Flow instability inception prediction using eigenvalue analysis

Shenren Xu *[1] and Zhihao Wu [1]
[1] *School of Power and Energy, Northwestern Polytechnical University, Xi'an, 710072, China*

The compression system in turbomachines, e.g., aircraft engines and gas turbines, when operating under off-design conditions, exhibits flow instability such as surge, rotating stallm leading to performance deterioration, noises and structural damages. Inability to accurately predict the condition under which such flow instability will happen severe hinders the development of high performance compression system. In this work, an eigenvalue analysis method is developed to predict flow stability commonly seen for turbomachines operating at near stall conditions. The eigenvalue analysis is fully based on the steady state three-dimensional Reynods-averaged Navier-Stokes equations and thus the stability boundary is fully consistent with the one that is predicted by the time-accurate flow simulation, i.e., URANS, but two to three times faster. The method is applied to the computation of stability boundary of (i) the laminar flow around a two-dimensional circular cylinder, (ii) the flow around a quasi-three-dimensional compressor anuular cascade, and (iii) flow around a three-dimensional compressor rotor. The method developed here has the potential to revive the once-popular eigenvalue method for prediction rotating stall and surge, which was based on lower-fidelity flow models and provide industry with tools to accurately predict the stall line in the early design stage.

*Email address: shenren_xu@nwpu.edu.cn

I. The nonlinear flow solver

A. Governing equations

B. Spatial discretization

II. Stability analysis

A. Time-domain unsteady approach

B. Eigenvalue approach

III. Eigenvalue analysis for large sparse matrices

IV. Results

A. Laminar flow around a two-dimensional circular cylinder

1. Steady state calculation

2. Unsteady calculation

3. Eigenvalue analysis

B. Rotating stall for an annular compressor cascade

1. Steady state calculation

2. Unsteady calculation

3. Eigenvalue analysis

C. Rotating instability for an axial compressor rotor

1. Steady state calculation

2. Unsteady calculation

3. Eigenvalue analysis

V. Conclusion

Acknowledgements

References

[1] Allmaras, S. R., and Johnson, F. T., "Modifications and clarifications for the implementation of the Spalart-Allmaras turbulence model," *Seventh international conference on computational fluid dynamics (ICCFD7)*, 2012, pp. 1–11.

[2] Langer, S., "Agglomeration multigrid methods with implicit Runge–Kutta smoothers applied to aerodynamic simulations on unstructured grids," *Journal of Computational Physics*, Vol. 277, 2014, pp. 72–100.

[3] Hascoët, L., and Pascual, V., "The Tapenade Automatic Differentiation tool: Principles, Model, and Specification," *ACM Transactions On Mathematical Software*, Vol. 39, No. 3, 2013.

[4] Gebremedhin, A. H., Nguyen, D., Patwary, M. M. A., and Pothen, A., "ColPack: Software for graph coloring and related problems in scientific computing," *ACM Transactions on Mathematical Software (TOMS)*, Vol. 40, No. 1, 2013, p. 1.

[5] Cantwell, C. D., Moxey, D., Comerford, A., Bolis, A., Rocco, G., Mengaldo, G., De Grazia, D., Yakovlev, S., Lombard, J.-E., Ekelschot, D., et al., "Nektar++: An open-source spectral/hp element framework," *Computer Physics Communications*, Vol. 192, 2015, pp. 205–219.