# Efficient Navaid Inspection with Drones

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## ABSTRACT

A cornerstone of safe, reliable, and efficient aviation is the use of periodically calibrated navigational aids (navaid). Flight and ground inspections ensure the reliable operation of navaids within tolerances set by international regulatory frameworks. Small uncrewed aircraft systems (UAS) have become a valuable tool complementing both types of inspections, thereby reducing required flight times and/or inspection intervals of crewed flight inspections.

Small UAS can provide high accuracy measurements and results in the vicinity of navaids. These navaids include radio-based systems like ILS localizer and glide path transmitters, VOR, DME, or GBAS installations, and optical landing aids like VASI, PAPI, or runway lighting. The drone can conveniently operate on its pre-programmed flight path while the "crew" is safely located on the ground and controls the drone remotely.

The application of small UAS in the inspection of navaids requires a high level of commonality with legacy flight and ground inspections. This paper presents the UAS-based solution for navaid inspection as developed by the institution represented by the authors. To validate the commonality of flight and UAS-based navaid inspections, results from measurement campaigns are presented. Operational aspects regarding uncrewed flight and ground inspection are discussed and shared.

## INTRODUCTION

A key factor in aviation safety is the reliable and accurate operation of navigational aids (navaids). Their safe operation needs to be guaranteed by regular inspections and calibrations in order to fulfil international standards and recommended practices (SARPs) of the International Civil Aviation Organization (ICAO) and national regulations. As clearly described in [1], ICAO Annex 10 [2] and the ICAO Doc 8071 [3] allow for the utilization of uncrewed/unmanned aircraft sytems (UAS) for flight and ground inspection of such ground-based navigation aids for aviation.

Small UAS close the gap between ground and flight inspection (FI). For ground inspection of navaids, small drones can utilize the same receiver technology already in use for these kinds of checks. Instead of being operated from the ground, vehicles, or high masts, the inspection receiver and its antenna can be positioned directly and precisely at any chosen location for optimal measurements. In this way, all measurement locations necessary for navaid ground inspection as well as additional locations, can be reached flexibly and conveniently.

Small UAS with take-off masses of less than 25 kg are no substitute for flight inspection with crewed aircraft. Flight inspection and procedure validation must be oriented towards human pilots and their use of navaids and procedures. Thus, a human pilot has to be in the loop. Furthermore, the endurance and measurement capabilities of small UAS are limited compared to crewed flight inspection aircraft and associated FI procedures due to their size and achievable payload. Additionally, the measurement receivers/transceivers of crewed and small uncrewed aircraft are of different types. While crewed flight inspection aircraft should use measurement devices, which are based on aviation equipment according to [3], small UAS usually use scientific measurement equipment like the Rohde & Schwarz EVSD1000.

Thus, crewed FI aircraft use equipment which applies filtering for the aviation application while flying at significantly higher velocities compared to uncrewed aircraft. Thus, instead of replacing crewed flight inspection, specially equipped, small UAS can be a valuable supplement to conventional, crewed flight inspection.

The main benefit of using small UAS to support flight inspection is the reduction of crewed flight time, the reduction of emissions (noise and exhaust) and the generally lower expenses per flight hour. Additionally, in comparison, the flight crew is not exposed to enduring low altitude operations. The crewed flight time for calibration works is reduced by pre- or interim checks with small drones. As described in [1], frequent checks with drones at airports can ensure the correct operation of the navaid at certain intervals. Subsequently, the intervals for conventional, crewed flight inspections can be extended, so that in total fewer crewed calibration flights are necessary.

During commissioning or periodic flight inspection missions, the drone can be used to gather measurements prior to crewed flights. In this way, the navaid can be adjusted if necessary, based on the drone measurements. The subsequent crewed inspection then just must ensure that the navaid operates within tolerance. In this way, crewed flights are not required for calibration work and can focus on the check of the pre-calibrated navaid, also reducing crewed flight hours. The application of the UAS-based pre-calibration of navaids is most useful during the commissioning of newly installed navigation aids, or if some environmental constraints change.

This paper presents a family of small UAS complementing ground and flight inspection, describes their set-up, and shows results from measurement campaigns – especially in comparison to crewed flight inspection results. General considerations on using small drones for flight inspection missions are presented in [4]. Technical challenges like the propeller modulation and its effects on the measurements are described in [5]. First flight results from a different location were presented in [6].

## AEROFIS FLYBOT

Aerodata, the world leading manufacturer of flight inspection systems (FIS), has developed the AeroFIS Flybot family of small, uncrewed aircraft systems (UAS) for the (pre-) calibration of ground-based aviation navigational aids, capable of calibrating a multitude of radio and optical navigational aids.

### System Architecture

The general system architecture of the AeroFIS Flybot is depicted in Figure 1. The complete system consists of the UAS remote control, the FIS operator laptop computer, the DGNSS/RTK ground station, the drone platform, and the task specific FIS payload. This modular payload covers two main tasks.

The FI Core functionality includes recording, on-board processing, and transmission of flight/ground inspection measurements from the FI Sensor module.

The FIS sensor modules are easily interchangeable and provide the sensor specific to the measurement task. It can consist of radio NAVAID receivers and antennas like the R&S® EVSD1000 V/UHF Nav/Drone Analyzer, or optical sensors for the inspection of e.g. PAPI installations or infrastructure.

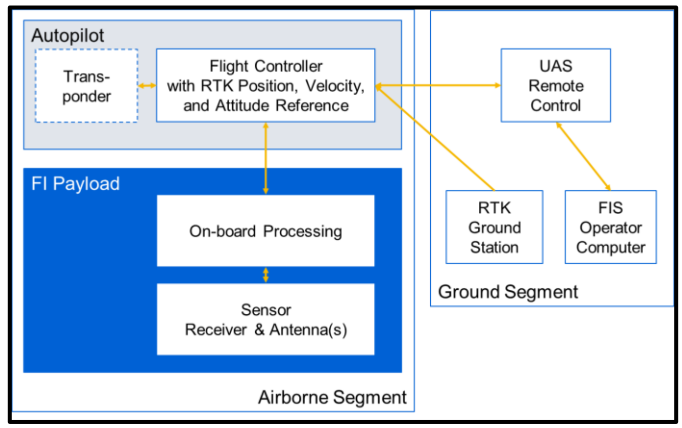


**Figure 1. AeroFIS Flybot System Architecture**

The AeroFIS Flybot architecture and capabilities can be implemented on several UAS platforms depending on the operators' requirements. The first implementation was done with the DJI Matrice 300 RTK UAS as depicted in Figure 2. This allows for a lightweight and convenient-to-use drone system.

**Figure 2. AeroFIS Flybot on DJI Matrice 300 RTK**

The first implementation on a non-DJI uses the Highdra, developed by the German-based company Starcopter GmbH, see Figure 3. The Highdra UAS is larger than the previous platform and allows for heavier payloads and significantly longer flight times. Both drone systems allow for the hot-swapping of the flight batteries. In this way the batteries can be exchanged without switching off the drone and its payloads, so that the flight can be continued immediately after the swap.

**Figure 3. AeroFIS Flybot on Starcopter Highdra**

## Software

The AeroFIS Flybot family of navaid inspection drones utilizes the well-proven AeroFIS software, which is globally operated on crewed flight inspection aircraft with AeroFIS systems, see Figure 4. Thus, the evaluation of the drone-based inspection measurements happens in the same way as in crewed flight inspection aircraft. This eases the fulfilment of the requirement towards the commonality between crewed and uncrewed inspection results significantly.

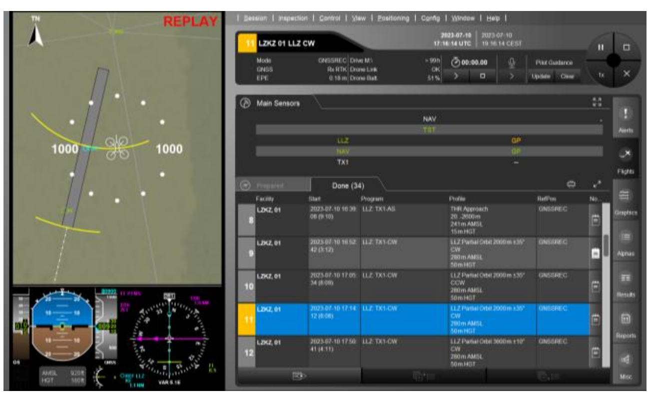


**Figure 4. AeroFIS software in application for AeroFIS Flybot**

Two persons – a remote pilot and a FIS operator – usually operate the AeroFIS Flybot. Similar to crewed flights, the remote pilot communicates with ATC, and controls and monitors the drone in flight. The FIS operator utilizes the AeroFIS software of the FIS operator laptop for the set-up of the drone flight profiles and the recording, supervision, and interpretation of the measurements. The flight inspection measurements and parameters are visualized in near real-time on the FIS operator laptop.

The planned flight inspection procedures are directly transmitted into the AeroFIS Flybot Remote Control software, which runs on the drone pilot's remote control, see Figure 5. Both platforms (DJI and non-DJI) use very similar applications for their remote controllers, providing the same functions with identical interfaces.

This software enables the pilot to get information on the planned procedures and their depiction in a map. In addition, the drone's flight controller can automatically follow these procedures precisely. The remote pilot can activate the automatic flight of these procedures by pressing a button, and can conveniently monitor the state of the UAS and the FIS components from the remote control. For this, the AeroFIS Flybot Remote Control software provides a map showing the drone position and the selected flight procedure, and a first person camera view of the drone.


**Figure 5. AeroFIS Flybot Remote Control App during ILS Localizer inspection**

The operation of the AeroFIS Flybot is highly automated. Departure and landing of the drone system as well as the flying of the mission can happen automatically and is easily commanded by interacting with the graphical user interface (GUI).

For best measurement performance, the drone and the installed receiving antenna or camera are always automatically oriented towards the navaid under inspection during the flight. The inspection receiver is automatically tuned to the frequency of the navaid from the AeroFIS facility database.

## AEROFIS FLYBOT PERFORMANCE

The main prerequisite for the operation of small drones in navaid inspection is the comparability of measurements with those of conventional, crewed flight inspections. For this reason, the AeroFIS Flybot has been tested and validated during several measurement campaigns at different airports. A comprehensive comparison of crewed and uncrewed navaid inspection is given in [6]. This paper concentrates on the repeatability of measurements, which is essential for the reliable inspection of navaids. Major prerequisites for the repeatability of the measurements are accurately calibrated sensors and an exact synchronization of all measurements with the position reference.

The measurements used for the following evaluation were recorded during a campaign conducted at an Australian airport in collaboration with AeroPearl Pty Ltd, the flight inspection service provider for Australia. For this, the uncrewed AeroFIS Flybot measurements will be compared to measurements from AeroPearl's Beechcraft King Air 350 flight inspection aircraft VH-FIY. Even though the campaign was intended to evaluate and demonstrate the system's capabilities regarding ILS and VOR inspections, this paper focuses on the repeatability of measurements, based on an example from the inspection of the glide path.

Figure 7 shows the measurements from glide path alignment and structure measurement runs for the AeroFIS Flybot in blue and for the King Air in red. The *x*-axis shows the distance to the threshold and coincides with the *x*-axis of the threshold coordinate system. The measurements were taken during approaches to the threshold of the runway. Only overlapping measurements (i.e. from positions where both aircraft flew) are analyzed. The AeroFIS Flybot flew at velocities of 5 m/s (darker blue line) and 10 m/s (lighter blue line) from a distance of 1.7 km to 0 km from the threshold. The King Air flew from 6 to 0 NM from the threshold at a speed of ca. 160 kt. Figure 6 shows a depiction of the approaches of the two aircraft.

The top part of Figure 7 shows the measured modulation depth of one King Air measurement run (red) and two AeroFIS Flybot measurement runs (blue) at different velocities. Both lines are at the expected 80 % value. The slight difference in the general shape of the lines originates in the different flight velocities and in the different measurement receivers. While the crewed aircraft is equipped with Aerodata AD-RNZ-850 flight inspection navigation receivers (which are based on aviation equipment), the AeroFIS Flybot is equipped with a Rohde & Schwarz EVSD1000 VHF/UHF Nav Analyzer. This device is a scientific analyzer and does not apply any filtering as in aviation equipment. The lower flight speed additionally leads to a higher resolution of the measurement, since both devices – AD-RNZ-850 and EVSD1000 - measure at a 10 Hz data rate.

The lower part of Figure 7 shows the measured deviations in µA for both devices. Both vehicles follow the same approach in general. Nevertheless, it can be seen that the flight path of the King Air deviates from that of the AeroFIS Flybot flights. Additionally, it can easily be seen that the automatic flights of the AeroFIS Flybot precisely follow the 0 µA line during the linear part of the glide path signal.

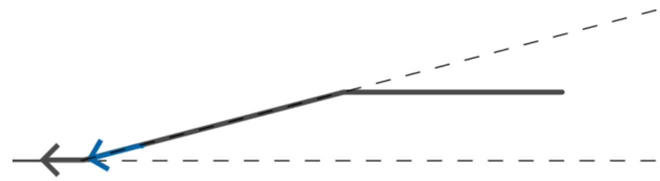

**Figure 6. Glide path alignment and structure run for AeroFIS Flybot in blue and AeroFIS equipped King Air in grey**

The lower part of Figure 7 shows the deviation error in µA for the measurements for both aircraft. Especially for the linear part of the glide path signal the measurements of crewed and uncrewed vehicles are nearly identical. At less than 500 m distance to the threshold, the deviation error begins to differ between the measurement systems. The main reason for this effect is that the aircraft's flight paths increasingly differed during this part of the approach. This can be clearly seen in the deviation measurements.

In both the deviation and the deviation error, measurement oscillations can be seen between 950 m and 800 m distance to the threshold. For this reason, this period is detailed in Figure 8. It is evident that the oscillations are present in both approaches of the AeroFIS Flybot. They even overlay very precisely at different flight speeds.

This leads to two conclusions from these measurements. First, the oscillations are actually present in the signal-in-space of the glide path transmitter. The King Air measurements additionally show that the oscillations do not affect the use of the signal by an aviation receiver. The second conclusion is that the time synchronization of the measurements is of highest accuracy. Without this quality of synchronization, the measurements would not coincide this well with each other – especially at different velocities.

The source of the oscillations could not be identified during the campaign. It is assumed that these could originate from multipath of structures in the vicinity.

## CONCLUSION

Small, uncrewed aircraft like the AeroFIS Flybot can be a valuable, accurate and convenient tool for NAVAID flight and ground inspection. The overall measurement quality was demonstrated by a direct comparison of the respective measurements, using identical software, algorithms and measurement techniques. The level of agreement of both systems demonstrates that small uncrewed aircraft systems can meet all requirements for flight inspections in the vicinity of a navigation aid.

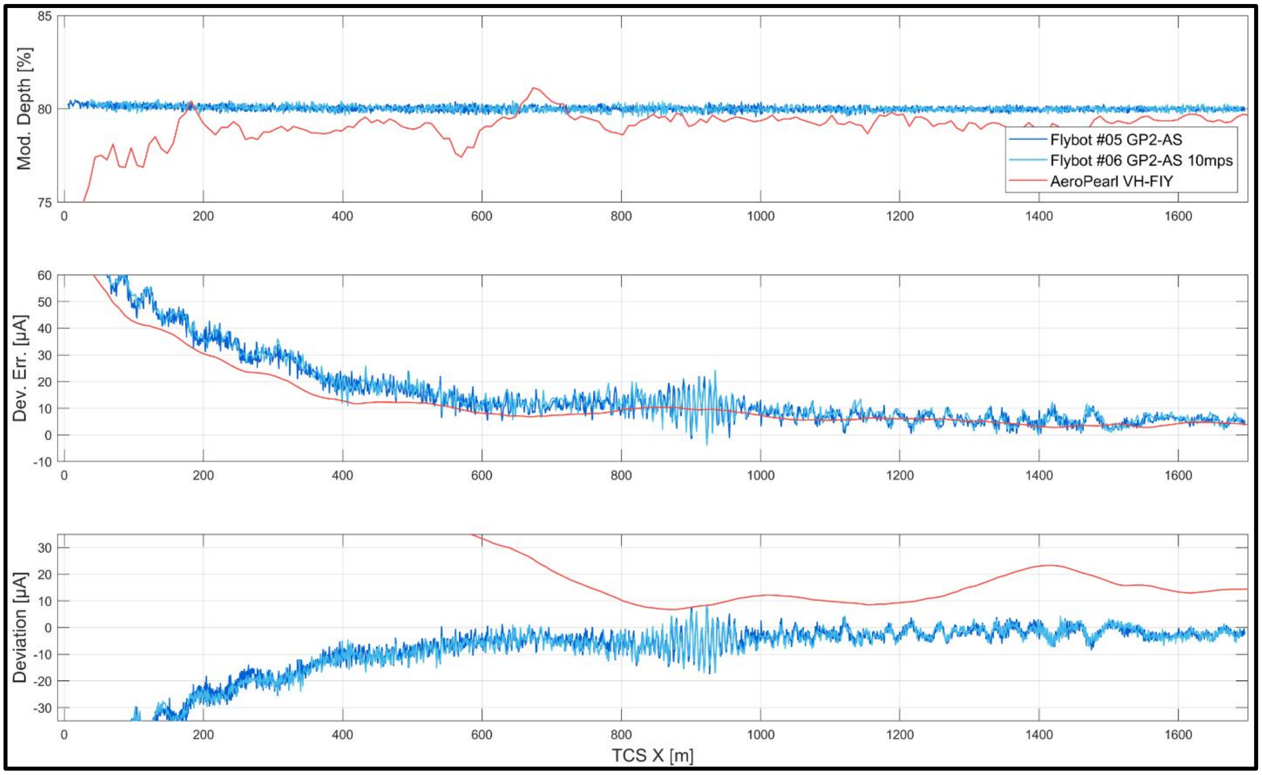


**Figure 7. Glide path alignment and structure. (AeroFIS Flybot in blue, AeroFIS equipped King Air in red)**

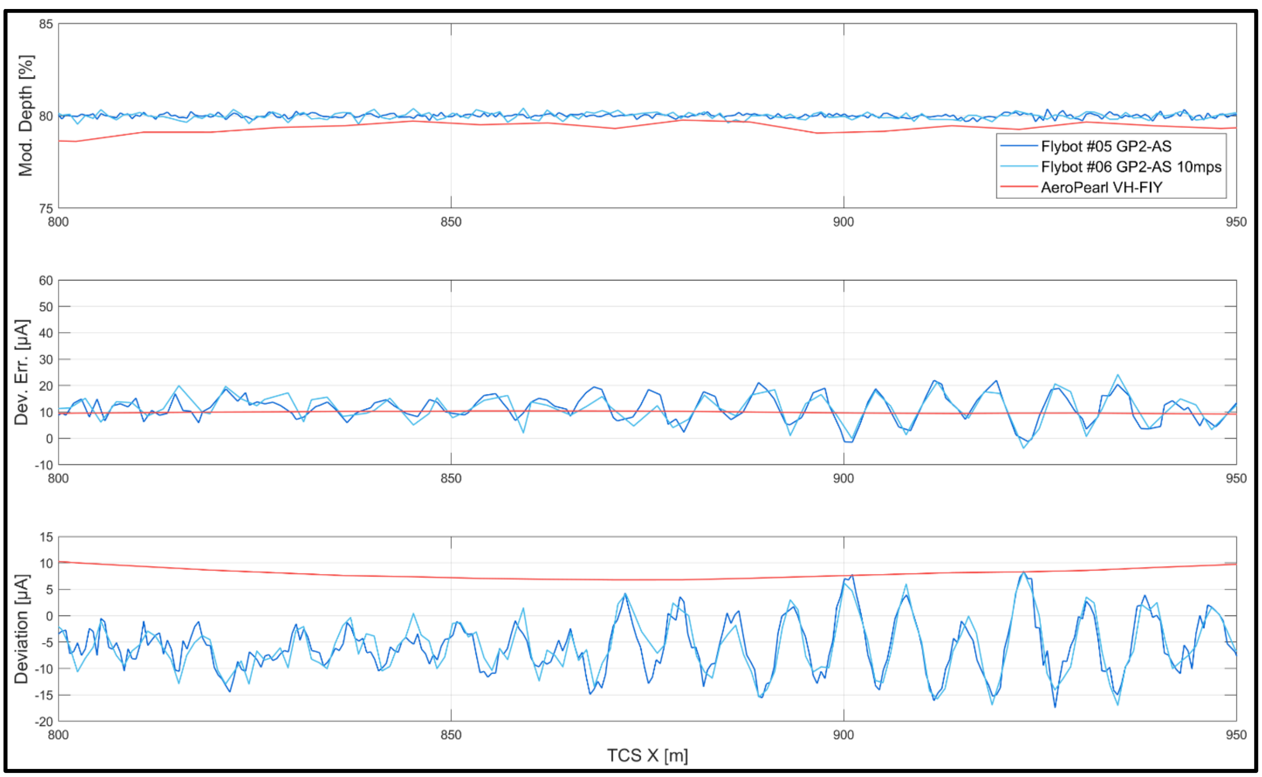


**Figure 8. Detail view of glide path alignment and structure. (AeroFIS Flybot in blue, AeroFIS equipped King Air in red)**

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**Figure 9. AeroPearl logo**

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