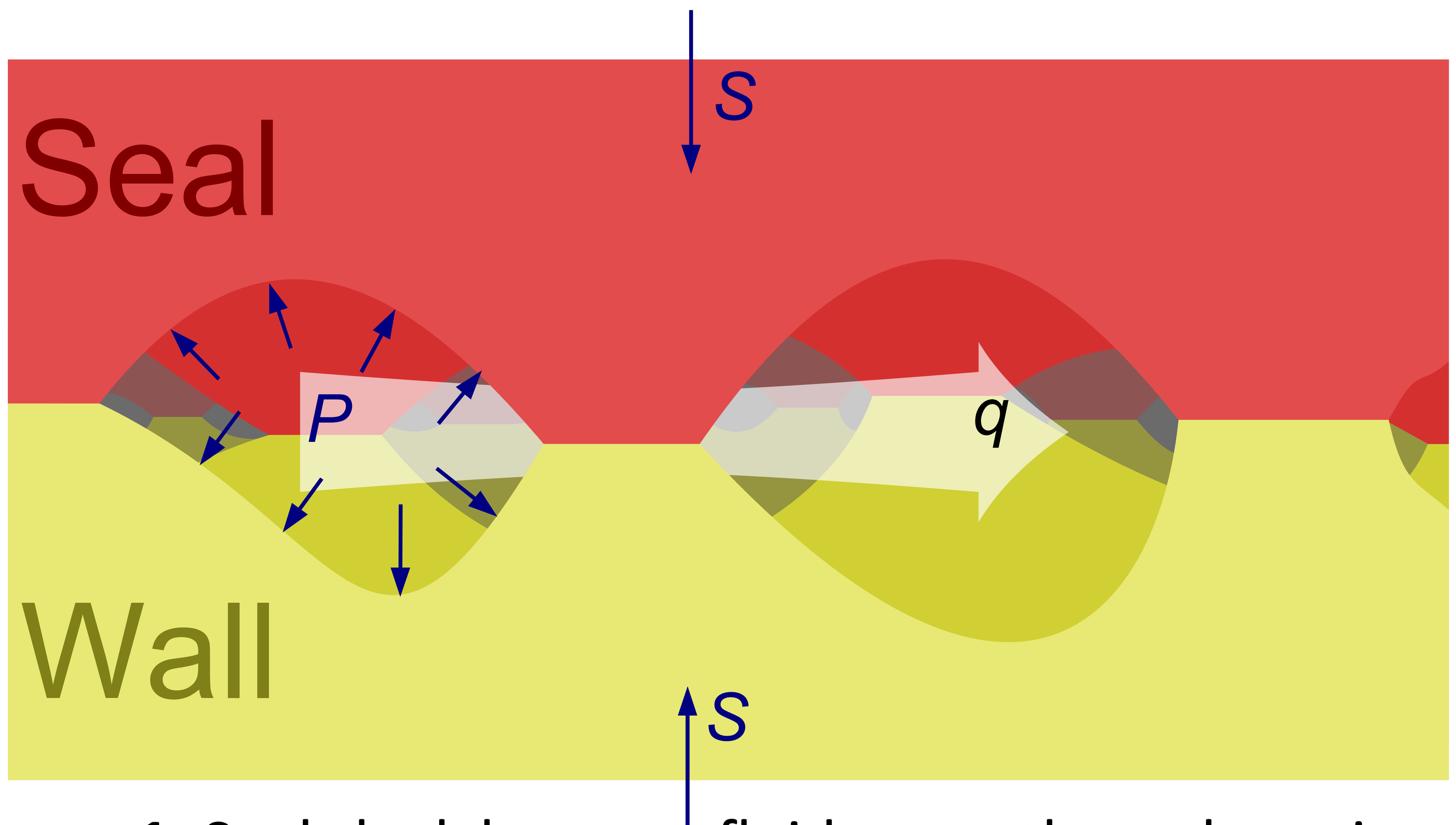

Figure 1. Seals leak because fluids seep through a microscopic network of caverns formed by surface imperfections.

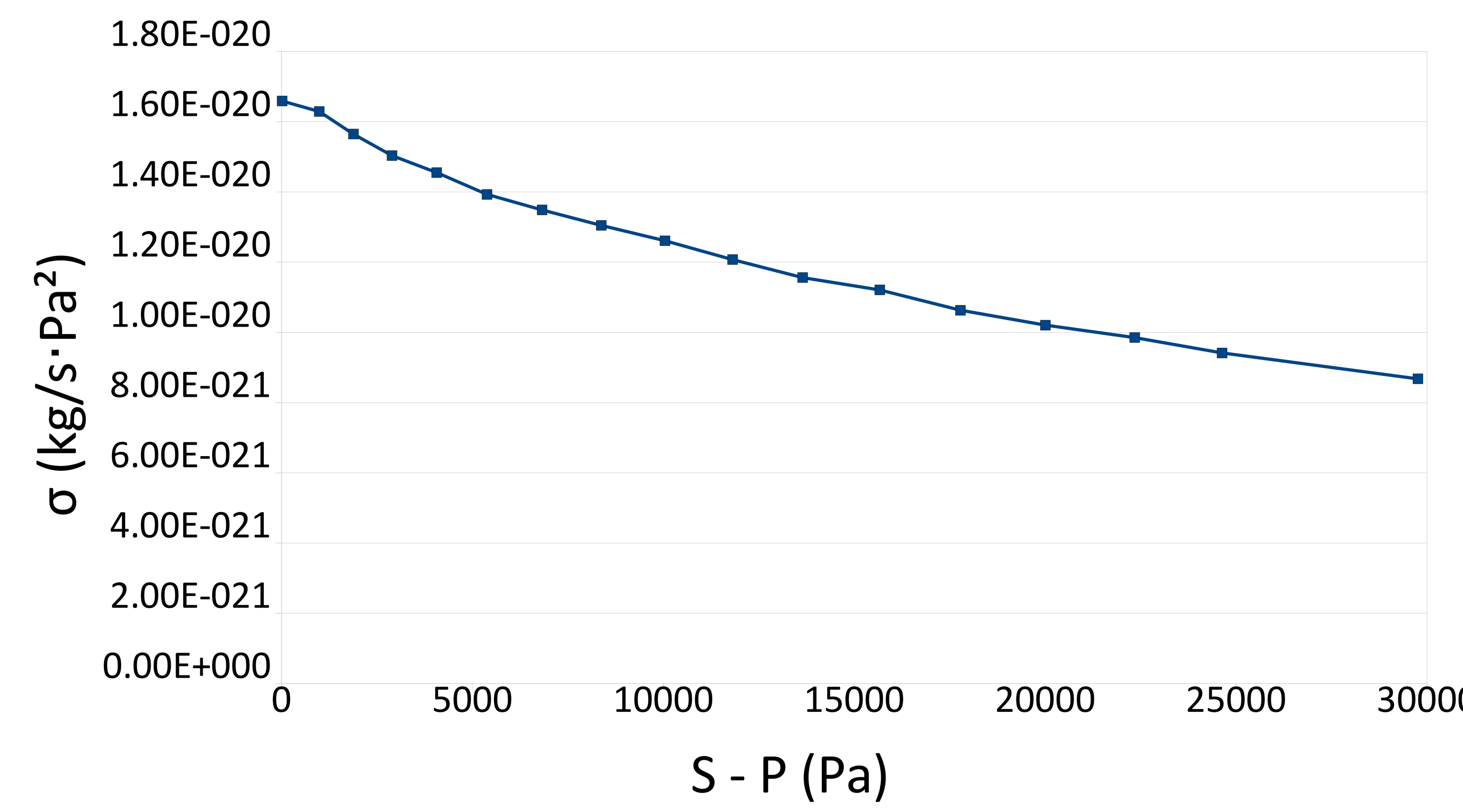

Figure 3. Conductance parameter σ as a function of $S - P$. As S – P increases, the void geometry becomes more constrained, and hence the conductance goes on decreasing – lesser flow will occur for the same pressure and pressure gradient. The graph begins to "level off", as it becomes more and more difficult to constrain the void geometry by increasing S.

Introduction: All compression seals leak fluids (Fig 1). We hypothesize that the leakage can be characterized using a homogenized scale PDE involving the linear mass flux q, the bulk average fluid pressure P and the seal's mechanical pressure S:

$$q = a(S, P, |\nabla P|)\ \nabla P$$

This equation will require a large 3 parameter correlation a to be evaluated. But, if we find some law that a follows, this will simplify the equation and reduce the amount of experimental data that goes in a.

To find such a law, we perform detail-scale mechanical & fluid dynamical simulations (see Fig 2).

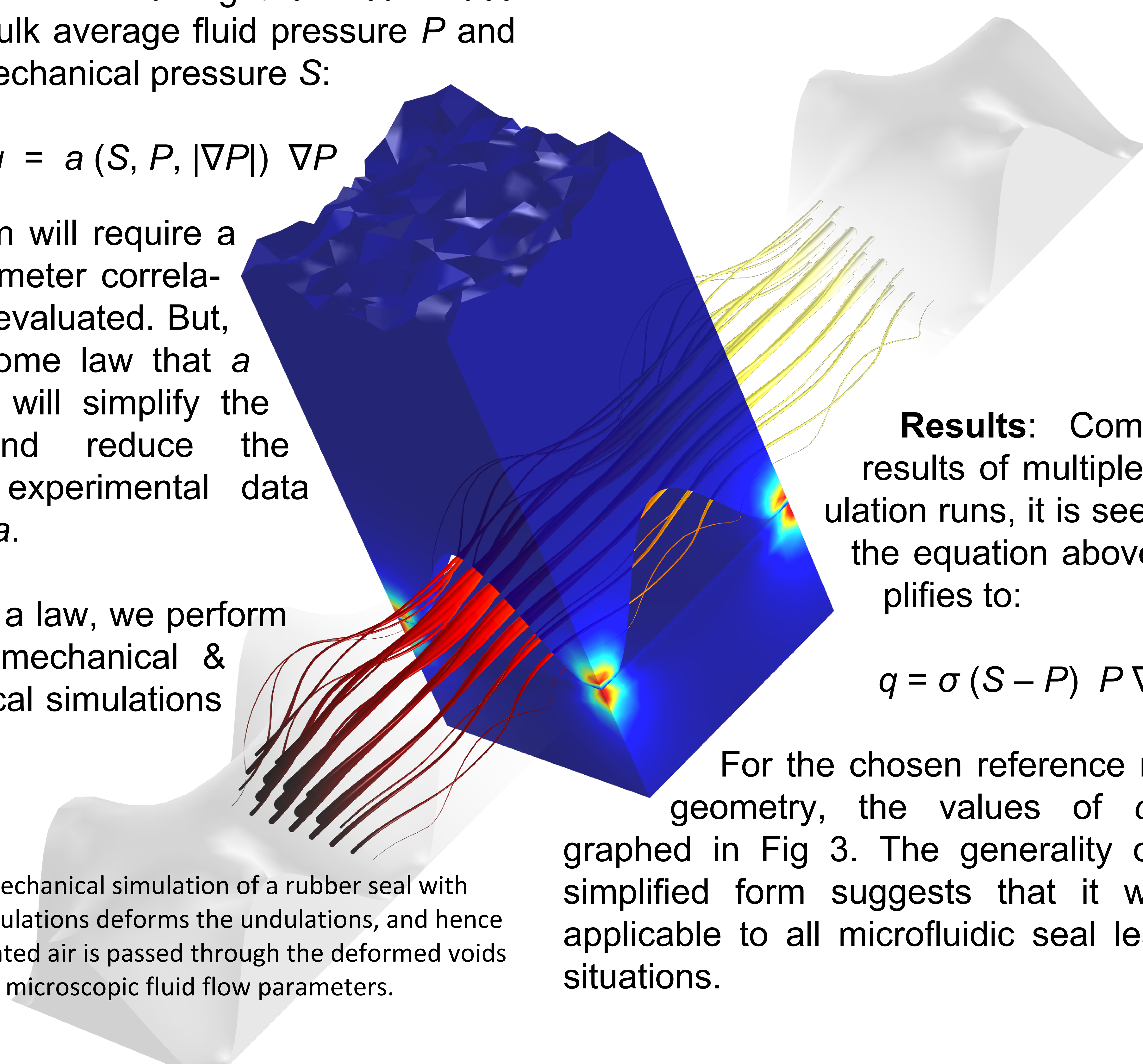

Figure 2. A mechanical simulation of a rubber seal with microscopic undulations deforms the undulations, and hence the voids. Simulated air is passed through the deformed voids to find microscopic fluid flow parameters.

Results: Combining results of multiple simulation runs, it is seen that the equation above simplifies to:

$$q = \sigma(S - P)\ P\,\nabla P$$

For the chosen reference microgeometry, the values of σ are graphed in Fig 3. The generality of this simplified form suggests that it will be applicable to all microfluidic seal leakage situations.

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