Using UAV multicopters as an extension of ILS ground measurements: This innovative idea has already become reality in Switzerland!

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BIOGRAPHIES

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Navigation Engineer / Project Leader

- Engineering graduate of SUPAERO: Ecole Nationale **SUP**érieure de l'**AERO**nautique et de l'Espace, Toulouse, France (university-level college for engineering in aeronautics and space).
- Navigation Engineer: ILS troubleshooting, commissioning and optimization: Conventional and optimized ILS, End-Fire Glide Path and slotted cable Localizer: certified instructor
- Project management in Navaids replacement
- Development and commercializaion of a mobile bench for ILS measurements (ground and air). Training and certification of the customers.
- Technical speaker at IFIS from 2006 to 2018.
- Trainer at the ENAC in Toulouse, France and at the skyguide Training Center

Klaus Theißen
Product manager for air navigation analyzers (Rohde&Schwarz, Germany)

- Diploma degree in electrical engineering (Dipl.-Ing.), 1993 - Technical University of Aachen, Germany
- Software development and digital signal processing for NavAids analysis
- Project management for R&S products (e.g. EVS300)
- Team leader for development of test systems and for development for air navigation receivers
- Papers and presentations at the IFIS between 2008 and 2018

ABSTRACT

Using UAV multicopters as an extension of ILS ground measurements: This innovative idea has already become reality in Switzerland!

By the end of 2015 in Geneva, the first successful trials with an UAV multicopter carrying an ILS receiver concluded the first stage of the feasibility study. Indeed, these very promising first ILS measurements provided skyguide engineers with many positive answers to their initial questions. Yes, it is possible and very purposeful to measure ILS signal in the farfield region with a multicopter. Yes, the stability and accuracy of the flight with a heavy and expensive payload were very acceptable. Yes, the accuracy and repeatability of the measurements fulfilled the expectations, and even much more. Yes, a very good level of correlation with flight checks has already been achieved.

Skyguide, the Swiss air navigation service provider, who had already developed a mobile bench for ILS ground measurements with a vehicle, has always put a lot of focus on ILS ground measurements techniques, in order to achieve the best possible repeatability and correlation with flight checks, as recommended by ICAO Document 8071.

For Localizers, skyguide had already successfully applied the "double" correlation technique between monitor data, ground and flight checks results. Indeed, for many years, the ground vehicle equipped with the skyguide software ILS Checker

interfaced to the ILS receiver R&S®EVS300 from Rohde&Schwarz and RTK GPS allowed for setting high standards in terms of LOC ground measurements.

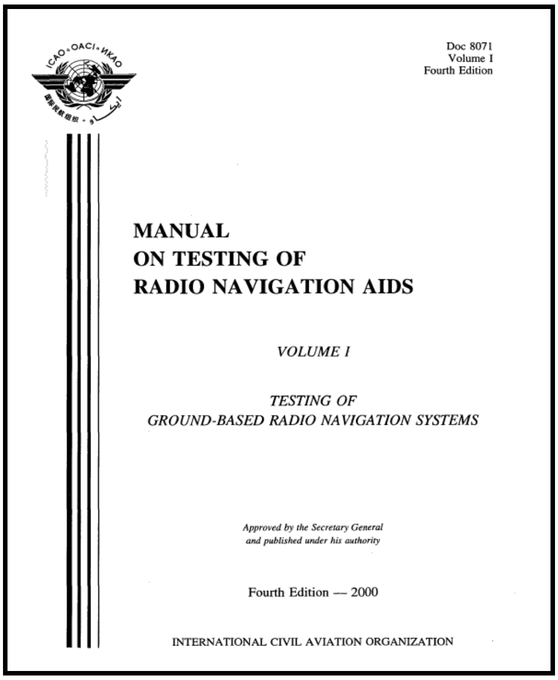
However, for Glide Path, the old fashioned method with a telescopic mast positioned at the threshold, thus in the nearfield region, has never reached an acceptable level of correlation with flight checks. Indeed, too close to the Glide Path, these measurements can only have a relative value, but no absolute value: if a change is detected in the nearfield, what will be the impact in the farfield? This question is nearly impossible to answer with such a technique.

The solution method is utilizing the measurement of the Glide Path at a distance of at least 1 km, thus it is required to lift the receiver to a minimum height of approximately 50 m, better 80 m if possible. Thus, UAV multicopter based measurements are the only way to meet this requirement and become simply necessary.

From the initial idea and concept to the implementation of a mature solution, this paper describes the development project, the multicopter based measurement system and its achievements in terms of repeatability and accuracy. Skyguide is now using an UAV multicopter with an R&S®EVSF1000 from Rohde&Schwarz for preventive and corrective ILS maintenance. It opens new horizons in term of ILS measurement techniques: for new ILS commissioning and replacement, it enables a very good preparation of the equipment before commissioning flight checks.

INTRODUCTION

According to the ICAO norms, ILS ground measurements for preventive maintenance are strongly recommended. Indeed, ICAO Document 8071 "Manual on Testing of Radio Navigation Aids" (Volume 1 Testing of Ground-Based Radio Navigation Systems) provides guidance on the extent of testing and inspection carried out to ensure that radio navigation systems meet the SARPs (Standards And Recommended Practices) in ICAO Annex 10. This document describes the ground and flight testing in terms of periodicity, tolerances (in reference to the SARPs) and methods.


Doc 8071
Volume I
Fourth Edition

MANUAL
ON TESTING OF
RADIO NAVIGATION AIDS

VOLUME I

TESTING OF
GROUND-BASED RADIO NAVIGATION SYSTEMS

Approved by the Secretary General
and published under his authority

Fourth Edition — 2000

INTERNATIONAL CIVIL AVIATION ORGANIZATION

Figure 1. Front Page of the current version of the ICAO Document 8071

Moreover, the current and future versions of Document 8071, especially paragraph 1.15 "Ground and Flight Inspection Periodicity" which contains nominal schedule, as a basis for determining the appropriate inspection intervals, raise the question of the possible extension of these intervals based on several criteria, such a "good correlation between concurrent ground and airborne results".

> **Determination of test/inspection intervals**
>
> 1.15.4 Many factors influence the choice of appropriate intervals for both ground and flight tests. These include the reliability and stability of operation of the equipment, the extent of ground monitoring, the degree of correlation between ground and flight measurements, changes in the operating environment, manufacturer recommendations, and the quality of maintenance. The complete programme of ground and flight inspections should be considered when determining test intervals.

Figure 2. Extract from Document 8071, Paragraph 1.15.4 "Determination of test/inspection intervals"

> **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, Paragraph 1.15.10 "Correlation as the basis for extending periodicity"

Thus, according to the ICAO recommendations, the achievement of good correlation places same or similar weight on both ground and airborne testing. That's why it is worth developing and using modern and accurate ground measurement techniques in terms of repeatability and resolution. Skyguide, in partnership with Rohde&Schwarz, had already developed such accurate and repetitive ground measurement tools and techniques. They had been described by the IFIS 2010 presentation "R&S®TS6300 ILS Test System, The modern automatic mobile bench for ILS ground measurements". Besides, the IFIS 2012 paper "How to get a good correlation between ILS ground measurements and flight checks? Thanks to modern and accurate ground measurement techniques this is a solvable challenge" had already initiated and documented this quest for correlation.

FROM IDEAS TO FIRST TRIALS

Systematic and automatic comparisons of the ILS ground measurements and flight checks have started in Switzerland in 2002. Thanks to the ground vehicle for Localizer measurements and the 22 m high telescopic mast for Glide Path measurements, a high degree of correlation had already been achieved, especially for Localizer. However, for Glide Path, these ground measurements, conducted at the runway threshold (approximately 300 m from the Glide Path), are too close and remain in the nearfield region. To reduce the unwanted nearfield effects it would be much better to conduct the measurements much further (at a minimum distance to the threshold of 1 km, ideally 1.5 km) and consequently much higher also (approximately at a height of 100 m). The first idea of a very high mast of 100 m aligned on the runway centerline has been of course quickly given up. The second idea consisted in using a balloon, in order to conduct elevator flights and measure elevation profiles. Due to the logistic difficulties in setting up such a system and its sensitivity to wind, this idea has also been given up.

WHY NOT USING AN UAV MULTICOPTER?

Thanks to the rapid progress in the UAV technology, it appeared feasible to carry our quite heavy payload (nearly 8 kg in 2015). Thus, after a first theoretical feasibility study, we decided to test this solution in Geneva in October 2015. The first assessment of the flight stability and control was very positive and encouraging. That's why we decided to trust this UAV and installed a measurement receiver and antennas on the drone. The goal was to conduct the very first trials of elevation profiles in the farfield region. Their very positive outcomes in term of accuracy, repeatability and correlation with flight check and ILS theory concluded the positive assessment of this new measurement method. This idea was no longer only a dream but became reality and opened new horizons in terms of measurement techniques.

Figure 4. Measurement results of the first trials (GP angle = 3.01°)

WHY USING AN UAV MULTICOPTER?

Correlation between ground measurements and flight checks

As described in the introduction, the achievement of good correlation places same or similar weight on both ground and airborne testing. However, using an UAV enables to extend the scope and possibilities of ground measurements. This new method is positioned right between the classical ground measurements on the runway inside the airport perimeter and the standardized and compulsory flight checks. The use of UAV represents an extension of the ground measurements tools, in order to achieve better and better correlation.

Localizer situation

Currently, ground measurements for Localizer are conducted with our vehicle equipped with a 5 meter mast. An excellent correlation between ground and flight has already been demonstrated for the Localizer. This has been the subject of the previous IFIS 2012 paper "How to get a good correlation between ILS ground measurements and flight checks? Thanks to modern and accurate ground measurement techniques this is a solvable challenge".

Figure 5. Measurement Vehicle in the Localizer Configuration

Repeatability

In order to assess the quality and the accuracy of a measurement system, repeatability is one of the key factors that has to be demonstrated and proved. Thanks to the GPS positioning, repeatability tests have been successfully validated:

- X-Axis (distance to threshold): The lateral accuracy of the vehicle positioning can be improved by current and validated satellite positioning techniques: GPS / SBAS or even GPS RTK (Real Time Kinematic) which ensures a much better accuracy (typically a 2 - 3 cm horizontal accuracy)
- Y-Axis (DDM): If the operator activates the compensation of the vehicle trajectory, the measurement system behaves like any mobile flight inspection system. Then, the result of the measurement (averaged DDM along the centerline) does not depend on the driver any more, but only on the Localizer signal in space. In these conditions, such a repetitive ILS test system enables to detect any small change (smaller than 0.5 µA) of the Localizer itself. Besides, these ground measurements correlate very well with the field and integral monitors.

High resolution and accuracy

With a sampling rate of 100 measurements per second, the R&S®EVS300 ILS/VOR Analyzer and its successors, the R&S®EVSF1000 and the R&S®EVSG1000 analyzers, provide a very high resolution: for the LOC modes, if the ground speed of the vehicle is 60 km/h (37 mph), the distance between samples is only 17 cm (6.5 inches). Whereas this inter-sample distance can be more than 8 m (27 feet) for an aircraft flying with a speed of 300 km/h (186 mph) and with a typical current sampling rate of 10 Hz. With a spatial resolution of 17 cm, this ILS test system is able to capture and measure high frequency phenomena and perturbations.

Correlation

The Localizer Course Structure mode along the runway centerline already shows a high degree of correlation for:

- The displacement error: a correlation better than +/- 0.5 µA
- The SDM on centerline: a correlation better than +/- 0.5 %
- The Course Alarms (averaged value along the centerline): a correlation better than +/- 2 µA

The Localizer Coverage mode also shows a good degree of correlation for:

- The ¼ sector widths: a correlation better than +/- 5 µA. As the ground measurements are not really conducted in the farfield of the Localizer, these results may differ by approximately +/- 5µA. However, the further, the better. Thus, conducting these sector width measurements with an UAV before the runway threshold in the final approach segment will enable to meet farfield conditions and improve the correlation. This is where the UAV measurements in the air can bring high added value.
- The ¼ sector widths in alarms (wide and narrow) conditions: a correlation better than +/- 2.5 µA.

Glide Path situation

Till end of 2017, ground measurements for Glide path have been conducted with a 22 meter telescopic mast installed at the runway threshold. At a distance of approximately 300 m from the Glide Path, these measurements are performed in the Glidepath's nearfied and not in the farfield - what is obviously the case for flight inspections. As the measurement conditions differ, the comparability of the results is reduced. The ground results in the nearfield strongly depend on the geometry of the site: forward and side slopes of the terrain. Therefore, their correlations are seldom satisfying for Glide Path.

Figure 6. Telescopic Mast at the runway threshold

If a change is detected in the nearfield, what will be the impact in the farfield? This question is nearly impossible to answer with such a technique. This can only be solved by measuring the Glide Path at a distance of at least 1 km or better 1.5 km. It is required to lift and carry the ILS receiver to a minimum height of approximately 80 m, better 100 m if possible. Thus, UAV multicopter based measurements are the only way to meet this requirement and become simply evident and necessary.

THE DEVELOPMENT PROJECT

The study and concept phases: from October 2015 to February 2016

After the first successful feasibility tests of October 2015, skyguide has decided to launch an internal project, in order to enable the deployment of this new measurement technique for preventive and corrective ILS maintenance and also for ILS commissioning. During this study phase, the cost-benefit-analysis has demonstrated that the business case will become (very) positive, as soon as the amount of periodic flight check hours will be reduced. The idea behind this project is not to replace flight check, as this is simply impossible from technical and legal points of view. The idea is to reduce the frequency of periodic flight checks, by fulfilling the Document 8071 criteria.

The development, test and training phases: from March 2016 to December 2017

In March 2016, the decision of realization has been taken. The goal to be achieved is to have an operational system, ready to be deployed end of 2017. During this phase, skyguide has played a central coordination role between the different stakeholders, especially between the UAV supplier Altigator and the ILS receiver supplier Rohde&Schwarz. The three development project schedules and outcomes had to be synchronized and coordinated:

- The customized development of the UAV by Altigator, based on skyguide specifications,
- The development of the brand new R&S®EVSF1000 VHF/UHF Nav/Flight Analyzer from Rohde&Schwarz,
- The skyguide internal development of the measurement software, the so-called "Preflight Checker EVS 3.0"

During this phase, several tests of the new UAV features, the new ILS receiver and the new measurement software have been conducted: in November 2016, February 2017, June 2017 and July 2017.

In parallel to the technical development, five drone pilots have been trained, in order to be autonomous from November 2017. The handover between Altigator and skyguide pilots took place mid November 2017. Finally, a last repetition of the new maintenance procedures has been conducted in December 2017 and has validated this new measurement concept.

The deployment phase

From January 2018, the use of the UAV multicopter for regular preventive ILS maintenance has been successfully deployed on both international airports Geneva and Zurich. For all CAT III ILS, skyguide has decided to set a monthly periodicity, in order to collect many data and document the seasonal effects (temperature, humidity). After this first evaluation phase, the deployment on other regional and military airports is scheduled from second semester 2018. After an intensive phase of data collection in 2018 and 2019, a systematic evaluation of Document 8071 criteria (stability, correlation between ground, flight and monitor measurements) will be conducted and presented to the Swiss Regulator end of 2019. The goal is to get the approval to reduce the flight check frequency from 2020. The first results from beginning 2018 are already very promising.

DESCRIPTION OF THE SOLUTION

AltiGator has been manufacturing professional RPAS (Remote Pilot Aircraft Systems) for highly challenging applications, since 2008. Based on this experience, the OnyxStar® ATLAS UAV used for this project has been tailor-made following Skyguide's requirements:

- A robust structure was designed to be able to embark the Rohde & Schwarz receiver, while still keeping an optimized aircraft size for transportation;
- The airframe of the ATLAS has been engineered in order to provide enough ground clearance to embed the ILS receiver with its antennas;
- Ensuring the best stability during the landing phase was essential in this application, involving this kind of equipment;
- A specific mounting system has been designed to secure the whole set of the embedded instruments and antennas;
- The high performance propulsion system of the aircraft, combined with strong batteries provides sufficient power to carry the payload while still having enough flight time to perform the measurements;
- Special care has been taken to protect the electronic parts of the UAV, to ensure mission fulfillment under demanding operational conditions;
- The navigation is based on GPS RTK positioning in accordance with the accuracy and repeatability requirements of the project.

The OnyxStar® ATLAS is 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 7. The UAV multicopter during the night tests in Zurich

The R&S EVSF1000 VHF/UHF Nav/Flight Analyzer

The R&S®EVSF1000 is a two-channel signal level and modulation analyzer (e.g. for simultaneous Localizer and Glidepath measurements). It is designed to be installed in flight inspection aircraft, a measurement car or aboard of a drone. It performs measurements on ILS, VOR and marker beacon ground stations e.g. during startup, maintenance and servicing and is also able to analyze ATC COM signals.

The R&S®EVSF1000 delivers precise, high-sensitivity analyses in the frequency range from 70 MHz to 410 MHz. Its hardware and software are largely identical to that of the R&S®EVSG1000 VHF/UHF Airnav/Com Analyzer, which is designed for ground measurements. The identical performance of the two instruments ensures that results obtained in flight, aboard of a drone and from the ground are comparable, as stipulated by the ICAO standards.

Figure 8. The R&S®EVSF1000

The R&S®EVSF1000 offers an extremely wide dynamic range that is achieved by means of switchable preamplifiers and selectable attenuators in combination with a high-level mixer. An integrated calibration generator with high long-term stability ensures accurate level measurements.

Due to its high sensitivity, low noise figure and narrowband filters, the R&S®EVSF1000 is able to deliver highly precise results even at large distances from the transmit system with the resulting low levels. The R&S®EVSF1000 also offers a wide input level range and steep-edged preselection filters that provide optimized interference rejection for ILS, VOR, marker beacon and COM measurements. As a result, the instrument features high intermodulation suppression and immunity to interference and can deliver reliable measurements even in the immediate vicinity of FM transmitters.

By using digital signal processing, the R&S®EVSF1000 offers outstanding accuracy during modulation analysis. The input signal is sampled at the IF using a high-precision analog-to-digital converter. FPGA technology is used to process results in realtime with the highest degree of reproducibility.

The R&S®EVSG-K1 option makes it possible to measure both carriers of a dual-frequency (2F) ILS system independently and simultaneously. The IF bandwidth of the adaptive filters for the carriers can be set down to 1 kHz to optimize the signal to noise ratio. The level and modulation values of each carrier (course and clearance) are measured and analyzed at the same time. This means that each carrier can be measured without switching off the other carrier. This approach also allows users to determine the phase relationship between the 90 Hz and the 150 Hz AF tones of the single carriers.

Its compact dimensions (95 mm × 177 mm × 360 mm) and low weight (3.7 kg) make the R&S®EVSF1000 ideal for integration to a measurement drone. The mechanical design of the R&S®EVSF1000 meets the requirements of RTCA DO-160G/Section 7.0 with respect to shock and the requirements of RTCA-DO160G 8.5.2 with respect to random vibration. The robust mechanical design and the excellent sensitivity of the two signal processing units make it ideal for parallel measurements of Localizer and Glide Path.

The R&S®EVSF1000 can be directly connected to the on-board system's DC power supply (11 V to 32 V). The instrument comes with an integrated power supply that bridges short-term interruptions (RTCA DO-160G, Section 16, Category A, DC power interruptions up to 200 ms) and fluctuations in the on-board supply voltage, so that they will not affect the mission or measurement accuracy.

The R&S®EVSF1000 can process up to 100 data records per second, making it possible to determine and analyze effects such as scallops and bends. Using an external (RTK) GPS, the instrument automatically links each data record to the correct GPS time- and location-stamp. The R&S®EVSF1000 records all measured data with the internal data recorder and is able to transmit this data at the same time via its LAN interface (streaming).

Thus the R&S®EVSF1000 base configuration includes all functions essential for drone and flight inspection and can determine characteristic system parameters – such as modulation depth, DDM and SDM – with high precision at a rate of 100 data records/s. Additionally it measures and decodes the identifier of the station under test and returns the ID pulse repetition rate, the ID code and the dash, dot and gap lengths. Spectrum and signal analysis options are available in addition.

The Preflight Checker software

During the last ten years, skyguide engineering and maintenance teams have gained experience and trust in its ground measurements system, composed of an ILS vehicle, a telescopic mast and its associated software ILS Checker. This in-house developed software enables the compensation of the vehicle trajectory in 2D along the runway centerline.

In 2014, the first version of the so-called Preflight Checker software with 3D trajectory compensation has been also internally developed, in order to enable pre-commissioning measurements of Glide Path. Indeed, it has been then possible to measure LOC and GP signals in the farfield aboard of a general aviation airplane for example. This has been the basis of the next software versions with the use of an UAV from 2015.

After the successful trials with an UAV in October 2015 and the decision of project realization in March 2016, an intensive phase of software development took place in spring and summer 2017. Thanks to this major upgrade, the latest version 3.0 of the Preflight Checker software enables now the following measurement modes associated to the UAV:

- Vertical Profile of the Glide Path:

Positioned in the farfield 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 farfield instead of in the nearfield, which is very worthfull for correlation purposes.

Figure 9. Picture of an "elevator" flight for a Vertical Profile measurement

Thanks to these "elevator" flights, the Preflight 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 parameters:

- Glide Path angle: 3.02° for the example below
- Displacement Error: -4.3 µA
- Both ¼ sector widths: -73.6 µA on the 150 Hz side and 74.7 µA on the 90 Hz side
- SDM: 80.0%
- and RF Level on centerline: -35.0 dBm

Figure 10. The Preflight Checker software in the Vertical Profile mode

As illustrated below by Figure 11, the Vertical Profile mode also enables to conduct the required measurements in alarm conditions:

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

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

- Mini Approach for simultaneous Localizer and Glide Path measurements

After the successful development and tests of the Vertical Profile mode, the second idea has consisted in flying a segment of the approach path and measuring simultaneously the Localizer and Glide Path 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.

Figure 12. Picture of a Mini Approach flight of the UAV

As illustrated below, the Preflight Checker software displays in live DDM course structures for both Localizer (in the upper part of the window) and Glide Path (in the lower 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 following parameters for LOC and GP:

- DDM displacement error
- SDM
- RF level
- Course / Clearance ratio
- ICAO percentage of the course structures
- Glide Path angle and RDH (Reference Datum Height above the runway threshold)

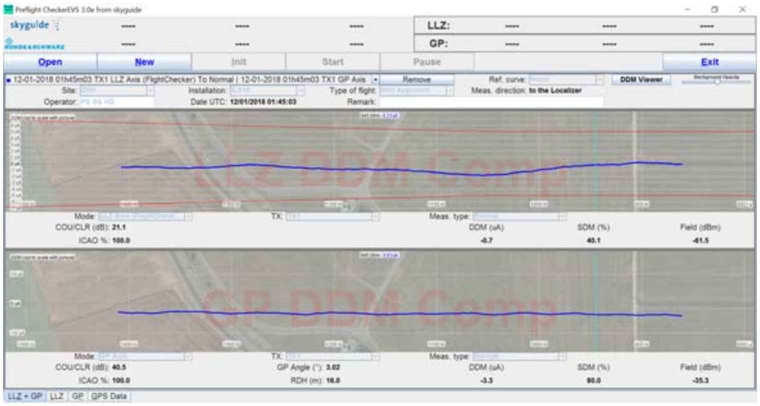


Figure 13. The Preflight Checker software in the Mini Approach mode (LOC in the upper part, GP in the lower part)

The software also offers the possibility to analyze especially the Localizer only and Glide Path only measurements. As illustrated below by Figures 14 and 15, the following curves are displayed and can be interpreted, in order to assess the accuracy of the UAV trajectory and thus the quality of the measurements:

- DDM Comp: the compensated DDM. This is the measured DDM compensated by the UAV trajectory (the blue curve in the upper part of the window)
- DDM Meas: the measured DDM from the ILS receiver (below the blue curve in the middle part)
- DDM Ref: the artificial "trajectory" DDM based on the UAV positioning (below the red curve in the middle part)
- SDM and RF Level in the lower part of the window.

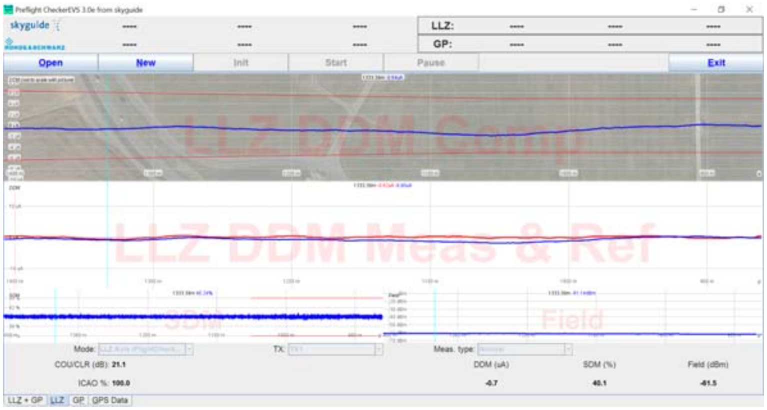


Figure 14. The Preflight Checker software in the Mini Approach mode: the Localizer only window

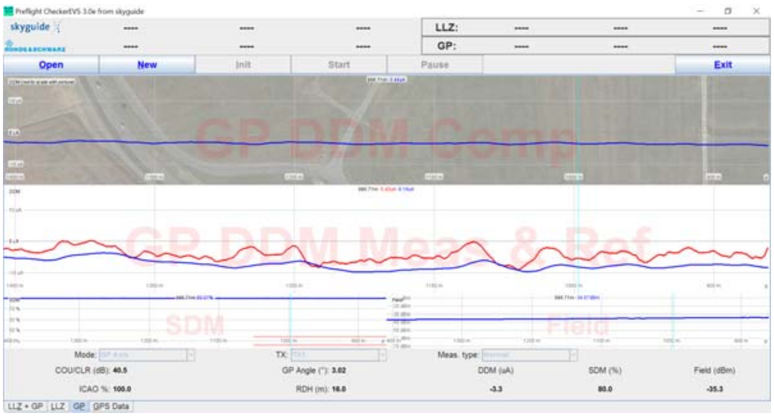


Figure 15. The Preflight Checker software in the Mini Approach mode: the Glide Path only window

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, as illustrated below by Figure 16, 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

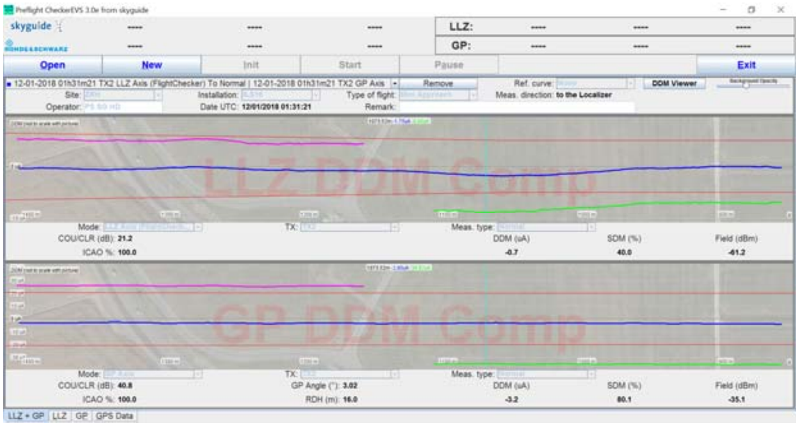


Figure 16. The Mini Approach mode in (simultaneous) alarm conditions

- Lateral Orbit of Localizer

  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 following parameters for LOC:
  - o Displacement Error: -0.1 µA below
  - o Both ¼ sector widths: -72.8 µA on the 150 Hz side and 73.2 µA on the 90 Hz side

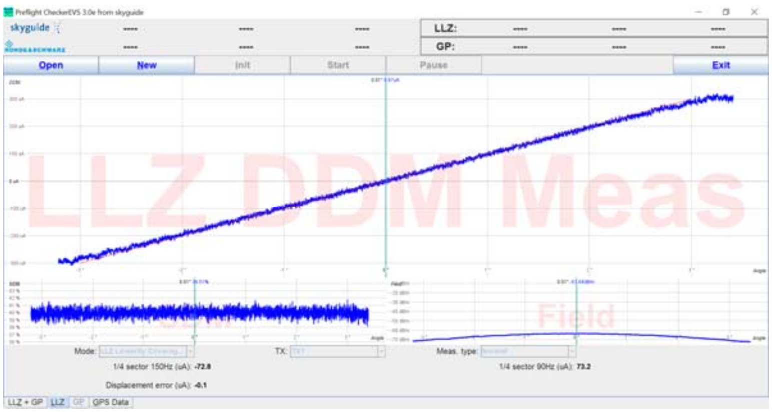


Figure 17. The Preflight Checker in the Lateral Orbit mode

The Lateral Orbit mode also enables to conduct the required measurements in narrow and wide alarm conditions of the Localizer ¼ sector widths.

Drone operations

From January 2018, the regular so-called "ILS Drone Maintenance" are performed in Geneva and Zurich international airports exclusively during the night, after the airport closure. Per ILS, (only) three UAV flight runs of maximal ten minutes are required:

- First run: Vertical Profile for Glide Path only, as illustrated above by Figures 10 and 11 (maximum 10 minutes long)
  - o First UAV ascent: TX1 normal,
  - o First UAV descent: TX1 lower alarm,
  - o Second UAV ascent: TX1 upper alarm ,
  - o Second UAV descent: TX1 narrow alarm,
  - o Third UAV ascent: TX1 wide alarm ,
  - o Third and last UAV descent: TX2 normal, finally automatic landing.

- Second run: Mini Approach for LOC and GP on TX1, as illustrated above by Figures 15 and 16 (maximum 10 minutes long)
    - First short Mini approach: LOC and GP in alarm conditions 90 Hz dominant (low angle),
    - Second long Mini approach: LOC and GP in normal conditions,
    - Third short Mini approach: LOC and GP in alarm conditions 150 Hz dominant (high angle),
    - Finally automatic landing.
- Third run: the same Mini Approach run as the second one but TX2

The total duration time of a full maintenance is shorter than one hour. In a first step, by conducting the measurements after the airport closure, we have of course decided to focus ourselves on the measurements itself, and not on the tower and traffic coordination. It is indeed easier and safer for ATC and for us. However, in a second step, on regional airports it might be feasible to conduct a 10 minute run (or shorter) in a dedicated slot between two arriving aircrafts. From second semester 2018, skyguide plans indeed to also deploy this UAV solution on regional airports.

ACHIEVEMENTS

Repeatability

In order to assess the repeatability of this system, the first measurements from January and February 2018 are compared in the following figures and tables.

- Vertical Profile of the Glide Path

The repeatability of the first Vertical Profile measurements is already very good, as documented by Table 1 and Figures 18 and 19:
    - maximum +/- 0.3 µA for the GP angle (+/- 0.0014°),
    - maximum +/- 0.2 µA for the ¼ sector widths (+/- 0.001°).

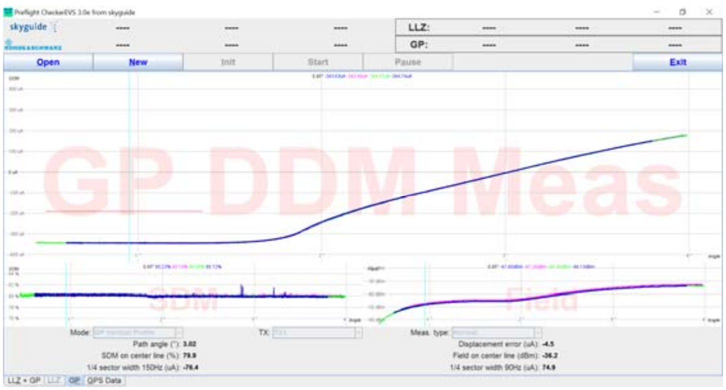


Figure 18. Repeatability Assessment for the Vertical Profile mode (4 curves: TX1/TX2 in January/February 2018)

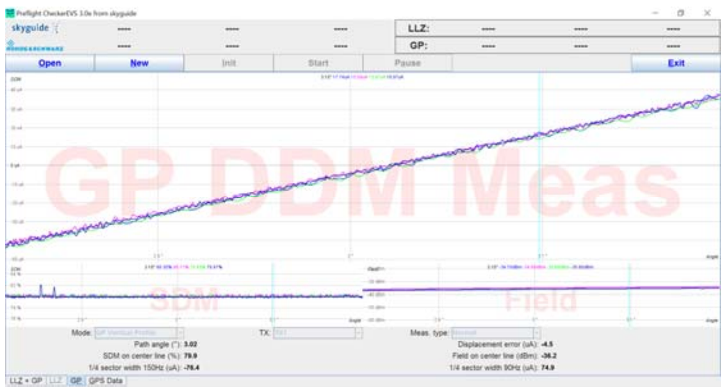


Figure 19. Repeatability Assessment for the Vertical Profile mode (zoom +/- 40 µA)

	TX1 January 2018	TX1 February 2018	TX1 deviation	TX2 January 2018	TX2 February 2018	TX2 deviation
GP angle in degrees	3.02°	3.02°	**+/- 0.0005°**	3.02°	3.02°	**+/- 0.0014°**
Displacement error in uA	-4.3 µA	-4.5 µA	**+/- 0.1 µA**	-5.0 µA	-5.6 µA	**+/- 0.3 µA**
¼ sector width 150 Hz in uA	-76.3 µA	-76.4 µA	**+/- 0.1 µA**	-75.9 µA	-75.9 µA	**0 µA**
¼ sector width 90 Hz in uA	74.7 µA	74.9 µA	**+/- 0.1 µA**	74.8 µA	74.5 µA	**+/- 0.2 µA**

Table 1. Repeatability Assessment for the Vertical Profile mode

- Mini Approach for LOC and GP

The repeatability of the first Mini Approach measurements is also already very good, as documented by Table 2 and Figures 20 and 21:

  - maximum +/- 0.1 µA for the LOC displacement error,
  - maximum +/- 0.1 µA for the GP displacement error and thus +/- 0.0005° for its associated GP angle.

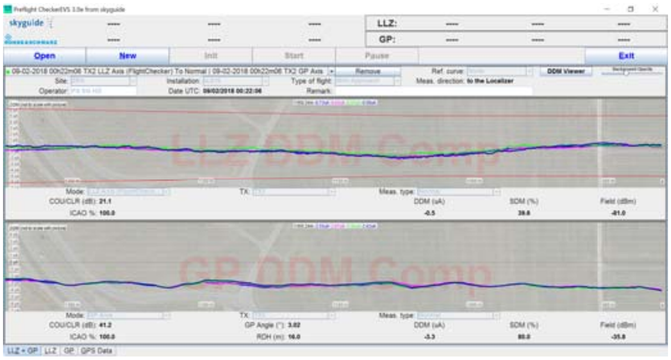


Figure 20. Repeatability Assessment for the Mini Approach mode (4 curves: TX1/TX2 in January/February 2018)

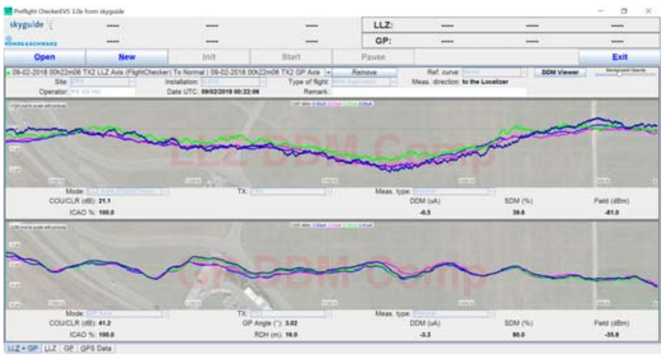


Figure 21. Repeatability Assessment for the Mini Approach mode (zoom: +/- 2 uA)

	TX1 January 2018	TX1 February 2018	TX1 deviation	TX2 January 2018	TX2 February 2018	TX2 deviation
LOC Displ. error in uA	-0.7 µA	-0.5 µA	**+/- 0.1 µA**	-0.7 µA	-0.5 µA	**+/- 0.1 µA**
GP angle in degrees	3.02°	3.02°	**+/- 0.0005°**	3.02°	3.02°	**+/- 0.0005°**
GP Displ. error in uA	-3.3 µA	-3.2 µA	**+/- 0.1 µA**	-3.2 µA	-3.3 µA	**+/- 0.1 µA**

Table 2. Repeatability Assessment for the Mini Approach mode

One of the main reasons of this very good repeatability of the ILS measurements is the accuracy and the repeatability of the UAV flight itself. Indeed, it manages to follow a defined trajectory with the accuracy of +/- 50 cm in both horizontal and vertical directions, as illustrated below by Figure 22.

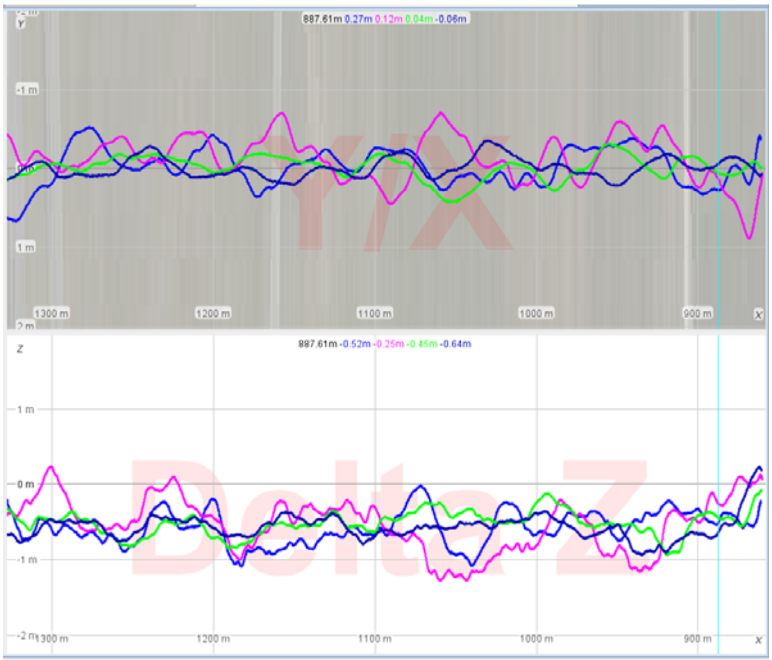


Figure 22. Assessment of the UAV flight accuracy and repeatability (zoom: +/- 2 m)

Correlation

In order to demonstrate the compliance to ICAO Document 8071 in term of correlation, skyguide has put in place a new ILS maintenance concept, by integrating these new UAV measurements. The new maintenance datasheets systematically integrate the "double correlation" principle, by comparing the latest flight check results with:

- the ground measurements, done either by the UAV multicopter or by the ground vehicle or both (for example with LOC course structure and alignment alarms)
- and the monitor data from the ILS itself

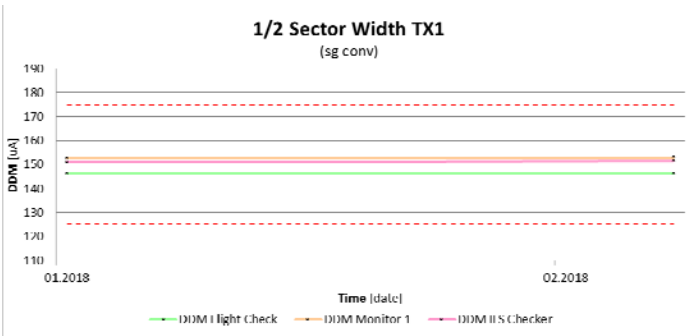


Figure 23. GP maintenance datasheet for correlation assessment

The upper part of Figure 24 below illustrates the very good correlation for GP Mini Approach between flight check (in blue) and UAV measurements (in pink). Their averaged values of the GP angle and the associated displacement errors are exactly the same: 2.99° and 2.0 uA. The red curves in the lower part illustrate the flight trajectories in the vertical plan: it has to be noticed that the UAV trajectory (+/- 4 µA) is more accurate than the flight check one (+ 20 µA max), which explains a better repeatability for the UAV measurements.

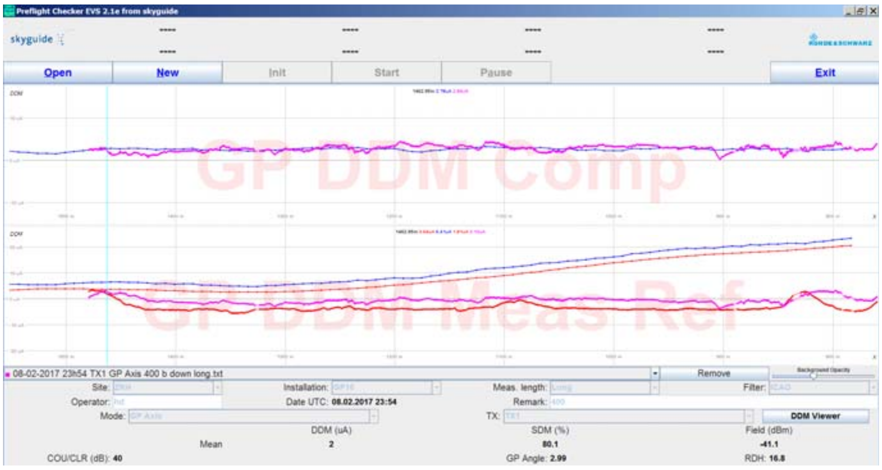


Figure 24. Correlation between flight check (in blue) and UAV measurements (in pink) for Mini Approach

NEW MEASUREMENT TECHNIQUES

As documented above for the regular preventive maintenance, the use of UAV multicopters also offers new possibilities for the preparation of ILS commissioning and also in case of corrective maintenance.

Preparation of ILS commissioning

Thanks to the use of the UAV and its farfield measurements, it is now possible to accurately conduct ILS pre-commissioning, especially for the Glide Path part. Before the use of the UAV - as it used to be impossible to predict the Glide Path angle and width - the corresponding flight check measurements had to be repeated, after each re-adjustment. This biggest unknown can now be accurately prepared and controlled by UAV measurements. Consequently, after such an accurate preparation, it should not be needed to repeat any flight check runs.

Corrective Maintenance

In case of pilot complaints and / or corrective actions, especially for Glide Path, it is now possible to assess accurately the ILS signal in the farfield region. In some cases (still to be defined: GP antenna, power amplifier replacements …), the UAV measurements, if repetitive and similar to the situation before the change, can document and prove the correct repair and thus enable the release of the system to operations. For Glide Path, without such UAV measurements, the situation used to be very unclear and the use of flight checks were necessary.

OUTLOOK AND CONCLUSION

In order to fully exploit the unique functionalities of the R&S®EVSF1000, further developments of the UAV measurement system are already scheduled for end of 2018. Not yet available with the version 3.0, the following improvements will be implemented for deeper analysis and investigations:

- Display of the unfiltered or / and filtered signals,
- Display of the Course only, Clearance only or Course + Clearance signals, in order to identify the source of the interference.

Besides, it is already scheduled to extend the use of the UAV multicopter for new types of measurements:

- VOR measurements: orbit and radial flights for preventive, corrective maintenance or preparation of commissioning
- Direction Finder
- Radar: measurement of the antenna diagrams
- PAPI calibration

Figure 25. The UAV multicopter over a VOR

After a few months of successful operation, the use of the UAV multicopter already represents a major step in the domain of the ILS maintenance. However, its current concept of operation and measurement is not frozen and still evolving with new ideas. This first step opens new horizons in term of CNS measurement techniques.

REFERENCES

IFIS 2010 presentation from Hervé Demule and Klaus Theissen: "R&S®TS6300 ILS Test System, The modern automatic mobile bench for ILS ground measurements"

IFIS 2012 paper from Hervé Demule and Klaus Theissen: "How to get a good correlation between ILS ground measurements and flight checks? Thanks to modern and accurate ground measurement techniques this is a solvable challenge"