

# DYNAMIC RESPONSE ANALYSIS OF AN EVTOL VEHICLE USING GVT-DERIVED STATE-SPACE MODELLING

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## ABSTRACT

This work presents a GVT-driven state-space aeroelastic framework aimed at predicting gust response and control-surface command response with reduced structural-model uncertainty. Free-body (suspended) ground vibration test data are directly employed to define the structural dynamics, while unsteady aerodynamics are represented through a rational function approximation of the generalized aerodynamic force matrix. A change-of-basis procedure is introduced to map the numerical aerodynamic operator onto the experimentally identified modal basis using measured modal parameters, yielding a coupled aeroelastic model suitable for both frequency- and time-domain simulations<sup>[1]</sup>. The proposed approach allows the use of experimental modal data beyond traditional flutter assessment, providing response predictions and load indicators that are relevant for industrial design activities and certification-by-analysis processes. The framework is demonstrated on the Vertical Aerospace VA-1X eVTOL aircraft (See Fig. 1), providing response predictions relevant to industrial design and certification-by-analysis.



**Figure 1** Vertical VA-1X model

## Introduction

Ground Vibration Testing (GVT) provides experimental modal parameters that are routinely employed to support aeroelastic stability assessments prior to first flight. For electric vertical take-off and landing (eVTOL) aircraft, suspended GVT configurations enable the identification of modal scenarios that closely approximate free-free boundary conditions, making experimental data particularly representative of in-flight structural dynamics.

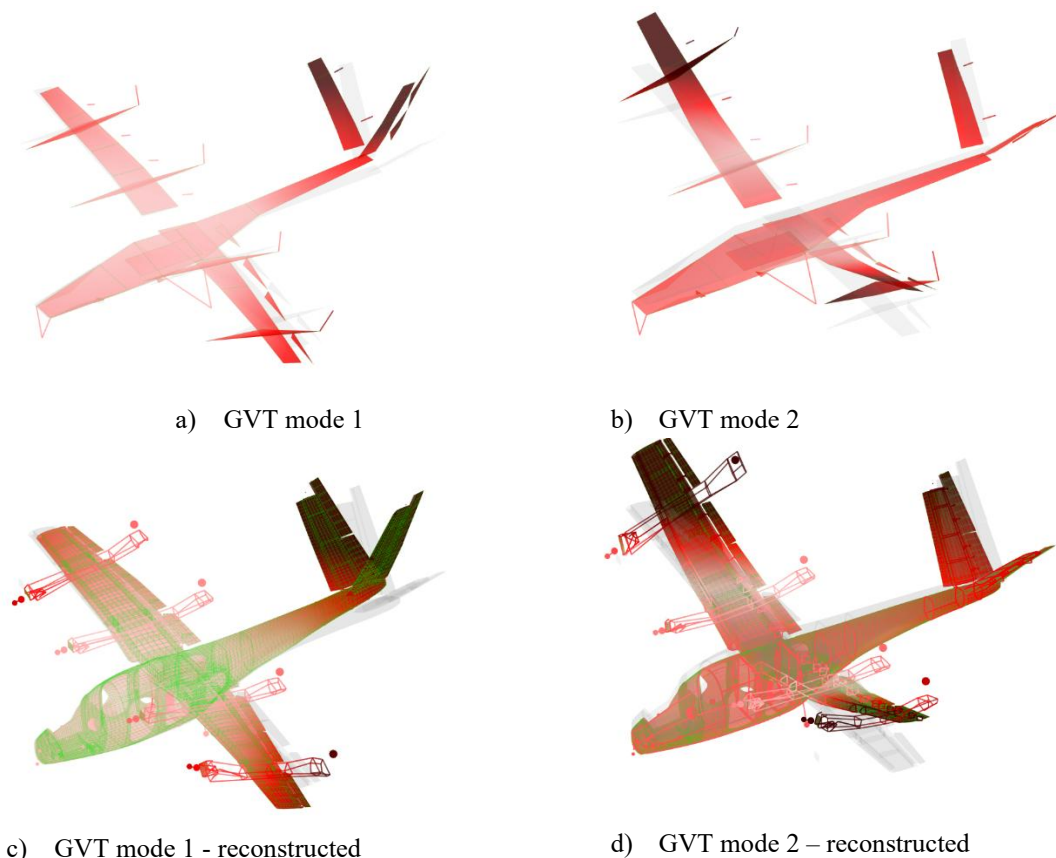
The use of GVT data in aeroelastic analyses is traditionally based on finite element model updating procedures, where numerical models are tuned to match experimentally identified modal properties before performing flutter or loads analyses. Although effective, these approaches often require extensive preprocessing which may limit their applicability during post-GVT assessments<sup>[2]</sup>.

Alternative approaches aim at directly incorporating experimental modal data into aeroelastic solvers, bypassing structural model updating. These methods are attractive for certification-oriented analyses but generally rely on customized solver modifications<sup>[3]</sup>.

The present work addresses this gap by proposing a state-space aeroelastic framework that directly exploits free-body GVT modal data to predict dynamic responses beyond classical flutter analysis.

### Methodological Description

The proposed framework defines the structural dynamics directly from free-body GVT modal parameters, including experimentally identified frequencies, damping ratios, and mode shapes, without requiring finite element model updating. This experimental modal basis is combined with a numerical aerodynamic model expressed in terms of generalized aerodynamic forces.



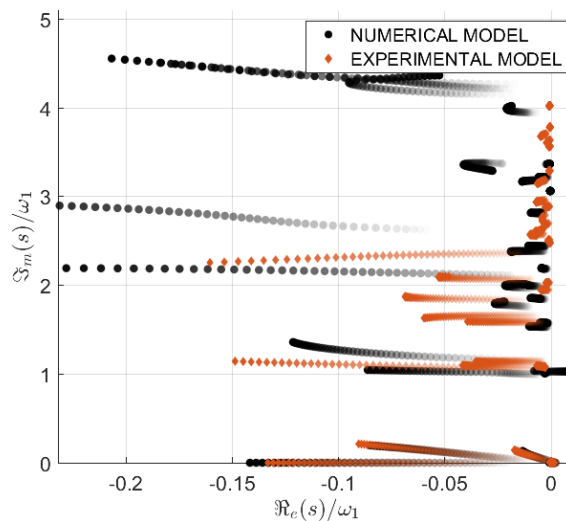
**Figure 2** Reconstruction of GVT modes via change of basis method

Unsteady aerodynamics are represented through a rational function approximation of the generalized aerodynamic force matrix, enabling a finite-dimensional state-space formulation suitable for time-domain simulations<sup>[4]</sup>.

A change-of-basis procedure (providing the reconstruction of the GVT modes as in Fig. 2) is introduced to map the numerical aerodynamic operator onto the experimental modal basis. The transformation coefficients are obtained by projecting numerical modes onto the experimental measurement space using a least-squares approach, ensuring energetic consistency between aerodynamic forces and structural generalized coordinates.

Previous results enabled the representation of the stability scenario as represented in Fig. 3, also including a control surfaces failure model.

The resulting state-space aeroelastic model will enable time-domain simulations, allowing the prediction of gust and control-surface command responses directly from experimental modal data.



**Figure 3** Stability scenario with GVT modes compared with the numerical model

## OBJECTIVES

- Directly integrate free-body GVT modal data into a state-space aeroelastic formulation without structural model updating.
- Map numerical aerodynamic operators onto experimental modal bases via an energy-consistent change-of-basis procedure.
- Predict gust-induced and control-command-induced responses for dynamic load and stability assessment.
- Support industrial design and certification-by-analysis activities, enabling future correlation with flight-test data.

## References

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