The contributions of a lightweight and innovative drone equipped with a fully integrated solution to optimize NAVAIDS flight inspection.

Abstract:
The modernization of NAVAIDS flight inspection takes a significant turn at DSNA with the introduction of a lightweight and innovative drone. This groundbreaking shift is attributed to the integration of a ground-operated drone solution. Our team of flight inspection experts has internally designed an innovative drone solution, characterized by its lightweight and operability, thanks to its fully integrated solution for flight inspection optimization.
This drone solution features a comprehensive system, entirely operated via a touch-screen tablet with cloud services. This intuitive interface ensures piloting, flight safety and drone flight inspection measurements. Its advanced sensors, TSO compliant, ensure real-time data collection, comparable to on-board aircraft systems. Rigorous comparative measurements, stemming from our expertise in ground-to-air correlation at DSNA, have been conducted on several air traffic open areas, confirming the reliability of our approach and emphasizing the resolution of complex technical and regulatory challenges. We have started to introduce our drone solution for Glideslope commissioning.
The innovation of this ground solution, with our expertise in flight inspection, redefines standards of quality and efficiency. It simultaneously reduces operational costs, environmental impact, and contributes to the reduction of carbon emissions and noise.

Biography: Mathieu Mahiques, air safety systems engineer in DGAC (French Civil Aviation Administration). Trained as an engineer at ENAC school (Civil Aviation Academy in Toulouse), then spent 11 years at the northern Air Route Traffic Control Center in Paris as an ATM systems permanent engineer, and for the last 7 years has been working in flight inspection services for radionavigation and GNSS resources as an engineer and head of the drone project and professional drone pilot.

1. Introduction

The flight inspection of radio navigation systems, such as instrument landing systems (ILS) and VOR (VHF Omnidirectional Range) stations, is essential and mandatory to guarantee the safety and efficiency of flight operations. Traditionally carried out by aircraft equipped with specific sensors, this process is constantly evolving to meet economic needs and optimize runway occupancy times. Like many flight inspection operators, DGAC has developed an innovative approach using drones for these inspections. This paper examines this method in detail, highlighting the internal development by the DGAC's flight inspection team, the dedicated Android software, the technical specifications of drones, as well as flight authorizations and operational risk assessment (SORA).
In France, DGAC is responsible for the flight inspection of radio navigation equipment, not only in France but also in the overseas territories, as France has at least one island in each ocean. With the need to intervene in remote areas accessible only by airliner, it was crucial for us to develop light, transportable drones. These drones enable rapid and effective intervention, guaranteeing the continuity of air navigation services in varied and often remote environments.

2. Flight inspection method using drones

The flight inspection of radio navigation equipment, traditionally carried out by aircraft equipped with specific sensors, faces logistical and financial challenges. Integrating drones into this process offers an efficient and cost-effective solution. The DGAC's flight inspection team has developed a method that is both light and robust. It involves equipping drones with special, miniaturized sensors capable of measuring the signals emitted by ILS and VOR installations, all within a reduced footprint.
Summary of the main families of existing UAVs:

- Less than 900 g: currently impossible to use to carry measuring equipment on board
- Between 1 kg and 4 kg: not very suitable for carrying measuring equipment
- Over 4 kg: very suitable for aerial work such as ILS/VOR measurements

While all flight inspection operators generally opt for drones weighing more than 4kg because of the weight of the equipment to be lifted, the DGAC has opted for a difficult option, choosing drones in the 1kg to 4kg range to guarantee ease of use and compatibility with airliner transport. What's more, the reduced size and ease of installation will make them easy to use and deploy in local maintenance operations.

2.1. Drone Equipment :

The equipment of drones for flight inspection monitoring of radio navigation systems is crucial to guarantee accurate and reliable measurements:

RTK GPS receivers and base station:

The measurement system is equipped with RTK GPS receiver for measurements accurate to the nearest centimeter. Equipped with a lightweight RTK base station to manage the differential GPS, and a long-range datalink, it provides the GPS correction to reach the measurement the accuracy needed for calibration. The on-board system the drone also incorporates a synchronization card so that each measurement taken is synchronized with its position in real time, guaranteeing perfect correlation between the signal from an ILS or VOR and its position in space.

Photo 1 : Datalink RTK base station

Receiver for ILS and VOR signals:

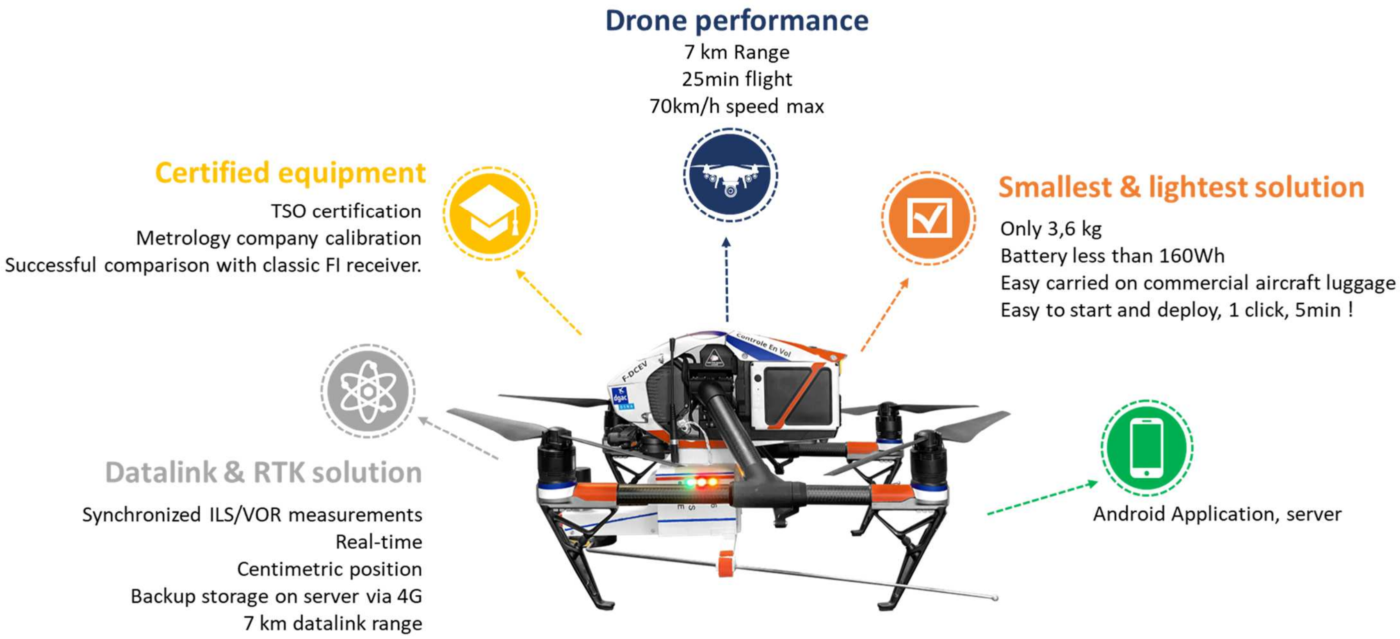
The on-board measurement equipment includes an antenna and a compliance ILS/VOR TSO (Technical Standard Order) receiver. This avionics equipment is specially designed to ensure accurate and reliable measurements of the signals emitted by the ILS and VOR installations, thus guaranteeing the accuracy of the data collected by the drone in the same way as it is used by an aircraft. In addition of TSO compliance this receiver has been validated internally within the DGAC flight inspection department and qualified by TRESCAL a metrology specialist. The receiver output data are also calibrated to ensure accurate and reliable measurements. This calibration stage guarantees the accuracy of the data collected by the drone and ensures compliance with current regulatory standards.

Technical characteristics of the drones:

The drone use for flight inspection of radio navigation systems have been carefully selected to meet the specific requirements of flight inspection missions. They are compact in size, weighing around 3.6 kg including payload, making them easy to transport and maneuver. Their battery capacity is less than 160Wh, making them easy be carried by airliner, while offering a flight autonomy of around 25 minutes. Transport cases adapted for travel have been developed to optimize and facilitate transport and deployment with a ready-to-fly drone.

Radio datalink:

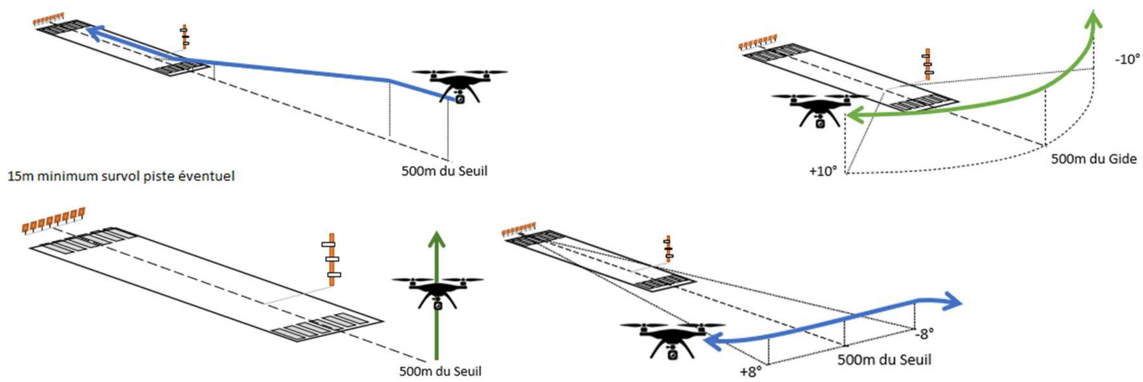
The drones are equipped with a robust radio datalink enabling communication with the ground station, RTK base station, up to a distance of 7 km. This two-way communication is essential for RTK GPS corrections and for receiving real-time data collected during measurements. The drone itself has its own telemetry for a distance of up to 7km. However, to reach these distances, it is necessary to obtain specific authorization to fly out of sight (BVLOS) and at height above the 120m authorized in Europe.



Graph 1 : Drone solution features

2.2. Mission planning :

Before each mission, detailed planning is carried out to determine optimal flight paths, considering weather conditions, potential obstacles and restricted areas. This planning is essential to ensure safe operations. Professional UAV flight inspection pilots carry out this task in collaboration with local maintenance and air traffic control. There are several standard flight paths, mainly corresponding to aircraft flight paths. So that the ATCO (Air traffic control operator) can easily match all the measurements to those already taken in the aircraft.



Graph 2 : Typical drone trajectories in French for air traffic control operator

2.3. Execution of the mission :

Once on site, still in direct coordination with the ATCO via a VHF radio and a recognizable calibration callsign, the 2 flight inspection drone pilots position themselves at the location established with local maintenance. The entire mission is managed via the tablet and the Android software. The drone can then begin its pre-established trajectories with the ATCO. The sensors record the signals emitted by the ILS and VOR installations. At the same time, the drone's position data is synchronized to enable precise analysis of the performance of these radionavigation systems via the tablet software. The information is fed directly back to local maintenance for system adjustment and configuration. The close collaboration with the ATCO guaranteed the success and safety of the operation. In other words, the ease and reliability of the system enabled to operate on open to commercial traffic airport, and during the day.

2.4. Data analysis :

The data collected and recorded via the Android software are also saved internally in the drone in the event of a telemetry system failure. These data are analyzed in real time or reviewed subsequently by experts from the flight inspection team and/or maintenance ground staff. This analysis is used to identify any faults or anomalies in the ILS and VOR installations, and to check that they comply with regulatory standards. The data is synchronized with a remote server via 4G/5G, enabling a report to be drawn up.

For example, Glide antenna adjustments can be edited after the drone flew overhead.

M Type GP Antenna Adjustment			
Nominal Angle :	3.00 °	UHF Frequency :	333.80 MHz
Antenna Nulls			
Upper Antenna	2.11 °	4.00 °	5.88 °
Middle Antenna	2.94 °		5.79 °
Lower Antenna			5.66 °
FSL			
Upper Antenna	0.24 °	0.22 °	0.23 °
Middle Antenna	0.09 °		
Recommended FSL for height adjustment :		0.10 °	
Manual FSL for adjustment :			
FSL used for height adjustment :		0.10 °	
Desired Alignement at high angle		5.90 °	
Lower antenna height adjustment		-19 cm	
Middle antenna height adjustment		-17 cm	
Upper antenna height adjustment		-5 cm	

*Note : Middle Antenna has to be placed, if possible, at equal distance of Upper and Lower antenna in order to maintain good alignment at high angle (2*Descent Angle - FSL)*

Graph 3 : Glide antenna adjustement

3. Development of a dedicated Android software

To manage mission planification, monitor drones in real time and analyze the data collected, the DGAC's flight inspection team has developed internally a dedicated Android software. All phases of this design consider the know-how of our specific experience in the field of flight inspection. The software, developed specifically for the flight inspection with drone, offers an all-in-one solution, integrating all the functionalities required for mission planning, execution and analysis. Thanks to a comprehensive, easy-to-use interface, the solution can be transposed to ground maintenance activities.

3.1. Software features :

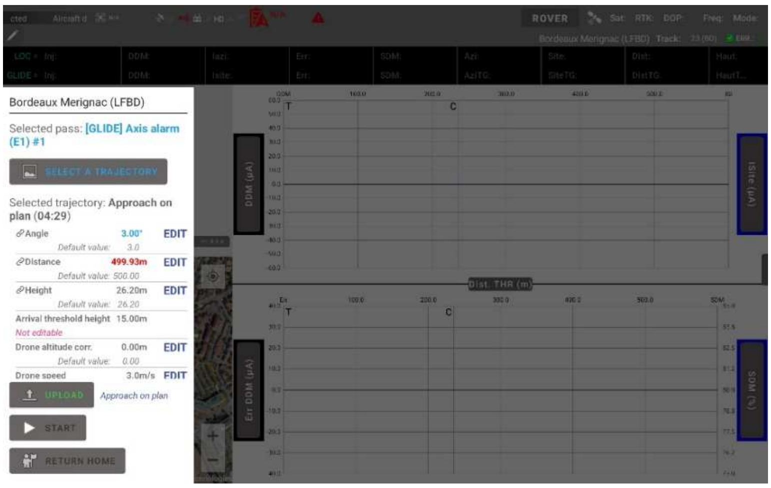
The software offers a complete set of functionalities designed to optimize each stage of the drone flight inspection process, which is so specific compared to aircraft operation.

Mission planning:

Operators can plan missions by specifying flight parameters and areas of interest directly from the software. A database can be used to plan a VOR or ILS mission with all its characteristics. Mission planning includes: flight trajectories definition, specification of waypoints and areas to be inspected, modification and adaptation trajectories instantaneously to save preparation time.

Trajectories optimization:

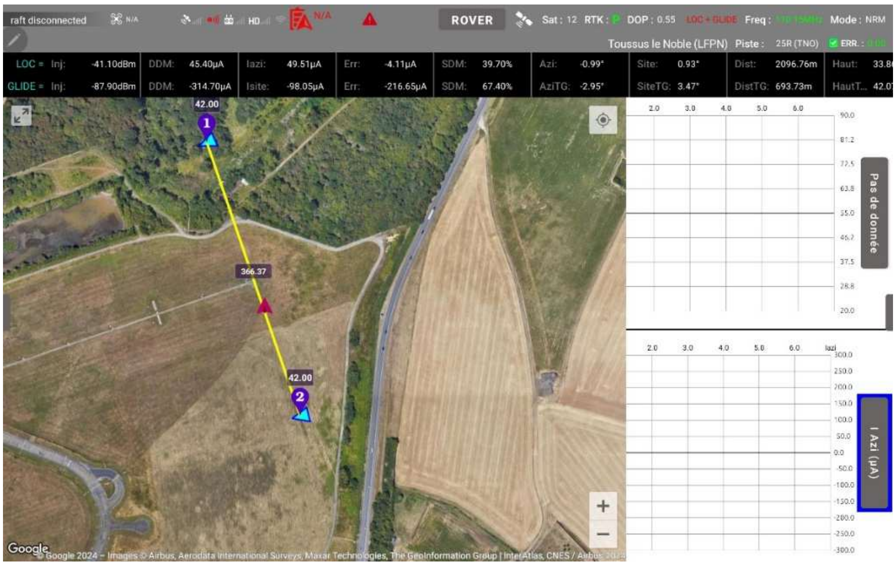
The software automatically generates optimized flight paths based on the parameters defined during mission planning. This ensures complete and effective coverage of the target area, while minimizing risks and optimizing the use of the drone.



Graph 4 : Drone trajectory management

Real-time drone tracking:

During missions, the software provides real-time drone tracking, giving operators a detailed view of the drone's position, altitude and status. This feature allows operators to actively monitor the progress of the mission and make decisions in real time if necessary.



Graph 5 : Real time drone evolution on LOC sector

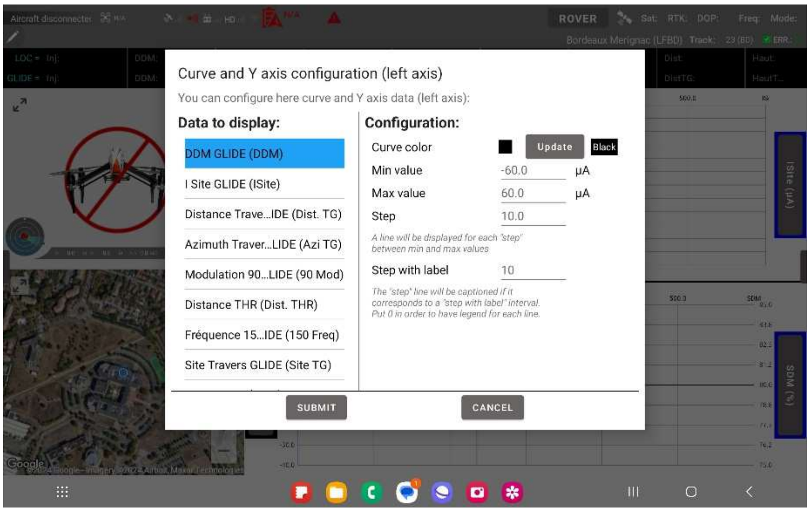
Data analysis and measurements:

The software enables real-time analysis of the data collected by the drone during the mission. Operator can view the measurements and calculations in real time, as well as the measurement curves, for an instant assessment of the performance of the ILS and VOR installations inspected. A previous record can be replayed even during a mission.

Graph 6 : Real time VOR measurement on radial

Customized settings:

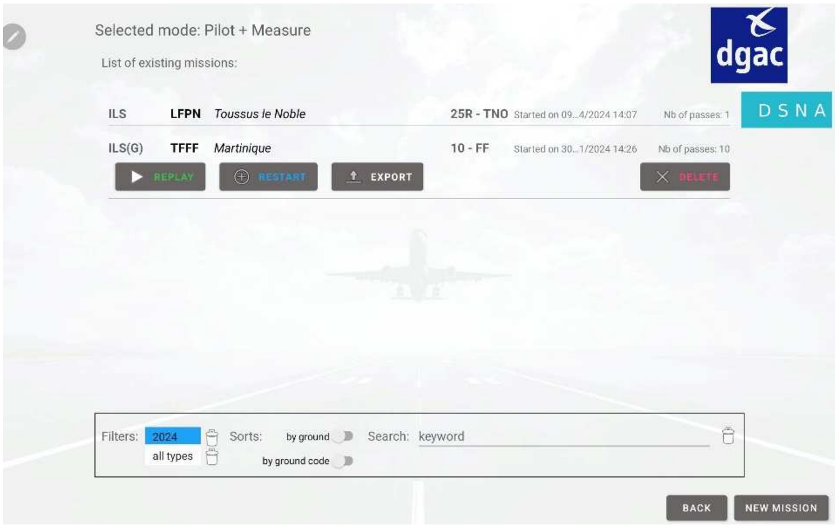
Operator can configure the software and the measurement curves according to the specific needs of each mission or flight pattern. This allows flexible adaptation to the flight conditions and specific requirements of each inspection site. Default configuration files in JSON format allow operators to have their own configuration.



Graph 7 : Software graph customization

4G/5G Synchronized Database:

The software is synchronized with an online database via a 4G/5G connection, enabling missions to be imported and exported in XML and CSV formats, and data collected to be backed up. This functionality always guarantees the availability and integrity of the data. However, the software can operate offline.



Graph 8 : Software mission menu

3.2. Intuitive user interface :

Operating a drone in airspace is not an easy task, so it is essential to offer the remote pilot an intuitive software that does not require excessive focus. The software's user interface is designed to be user-friendly and intuitive, enabling operators to navigate easily between the various functions and make real-time decisions based on flight conditions and measurements taken. The software brings together all the functions a user needs to carry out ILS/VOR measurements using a drone.

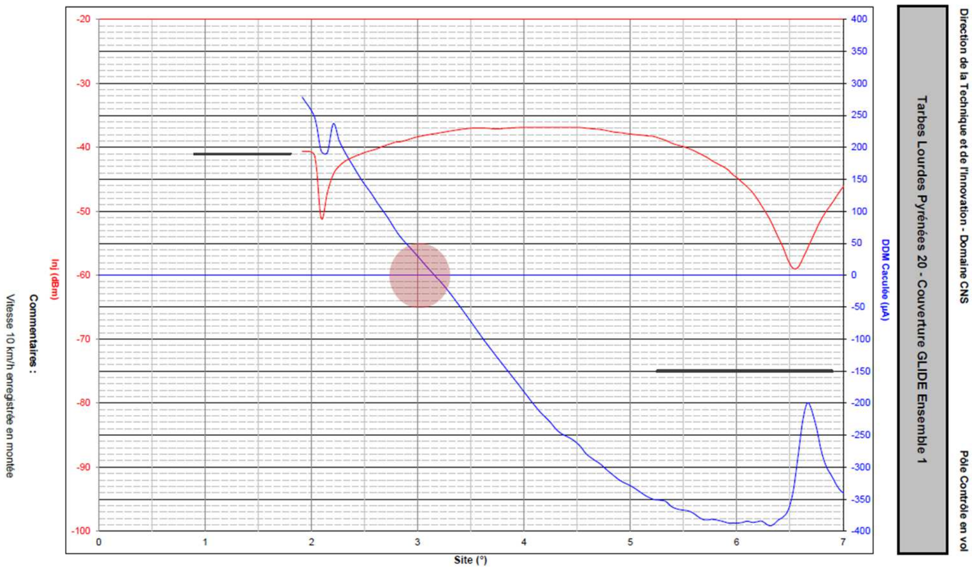
4. Drone flight tests on ILS and VOR and measurements carried out

The flight tests on the ILS and VOR installations are carried out with methodological rigor, allowing a direct comparison with the data collected by the flight inspection aircraft. This methodology is already used within the DGAC between flight inspection and local ground maintenance, known as ground/air correlation. We have used the same tried and tested methodology for a drone/air correlation.

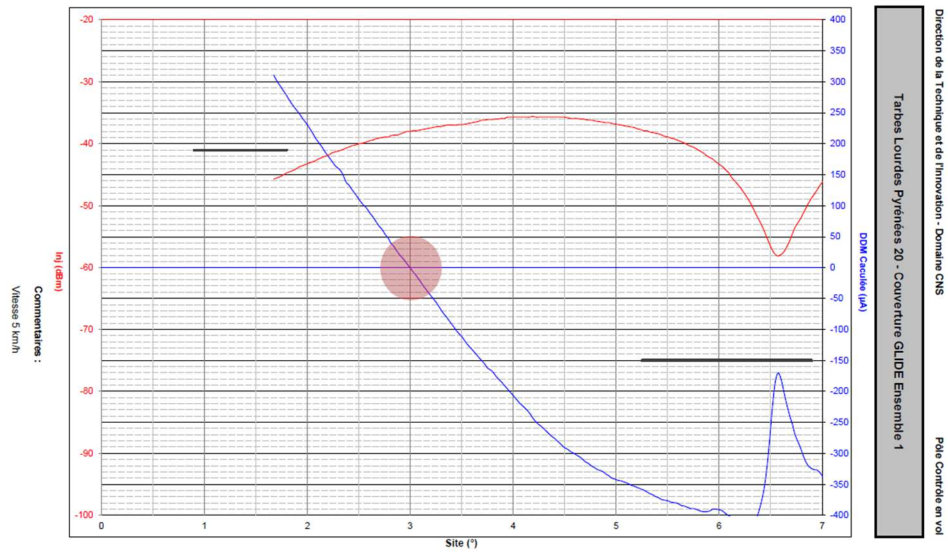
4.1. Confidence and consistency of the results:

These tests involve repeating the measurements to ensure the reliability of the results. Repeating the measurements makes it possible to check the consistency of the data collected by the drones on different runs, thus ensuring the accuracy of the information gathered. This approach strengthens confidence in the results obtained and enables any anomalies or variations in the data to be identified. We have seen, for example, that the speed of the drone has an influence on the measurement, as it does in aircraft, known as drag.

Here is an example of GLIDE coverage before and after drone speed adjustment.



Graph 9 : Glide covering with 0.2° axe error



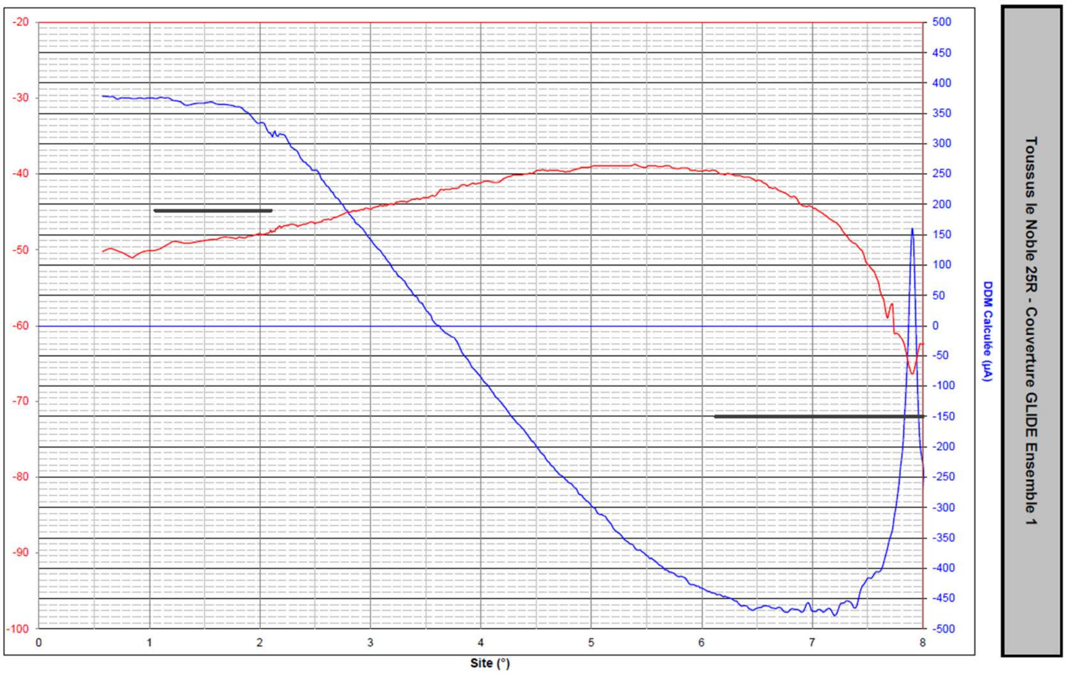
Graph 10 : Glide covering with 3° axe no error

4.2. Aircraft comparison tests :

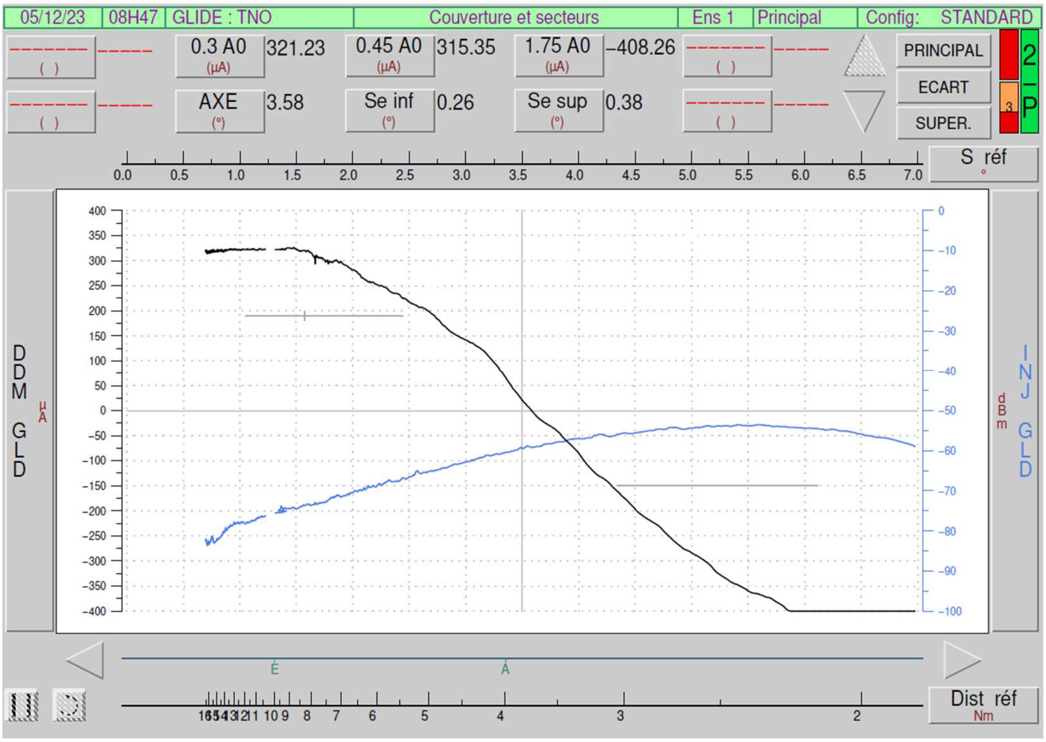
In the aircraft comparison tests, the data collected by the drones is compared with the one recorded by the flight inspection aircraft. The comparison of UAV and aircraft data was considered throughout the design of the Android software. Particular care has been taken to ensure that the data is presented in a similar way, whatever the means of measurement: drone or aircraft. This comparison validates the performance of the drone solution as a tool for preparing flight inspection on radionavigation equipment for ground maintenance. It also provides a cross-validation of measurements, reinforcing the reliability of the data collected by the drone. In collaboration with the ATC, we were able to carry out simultaneous measurements between the flight inspection aircraft and the drone, at the same time and under the same conditions.

Photo 2 : Drone and aircraft from French flight inspection unit on Paris - Toussus le Noble airport

Here is an example of GLIDE coverage results between the run of the drone and the calibration aircraft, with an axis found for both at 3.58° :

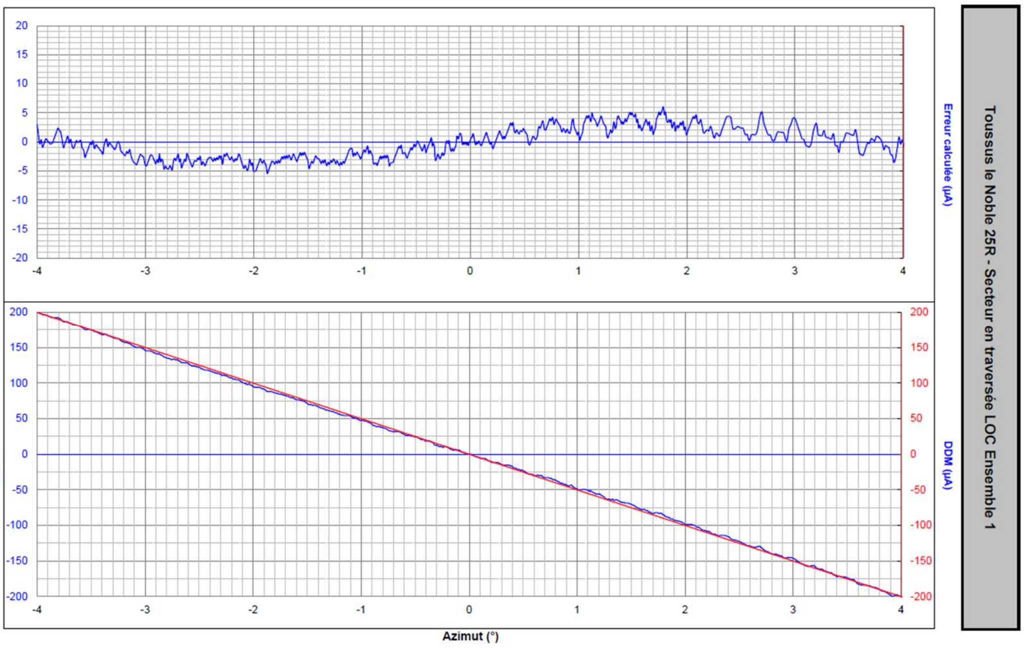


Graph 11 : Drone GLIDE coverage

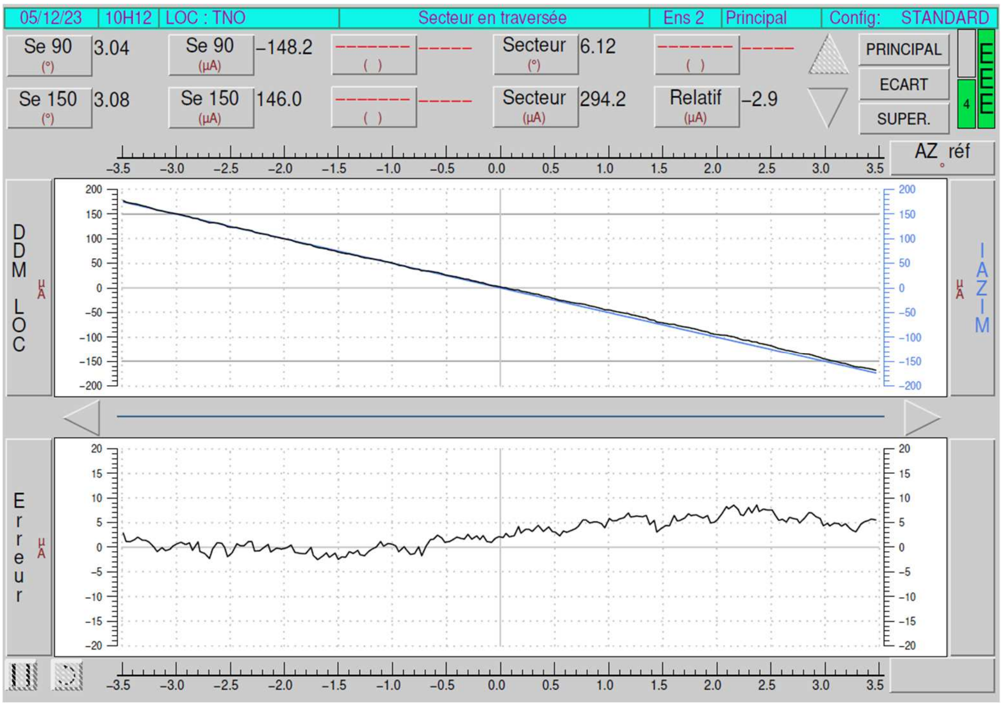


Graph 12 : Aircraft GLIDE coverage

In this other case, a LOC sector found by the plane and the drone, with a sector low and up as 0.38°:



Graph 13 : Drone LOC sector



Graph 14 : Aircraft LOC sector

4.3. Software comparison tests :

Another essential component of drone flight tests on ILS and VOR is the comparison of calculations carried out in real time with those performed by the CARNAC calibration software (SAFRAN) used in French flight inspection aircraft. This considers both the calculations generated by the trajectography and the calculations at the end of the run. This validation process real-time calculations and end-of-run measurements guarantees the accuracy of the data collected by the drones. Any discrepancies between the drone measurements and the expected results calculated by the software are analyzed and validated. This enabled us to validate our calculations. For example, here we have the A2 field nulls automatically computed:

Graph 15 : Fort de France (West indies) GLIDE with A2 null field

This approach, with different types of tests, guarantees the consistency and accuracy of the data collected by the drone.

5. Flight Authorizations and Operational Risk Assessment (SORA)

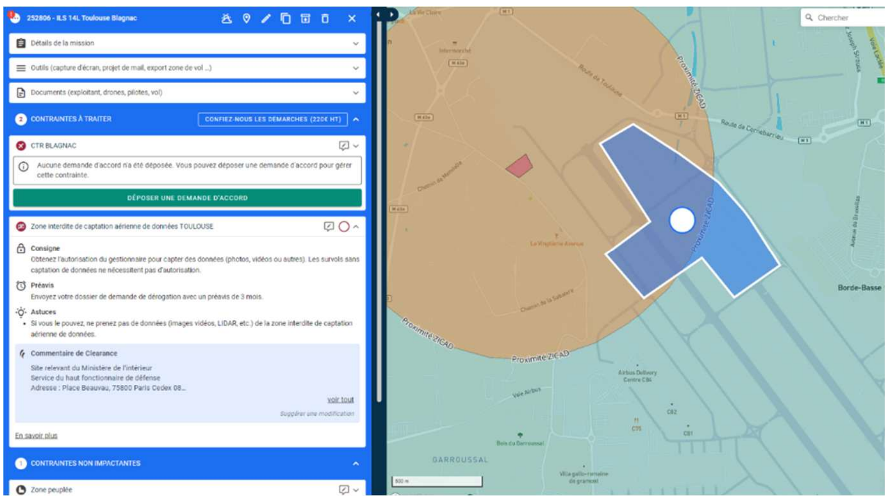
The use of drones for flight inspection of radionavigation systems requires specific authorizations and an in-depth assessment of operational risks in accordance with the regulatory framework in force. The French Civil Aviation Administration and Europe Aviation Safety Agency have put in place a rigorous process to guarantee the safety and compliance of these operations.

5.1. Flight authorizations :

Obtaining flight authorizations is a crucial step in ensuring the safety and compliance of drone flight control missions.

Procedure for obtaining authorizations :

Before each mission, the DGAC flight inspection drone team begins the process of obtaining flight authorizations. This procedure involves submitting a detailed request to the relevant authorities, describing the parameters of the mission, the planned flight zones and the safety measures in place. In France, we use specially adapted tools (CLERANCE) to define the mission and submit it for authorization.



Graph 16 : Toulouse Airport mission preparation on Clearance software

Safety considerations:

Flight authorizations are issued considering various safety factors, such as restricted flight zones, controlled airspace and safety rules in force. The main objective is to ensure the safety of flight operations and to minimize the risks to people and property on the ground. Various restrictions may be requested, both technical restrictions on the drone, parachute, circuit breaker, etc., and restrictions on flight paths.

Coordination with the competent authorities:

The flight control team works closely with the relevant authorities, including air navigation services and airspace control organizations, to obtain the necessary flight authorizations. This coordination ensures efficient mission planning and smooth integration of drones into the airspace. This coordination enables us to fly over open terrain and during daylight hours.

5.2. SORA (Specific Operations Risk Assessment):

The assessment of operational risks using the SORA methodology is an essential step in guaranteeing the safety of drone flight control operations.

- **Low (L) :** déclaration de l'exploitant. L'autorité peut cependant vérifier cette déclaration en demandant des justifications supplémentaires
- **Medium (M)** : L'exploitant apporte des éléments objectifs pour justifier du -niveau de sécurité (mesures, essais, données quantitatives, etc.) Lorsqu'il s'agit d'un OSO portant sur la navigabilité, la conception de l'UAS est vérifiée par l'AESA.
- **H : High** : Le niveau de sécurité est validé par une entité tierce. Lorsqu'il s'agit d'un OSO portant sur la navigabilité, l'UAS est certifié par l'AESA.

Les tableaux ci-après reprennent chaque OSO en fonction des niveaux de SAIL de notre opération de I à IV

OSO		SAIL				JUSTIFICATION
		I	II	III	IV	
Critères techniques UAS						
OSO#01	Opérateur UAS compétent et/ou approuvé	-	L	M	H	*(Plan de formation générale. Formation de l'équipage spécifique sur l'UAS concerné. Expérience de l'opérateur et précédentes opérations. Checklist et manuel d'entretien)*
OSO#02	Constructeur UAS compétent et/ou approuvé	-	-	L	M	*(Standards de qualité (matériaux, pièces) du constructeur. Politique de contrôle qualité, contrôle de conformité, traçabilité. Expérience et activités du constructeur.)* Non nécessaire en SAIL II
OSO#03	Maintenance UAS assurée par une entité compétente et/ou approuvée	L	L	M	M	*(Procédures de maintenance du MUE Respect des recommandations constructeur. Formation/autorisations/maintien de compétence du personnel Archivage des actions de maintenance)*
OSO#04	UAS développé selon des standards reconnus par l'autorité	-	-	-	L	*(La fiabilité du design assure un risque faible d'accident. Expertise de laboratoire ou d'organisme tiers)* Non nécessaire en SAIL II
OSO#05	UAS conçu selon des standards de fiabilité et de sécurité	-	-	L	M	*(Caractéristiques de l'UAS permettant de réduire les risques et les conséquences d'une défaillance. Stratégies de détection des défaillances.)* Non nécessaire en SAIL II
OSO#06	Performances du Lien C2 appropriées pour la mission	O	L	L	M	*(Les canaux de fréquences utilisés sont autorisés aux puissances émises. Niveau d'assurance de la qualité des liaisons C3. Outils permettant au pilote de vérifier la qualité des liaisons pendant le vol)*
OSO#07	Inspections de l'UAS pour assurer la validité du ConOps	L	L	M	M	*Stratégies d'inspection de l'UAS Checklist ou historique d'inspection*

Graph 17 : Part of SORA example

SORA methodology:

The SORA methodology, developed by the European Aviation Safety Agency (EASA), provides a structured framework for assessing the risks associated with specific drone operations. This methodology considers various factors such as the operational environment, the drone's characteristics and the safety measures in place.

Identification of risks:

The SORA risk assessment identifies the hazards associated with the use of drones for flight inspection of radio navigation systems. These risks may include interference with air traffic, collisions with obstacles or technical failures of the drone.

Risk Mitigation:

Once risks have been identified, appropriate mitigation measures are put in place to reduce the risks to an acceptable level. This may include the adoption of specific operational procedures, the use of advanced safety technologies or the training of personnel involved in flight inspection operations.

Validation and monitoring:

Risk assessment using the SORA methodology is an iterative process, requiring continuous validation and monitoring of the mitigation measures implemented. This approach ensures that flight inspection operations remain safe and compliant with current regulatory standards. The DGAC's flight inspection department is working on the implementation of a generic SORA for drone flight inspection, which will make it easier for drones to operate in the field.

6. Advantages of preparing flight inspection of ILS and VOR by drone

The use of drones for the flight control of radio navigation systems, such as instrument landing systems (ILS) and VOR (VHF Omnidirectional Range) stations, offers several benefits in combination traditional methods using specialized aircraft.

Impact on air traffic:

The use of drones for flight inspection means that air traffic disruptions caused by traditional inspections carried out by special aircraft can be avoided. By reducing dependence on time slots reserved for inspections, drones help to keep air traffic flowing smoothly.

Cost savings:

Compared with special mission aircraft, drones are more economical to operate in terms of operating and maintenance costs. Their use offers significant savings for regulators and air operators, while delivering equivalent performance in terms of data collection and measurement accuracy. But with these drones, and for regulatory reasons, this solution only make it possible to prepare and reduce the number of flight inspection hours..

Environnemental impact :

Drones are more environmentally friendly than traditional aircraft, as they emit fewer greenhouse gases and produce less noise during their operations. By reducing the environmental footprint of in-flight inspections, drones contribute to the preservation of airborne and terrestrial ecosystems, while meeting growing demands for environmental sustainability.

Reduced in-flight time:

The use of drones reduces the time needed to carry out flight inspections in aircraft, resulting in increased availability of runways and optimized flight operations. By minimizing traffic disruption and speeding up the inspection process, drones help to improve the operational efficiency of flight inspections. The use of drones is perfectly suited to the commissioning of ILS and VOR before the aircraft runs overhead, thus reducing the number of hours flown, with all the impact that this entails.

Implementation for ground maintenance :

This simple, lightweight, easy-to-use drone system can easily be transposed and used by all ground maintenance teams looking for a way of carrying out countermeasures easily in the air, to remove any doubts and check a system before a calibration, or in remote areas such as France's overseas territories, to be less dependent on the calibration aircraft, which cannot come and check equipment on request.

7. Conclusion

The in-flight inspection of ILS and VOR radio navigation equipment using drones represents a significant advance in the field of flight inspection. Thanks to an in-house development by the DGAC's flight inspection team, the dedicated Android software and compliance with flight authorizations and operational risk assessment, this method offers a solution that is consistent with measurements carried out in aircraft. In addition, this method enhances efficiency and safety to guarantee the reliability of radionavigation installations, thereby optimizing the work of ground teams and flight inspection.

The future of this solution promises even more remarkable developments. BVLOS (Beyond Visual Line of Sight) could be integrated, enabling drones to fly out of the operator's direct line of sight, thereby extending the possibilities of flight inspection. In addition, the integration of VTOL (Vertical Take-Off and Landing) drones, capable of a flight autonomy of more than 2 hours, opens new prospects in terms of mission duration and range. These future developments will further enhance the effectiveness and flexibility of flight inspection of radio navigation systems.

Photo 3 : VTOL, Future of drones ?

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Air traffic controlers from Tarbes, Toulouse, Limoges, Toussus-le-Noble, Martinique Airports