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From jet turbines to human hearts: fluid dynamics mapping with MRI

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Introduction: Flow-sensitive magnetic resonance imaging (flow MRI) is a powerful tool to non-invasively assess the cardiovascular hemodynamics in-vivo. With the acquisition of time-resolved 3-dimensional data with 3-directional velocity encoding, the method can be used to fully characterize the complex geometric and hemodynamic situation [1]. Flow information, however, is also required in many engineering applications such as the optimization of turbine aerators [2]. Technical flow is commonly measured with laser-optical methods, characterized by the necessity of transparent models, limited data dimensionality and time-consuming experiments and data analysis, constraining experimental investigations of geometries with higher complexity [3]. In this abstract, an overview about the potential of flow MRI in combination with modern rapid prototyping is given with respect to fluid dynamics mapping underlined with examples from engineering and clinical applications.

Methods: MR compatible flow models were produced via rapid prototyping and measured at a clinical routine 3 Tesla MR scanner. All data presented in Figs. 1-3 were acquired with a phase contrast gradient echo sequence with an isotropic spatial resolution of 1-2 mm. Fig. 1 presents 3D MR flow measurements of two components in a cooling passage of a turbine blade [4], Fig.2 two frames of a 4D flow data set acquired in a fluidic oscillator [5]. Fig. 3 shows streamlines of one time frame of a 4D flow data set acquired in an in-vitro model system to investigate the impact on the hemodynamics of different attachment positions of a left ventricular assist device to the aorta, as an important information for the heart surgeon [6].

Limitations: The spatial resolution of flow MRI data is limited by the signal to noise ratio and is in the range of slightly less than 1 mm (for magnetic field strengths as used in clinical routine). The acquisition of 4D flow data of dynamic processes is only feasible in period flow since data acquisition has to be synchronized with the flow cycle while dividing data acquisition over many flow cycles. In this case the temporal resolution is limited by repetition time TR of the measurement sequence, typically ~5 ms. Advanced sequence strategies allow the acquisition of real-time velocity data in 2D slices with 1-directional velocity encoding with a spatial resolution of ~1.5 mm and a temporal resolution of ~40 ms. Flow velocities can be acquired in a range from less than 1 mm/s up to more than 5 m/s.

Discussion: Flow-sensitive MRI provides functional information of fluid dynamics not obtainable with any other modality and has the potential to open up new horizons in interdisciplinary research fields. Using rapid prototyping model geometries and boundary conditions can be altered quickly and easily and offers with flow 4D-MRI a comprehensive analysis of fluid dynamics in terms of optimization processes and support for the development of flow simulations using CFD. Due to the limited spatial resolution of flow MRI, it would be

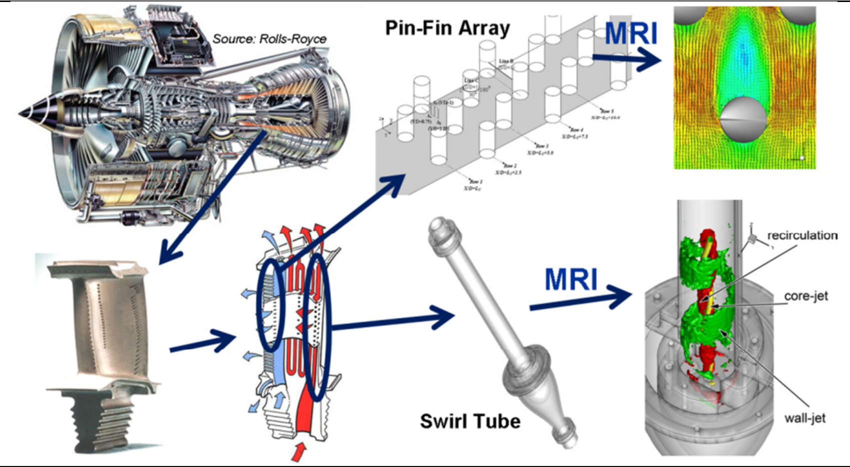

Fig. 1: Example of two components (Pin-Fin Array and Swirl Tube) in a cooling passage in a turbine blade that have been measured using flow-sensitive MRI. The investigation of different geometric structures in the swirl tube revealed novel arrangements in the twisting flow pattern. The relatively short scan times and the comprehensiveness of the available data open up unique possibilities to investigate and understand complex flows.

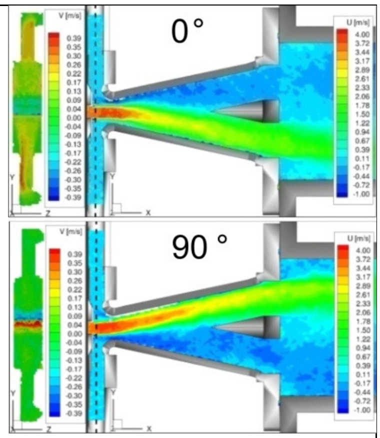

Fig.2: 2 different switching status time frames within the periodic cycle in a fluidic oscillator. The colour-coding of the contour plot shows the velocity distribution in the axial direction.

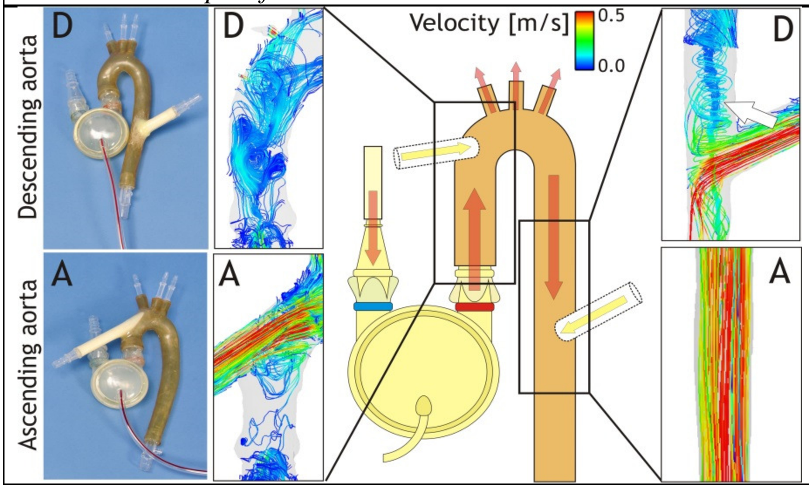

Fig.3: 3D flow visualization in the two different in-vitro models simulating different connections of a left ventricular assist device (LVAD) to the aorta analogously to routine surgical approaches (A: ascending aorta, D: descending aorta). Note the massively altered flow in the ascending and the descending aorta when the blood support (with continuous blood flow) from the LVAD enters the descending aorta.

of interest to constrain fluid dynamics by interlacing MR flow data and CFD, which may be of particular interest e.g. in regions near (vessel) walls or in case of transient or turbulent flow regimes.

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