PBL Program Producing Flying Robot in Mechanical and Aerospace Engineering Department

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Abstract. More and more mechanical and aerospace engineering departments of Universities and Colleges are adopting Project-Based Learning (PBL). One of the main purposes of PBL programs is the practical understanding of the relationship between classroom lectures on traditional theories, e.g., material mechanics, fluid dynamics, dynamics of machinery, and control engineering, and real phenomena of mechanical systems. Moreover, we need to take the use of recent digital manufacturing (e.g., 3D printers, CAD/CAM, and CAE) into account as recent educational content and methods. This paper introduces a novel trial of using PBL at Nagoya University. More specifically, the new program provides students with the experience of producing flying robots and introduces the above relationship and digital manufacturing.

1 Introduction

In recent years, many mechanical and aerospace engineering (MAE) departments of Universities and Colleges are adopting Project-Based Learning (PBL) [1], [2]. One of the main purposes of PBL programs is the practical understanding of the relationship between classroom lectures of traditional theories, e.g., material mechanics, fluid dynamics, and control engineering, and the real phenomena of mechanical systems. Moreover, we need to take the use of recent digital manufacturing (e.g., 3D printers, CAD/CAM, CAE) into account as recent educational content.

However, many MAE departments in Japan still use old-fashioned machinery for undergraduate lab classes due to budget constraints. In these lab classes, the integration of plural theories for manufacturing is not discussed. Generally, each lab class offers single experimental program for each traditional theory, e.g., an inverted pendulum control experiment program for understanding the control engineering theory. Subsequently, the technological gap between MAE departments and real industries may be enlarged because real industries emphasize the optimal integration "SURIAWASE (in Japanese)" of plural theories for high-quality high-efficiency manufacturing. Moreover, the recent increase in "passive engineers" in digital manufacturing is a concern. Digital manufacturing seems to be a black box for passive engineers. Taking these factors into account, the MAE department at Nagoya University (NUMAE) is now considering a new PBL program, "Design Practice." This program focuses on the following two elements: (i) The students consider the relationship between the integration of traditional plural theories and practical mechanical design, and (ii) the students experience the recent digital manufacturing effectively. The Design Practice program involves "Producing a Flying Robot" as a specific PBL theme. When designing a flying robot, the body strength and weight (material mechanics), aerodynamic shape (fluid dynamics), actuating system and control mechanisms/algorithms (dynamics of machinery and control engineering) all need to be considered. The integration of these considerations can lead to the development of a high performance flying robot. Simultaneously, parts of the robot, e.g., the wing rib, correspond to a good example of a digitally manufactured product.

The new program "Design Practice" begins in October 2019, and this paper reports on the plan for implementing the program with a focus on the development of a novel flying robot design for educational purposes.

2 Flying robots for the PBL program

The flying robot in the Design Practice program is a glider model without a power generation mechanism, as illustrated in Figs. 1 and 2. Figure 1 shows (a) the overview of the model and (b) the materials used to build the model. Although its length and wingspan are 1.20 m and 0.80 m, respectively, it weighs only 0.27 kg. The longitudinal direction core rod made of carbon pipe is lightweight, tough, and hard to break. These characteristics are well-suited for repeated experiments by beginners. It can fly by using an initial thrust force provided by a rubber tension based takeoff mechanism

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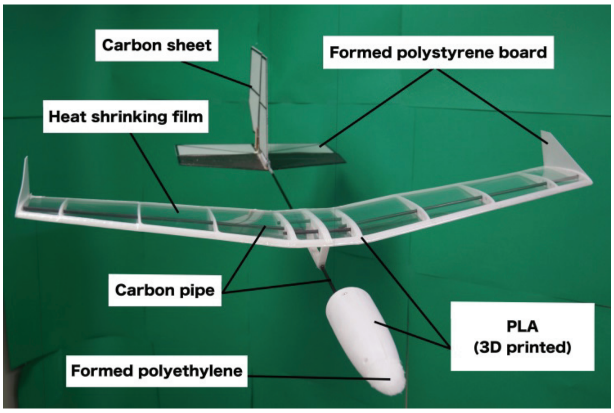
(a) Overview.



(b) Materials.

Fig. 1. Example of a flying robot for project-based learning.

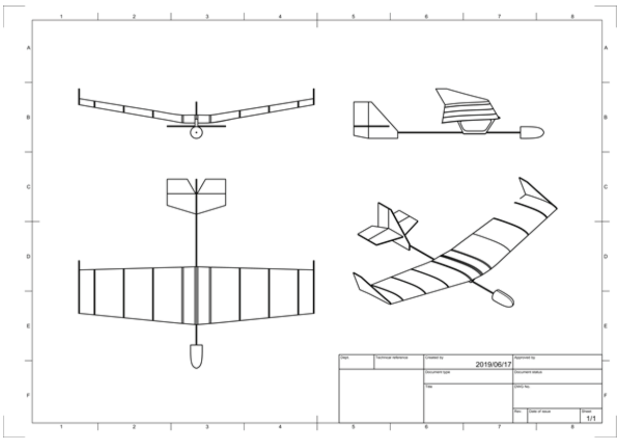
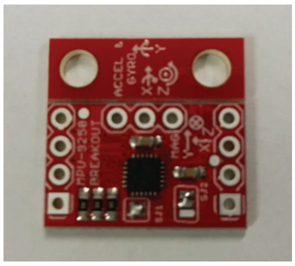


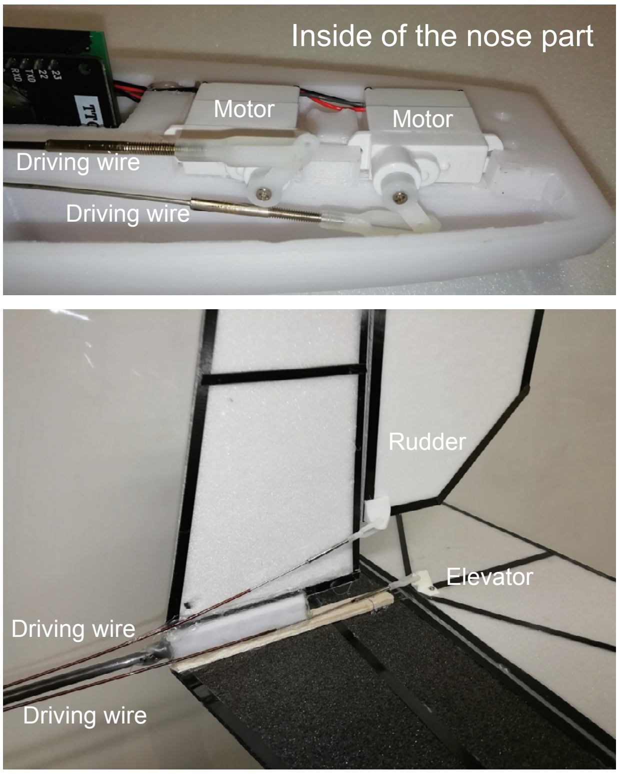
Fig. 2. Drafting of the flying robot.

or a throwing motion from an operator. During flight, it can control its posture using two types of feedback control mechanisms for yawing and pitching controls. In this program, the general PID control algorithm is applied to the controllers, and their feedback gains are tuned by trial-and-error.

The control mechanism includes an attitude heading reference system (AHRS) sensor (Fig. 3a), a microcomputer (Espressif Systems Co., Ltd., ESP32-DOWDQ6), and an actuation system consisting of microservomotors and link mechanisms (Fig. 3b). The block diagram of the control mechanisms is shown in



(a) AHRS sensor.



(b) Motors and driving wires (link mechanisms).

Fig. 3. Feedback control devices.

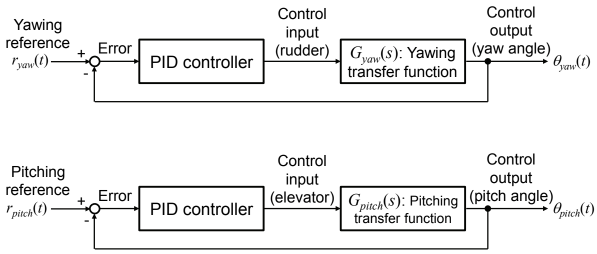
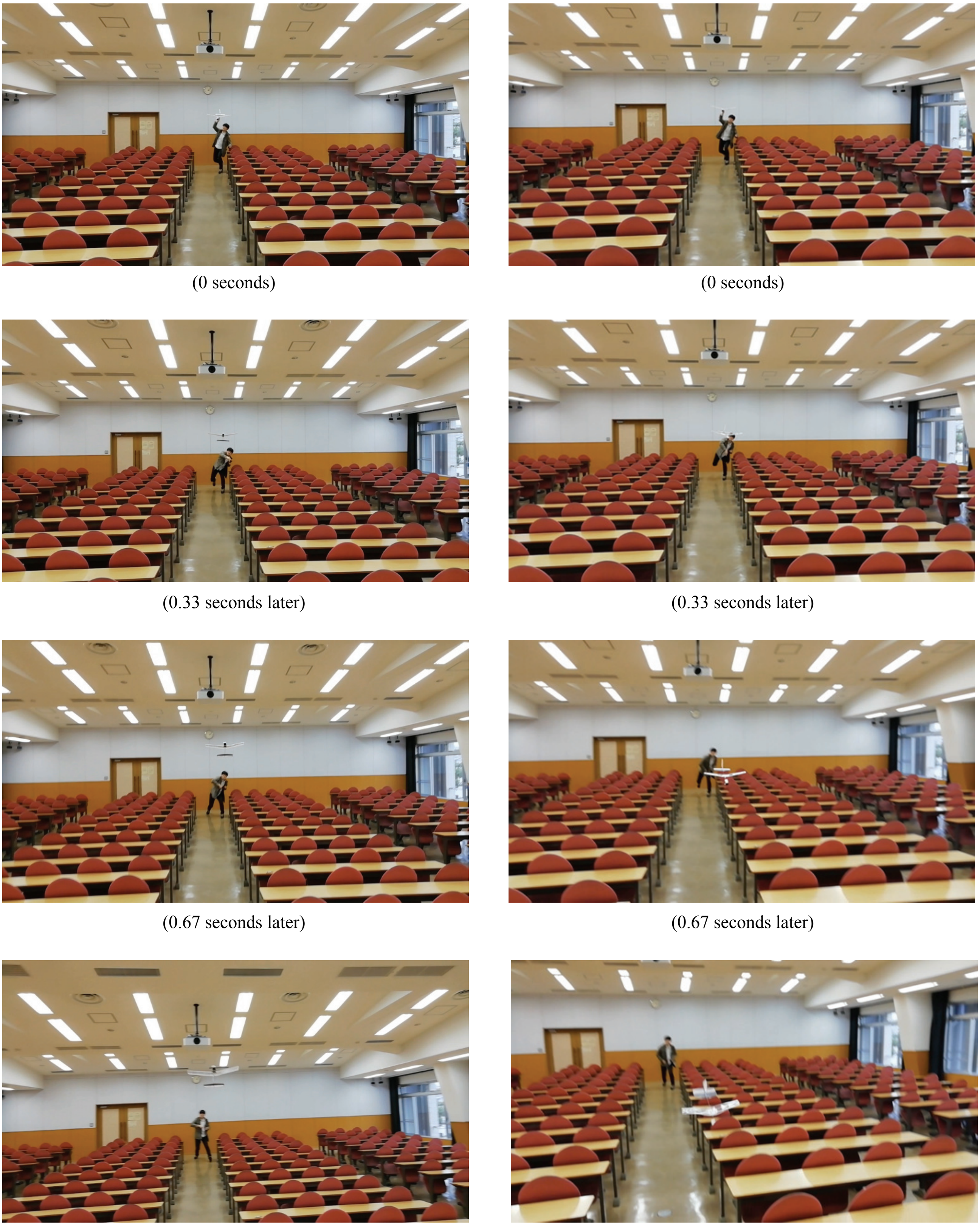


Fig. 4. Feedback control devices.

Fig. 4. The yawing and pitching references are set to 0 in the experiments. If the optimal feedback controls are realized, this can increase the flight distance. The states of the real experiments with and without the feedback control are shown in Fig. 5. From a comparison of both of the cases, it is easy to understand that the PID control realizes stable flight. The first author has released movies of this flying robot with and without feedback controls [3]. From this model, it is easy to understand the effectiveness of the control engineering theory. To experience digital manufacturing, a part of the wing is



(0 seconds) (0 seconds)

(0.33 seconds later) (0.33 seconds later)

(0.67 seconds later) (0.67 seconds later)

(1.0 second later) (1.0 second later)

(a) w/ feedback control (from the top to the bottom: 0 seconds, 0.33 seconds later, 0.67 seconds later, 1.0 second later).

(b) w/o feedback control (from the top to the bottom: 0 seconds, 0.33 seconds later, 0.67 seconds later, 1.0 second later).

Fig. 5. The real experiments: (a): w/ feedback control, (b): w/o feedback control.

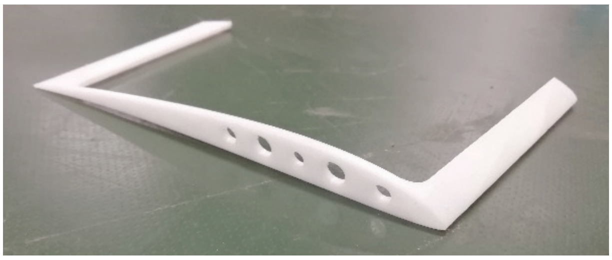


Fig. 6. A part of the wing created by a 3D printer.

Table 1. Major specifications of the flying robot.

Length	1.20 m
Wingspan	0.80 m
Wing area	1.41 X 10^{-1} m^2
Average chord length	0.175 m
Dihedral	10 deg
Angle of incident	5 deg
Sweepback angle	3 deg
Weight	0.27 kg

Table 2. The schedule of PBL program.

1st week	Guidance of "Design Practice"
2nd week	Guidance of "Flying Robot" and Safety Education
3rd week	Introduction of theoretical issues
4th–9th weeks	Production work (first half)
10th week	Midterm check
11th–13th weeks	Production work (later half)
14th week	Flying competition
15th week	Review meeting

created using a 3D printer, as shown in Fig. 6. The use of the 3D printer is also effective for maintaining the manufacturing pace of most of the students in comparison to when the manufacturing is completed by hand.

The major specifications of the flying robot are summarized in Table 1. One robot costs approximately USD 20, excluding the startup facilities such as a PC with software, the 3D printer, and a laser cutter.

3 PBL program

This program begins from the fall semester 2019 and will last 15 weeks (October–January, 135 min. per week). Its schedule is summarized in Table 2. One team consists of six students, and they will produce one flying robot with the members' cooperation. There are nine teams for one semester, and the advisers consist of one faculty member and two teaching assistants (graduate students). After two-weeks of guidance and safety education (in the first and second weeks), lectures on flight dynamics will be provided in the third week by using original documents based on typical textbooks [4], [5].

In this program, each team will design its flying robot by taking various trade-offs and constraints into account. These considerations are strongly related to traditional plural theories such as material mechanics, fluid dynamics, and control engineering. For example, the students have to balance strength improvements and saving weight. They also consider the relationships of the shapes of the control parts, control performance, and the actuating mechanism implementation. This characteristic is quite different from conventional single experimental programs mentioned in the introduction section. Therefore, the integration of plural theories is required in this program. Simultaneously, to avoid the difficulties of the integration of beginners, this program uses a sample robot produced by the teaching assistants a priori. However, the target of the program is to produce a flying robot that performs better than the sample.

From an educational point of view, the contents of the last two weeks (the 14th and 15th weeks) are very important. This involves a competition, from which each team can gauge the performance level of their robot. Moreover, the review meeting is also important as they can discuss the theoretical reasons why their robots performed well or poorly in comparison to the sample robot. Finally, all the students must summarize their activities, results, and considerations in a final report. They are evaluated not from their performance in the competition but through the final report.

Ideally, it is desirable that the students experience a comparison between a numerical simulation and the response of the flying robot. However, as a temporal restriction, it is difficult to include this option for undergraduate programs, and numerical simulation is expected to be used in graduate programs.

4 Conclusion

Taking recent experimental education circumstances in mechanical and aerospace engineering (MAE) departments into account, this paper introduced a novel project-based learning (PBL) program, Design Practice, which is beginning in October 2019 at Nagoya University. This program focuses on the optimal integration of traditional plural theories and the experience of recent digital manufacturing. We chose "Producing a Flying Robot" as a specific theme and discussed a novel flying robot design for educational issues. Its educational effect and subjects will be reported at another opportunity.

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