

FLIGHT OPERATIONS AND TESTING OF A 450 KG EXPERIMENTAL GYROPLANE UAV

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Abstract

Future aviation systems must combine high maneuverability, operational flexibility, and stringent safety standards, particularly for operations in confined or complex environments. Within the S²TOL project, the German Aerospace Center (DLR) investigates an advanced gyroplane-based unmanned demonstrator designed for short and steep takeoff and landing. This paper presents a demonstrator platform (450 kg MTOM) and a comprehensive operational framework that integrates risk-based regulatory compliance (e.g., SORA), restricted airspace operations, and a multi-layered technical safety concept. Central elements include clearly defined flight crew roles, standardized procedures, and a robust emergency response strategy, complemented by simulation-based training and validation. The presented approach demonstrates that simulator-based flight preparation significantly enhances the safety and efficiency of experimental UAV flight testing. The presented methodology provides transferable insights for future unmanned systems, particularly those involving novel configurations and demanding mission profiles.

Keywords: Short Takeoff and Landing (STOL) / Steep Approach, Experimental Flight Testing, Safety Management, Simulation-Based Training

1. Introduction

Unmanned aircraft systems (UAS) with advanced takeoff and landing capabilities are gaining increasing relevance for future aviation applications such as urban mobility, surveillance, cargo transport, and emergency response operations. [1]. Such systems must be capable of precise maneuvers, steep takeoffs and landings, and reliable operations in confined or challenging environments [2]. The growing complexity of these systems creates a corresponding need for experimental flight testing and validation methodologies to ensure safe and reliable operation.

Within the S²TOL (Silent Short Takeoff and Landing) project, these challenges are systematically addressed by DLR through the development and experimental evaluation of an advanced gyroplane-based short and steep takeoff and landing concept [3]. Flight performance and handling qualities of the developed aircraft are assessed using a demonstrator platform based on the basic airframe structure of an existing gyroplane. The demonstrator has a maximum takeoff mass of 450 kg, corresponding to a weight-based scaling factor of 1:3 compared to the conceptual design. The concept and the 450 kg demonstrator are shown in Figure 1.

Gyroplanes feature a hybrid design that combines elements of fixed-wing aircraft and helicopters [4]. Lift is generated by an autorotating main rotor, while a separate propulsion system provides forward thrust. This arrangement enables short takeoff distances, straightforward operational handling, and inherently stable flight characteristics. Moreover, gyroplanes possess inherent safety features due to the autorotating rotor [5], which still works in case of engine failure like a parachute. These features



(a) Conceptual design of the S²TOL aircraft configuration showing the intended system layout



(b) Experimental gyroplane-based flight demonstrator for system integration and flight testing

Figure 1 – From conceptual design to flight testing: comparison of the S²TOL configuration (a) and the corresponding experimental demonstrator (b)

make gyroplanes particularly suitable as experimental platforms for uncrewed flight testing, allowing rapid evaluation of different configurations and control strategies [6].

Addressing these challenges requires a systematic approach to operational safety and flight testing [7, 8]. The proposed approach integrates a comprehensive operational concept with clearly defined roles for the flight test crew, and establishes standardized procedures, checklists, and workflows. The main contributions of this work are:

- the development of a gyroplane-based unmanned demonstrator for short and steep takeoff and landing research,
- the implementation of an integrated operational and safety framework combining SORA-based risk assessment, restricted-airspace operations, structured flight test procedures, and FPV/VLOS crew coordination,
- the integration of a simulation-supported mission planning and training environment based on the operational FPV ground control station,
- and the validation of the simulation and operational training approach using real flight test data, pilot feedback, and operational performance metrics.

2. Flight Operations and Safety Management

2.1 Regulatory Approaches for Risk Assessment in Unmanned Aircraft Operations

Unmanned aircraft operations are subject to different regulatory frameworks worldwide, each aiming to ensure safe integration into the airspace while managing operational risks. In Europe, the Specific Operations Risk Assessment (SORA) approach is applied under the EU Drone Regulation 2019/947 for operations in the “Specific” category [9]. Originally developed by the Joint Authorities for Rulemaking on Unmanned Systems (JARUS) [10], SORA has become an internationally adopted methodology and is also used as a regulatory basis or reference framework in several non-European countries. It provides a structured methodology to evaluate operational hazards, define mitigation measures, and assign responsibilities for safety-critical tasks, thereby enabling risk-informed approvals of higher-complexity flights. In Germany, compliance with SORA is mandatory for operations beyond the open category.

In the USA, unmanned flights are governed by FAA 14 CFR Part 107 [11], which establishes operational limitations and safety requirements. While there is no direct SORA equivalent, operators seeking waivers for flights beyond the standard limitations—such as BVLOS or flights over people—must provide a detailed safety risk assessment, including contingency procedures, operational

constraints, and mitigation strategies [12]. Recently, the FAA has published a Notice of Proposed Rulemaking for 14 CFR Part 108 [13], which aims to establish a standardized regulatory framework for routine BVLOS (Beyond Visual Line of Sight) operations. This development is expected to significantly reduce the reliance on individual waivers by transitioning from case-by-case approvals toward a more structured rule-based certification process.

Similarly, in Canada, the Special Flight Operations Certificate (SFOC) requires operators to submit comprehensive risk assessments, standard operating procedures, and safety management documentation for approval of higher-risk or non-standard operations [14]. The Canadian framework is largely aligned with the JARUS SORA methodology and incorporates risk-based principles derived from it. Australia uses the CASA Part 101/102 framework, which mandates risk evaluations and operational approvals for complex or BVLOS flights [15]. In the United Kingdom, the Civil Aviation Authority (CAA) Operational Authorisation, as described in CAP 722, enforces risk-based assessments comparable to SORA, including detailed operational procedures and contingency planning [16].

Despite differences in regulatory terminology and specific requirements, all methodologies share common principles: identification of operational hazards, allocation of decision authority, definition of intervention procedures, and documentation of mitigation measures. These risk-based approaches provide a foundation for reliable unmanned flight operations and facilitate the integration of innovative aircraft technologies and complex mission profiles across different jurisdictions.

2.2 Flight Operations in a Designated Test Airspace

The flight operations with the S2TOL demonstrators are conducted under the Specific Operations Risk Assessment (SORA) framework with a Specific Assurance and Integrity Level (SAIL) II, corresponding to a moderate operational risk level and associated mitigation requirements [9]. Due to the experimental nature of the S²TOL project, all flights are conducted within a small predefined test area seen in Figure 2).

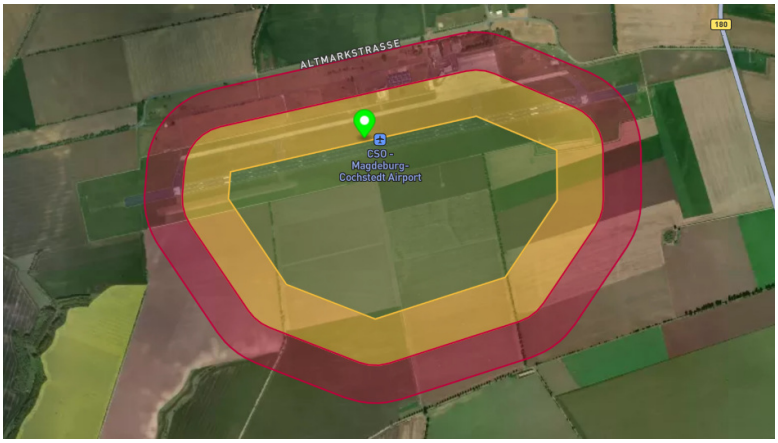


Figure 2 – Permitted operational flight area for the experimental demonstrators within the restricted test environment (Map data: © Mapbox, © OpenStreetMap contributors).

The flight campaign is conducted at the National Experimental Test Center for Unmanned Aircraft Systems in Cochstedt, Germany, a dedicated UAS research airfield operated by DLR. Operations take place within a predefined airspace volume of 2000 × 1000 × 150 m (see Figure 2). The relatively limited size of this operational volume is primarily driven by VLOS requirements, ensuring that the aircraft remains within visual line of sight of the flight crew throughout all phases of flight. Continuous adherence to these boundaries is a key operational requirement and significantly influences mission planning and execution.

To support safe operation within the confined test environment, the position of the aircraft is continuously monitored in order to identify and react to potential deviations from the approved operational

area. The limited maneuvering space requires continuous consideration of environmental effects such as wind conditions and altitude restrictions, particularly during steep takeoff, landing, and emergency procedures. Although the remote location significantly reduces the probability of conflicts with surrounding air traffic, precise flight planning and continuous trajectory monitoring remain essential for safe operations.

Ground risk mitigation is achieved through the use of a sparsely populated test site, combined with defined ground safety buffers. In addition, a dedicated flight operations coordinator continuously supervises the operational area and the overall flight operation to ensure compliance with operational procedures. Operational constraints regarding maximum flight altitude, speed, lateral flight boundaries, and allowable environmental conditions are further enforced to reduce both the probability and potential consequences of off-nominal events or loss-of-control scenarios.

Air risk mitigation is further supported by the temporarily established Aerodrome Traffic Zone (ATZ), strategic flight planning, and continuous monitoring of the aircraft position and velocity relative to the approved operational volume. Operations are additionally restricted to a predefined test area within the ATZ. As the ATZ does not fully exclude other airspace users, VLOS-based detect-and-avoid procedures are required to ensure safe separation and maintain situational awareness throughout all phases of flight. A geofencing function is implemented to ensure containment within the approved operational area. In the event that the UAS approaches or exceeds the predefined operational boundaries, flight termination is initiated. Furthermore, the confined maneuvering space requires continuous consideration of wind conditions, terrain clearance, and available maneuvering margins, particularly during steep takeoff, landing, and contingency procedures.

2.3 Flight Crew Roles and Responsibilities

Safe operation of the experimental UAV is ensured by a clearly defined allocation of flight crew responsibilities, as required by the German Federal Aviation Office (LBA) and specified in the Operations Manual (OM) (see Figure 3):



(a) VLOS pilot and airspace observer performing visual monitoring during flight operations



(b) FPV pilot and flight test lead operating the FPV ground control station during flight testing.

Figure 3 – Operational crew setup during flight testing, showing the distributed roles between FPV ground station operation and VLOS-based visual monitoring during experimental flight operations.

- Flight Test Lead (FTL): Responsible for coordination of the flight test campaign, operational supervision, and decision-making in nominal and off-nominal situations.
- FPV Pilot: Directly controls the aircraft from the ground station using a first-person-view interface and executes the planned test maneuvers.

- VLOS Safety Pilot / Pilot in Command (PIC): Maintains continuous visual contact with the aircraft, monitors the surrounding operational area, and retains final authority to intervene by taking over the control authority if required to ensure flight safety.
- Airspace Observer: Monitors the surrounding airspace for conflicting traffic and external hazards during flight operations.

All crew members are trained according to the Emergency Response Plan (ERP) and participate in mission-specific briefings prior to each flight. Clearly defined decision authority, escalation paths, communication procedures, and abort criteria ensure coordinated responses during all phases of operation.

2.4 Aircraft Configuration and Safety Features

The demonstrator is based on a gyroplane configuration with a maximum take-off mass of 450 kg and two electric pusher propellers. Built on an MTOfree airframe with landing gear, horizontal and vertical stabilizers, the demonstrator features a 7.99 m main rotor selected to remain below the 8 m rotor diameter threshold associated with SAIL II operations, and serves as a versatile platform for testing propulsion, aircraft configuration, and flight behavior. Propulsion is provided by two Geiger HPD20 motors (20 kW continuous, 28 kW peak power) driving 1.40 m three-blade counter-rotating carbon propellers, while rotor pre-rotation is achieved with an HPD14 motor [17]. Energy is supplied by six 3.1 kWh batteries.

The flight system is mounted on a modular carrier plate in the forward fuselage section, integrating the onboard computer, sensors, inertial measurement unit, and buffer battery. The modular design enables rapid exchange between different demonstrator configurations, including a ducted-propeller variant [3], in less than one hour, supporting efficient evaluation of alternative system architectures. The control system includes servos for rotor pitch and roll control, rudder and brake actuators, and a planned fifth servo for propulsion vector tilting to enhance takeoff performance.

To enable controlled uncrewed flight operations, the demonstrator incorporates multiple redundant safety systems (see Figure 4).

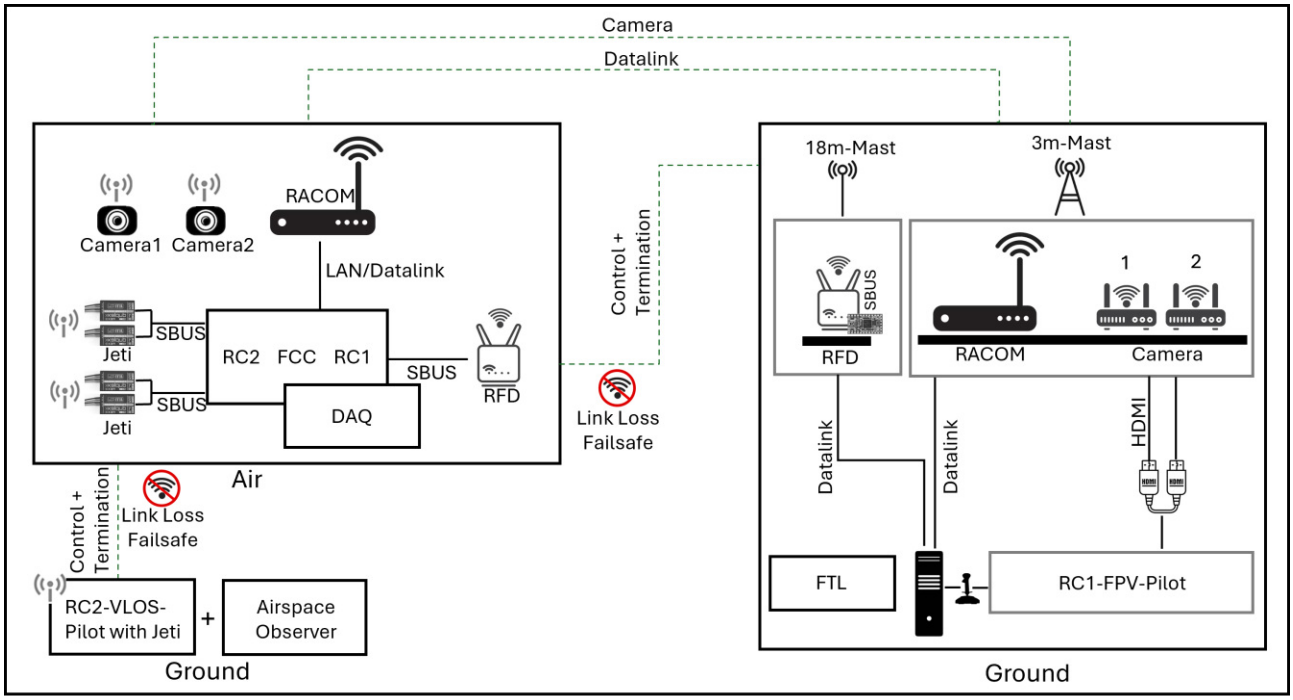


Figure 4 – System architecture and redundancy concept of the UAV, including flight control, data links, and safety-critical fail-safe paths.

Two onboard cameras provide a first-person-view (FPV) feed to the ground station, enabling the remote pilot to maintain situational awareness throughout all flight phases. The communication architecture is designed with multiple redundant communication links to ensure reliable command and telemetry transmission. The primary control link consists of an RFD868x unit [18], while four Jeti links provide backup communication for the VLOS pilot.System data are transmitted via the Racom RipEX system [19], enabling continuous real-time monitoring of aircraft position, altitude, speed, and system status.

A dedicated failsafe concept is integrated into the propulsion and flight control system. In the event of a critical system failure or loss of communication (link loss failsafe), the propulsion system is automatically shut down and a predefined rudder deflection is commanded to initiate a controlled spiral descent. This maneuver is designed to ensure containment of the aircraft within the predefined operational volume, thereby contributing to the overall safety objectives defined within the SORA-based operational risk assessment framework. A termination function is additionally available to safely abort the flight if required. The implemented failsafe modes were successfully validated by simulation and ground testing.

To support manual flight control and improve handling qualities, a Stability Augmentation System (SAS) was implemented to stabilize pitch, roll, and yaw throughout all flight phases, thereby reducing pilot workload. In addition, a basic autopilot system is available to maintain altitude and heading during precision maneuvers and low-altitude operations. Control commands are issued by the operator via target values for pitch, roll, and yaw.

2.4.1 Simulator Environment and HMI Consistency

To enhance operational safety and support experimental flight testing, the S²TOL project integrates a simulation-based framework combining system validation, flight crew training, and iterative refinement of operational procedures. The simulator was implemented on the same FPV ground control station platform used for flight testing [20]. All primary control interfaces — including stick, throttle lever, control panels, and display systems — were used in the same manner as in the real FPV station, ensuring a consistent human-machine interface (HMI) between simulation and flight operation. While the control setup remained unchanged, real-time telemetry data were replaced by outputs from the simulation model. The resulting setup is shown in Figure 5, depicting the FPV ground control station. A pre-existing gyroplane simulation model, previously validated using flight data from a manned MTOsport gyroplane [21], was used within the simulation environment and adapted for the experimental UAV configuration.



Figure 5 – FPV ground station and corresponding simulator setup used for flight testing and pilot training.

Visual feedback was generated using the X-Plane[1] simulation environment, providing an immersive and operationally representative setup. In addition, the RC transmitter used by the VLOS pilot was integrated into the simulator to enable realistic handover training and coordinated pilot interaction. The simulator environment was specifically used to train the handover procedures between FPV and VLOS pilot, including continuous mirroring of control inputs to ensure immediate intervention capability in emergency situations. This high level of interface consistency ensured that operational procedures and pilot interactions trained in the simulator can be directly transferred to real flight operations.

2.4.2 Simulation Model Validation and Continuous Improvement

The model is based on a high level of physical fidelity and already reproduces the behavior of the aircraft well in cruise, climb, and descent conditions (see Table 1). It represents a complete simulation model covering the full operational flight envelope relevant for training and mission preparation, including takeoff, landing, and nominal flight operation. The validation aims to ensure that the overall system behavior is sufficiently well represented to support situational awareness and procedural training. In this context, the model captures the main characteristics of the aircraft's flight behavior with adequate fidelity for operational preparation. These assessments refer primarily to the initial flight tests with a 360 kg demonstrator. Continuous improvements are being addressed within ongoing and future flight test campaigns as additional measurement data becomes available.

Table 1 – Comparison of flight test data and simulation results for cruise, climb, and descent conditions under varying indicated airspeeds (IAS) and thrust lever positions (Throttle)

Condition	Source	IAS [km/h]	Throttle [%]	P_{el} [kW]	η_{RH} [deg]	n_R [rpm]	n_M [rpm]	H_p [m/s]
Cruise	Flight Data	72	53	14.5	3.0	360	2050	–
	Simulator	72	–	17.1	2.9	–	2110	–
	Flight Data	85	63	17.2	2.1	363	2220	–
	Simulator	85	–	17.1	2.1	–	2220	–
	Flight Data	95	65	17.5	1.5	365	2250	–
	Simulator	95	–	17.6	1.5	–	2320	–
	Flight Data	105	100	19.5	1.0	370	2450	–
	Simulator	105	–	19.6	0.9	–	2460	–
Climb	Flight Data	82	100	21.7	2.5	363	2340	2.0
	Simulator	82	100	21.7	2.5	–	2338	1.8
Descent	Flight Data	87	31	3.7	2.0	360	1620	-5.0
	Simulator	87	–	3.7	1.7	–	1710	-4.2

For several representative parameters — including electrical power P_{el}, rotor pitch angle η_{RH}, rotor speed n_R, motor speed n_M, and vertical speed H_p — deviations between simulation and flight data remained within an acceptable range, typically below 10%. The results presented here are representative of the investigated parameter set, while further variables are currently under evaluation. For instance, at an airspeed of 72 km/h, the rotor pitch angle was measured at 3° in flight and 2.9° in simulation, corresponding to a deviation about 0.1°. Comparable agreement was observed for electrical power and motor speed across the investigated operating range.

The motor speed showed a mean absolute percentage error (MAPE) below 5%, while electrical power and rotor pitch angle remained within approximately 10% deviation (see Figure 6). Overall, these results already indicate a good level of model fidelity, suitable for simulation-based training and flight test preparation.

[1] https://www.x-plane.com/

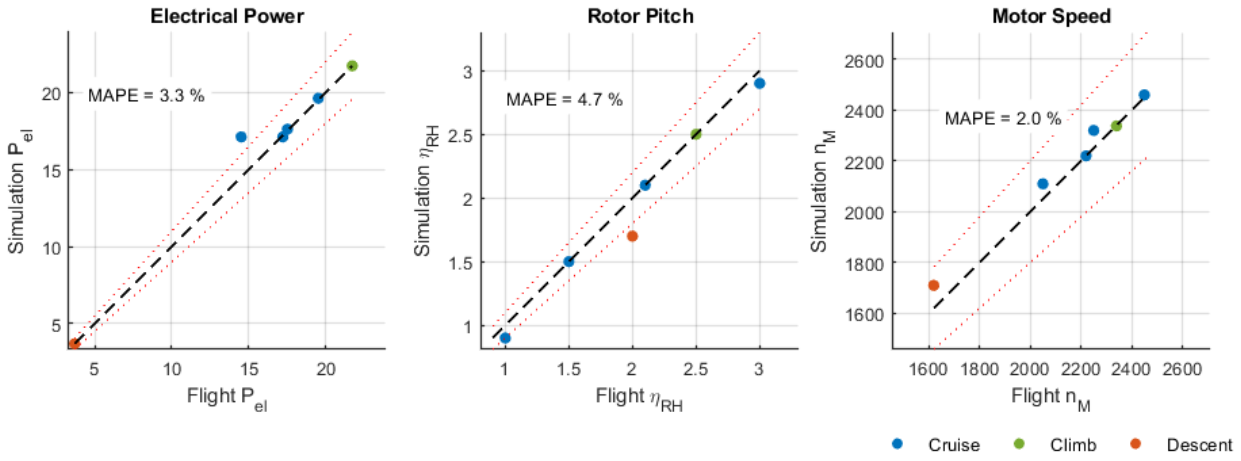


Figure 6 – Comparison of simulated and measured flight data. Data points are color-coded by flight phase (cruise, climb, descent). The dashed line indicates perfect agreement, while the dotted lines represent a ±10% deviation band.

2.5 Aircraft Configuration Modifications Between Flight Tests

To improve takeoff characteristics and reduce the risk of tail strikes, several configuration modifications were implemented following the initial flight tests (see Figure 7). A 10 kg ballast mass was installed at the foremost fuselage position, shifting the aircraft center of gravity forward by approximately 5 cm. This forward CG shift reduced the nose-up pitching tendency and improved longitudinal stability, particularly during takeoff rotation.

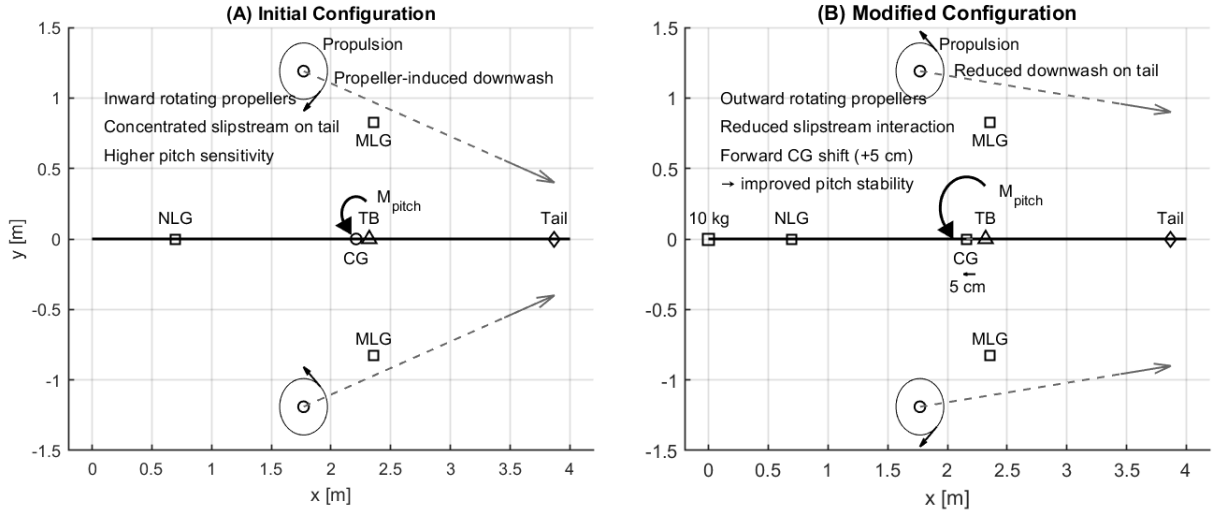


Figure 7 – Overview of configuration changes between initial and modified aircraft setup, including direction of propulsion rotation, slipstream effects, and center of gravity shift, and their impact on longitudinal stability characteristics (M/NLG - Main/Nose Landing Gear, CG - Center of Gravity, TB - Teeter Bolt).

In addition, the propulsion system configuration was modified by reversing the propeller rotation direction, which reduced the effective slipstream impingement on the horizontal tailplane and thereby decreased the propeller-induced nose-up pitching moment during flight. Combined with a forward-shifted center of gravity, these changes improved the longitudinal stability characteristics of the aircraft, particularly during takeoff and landing. As a result, the aircraft exhibited a more nominal and

predictable pitch response, especially during rotation, which significantly enhanced handling qualities and reduced pilot workload during subsequent flight tests.

3. Simulation-Based Flight Mission Planning and Training

Simulation-supported mission planning and crew training were developed as integral elements of the overall flight test methodology. The applied approach combines mission planning, simulator-based procedure evaluation, crew training, and iterative model refinement within a continuous feedback loop. Flight test data, operational observations, and pilot feedback were progressively incorporated into the simulation environment to improve model fidelity, operational procedures, and overall flight safety. This iterative process enabled continuous refinement of both technical systems and human-machine interaction, contributing to increased operational reliability throughout the flight campaign.

Figure 8 illustrates the iterative workflow used throughout the flight test campaign. Planned mission profiles and operational procedures were evaluated within the simulation environment prior to flight testing. The simulator supported mission planning, controller assessment, crew training, and validation of operational constraints associated with the restricted test area. Flight test data and pilot feedback were continuously integrated to refine both the simulation model and operational procedures.

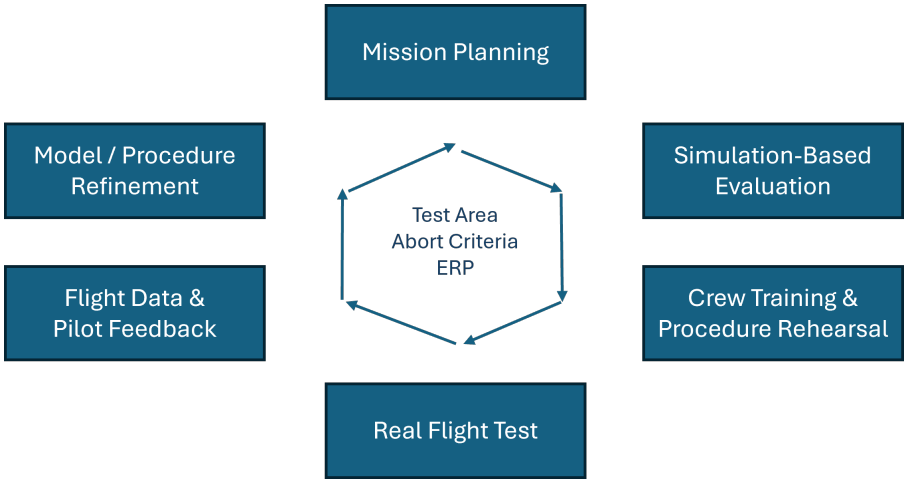


Figure 8 – Simulation-based workflow for mission planning, crew training, and flight test preparation. Flight test procedures are iteratively evaluated and refined using simulation, flight data, and pilot feedback to support safe and efficient operation within a restricted test environment.

3.1 Mission Planning and Procedure Validation

Prior to each flight test, the planned mission profiles were systematically rehearsed and refined in the simulation environment. The simulator was used to design and evaluate mission profiles to ensure that the available flight envelope within the restricted test area could be utilized in a safe and meaningful manner. This included straight-and-level flight at different airspeeds as well as climb and descent maneuvers for model validation purposes, in addition to dedicated investigations of rudder effectiveness and asymmetric thrust behavior.

The simulation environment further supported the evaluation of flight controller configurations and control-law behavior under representative maneuver conditions. Mission profiles were optimized with respect to the spatial limitations of the restricted test area, including the identification of operational boundaries and abort criteria. Overall, the simulator enabled the definition of feasible and efficient test procedures tailored to the constraints of the operational environment.

3.2 Flight Crew Training and Operational Preparation

The flight crew underwent structured simulator-based training to familiarize themselves with the aircraft handling characteristics, operational limitations, and emergency procedures. Particular emphasis was placed on takeoff and landing behavior, operation within confined airspace, coordination between FPV and VLOS pilot, and reliable execution of pilot handover procedures during phases close to operational limits.

Standardized operational procedures, checklists, and workflows were developed to ensure consistent and safe execution of all flight tests. A dedicated Emergency Response Plan (ERP), including standardized communication and intervention strategies, was implemented and rehearsed prior to all flight operations. For flight test preparation, a structured checklist was used covering pre-flight activities on the day before the mission, crew briefings, start-up and launch procedures including all safety checks, as well as post-flight debriefing. In addition, the checklist defined monitoring tasks during flight execution and included required configuration steps for the FPV ground control station and the remote control system. Within the flight test team, an open communication culture was maintained, ensuring that all team members had an equal opportunity to raise concerns and that operational safety considerations from any individual were actively taken into account.

3.3 Simulation Fidelity and Operational Experience

The influence of simulation fidelity on operational performance became evident throughout the flight test campaign. During the initial flight, discrepancies between the simulation model and the actual aircraft configuration—particularly regarding center-of-gravity position and pitch response—resulted in increased workload and reduced handling predictability. In addition, the simulator environment available prior to the first flight did not yet fully correspond to the actual flight test setup. In particular, different display layouts were used and several flight-relevant indications and system functions were not yet integrated into the simulator. As a result, the transfer from simulator training to real flight operation was impaired, contributing to an additional increase in crew workload during the first flight campaign. Subjective assessments during this phase indicated high workload, limited situational awareness, and moderate handling quality, reflecting incomplete model fidelity and limited operational familiarity.

Through iterative refinement of the simulation environment and progressive integration of flight test data, operational consistency was significantly enhanced. This included improvements to autopilot representation, refinement of key aircraft parameters, and optimization of display logic based on operational feedback. Technical modifications to the demonstrator, such as adjustments to the center-of-gravity position and changes in propeller rotation direction, further contributed to improved handling characteristics.

By the third flight campaign, workload was considerably reduced, situational awareness had markedly improved, and handling quality showed moderate enhancement. A previously identified issue related to autopilot-assisted FPV-to-VLOS handover was resolved after extending the simulation environment to fully represent autopilot behavior and validating the corresponding procedures prior to flight.

Overall, the results demonstrate the strong coupling between simulation fidelity, aircraft configuration accuracy, and crew performance. Even small deviations in key parameters were found to significantly affect handling qualities and crew perception, highlighting the importance of high-fidelity simulation for training, procedure validation, and safe experimental flight operations. Across the three flight tests, no safety-critical system activations occurred, demonstrating the effectiveness of the implemented operational and technical safety measures. In addition, a progressive reduction in workload, an increase in situational awareness, and the resolution of procedural issues were observed between successive flight tests. These improvements reflect the effectiveness of the iterative development approach combining simulation refinement, structured operational procedures, and flight test feedback.

Overall, the findings show that simulation-based training, supported by validated system models and structured operational concepts, enhances both operational safety and crew performance in experimental flight testing.

4. Limitation and Transferability

Despite the promising results, several limitations must be considered when interpreting the findings of this study. The flight test campaign was conducted within a restricted and controlled airspace. Although this environment provides a high level of safety, it also imposes operational constraints, particularly regarding maneuvering space, flight duration, and environmental variability. As a result, the presented operational procedures and mitigation measures are optimized for confined test environments and may require adaptation for operations in more complex or less controlled airspace. Environmental conditions during the flight tests were limited to moderate and well-monitored weather scenarios. The impact of strong winds, turbulence, or adverse weather conditions on both flight performance and system robustness is therefore not fully captured in the current dataset.

Despite these limitations, the proposed operational and safety concept demonstrates a high degree of transferability. Core elements such as the risk-based approach following SORA principles, the structured definition of crew roles and responsibilities, and the integration of simulation-based training are largely platform-independent and can be applied to a wide range of unmanned aircraft systems.

In contrast, certain aspects remain platform-specific, particularly those related to the gyroplane configuration, such as autorotation dynamics, rotor behavior, and the interaction between rotor and propulsion system. These characteristics must be carefully considered when transferring the methodology to other aircraft types. Overall, the presented approach provides a scalable foundation for reliable and safe experimental flight testing.

5. Conclusion

This paper presented an integrated operational and safety framework for experimental flight testing of a gyroplane-based unmanned aircraft. The results show that the combination of risk-based operational procedures, restricted-airspace flight operations, and high-fidelity simulation-based training enables safe and reliable execution of complex flight test campaigns in confined environments.

Validation against real flight test data showed strong agreement between simulation and measured aircraft behavior, with deviations typically remaining below 10% for the investigated performance parameters. These results confirm the suitability of the simulation environment for both flight test preparation and pilot training.

A key outcome of the flight campaign was the observed influence of simulation fidelity on operational performance. Iterative refinement of the simulation model and training procedures significantly reduced pilot workload while improving situational awareness and handling quality across successive flight tests. The implemented multi-layer safety concept, including redundant communication architecture, and predefined failsafe procedures, proved effective throughout the campaign, during which no mission-critical events occurred.

Overall, the presented methodology demonstrates the value of combining flight testing, simulation, and structured operational procedures within a continuous feedback process. Although developed for a gyroplane-based demonstrator, the proposed approach is largely transferable to other unmanned aircraft systems and provides a scalable foundation for future experimental UAV operations involving novel configurations and demanding mission scenarios. Further flight tests are currently being conducted to extend the available dataset and further improve simulation fidelity and model validation.

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