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Control of unsteady wake flows using local oscillation of body surface: a data assimilation study

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Abstract

Variational data assimilation (DA) can expand active flow control techniques to design wall actuators such as synthetic jets or plasma discharges which are difficult to model computationally due to ambiguous boundary conditions at the wall. Here, the control vector for the DA problem is formed by the initial flow and the solid boundary conditions for the body, that means its tangential speed at all times where no particular form is prescribed to the body motion. The control domain takes into account the modeled body surface by means of a direct forcing immersed boundary method (IBM). We consider a configuration of reference flow past a rotationally oscillating cylinder given by Mons & Sagaut, 2017, J. Fluid Mech. The proposed methodology is applied to the reconstruction of a reference flow generated by a partial control restricted to an upstream part of the cylinder surface as given by Bergmann & Cordier, 2006, Phys. Fluids. DA is also employed to build wall conditions for a direct numerical simulation (DNS) of flow around an airfoil with local oscillation, from synthetic observations of the wake flow downstream the body.

Data assimilation for flow spatio-temporal reconstruction

Goal

Provide a DA technique integrating experimental data and DNS to reconstruct the flow dynamics around complex stationary or moving geometries

Control volume technique

Lack of info outside \( \Omega \)  

Partial estim. of \( C_{\alpha} \)

Not be able to evaluate unsteady term \( \int_{\Omega} \nu u \cdot \nabla \delta u \, dV \)

Partial estim. of \( C_{\alpha}^{\text{g}} \)

Present strategy

body boundary cond. \( u(x|s_0, t) \) in DA control vector

Boundary forcing estimation through VDA

Problem

Recover a system’s state \( X \) obeying a dynamical law \( M \), given observations at \( t' \) separated by \( \Delta t \):  

\[ \partial_t X(x, t) + M(X(x, t), \gamma(t)) = 0 \]

\( \chi(x, t_0) = \chi_0(x) + r(x) \)

Dynamical model

\[ \frac{\partial u}{\partial t} = -\nabla p - \frac{1}{\rho} \nabla \cdot \nabla u + (u \nabla)u + r(x) + f \]

Numerical method

Incompact3d

Evaluation of forcing

IBM for simulating flows with moving rigid boundaries

Gronskis et al., 2016, Comput. Fluids

Data Assimilation - Cost Functional

Minimization problem

constraint \( \Rightarrow \) state dynamics \( \Rightarrow \) dependence of the system’s state variable \( \gamma \):  

\( X = u(\gamma) \), \( \gamma = (\chi(x), \gamma(t)) = (u(x|s_0), u(x|s_0, t)) \)

Objective

lowest discrepancy between observations and state variable

\( J(\gamma) = \int_{t_0}^{t_f} \left[ \frac{1}{2} \int_{\Omega} \left( \chi(x, t) - \chi_0(x) \right)^2 \, dx \right. \, dt + \int_{t_0}^{t_f} \left. \frac{1}{2} \int_{\Omega} \left( \nabla \cdot \left( \chi(x, t) - \chi_0(x) \right) \right)^2 \, dx \right] \, dt \)

Control on the Initial and Wall Condition

Flow configuration

rotational speed of the cylinder at \( Re=10000 \):  

\( \omega(t) = A \sin(2\pi t) \)

Conclusion and Outlook

- A new method for reconstructing the flow field from limited measurements where no velocit information is available in a neighborhood of the solid boundary has been introduced.
- Though being restricted to reasonable mesh resolution at the body surface, present technique allows for an accurate pressure reconstruction in a region close to the solid boundary.
- The addition of a penalization term for the wall condition in the cost function allows us to prevent drastic changes in the temporal solution during the optimization process.
- Introducing a moving boundary cond. as a control parameter will extend VDA to FSI.

References

Gronskis et al., to appear in Exp. Fluids