A Study on Development of Reliability Assessment Method for Industrial Drone

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ABSTRACT

In the past, drones have been developed for military use. Recently, however, the use of drones in industrial and civilian markets has been spreading rapidly because of their potential for various applications. The main application areas of industrial drones are aerial photography, logistics transportation, lifesaving, policing, wildfire monitoring and spraying agricultural pesticide. The reliability assessment and performance test methods of drones are not systematically established against such a rapidly growing market situation until these days. Therefore, in this study, we developed reliability assessment methods and test equipment that can evaluate reliability of drone by performance test, environmental test, safety test and life test method, which can be used to ensure safety of individual users and reliability of industrial drones. In the development of the reliability assessment method for industrial drones, we tried to verify drones' reliability and to show the acceptable minimum limit required by manufacturer's general specification. Furthermore, it is expected that we possibly obtain the degradation measure of the flight performance and the durability through the comprehensive performance and life test via applying the usage history and practical load in the laboratory. The developed methods were set up reflecting international standards, user requirements and field operating conditions. Since the field failure data of industrial drones has been reported rare in the manufacturing companies and research institutes until now. We think that it is necessary to obtain more than thousand's hours of the actual usage history and the failure data in order to correct or supplement the developed reliability assessment method in the future.

1. INTORODUCTION

The shape of a typical small industrial drone is shown in Fig. 1. The main components of the drone are composed of five parts: frame, drive motor, propeller, flight control unit and battery. Therefore, it is necessary to develop an evaluation technique that combines mechanical and electrical fields in order to evaluate the reliability of drones. In this study, we mainly focused on the development of evaluation methods to check mechanical parts and system performance. Several testing and evaluation techniques related to safety have been discussed for the electrical components. The most of industrial drone makers are assembling the core components, which are supplied by third party, such as flight controllers, sensors and batteries without manufacturing their own components and these components have passed their respective performance and safety certifications. Therefore, the integrated flight performance of the system can be exerted when the functions of these parts are operated successfully, and the reliable evaluation of the reliability of the individual parts can be achieved by surveying the integrated flight performance.

Figure 1. The shape of typical small industrial drone.

2. RELIABILITY ASSESSMENT METHOD FOR DRONES

The General procedure for the development of reliability assessment method in Reliability Assessment Center at Korea Institute of Machinery and Materials (KIMM RAC) is represented in Figure 2. As shown in Fig. 2., the developed reliability assessment method is based on failure mode and field operating condition. International test standard and test effectiveness analysis are also surveyed throughout the development procedure.

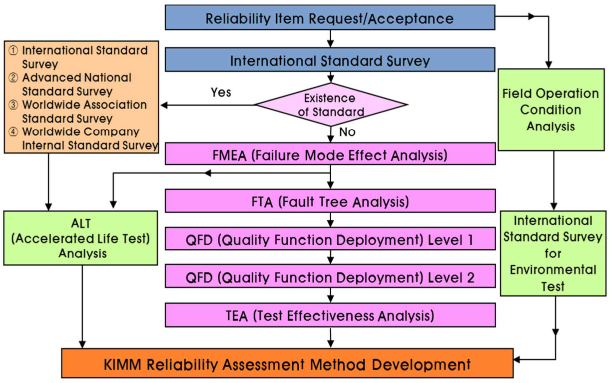

Figure 2. Procedure for the development of reliability assessment method.

2.1. Reliability assessment items for drones

The reliability assessment items developed through FMEA, FTA, QFD and TEA are composed of four fields. Those are general performance, environmental resistance, safety and life evaluation, and reliability assessment items for each field are shown in Table 1..

Table 1. Reliability assessment items for drones.

Classification	Assessment item
General Performance	Hovering performance
	Maximum ascent rate
	Thrust force
	Return to home function
	Maximum flight speed
	Maximum flight time
	Flight altitude limit function
	Fuselage frame vertical strength
	Obstacle avoidance
	Wind resistance
Environmental Resistance	Vibration by transportation
	Drop
	Low temperature
	High temperature
	Solar radiation
	Dust blow
	Humidity
	Rain
Safety	Insulation resistance
	Withstanding voltage
	Electro-magnetic compatibility
Life	Accelerated life test

The failure criteria for each assessment item in the general performance test were determined based on the product specifications of the drone manufacturers. In case of environmental test, MIL-STD-810G and the field operating conditions were considered in combination. Since the safety related flight performance was partly evaluated in the general performance test, only the assessment of insulation, withstand voltage and electromagnetic compatibility was considered in the safety assessment items. In this paper, detailed test methods and criteria for each assessment item are not described due to the page limitation but the development of test equipment and the accelerated life test design for the drone are dealt in Sections 2.2 and 2.3.

2.2. Development of test equipment

The industrial drones covered in this study are small, with a take-off weight of less than 50 kg and the flight altitude is limited to less than 150 m in aviation safety law. The main test equipments developed for the reliability assessment for these drones are flight performance tester, outdoor wind blower and accelerated life test equipment. The assessment items and features of each equipments are described in Table 2. The three developed reliability evaluation equipments is shown in Fig. 3 to 5.

Table 2. Features of developed test equipment.

Test equipment	Assessment items	Features
Flight Performance tester	Hovering	Accurate flight performance test with optical sensor. Ability to measure altitude using wire sensor and forcibly return in emergency. Outdoor test possible with easy movement.
	Maximum ascent rate	
	Return to home	
	Flight altitude limitation	
Outdoor Wind blower	Maximum flight speed	Outdoor test possible with GPS signal reception. Easy operation and maintenance. Wind tunnel and rainfall tests using various optional devices.
	Maximum flight time	
	Wind resistance	
	Rainfall	
Accelerated life test equipment	Thrust force	Reliability of equipment due to simple structure. Low-noise, eco-friendly via electric motor drive. Ability to perform individual and complex movements of rolling, pitching and yawing.
	Frame strength	
	Accelerated life test	

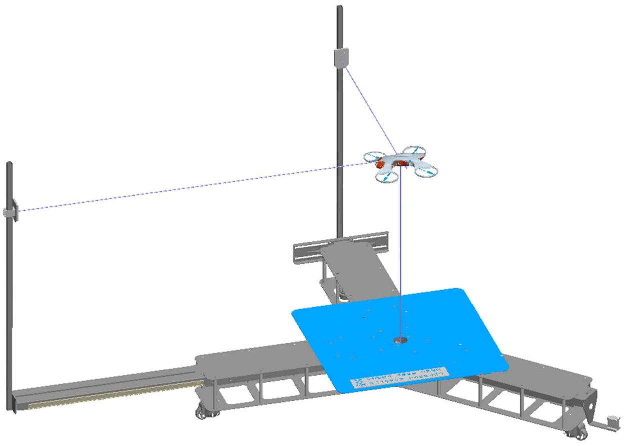

Figure 3. Flight performance tester

Figure 4. Outdoor wind blower

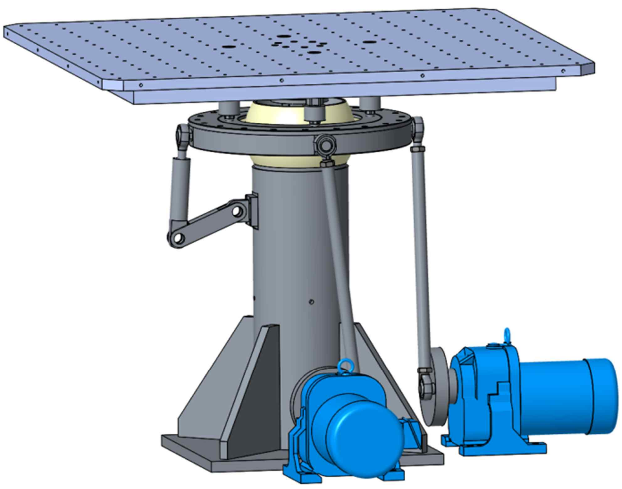

Figure 5. Accelerated life test equipment

2.3. Accelerated life test method

In order to demonstrate the reliability of drone, the warranty life considering the on-site operating conditions is determined and the accelerated life test is designed after calculating the acceleration factor according to success run test time and the acceleration model.

2.3.1. Determination of warranty life

The average equivalent warranty life of industrial small drones was determined to one year through a working group discussion of manufacturers, consumers and reliability experts. The average single flight time of a small drone is about 25 minutes, considering the capacity of the battery. When flying 4 times a week, the total flight time can be estimated 80 hours a year for 48 weeks except holiday. The failure rate for 25 minutes, one flight time that meets the warranty life of 99.9% mission success rate with no breakdown or crash during the 80 hours flight time of the drones can be calculated by Eq. (1).

$$R(t) = e^{-\lambda t} \geq 0.999$$

$$\lambda = \frac{-\ln R}{t} = \frac{-\ln(0.999)}{25} = 4.002 \text{ x}10^{-5} \tag{1}$$

Where, t means one flight time, λ means failure rate and R means mission success rate.

Assuming that the drones follow the Weibull lifetime distribution and the main failure mode comes from the flight control module including sensors, where these failures occur mainly in the field. We can apply the shape parameter of Weibull distribution as 1.1 and use Eq. (2) and (3), the B_{10} life of the drones at a confidence level of 90% can be calculated as 3,040 minutes.

$$\lambda(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \leq 4.002 \times 10^{-5}$$

$$\eta = \left(\frac{\beta \cdot t^{\beta-1}}{\lambda}\right)^{\frac{1}{\beta}} \tag{2}$$

$$B_{10} = \eta \cdot (-\ln \cdot (1-p))^{\frac{1}{\beta}} \tag{3}$$

Where, η means the scale parameter of Weibull distribution, β means the shape parameter of Weibull distribution, t means warranty time(80 hours) and p means unreliability.

2.3.2. Calculation of success run test time

When we have 2 test samples, success run test time to guarantee B_{10} life 3,040 minutes is calculated as 26,728.32 minutes by Eq. (4).

$$t_n = B_{10life} \cdot \left[\frac{\ln(1-CL)}{n \cdot \ln(1-p)}\right]^{\frac{1}{\beta}} \tag{4}$$

Where, t_n means success run test time, B_{10life} means warranty life(3,040 min.) and CL means confidence level.

2.3.3. Accelerated life test design(p27-28)

The accelerating life test was designed by assuming that the motor speed for normal flight of the drone is 40% of the rated speed and the motor speed for the accelerated life test is 100% of the rated speed. The acceleration factor can be calculated by Eq. (5) and accelerated life test time can be obtained by dividing the success run test time by the acceleration factor as shown in Eq. (6).

$$AF = \left(\frac{V_{test}}{V_{field}}\right)^m = \left(\frac{V_{max}}{0.4V_{max}}\right)^1 = 2.50 \tag{5}$$

$$t_{na} = \left(\frac{t_n}{AF}\right) = \left(\frac{26728.32}{2.50}\right) \approx 180 \text{ hours} \tag{6}$$

Where, AF means acceleration factor, $V_{test,field,max}$ means the test, normal and max speed of motor respectively, m means speed acceleration model index and t_{na} means accelerated life test time.

Rolling, pitching and yawing motion test cycle diagram for accelerated life test are represented in Fig. 6 to 7.

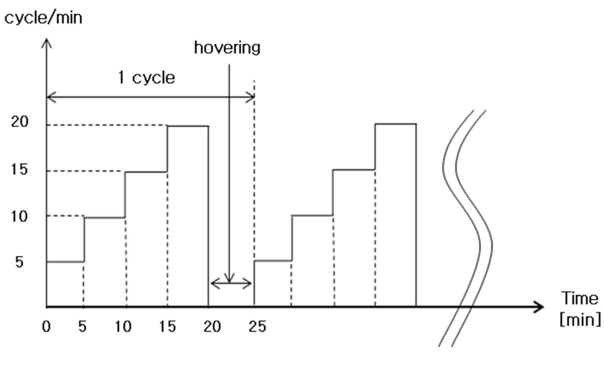

Figure 6. Rolling and pitching motion test cycle diagram for accelerated life test

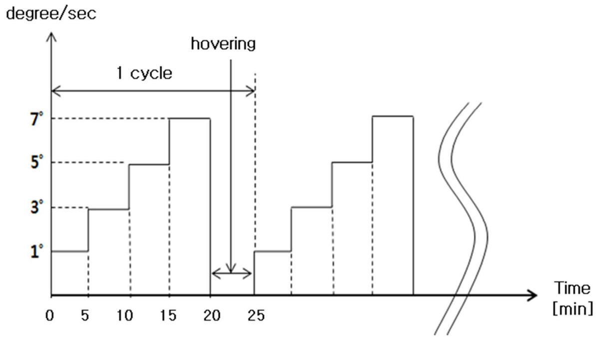

Figure 7. Yawing motion test cycle diagram for accelerated life test

The designed accelerated life test method; fix the drone to the base of the test equipment which shown in Fig. 5 and keep it at 40% of the maximum thrust with providing wired power supply. Then move the base in the rolling, pitching and yawing directions, the rolling and pitching angles are determined to (15 ± 1) ° and (15 ± 2) °, respectively based on the specification of drone manufacturers. After the base was operated for five minutes at 5 ° per minute in the rolling and pitching directions and at 1 ° per second in the yawing axis as shown in Fig. 6 and 7, rolling and pitching motion are increased their speed to 5 times per minute at every 5 minute intervals, for yawing motion is increased its speed to 2 degrees per second at every 5 minute. These motions of base are kept for 20 minutes and the last 5 minutes of test cycle is composed of hovering, that is, no motion of the base. This test cycle is repeated until 180 hours. The acceptance criterion of the developed reliability assessment method is accelerated lifetime test of two samples, and both of them must operate without failure for 180 hours. If the sample passes the criterion, it can be said that an average one year equivalent life span of B_{10} 3,040 minutes of flight time at a confidence level of 90% is guaranteed.

3. CONCLUSION

In this study, reliability assessment method of industrial small drones was developed. We used FMEA, QFD and TEA techniques for systematic development of the evaluation method. The reliability assessment method of the drones was composed of 22 assessment items including 10 general performance test, 8 environment resistance test, 3 safety and accelerated life test. Three kinds of test equipments were developed to evaluate the flight performance and life time of the drones, and 180 hours accelerated life test method was proposed for two test samples. In the future, if the field failure data is accumulated in actual use condition, it is considered that the reliability assessment method of this study should be modified and supplemented so that it becomes more realistic.

ACKNOWLEDGEMENT

This study was supported by the Ministry of Trade, Industry and Energy, so we would like to thank the people concerned.

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BIOGRAPHIES

Jong-Won Park received his B.S. and M.S. degrees in Mechanical Engineering from Hongik University in 1996 and 1998 respectively, Korea. He received his Ph.D. degree in Fluid Power System Control Engineering from Seoul National University in 2003, Korea. Since 2003, he has joined in Reliability Assessment Center in Korea Institute of Machinery and Materials (KIMM). Currently, he is a principal researcher at Reliability Assessment Center in KIMM. His main research interest is mechanical system analysis and control, reliability assessment via accelerated life test, system reliability analysis and artificial intelligence.

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