Impact of Fluctuation Induced Asymmetric Propagators on the Accuracy of Phase Contrast Velocimetry.

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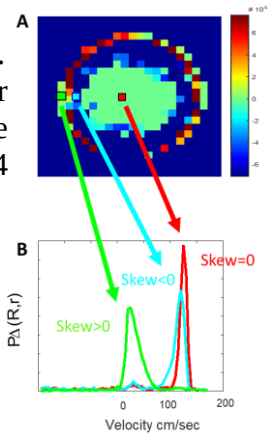
Introduction: Phase contrast velocimetry (PCV) is widely used to image velocity fields non-invasively. An often overlooked assumption in the theory of PCV, which may not be met in complex or unsteady flows, is that the intravoxel displacement distributions (propagators) are symmetric. We have shown that higher moments of the displacement distribution (variance, skewness and kurtosis) can significantly impact the accuracy of PCV [1], with phase error,

$$\varphi_{error}(\boldsymbol{r}) = tan^{-1}\left(\frac{-\frac{q^3}{3!}Skew(P_\Delta(R,r))}{1-\frac{q^2}{2!}Var(P_\Delta(R,r))+\frac{q^4}{4!}Kurt(P_\Delta(R,r))}\right)$$

Here, we present pipe flow measurements up to the transition to turbulence, where rapid intravoxel velocity fluctuations can produce broad, asymmetric displacement distributions and PCV errors.

Materials and Methods: PCV and Fourier Flow Imaging (FFI) were performed on water flow (1 g/L CuSO4) through a straight pipe of 3mm diameter. PCV measurements used a flow compensated gradient echo sequence [Bruker Flowmap, Te = 5 ms , Tr = 20 ms, matrix 64 x 64, FOV 1.0 cm x 1.0 cm, slice thickness 1mm]. Corresponding high-resolution FFI was achieved by acquiring 64 q-values. Measurements were made for a range of flow rates and q values.



Results and discussion Figure 1a shows example skewness map from FFI (flowrate 508ml/min). b) velocity distribution from selected voxels. The inner wall voxel (green) shows positive skewness and high variance. The second ring closer in (Blue) shows negative skewness and high variance. The central voxel (Red) shows zero skewness and low variance.

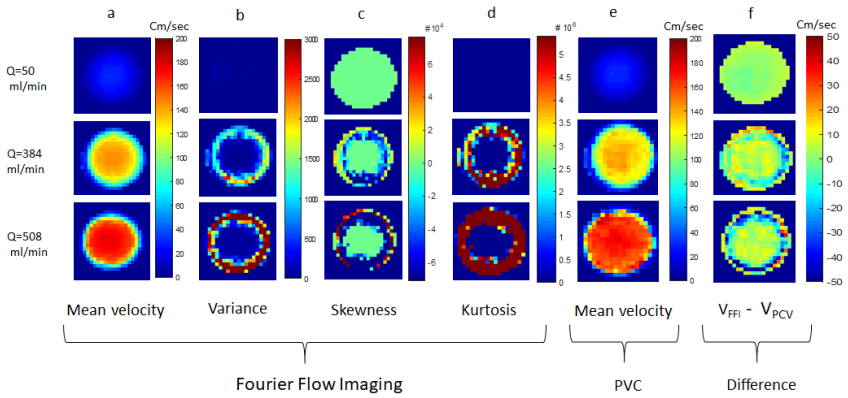


Figure 2, shows FFI and PCV results for three different pipe flow rates. For each FFI voxel the moments of the displacement distribution were calculated, giving spatial maps of the mean (a), variance (b), skewness (c) and kurtosis (d). Column (e) show mean velocity measured by PCV. Column (f) difference/error (FFI-PCV).

- $P_\Delta(\boldsymbol{R},\boldsymbol{r})$ high positive skewness and high variance – **PCV underestimates velocity**
- $P_\Delta(\boldsymbol{R},\boldsymbol{r})$ high negative skewness and high variance – **PCV overestimates velocity**
- $P_\Delta(\boldsymbol{R},\boldsymbol{r})$ zero skewness – PCV accurate velocity

Conclusion. We show that rapid fluctuations in the velocity field, can produce broad asymmetric intravoxel displacement distributions, which can result in an underestimation or an overestimation of the true mean velocity, in agreement with our theoretical analysis [1].

References: [1] Vallatos A, Mubarak H, Holmes W. Journal Magnetic Resonance. 2018; 296:121-129.