Linear stability analysis of spiral vortex breakdown in presence of a spherical object in constricted pipe

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MOTIVATION
Vortex breakdown, a commonly reported phenomenon of swirling flows, normally associated with a sudden change from columnar state to the flow topology as the azimuthal component of velocity grows compared to the axial component. A number of experimental, numerical and analytical studies have been conducted on the axisymmetric vortex breakdown and its stability.

Meliga and Gallaire (2011)
- Classical vortex breakdown,
- Constricted pipe,
- Viscous flow

Pasche et al. (2014)
- Single helical vortex breakdown,
- No stagnation point,
- Probable reason: Adverse pressure gradient.

Present study combines a so-called classical axisymmetric vortex breakdown analysis with an adverse pressure gradient induced by a spherical object at an intermediate $Re$, in linear stability analysis framework.

Objectives:
- The effect of a downstream sphere on the base flow topology
- Helical mode instability in presence of a downstream sphere

PROBLEM FORMULATION
Base flow configuration:
$$
\frac{\partial u}{\partial t} + \nabla \cdot (u \otimes u) - \frac{1}{Re} \Delta u + \frac{\partial}{\partial z} \left( \frac{u}{r} \right) + \frac{1}{Re} \frac{\partial}{\partial z} \left( \frac{v}{r} \right) = 0,
$$

Base flow map for axisymmetric stable solutions

RESULTs
Base flow velocity with vortex breakdown

CONCLUSION
Spiral vortex breakdown in presence of sphere was illustrated using linear stability analysis. Various base flow patterns characteristic of the columnar, decelerated, vanishing and developed breakdown states have been identified. Formation of UERR and USSP has been detected. It has been shown that instability of helical eigenmodes takes place in this recirculation region and not necessarily due to the breakdown state while all the breakdown states are unstable to the helical mode disturbances.

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REFERENCES