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D3.10 Flight Readiness Review Demonstrator with Advanced Wing

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Glossary

SW	Soft-ware
HW	Hard-ware
ERP	Emergency Response Plan
GVT	Ground Vibration Test
CONOPS	Concept of Operations
LPV	Linear Parameter-varying
GCS	Ground Control Station
EDBC	Magdeburg-Cochstedt Airpor
RC	Remote Control

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1 Executive Summary

This deliverable presents a comprehensive analysis of the flight readiness of a demonstrator aircraft equipped with the -1 wing. The main objective of this report is to assess key factors that contribute to the flight readiness, ensuring the safe and successful operation of the aircraft. The evaluation encompasses various crucial aspects, including the airworthiness of the -1 wing, outcomes of the ground vibration test, system performance evaluation, flutter prediction, and the concept of operations (CONOPS) and emergency response plan (ERP).

The assessment of the -1 wing's airworthiness verifies its structural integrity and ability to withstand the design load, ensuring its suitability for flight operations. The ground vibration test provides valuable insights into the structural dynamics of the aircraft, validating the simulation model and enabling accurate predictions. System performance evaluation ensures the functionality and reliability of critical systems, such as the direct drive mechanism, remote control system, and telemetry system.

Accurate flutter prediction is essential for flight safety, and the report addresses this by conducting thorough analyses and calculations to estimate the flutter speed with confidence. Additionally, revisions to the CONOPS and ERP are undertaken to align operational procedures and emergency response protocols with the specific requirements of the flight test location, Magdeburg-Cochstedt Airport (EDBC).

By considering these vital factors, this report ensures a comprehensive evaluation of the demonstrator aircraft's flight readiness. The findings and insights derived from this analysis inform further improvements and optimizations, ensuring the safety, performance, and successful integration of the advanced -1 wing into the demonstrator aircraft.

2 -1 Wing Airworthiness Test

The detailed description is already documented in the deliverable [2]. This chapter provides a comprehensive overview of the airworthiness test conducted on the -1 wing to validate its ability to withstand a design load of 4 g.

The preparations are made on both the hardware and simulation sides before the test.

During the test, specific locations on the wing are loaded using sandbags to simulate distributed load conditions experienced during flight. Seven sections on each side of the wing are chosen to distribute the load effectively, considering the wing skin's load-bearing capability. A simulation study is conducted to determine the optimal weight of sandbags required to represent the flight shape accurately.

To ensure stability during testing, a wing stand is assembled and fixed to the ground, and the wing is positioned upside down to utilize gravitational force. Sandbags are placed on the wing's surface, with a rubber mat used to prevent slipping and minimize pressure on the wing skin. The setup ensures the safety and integrity of the -1 wing, which is known for its flexibility and potential deflection under a 4 g load.

The results of the airworthiness test indicate that the -1 wing successfully sustains the load, with a measured deflection of 0.24 m compared to the simulation result of 0.32 m. It is important to note that the measurement includes some deviation related to the tape used. These findings affirm the readiness and capability of the -1 wing to withstand the designated load conditions.

Overall, the airworthiness test demonstrates that the -1 wing meets the necessary criteria and can effectively support the intended design load, providing valuable insights for integration of the wing into the aircraft and the futer flight test.

3 System Test

This chapter provides a detailed description of the system tests conducted to ensure the flight readiness of the demonstrator. Several specific tests were performed to evaluate different aspects of the system's functionality and performance. One such test was the direct drive test, which involved applying wing and flap loading to assess the performance and responsiveness of the direct drive mechanism. Additionally, a range test was conducted for both the remote control system and the telemetry system to assess their effective range and reliability in transmitting and receiving data during flight operations. These tests collectively contribute to the overall assessment of the demonstrator's system readiness, ensuring that all crucial systems are functioning optimally and capable of supporting safe and successful flight operations.

3.1 Direct Drive

Direct Drive's position controller tuned first without load and the position following performance tested with load during flight tests and on a spring based test bench as well. The first flight tests gave the possibility to test the Direct Drive under load, because it had no role yet in those, since these tests goal was to test the autopilot basic functionalities and Direct Drive is not used for controlling the aircraft, it's goal is only the flutter suppression.

3.1.1 Flight Data Analysis

During the analysis of the flight data I selected parts from the flight log which was in higher speed and with higher deflection of the control surfaces which are both increase the load on the actuator. Position accuracy and errors calculated as just the difference between commanded and measured position in each measurement point regardless of the frequency or shape of the signals. Table 1 shows the results of the analysis.

DD	**Avg. Accuracy**	**Max Pos. Err.**	**Max defl.**	**Velocity**	**Event**
	[+-deg]	[+-deg]	[+-deg]	[m/s]	
Left	0.0304	0.3296	3	54	flutter controller signal (with steps)
Left	0.1459	1.8183	2.7	37	chirp
Right	0.1462	1.2882	2.7	37	chirp
Left	0.0194	0.2197	10	40	slow manuvre
Right	0.0250	0.2554	10	40	slow manuvre

Table 1: Direct Drive position tracking performance during flight tests

3.1.2 Spring Based Test Bench

We built a test bench to test the Direct Drive's position following efficiency under load. For the test bench we used springs in both motor rotation direction with determined maximum forces. Figure 1 shows the test bench.

Test bench load: we had no accurate torque requirement values for the actuator, so we chose much higher values which can effects it during operation. We had estimated maximum values about hinge moments around 0.44 Nm so we chose that for one and 1.04 Nm for another one which is around the double of it (we neglected the difference between hinge moments and motor torque). Position errors calculated as before: the difference between commanded and measured position in each measurement point regardless of the frequency or shape of the signals.

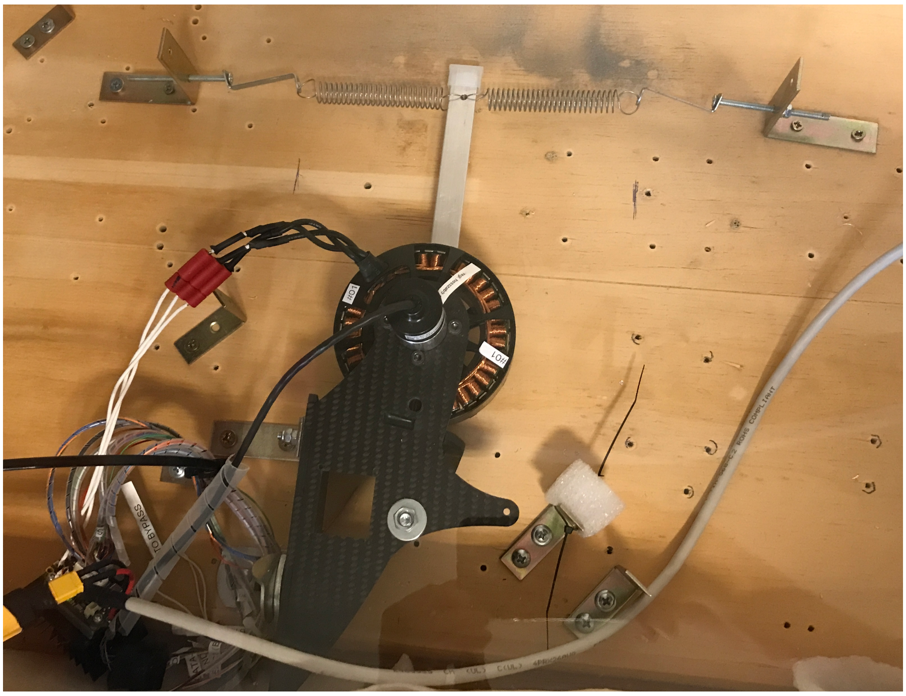

Figure 1: Spring based test bench to test the performance of the Direct Drive under load

The results of the test shown on the table 2.

Max Pos. Err.	**Max Pos. Err.**	**Max defl.**	**Load**	**Signal**
[+-deg]	[cnt]	[+-deg]	[Nm]	
0.9494	319	10	0.4439	sin 20 Hz
1.0536	354	10	0.4439	sin 25 Hz
1.6786	564	10	0.4439	sin 30 Hz
0.7262	244	10	1.046	sin 10 Hz
1.0208	343	10	1.046	sin 20 Hz
0.8899	299	10	1.046	sin 25 Hz
1.7768	597	10	1.046	sin 30 Hz

Table 2: Direct Drive position tracking performance on test bench

3.1.3 Conclusion

Based on the data analysis of the first flight tests and the results of the tests on spring based test bench we was able to determine that the Direct Drive is capable to bring the required performance, so it was ready for the flight tests with the flutter controllers.

3.2 Remote Control System range test

To mitigate the chance for the PFLEX to share the fate of its predecessor, we conducted RC(Remotely Controlled) radio range tests with several systems used at LLS. Namely JETI DS-26, JETI DC-16NG, Graupner and PowerBox Core. We used different receiver configurations for each in a recommended configuration for standard RC systems, to maximize system capability and minimize unnecessary complexities.

A mock-up was built 2 to simulate the best possible antenna layout on the V-tail section of the PFLEX With that, all antennas with shared base frequency ranges were kept at least one λ distance from each other to minimize interference. We were able to keep a similar layout later with the retrofitted V-tails.

Figure 2: Mock-up used during RC range test

The tests were conducted in the following way. A pair of systems were assembled to the mock-up, and it was attached to a DJI drone. The operator of the drone flows up to different, predefined altitudes. The rest of the team was using the GCS car to drive away from the drone location to be able to take measurements at different distances. Due to the weight of the mock-up giving us limited flight time with the drone, only point measurements were made. At each pre-defined distance, the drone went to a set of pre-defined altitudes, where we manually noted down the antenna quality values measured by the RC system.

Table 3 shows the main results of the range test made for the RC system and antenna layout selection. The measurement was noted on different altitudes, at different distances. Due to the mock-up configuration, precise alinement between the mock-up and the radio orientation were not possible to make. Measurements were noted when the drone was at 50m, 100m, 150m and 200m altitudes. In the table on the 150 and 200m results will be shown, because that is the closest to the expected altitude of a normal mission.

Distance	Altitude	REX3	RSat2	RSat 900NG	RSat 900	PBR-5S	gr32	Falcon6
500	150	7-8	6-7	7-8	5-7	- -	- -	- -
	200	7-9	6-8	8	5	- -	- -	- -
1000	150	5-7	5-7	6-7	4-5	- -	- -	- -
	200	5-7	5-5	7-9	5	- -	- -	- -
1400	150	4-5	4*	5-7	-	70%*	50%*	60%
	200	4-8	5*	7-9	4*	75%*	60%*	90%
2000	150	3-5	-	5-7	-	40%*	50%*	70%
	200	4-6	-	6-7	-	60%*	20%*	80%

Table 3: Remote Control system range test results

The values marked with (*) in table 3 are test points, where the given radio either gave continuous critical reception warning or signal-loss warning as well, regardless of the reception values shown by the radios. The values marked with(-) are points, where no useful measurements could be made due to full reception loss. the values marked with (- -) are points, where the measurement was intentionally skipped, due to technical limitations of our faulty DJI battery and cold weather. The 1400m distance reception point was used instead of 1500 since we had a critical reception loss with TFLEX around the same distance and lower altitudes. The used radio on the TFLEX was a gr32, an RSat2 and a REX3 variant with simple wire antenna.

The two main takeaways from this range test were the following:

- We were able to reconstruct a similar range pattern with a configuration similar to TFLEX, indicating the need to update to better antennas.
- We were able to select the main and backup system and their antenna configuration for the PFLEX.

3.3 Telemetry System range test

To have confidence in the updated telemetry system, an additional range test was done to access the nominal range and data rate of each telemetry module.

A simple platform was made, to hold the two telemetry radio modules along with a battery and a pixhawk flight control computer. The platform was attached to a DJI drone via a 10m long cable. As a nominal altitude, the drone were positioned at 100m, and the ground control station was driven. The quality of the datastream and the radio connection were monitored during driving.

This test were repeated for the 3DR-Sikk 433Mhz telemetry system as well as for the RFD 868Mhz system. The 433Mhz telemetry module used dipole antennas on each side - as it as intended to be on the demonstrator as well.

Due to the used software, no data is logged during the tests. However, we observed the following behaviours:

- The 433Mhz dipole antenna connection and data rate stability were highly dependent on the orientation of the two antenna. This is expected, since these modules are linearly polarized antennas, thus having maximum reception values only, when the two antenna is well aligned in 3D orientation relative to each other.
- The 433Mhz system had reception problems already between 0.6-0.8km, due to the already mentioned polarization problem.
- The 868Mhz system showed stabled reception values at every distance.
- The 868Mhz system showed stabled reception independently of the orientation of the modules and their antenna. This is expected since it uses 2 dipoles instead of one, thus it can cover the full 3D plane, without compromise.
- Both systems showed better reception values in close range and in the laboratory, than during the tests when the two modules were at least 50-100m distance from each other.
- The 868Mhz system had higher datarate in all operable distances, roughly double as we had with the 433Mhz. That is expected, due to their usable frequency bands.

4 Ground Vibration Test

The ground vibration test (GVT) plays a crucial role in validating the accuracy of the simulation model and gaining deeper insights into the structural dynamics of the aircraft. By conducting the GVT, valuable data is obtained, which can be utilized to update and refine the simulation model. The updated model, incorporating the data from the GVT, enables more accurate simulations to be performed.

One of the key benefits of utilizing the updated model is the improved prediction of flutter speed, which holds significant importance for the upcoming critical flutter test. By incorporating the refined dynamics information into the model, a more precise estimation of the flutter speed can be achieved, enhancing the understanding of the aircraft's dynamic behavior under critical conditions.

For detailed information on the GVT procedure and the outcomes obtained, please refer to deliverable [2, §4]. This deliverable provides comprehensive insights into the GVT process, including the methodology, instrumentation, data collection, and analysis techniques utilized. The presentation of the GVT results in the deliverable offers a comprehensive overview of the dynamic characteristics observed during the test, facilitating a deeper understanding of the aircraft's structural dynamics and informing further optimizations and improvements in the simulation model.

5 Flutter Prediction

As the critical flutter test approaches, it becomes crucial to ensure the accuracy and confidence in the predicted flutter speed derived from simulations. To achieve this, a rigorous process of cross-checking and validation is undertaken to assess the reliability of the flutter speed calculations. Multiple partners and independent methods are involved in conducting flutter calculations to obtain a comprehensive and robust analysis. This approach mitigates the risk of relying solely on a single calculation method and enhances the overall confidence in the predicted flutter speed. By involving different partners and employing diverse calculation techniques, the flutter calculations undergo rigorous scrutiny, enabling a more accurate determination of the flutter characteristics and facilitating informed decisions for the critical flutter test.

5.1 Pre-Flight Flutter Checks at DLR

To verify the assumptions for the controller design and to ensure a safe flight test, several flutter computations have been conducted. First, the structural dynamics of the model was updated. The eigenfrequencies and damping values identified in the GVT were used to update the generalized stiffness K_{hh} and damping matrices B_{hh}. Further, the modes shapes were taken and mapped to the structural grid of the theoretical model. This way a consistency of the splining method and the aerodynamic grid with the models used for the controller design was ensured.

The updated modal data was then used in two different classical flutter methods, the p-method and the pk-method. The p-method relies on a rational function approximation of the unsteady aerodynamics and solves for the eigenvalues of the system matrix as a function of flight speed. The pk-method solves the eigenvalue problem in the frequency domain by iteratively adjusting the interpolated complex valued generalized aerodynamic forces to the desired reduced frequency.

The GVT updated model showed an interesting behavior, since the antisymmetric flutter mechanism disappeared and the symmetric flutter was delayed to about $55\,\mathrm{m/s}$ to $56\,\mathrm{m/s}$. The modal mass of the symmetric torsion mode was modified by scaling down the modeshape to 80% of its identified magnitude to check whether these results were robust against potential inaccuracies of the identified modal mass. The flutter speed of about $55.5\,\mathrm{m/s}$ was confirmed. Modifying the torsional modeshape as described before reduced the expected flutter speed only slightly to just under $55\,\mathrm{m/s}$ as can be seen in figure 3.

Other partners confirmed the flutter speed of about $55\,\mathrm{m/s}$ to $56\,\mathrm{m/s}$ with independent calculations.

These flutter results were verified once more by using the updated modal model in the nonlinear simulation model. The nonlinear model was linearized about various trim points covering the speed range of interest. The resulting state space models were then passed on to the open and closed loop time domain simulations

5.2 Open and Closed-Loop Simulations

Based on the GVT updated structural modes shapes, frequencies and damping a simulation was set up. The aeroelastic model was trimmed and linearised for several airspeeds. This set of linearised models was then combined to a linear parameter varying (LPV) model, which formed the basis of the simulation model. As mentioned before, the flutter speed with the GVT update was determined to be $56\,\mathrm{m/s}$, which was confirmed based on the performed simulations. Figure 4 shows the evolution of the

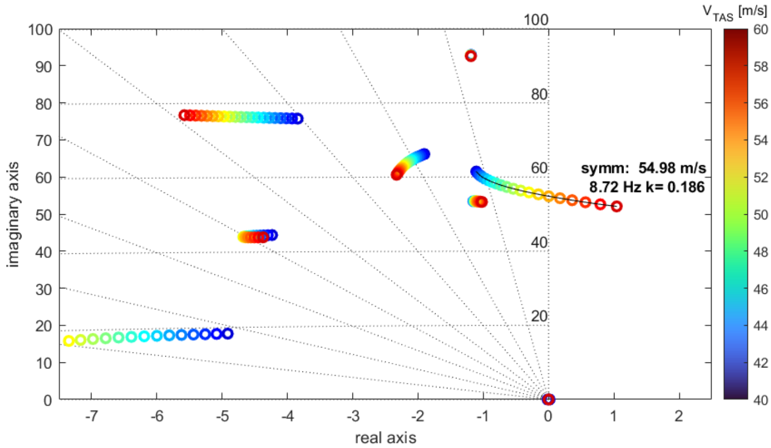

Figure 3: polemap of the pre flight flutter check with the identified symmetrical torsional mode shape scaled to 80%.

structural modes over time at $55\,\mathrm{m/s}$ and $56\,\mathrm{m/s}$, when the aircraft is disturbed by a pulse on the most outer ailerons after $1\,\mathrm{s}$. It is clearly visible that the aircraft is still stable for $55\,\mathrm{m/s}$, as the vibrations are slowly decaying, and is unstable for $56\,\mathrm{m/s}$, indicated by a slow increase in the structural modes amplitude.

With flutter control the increase in amplitude is suppressed at $56\,\mathrm{m/s}$ for both the flutter controller by DLR and SZTAKI. This is shown in Figure 5. This insight provided further confidence that the flutter controllers should be ready for flight testing.

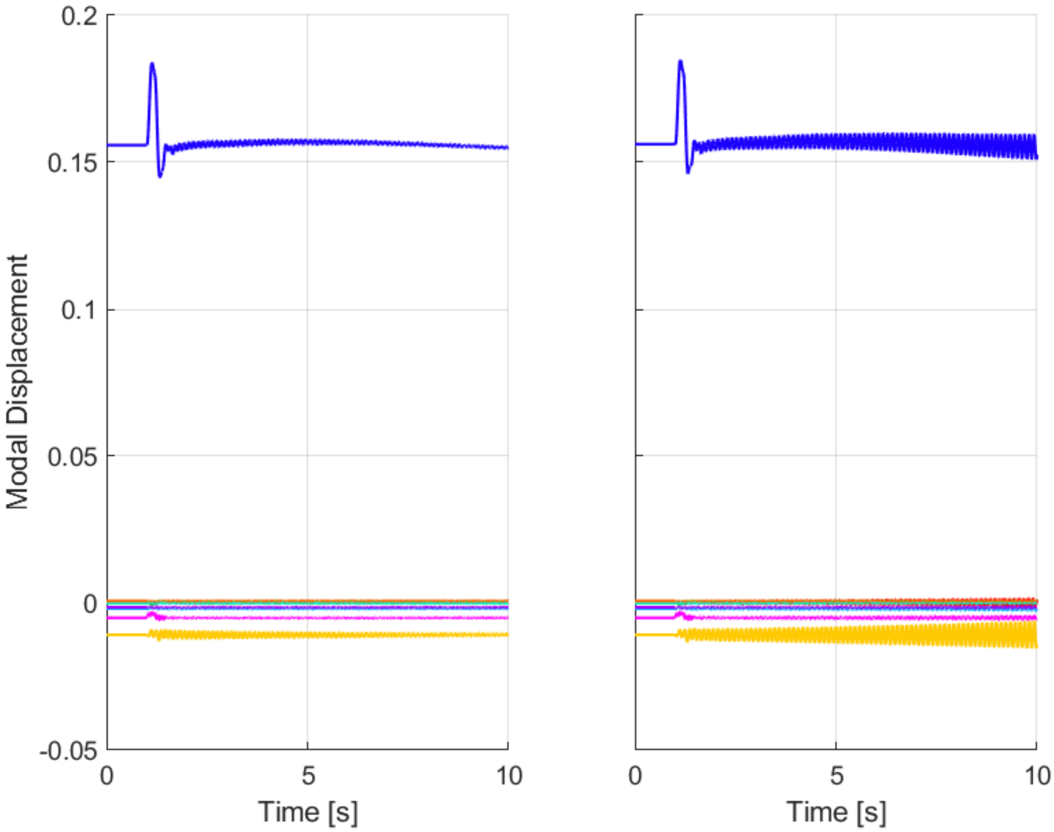

Figure 4: Open-loop simulation of the structural modes at $55\,\mathrm{m/s}$ (left) and $56\,\mathrm{m/s}$ (right).

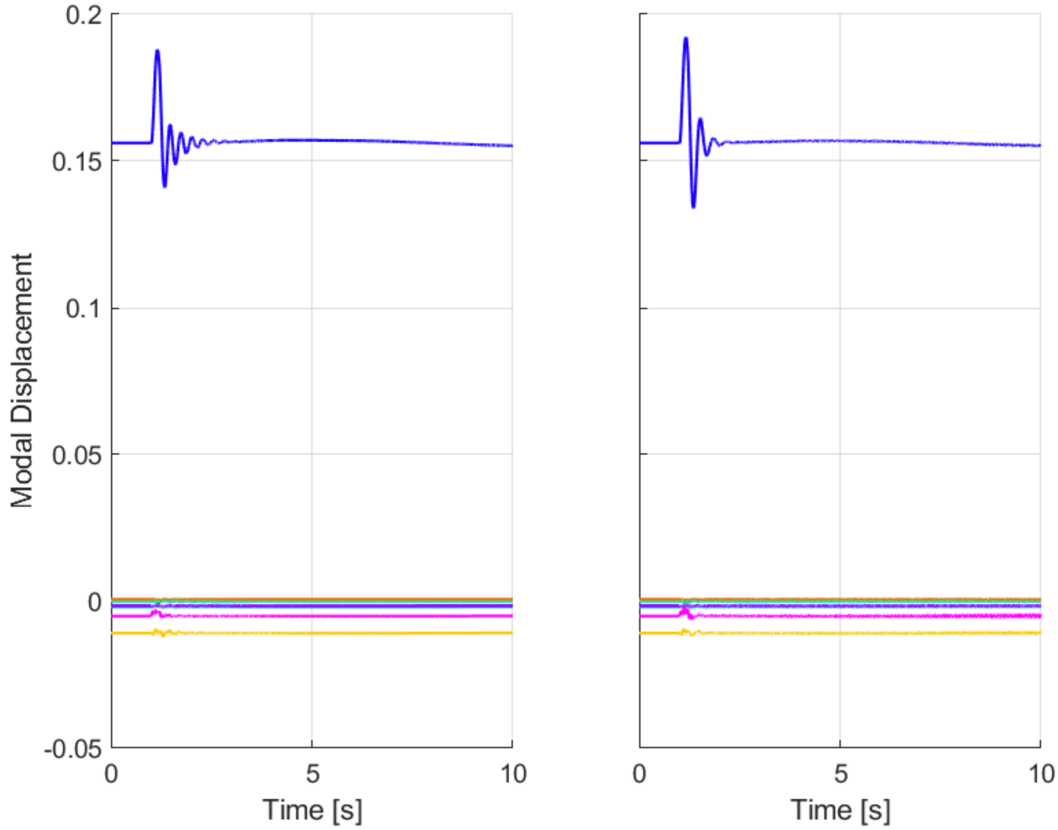

Figure 5: Closed-loop simulation of the structural modes at $56\,\mathrm{m/s}$ with DLR (left) and SZTAKI (right) flutter controller.

6 CONOPS and ERP

Concept of operations (CONOPS) and emergency response plan (ERP) are essential components ensuring the safety of flight tests. Given that the flight test will take place at a new location, specifically Magdeburg-Cochstedt Airport (EDBC), a thorough review and revision of the CONOPS have been conducted. The purpose of this revision is to align the operational procedures and protocols with the specific requirements and characteristics of the EDBC airport. For more detailed information regarding the revised CONOPS, please refer to deliverable [1]. This deliverable provides comprehensive insights into the updated operational framework, including flight procedures, coordination protocols, and emergency response measures tailored to the EDBC location, thus ensuring a safe and efficient flight test environment.

7 Conclusion

In conclusion, this report highlights the critical steps taken to ensure the flight readiness of the demonstrator aircraft with the advanced wing. The airworthiness test conducted on the -1 wing confirms its ability to sustain the design load of 4 g, providing essential insights into its structural integrity. Furthermore, the revision of the Concept of Operations (CONOPS) and Emergency Response Plan (ERP) for the flight test at Magdeburg-Cochstedt Airport (EDBC) enhances operational procedures and safety measures.

The comprehensive ground vibration test (GVT) validates the simulation model and enhances understanding of the aircraft's structural dynamics, enabling more accurate predictions. Additionally, system tests, including the direct drive test and range tests for the remote control and telemetry systems, ensure the functionality and performance of key systems crucial for flight readiness.

These evaluations and tests collectively contribute to the overall confidence in the flight readiness of the demonstrator. The findings and insights gained from these assessments inform further optimizations and improvements in the design, ensuring the aircraft's safety, performance, and successful integration of the advanced wing.

Overall, the diligent execution of airworthiness tests, revisions in CONOPS and ERP, comprehensive GVT, and system tests establish the demonstrator aircraft's flight readiness. The accumulated knowledge and data generated throughout this process lay the foundation for successful flight operations.

8 Bibliography

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