

Implementation of UAS-Based ILS Flight Inspection Procedures in Colombia: Advances, Operational Analysis, and Challenges

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Juan Carlos Lopez is a Technical Advisor with more than 18 years of professional experience in aeronautical communications and navigation aids. He holds a degree in Aeronautical Electronics Technology from the Colombian Aerospace Force Non-Commissioned Officers Technical School, an institution dedicated to the technical and professional training of military personnel. Throughout his career, he has specialized in the operation, maintenance, and modernization of communication and radio navigation systems. He has actively contributed to research, development, and innovation projects involving Unmanned Aircraft Systems (UAS), technological prototypes for radio navigation aids, and UAS-based procedures for PAPI light calibration and certification. His research interests include applied aeronautical electronics, UAS-based inspection systems, and the development of innovative CNS/ATM technologies to enhance aviation safety and operational efficiency.

ABSTRACT

In recent years, global initiatives have promoted the use of Unmanned Aircraft Systems (UAS) for the flight inspection of air navigation aids. In this context, Colombia is exploring the implementation of UAS-based procedures for the inspection of Instrument Landing Systems (ILS), driven by the need to reduce costs and operational complexity. This paper presents current advances in the use of UAS for flight inspection activities in Colombia. The study analyzes the main conditions and challenges associated with the implementation of UAS-based flight inspection in the Colombian context. These include the characteristics of Colombian airspace, terrain conditions, geographic location, the distribution of navigation aids, and the current procedure used for conventional flight inspection. As a case study, the paper presents preliminary results from an ongoing research project developed at Universidad Distrital Francisco José de Caldas in collaboration with the Colombian Aerospace Force. The project aims to develop a UAS-based methodology for ILS flight inspection and builds on previous successful testing and certification processes for the calibration of PAPI lighting systems using UAS. In addition, the paper examines a flight inspection exercise conducted at Pereira Airport, where a UAS-based ILS inspection trial was carried out by the Colombian Civil Aviation Authority in collaboration with Korea Airports Corporation. Finally, a cost comparison between conventional and UAS-based flight inspection procedures is presented.

INTRODUCTION

Flight inspection of navigation aids such as Instrument Landing Systems (ILS) is a critical activity for ensuring the safety, reliability, and operational continuity of air transport systems. Traditionally, these inspections are conducted using manned aircraft equipped with specialized signal analysis systems, which require substantial logistical coordination, highly trained personnel, and significant financial resources. These constraints become even more pronounced in countries with challenging geographic and operational conditions.

Colombia represents a particularly demanding environment for flight inspection activities. Owing to its location in the tropical region and the presence of the Andean Mountain range, the country is characterized by complex topography, high-altitude aerodromes, steep terrain, and a concentration of air navigation infrastructure in mountainous areas. As a result, flight inspection operations face greater operational complexity, higher costs, and limited inspection capacity. In addition, the growing number of navigation aids deployed across the country creates a sustained demand for periodic inspections, placing further pressure on existing resources.

In this context, Unmanned Aircraft Systems (UAS) have emerged as a promising technological alternative to support or partially replace conventional flight inspection methods. International experience has demonstrated the feasibility of using UAS to measure navigation signals, particularly in near-field scenarios, as well as to support complementary activities such as calibration and system validation. In Colombia, recent initiatives led by the Civil Aviation Authority, the Colombian Aerospace Force, and academic institutions have begun exploring the use of UAS in this field through experimental campaigns and partial certifications, including UAS-based procedures for PAPI calibration.

Despite these advances, the implementation of UAS-based flight inspection procedures for ILS in Colombia remains at a developmental stage and requires further analysis of operational conditions, methodological adaptations, and validation of technical and economic feasibility. Procedures must be defined in a way that remains consistent with ICAO standards while taking advantage of the operational benefits offered by UAS platforms.

This paper presents current advances in the implementation of UAS-based ILS flight inspection procedures in Colombia. It characterizes the national operational scenario, describes the conventional inspection process and its associated costs, and reviews recent national experiences involving UAS. In addition, it proposes a methodological framework for UAS-based ILS inspection, including system architecture and flight patterns adapted to UAS capabilities. Finally, it presents a comparative cost analysis of conventional and UAS-based inspection procedures, highlighting the potential benefits and challenges associated with this emerging technology.

CURRENT CONDITIONS FOR FLIGHT INSPECTION OF NAVIGATION AIDS IN COLOMBIA

Geographic Conditions and Navigation Aid Infrastructure in Colombia.

Colombia is in the tropical region of the Earth, at the northwestern end of South America. The country is crossed from the southwest to the north by the Andes Mountain range, where its main cities and airports are located; consequently, most of its air routes and air navigation service infrastructure are concentrated in this region. Due to its tropical location, Colombia does not experience four distinct seasons such as winter, spring, summer, and fall. Instead, local climate conditions are largely

determined by altitude above mean sea level, resulting in relatively stable weather throughout the year, with only moderate variations associated with wetter or drier periods. These seasonal variations generally do not significantly affect air operations, allowing flight activities, including flight inspection missions, to be conducted year-round.

Given the distribution of the Colombian population, the country's main cities and, therefore, its major airports are concentrated in the Andean region, where the Andes Mountain range reaches elevations of up to 5,775 m (18,947 ft) above mean sea level (MSL) within Colombian territory. As a result, the infrastructure that supports air operations—including air routes, aerodromes, navigation aids, radars, and other equipment used for the provision of air navigation services—is also concentrated in this region. This area is characterized by high mountains and deep valleys, which pose significant challenges for the installation and operation of radioelectric equipment, as well as for its flight inspection, calibration, and proper maintenance. Figure 1 shows a map of Colombia highlighting the Andean region and the location of navigation aids and major airports, providing the reader with an overview of the terrain-related difficulties and the specific technical challenges that air operations face in the country.

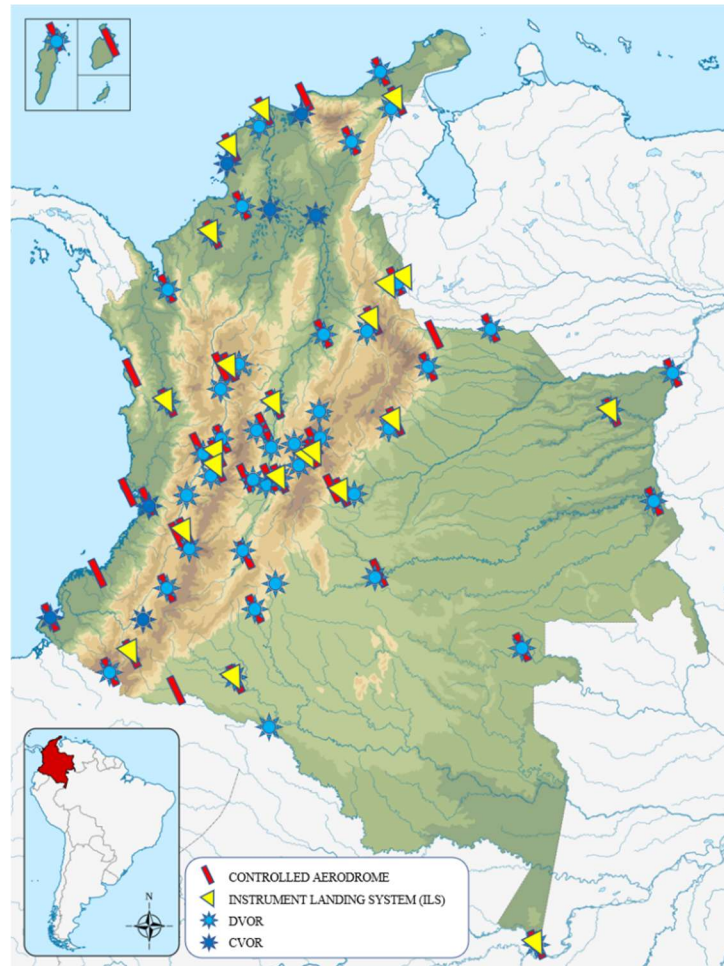


Figure 1. Map of Colombia showing controlled aerodromes (46 civil and 7 state aviation), ILS facilities (17 at civil aerodromes and 5 at state aerodromes), and VOR facilities (46 DVOR and 7 CVOR).

Source: Prepared by the authors based on information from the Colombia AIP and PNA

Current Flight Inspection Procedure for Navigation Aids.

At present, the flight inspection of navigation aids such as ILS and VOR in Colombia is performed using a manned Beechcraft B200 Super King Air aircraft equipped with a Normarc NM 3625B flight inspection console for air navigation aids. This aircraft is used to inspect both civil aviation infrastructure and military aviation infrastructure. The onboard crew consists of the pilot, copilot, and an engineer specialized in operating the flight inspection console. On the ground, the inspection team includes an engineer specialized in navigation aid flight inspection, an ATSEP (Air Traffic Safety Electronics Personnel)

technician responsible for equipment calibration, and aerodrome personnel such as the air traffic controller. Figure 2 shows the aircraft and the flight inspection console during an inspection procedure.

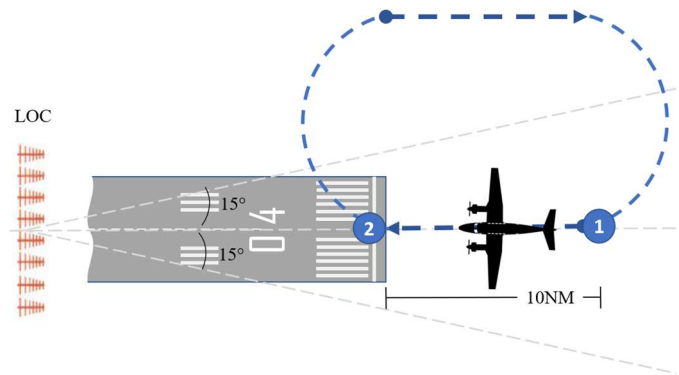


Figure 2. Beechcraft B200 Super King Air during a flight inspection procedure.

The ILS flight inspection procedure consists of a series of flight patterns in which the parameters associated with the ILS signal are measured, in accordance with the provisions of ICAO Doc. 8071, *Manual on Testing of Radio Navigation Aids*. As an illustrative example, two flight patterns and their corresponding measured parameters are described below, as they would be performed in a conventional flight inspection procedure.

1. Approach Path Flight Pattern:

The flight inspection aircraft crosses Point 1 along the approach path, located 10 nautical miles from the runway threshold, at an altitude of 3,300 ft above mean sea level, centered on the localizer axis and aligned with the runway heading. The aircraft then proceeds toward the threshold along a descent path with a glide angle of three degrees (3°) relative to the plane containing the glide path antennas. It continues to Point 2 at the runway threshold and then executes a missed approach by turning right and climbing back to 3,300 ft above mean sea level to repeat the flight pattern.

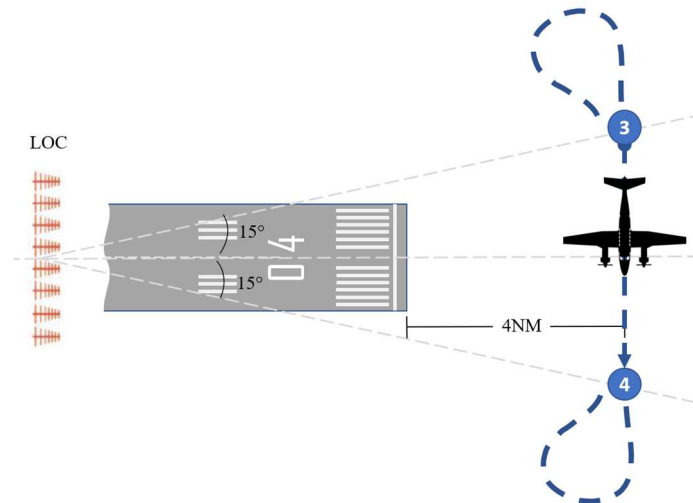


Measured parameters: Balance, modulations, on-course alarm, alignment, and course structure.

2. Transverse Flight Pattern:

The flight inspection aircraft flies at an altitude of 2,100 ft above mean sea level along a trajectory perpendicular to the extended runway centerline, from Point 3 to Point 4 and vice versa. These points are located 4 nautical miles from the runway threshold and displaced by fifteen degrees ($\pm 15^\circ$) on either side of the localizer axis. After completing one transverse pass, the aircraft waits for air traffic control clearance before repeating the operation in the opposite direction.

Measured parameters: Course sector, off-course margin at $\pm 10^\circ$, off-course margin at $\pm 35^\circ$, wide alarm, narrow alarm, operational coverage, identification, and standby power.



The procedure described above ensures compliance with international flight inspection standards [1]. However, its execution poses significant logistical and cost-related challenges for the Colombian government. As shown in Figure 1, the country's infrastructure includes many ILS facilities (20 Category I and 2 Category III) and VOR facilities (46 DVOR and 7 CVOR). Each of these systems must be inspected every six months or annually, depending on the inspection results and the corresponding certification requirements [2]. This creates a high workload for the flight inspection aircraft, which remains in operation for most of the year. It also limits the expansion of national air navigation infrastructure since inspection and certification capacity are constrained. In terms of cost, each inspection requires an average of 6 flight hours. During this time, the aircraft consumes fuel, the aerodrome must be closed, disrupting the normal flow of air traffic operations and the associated economic activity, and both the airborne and ground-based teams must remain available to carry out all tasks involved in the inspection procedure.

These limitations have led to the search for alternatives that can reduce operational costs, expand technological capabilities, and increase the number of inspections performed each year. In this context, the feasibility of implementing Unmanned Aircraft Systems (UAS) to support flight inspection activities is currently being studied. As demonstrated by studies conducted worldwide [3], [4], [5], [6], [7], [8], [9], the use of UAS for the flight inspection of air navigation aids is technically feasible and can reduce the operational costs associated with this task. In addition, it may help extend the certification interval of each navigation aid, thereby enabling adequate inspection of all facilities with a lower logistical burden than that required under the current approach.

Costs Associated with the Current Flight Inspection Procedure

The following section presents a cost analysis of the ILS flight inspection procedure described in the previous section. The analysis considers the inspection of a single ILS facility, including both the localizer and glide slope, which may require up to 6 flight hours. Two human teams are included among the required resources. The first is the onboard crew, composed of the pilot, copilot, and the engineer responsible for operating the flight inspection console. The second is the ground team, composed of an engineer specialized in the inspection procedure, an ATSEP technician responsible for ILS operation, and an air traffic controller who manages aerodrome traffic during the operation. To estimate personnel-related costs, salary tables from Colombian state entities such as the Civil Aviation Authority and the airline SATENA were used, since flight inspection in Colombia is entirely the responsibility of the State and is carried out by government personnel.

The analysis also includes physical resources and other activities that generate an hourly cost for each inspection flight. These include aircraft operating costs such as fuel consumption, maintenance, and engine program costs, as well as costs associated with the use of airport facilities. The latter include operational disruption costs resulting from runway closure, the logistics of transporting personnel and equipment, the use of airport infrastructure, and other related airport services.

In addition, the cost analysis includes a section on equipment acquisition costs since these assets are essential for conducting the inspections and represent a significant investment for the entity responsible for performing them. As noted earlier, in

Colombia this responsibility lies directly with the Colombian State, which has the authority to carry out these inspections and is therefore responsible for acquiring the required equipment, including the flight inspection aircraft, the navigation signal analyzer, the RTK station, and other necessary components.

Resource		Hourly Cost (USD)	Inspection Duration (LOC+GP)	Total Cost (USD)
Personnel	Beechcraft B200 Super King Air pilot [10]	\$50	6 hours	\$300
	Beechcraft B200 Super King Air copilot [10]	\$30		\$180
	Engineer specialized in operating the NM3625B console [11]	\$50		\$300
	Ground engineer specialized in ILS inspection [11]	\$50		\$300
	ATSEP technician specialized in the aerodrome ILS [11]	\$38		\$228
	Air traffic controller [11]	\$38		\$228
Other Costs	Fuel Consumption (113 gal/h at USD \$6.28 per gallon)[12]	\$710		\$4,260
	Operational disruption costs (runway closure)	\$1,000		\$6,000
	Aircraft maintenance [12]	\$500		\$3,000
	Personnel and equipment transport logistics	\$100		\$600
	Use of airport facilities and services [12]	\$100		\$600
	Engine maintenance program [12]	\$550		\$3,300
Total cost of one LOC+GP inspection		\$3,216		\$19,296

Equipment Acquisition	Beechcraft B200 Super King Air aircraft [12]	\$2,642,500
	Normarc NM 3625B navigation signal analyzer	\$4,000,000
	RTK positioning station	\$20,000
	Air-to-ground communication system	\$8,000
Total equipment acquisition cost		\$6,670,500

Table 1. Cost analysis of the current ILS flight inspection procedure.

The cost analysis presented in the table does not include other cost items that may increase the hourly cost of the inspection, such as taxes, administrative fees, insurance, hangar costs, equipment depreciation, and other related expenses. It is estimated that the hourly rate may rise to as much as USD 5,000 when all associated variables are taken into account [13].

BACKGROUND ON THE USE OF UAS FOR FLIGHT INSPECTION IN COLOMBIA

The following section presents an analysis based on publicly available sources documenting initiatives related to the use of UAS for the flight inspection of ILS, VOR, and PAPI systems in Colombia. Although this technology has not yet reached full maturity in the country, several documented initiatives and practical exercises have been carried out to support the implementation of UAS for flight inspection purposes. These initiatives have been led by the Civil Aviation Authority [14], the Colombian Aerospace Force [15], the State Aviation Aeronautical Authority, and Universidad Distrital Francisco José de Caldas, where this topic is being developed as part of a Ph.D. research project in Engineering.

UAS-Based ILS Inspection Exercise Conducted at Matecaña Airport in Pereira

In April 2022, a UAS-based flight inspection trial was conducted for the ILS and VOR/DME systems at Matecaña International Airport in Pereira, Colombia. The exercise was led by the Colombian Civil Aviation Authority (Aerocivil) in collaboration with the Inter-American Development Bank and Korea Airports Corporation (KAC). A DJI Matrice 210 RTK UAS equipped with ADS-B and GNSS+RTK was used, carrying as payload a navigation aid signal receiver, an ILS/VOR/glide path receiving antenna, and additional LoRa and TACAN/DME antennas. The tests were conducted during the early morning, with the airport closed and under visual line-of-sight (VLOS) conditions.

The objective of the exercise was to demonstrate and evaluate the use of UAS as a complementary system for more frequent measurements, pre-calibration activities, and system readiness prior to the final inspection, with the potential to reduce both costs and flight hours of the flight inspection aircraft. The State reported that the near-field measurements obtained with the drone were within tolerance limits and closely matched the far-field measurements obtained with the flight inspection aircraft, supporting their validity as a complement to the conventional flight inspection system. The results of this trial were documented and published in a Study Note submitted to the Technical Commission of the 41st Assembly of the International Civil Aviation Organization (ICAO), under the title “Trial/Demonstration of RPAS/UAS (Drones) Flight Inspections of the ILS and VOR/DME Radio Navigation Systems at Matecaña International Airport in Pereira.” [14]



Figure 3. ILS localizer at Matecaña Airport, Pereira [16].

UAS-Based Calibration of PAPI Lights

In 2023, the first documented field trial for the inspection of PAPI lights using a UAS was conducted at the Air Maintenance Command (CAMAN) of the Colombian Aerospace Force. The exercise was led by the Aeronautical Innovation Research and Technological Development Center (CETIA) and reported by the State Aviation Aeronautical Authority (AAAES). In addition to the UAS, a total station and a GNSS RTK module were used to obtain position measurements, determine reference points, and measure heights from the UAS platform. The objective of this initial exercise was to verify the performance of the PAPI lights, confirm the validation procedure, and assess compliance with international standards, while identifying the need for additional testing to further refine the method [17].

Later, in 2024, the AAAES conducted a UAS-based data acquisition exercise for the ILS signal and PAPI light calibration at the aerodrome of Air Combat Command No. 2 (CACOM-2) in Villavicencio, Colombia, in collaboration with a private company. The objective of the exercise was to test the inspection and data acquisition procedure for the systems in order to enable preliminary adjustments and refine the certification procedure, with a focus on the inspection of the localizer, glide slope, and PAPI lights in accordance with the Colombian Aeronautical Regulations for State Aviation (RACAE). AAAES reported that, because this was a preliminary trial, it was considered an exploratory assessment of the capability and that additional testing would be required to further refine the system certification procedure [18].

These previous trials led to the certification, in September 2024, of the Colombian Aerospace Force (FAC) by the State Aviation Aeronautical Authority for the procedure used to calibrate PAPI lighting systems with a UAS, making Colombia the second country after France to certify this methodology. The certification was achieved through the calibration of the PAPI lighting system at the Air Maintenance Command (CAMAN) aerodrome using a procedure developed as a research project by the FAC Directorate of Science and Technology and carried out through the Aeronautical Innovation Research and Technological Development Center (CETIA). As a result, the Authority issued a regulatory circular authorizing the use of UAS-based PAPI calibration procedures at military aerodromes, establishing a potential precedent for their future use at civil airports. The

certified procedure highlights operational benefits such as lower operating costs, reduced aerodrome downtime, and decreased human risk exposure [15].

Following certification, the capability was deployed during 2024 and 2025, leading to the UAS-based certification of the PAPI lighting systems at the aerodromes of CAMAN, Air Combat Command No. 1 (CACOM-1), the Juanchaco Naval Air Base of the Colombian Navy, and the Tolomaida Military Fort of the Colombian Army [19]. In March 2026, a technical operation was reported at Almirante Padilla Airport in Riohacha to verify the PAPI lighting system using UAS, with the objective of advancing toward the authorization of nighttime operations. The UAS phase was carried out by the specialized calibration team for lighting systems and navigation aids of the Colombian Aerospace Force, enabling high-precision inspection and reducing the need for manned aircraft during part of the process. However, the final validation was performed in flight using a Bell 212 helicopter operated by the National Police to confirm system performance under actual approach conditions [20].

METHOD FOR UAS-BASED FLIGHT INSPECTION


A dissertation project is currently being developed within the Ph.D. in Engineering program at Universidad Distrital Francisco José de Caldas in Bogotá, with the aim of proposing a method for the flight inspection of ILS using UAS. Since the project is still under development, this paper presents preliminary results derived from the state of the art in the research field, including the parameters to be measured during the inspection procedure and a review of unmanned aircraft that have been used in similar projects worldwide for this purpose. In addition, a UAS-based system proposal for flight inspection is presented.

The objective is to achieve the capability to verify the parameters established in ICAO Doc. 8071 for the signals transmitted by the localizer and glide path, as shown in Table 2:

ILS Component	Steps in the Flight Inspection Procedure
<p style="text-align: center;">Localizer LOC</p>	<ul style="list-style-type: none"> • Verification of localizer beam coverage. • Verification of transmitter modulation. • Verification of course alignment for both transmitters. • Verification of the absence of false courses and nominal course width. • Verification of maximum, minimum, and nominal localizer width. • Verification of localizer on-course alarms.
<p style="text-align: center;">Glide Path GP</p>	<ul style="list-style-type: none"> • Verification of modulation for both transmitters. • Verification of glide path width and nominal angle. • Verification of maximum and minimum glide path angle (width alarms). • Safety pass at maximum width to verify the absence of false glide paths below the nominal angle. • Final verification.

Table 2. Parameters to be verified during ILS flight inspection [1], [21].

According to the literature review conducted, different types of UAS have been used in similar projects around the world. Some of these platforms and their main characteristics are presented in Table 3.

	Manufacturer:	ONIXSTAR
	Model:	HYDRA-12 [22]
	Type:	Hex copter
	Number of rotors:	2x6 (X12)
	MTOW:	23 Kg
	Maximum payload:	12 Kg
	Maximum flight time:	25 min (without payload)
	Power source:	Batteries
	Country:	Germany

	Manufacturer: Model: Type: Number of rotors: MTOW: Maximum payload: Maximum flight time: Power source: Country:	ONIXSTAR FOX[23] Quadcopter 2x4 (X8) 11 Kg 5 Kg 44 min (without payload) Batteries Germany
	Manufacturer: Model: Type: Number of rotors: MTOW: Maximum payload: Maximum flight time: Power source: Country:	ONIXSTAR XENA PX [24] Quadcopter 2x4 (X8) 4.5 Kg 1 Kg 37 min (without payload) Batteries Germany
	Manufacturer: Model: Type: Number of rotors: MTOW: Maximum payload: Maximum flight time: Power source: Maximum flight height: Country:	AEROXESS HERCULES ONE-T [25] Tethered Tri copter 2x3 (Y6) 15 Kg 5 Kg Unlimited Electrical mains supply 50 m Germany
	Manufacturer: Model: Type: Number of rotors: MTOW: Maximum payload: Maximum flight time: Power source: Country:	FOXTECH GAIA 160HY [26] Hybrid hex copter 1x6 (X 6) 21 Kg 5.5 Kg 175 min (without payload) Batteries + gasoline China
<p>MAPPING, SURVEILLANCE, INSPECTION, CARGO</p> 	Manufacturer: Model: Type: Number of rotors: MTOW: Maximum payload: Maximum flight time: Power source: Country:	BETA UAS IRIS [27] Quadcopter 1x4 (X 4) 25 Kg 7 Kg 45 min. (without payload) Batteries Indonesia
	Manufacturer: Model: Type: Number of rotors: MTOW: Maximum flight time: Power source: Country:	ZIYAN UAS FALCON 10 [28] Helicopter 1x2 7 Kg 50 min. (without payload) Batteries China

	Manufacturer:	<i>DJI ENTERPRISE</i>
	Model:	MATRICE 300 RTK [29]
	Type:	Quadcopter
	Number of rotors:	1x4 (X 4)
	MTOW:	9 Kg
	Maximum payload:	2.7 Kg
	Maximum flight time:	55 min. (without payload)
	Power source:	Batteries
Country:	Manufacturing facilities in the United States, Germany, the Netherlands, Japan, South Korea, Beijing, Shanghai, and Hong Kong	
	Manufacturer:	<i>DJI ENTERPRISE</i>
	Model:	MATRICE 350 RTK [30]
	Type:	Quadcopter
	Number of rotors:	1x4 (X 4)
	MTOW:	9.2 Kg
	Maximum payload:	2.7 Kg
	Maximum flight time:	55 min. (without payload)
	Power source:	Batteries
Country:	Manufacturing facilities in the United States, Germany, the Netherlands, Japan, South Korea, Beijing, Shanghai, and Hong Kong	

Table 3. UAS identified in the literature review and used in related flight inspection projects.

A proposed system for conducting the ILS flight inspection procedure using a UAS is presented below. This system proposal is shown in Figure 4:

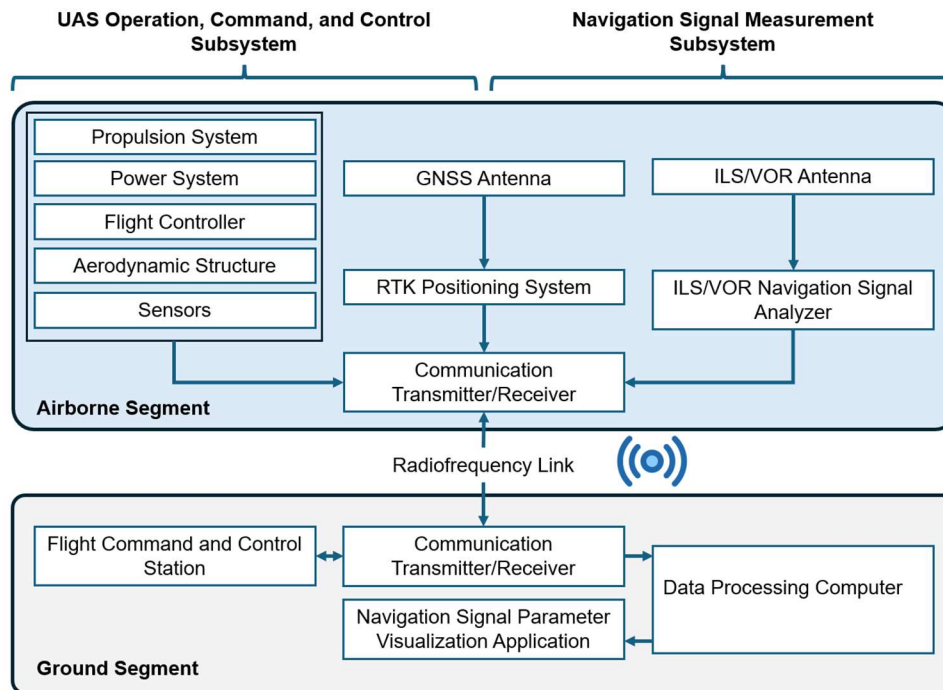


Figure 4. Proposed system architecture for UAS-based ILS flight inspection

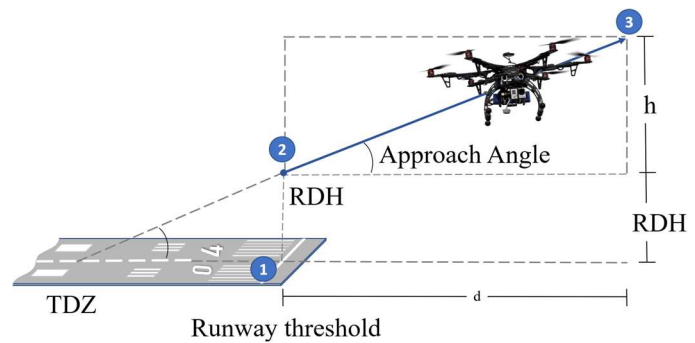
The system should consist of two main subsystems: the UAS operation, command, and control subsystem, and the navigation signal measurement subsystem. These are in turn divided into an onboard segment and a ground segment. The first subsystem requires components that are common to most unmanned aircraft systems, including the propulsion system, power system, flight controller, aerodynamic structure, and sensor suite in the onboard segment, as well as the flight command and control station in the ground segment.

The second subsystem requires, in its onboard segment, specialized equipment for monitoring the navigation signals transmitted by the ILS, such as the ILS/VOR antenna and the ILS/VOR navigation signal analyzer. In its ground segment, it requires a computer system with specialized software for data processing and visualization of the navigation signal parameters transmitted by the ILS. In addition, a set of components is required to support both subsystems, that is, components needed for the operation of each of them. These include the GNSS RTK positioning system with its corresponding antenna, as well as a communication transmitter and receiver set to establish a radiofrequency link between the onboard segment and the ground segment.

The UAS-based ILS flight inspection procedure consists of a series of flight patterns in which the same ILS signal parameters currently measured with the flight inspection aircraft are evaluated. As an illustrative example, two flight patterns and their corresponding measured parameters are described below, as they would be performed in a UAS-based flight inspection procedure.

1. UAS Approach Path Flight Pattern:

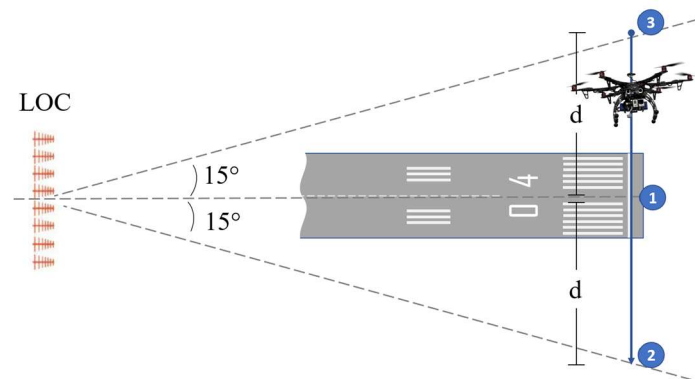
The UAS takes off from the runway threshold at Point 1 and climbs to the Reference Datum Height (RDH) at Point 2, where it begins a displacement along the approach path, defined according to the declared approach angle for the runway. The UAS then continues in a straight line until reaching Point 3. The procedure may be repeated by returning to Point 2 along the same path while measuring the parameters required for the inspection procedure.



Measured parameters: Balance, modulations, on-course alarm, alignment, and course structure.

2. UAS Transverse Flight Pattern:

The UAS takes off from the runway threshold to perform a flight pattern along a trajectory perpendicular to the extended runway centerline, flying from Point 1 to Point 2 and then to Point 3 while maintaining a constant altitude. This allows the UAS to perform a sweep from $+15^\circ$ to -15° on either side of the localizer axis while measuring the parameters required for the inspection procedure.



Measured parameters: Course sector, off-course margin at $\pm 10^\circ$, off-course margin at $\pm 35^\circ$, wide alarm, narrow alarm, operational coverage, identification, and standby power.

Costs Associated with the UAS-Based Flight Inspection Procedure

Table 4 presents a cost analysis of the ILS flight inspection procedure using a UAS. The analysis considers the inspection of a single ILS facility, including both the localizer and the glide slope. It is estimated that, when using a UAS, this inspection could be completed in a maximum of 2 hours. In addition, the procedure could potentially be carried out in segments during available runway time windows between flights, thereby reducing the operational impact associated with runway closure. However, for the purpose of the cost estimation, it is assumed that the airport would need to be closed for a maximum of 2 hours.

Unlike the procedure performed with manned aircraft, the entire human team in the UAS-based procedure remains on the ground, which facilitates coordination and communication between the flight team and the navigation aid configuration team. This team would consist of a UAS pilot, an engineer specialized in the interpretation of data provided by the navigation signal analyzer, and an ATSEP technician specialized in ILS operation. The role of the air traffic controller would be limited to maintaining the aerodrome closure during the procedure, without the need to provide ATC services to an aircraft in flight. Personnel-related costs were calculated using the same methodology applied in the cost analysis of the manned flight inspection procedure. Other elements generating hourly costs for inspection flights were also included in the analysis.

It is important to note that this analysis is based on a theoretical procedure that is still under validation. Therefore, the estimated costs should be understood as a projection of the values that could be achieved if the procedure is validated and carried out at an aerodrome under real operating conditions.

Resource		Hourly Cost (USD)	Inspection Duration (LOC+GP)	Total Cost (USD)
Personnel	UAS Pilot	\$30	2 hours	\$60
	Engineer specialized in operation of the navigation signal analyzer	\$50		\$100
	ATSEP technician specialized in the ILS installed at the aerodrome	\$38		\$76
Other Costs	Fuel consumption (electrical energy for battery charging)	\$0.39112		\$0.78224
	Operational disruption costs (runway closure)	\$1,000		\$2,000
	Unmanned aircraft maintenance	\$20		\$40
	Personnel and equipment transport logistics	\$40		\$80
Total Cost of One LOC+GP Inspection		\$1,178		\$2,357

Equipment Acquisition	DJI Matrice 350 RTK UAS	\$50,000
	R&S EVSD1000 navigation signal analyzer	\$100,000
	RTK positioning station	\$20,000
Total Equipment Acquisition Cost		\$170,000

Table 4. Cost analysis of the UAS-based flight inspection procedure.

Electricity Consumption Costs for Battery Charging

About fuel consumption, although the UAS does not require petroleum-based fuel for operation, it does consume electrical energy to charge its batteries. For this calculation, the energy consumption of a DJI Matrice 350 was used as a reference. The endurance of this platform was evaluated with a 2 kg payload, like that of a commercially available navigation signal analyzer such as the R&S EVSD1000, yielding an estimated flight time of 20 minutes. Under these conditions, three full battery charge cycles would be required to achieve 60 minutes of flight time. This UAS uses TB65 batteries rated at 5880 mAh, 44.76 V, and a nominal energy of 263.2 Wh, equivalent to 0.2632 kWh per battery. Assuming an additional 10% to account for charger and battery losses, the energy drawn from the electrical grid would be 0.292 kWh per battery. For the battery pair used by the platform, this corresponds to 0.585 kWh per full charge, providing approximately 20 minutes of flight endurance. Therefore, 1.755 kWh would be required for one hour of flight inspection.

Based on electricity tariffs published for Bogotá by the local provider, the cost of electricity was taken as USD 0.22286 per kWh. Accordingly, the cost of electrical energy in Bogotá, Colombia, for three full battery charges (sufficient to support one hour of UAS flight) would be USD 0.39112.

Cost Comparison: UAS vs. Manned Aircraft

Based on the information presented in the previous sections, a cost comparison is provided below between the conventional flight inspection procedure performed with a manned aircraft and the proposed procedure using a UAS. For the analysis of the manned-aircraft procedure, the Beechcraft King Air B200 and the Normarc NM3625B navigation signal analyzer were considered, as these are the systems currently used to conduct flight inspection of navigation aids in Colombia. In contrast, for the analysis of the UAS-based procedure, a DJI Matrice 350 RTK carrying a Rohde & Schwarz EVSD1000 navigation signal analyzer as payload was theoretically considered as the reference configuration.

Resource		B200 Hourly Cost	UAS Hourly Cost	Hourly Cost Ratio: UAS/ Manned	B200 Total Inspection Cost (6 h)	UAS Total Inspection Cost (2 h)	Inspection Cost Ratio: UAS/ Manned
Personnel	Pilot	\$50	\$30	60%	\$300	\$60	20.0%
	Copilot	\$30	/	0%	\$180	\$0	0%
	Engineer specialized in operation of the flight inspection console	\$50	\$50	100%	\$300	\$100	33.3%
	Ground engineer specialized in ILS inspection	\$50	/	0%	\$300	\$0	0%
	ATSEP technician specialized in the ILS installed at the aerodrome	\$38	\$38	100%	\$228	\$76	33.3%
	Air Traffic Controller	\$38	/	0%	\$228	\$0	0%
Other Costs	Energy Consumption	\$710	\$0.39112	0.05509%	\$4,260	\$0.78224	0.01836%
	Operational disruption costs (runway closure)	\$1,000	\$1,000	100%	\$6,000	\$2,000	33.3%
	Aircraft maintenance	\$500	\$20	4%	\$3,000	\$40	1.3%
	Personnel and equipment transport logistics	\$100	\$40	40%	\$600	\$80	13.3%
	Use of airport facilities and services	\$100	/	0%	\$600	\$0	0%
	Engine maintenance program	\$550	/	0%	\$3,300	\$0	0%
Total Cost of One LOC+GP Inspection		\$3,216	\$1,178	36.64%	\$19,296	\$2,357	12.21%

		Manned Aircraft Inspection	UAS Inspection	UAS/Manned Cost Ratio
Equipment Acquisition	Aircraft	\$2,642,500	\$50,000	1.89%
	Navigation signal analyzer	\$4,000,000	\$100,000	2.5%
	RTK positioning station	\$20,000	\$20,000	100%
	Air-to-ground communication system	\$8,000	/	0%
Total Equipment Acquisition Cost		\$6,670,500	\$170,000	2.55%

Table 5. Cost Comparison: UAS vs. Manned Aircraft

As shown in Table 5, some resources required for the manned-aircraft procedure are not needed in the UAS-based procedure. These include, for example, the aircraft copilot, a second ground-based engineer specialized in ILS inspection, an air traffic controller, and the costs associated with the use of airport facilities and services for a manned aircraft, which are not required for the UAS due to its size and operating characteristics.

The table compares both hourly costs and total inspection costs. In addition, it presents a comparison of equipment acquisition costs. About hourly cost, the analysis shows that the cost of conducting the inspection with a UAS is 36.64% of the conventional cost per inspection hour, representing a 63.36% reduction in the cost per flight inspection hour. If the potentially shorter inspection time required by the UAS is also considered, with an estimated ratio of 3:1, the analysis presented in the table indicates that the total cost of each inspection performed with a UAS is only 12.21% of the traditional cost. This represents an 87.79% reduction in total inspection cost.

Equipment acquisition is perhaps the greatest limiting factor for an organization seeking to develop the capability to conduct flight inspection procedures. In this regard, the table shows that the cost of the equipment required to perform the inspection with a UAS is only 2.55% of the cost of conventional equipment. This is primarily due to the substantial cost difference between a manned aircraft and a UAS, as well as the difference in cost between a flight inspection console adapted for a manned aircraft and a navigation signal analyzer small enough to be carried by a UAS. This figure represents a 97.45% reduction in equipment acquisition cost.

CONCLUSIONS

Although ICAO does not explicitly address the use of UAS for flight inspection in Doc. 8071, it does leave room for the development of research initiatives aimed at this purpose through the following statement: *“1.18.2 Remotely piloted aircraft systems (RPAS) or unmanned aerial vehicles (UAV) should be assessed to determine that they provide the payload capability, speed and range necessary to conduct a flight inspection for navigation aids as recommended herein in a cost-effective manner. RPAS can and have been used for special and advanced measurement applications which are difficult to achieve with traditional ground and flight measurement capabilities. Nothing in this manual is intended to prevent the development of such capabilities. Some States are studying how the use of RPAS can help in making more regular measurement checks with the aim to reduce the periodicity of a full flight inspection with a typical flight inspection aircraft. (...)”*

The Colombian scenario, characterized by complex geography with mountain ranges, high peaks, low-altitude valleys, high-elevation aerodromes, and a high concentration of navigation aids in the Andean region, poses significant challenges for conventional flight inspection. In this context, UAS offer advantages in terms of flexibility, accessibility, and adaptability to demanding operational environments.

The implementation of UAS for navigation aid inspection in Colombia is currently in a development and validation phase, with important progress such as the certification of procedures for PAPI light calibration. Nevertheless, additional processes of experimental validation, methodological standardization, and regulatory development are still required for the full adoption of this technology in the inspection of ILS systems. The incorporation of UAS-based methodologies can increase inspection frequency, reduce the operational workload of the flight inspection aircraft, and improve the availability and reliability of navigation aids. This directly contributes to strengthening operational safety and supporting the growth of CNS/ATM infrastructure in Colombia.

The cost analysis shows that UAS-based inspection procedures can reduce inspection costs by 63.36% on an hourly basis. This may represent a reduction of up to 87.79% in total inspection cost when considering that the manned-aircraft procedure may require up to 6 hours, whereas the UAS-based procedure may take approximately 2 hours. However, this time estimate is variable, as it depends on factors external to the process itself. An inspection may take longer depending on the number of passes required to ensure proper data collection; therefore, the actual cost reduction will depend on the efficiency of each procedure. It is also important to consider that, in the case of the manned aircraft, closure of the aerodrome runway is strictly necessary to avoid safety risks while the aircraft is operating. In contrast, with a UAS it is theoretically possible to collect data during the intervals between aircraft movements, due to the ease with which the system can be deployed and the short time required to perform the flight patterns. Under this scenario, runway closure time could be reduced to zero, which would eliminate the estimated value included in the table under the item “Operational disruption costs (runway closure),” thereby further increasing the cost difference between the two types of procedures.

The cost of the equipment required to perform flight inspection with a UAS is only 2.55% of the cost of traditional equipment. This represents a 97.45% reduction in equipment acquisition cost, which implies that, once the capability to conduct flight inspections with UAS has been developed, it will be highly feasible for the organization to acquire additional systems and perform simultaneous inspections. This would help overcome the logistical limitation currently present in Colombia, where only one aircraft is available to inspect all navigation aids across the country, both in civil aviation and State aviation.

Despite the identified benefits, the current state of the technology and the regulatory framework suggests that, in the short term, UAS should be regarded as a complementary tool to traditional flight inspection systems. Experiences in Colombia, such as those conducted at Pereira Airport and by the Colombian Aerospace Force, show that UAS are useful for pre-calibration, verification, and frequent monitoring activities, while final certification still depends on manned aircraft.

RECOMMENDATIONS

It is recommended that UAS be implemented gradually as a complement to traditional flight inspection systems, prioritizing their use in pre-calibration activities, periodic verification, and continuous monitoring of navigation aids. It is essential to advance the development of regulatory guidelines that enable the use of UAS in navigation aid inspection activities, aligned

with ICAO recommendations and adapted to the Colombian context, including aspects such as certification, operational safety, and risk management.

It is necessary to develop technical manuals and standardized procedures for UAS-based inspection, ensuring the traceability of measurements and their comparability with the results obtained using manned aircraft.

FUTURE WORK

Future work should focus on the following areas:

- Experimental validation of the proposed method under real operating conditions
- Development of regulatory frameworks aligned with ICAO recommendations.
- Evaluation of BVLOS operations to expand inspection coverage.
- Quantitative comparison of measurement accuracy between UAS and manned aircraft systems
- Investigate UAS configurations, such as hybrid or fixed-wing platforms, that can increase flight endurance, expand inspection coverage, and reduce dependence on multiple battery cycles.
- Develop studies to assess the impact of UAS implementation on operational safety, including risk analysis, threat mitigation, and system reliability in comparison with traditional methods.

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DECLARATION OF USE OF AI TOOLS

During the preparation of this manuscript, the authors used GPT-5.4 IA model for the purposes of English language proof-reading. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

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