

Flight Safety Inspection of FPV Unmanned Aircraft

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Abstract—With the development of low-altitude economy, FPV unmanned aircraft has been widely applied in various fields, such as the flight racing competitions, tracking the ground targets and emergency rescue, etc.. Due to the characteristics of FPV unmanned aircraft, namely fast flight speed, limited observation angle, and high technical requirements for the operator, it is easily to cause various flight accidents in low-altitude airspace. The flight safety inspection for FPV unmanned aircraft is important to ensure the successful completion of the flight mission in low-altitude airspace. It is proposed to adopt the full-cycle control strategy in the pre-flight, in-flight, and post-flight stages. In the pre-flight stage, the preventive inspections before flight was proposed to focus on the components of FPV unmanned aircraft, the current flight environment in low-altitude airspace, and the legal certification of the operator. In the in-flight stage, a real-time flight monitoring mechanism was established to track the relative parameter thresholds of flight controller dynamically, such as battery voltage, video transmission delay, and signal strength. The corresponding emergency response strategies for flight accidents was deployed. In the post-flight stage, the battery was maintained, the flight black box logs is analyzed, and the cause of accidents is tracked as well. In addition, low-altitude ethics was considered in the whole flight inspection process. Finally, the coordinated control strategy was achieved, which can provide a standardized inspection paradigm to ensure the flight safety of FPV unmanned aircraft.

Keywords—first-person view (FPV); unmanned aircraft; flight safety inspection; low-altitude ethics

I. INTRODUCTION

With the development of the low-altitude economy, the application scenarios of FPV unmanned aircraft have been continuously expanded[1]. While facilitating humanity's transition from the current two-dimensional space to a new three-dimensional lifestyle[2], it has also brought about many low-altitude safety risks[3].

Currently, some scholars have conducted the low-altitude threat analysis for FPV unmanned aircraft from the various application fields[4]. At the military level, the high-speed mobility and low-altitude penetration

capability of FPV unmanned aircraft can enable it to carry explosives for precise strikes. The low-cost feature makes it easily as a carrier for swarm tactics to paralyze the air defense systems. In terms of public safety, it is easy to lose control and collide with the pedestrian, vehicles or power lines due to the temporary signal interference or operational errors[5]. The risk of lithium battery explosion can cause fires, and the dependent characteristic of FPV glasses will increase the blind spot of the field of vision, which may increase the probability of collision accidents. In terms of low-altitude ethics, the first-person perspective of FPV unmanned aircraft can secretly photograph sensitive facilities or personal privacy, and intrude into the no-fly zone of the airport to interfere with flight take-offs and landings[6]. At the level of illegal application, FPV unmanned aircraft has been used for smuggling contraband, prison deliveries, even the terrorist attacks. These threats have exacerbated the complexity of prevention and control due to the ease of device modification and the difficulty in tracking, which will cause a dual challenge of technological abuse and lagging regulation[7]. From the current perspective of low-altitude threat sources, the low-altitude flight risks of FPV unmanned aircraft mainly include technical risks, environmental risks[8], human factor risks, and regulatory and compliance risks, etc..

Correspondingly, the flight safety inspection of FPV unmanned aircraft is an important procedure to reduce the various low-altitude risk. The following paragraph will introduce the full-cycle control strategy of flight inspection in the pre-flight, in-flight, and post-flight stages, and incorporate low-altitude ethics into the whole flight inspection process to ensure the flight safety of FPV unmanned aircraft..

II. PRE-FLIGHT INSPECTION

The pre-flight inspection is the first step to ensure flight safety of FPV unmanned aircraft in low-altitude airspace, which mainly includes the equipment safety inspection of FPV unmanned aircraft, the current flight environment, the operator qualification and the flight compliance verification. Each step of the pre-flight inspection is extremely important for ensuring flight safety in the low-altitude airspace. The basic operation procedures of the pre-flight inspection is required to carry out the professional training for the operators and the relevant maintenance personnel of FPV unmanned aircraft, which is shown in Fig.1.

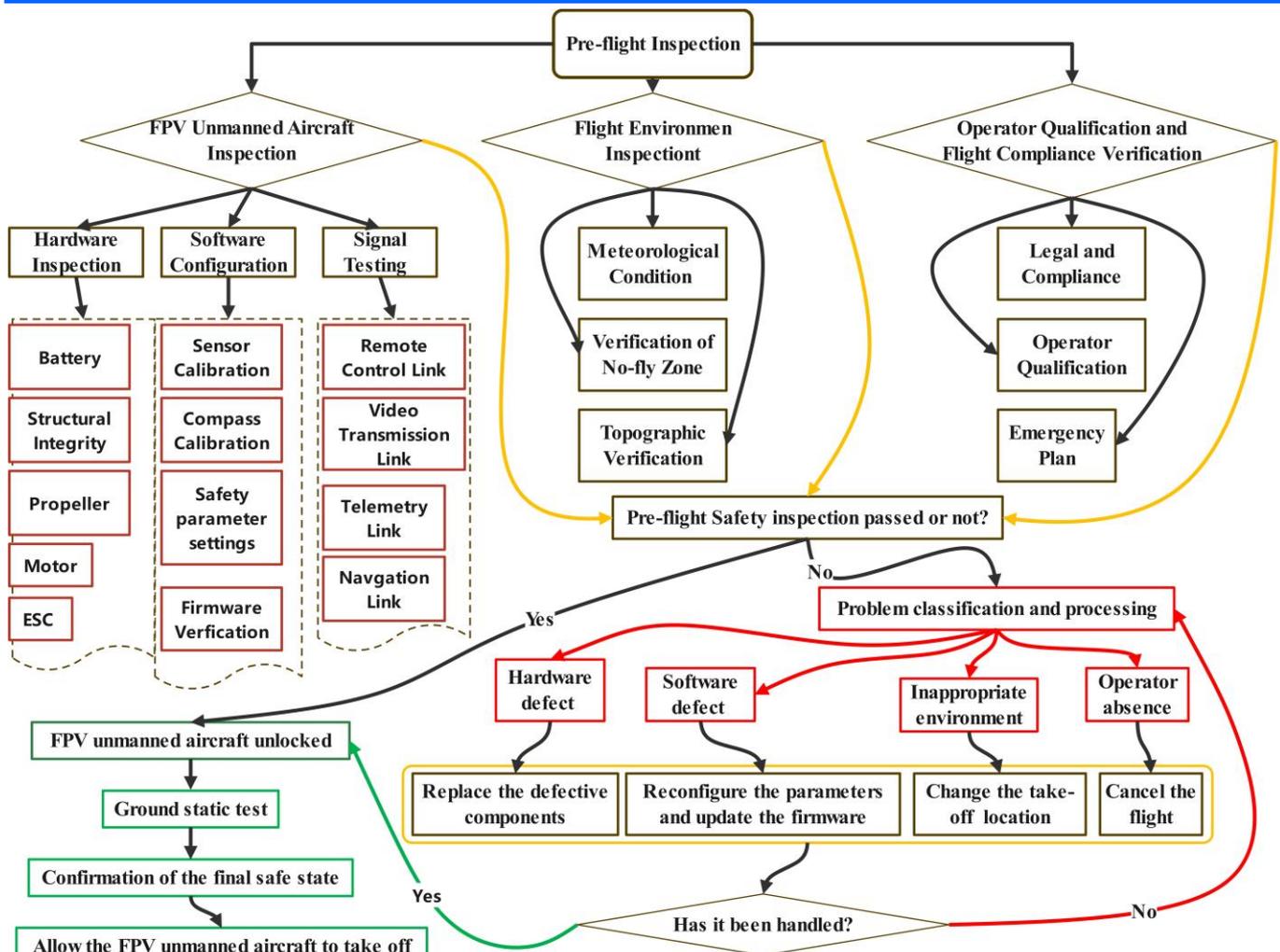


Fig.1. Pre-flight safety inspection procedure of FPV unmanned aircraft

A. Safety Inspection of FPV Unmanned Aircraft

In the safety inspection of FPV unmanned aircraft, it mainly focuses on three parts, namely hardware inspection, software inspection and signal testing.

The strict hardware safety check should be carried out on the FPV unmanned aircraft[9]. Firstly, all the batteries need to be carefully checked to ensure that the appearance is intact without bulges, damage or leakage, the individual voltage is normal and within a safe range, and the batteries are firmly installed. Secondly, a comprehensive review of the structural integrity of the fuselage needs to be conducted to ensure that the frame has no cracks, fractures or obvious deformations, the screws and nuts are tightened without looseness, and all the components are reliably connected[10]. Next, the propellers need to be inspected one by one to ensure the propellers are free from bending, deformation, notches or cracks. The propellers are installed in the correct direction. The lock nuts and the propellers need to be fully tightened. Then, the operator needs to manually rotate each motor gently to feel if its rotation is smooth without any abnormal noise. The operator needs to observe if the motor base is fixed without looseness. At the same time, the electronic speed controller (ESC) should be firmly installed, and the cable connections need to be free from looseness, false

soldering, or damage. Finally, it is essential to ensure that the video transmission and remote control receiving antennas are securely fixed and undamaged, and the positions are reasonable to avoid the obstructions. Any abnormality found in any inspection must be eliminated before proceeding to the next step.

In the software inspection, it usually includes the following steps. Firstly, the sensor and compass calibration of flight control unit are required away from the strong magnetic fields to ensure the accuracy of the magnetic field data. In order to improve the reliability of the accelerometer and gyroscope data in IMU calibration, the FPV unmanned aircraft needs to be placed horizontally and to complete the calibration process. Next, the correct settings of key parameters need to be checked in the flight control parameter adjustment software, which includes the failure protection behavior, the normal function of the flight mode switching, and the electronic fence settings. At the same time, it is necessary to check whether the firmware versions of the core devices such as the flight control, remote controller, receiver, and video transmission are all the latest or compatible with each other to avoid faults caused by the version mismatches. Finally, it needs to be confirmed through the ground station or OSD information that all sensor states are normal and the key flight information is clearly readable in the FPV screen. Any abnormal

parameter settings or calibration failures must be completely resolved before taking off.

In the signal testing, it usually includes the following tasks. For the remote control link, it is necessary to check the strength of the remote control signal and the response delay. For the video transmission link, it is essential to confirm the picture clarity, latency and anti-interference capability. For the telemetry link, it needs to verify the quality of the real-time flight data. For the navigation link, it is useful to ensure that the number of navigation satellites meets the positioning requirements and the positioning is stable.

B. Flight Environment Inspiration

In the inspection of the flight environment, the main contents include the check of the current meteorological condition, the verification of No-fly zone in the target flight area and the topography.

The flight environment assessment is a key factor to ensure the flight safety in low-altitude airspace. Firstly, the current meteorological conditions will be checked to confirm that the real-time wind speed is below the safety threshold, and there is no severe adverse weather conditions[11]. Secondly, the official aviation maps or professional apps needs to be used to verify whether the planned flight area is within the airport clear zone, military control zone, sensitive facilities, etc., and ensure the compliance with low-altitude management regulations. At the same time, it is necessary to conduct on-site terrain environment investigation, identify and avoid physical obstacles such as high-voltage transmission line towers, tall buildings, dense forests, etc., and assess whether the site clearance conditions are sufficient. In addition, it is essential to check whether there are strong electromagnetic interference sources around the flight area. When the environmental hazards are not eliminated, FPV unmanned aircraft are not allowed to take off.

C. Operator Qualification and Flight Compliance Verification

In the operator qualification and flight compliance verification, it mainly consists of the legal and compliance, the operator qualification and the corresponding emergency plan.

Before the flight, the following checks must be conducted. Firstly, it is necessary to verify whether the operator holds valid certificates and has the operating qualifications for the current unmanned aircraft[12]. Secondly, it is essential to confirm that the flight has been legally reported or approved in the target airspace. The flight altitude, area and time will strictly comply with the requirements of low-altitude airspace management. Finally, it is important to simultaneously check whether the emergency response plan is complete, including the handling procedures in case of loss of control, emergency contact persons and contingency plans for forced landing. If any of the above three checks fails, the flight should be prohibited.

After the above three types of pre-flight inspection are completed, it is necessary to determine whether the safety inspection has been passed. If it is successful, FPV unmanned aircraft will be unlocked and the ground static tests will be conducted to determine the final safety status and allow to take off. If the safety check fails, the relative problems should be classified and dealt with. If it is a hardware defect, the defective component needs to be replaced. If it is a software failure, the software parameters should be reconfigured and the firmware be updated as well. If the current environment is not suitable for flight, the take-off location should be changed. If the operator lacks the operation qualifications, the flight task should be canceled. If the problem has been resolved, the FPV unmanned aircraft will be re-entered the unlock state. Otherwise, the relevant safety issues will be continuously processed in a loop until it meets the corresponding requirements of the safety flight inspection.

III. IN-FLIGHT INSPECTION

In-flight inspection is an important part to ensure the flight safety. The real-time flight data should be checked, especially the battery voltage, sensors status and the quality of communication links, etc., which can dynamically avoid the environmental risks. If an emergency occurs during the flight, the emergency response action should be activated, such as automatic return or emergency avoidance in case of faults. The core significance of in-flight inspection is to convert the uncontrollable sudden risks into manageable thresholds, preventing the flight crashes caused by human or environmental factors, simultaneously ensuring public safety and airspace order, and providing a complete data chain for accident investigation. It is an indispensable step for the flight safe operation of FPV unmanned aircraft.

The basic procedure of in-flight inspection of FPV unmanned aircraft is shown in **Fig.2**. In the in-flight safety inspection stage, the flight status of FPV unmanned aircraft, the surrounding environmental risks along the low-altitude flight path, and the compliance with low-altitude airspace regulations need to be scanned simultaneously in real time.

It can be seen from **Fig.2**, the whole in-flight safety inspection is a continuous cyclic detection process. In the course of FPV unmanned aircraft condition monitoring, the core detection units mainly include the battery health status, sensors status and communication link. In the course of the environmental risk scanning, it mainly focuses on the obstacle detection and meteorological condition. As for the low-altitude airspace compliance verification, it refers to the electronic fence, the nearby aircraft detection and the flight altitude values.

All of the above data are aggregated as the input datasets for the classification of risk levels. When the single item anomaly of the input datasets occurs, the basic response will be activated. When two item anomalies are detected, the intermediate response will be activated. If the critical system failure is displayed,

the advanced response will run immediately. After the completion of the three types of responses, the continuous detection of flight safety will be carried out.

In the in-flight safety inspection stage, the triple monitoring tasks, along with the corresponding three-level response and closed-loop management, focuses

on the key parameters such as batteries, sensors, and obstacles, which will ensure the in-flight safety in low-altitude airspace.

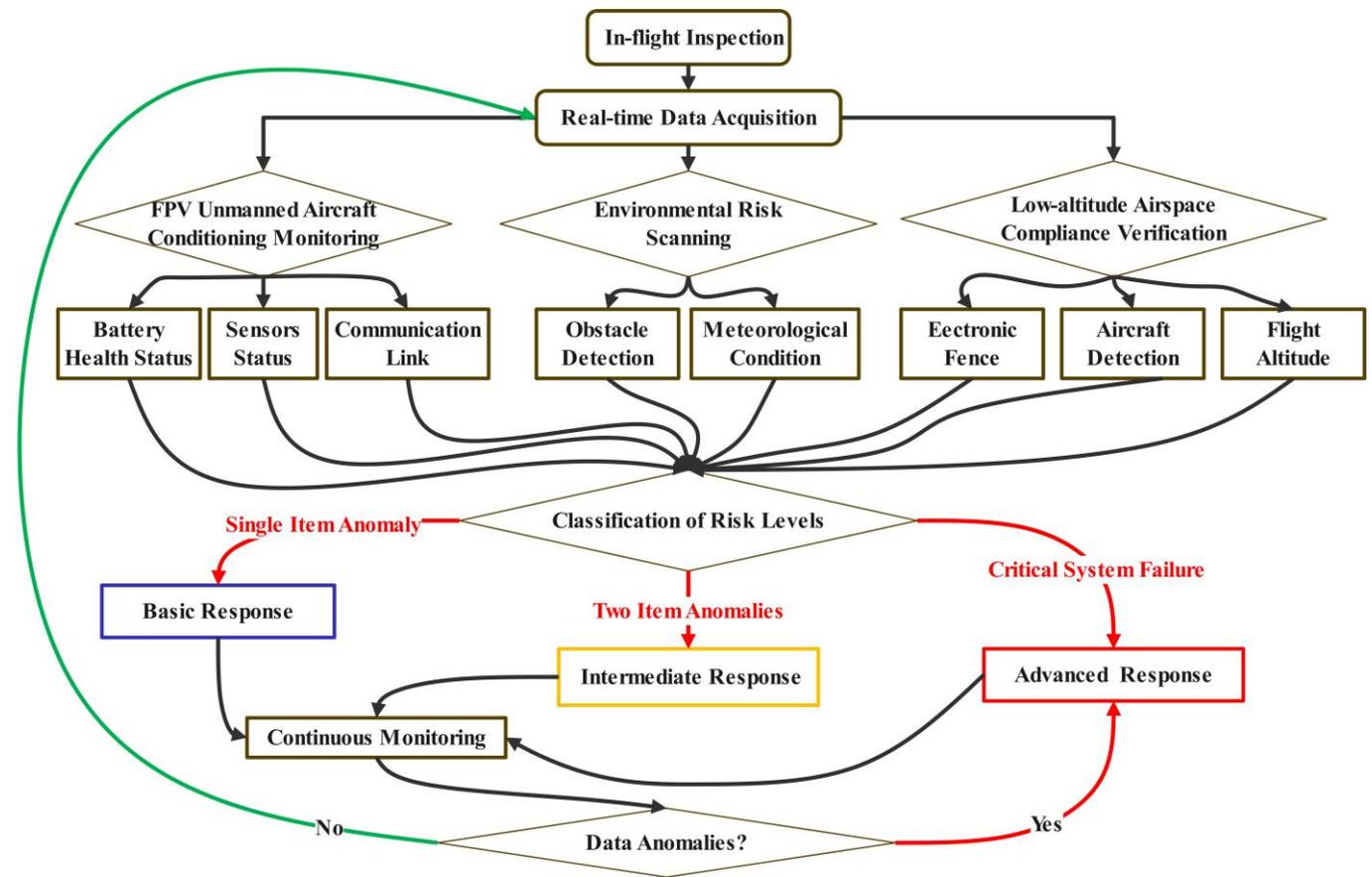


Fig.2. In-flight safety inspection procedure of FPV unmanned aircraft

IV. POST-FLIGHT INSPECTION

Post-flight safety checks are the core phase for ensuring the continuous airworthiness of FPV unmanned aircraft. The safety inspection after the flight is a crucial step for ensuring equipment performance, flight safety, and prolonging the service life. The check procedure significance cannot be ignored. It can guarantee the safety of the next flight and prevent potential risks. The inspection after the flight can promptly identify damages or potential hazards that may occur during the operation of the equipment, such as cracks in the propeller, loose motors, or deformed battery casings. If these issues are not detected, they may lead to loss of control, crashes, or even safety accidents during the next flight. Through regular inspections, unexpected incidents caused by mechanical failures can be effectively avoided, and overall flight safety can be improved. Moreover, it can maintain the equipment's performance and extend its service life. After the unmanned aircraft operates in complex environments, it is prone to accumulate dust, moisture, or foreign objects, which can affect the normal operation of the cooling system and electronic

components. Regular cleaning and inspection help keep all components in good condition, slow down the aging process, and thereby extend the overall service life of the aircraft. Finally, ensuring data integrity and task reliability. After the flight, the stored data needs to be managed, including exporting flight logs, analyzing whether the height curves are abnormal, confirming the completeness of image data and the matching degree of position and attitude information, etc. These data are not only the core of the task results but also provide reference for subsequent flights. If data loss or abnormalities are found, supplementary flights can be taken promptly to ensure the quality of the operation meets the standards.

IV. Complying with regulatory requirements and strengthening operational norms awareness

In accordance with the requirements of the Civil Aviation Administration and relevant management departments, drone operators are obligated to fulfill tasks such as real-name registration and legal flight. The routine inspection after flight, as a part of the standard operating procedures, reflects the professional competence and responsibility of the pilots, and helps to establish a standardized operation system. This is particularly applicable to professional

application scenarios such as education, mapping, and agricultural pest control.

Combining with the in-depth detection of the hardware and software, the traceability of flight data, and the compliance verification, the safety flight inspiration of consumable life cycles will be executed to generate the traceable flight safety reports, which will enhance the quality of flight safety inspections in low-altitude airspace. The basic procedure of post-flight inspection of FPV unmanned aircraft is shown in Fig.3.

It can be seen from Fig.3 that the whole safety inspection procedure in the post-flight stage is to carry out as a series of the relative operations after landing. The ground safety inspector needs to conduct a

hardware inspection and download the flight data of FPV unmanned aircraft. A comprehensive diagnosis will be performed to determine the classification level of the fault. According to the fault grading, it generally includes the regular maintenance, the on-site repair and the depot repair. After the operation, the corresponding repair report will be generated, which includes the technical activities, the compliance filing, the closed-loop verification and the preventive maintenance programs. It should be noted that a power-on self-check operation is required in the closed-loop verification process. If the verification is successful, it is allowed to take off. Otherwise, it will re-enter the maintenance process.

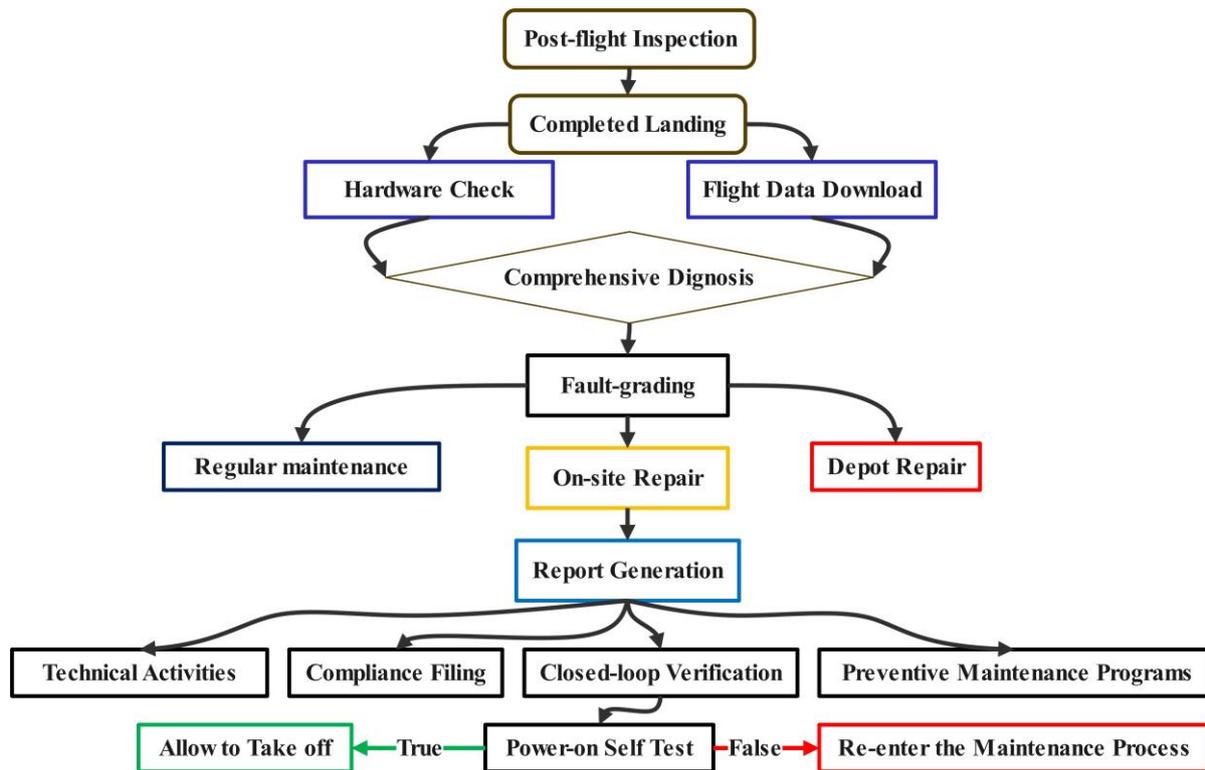


Fig.3. Post-flight safety inspiration procedure of FPV unmanned aircraft

V. LOW-ALTITUDE ETHICS AND FLIGHT INSPECTION

Low-altitude ethics is an important auxiliary measure in the flight safety inspection of FPV unmanned aircraft flights. Low-altitude ethics injects humanistic warmth into the safety of drone flights. The following paragraph will explore the integration strategy of low-altitude ethics and unmanned aircraft flight safety inspections.

The integration and application process of low-altitude ethics and the above flight safety inspection technology is shown in Fig.4.

It can be seen from Fig.4, low-altitude ethics will integrate into the entire stages of flight safety inspection of FPV unmanned aircraft.

In the pre-flight safety inspection stage, the core of low-altitude ethics is the preemptive risk mitigation, which includes establishing the ethical geographic information in the flight area, constraining

the operation behavior and pre-checking the ethical function of the payload. Before FPV unmanned aircraft is taken off, the low-altitude environment should be assumed to be in a vulnerable state, and the ground personnel, animals, and sensitive buildings should have the dignity of undisturbed space. Clearly defining the responsibility of low-altitude ethics should not start after the accident occurs, but should begin before FPV unmanned aircraft is powered on.

In the in-flight safety inspections stage, the core of low-altitude ethics lies in the principle of minimizing risk, which includes the real-time ethical decision-making, the ethical priority handling rule and the ethical decision log. The operator is in an aerial perspective and is prone to ethical desensitization due to the thrill of technology. At this point, a low-altitude ethical restraint mechanism needs to be established to adhere to the minimal intervention, to reduce light

pollution and noise pollution, and to adopt the technical self-discipline to resist the subjectivity of the operator.

In the post-flight safety inspection stage, the core of low-altitude ethics is digital legacy, which includes the privacy data processing, noise and light pollution compensation and data ownership. The end of the flight does not mark the end of low-altitude ethical responsibilities. The high-definition terrain data, facial information, and building structures collected by FPV unmanned aircraft belong to low-altitude privacy

assets, and the operator has the absolute obligation to keep and destroy them. Therefore, it strictly fulfills the responsibility for the proper disposal of data, thoroughly clearing the private images and implementing the ecological compensation for the disturbed environment. In short, low-altitude ethics will elevate the safety inspection of flights from a technical fault detection to a low-altitude civil contract that can safeguard the harmonious coexistence of the sky and the earth.

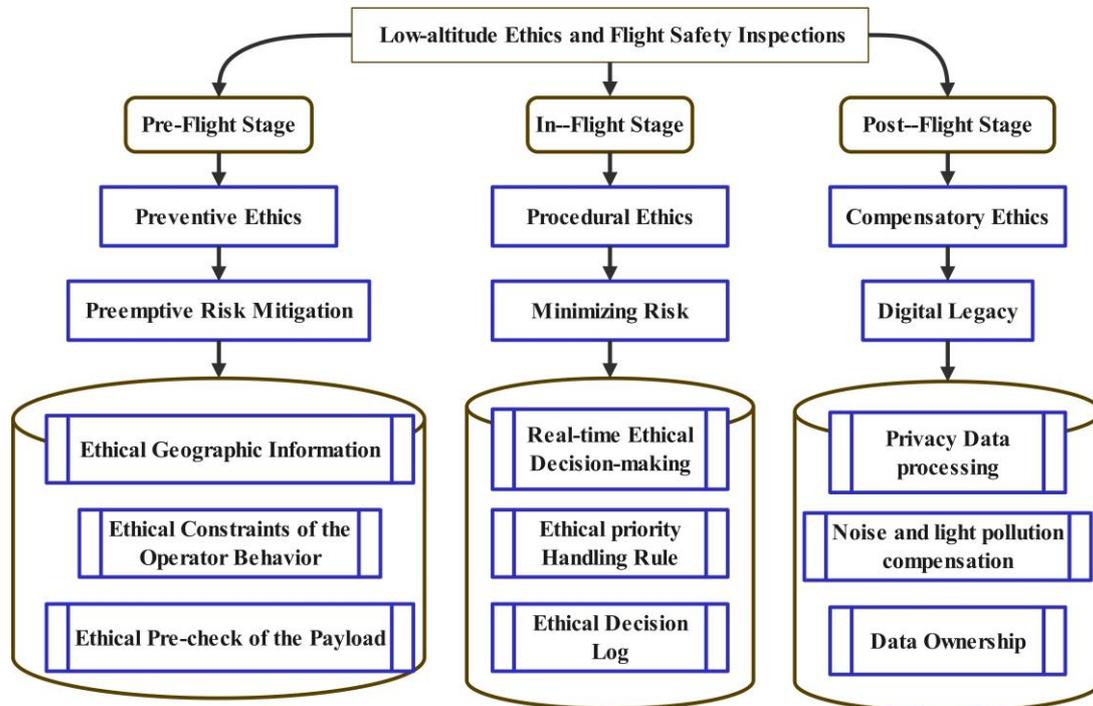


Fig.4. Integration concept of low-altitude ethics and flight safety inspection

VI. CONCLUSION

The flight safety inspection of FPV unmanned aircraft is an important procedure to ensure the orderly development of low-altitude economy. Traditional flight safety inspections usually focus on a specific aspect of the inspection. A systematic inspection process for flight safety is proposed, which includes the differentiated safety inspection methods for flight safety in the pre-flight, in-flight, and post-flight stages. The integration concepts of low-altitude ethics and flight safety inspections is explored as well.

As the scope of low-altitude flight activities continues to expand, there will be an increasing number of FPV unmanned aircraft in low-altitude airspace. At the same time, the relative AI algorithm will be applied in the various fields in low-altitude airspace widely. How to achieve a balance between low-altitude flight operations and low-altitude ethics will be a new challenge in the future.

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