NONLINEAR AEROELASTIC BEHAVIOUR OF FLEXIBLE HAPS WINGS AND ITS IMPACT ON LOAD DISTRIBUTION, TRIM AND CONTROL.

Oleh Havaza, Dmyro Konotop

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute",
Prospect Beresteiskyi 37, 03056, Kiev
Ukraine

ABSTRACT

High Altitude Platform Stations (HAPS) impose exceptionally strict mass constraints while operating with very high aspect-ratio wings that can experience large elastic deflections. Such flexibility introduces a nonlinear feedback between structural deformation and aerodynamic loading, which may redistribute spanwise loads, shift trim conditions, and alter control surface effectiveness. These effects can reduce control authority, change performance margins, and increase susceptibility to adverse aeroelastic phenomena. The main research questions addressed in this contribution are: (i) how to efficiently predict deformation-induced aerodynamic load redistribution for highly flexible HAPS wings in a nonlinear setting, (ii) how to quantify its influence on trim and controllability, and (iii) how to use these predictions to support mass-driven structural tailoring that balances minimum weight with aeroelastic robustness.

To answer these questions, we employ a nonlinear aeroelastic workflow enabled by a previously published symbolic reduced-order framework based on science analogies. In the underlying formulation, a lifting surface is represented as a principal scheme assembled from three element families: aerodynamic, elastic, and inertial. Each element is characterized by compact parameter matrices (up to 6×6) associated with six degrees of freedom. The global coupled model is obtained via recurrent transformation rules for serial, parallel, and star connections with systematic node condensation, analogous to electrical circuit reduction. This yields an equivalent "aeroelasticity matrix" in explicit symbolic form and reduces reliance on large-scale matrix operations typical of conventional high-dimensional numerical workflows. The core method was previously described for standard aeroelastic benchmarks including wing load distribution, divergence, control surface effectiveness, and flutter prediction [1].

Building on that foundation, the present work focuses on the HAPS use case and emphasizes nonlinear, large-deflection effects. Within the reduced-order framework, geometrically nonlinear structural response is accounted for to capture the deformation levels characteristic of flexible HAPS wings, and the resulting deformation-dependent aerodynamics is evaluated to quantify spanwise load redistribution. The workflow then assesses trim changes and trends in control effectiveness as functions of candidate stiffness and mass distributions. These explicit dependencies between design variables (e.g., stiffness tailoring and mass distribution) and aeroelastic characteristics provide actionable guidance for early design decisions: they support rapid parametric exploration and enable mass-driven optimization aimed at minimizing structural weight while preserving required control authority and adequate aeroelastic margins. The general significance of the contribution is an efficient, design-oriented route to integrate nonlinear aeroelastic effects into early HAPS wing sizing and optimization, thereby improving the balance between minimum mass and aeroelastic robustness and reducing the risk of unfavorable aeroelastic behavior in highly flexible configurations.

References:

[1] Havaza, O., Sukhov, V., Nikitin, R., "Mathematical method for prediction aeroelastic phenomena and multidisciplinary optimization lifting surfaces of flight vehicle at preliminary stage design", IFASD 2024, Tracking No. 235. (conf.ifasd2024.nl)