CNS Drone SkyRF® measurement system maturity, evolution ongoing

Hervé Demule, Skyguide

Domien De Ruyck, Intersoft Electronics Services

Hervé Demule
Navigation Engineer / Senior Project Leader
Skyguide, Swiss Air Navigation Services
Geneva, Switzerland
Tel: +41 22 517 41 27
E-mail: herve.demule@skyguide.ch

Domien De Ruyck
Managing Director
Intersoft Electronics Services
Zottegem, Belgium
Tel: +32 93 24 71 45
E-mail: domien.de.ruyck@intersoft-electronics.com

BIOGRAPHIES

Hervé Demule, navigation engineer and senior project leader at Skyguide, is an engineering graduate of SUPAERO (Ecole Nationale Supérieure de l'Aeronautique et de l'Espace, Toulouse/France) and has accumulated extensive experience with ILS troubleshooting, commissioning and optimization. As project manager of many navaid replacements as well as with development and commercialization of a mobile bench for ILS measurements (ground and air) he has proven his great expert skill in these fields. On the educational side, he is also a certified instructor and a technical speaker. The Skyguide CNS Drone SkyRF® is one of his innovations.

Domien De Ruyck graduated from the Royal Military Academy in Brussels with an M.Sc. in Telecommunications. As Managing Director of Intersoft Electronics Services, channeling 35 years of experience in developing RF measurement equipment and Radar Analysis Support Systems (RASS), he is committed to provide the best support to their partners worldwide – to make the sky safer.

ABSTRACT

After presenting the initial successful deployment at IFIS 2018, and the analysis of the first 4 years in operation at IFIS 2022, a second generation of the CNS Drone SkyRF® has been co-developed by Skyguide and Intersoft Electronics. The new transceiver by Intersoft Electronics is not only capable of measuring LOC, GP and DME simultaneously and in high resolution, but also VOR / DME, RADAR, and any other CNS equipment. All of this lighter (transport in checked flight luggage) and with extended autonomy and range.

We got very convincing results (with easier use and better efficiency), reaping the benefits of the previous ground work. The current degree of maturity allows for continuing the financial savings of more than 50% of flight inspection aircraft hours. The approval to reduce the flight inspection aircraft hours is maintained due to the continued excellent correlation to flight check measurements demonstrated to the Swiss regulators (civil and military).

This is only the starting point: the current CNS Drone SkyRF® is already prepared for autonomous and BVLOS flight and entering the flight check domain in the future. Furthermore, ICAO Doc 8071 about navaids testing is being adapted with significant contribution by our 6 years of experience.

ICAO DOC 8071 and its Recommendations with Regards to ILS

ICAO Document 8071 [1] "Manual on Testing of Radio Navigation Aids" provides general guidance on the extent of testing and inspection carried out to ensure that radio navigation systems meet the standards and recommended practices (SARPs) specified in ICAO Annex 10 [2].

The document describes the ground and flight testing in terms of periodicity, tolerances (in reference to the SARPs) as well as the respective relevant methods. Moreover, it suggests a nominal schedule, as a basis for the determination of an appropriate inspection intervals. However, it also raises the question of a possible extension of these intervals based on several criteria, such as for example a "good correlation between concurrent ground and airborne results". The next two figures show the relevant sections of Document 8071.

Correlation as the basis for extending periodicity

1.15.10 A typical basis for extending the interval between required measurements without degrading ILS integrity is correlation. Any individual measurement is normally expected to be repeatable over time without adjustments to the equipment. Correlation between ILS measurements made both on the ground and in the air at the same or nearly the same time is also expected. This places equal responsibility on ground and airborne personnel and helps identify common-mode measurement errors. An additional requirement to extend flight inspection intervals is the influence of near- and far-field environments on the signals. These effects can be determined with a flight inspection aircraft. The following paragraphs give illustrations of the correlation technique.

Figure 3: Extract from Document 8071 [1], Paragraph 1.15.10 "Correlation as the basis for extending periodicity"

Based on the above presented extracts, one can conclude that, in accordance with the recommendations given by ICAO in DOC 8071, the achievement of good correlation places the same, or at least similar weight on both, ground and airborne testing.

Furthermore, the latest update of document 8071 [1], published in 2018, opens up the possibility to use drones (RPAS / UAVs) for ILS measurements, in order to reduce the flight check periodicity. The next figure shows an excerpt of the relevant section from the latest revision of document 8071 [1].

Since 2022, the integration of drone check good practices into a new version of Document 8071 are discussed at the ICAO Navigation System Panel. The idea is to write and integrate some generic guidelines, based on existing drone check procedures deployed in experienced States, in particular in Switzerland with Skyguide.

SYSTEM MATURITY

Skyguide Experience

After the first successful tests in 2015 and the development phase in 2016 and 2017, the system has been deployed from 2018 for ILS preventive maintenance. Thus, it is very mature, with operational experience at Skyguide of more than six years, as well as being already the second-generation drone, measurements, procedures and handling have been further optimized, especially in regarding usability and versatility. This is a product developed by users (Skyguide ANSP) for users (ANSP, Airport, CNS maintenance organizations). It of course profits from the experience and the daily use of Skyguide Navigation engineers and maintenance technicians.

Intersoft Experience

Most of the major RADAR manufacturer buy their measurement tools from Intersoft Electronics, which has been selling RASS products for 35+ Years. In addition to RASS, CNS upgrade projects (PAR-80, PSR, SSR) are executed, and RADAR technology is provided. Drone development began only a few years ago, but 35+ years of RF experience were utilized to implement this. The same principles apply for RF transceivers used on the ground or on a drone.

Business Development

Not only in Switzerland, the ILS drone check concept has also been deployed operationally in Belgium by its Air Navigation Service Provider, Skeyes, end of 2022, FAA in USA and IE Luftfahrt und Service GmbH in Germany as from 2024. Moreover, many demonstrations and proofs of concept have been successfully conducted in the following countries for the following ANSP and events: Dubai Air Navigation Services, Portugal, USA for the FAA and the US Air Force, Germany, for the Belgian Air Force and Air Services Australia (with the first generation of the product), Airspace World Geneva in 2023 and 2024 (with ILS/DME and VOR/DME demonstrations)

SYSTEM DESCRIPTION

Drone

Drone agnostic solution

As the SkyRF measurement platform is a drone agnostic platform, multiple drone types can be used for CNS measurements. Table 1 containts the configurations that have been tested or are deployed in operations.

- A specific mounting system has been designed to secure the whole set of the embedded instruments and antennas.
- The improved design of the flying frames and drive systems allows you to fly more efficiently and stably, even in extreme conditions.
- The drones are able to carry at least 2kg and keep a flight time of minimum 30 minutes

Table 1. Tested and/or deployed drone configurations

Manufacturer	Type
DJI	M300 RTK
DJI	M350 RTK
Inspired Flight	IF1200A
Freefly Systems	Alta X

Figure 1A

Figure 1B

Figure 1C

Figure 1. Tested and/or deployed drone configurations. 1A. DJI M350, 1B. IF1200A, 1C. Alta X

Depending on the CNS application that needs to be measured, specific items are mounted to the drone. Some examples are:

- Antennas (including cabling to skyRF and customized holders based on the selected drone)
- Camera
- RF resistant blades

<u>Automatic Flights (Waypoints)</u>

The selected drones are navigating automatically, based on a preconfigured waypoint flight that precisely follows a programmed path. While it is always possible for the pilot to take on manual control at any moment of the operation, the automation concerns all the phases of the flight, including take-off and landing. This makes the measurements process much easier and precise as repeatability is not affected by the human factor. Each specific navigation needs to be configured once and then stored in order to be loaded and repeated at will.

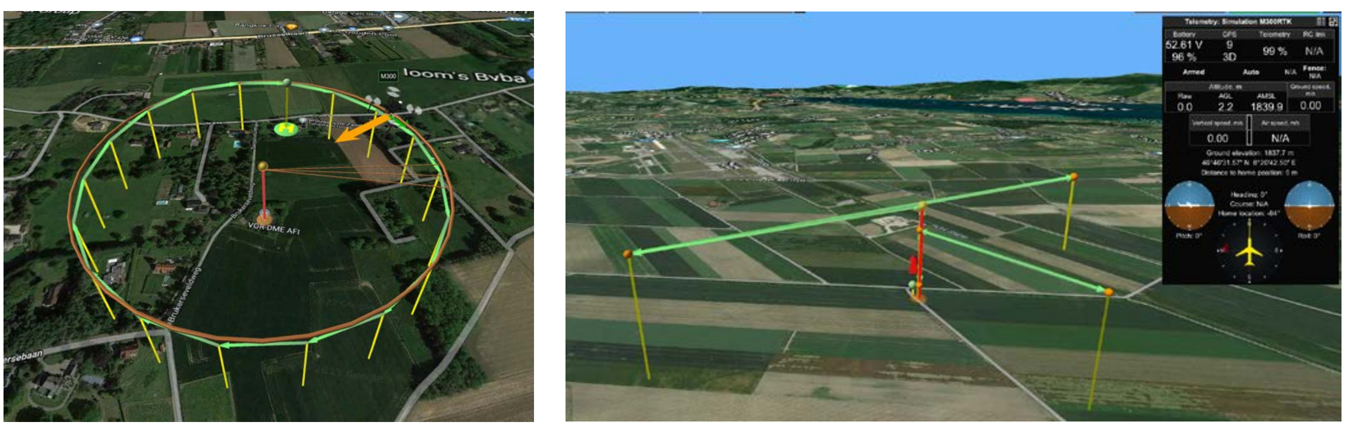

Figure 2. Illustrations of preconfigured waypoints in a general mission planning software

<u>Accurate Drone Location</u>

In order to provide high accurate measurements, the drone needs to deliver its position based on GNSS, enhanced with RTK[1] corrections. In the drones listed above, RTK is available on board. With this functionality, SkyRF can achieve centimer-level

[1] RTK = Real Time Kinetic

positioning accuracy by integrating the RTK corrections through an NTRIP[2] service. The following positional accuracy can be obtained:

- Horizontal: 1cm ±1ppm (RMS)
- Vertical: 2cm ±1ppm (RMS)

In most countries, a governmental funded network is available to provide information about D-GPS corrections. This network is called an NTRIP or RCMS network. You can connect to it through WiFi or mobile network. In case such a network is not available, the SkyRF drones can use portable stations to obtain an accurate position.

However, if the local NTRIP or global services are unavailable or not feasible, a base station is deployed at the flying location to ensure accurate and real-time corrections for optimal positioning. An RTK service is utilized to enhance aircraft positioning, often requiring the deployment of a base station at the flying location for effective differential corrections.

The base station communicates with GPS signals, and the drone receives both the signals and correctional position data from the base station. This results in highly accurate drone positioning, with precision up to 2 cm.

<u>Safety</u>

Based on the flight location, regulators require extra safety equipment mounted to the drones. Following solutions are available:

- FTS: Flight Termination System: It consists of the components onboard a vehicle that provide the ability to end that vehicle's flight in a controlled manner. The controller for the FTS is separate from the drone controller, but for some suppliers, it can be mounted physically on the controller.
- Parachute Solution: Optionally, a parachute can be mounted on the drone. When selecting the solution, following options are taken into account: autonomous deployment, lightweight, simple installation, reusable system.

<u>SkyRF Transceiver</u>

The SkyRF Transceiver, equipped with multiple Software Defined Radios (SDRs), can simultaneously measure multiple systems, such as an ILS Localizer, Glide Path and DME. Custom connectors, developed in-house, enable attachment to selected drones. Annual calibration is included as part of the maintenance procedure.

Figure 3. SkyRF Transceiver

<u>Connections</u>

[2] Networked Transport of RTCM via Internet Protocol

- Power ON/OFF button;
- 2 x SMA ports to capture the RF signals from the connected antennas;
- 1 x SMA port to connect an antenna for data exchange over Wi-Fi;
- Interoperability Link: The link between the SkyRF Transceiver and the drone exchanges data and power (24V);
- Optionally, this link provides an output to an antenna to connect to a cellular network. This allows a connection for BVLOS[3] measurements.

Network

Live monitoring of measured data is available on the ground station (laptop or tablet) via a Wi-Fi or cellular data connection. The SkyRF device records the data, ensuring no data is lost if the connection to the ground station is interrupted. When the connection is restored, live streaming resumes seamlessly.

To enhance security, a VPN solution can be implemented to protect the transmission between the drone and the computer.

Figure 4. SkyRF Monitoring

Software

Depending on the CNS application to measure, specific software is installed on the SkyRF and the ground station.

Table 2. Software per application

CNS Application	Software	Software Owner
ILS/DME	ILS/DME Drone Checker Software	Skyguide
VOR/DME	VOR/DME Drone Checker Software	Skyguide
TACAN	TACAN Software	Intersoft
PSR/SSR	Uplink and Downlink Module	Intersoft

[3] BVLOS = Beyond Visual Line Of Sight

CNS Application	Software	Software Owner
PAPI	PAPI Angle Measurement Software	Intersoft

<u>The ILS/DME Drone Checker Software</u>

Thanks a major upgrade in 2022 and 2023, the latest version of the ILS / DME Drone Checker software enables reprocessing capabilities and simultaneous measurements of the LOC, GP and DME with the following modes:

- GP/DME Vertical Profile

Positioned in the far-field region of the Glide Path, at a distance to the threshold of at least 1 km or 1.5 km, the UAV multicopter simply follows a vertical trajectory up to a height of approximately 80 m to 120 m. The idea is to reach an elevation angle of at least 4°, for a 3° Glide Path. The principle of this measurement mode is the same as the old one with the telescopic mast at the runway threshold. The only, but major, difference consists in conducting the measurement in the far-field instead of in the nearfield, which is very worthful for correlation purposes. Thanks to these "elevator" flights, the ILS DME Drone Checker software enables to calculate and display in live the following curves for Glide Path: DDM, SDM and RF Level versus Elevation Angle. Without any post-processing time, it also immediately computes the significant GP and DME parameters. As illustrated below, the Vertical Profile mode also enables to conduct the required measurements in normal and alarm conditions:

  - Lower and upper angle alarm conditions
  - Narrow and wide alarm conditions of the ¼ sector widths

Figure 5: The drone trajectory during the Vertical Profile mode

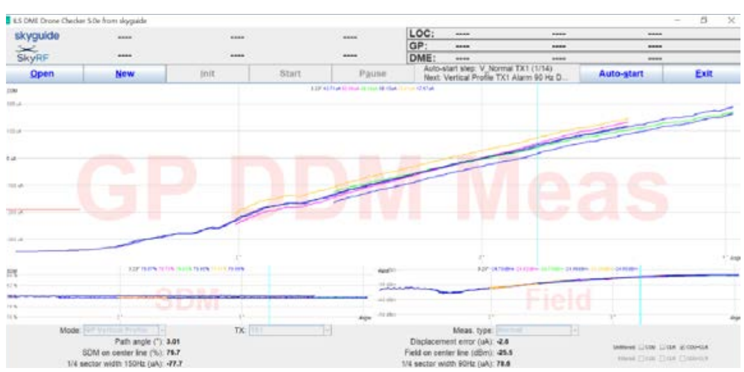

Figure 11: GP Vertical Profile mode in normal and alarm conditions: normal, lower, upper, narrow and wide alarms

Figure 6: DME Vertical Profile mode

- Mini Approach for simultaneous LOC, GP and DME measurements

The Mini Approach Mode consists in flying a segment of the approach path and measuring simultaneously the Localizer, Glide Path and DME signals, like any conventional flight check systems. Depending on the sites, the lengths of this approach segment vary today from 400 m to 800 m, in the short final region (typically in the area of point B, 1 km before the threshold). The length of these "Mini Approaches" flights may be increased in the future, depending on the battery autonomy, the UAV speed and of course the need for longer measurements. Better than the "vertical slice" measurements of the Elevation Profile, the Mini Approach mode computes **averaged** values of the key parameters, and thus enables an excellent correlation with the averaged flight check results in the same region. As illustrated below, the ILS DME Drone Checker software displays in live DDM course structures for Localizer (in the upper part of the window) and Glide Path (in the lower part) and DME (in a dedicated part). For accuracy and repeatability reasons, it compensates of course the trajectory errors in 3D. Without any post-processing time, it also immediately computes and averages the significant parameters for LOC, GP and DME.

Figure 7: The drone trajectory during the Mini Approach mode

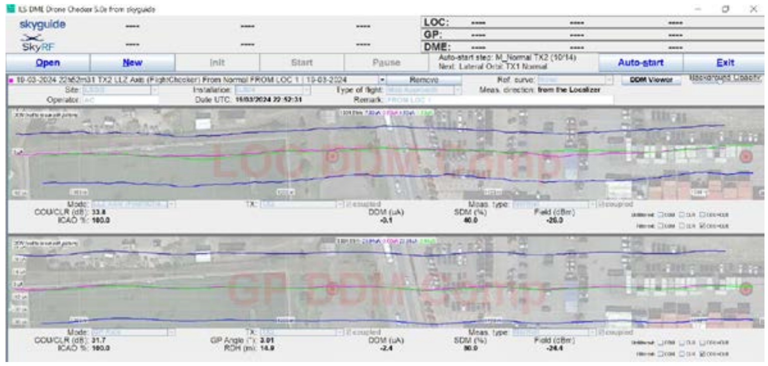

Figure 8: The ILS DME Drone Checker software in the Mini Approach mode (LOC in the upper part, GP in the lower part)

These averaged parameters such as DDM, GP angle, Course / Clearance ratio RDH are the ones, which can be compared and assessed for correlation with flight check, because they are measured in the same conditions. Finally, the Mini-Approach mode also enables to conduct the required measurements in (simultaneous) alarm conditions:

- o Left and Right alarm conditions for the Localizer
- o Lower and upper angle alarm conditions for the Glide Path

- Lateral Orbit for simultaneous LOC and DME measurements
  The software also offers the possibility to measure the linearity coverage of the Localizer in its farfield region. The UAV follows a circular or "orbit" trajectory centered on the LOC. Without any post-processing time, it immediately computes the significant parameters for LOC and DME

Figure 9: The drone trajectory during the Lateral Orbit mode

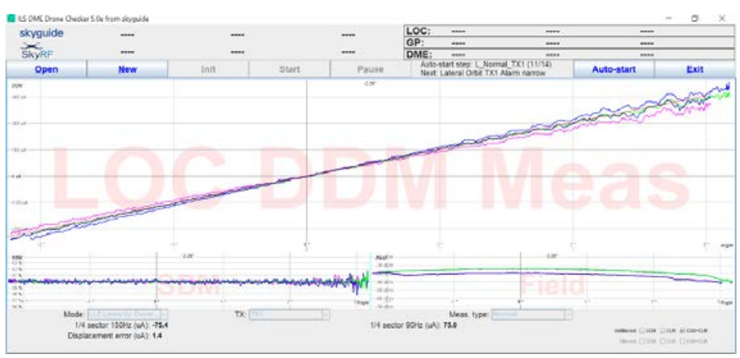

Figure 10: The ILS DME Drone Checker in the Lateral Orbit mode in normal and alarm conditions

Reproducibility

Dedicated GP Vertical Profile measurements under the same conditions have been conducted in order to assess and quantify the reproducibility of the measurements and the flight trajectories. The measured standard deviations [σ] for 15 UP measurements (in the ascending direction) and 14 DOWN measurements (in the descending direction) are as follows:

- maximum 1 µA for the GP angle parameter (0.005°)
- maximum 0.5 µA for the ¼ sector widths 90Hz and 150Hz parameters

These standard deviations of 1 µA and 0.5 µA, respectively, not only demonstrate but also quantify the excellent reproducibility. The key factor to achieve such excellent results is the very good flight path reproducibility.

Figure 11: GP Vertical Profile mode for fifteen UP measurements

Correlation as main criterion for flight check reduction

As mentioned previously in the introduction, according to ICAO DOC 8071 [1], the correlation between ground, drone and flights checks and between monitor and flight checks, are key to demonstrate equipment integrity, which could be used to argue for a change of the flight check periodicity and program. Over the last years, the NAV services of Skyguide collected data with ground as well as drone-based ILS measurements. It could be clearly concluded that this data collection and analysis demonstrate the ability to produce repeatable and quantifiable results, which not only correlate very well with the results from the flight checks, but also stay well within the tolerances set by ICAO.

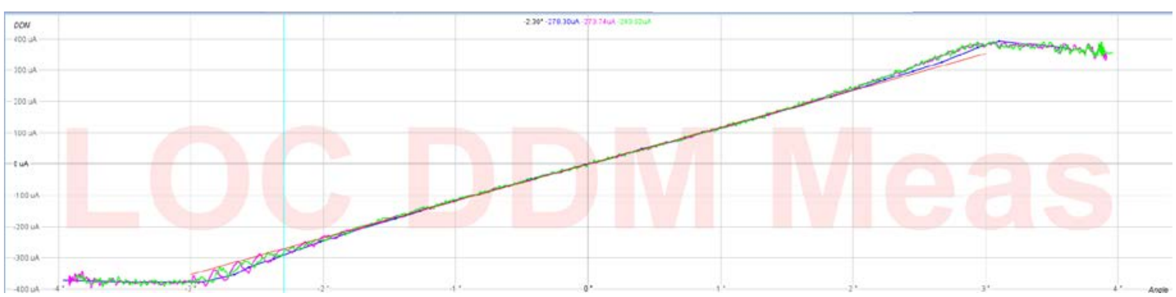

Figure 12: Correlation between flight (in blue) and drone check (in green and pink) for a LOC Linearity Coverage

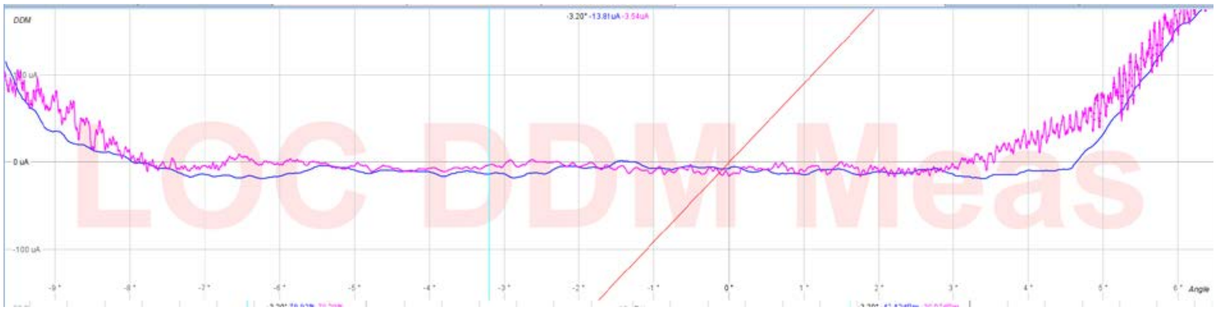

Figure 13: Correlation between flight (in blue) and drone check (in pink) for a End-Fire GP Transverse Structure

It has also been demonstrated that ground and drone checks are able to detect environmental effects and that, overall, they are as reliable as the results from flight checks. As proposed by ICAO Document 8071 and as the criteria mentioned in sections 1.15.8 and 1.15.9 are fulfilled, the Swiss regulators (civilian FOCA and military MAA) agreed to reduce the ILS flight check program.

The VOR/DME Drone Checker Software

- Orbit Mode for simultaneous VOR and DME measurements

The VOR/DME Drone Checker software offers the possibility to reprocess previous measurements and to measure simultaneously the VOR and DME signals along a circular orbit. Without any post-processing time, it immediately computes the significant parameters for VOR and DME: VOR azimuth error, AM Mod Depth 30 Hz and 9960 Hz, and DME error, as illustrated below:

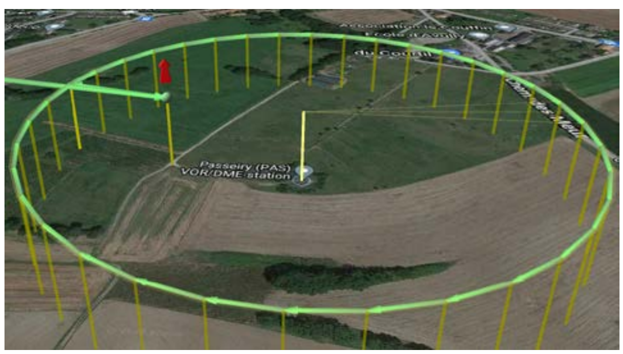

Figure 14: The drone trajectory during the Orbit mode

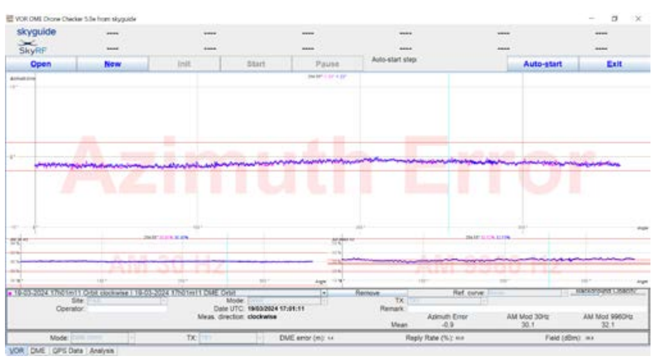

Figure 15: The VOR DME Drone Checker in the Orbit mode (VOR window)

Figure 16: The VOR DME Drone Checker in the orbit mode (DME window)

- Radial Mode for simultaneous VOR and DME measurements

The VOR/DME Drone Checker software also offers the possibility to measure simultaneously the VOR and DME signals along a radial trajectory (To and from the VOR, in both direction). Without any post-processing time, it immediately computes the significant parameters for VOR and DME: VOR azimuth error, AM Mod Depth 30 Hz and 9960 Hz, and DME error. Besides, it is also possible to overfly the VOR/DME and document its cone of silence.

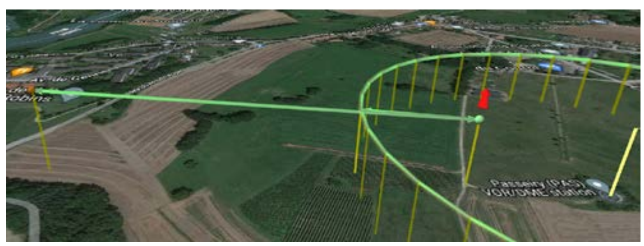

Figure 17: The drone trajectory during the Radial mode

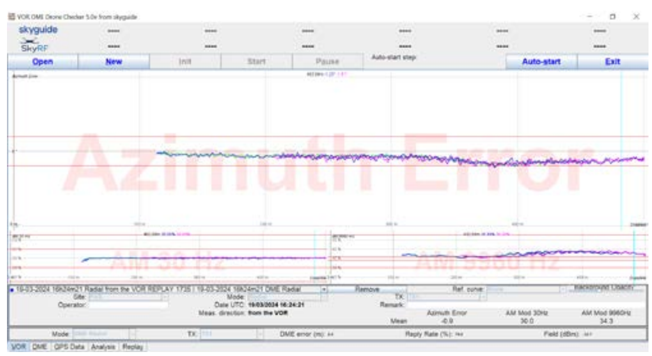

Figure 18: The VOR DME Drone Checker in the Radial mode (VOR window)

<u>Autonomous measurements</u>

The measurements are fully autonomous with autostart and stop function. Based on the location of the drone, the software automatically starts and stops the data measurement. As the ILS/DME and VOR/DME Drone Checker software are running on the processing PC aboard the drone, the system is fully autonomous and does require any measurement datalink to the ground PC. The ground PC "only" enables to follow the sequence of measurements.

Live monitoring of measured data is available on the ground station (laptop or tablet) via a Wi-Fi or cellular data connection. The SkyRF device records the data, ensuring no data is lost if the connection to the ground station is interrupted. When the connection is restored, live streaming resumes seamlessly

This is a major technical evolution which would already enable to conduct BVLOS (Beyond Visual Line of Sight) flights. The limiting factor is no more the technical capability, it is currently the flight authorization. Technically, the CNS Drone SkyRF® is BVLOS ready.

PAPI Angle Measurement Software

To maintain the correct trajectory, the aircraft should be at a 3° angle relative to the glidepath (GP). If the angle exceeds 3.2°, the aircraft is slightly high, and if it exceeds 3.5°, the aircraft is considered too high. Conversely, if the angle is below 2.8°, the aircraft is slightly low, and if it falls below 2.6°, the aircraft is considered too low.

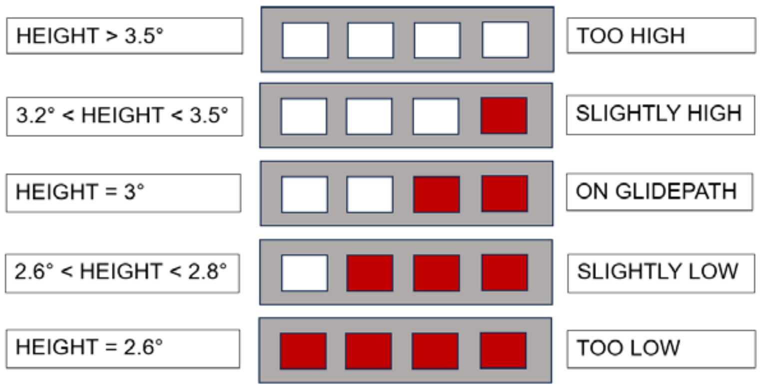

Figure 19: PAPI Tolerances

The drone is positioned at a distance of 300m from the GP. This implies that for each state of PAPI, the altitude needs to be calculated to verify the PAPI tolerances.

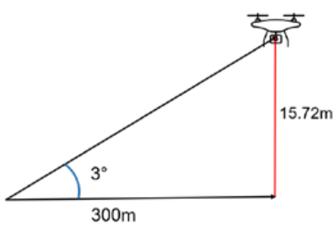

Figure 20: Distances

Figure 21: Vertical PAPI Flight Pattern

This table portrays the altitudes at each state:

State	Altitude (m)
Too high	< 18.35
Slightly high	16.77 < Altitude < 18.35
On glidepath	≈15.72
Slightly low	13.62 < Altitude < 14.67
Too low	>13.62

Table 3: PAPI States

Furthermore, for the horizontal coverage of PAPI, a specific horizontal path will be followed. In this context, the exact height and distance are not critical factors, as the necessary parameters have already been assessed through the earlier vertical path and, notably, the distance doesn't significantly impact PAPI operations.

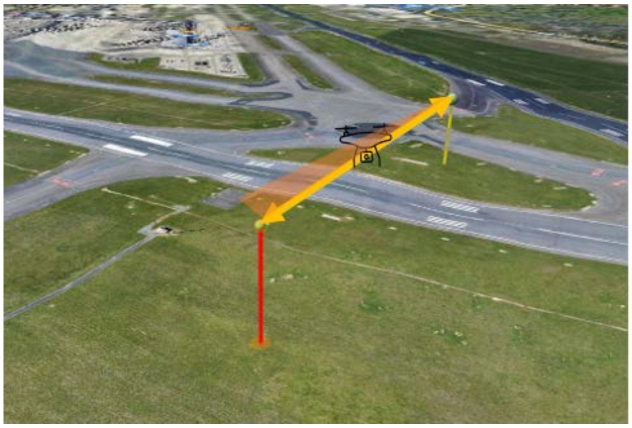

Figure 22: PAPI horizontal coverage

Recording the states is achieved by capturing images using an external camera with an 8k resolution, ensuring superior overall image quality. The images are equipped with EXIF data, which typically includes exposure settings, date and time, GPS location, altitude, and more. To ensure accurate detection for PAPI tolerances and angle transition, a frame rate of 30 images per second will be utilized. As a PAPI inspection flight takes about 2 minutes, 3600 pictures will be processed.

Classic image processing techniques utilizing light detection are employed. Pictures are transformed into binary images, and subsequent filtering processes such as erosion and dilation are applied to easily detect light spots.

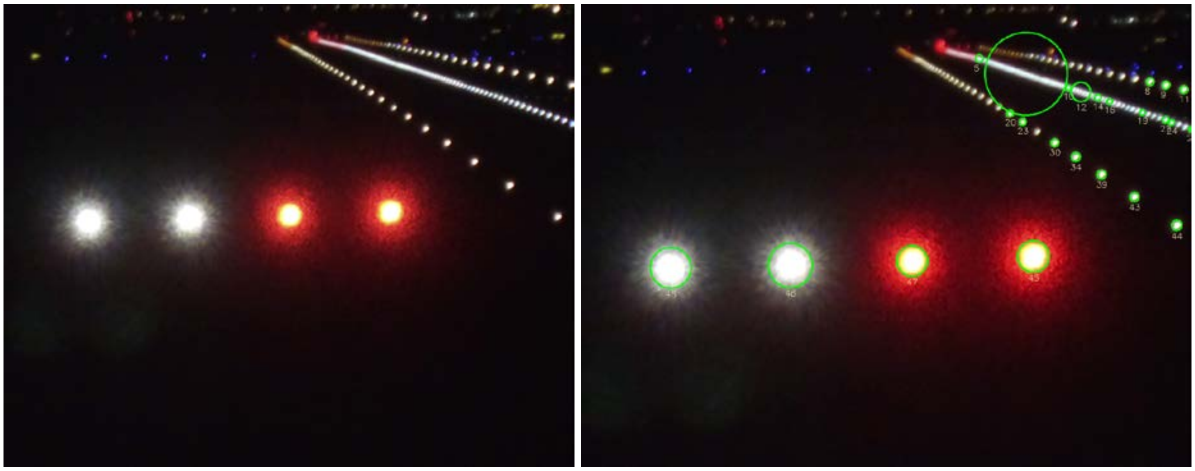

Figure 23: Image Processing

A trained AI model will detect the PAPI states and compare them based on the differential altitude at which the light states are detected.

An automatic LaTeX report is generated based on the measurements taken from the drone, outlining any potential issues encountered and performing various checks. These checks include verifying the correct states of PAPI at specific altitudes and determining their success. Additionally, a manual check can be conducted if necessary.

BENEFITS

There is a range of benefits making it worthwhile to operate this CNS Drone SkyRF®, from technical and quality to efficiency and financial.

Corrective Maintenance

In case of ILS/DME or VOR/DME outage or even in case of pilot complaints, the CNS Drone SkyRF® is an excellent short term solution. Very flexible and reactive, it can be deployed in few hours after an outage or complaint, in order to understand, diagnose and solve the issue, before the arrival of the flight check crew. In many cases, the intervention of flight check is no more needed. In Switzerland, a good concrete example is the repair of the VOR/DME "WIL" and its VOR antenna replacement within a few days. Thanks to the use the CNS Drone SkyRF®, the system could be pre-tuned and the re-commissioning flight check has been very efficient without any flight repetition because every parameter has been already perfectly adjusted.

Preventive Maintenance

In Switzerland, since 2018, the regular drone check measurements are fully integrated into the ILS/DME and VOR/DME maintenance schedules. They are conducted monthly for every CAT III ILS and quarterly for every CAT I ILS and VOR. They take only 15 minutes for a full ILS measurement program, including 6 vertical profile, 4 lateral orbit segments, and 4 mini approach segments. The essential vertical profile measuring the GP is only around 7 minutes, which can even be broken down into 2 minute parts, which could be done between flights, on very busy airports.

Pre-commissioning

Perfect preparation and pre-tuning for newly commissioned CNS equipment reduces the overall commissioning time, makes for an easier tuning as well as saving aircraft hours. This results in a less time-consuming and overall more efficient project, directly translating to lower costs.

A concrete example is the complex End-Fire Glide Path optimization and commissioning flight check: while it used to take around three weeks of repeated flight inspection aircraft passes for tuning and adjustments a few decades ago, checking and re-checking, this has continually been reduced in the last years:

- from three weeks a few decades ago to one week (a 18.3 hour flight check for the LSZH 34 End-Fire Glide Path in 2004) thanks to the ground check

- From 18.3 hours in 2004 to 7.8 hours in 2024 for the LSZH 34 End-Fire Glide Path in 2024 (approximately a 60% reduction) thanks to the drone check pre-commissioning. Indeed, no flight repetition has been needed because every parameter (glide path angle and width, transverse structure) had been perfectly tuned during the drone check pre-commissioning phase. It could not have been more efficient.

This almost unbelievable progression of time and cost savings shows that the great potential of these CNS Drone SkyRF® measurements can be realized in operations.

Airport Capacity und Flexibility of Operation

By having much shorter measurement times, compared to a flight inspection aircraft, the CNS Drone SkyRF® will also increase airport capacity for very busy airports, as the runway / ILS will not have to be closed as long. The drone check measurement can be broken down into 2-minute parts, which could be done between flights, on very busy airports.

ATC Operational Impact / Safety

The CNS Drone SkyRF® with its flight characteristics only occupies a small airspace volume in front of the ILS and does not need attention of the air traffic controller for any patterns within and around the airport area, as a flight inspection aircraft would. This reduced complexity results in additional safety and workload relief for ATC.

Environmental

Reducing the daytime and nighttime inspection aircraft flights results in less noise for the airport area, which is a much appreciated benefit in the political arena, especially for the two main airports in Switzerland (Geneva and Zurich).

As these airports have a night curfew, the lowest traffic times are between 23:00 and 06:00. Although the airport remains open, scheduled airline traffic is only allowed in exceptional cases in that timeframe. Since the flight inspection aircraft needs to fly unusual patterns, blocking a lot of airspace in the process, the preferred time to do this is when no other traffic (i.e. the aforementioned regular airline traffic) conflicts with those flight paths.

Obviously, this creates additional disturbance for the population living in the vicinity of those airports, which is neither healthy (preventing night-time sleep) nor politically desirable.

With the CNS Drone SkyRF®, Skyguide could avoid around 33% of daytime noise, and 67% of night-time noise, compared to the year 2020. This is also greatly appreciated by the local population and adds good-will towards the operation.

Additionally, there are also significant CO_2 savings, for which (among other contributions) Skyguide has received the Green ATM (level 3) badge from CANSO.

Transportability

Allowing for easy and safe transport of the CNS Drone SkyRF® and its payload, namely the SkyRF® transceiver and its associated antennas and fixtures (as well as the accessories, like the remote control, etc) has been a priority for this second-generation CNS Drone SkyRF®. Consequently, the selection of the drone platform included transport size and enclosure.

One of our selected drone platforms of choice is currently the DJI M300 / M350, fulfilling the positioning/connectivity and payload requirements, as well as being foldable for transport. Concretely, this drone can be folded to fit into a specially fitted and protected suitcase which can be checked in as airline luggage, in contrast to the first generation selected in 2015 – with its higher payload weight that drone has been heavier and bulkier. The remaining parts and accessories are then put into additional luggage.

Note: In the future, the integration may also be done onto drones beyond multi-copters, where the mission requires more capabilities than offered by those (e.g. fixed wing / vertical take-off, for extended range and higher speed).

Financial

As outlined in the list of benefits, the resulting financial advantages are distributed across a wide range, allowing for multiple interesting business cases, depending on the type of operation.

The concrete savings that have been realized across the board of all the benefits extend far beyond the maintenance organization, also going into the air navigation, airport, and environmental areas.

One of the main areas for maintenance **savings is the reduction of flight inspection aircraft hours:** due to the high quality of the CNS Drone SkyRF® measurements, the flight inspection aircraft hours could be **reduced by around 53%** on average, compared to the year 2020! Converted to money, the flight inspection hours saved have a value of more than EUR 20 000 yearly *per ILS* measured. This is the major business case used by Skyguide.

This reduction has been achieved by demonstrating the case to the competent authorities, using the data gathered in operation in all seasons, with statistical analyzes. The Swiss Civil Aviation Authority (Federal Office of Civil Aviation, FOCA), as well as the Military Aviation Authority (MAA) have both accepted this reduction which has also been approved by the flight inspection service provider as the certifying entity.

Not only is this reduction officially approved, but since Skyguide has now established a proven methodology for demonstrating this to the relevant entities, this can be replicated internationally, so any CNS Drone SkyRF® operation could benefit from recurrent savings like this.

Another major business case for very busy is the airport capacity increase by saving runway downtime. This applies especially to very busy 24-hour airports, where the ILS can be measured in-between flights, during times of low traffic. The savings potential in this case is even greater, as the flight inspection aircraft otherwise occupies time which could be used for many airline starting/landing slots.

CONCLUSION

After more than six years of successful operation and the subsequent ILS flight check reduction in Switzerland, the use of the CNS Drone SkyRF® has already been deployed internationally. The latest major evolution (autonomous measurements, increase of the autonomy and range, much better transportability and usability) represents a major step in the domain of the CNS maintenance. This second concrete step opens new horizons in term of CNS measurement techniques with extended range and BVLOS flights.

By entering more and more into the flight check domain, the CNS Drone SkyRF® defines the future of Navaids calibration.

REFERENCES

[1] ICAO, Document 8071 - Manual on Testing of Radio Navigation Aids, Montréal: International Civil Aviation Organization, 2019.

[2] ICAO, Annex 10 - Aeronautical Telecommunications - Volume I - Radio Navigational Aids, 7th edition, Montréal: International Civil Aviation Organization, 2018.

[3] IFIS 2018 paper from Hervé Demule and Klaus Theissen: "Using UAV multicopters as an extension of ILS ground measurements: This innovative idea has already become reality in Switzerland"

[4] Drones for ILS - Report 06/2020 from Hervé Demule, Christoph Brem, Pascal Schmid, Sven Gloor submitted to theSwiss Federal Office of Civil Aviation "Drones for ILS Measurements. Proposal to Reduce Check Flights".

[5] IFIS 2022 paper from Hervé Demule and Klaus Theissen: "Using UAV multicopters as a complement of ILS/VOR ground and flight measurements: our feedback and experience after more than four years of successful operations"