

GROUND EXPERIMENTAL TESTS AND FLIGHT TEST DESIGN FOR A FLEXIBLE AIRCRAFT FLYING DEMONSTRATOR

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ABSTRACT

Flexible aircraft present unique challenges in terms of structural dynamics, aeroelastic behavior, and flight control, particularly when transitioning from conceptual design to a fully operational flying demonstrator. The TU-Flex concept has been developed as a modular flying platform to explore the flight dynamics of flexible transport aircraft configurations [1].

Two versions of the demonstrator have been built: the TU-Flex FW (Flexible Wing), representing the baseline flexible configuration, and the TU-Flex FW-P (Flexible Wing with Pod), which incorporates additional tip masses on the wings. These pods reduce the structural frequencies of the wing, increasing the coupling between wing flexibility and aircraft flight dynamics, thereby simulating the behavior of a very flexible aircraft while retaining the same wing structure. This approach enables a progressive validation of aeroelastic and flight dynamic models, from moderate to higher structural dynamic complexity [2].

The main objective of this research is to define, implement, and experimentally validate a structured, low-risk bottom-up airworthiness and flight-test preparation strategy for a highly flexible aircraft demonstrator, ensuring that updated structural, aeroelastic, and inertial models accurately represent the full-vehicle dynamics prior to system identification campaigns.

The TU-Flex demonstrator has been fully assembled, including its primary structure, modular wing components, and integrated electric propulsion and avionics systems, as shown in Fig. 1. Prior to flight testing, a comprehensive series of ground tests and evaluations is required to assess the airworthiness of both the FW and FW-P configurations.

The demonstrator has been developed following a bottom-up validation approach that has already resulted in well-tuned structural model. The aeroelastic model was further refined using data from a dedicated wind tunnel campaign, which provided essential validation data and enabled testing of a maneuver load alleviation controller at different points of the flight envelope.

Up to now, the TU-Flex flight test campaign was designed using a preliminary aircraft model. The current model incorporates updates from the wind tunnel campaign and must also reflect the actual structural dynamics of the complete aircraft rather than the wings alone. Consequently, a full-vehicle structural update is required prior to flight testing.

The validation process begins with a full-vehicle structural update, including verification of the aircraft's weight and balance and a full-aircraft Ground Vibration Test (GVT). These activities ensure that the center of gravity remains within the allowable envelope, that all structural modes predicted by the model are present in the real aircraft, and that their frequencies match expected

values without the occurrence of unexpected modes. To represent flight-like free-free dynamics, the aircraft is isolated from the ground using a dedicated suspension system, as shown in Fig 2. In addition, the aircraft's inertia properties are measured using a separate hanging setup and the pendulum method, providing accurate inertia data under fully loaded conditions.



Figure 1. TU-Flex-FW Taxi Test.



Figure 2. TU-Flex-FW GVT.

The final stage of the TU-Flex validation strategy involves flight testing. The flight test campaign is structured into three phases, of which this study focuses on the first: Operational Flight Tests. This phase is dedicated to verifying the basic operability and airworthiness of the integrated platform prior to expansion toward more demanding flight conditions.

Operational Flight Tests commence with ground-based evaluations covering communication and transponder performance, flight control functionality, propulsion system behavior, and electrical and avionics integrity. These tests are complemented by low- and high-speed taxi tests, reaching up to approximately 80% of take-off speed, to assess controllability, braking performance, maneuverability, and communication robustness under progressively more demanding conditions.

The maiden flight follows a standard and conservative profile, with the objective of confirming basic aircraft operability and correct system functionality. Subsequent qualification flights are used to verify performance, progressively familiarize the pilot with handling characteristics, and gather qualitative and quantitative feedback on flight and handling qualities. The flight envelope is expanded incrementally, with all maneuvers pre-trained in a Simulation Test Environment.

This stepwise validation approach ensures flight safety while progressively increasing confidence in the TU-Flex flight dynamics and control behavior, ultimately preparing the platform for system identification and advanced aeroelastic investigations. The presented bottom-up strategy (encompassing structural ground testing, full-aircraft GVT, inertia measurements, taxi testing, and initial flight operations) provides a high-fidelity and low-risk framework for assessing airworthiness and system functionality. The resulting validated mass properties, structural modes, and initial flight observations form a robust foundation for subsequent flight test campaigns and the development of advanced control strategies for very flexible aircraft configurations.

References

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