TMULTIPHYSICS COMES ALIVE: CAPTURING THE BEHAVIOR OF A LIVING HUMAN HEART

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ABSTRACT

Breaking the limitations of a single physical domain is the next transformative horizon for simulation. When we consider the potential for Multiphysics, the applications to real world problems could become limitless. Important societal topics such as human health could be addressed to push these boundaries. Cardiovascular disease is today the leading cause of death worldwide and growing, with CVD-related deaths expected to reach 23 million each year by 2030. In response, there has been a surge of activity by medical researchers, device manufacturers, clinicians, and regulators to address the issue. Yet progress in developing new techniques to apply our understanding of human heart function to the design of effective treatments as well accelerate the approval process for new treatments has lagged other industries. The lack of reliable realistic simulation models of the human heart and its environs has limited the ability to predict in-vivo device performance, and contributed to the rapid growth in recalls. To address this limitation, SIMULIA has established a cross-functional community of experts and launched a project to systematically develop increasingly realistic models of the human heart to facilitate innovative device development. In this paper, we present progress on this project to date.

The human heart function is exceedingly complex and displays several tightly coupled multiphysical and multiscale effects. As part of a systematic approach to build a simulation foundation for the medical industry, our initial model focused on the electromechanical cardiac system suitable to support design and testing of devices such as stents, valves and pacemakers. We first describe the approach to capture cardiac geometry, muscle fiber orientation, and nonlinear mechanical response. Next, we describe a coupled electromechanical model that enables electrical stimulation of the heart. Next, we describe an efficient fluid-structure interaction (FSI) technique to capture the coupled heart-blood interaction effects. Finally, we describe the assembly of the entire 3-physics electrical-mechanical-fluid system, the specific simulation scenarios, and discuss the results.

A project as ambitious as this necessarily involves starting with the basics and incrementally building complexity over time while validating intermediate models and approaches. We therefore also discuss potential next steps, including systems simulation to capture larger scale effects (e.g. circulatory system) and additional physics co-simulation to develop higher fidelity models

for human tissue and blood (i.e., cellular level). Through this systematic effort, we believe Multiphysics simulation can ultimately reduce the scope and time frame of clinical trials by simulating the effects of population variations using optimization-like techniques. Not least is the (required) ability for multiple domain experts to share information and insights while protecting proprietary knowledge. These more sophisticated aspects of the project require the development of a modern multiphysics/multiscale platform with collaboration and optimization capabilities inbuilt. We therefore conclude with a brief overview of the 3DEXPERIENCE platform designed to transform the practice of multiphysics and thus of realistic human simulation.