devKopter, Multicopter Development Platform for Engineers

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***Abstract*—** In this paper, we introduce the development of a standard flight platform for verification of small UAV research and development. We conduct a study on the performance and safety of the standard flight platform through requirements analysis of standard flight platform, platform design process, and manufacturing and testing process. Also, we introduce ongoing researches on PILS / HILS system for simulation-based mission verification.

Keywords—multicopter, flight test, PILS, HILS

I. INTRODUCTION

Due to the growth of the drones' market over the last few years, the area of applications of drones has expanded to various fields including aerial imaging, agriculture, delivery, infrastructure maintenance and public service. Through researches on communication, flight control, artificial intelligence, and so on, various technologies are being developed to utilize drones in various fields. However, there is little research on the flight platform for the verification of development technologies. In general, researchers of drone-related engineering are using DJI platforms such as Matrice series, but they have troubles with study related to the heavier payload or high-performance equipment due to the weight limit of those platforms. Despite the difficulties mentioned above, researchers do not want to build their own drone. Because of uncertainties about the accuracy of aircraft performance and the risks of accidents during flight, researchers are accustomed to buying commercial drone instead of building their own drones. If researchers are using commercial drones, the aircraft performance and safety of the flight platform must be verified individually. Moreover, if the flight platform is changed to improve the R & D work, the flight test must be run again to predict aircraft performance and safety.

This paper introduces the standard flight platform with multicopter configuration ("devKopter") for research verification and introduces the requirements analysis and development process for the devKopter. The goal of this research is to provide a standard aircraft performance database and engineering drone model that demonstrates flight performance and safety through the process of manufacturing, simulation and flight test

II. REQUIREMENTS

The requirements of the airframe, components and engineering model for the development of the standard flight platform have been established as follows:

A. Airframe

- Mounting space: Installation space of flight control computer and mission computer with minimum 150 (W) x150 (D) x100 (H) mm
- Component replacement: Frame structure and installation interface for major components (FC, battery, radio and telemetry) and standard mounting holes (VESA)
- Aircraft transport: foldable or detachable arm structure to enhance the transport capability of the aircraft

B. Components

- Various flight control computer support: Open source based Pixhawk, Cube flight control computer and self-developed flight control computer
- High-performance mission computer support: High-performance mission computer for large-scale operation such as AI, SLAM, image processing
- Convenient installation of mission equipment: Provides external power (12V and 5V) interface for installation of mission equipment such as EO/IR, LIDAR, stereo camera, fusion sensor

C. Engineering Model

- Wind tunnel test: Constructing a drag force database for predicting power consumption in forward flight or environmental conditions (windy day)
- Flight test: Preliminary verification and data provision of performance and safety of airplane
- Mission simulation: PILS / HILS construction for simulation-based mission analysis

III. Design Process

A. Conceptual design

We collect the database regarding to development drone platforms, we acquire aircraft performance index such as MTOW, diagonal length, payload weight, and flight time. We investigate the existing development platforms and perform the initial design so that devKopter can fly for about 20 minutes with a payload of about 2 kg.

TABLE I. Performance Index of Various Drone Platforms

	MTOW (kg)	**Propeller Size (in)**	**Diagonal Length (mm)**	**Payload weight (g)**	**Flight time (min)***
DJI Matrice 100	3400	13	650	1000	22 - 13
DJI Matrice 600 pro	15500	21	1133	6000	32 - 16
Intel RTF	1900	9	360	500**	20 - N/A
Aerotenna RTF	4000	15.5	600	N/A	50 - N/A

* w/o payload – w/payload, ** guess value

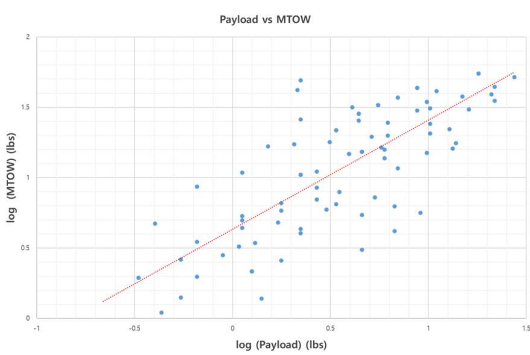

Fig. 1. Payload vs. MTOW

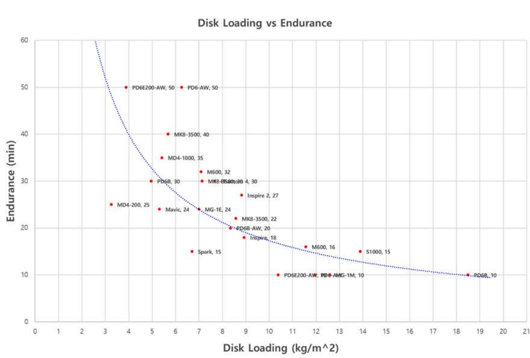

Fig. 2. Disk Loading vs. Endurance

AUVSI presented graphs of hand launched and small VTOL UAS with respect to payload weight, endurance time, range, and size[1]. In this paper, we focus on the small VTOL UAS within 55lbs(25kg) and re-calculate the regression equation between maximum takeoff weight and payload weight. Fig. 1 shows Fig. 1 shows an exponential relationship (linear in log-scale) between maximum takeoff weight and payload weight. According to the regression equation, the drone with 2kg payload corresponds to the drone that has maximum take-off weight of about 7 ~ 8kg.

When the various types of drones have the same battery capacity, the lightest drones can fly long. We analyze statistical relationships between flight times and disk loading using information from several types of commercial drones. Fig. 2 shows an inverse relationship between the weight of the drones versus disk area (disk loading) and flight time. For drones with a take-off weight of 7 ~ 8 kg for a 20-minutes flight, the propeller diameter can be estimated to be approximately 18 to 20 inches.

For a drone in hovering condition, the power required P_{req} at a given weight W is given by

$$P_{req} = \frac{W^{\frac{3}{2}}}{FM\sqrt{2\rho A}} \quad (1)$$

where FM is figure of merit of the rotor, ρ is air density, and A is the total disk area[2].

The capacity of a battery is described in ampere-hours. Typically, the battery run time is the capacity divided by the current. However, if the required current is higher than the 1-hour discharge current, the battery run time will be shorter than expected (Peukert effect). Battery run time t can be estimated by discharging current I, capacity C, and rated discharging time H .

$$t = H\left(\frac{C}{IH}\right)^{k} \quad (2)$$

where k is the Peukert constant.

Combining (1) and (2), battery capacity C can be written in following form

$$C = H\frac{W^{\frac{3}{2}}}{\eta_M VFM\sqrt{2\rho A}}\left(\frac{t}{H}\right)^{\frac{1}{k}} \quad (3)$$

where η_M is efficiency of motor and V is volts[3].

Battery capacity can be estimated by approximately 20000~22000mAh for given conditions.

B. Detail design

Based on the design variables derived from the conceptual design process, the major products (motor, ESC, propeller, battery) for devKopter are listed in Table 2. Total weight without battery is 3.74 kg and maximum takeoff weight is 8.34 kg. Moreover, airframe is manufactured with a detachable arm reflecting the requirements of the standard flight platform.

Fig. 3. devKopter Configuration

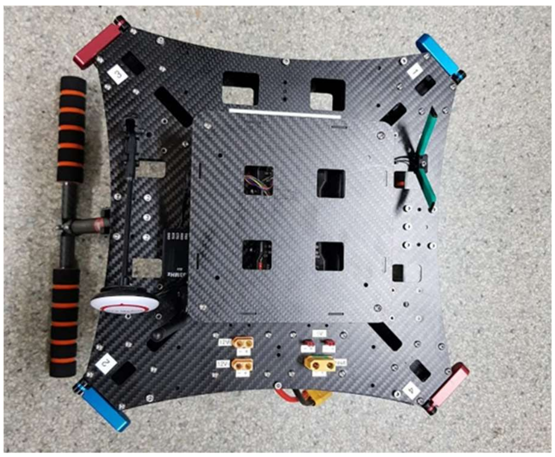

Fig. 4. devKopter Mainframe

Fig. 5. devKopter Detachable Arms

TABLE II. LISTS OF COMMERCIAL ITEMS USED IN MANUFACTURING

	Vendor	Specification	Weight (g)
Motor	T-Motor U7 V2.0	420 Kv	250
Propeller	T-Motor	Diameter 18 in Pitch 6.1	37
ESC	Hobby wing X-Rotor	Max 60 A	90
Battey	Tattu plus	10,000 mAh	1520
		16,000 mAh	2130
		22,000 mAh	2580
FC	Pixhawk	-	N/A

IV. DATABASE FOR ENGINERRING MODEL

A. *Performace Analysis*

In order to estimate the flight time of the devKopter, the hovering flight time is calculated using the currently developed CLOUDS(Conceptual Layout Optimization of Universal Drone Systems) program[4]. Analysis conditions for take-off weight and battery capacities are 5.74 kg and 16000 mAh, respectively. As a result, 32-minutes flight time is estimated.

B. *Hovering Flight Test*

In order to compare with the predicted results of the design program, the flight test is performed according to the test conditions and the flight time is measured as 33 minutes. In the case of flight test and numerical analysis, below 10% of the remaining battery capacity is set as a termination condition. Even if there is about 1-minute difference between flight test and numerical simulation, this difference is acceptable since the exact comparison of the remaining battery capacity in actual flight is almost impossible

Fig. 6. devKopter Test Flight

Fig. 7. Windtunnel test

C. *Windtunnel Test*

In addition to in hovering flight tests, wind tunnel tests are carried out to measure the force and moment of devKopter in response to changes in wind speed. In order to construct a wind tunnel test model, the flight control computer is removed and sensor equipments are installed to directly measure the RPM of the individual motors. The forces and moments are measured in the wind speed range from 0m / s to 15m / s with various RPM conditions of front and rear motors.

The drag database obtained from the wind speed test are supplemented with the CLOUDS program and data from PILS and HILS.

V. Simulation Based Application

A. *PILS*

The PILS system is currently under construction to compare the performance of the aircraft in various mission situations by using the surrogate model of motor, propeller, and battery. By simulating the control algorithm of the drone and the actual operating environment (GPS and IMU sensor signals), we visualize the movement of the drone on the simulator, tune the parameters of flight controller and collect databases that are similar to the actual flight conditions.

B. *HILS*

After building PILS system, we will develop HILS system that uses actual drone parts, not surrogate models. In actual flight tests, crashes may occur during the flight and it may take a long time to prepare for the flight again The HILS simulates flight environment conditions and evaluates the flight performance of various mission situations. In addition, the safety and robustness of the drone can be verified through over time by testing.

VI. Concluding Remarks

Through the analysis and design procedure of the development platform, we make the drones suitable for the target requirements and conduct the performance estimation and verification. Through the wind tunnel tests, the drag force database of drone with the 1000mm-diagonal length is collected and, it can be supplemented with the database focused on the small drones. After the ongoing construction of the PILS / HILS, the results of this study will be open to the public so that more researchers can access it.

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