

The effect of vortex ring state on aeroelasticity of rotor blades

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The Vortex Ring State (VRS) is a hazardous aerodynamic condition encountered by the rotorcraft during steep or vertical descent, characterised by highly unsteady inflow, loss of thrust efficiency, and increased vibration levels [1]. While VRS has been extensively studied from an aerodynamic and flight dynamics perspective, its influence on the rotor blade aeroelastic behaviour during the design phase remains insufficiently investigated. This paper aims to examine the effect of VRS on rotor blade aeroelastic stability and response by developing and coupling a VRS inflow model with a blade aeroelastic model.

The aeroelasticity of the rotor blade is modelled by coupling a two-degree of freedom flap-pitch system with an unsteady strip theory model, expressed in matrix form to capture inertial, damping and stiffness effects. The coupled model enables the investigation of how abnormal inflow conditions associated with VRS influence dynamic stability margins [2]. A VRS inflow model based on the momentum theory is developed and extended using empirical corrections to eliminate the singularities and represent the unstable descent regimes accurately. A baseline inflow curve is constructed using a polynomial fit to ensure the continuity across climb and descent conditions following the approach described in [3].

Figure 1 shows the developed VRS model from a baseline case which successfully predicts the realistic inflow behaviour across the VRS region. The blue and red curves represent the momentum theory model, the black curve represents the corrected the baseline model by eliminating the singularity and the purple curve illustrate the VRS region for advanced ratio equal to zero. This model will be combined with the already existing aeroelastic model of a hingeless rotor blade. The full paper will investigate the effects of VRS on the stability margins as well as the dynamics loads of the blade in descent flight as well as the effects of system parameters on the stability of the blade. The results will provide valuable insights into the aeroelastic stability of rotorcraft operating in VRS condition and to support improved rotor design and optimization for enhanced safety and performance.

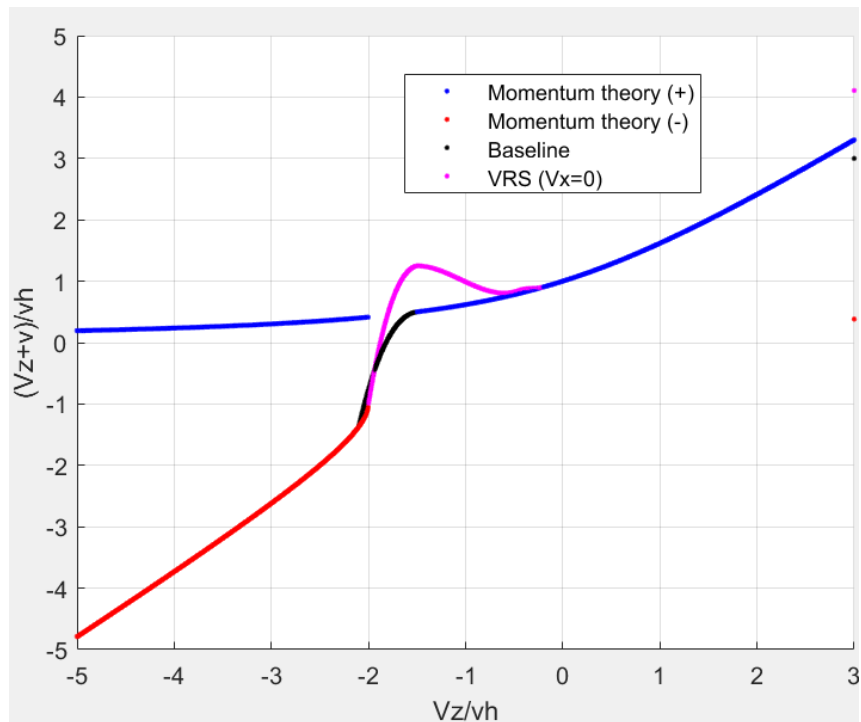


Figure 1 VRS model development

References

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- [3] J. Wayne, "Model for Vortex Ring State Influence on Rotorcraft Flight Dynamics/ TP-2005-213477," NASA, Ames Research Center, Moffett, California, 2005.