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Experimental Geometry Reconstruction for Numerical Model Validation of a Full-Scale Morphing Aileron Demonstrator

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1. Introduction

Morphing control surfaces are increasingly considered enabling technologies for improving aerodynamic efficiency, reducing the drag penalties associated with conventional hinged devices, and supporting future sustainable aircraft. Within the Clean Aviation HERWINGT (Hybrid Electric Regional Wing Integration Novel Green Technologies) project [1], a full-scale morphing aileron demonstrator has been developed to investigate continuous trailing-edge shape adaptation under representative structural and aerodynamic loading conditions. The maturation of such adaptive structures requires accurate experimental reconstruction of the deformed geometry, both to verify the achieved morphing shapes and to quantify deviations caused by manufacturing, assembly, actuation, and loading effects. This work presents an experimental geometry-reconstruction workflow for the HERWINGT morphing aileron, aimed at generating quantitative full-field data for validation of the numerical aero-structural model used during design. The main contribution is the reconstruction and merging of multi-camera optical measurements into a single three-dimensional geometry suitable for direct comparison with numerical predictions. Laboratory and wind tunnel tests are considered to assess the response in controlled and aerodynamically loaded configurations.

2. Methodology

The experimental campaign was conceived to characterize the morphing aileron through quasi-static, dynamic, and aerodynamic tests. The demonstrator surfaces were prepared with a stochastic speckle pattern for optical full-field measurements. A multi-camera system was arranged around the test article to capture the surface deformation without physical contact and with sufficient spatial coverage for geometry reconstruction. The laboratory optical setup, including the speckled aileron surface and the camera/lighting arrangement adopted for Digital Image Correlation (DIC), is shown in Figure 1.

The processing strategy was based on two stereo camera systems, identified as System 0_1 and System 2_3 in the measurement layout. Separate acquisitions were performed for the lower and upper surfaces over a morphing-angle range from 0° to 14°, with 2° increments. For each configuration, the image data were processed to obtain three-dimensional point clouds of the measured surface. Overlapping regions between the two stereo systems enabled the reconstruction of a single full-field geometry from the two partial views, while preserving the spatial information required for subsequent model correlation.



Figure 1. Laboratory optical measurement setup with speckled aileron surface and camera/lighting arrangement for DIC acquisition.

To merge the reconstructed point clouds, a rigid roto-translation was computed using six points visible in both datasets. The point cloud associated with System 0_1 was transformed into the reference frame of System 2_3, and the alignment quality was verified on the common points. This procedure combines multiple optical views into one consistent experimental geometry that can be mapped onto the numerical model surface for validation. The point-cloud alignment procedure and a representative reconstructed surface map are reported in Figure 2.

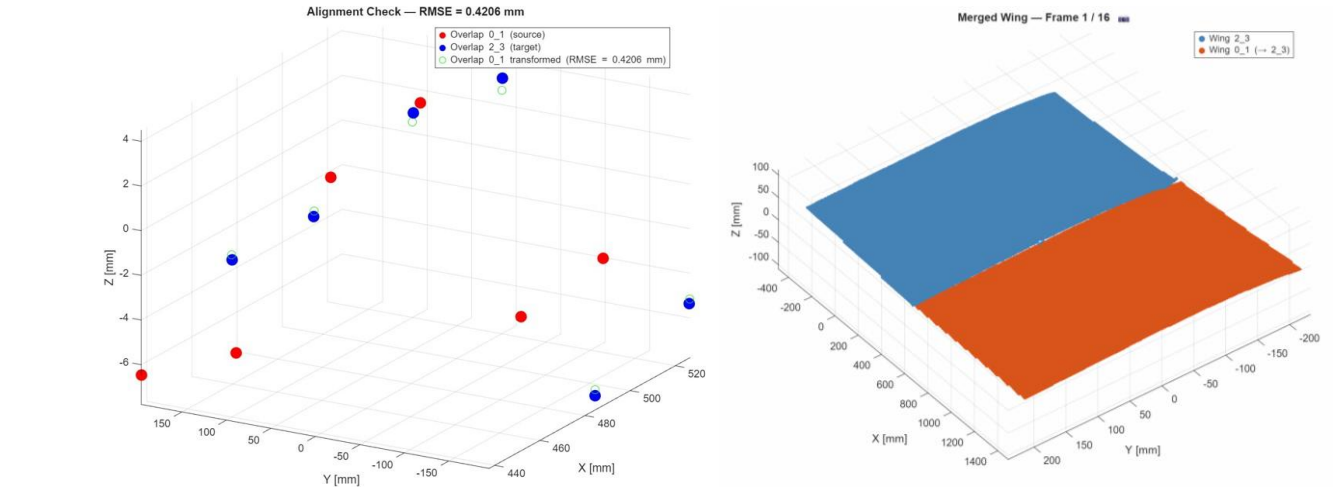


Figure 2. Point-cloud alignment check and representative reconstructed surface map used for full-geometry reconstruction.

Following the laboratory campaign, the morphing aileron was installed in the wind tunnel. The optical setup was adapted to the constraints of the wind tunnel environment, including limited optical access, camera positioning around the test section, and aerodynamic loading. The wind tunnel installation, with the speckled surfaces prepared for optical reconstruction, is shown in Figure 3. This second phase extends the reconstruction workflow to flow-on conditions and generates experimental shape data for assessing the influence of aerodynamic loads on the achieved morphing configuration.



Figure 3. Morphing aileron demonstrator integrated in the wind tunnel test article with speckled surfaces for optical reconstruction.

3. Results

The laboratory tests confirmed the feasibility of applying DIC-based full-field measurements to the full-scale morphing aileron demonstrator. As shown in Figure 1, the adopted speckle pattern and camera arrangement provided adequate surface visibility to reconstruct both the lower and upper surfaces throughout the 0° to 14° actuation range. The reconstructed point clouds captured the spanwise and chordwise deformation of the compliant surface, including the progressive out-of-plane displacement associated with the morphing motion.

The merging procedure provided a consistent full-geometry reconstruction from the two stereo systems. As illustrated in Figure 2, the alignment check on the common reference points yielded a representative RMSE of 0.4206 mm, demonstrating that the two partial point

clouds could be combined with sub-millimetre residual error at the overlap locations. The reconstructed displacement map in Figure 2 further shows the capability of the workflow to quantify the three-dimensional surface evolution of the aileron. For the representative configuration reported, the measured Z-coordinate spans approximately from -6.105 mm to 19.17 mm, confirming the sensitivity of the method to morphing-induced shape changes.

The wind tunnel installation further demonstrated the applicability of the optical measurement approach in an aerodynamically relevant environment. As visible in Figure 3, the test article was equipped with speckled surfaces accessible through the available optical windows, allowing the laboratory reconstruction logic to be extended to flow-on tests. This represents a key step toward quantitative comparison between unloaded and aerodynamically loaded configurations, and toward validation of the numerical aero-structural model against experimentally reconstructed deformed geometries.

Overall, the proposed methodology provides full-field three-dimensional geometry data with sub-millimetre point-cloud merging accuracy, enabling direct correlation between measured morphing shapes and numerical aero-structural predictions. The workflow contributes to the experimental maturation of morphing-wing technologies within HERWINGT and supports reliable design and validation tools for future adaptive aircraft structures.

4. Acknowledgments

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5. References

[1] Clean Aviation Joint Undertaking, HERWINGT - Hybrid Electric Regional Wing Integration Novel Green Technologies, Grant Agreement No. 101102010, European Union, 2023.