Standardization and Practice of UAS Application in Navaid Lights Flight Inspection in China

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ABSTRACT

Flight Inspection Center of Civil Aviation Administration of China (CAAC) has been deeply engaged in the field of Unmanned Aircraft System (UAS)-based flight inspection. Relying on the dedicated UAS, full-scope inspection coverage for all Navaid Lights items has been realized. It has completed pre-commissioning tests and periodic flight inspections of Navaid Lights at multiple airports, issuing standardized and valid flight inspection reports. Based on the measured Navaid Lights inspection data, an uncertainty evaluation model for Precision Approach Path Indicator (PAPI) light angle measurement has been established, promoting the integration of UAS-based flight inspection technology into the national laboratory system. Meanwhile, under China's UAS legal framework, the Specific Operations Risk Assessment (SORA) for flight inspection scenarios has been completed, and the flight safety support system in complex environments has been continuously improved. This provides important support for the standardized development and industry recognition of UAS-based flight inspection technology.

INTRODUCTION

Traditional Navaid Lights flight inspection has limitations such as long airspace occupation, human errors from pilot visual judgment, and high overall operation cost. In recent years, UAS technology has become an important development direction in flight inspection thanks to its high flexibility and controllable cost. Countries around the world are advancing its application in Navaid Lights flight inspection. With China’s airport construction expanding to remote and complex terrain areas, conventional manned flight inspection is further limited by terrain and weather conditions, leading to a growing demand for UAS-based flight inspection.[1]

Many countries have developed multiple dedicated systems for UAS-based Navaid Lights flight inspection, all capable of effectively judging PAPI light angles, with relevant technical applications becoming mature.[2] CAAC has also issued a series of standard documents for UAS flight inspection and kept promoting standardized application. The released technical and management standards are systematically and targeted integrated into actual UAS flight inspection scenarios. Through standard implementation, the process is regulated, results are unified, efficiency is improved, and risks are controlled.

This paper focuses on the standardization and practice of UAS-based Navaid Lights flight inspection in China:

Promote the standardized application of UAS Navaid Lights flight inspection. After sufficient flight trials, relevant technical and management standards are systematically integrated into the full inspection process. Standardized and valid flight inspection reports are issued to achieve unified results and regulated procedures.

Establish an uncertainty evaluation model for PAPI light angle measurement based on measured data, and integrate UAS flight inspection technology into the existing national laboratory system for manned aircraft to lay a metrological foundation for standardization.

Complete SORA and implement mitigation measures for flight inspection scenarios under China’s UAS legal framework and airspace management characteristics, and build an adapted flight safety support system.

UAS FLIGHT INSPECTION STANDARD SYSTEM OF CHINA

China’s UAS-based Navaid Lights flight inspection standard system consists of technical standards and management standards. Technical standards focus on inspection operations, defining flight methods, parameter ranges, inspection items and other technical requirements to provide a technical basis for UAS-based flight inspection. Management standards center on operational safety control, regulating airspace use, equipment management, risk prevention and other processes to provide safety assurance for actual operation.

Current technical standards related to multi-rotor UAS-based flight inspection mainly cover[3]:

1. Regulate the UAS flight inspection system, defining core indicators such as modular design, positioning accuracy, anti-jamming capability, environmental adaptability and reliability of airborne and ground subsystems;

2. Specify working frequency band, transmission rate, bit error rate, anti-jamming performance and encryption requirements for dedicated air-ground data links;

3. Clarify Navaid Lights flight inspection requirements, specifying inspection items, operating procedures and parameter standards for PAPI lights, approach and runway lighting systems.

Management standards cover a wide range, with core contents related to UAS Navaid Lights flight inspection focusing on three aspects[4]:

1. Airspace management: UAS used for flight inspection shall not operate in mixed airspace with manned aircraft. Isolated airspace shall be designated with defined horizontal/vertical boundaries and operating hours. Flight inspection activities shall apply and report plans in advance;

2. Equipment management: UAS shall complete real-name registration, mark product identification codes and other information, undergo regular inspection, calibration and maintenance, and update performance parameters in a timely manner after modification to maintain continuous airworthiness compliance;

3. Safety management: Establish safety management systems and emergency response plans, complete SORA for flight inspection scenarios. Beyond visual line-of-sight flight in Navaid Lights items shall meet corresponding qualifications and monitoring requirements, and liability insurance and flight data retention shall be implemented.

PRACTICAL APPLICATION OF UAS-BASED NAVAID LIGHTS FLIGHT INSPECTION

Construction of Standard-Compliant UAS Flight Inspection System

To comply with Chinese technical standards such as Technical Requirements for Navaid Lights Flight Inspection Based on UAS and airworthiness regulations, the UAS platform must meet multi-dimensional core compliance indicators. Under the UAS classification rules of China, small UAS (takeoff weight 7-25 kg) are preferred to minimize airspace operation restrictions and improve operational flexibility while carrying full Navaid Lights flight inspection payloads. The positioning system uses RTK technology to achieve centimeter-level positioning accuracy. It supports full-flight data recording to completely store flight paths, parameter settings and inspection data for safety management and data review. The air-ground data link shall comply with dedicated communication standards to ensure continuous transmission of real-time light images, UAS position and other key data with strong anti-jamming capability to adapt to complex airport electromagnetic environments. Based on the above requirements, the modified DJI M350 is selected as the UAS flight inspection platform.[5]

The UAS flight inspection system adopts a modular design, consisting of four parts: UAS and payload, differential ground station, ground controller and inspection module. The inspector controls the UAS through the ground controller. The UAS collects Navaid Lights images through its payload and transmits real-time light images to the inspection module via the measurement and control data link. The inspection module uses machine learning-based image recognition technology to interpret image data. The UAS position is obtained by onboard GNSS, and RTK signals from the differential ground station are used to improve positioning accuracy.

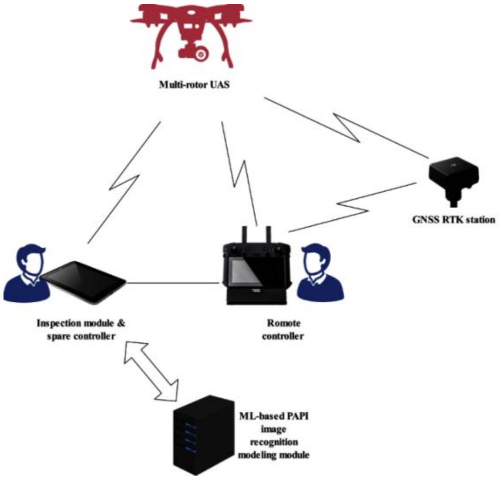

Figure 1. Composition of UAS-based Navaid Lights Flight Inspection System

Implementation of UAS-based Navaid Lights Flight Inspection in Multiple Scenarios

Since first UAS-based Navaid Lights flight inspection test at Qinghai Golog Airport in September 2017, large-scale practical verification has been gradually completed in various typical scenarios. The inspection covers large hub airports (Beijing Daxing International Airport, Hong Kong International Airport), plain airports (Chengde Puning Airport), high-altitude plateau airports (Qinghai Golog Airport, Tibet Nyingchi Mainling Airport), desert environment airports (Xinjiang Yecheng Airport), etc., comprehensively verifying the adaptability and reliability of UAS flight inspection under different terrains, altitudes and climates.

Table 1. Progress of UAS-based Navaid Lights Flight Inspection Tests in China

No.	Time	Location	Duration	Test Purpose
1	Sep. 2017	Qinghai Golog Airport	128 min	First flight inspection test to verify feasibility
2	Feb. 2019	Beijing Daxing Airport	375 min	Verify data consistency with manned aircraft
4	Jun. 2021	Nyingchi Mainling Airport	110 min	Verify reliability at high altitude and different lighting conditions
5	Aug. 2023	Chengde Puning Airport	30 min	Verify upgraded platform function and reliability
6	Aug. 2023	Hong Kong International Airport	90 min	Verify inspection effect at busy airports
7	May 2024	Hong Kong International Airport	180 min	Verify ILS and VOR inspection effects
8	Jul. 2025	Xinjiang Yecheng Airport	30 min	Verify reliability in desert and strong wind environment
9	Sep. 2025	Ngari Burang Airport	40 min	Pre-commissioning inspection of Navaid Lights at high-altitude plateau
10	Oct. 2025	Luntai Airport, Bayingolin	40 min	Pre-commissioning inspection of Navaid Lights in Gobi strong wind
11	Oct. 2025	Nyingchi Mainling Airport	90 min	Periodic inspection of Navaid Lights at high-altitude plateau

No.	Time	Location	Duration	Test Purpose
12	Dec. 2025	Chengde Puning Airport	120 min	Demonstration flight for authority to obtain UAS operation qualification

Ngari Burang Airport in Xizang is highly representative. At an altitude of 4,250 meters and surrounded by mountains, it faces high safety risks for low-altitude maneuvering of manned aircraft due to high altitude, complex terrain and border control. The Navaid Lights on the secondary approach side of Runway 09 could not be inspected by manned aircraft, so the Navaid Lights remained unused after installation for lack of valid inspection reports. UAS technology successfully solved this industry problem. Using the UAS to inspect light angles and combining with manned flight inspection, the airport achieved complete Navaid Lights inspection.

Figure 2. Collaborative Inspection of High-Altitude Plateau Airport by UAS and Manned Aircraft

Based on domestic technical standards and practice, four standardized flight methods are established to cover all Navaid Lights flight inspection items:

1. Vertical: Performed 2 km from the runway threshold to capture the PAPI color transition moment and confirm the color transition angle;

2. Level Run: Fly along the extended runway centerline at 2 nautical miles offset and altitude ⩽300 m to verify light angle and sequence;

3. Level Arc: Fly a horizontal arc ±10° azimuth around the runway threshold at radius 4 nautical miles and altitude ⩾300 m to verify PAPI coverage angle;

4. Approach: Conduct approach according to published procedures and descent gradient starting 4 nautical miles from the threshold to inspect light sequence, brightness level, obstacle clearance and other items.

Analysis of Validity and Effectiveness of Flight Inspection Results

The inspection results of Ngari Burang Airport were verified by subsequent manned aircraft re-inspection. Pilots observed normal Navaid Lights during approach, and no abnormal feedback was received during long-term operation, which fully proving the accuracy and reliability of UAS inspection results and providing key technical support for the official opening of the lighting system. In addition, consistency comparisons between UAS and manned aircraft have been carried out at Beijing Daxing International Airport, Hong Kong International Airport and other airports. The measured PAPI color transition angles by UAS show very small deviation from design values and high consistency with manned aircraft results, meeting relevant standard requirements.

FAC ID	Elev	Azimth	Range	Height	HDG	Pitch	Date Time	Profile
ZULT04	2.89	-0.1	1512.7	78.2	71.5	-2.3	2025-10-21 10:32:31	Vertical

Figure 3. Software Interface in UAS-based Navaid Lights Flight Inspection

UAS FLIGHT INSPECTION AND NATIONAL LABORATORY SYSTEM

Core Value of Integration into National Laboratory System

The ILAC-MRA is the core mechanism for global mutual recognition of laboratory testing and calibration results. In China, the China National Accreditation Service for Conformity Assessment (CNAS) is a signatory member. China’ s manned aircraft Navaid Lights flight inspection has established a full-process management system in strict accordance with ISO/IEC 17025 and been fully accredited by CNAS, achieving global mutual recognition of inspection results and granting authority to inspection data through unified metrological standards and quality control.

Integrating UAS-based Navaid Lights flight inspection into CNAS is an inevitable requirement for technical standardization and a key support for industrial application:

It unifies UAS and manned aircraft inspection in standards, specifications and data validity;

CNAS accreditation eliminates industry concerns about UAS data reliability and improves technical acceptance;

It forces UAS inspection to improve metrological accuracy, equipment calibration and full-process quality control, laying a foundation for large-scale compliant application.

Uncertainty Evaluation of PAPI Light Angle Measurement

Uncertainty evaluation is a core requirement of ISO/IEC 17025. As the only calibration parameter in UAS-based Navaid Lights flight inspection, accurate evaluation of PAPI angle measurement uncertainty is critical. Based on multi-scenario measured flight data, an uncertainty evaluation model for PAPI light angle measurement adapted to UAS inspection scenarios is built to provide metrological support for integrating UAS flight inspection into the national laboratory system.[6]

The model for PAPI angle measurement can be expressed as:

$$Y = X + \Delta_1 + \Delta_2 + \Delta_3 + \Delta_4$$

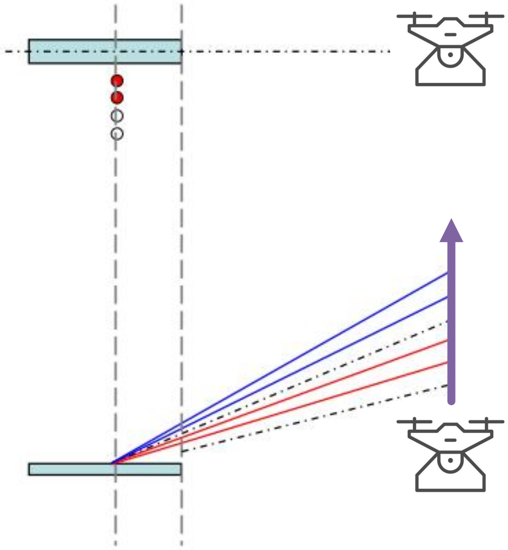

Figure 4. Flight Methods for PAPI Angle Measurement

Where Y is the color transition angle, X is the instrument reading by UAS inspection system, Δ_1 is the influence of UAS positioning, Δ_2 is the influence of database, Δ_3 is the influence of inspector reading, Δ_4 is the influence of distance between PAPI light and runway centerline.

Type A and Type B evaluations are combined to quantify each error source:

Type A evaluation: Multiple independent repeated measurements of PAPI angles are conducted at the same airport in a short period. The experimental standard deviation is calculated. The Type A standard uncertainty of each light ranges from $4.5\times 10{-3}°$ to $5.5\times 10{-3}°$.

Type B evaluation: Non-statistical errors are analyzed and evaluated item by item:

1. RTK positioning accuracy

The positioning accuracy of the UAS under RTK mode is 1 cm + 1 ppm (horizontal) and 1.5 cm + 1 ppm (vertical). Taking Light No.1 as an example, the standard color transition angle is 2.42° , and the distance between the UAS and the PAPI is 2 km. The resulting standard uncertainty u_{B1} is:

$$\theta = \tan^{-1}\left(\frac{2000\tan 2.42° - 0.017}{2000 + 0.012}\right) = 2.4195°$$

$$u_{B1} = \frac{|\theta - 2.42°|}{k} = 2.04 \times 10^{-4°}$$

$u_{B1}$for each light ranges from$2.04 \times 10^{-4°}$ to $2.07 \times 10^{-4°}$.

2. Database mapping error

Maximum horizontal/vertical positioning error from database is 4 cm. The standard uncertainty u_{B2} for light 1 is:

$$\theta = \tan^{-1}\left(\frac{2000\tan 2.42° - 0.04}{2000 + 0.04}\right) = 2.4188°$$

$$u_{B2} = \frac{|\theta - 2.42°|}{k} = 4.87 \times 10^{-4°}$$

u_{B2} for each light ranges from $4.69 \times 10^{-4\circ}$to $4.87 \times 10^{-4\circ}$.

3. Inspector operation

The typical reaction time of the inspector to the PAPI color change is 0.1 s, and the vertical climbing speed of the UAS is 1.2 m/s. The resulting maximum vertical error is 12 cm, and the introduced standard uncertainty u_{B3} is:

$$\theta = \tan^{-1}\left(\frac{2000\tan 2.42° - 0.12}{2000}\right) = 2.4166°$$

$$u_{B3} = \frac{|\theta - 2.42°|}{k} = 1.400 \times 10^{-3\circ}$$

u_{B3} for each light ranges from$1.398 \times 10^{-3\circ}$to $1.400 \times 10^{-3\circ}$.

4. Distance between PAPI light and runway centerline

Taking Light No.1 as an example, the distance between Light No.4 (closest to the runway) and the runway centerline is 45 m, and the spacing between adjacent lights is 9 m. The standard uncertainty u_{B4} introduced by the distance between the PAPI lights and the runway centerline is:

$$\theta = \tan^{-1}\left(\frac{2000\tan 2.42°}{\sqrt{2000^2 + (45 + 3 \times 9)^2}}\right) = 2.4184°$$

$$u_{B4} = \frac{|\theta - 2.42°|}{k} = 6.39 \times 10^{-4\circ}$$

u_{B4} for each light ranges from $3.69 \times 10^{-4\circ}$ to $6.39 \times 10^{-4\circ}$.

Combined standard uncertainty Light No.1 is:

$$u_C = \sqrt{u_A^2 + u_{B1}^2 + u_{B2}^2 + u_{B3}^2 + u_{B4}^2} = 5.7 \times 10^{-3\circ}$$

The other lights are calculated in the same manner. The combined standard uncertainty is less than 0.02° , and the expanded uncertainty (with a coverage factor k=2) ranges from $9.5 \times 10^{-3\circ}$to 0.0115◦ , which fully meets the metrological accuracy requirements specified in relevant international and Chinese standards.

Practice of Integrating UAS Flight Inspection into National Laboratory System

Based on the PAPI light angle measurement uncertainty model, standardized UAS inspection system design and multi-airport verification, Flight Inspection Center (CFI) plans to complete the integration of UAS flight inspection technology into the national laboratory system in 2026.

Three key tasks are promoted:

1. Data equivalence verification: Large-scale blind comparison and consistency analysis between UAS and manned aircraft inspection results have been carried out, covering PAPI angle, coverage, brightness and other items. UAS data shows small deviation and high consistency with manned aircraft data. The next step is to conduct UAS-to-UAS consistency flights.

2. Full-process quality control system: Compiled UAS Flight Inspection Operation Manual covering equipment, personnel, procedures and data lifecycle management. Technical standards are available. Refined documents are being improved with platform iteration.

3. Metrological traceability system: The core difficulty is to link core indicators to national metrological benchmarks. Research on calibration and traceability of positioning accuracy, luminosity and other parameters is ongoing to remove technical barriers for CNAS accreditation.

CONSTRUCTION OF UAS FLIGHT INSPECTION OPERATION SYSTEM AND SORA ASSESSMENT

In accordance with the Interim Regulations on Flight Management of Unmanned Aerial Vehicles and Civil Unmanned Aircraft Operation Safety Management Rules (CCAR-92), organizations conducting civil UAS flight activities shall pass operational safety assessment and obtain a UAS operation certificate and specifications from the competent authority.[7]

CFI has completed operational qualification certification for UAS application in Navaid Lights and navigation facility inspection, carried out comprehensive operational risk assessment under the current regulatory framework, and obtained special operation authorization for flight inspection.

Core Logic of International SORA Assessment Framework

SORA is a systematic method integrating ground and air risks, providing decision support for regulators, operators, ATC units to determine whether UAS can operate safely under preset confidence levels. It follows Joint Authorities for Rulemaking on Unmanned Systems (JARUS) SORA guidelines, takes full-process safety risk management as the core, assesses potential risks of specific operations, and defines safety requirements to meet the Target Level of Safety (TLOS).[8]

SORA helps operators identify risks and reduce them to acceptable levels through targeted mitigation measures, providing standardized guidance for safety judgment.

Localized Adaptation and Implementation of SORA in China

In accordance with national UAS regulations, CCAR-92 and Interim Regulations on Trial Operation of Specific UAS, CFI of CAAC applies SORA to analyze risks of UAS flight inspection scenarios, develops mitigation measures, completes operational safety assessmentn, and carries out trial UAS flight inspection at civil airports to support safe promotion.

SORA Assessment Process and Key Indicators for Flight Inspection Scenarios

SORA takes ground risk and air risk as core dimensions, follows Steps #0 to #9, and generates a SORA report as the core of the comprehensive safety portfolio.

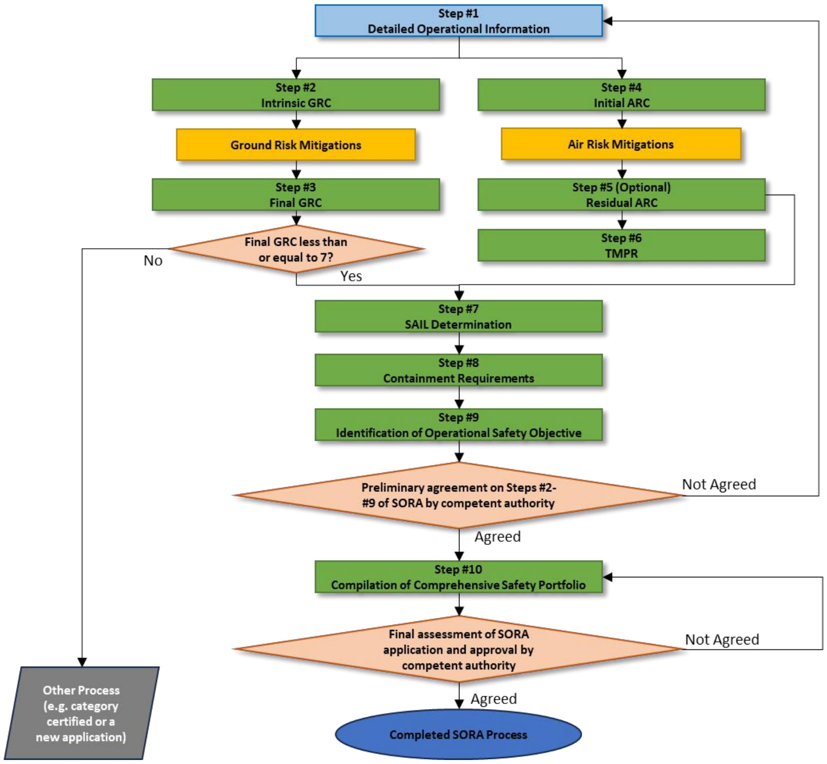

Figure 5. SORA assessment process

Operation conditions:

Flight time is 09:00-19:00 (night operations are not permitted under current regulations temporarily), flight altitude ⩽ 120 m, payload limit ⩽ 2 kg. Light rain and light snow are allowed meteorologically; the UAS can operate normally at wind speeds up to 12 m/s. Spatial and temporal separation from manned aircraft airspace is required for operation.

UAS performance: DJI M350 RTK; max payload 2.7 kg; max speed 23 m/s; max altitude 7,000 m; wind resistance 12 m/s; IP54; operating temperature -20 ℃ to 50 ℃ ; RTK FIX accuracy ± 0.1 m; dual control; endurance up to 6 hours; communication range up to 20 km.

Ground Operation Risk

After initial ground risk calculation and mitigation implementation, the final Ground Risk Class (GRC) is 2.

Air Operation Risk

UAS operates below 120 m AGL in isolated airspace with approved flight plans. Initial Air Risk Class (ARC) is assessed as b.

Air risk mitigation measures:

Strategic: Operate in airport clearance area during no-flight windows of at least 1 hour; establish temporary isolated airspace.

Tactical: Dedicated ATC liaison and observer; obstacle avoidance system; quick descent and landing capability.

Final air risk class remains ARC=b.

SAIL Value Calculation

With GRC=2 and ARC=b, the Specific Assurance and Integrity Level (SAIL) is II, indicating highly confident controllable operation.

OSO Judgment

For SAIL II, 24 Operational Safety Objectives (OSO) are evaluated. Four objectives are medium robustness (M), and the rest are low robustness (L) or optional (O). Mitigation measures for medium robustness items are supplemented in the UAS Operation Manual (CCAR-92).

Overall Conclusion

UAS-based PAPI light flight inspection at domestic airports has passed systematic SORA assessment with GRC=2, ARC=b, SAIL=II. Most safety objectives are satisfied, and medium robustness items are under control, providing complete safety evidence for trial operation.

Construction of China’ s UAS Flight Inspection Operation System

To build a UAS flight inspection operation system compliant with CAAC regulations, CFI of CAAC has completed operational certification, compiled SORA Report for PAPI Light UAS Flight Inspection and UAS Operation Manual, passed on-site flight verification, and formed standardized operational capability.

The UAS Operation Manual regulates operation organization, personnel qualification, flight procedures, special operations and emergency response. Standardized processes are established for UAS transfer, electronic fence management and temporary airspace approval to achieve full-chain closed-loop control.

On this basis, CFI has established an integrated operation and control mechanism: flight plans shall be submitted on the Unmanned Aircraft Operation Management System (UOM) by 12:00 the day before task implementation; during flight, real-time monitoring and data recording of key parameters such as UAS trajectory, altitude and speed shall be conducted through a dedicated cloud platform to ensure controllable operation and traceable risks.

The operation system and standard construction provide institutional support for safe and reliable UAS operation in multi-scenario and complex environments, promote standardized and large-scale application of civil aviation UAS flight inspection, and contribute to the improvement of the UAS operation management system.

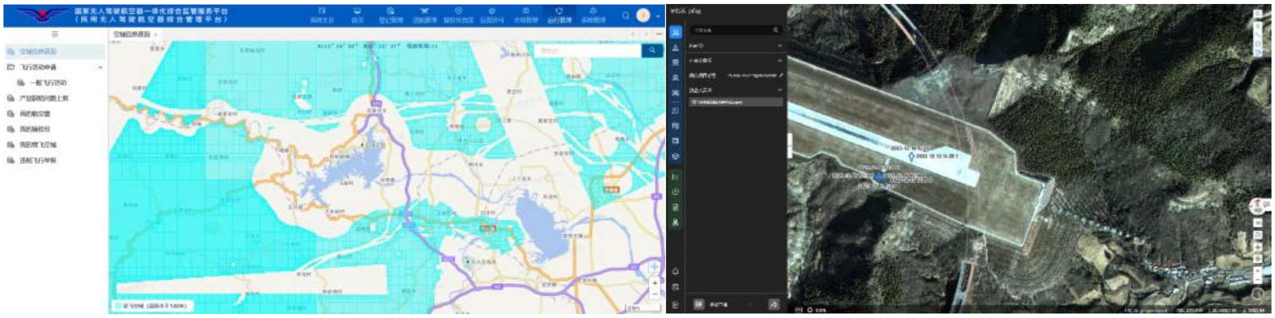

Figure 6. UOM Platform(Left) and UAS Cloud Platform(Right)

CONCLUSIONS

This paper presents the standardization and practice of UAS-based Navaid Lights flight inspection in China. The CFI of CAAC has established an integrated UAS-based Navaid Lights flight inspection system covering standard system, technical equipment, metrological evaluation and safe operation, capable of performing full-item inspection and issuing standardized and valid flight inspection reports. The PAPI light angle measurement uncertainty model based on measured data meets ISO/IEC 17025 metrological requirements and supports the integration of UAS flight inspection into the national laboratory system. The localized SORA risk assessment and operation system developed under domestic regulatory framework achieve controllable risks. These achievements provide solid support for the further application and development of UAS flight inspection in China.

FUTURE WORK

As an important supplement to manned aircraft flight inspection, UAS flight inspection will be prioritized for deployment at high-altitude plateau and complex terrain airports.

Accelerate the integration of UAS flight inspection technology into the CNAS national laboratory system, enhance metrological traceability and full-process quality control, and achieve equivalent mutual recognition with manned aircraft inspection results.

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