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STUDENT DESIGN PROCESSES IN INTERDISCIPLINARY COLLABORATION ACTIVITIES IN AERONAUTICS ENGINEERING EDUCATION

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Abstract

This paper focused on the student fabrication phases of aircraft hardware design project under the university curriculum in Japan. In this project student teams design, build, and fly their original flying robots. Fabrication timelines of 10 student teams were compared through collected data during each semester and some characteristics of student building activities were shown.

1 Introduction

Aircraft design is a complicated process and learning design processes of aircraft is one of the key components of aeronautics department of universities. These days many universities take curriculum of aircraft design. Some universities' curriculums include a conceptual design phase as a main point of classes[1], and others make aircraft design project in which students develop real world aircraft[1][2][3]. One of the difficulties of aircraft design education is in assessment of student activities because the design process of aircraft is very complex and getting the objective evidences of student design processes becomes a trouble. One of the reason is a shortage of observation period of staffs who have to manage the project and their researches at once. This paper shows one example of attempts of getting quantitative data of student design activities, especially in fabrication phases of aircraft design project in Japan.

2 Aircraft Design Process in Flying Robot Project

The context of this study is a team collaboration class in aeronautics education in Japan in which students design, build and fly the original aircraft - the Flying Robot Project at the University of Tokyo. In this program, students design, build and fly their original indoor flying robot as a team of 3-6 members, each of whom belongs to different departments and have different backgrounds. The knowledge and skills that students are expected to acquire through this program are summarized as: 1) fundamental knowledge related to the development of the aircraft and devices, 2) skill of applying the knowledge to design and development of real world aircraft and devices, and 3) soft skills including taking good communication with members and managing the team schedule of the development [4].

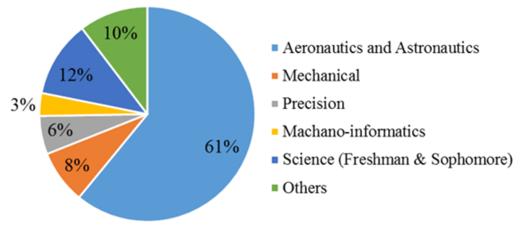

Fig. 1 Student Major

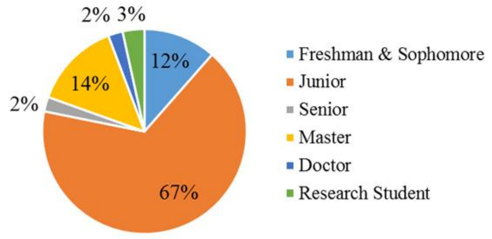

Fig. 2 Student Grade

This project began 2010 under a curriculum of the school of engineering as a project-based learning class which can open only in summer semesters. From 2012 winter semester the project

has been performed under the Boeing Higher Education Program [5] and students can receive the class at every semester. One of the characteristics of the class is the student collaborations consisted of interdisciplinary members.
Fig. 1 and Fig. 2 show the student major and grade distribution in the past students respectively. 87 students attended the class from 2012 winter semester, 2013 summer, 2013 winter, 2014 summer, 2014 winter, 2015 summer, and 2015 winter. 61% of the students belongs to the department of aeronautics and astronautics in Fig. 1. 67% of the students consisted of junior in Fig. 2.

2.2 Schedule Overview

Tab. 1 shows a schedule overview of our project. In the first half of the class, the students received an introduction and lectures about the flying robot theories. In the latter half, they engaged in their own team activities, especially of building real world aircraft in a workshop. Detailed schedule is determined in each semester, taking into consideration about levels of prior-knowledge and prior-experiences of students.

Tab. 1 Schedule Overview of the Project in the 2014 S Semester

Week No.	Date	Place	Contents
1st~7th	4/16~ 6/3	/Classroom /Workshop	/Aircraft lecture & exercise /Conceptual design /Preliminary design /Detail design
8th ~13th	6/4~ 7/16	/Workshop	/Detail design /Fabrication /Experiment /Ground Test
1st Flight Test	7/9	/Gymnasium	
2nd Flight Test	7/14	/Gymnasium	
Final Presentation	7/16	/Workshop	

2.3 Design Requirements

A problem in project-based learning that serves to organize and drive activities is required essentially in order to encourage student activities [6]. In this regard, we set the following constraints as design requirements of aircraft, considering situational factors of Japan's universities circumstances.

- UAV has to be flown indoors easily by radio control
- The maximum empty weight of UAV is 200g

About the first requirement, our country doesn't have enough ground space and flight test places near the university are limited. In addition, our project spends only 4 months developing the aircraft and it is difficult to build large size outdoor UAV under the university curriculums. Therefore, we give students the first constraints: making indoor flying robots.
Also, the second constraint facilitate students developing "not-huge" aircraft for them. The number of weight constraint was determined by several faculties according to a regulation of the All Japan's Indoor Flying Robot Contest, which is one of robotics competition in JSASS [7].

2.4 Conceptual Design and Preliminary Design

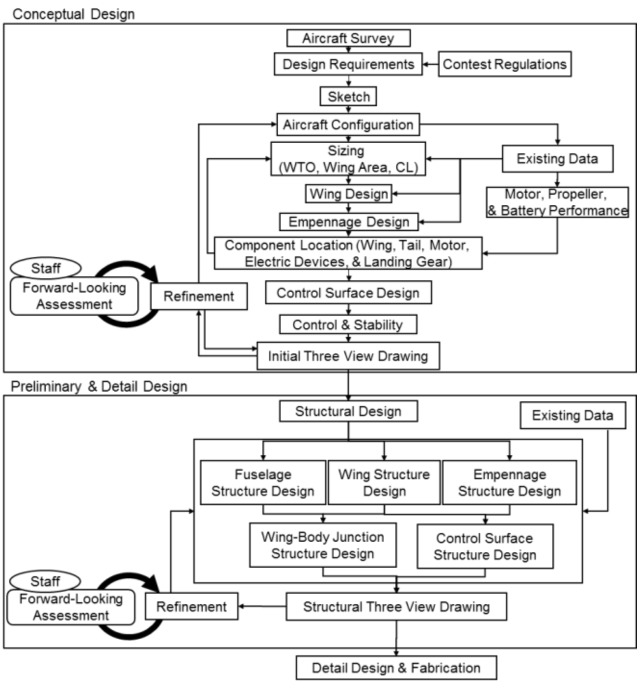

Fig. 3 Conceptual Design, Preliminary & Detail Design (Partly)

An overview of conceptual design and preliminary design belongs to the following chart (Fig. 3). In these phases, short-term objectives of our students are to make initial three view drawings (Fig. 4) and structural three view drawings (Fig. 5). First, the initial drawing is submitted to the project staffs and received assessment and feedback. The feedback is decided with the instructor discussions based on their knowledge and experiences of building and managing the past flying robots. The facilitations about the drawing help students design higher spec aircraft. After students decide the initial three view drawings, they consider about structures of aircraft. In this phase the structural drawings of the aircraft requires in order to decide how to make it.

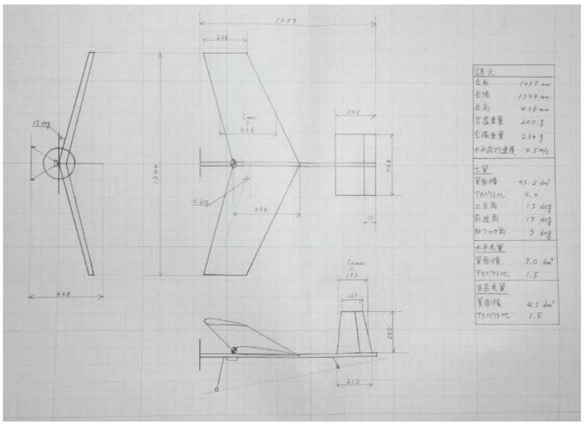

Fig. 4 Initial Three View Drawing (Team A in 2015 S)

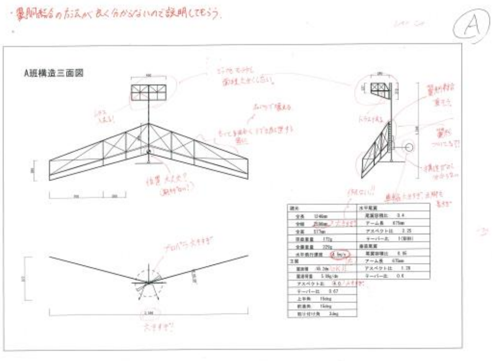

Fig. 5 Structural Three View Drawing & Staff Feedback (Team A in 2015 S)

2.5 Conceptual Design and Preliminary Design

After finishing writing the structural drawings, students start fabricating parts of the aircraft. Fig. 6 shows the overview of the detail design and fabrication phases. We think this phase is little difficult for our university students because almost all of them don't have enough experiences and knowledge of crafting real world components. Therefore staffs have to monitor student activities frequently and advise them at the situation demands, taking into consideration of student prior-knowledge. Real situations of the feedback of us instructors are more complicated than the following charts.

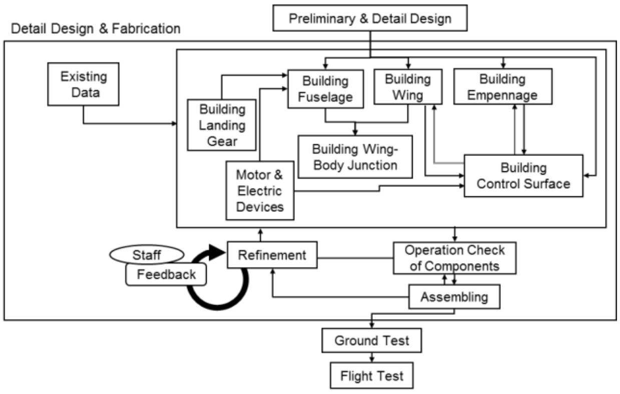

Fig. 6 Detail Design & Fabrication

When students complete the flying robots, we operate ground test and flight test in gymnasium. Student can evaluate the aircraft performances and check some problems of their vehicles. The test is one of the most important point of this project, so we plan the flight test several times as much as time allows.

In the end of semester, the final presentation session is prepared and student have to report their activities before several aeronautics professors.

Fig. 7 Final Presentation

3 Research Methodology

3.1 Research Questions and This Paper Contributions

This study began in order to seek to answer the following research questions.

- How do aircraft hardware design project under the university curricula in Japan affect Japanese aerospace students?
- What learning system in aircraft hardware design project under the curriculum in Japan can help students design, build and fly their own aircraft?
- What learning system in aircraft hardware design project under the curriculum in Japan can help staff facilitate student design activities of their aircraft?

Though long term study and broad data set are required in order to illuminate these questions, our project began 6 years ago and we started getting detailed information of the student activities 3 years ago, so we haven't yet acquired enough information of the project and have to continue acquiring evidences of student activities in the project. In addition, we should organize the past data for improving the next year project. For the reasons mentioned above, this paper focuses on the following research question.

- What design processes and activities, especially in a fabrication phase of aircraft do student teams in aircraft hardware design project under the university curricula in Japan?

Recently some universities are revealing the student conceptual design phases of aircraft using reputation design reports and design presentations [8][9], but illuminating aircraft fabrication phases of student project is very difficult because of the limitations of the educational circumstances [1]. This paper focused on the student fabrication phases of aircraft hardware design project and compared the difference of each teams.

3.2 Design Process Timeline Research

Atman made design process timeline as assessment tool of student design activities [10][11].
Her research team record the student design activities using video and voice recordings and expressed the processes as the timeline (Fig. 8).

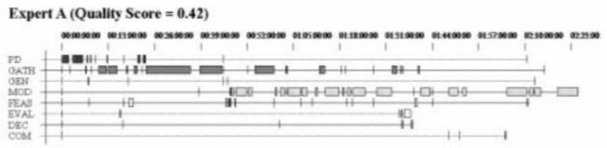

Fig. 8 One of the Design Process Timeline [11]

She imposed three hours design task of participants including freshman in engineering, senior in engineering and expert engineer. She concluded that expert spend more time defining problems and gathering information and they also need more time of total design time.
We tried to apply this methodology to analyze aircraft design project. However, the aircraft design process is very complicated in comparison with Atman's examples even if it is organized by students under the university curriculum. In addition, student fabrication activities spend several tens of hours, so we have to consider how to record it.

3.3 Data Collection

In this paper, we utilized the following four methods as the data collection tools.

- Online Calendar
- Student Blogs
- Mail Documents
- Video Recordings

First, we shared the calendar with student teams online and they can manage the fabrication schedule freely. Second, we committed the students to submit the weekly report on web site: Boeing Higher Education Program [5]. We also confirmed student activities with e-mails, so we managed student activities not only meeting in person but also through online system. Finally, we records the video during each class term. These data can help staffs grasp the student design activities.

3.4 Participants and Products

In this paper we compared the design processes of 10 student teams in the past project from 2014 summer, 2014 winter, and 2015 summer semester. The team compositions of each semester were as Tab. 2. Each team products were shown in Fig. 9.

Tab. 2 Team Compositions

Team	Members
2014 S A	Two Precision M1, One Mechanical M1, One AeroAstro B4, & One Mechanical B4, One AeroAstro Research Student
2014 S B	Three AeroAstro B3, One System Innovation B3, & Two Science B2
2014 S C	Four AeroAstro B3, & One Science B2
2014 W A	Five AeroAstro B3, & One Precision Research Student
2014 W B	Two Precision M1, One Material B3, One AeroAstro Research Student
2015 S A	Two AeroAstro B3, One Biological Sciences B3, & Two Sciences B2
2015 S B	Two AeroAstro B3, & Three Sciences B2
2015 S C	Two AeroAstro B3, One Mechanical M1, One Sciences B2, & One Sciences B1
2015 S D	Two AeroAstro B3, One Mechanical B3, Three Mechano-Informatics B3, One AeroAstro M1, & One Research Student
2015 S E	Three AeroAstro B3, & One Chemistry and Biotechnology D1

*"2014 S A" means Team A in 2014 summer semester.
*"2014 W B" means Team B in 2014 winter semester.
**AeroAstro: department of aeronautics and Astronautics
**Mechanical: department of mechanical engineering
**Precision: department of precision engineering
**System Innovation: department of system innovation

3.5 This paper limitations

This approach have several limitations. The case study showed only limited phases of interdisciplinary collaborative activities in aircraft development projects. In addition, the researchers are adding to the project as the instructor, so influences to the students must be taken into account. Other factors such as previous experiences of students also can influence the research.

In addition, students often wrote only the schedules of using the workshop on the calendar, so we missed their activities out of the class. However their building activities could not continue out of the workshop room because we limited their crafting works only in the workshop. Therefore we can estimate their building time of aircraft development.

Fig. 9 Flying Robots (Upper: in 2014 Summer Project, Middle: in 2014 Winter

4 Findings

We showed the timeline of student teams' fabrication phases of aircraft through the above data collection methods.

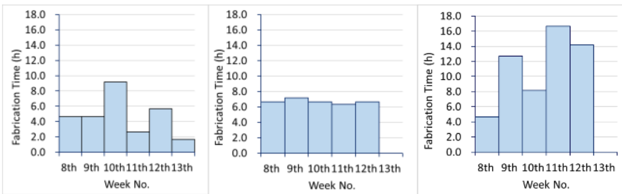

Fig. 10 Fabrication Timeline (Left: Team A, Center: Team B, & Right: Team C in 2014 S)

For Team A in the 2014 summer semester, this team consisted of higher grade students than senior. Although some time variation was happened like two peaks at 10th and 13th weeks and it becomes the lowest at 11th week, however, they keep their working time in each week consistently. We staff team thought this team members include many graduate students and they have sufficient scheduling skills. The team

B consisted of undergraduate students. They could keep their activity with complete consistency. Only this team in this ten graphs could keep their fabrication time equally, this graph's characteristics is different from other timelines. The team C's timeline shows two peaks. This shape has a little similarity with the timeline of the team A, but the peak of team C's timeline is at the 11th week, which is the last week of a flight test. Their aircraft characteristics is transportability. The aircraft was designed as it can be decomposed into small parts and they struggled with how to realize their design into real world product. They spend unexpected much time making wing structures and finally their fabrication time became the longest.

4.1 Two teams in the 2014 winter semester

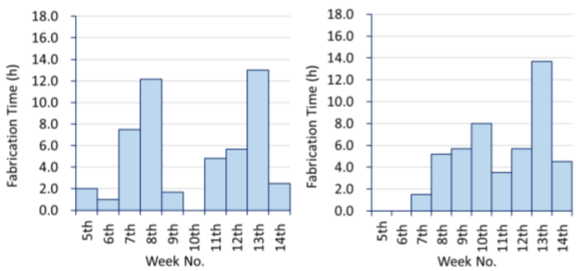

Fig. 11 Fabrication Timeline (Left: Team A, Right: Team B in 2014 W)

Fig. 11 shows a fabrication timeline of the team A and B in the 2014 W semester. The graph of the team A shows two peaks attributed by two weeks of the flight tests. The first is begun with a low rising and comes to the peak at 8th week, which is just before the first flight test week. The second peaks has a similar shape of the first, except for some fabrication times are ensured in 10th and 11th week, which is just before the second peak.

The staffs assessed the schedule of the team was sophisticated for developing the aircraft because they used the fabrication time effectively and their products met fabrication deadlines. We assumed that one of causes of their failures was a lack of knowledge about ornithopters [12]. A flapping wing theory at low Raynolds numbers was remained unsolved and it was difficult for the junior students to comprehend it. Dealing with these unforeseen themes which even staffs don't know is one of our future works.

The graph of the team B shows a fabrication timeline of the team B. The timeline demonstrates two peaks. The first peak is at 10th week, which is later than the team A in the same semester. Since they had to redesign their aircraft configuration at first, they didn't spend much time in the workshop room from 5th week to 7th week. Another reason was that they weren't accustomed with an adjustment of a schedule of the interdisciplinary team. The fabrication time becomes low at the11th week and the highest at the 13th week. We think that this graph is composed of two elements. The first element is a schedule of the aircraft. The aircraft except for the auto pilot system was completed at 7th January: the first date of the 12th week. Activities of developing the aircraft shows the first peak. The second element is to develop auto pilot system, especially about implementing it on the real aircraft. Although they had developed the almost all of the auto pilot system at 11th week out of the workshop room, they met some troubles when they put it on the aircraft. Some devices was crashed in the ground test and they had to prepare alternative parts. Some electrical vibrations was happened when they connected the system with the aircraft motor and they spent much time improving the system. Therefore the highest peak came just before the final week. Nevertheless many problems occurred they could complete the autonomous controlled aircraft and the flight performance was evaluated as splendid one by the staffs [12][13].

4.2 Five teams in the 2015 summer semester

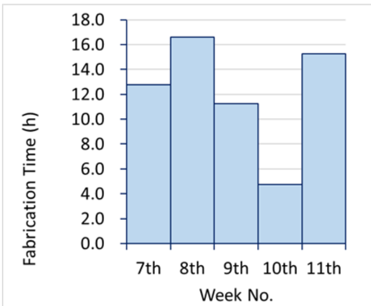

Fig. 12 Fabrication Timeline (Team A in 2015 S)

Fig. 12 shows a fabrication timeline of the team A in the 2015 summer semester. This graph has two peaks. The first peak is caused at 8th week before the time decreases. The time becomes the lowest at the last week of the flight test and the team needed to spend much time completing the aircraft at the final week.
This team was composed of some members who had some experiences of developing real world aircraft and they took care of their schedule at first. This is one of the causes of the first peak. However they also paid attention to an accuracy of the structure of components, especially in building a main wing. In addition the diversity of members' grades and departments brought a difficulty of an adjustment of the team schedules. Finally their team needed more time at the last fabrication week.

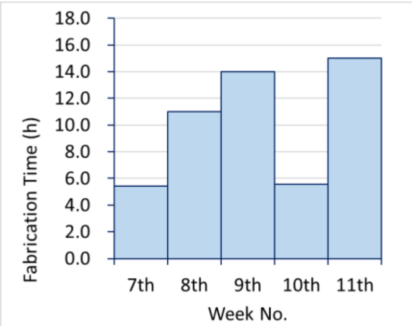

Fig. 13 Fabrication Timeline (Team B in 2015 S)

Fig. 13 shows the timeline of the team B in the 2015 summer semester. These team members came from two departments. The team's experience of building aircraft was lower than the team A and fabrication time at the 7th and 8th weeks was shorter than the team A and C. They needed more time to be accustomed with the building works than the experiencer and the time peak was at 9th week. Then the time decreased at the 10th week and they spent the longest hours completing the products at the final week. One of the causes was they could not predict concrete works for finishing the products such as assembling the components and adjusting them and they underestimated the time required for it. It brought the lowest peak just before the flight test week.

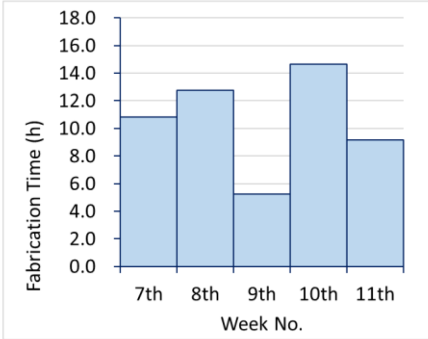

Fig. 14 Fabrication Timeline (Team C in 2015 S)

Fig. 14 shows the timeline of the team C. The concept of their aircraft was an aircraft which had an inverted gull wing. The reason they decided this concept was they liked its coolness and the members had high motivations of completing it. They didn't have much experience of design, but had some kinds of skills of predicting the building process. They actively asked the staffs about their experiences of developing flying robots and they could estimate their concrete works properly. In addition, developing the peculiar concept of the wing gave the team an effective pressure. They didn't had an enough confirmation of completing the wing, so they planned their works with time to spare. After all their timeline shows two peaks and the second peak is at 10th week, which is the last week of the flight test.

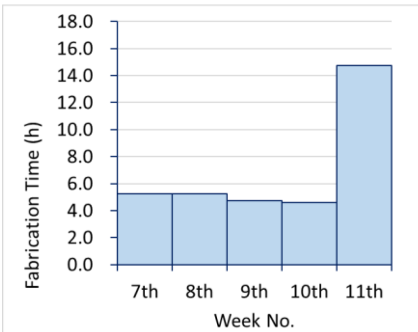

Fig. 15 Fabrication Timeline (Team D in 2015 S)

Fig. 15 shows the schedule of the team D in the 2015 summer semester. This team spent the shortest time working in the workshop room in this semester. Eight members from different grades and majors participated in this team, so the team leader struggle to adjust the team schedule. Their purpose was to develop an autonomous aircraft and they had to build not only an aircraft but also auto pilot system which they could not imagine how to make. As a result, they did not realize how many hours they spent until the last week. Although they tried to work as much as possible at the last week, but they could not complete the auto pilot system and did only a test flight of the aircraft without the system.

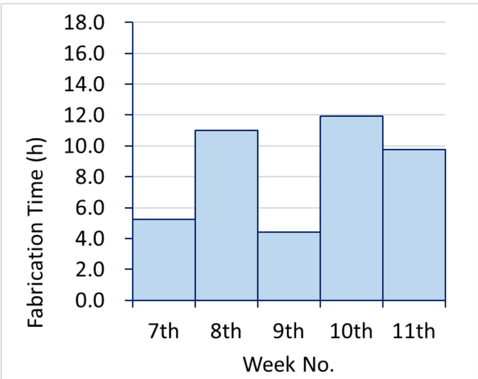

Fig. 16 Fabrication Timeline (Team E in 2015 S)

Fig. 16 shows a fabrication timeline of the team E in the 2015 summer semester. This team consisted of four members who did not have much designing and building experiences. The concept was to develop a tailless wing aircraft which almost all of the teams in this project had not tried and completed. They struggled to keep their motivations because this aircraft belonged in the unforeseen discipline and they could not imagine what was needed in order to fly it stably. Although they met some troubles in building such as a change of the shape of the main wing, they completed the vehicle with short time relatively because the number of the aircraft components was less than a conventional aircraft. However their aircraft could not take off at a flight test because of a lack of a stability.
Tab. 3 is a summary of above seven fabrication timeline.

Tab. 3 Sum and Average of Fabrication Time

	Fabrication Week No.	Total [h]	MEAN (S.D.) [h]
2014 S A	8th ~13th	23.8	4.8 (2.4)
2014 S B	8th ~13th	26.8	5.6 (2.5)
2014 S C	8th ~13th	51.7	9.4 (5.8)
2014 W A	5th~14th	48.3	5.0 (4.4)
2014 W B	5th~14th	47.7	4.8 (3.9)
2015 S A	7th~11th	47.8	12.1 (4.1)
2015 S B	7th~11th	45.6	10.2 (4.1)
2015 S C	7th~11th	41.8	10.5 (3.2)
2015 S D	7th~11th	29.3	6.9 (3.9)
2015 S E	7th~11th	37.1	8.5 (3.1)

5 Discussion

In this section the seven fabrication timelines are compared in terms of characteristics of graph shapes.

5.1 Characteristics of Fabrication Timeline

5.1.1 Ideal pattern and inappropriate pattern of fabrication timeline

We thought the team A in the 2014 winter semester had good skills of scheduling and they could finish building three types of aircraft in one semester. We thought this timeline has a characteristics of an ideal pattern of fabrication. The left picture of Fig. 17 shows the ideal pattern. In this pattern fabrication time goes up at first and remains flat for securing the development time and finally goes down before a flight test. This pattern can give a team a time margin before a flight test.

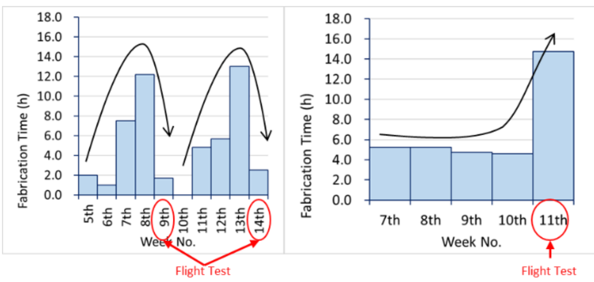

Fig. 17 Ideal Pattern (Left: Team A in the 2014 Winter Semester) and Inappropriate Pattern (Right: Team D in the 2014 Winter Semester) of Fabrication Timeline

The right picture of Fig. 17 shows an inappropriate pattern of fabrication timeline such as the team D in the 2015 summer semester. This timeline begins with low time and stay flat before a flight test comes. Just before the deadline a team come up with its condition and spend more time. As a result, timeline becomes high at the last part of the fabrication phases.

5.1.2 Slump shape

We paid attention to the timeline of the team C in the 2015 summer semester. Though this pattern is similar to the ideal pattern of the fabrication timeline, this have a sudden decrease of fabrication time at the middle of weeks. This phenomenon can also be seen in the timelines of the team B in the 2014 winter semester and the team A, B, and E in the 2015 summer semester. We called it "slump shape" of the timeline.

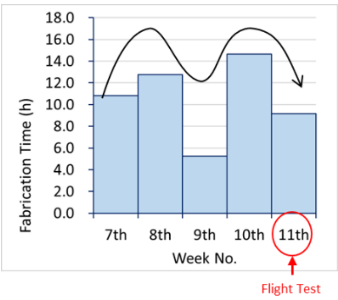

Fig. 18 Ideal Pattern with Slump Shape (Team C in the 2015 Summer Semester)

Fig. 19 shows the timeline of the team A in the 2015 summer semester. This team did the activities as the ideal pattern of fabrication at first, however some troubles with wing design caused the slump shape at the 10^{th} week and the latter part of the timeline became like the inappropriate pattern.

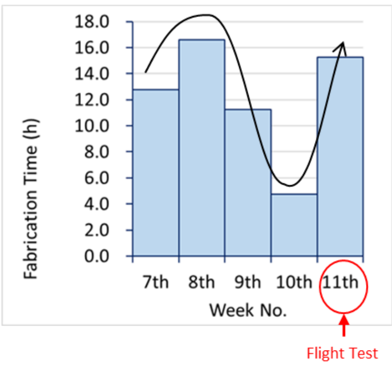

Fig. 19 Ideal Pattern and Inappropriate Pattern with Slump Shape (Team A in the 2015 Summer Semester)

6 Conclusion and Future Works

In conclusion, we explained about how student fabrication processes were different in each team through the fabrication timelines. From these timelines we hypothesized the characteristic of the timeline pattern: ideal pattern, inappropriate pattern, and slump shape. However these data didn't include the sufficient detailed information of student activities. For example we could not know their works out of the class. In next semester we continue attending the aircraft design class and compare and contrast these differences.

Acknowledgement

The Flying Robot Project has been performed under the Boeing Higher Education Program. We greatly appreciated all the members and the students who participated in this project.

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