

# TRANSONIC WIND TUNNEL TESTING OF SWITCHABLE VORTEX GENERATORS FOR LOAD ALLEVIATION AND STALL CONTROL

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## ABSTRACT

The increasing flexibility of modern high-aspect-ratio wings and the demand for higher aerodynamic efficiency motivate the development of flow control devices capable of mitigating aerodynamic loads, particularly those arising from atmospheric gusts and pilot-initiated manoeuvres, which can adversely affect structural integrity and flight performance at high speeds. Flow control is similarly needed in high-lift settings, where extensive flow separation on outboard wing sections can compromise control-surface effectiveness and manoeuvrability. This work presents the mechanical design and experimental investigation of a dual-function flow-control concept, referred to as the Switchable Vortex Generator (SVG), developed to enable both aerodynamic load alleviation at high speed and flow separation control in high-lift conditions.

The SVG concept is based on a single rotating vortex vane whose orientation relative to the incoming flow determines its aerodynamic function. When aligned with the local flow, the device remains aerodynamically inactive. At intermediate orientations, the vane acts as a vortex generator, promoting boundary-layer energisation and delaying flow separation. At larger deflections, the vane behaves as a spoiler-like device, producing lift reduction and load alleviation suitable for transonic operating conditions [1, 2]. The ability to switch between these configurations using a single mechanical element provides a compact and versatile alternative to conventional fixed or single-purpose flow-control devices.

Two complementary demonstrators have been developed and manufactured. The first one is an active SVG (ASVG), in which the vane orientation is continuously controlled using an electric actuator coupled to a backlash-free harmonic drive transmission, enabling precise positioning over a wide range of deflection angles. While this configuration allows accurate and flexible control of the vane orientation, the achievable response speed is inherently limited by actuator dynamics and transmission constraints. A second demonstrator, referred to as the semi-active SVG (S-ASVG), has therefore been developed as an alternative actuation concept. The S-ASVG is designed to prioritise rapid deployment and robustness in response to gust perturbations. In this configuration, an asymmetric vortex vane is mounted such that, when engaged by an electromagnetic clutch, it is held in an unstable equilibrium relative to the incoming flow. Upon clutch disengagement, the vane is released and aerodynamic forces drive a rapid rotation towards a spoiler configuration, where the motion is arrested by integrated mechanical end-stops and a shock-absorbing mechanism.

A dedicated experimental campaign is planned in the CIRA transonic wind tunnel to assess the aerodynamic behaviour and functional performance of the proposed SVG concepts. The test matrix spans subsonic and transonic Mach numbers representative of relevant flight conditions, with systematic variation of vane deflection angle, total pressure level and vortex vane size. Forces and moments will be measured using a multi-axis load balance, complemented by wake measurements obtained using a wake rake system. For the active configuration, the influence of vane size and orientation on steady aerodynamic loads will be examined, while for the semi-active configuration particular emphasis is placed on the repeatability, timing and robustness of the deployment mechanism under transonic flow conditions.

## References:

- [1] Marino L., Kiat I., Eberle A., Sodja J.: Parametric study of a switchable vortex generator for load alleviation in transonic conditions. *Journal of Aircraft* 62(3), 579-593 (2025)
- [2] Marino L., Eberle A., Sodja J.: Three-dimensional parametric analysis of a switchable vortex generator for aerodynamic load alleviation at transonic speeds. AIAA 2025-0035. AIAA SCITECH 2025 Forum (2025)